Watershed Planning and Management

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Module 1: Watershed Management – Problems and Prospects

Lesson 1 Watershed and Its Management

1.1 Concept and Definition of Watershed

The word 'watershed' has different meanings. In British English it means a ridge line or a line which shows slopes in two different directions on its either sides. A ridge line is also a line connecting the points of highest elevation in a terrain. Therefore, ridge line is also known as 'watershed line' or a 'surface water divide'. In colloquial language the word 'watershed' is used to describe a path breaking event.

In American English, the word 'watershed' is used as a synonym for 'catchment' or 'basin' wherein rainwater or storm water gets collected from an area enclosed by a ridge line. This water eventually flows through the various drainage channels which merge with one another to form one or rarely more than one outfall(s) of a stream. Thus, 'watershed' is defined as an area enclosed within a watershed line. In this course, the word 'watershed' is used for a small basin or a small catchment representing a hydrological unit which drains all its rainwater into a stream. Therefore, it is independent in terms of its water in general and surface water in particular.

To distinguish a watershed -which generally implies a small catchment or a basin, Bali (1980) suggested an upper area limit of 2,000 km^2 for a watershed. This classification is an extension of the classification suggested by Rao (1975) for large river basins -with an area greater than 20,000 km^2, medium river basins –with an area between 2,000 and 20,000 km^2 and small river basins commonly referred to as watersheds.

Bali's classification of watersheds was probably reflected in the watershed classification by the All India Soil and Land Use Survey (AISLUS) in 1990. According to this classification, watersheds are further classified into 5 categories based on their areas as 'macro-watersheds - with area between 500 and 2,000 km^2, 'sub-watersheds' –with area between 100 and 500 km^2, 'milli-watersheds' –with area between 10 and 100 km^2, 'mini-watersheds' –with area between 1 and 10 km^2 as well as 'micro-watersheds' –with area less than 1 km^2.

A watershed is a physical entity consisting of the natural elements in it such as plants of various sizes and types which grow over various types of soil or rock layers. Additionally, watershed also comprises of all the artificial elements such as roads, bridges, tunnels, buildings, and burrow holes etc. which are mostly introduced in it by human beings and sometimes by other animals. In the next section, we shall discuss about the scope of watershed management.

1.2 Scope of Watershed Management

As we have already seen in the previous section, watersheds represent small basins. By delineating the ridgelines in a medium or a large river basin, the entire basin can be subdivided into a number of watersheds, each with an area within 2,000 km^2. Because of their compact size, it is always easier to manage watersheds rather than a river basin. In a well-managed watershed, all the natural resources such as soil, water, vegetation, etc. are conserved.

Vegetation or plants play a vital role in conserving the natural resources of a watershed such as soil and water. The underground components of the plants such as roots spread within the soil and thereby stabilize and reinforce the soil. This generally leads to soil conservation. The water infiltrates below the ground through the voids in the soil as well as through the interface between the root surface and the soil. The terrestrial components of plants such as stems, branches and leaves prevent the soil below it from getting directly exposed to sunlight as well as to the impact of raindrops. Thus, a significant part of the momentum and energy in rainwater is absorbed and thereby inducing/ accelerating the downward movement of rainwater through stem flow and infiltration. On one hand this process creates water bodies like the groundwater reservoirs and rivers, which are good sources of water and nutrients required for plant growth. On the other hand, this process also substantially reduces the soil erosion and the surface flow velocity of storm water.

Additionally, there will be release of ample amount of oxygen, generation of colorful and fragrant flowers, fresh leaves as well as fruits through the process of photosynthesis. This makes the entire watershed very pleasant for human beings, migratory birds, flying insects as well as all other animals. The fruits and leaves also serve as food for human beings and animals.

A watershed containing large amounts of vegetation is considered as a healthy watershed. It is also called a well-managed or a 'green watershed'. It has no or very limited soil erosion and also it has large reserves of groundwater as well as surface water. In general, it has most of its natural resources conserved.

Thus, the scope of watershed management involves all the actions and programs aimed at achieving an overall balance between utilization and conservation of natural resources in a watershed. It represents a sustainable approach for resource conservation through watershed management. In the next section, the Indian and global perspective to watershed management is discussed.

1.3 Watershed Management: Indian and Global Perspective

India has the second highest population of over 1.2 billion among all the nations [i.e., 17.1% of the world population], a seventh highest land area of 3.29 million km^2 among all the nations [i.e., 2.4% of the world area] and an annual river flow of 1869 km^3 out of an annual rainfall of about 4000 km^3 [i.e., 4% of the world water]. The rainfall distribution is highly uneven spatially with the highest annual rainfall of 11,690 mm in the north-eastern state of Meghalaya and the least annual rainfall of 150 mm in the western part of the north-western state of Rajasthan. The number of rainy days [i.e., number of days with a minimum recorded daily rainfall of 2.5 mm] varies from 5 to 150. The rainfall distribution is also very uneven temporally with about 75% of the annual rainfall occurring only in the four monsoon months of June to September. The average annual rainfall is 1160 mm which is slightly higher than the global average of 1110 mm. In the year 2010, the annual per capita water availability was estimated at 1588 m^3, which is considered as water stressed [i.e., between 1,000 and 1,700 m^3] as per the international norms. The per capita water availability was 5200 m^3 during the year 1951. The annual potential evapo-transpiration (PET) varies from 1,500 to 3,500 mm.

Although India has a well-developed precipitation pattern in the form of monsoons and an equally well developed drainage network consisting of 14 large river basins, 44 medium river basins and hundreds of small river basins, there is a huge stress on water and land resources due to continuous overexploitation. This has led to many adverse hydro-meteorological impacts like large scale soil erosion, excessive lowering of water table, extensive river/ ground water pollution due to municipal/industrial wastewaters, widespread loss of forests/ grass lands/ crop lands/ wetlands/ water bodies, silting of existing water bodies, frequent occurrence of floods/ droughts, alarming reduction in Himalayan glaciers etc. All these phenomena have generally made the Indian perspective in watershed management very vulnerable to climatic and anthropogenic factors. Thus, achieving sustainable water resources development and integrated watershed management are two major challenges in the Indian context.

In spite of this alarming scenario, there are hundreds of best management practices (BMPs) –adopted both in the government sector and the non-government sector over the entire length and breadth of India, which have been the bright spots in water and land resources management. These BMPs employ technologies which are either traditional or modern or a combination of both. Some of these BMPs -which were effectively implemented in different parts of India, are as follows:

1) An effective implementation of the ban on tree cutting policy by the local government authorities in the north-eastern state of Sikkim resulted in an increase in the forest cover from 44% in 1995-'96 to 47.59% in 2009 [Hindustan Times, 2010].

2) During 2000 to 2006, voluntary work by hundreds of people led by a spiritual saint near Jalandhar in the north Indian state of Punjab, resulted in the near total cleaning and rejuvenation of 35 km of Kali Bein River, which was heavily polluted by industrial effluents and garbage [The Times of India, 2007].

3) Over a 20-year period starting from 1974, a severely drought prone village of Ralegan Siddhi in the western Indian state of Maharashtra –even with an annual rainfall of about 200 mm, had transformed into a village with ample drinking water, food and fodder. This was possible due to the adoption of ridge to valley approach in watershed management through social forestry, grassland development, continuous contour trenching, loose boulder structures, brushwood dams, nulla bunds, percolation tanks, underground dams, gabion bunds, check dams, farm ponds, staggered trenches for arresting soil erosion and ban on free grazing [Hazare, 1994].

Global perspective on watershed management is having many similarities and some differences with the Indian perspective. Moreover, there are even bigger spatial and temporal variations in water/ pollutant distribution. It is also very much affected by soil erosion, excessive lowering of water table, extensive river/ ground water pollution due to municipal/industrial wastewaters, widespread loss of forests/ grass lands/ crop lands/ wetlands/ water bodies, silting of existing water bodies, frequent occurrence of floods/ droughts, alarming reduction in glaciers etc. These phenomena have resulted in major constraints due to water scarcity and land scarcity. However, in majority of the developed world and in many parts of the developing world, sufficient watershed management activities have been initiated in the government and non-governmental sectors.

The impact of these watershed management programs is varied ranging from failures with undesirable environmental and socio-economic consequences to significant benefits. To make the watershed management programs sustainable, land and water resources need to be managed together with an interdisciplinary approach. There is also a strong need to develop regional training and networking programs at all levels, especially when government agencies are not fulfilling their role in watershed management. The emergence of citizen-based watershed organizations in the United States and many other countries is a very positive development.

1.4 Timeline of Watershed Management Programmes in India

The watershed management concept in India starts from the pre-historic times. In the Shanti Mantra or the peace hymn of Yajur Veda –one of the four Vedas or treatises of knowledge in the ancient Indian philosophy –which is written/ codified in Sanskrit, there is a phrase which states that '…..prithivih shantih aapah shantir oshadhayah shantih…'. The meaning of this phrase is '…let there be peace on earth, water, vegetation…'. This is possibly one of the oldest references to watershed management. Additionally -in that hymn, peace is also sought in heaven, sky, Gods and in all natural entities/ living organisms -starting with the person reciting this Mantra.

The actual timeline of watershed management programmes in India starts from the 1950s during the First Five Year Plan, with the establishment of a number of Soil Conservation Research Demonstration and Training Centres (SCRDTCs) by the Ministry of Agriculture (MoA) of the Government of India (GoI). In 1956, 42 small [i.e., less than 1 km^2] experimental watersheds were established for monitoring the impact of land use changes and conservation measures on surface hydrology, soil loss reduction and biomass productivity improvement. In 1961-'62, the MoA, GoI sponsored a scheme for soil conservation in the catchments of River Valley Projects (RVPs) for preventing siltation in major reservoirs.

In 1974, all the SCRDTCs were reorganized under the Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun. A real breakthrough was achieved by CSWCRTI when watershed technologies were demonstrated under natural field settings using community driven approaches through four model Operational Research Projects (ORPs) in different regions of the country. The world famous Sukhomajri model in Haryana was also one of them. The Ministry of Rural Development (MoRD), GoI launched major nationwide watershed development programs like the Drought Prone Area Programme (DPAP) in 1973-'74 and Desert Development Programme (DDP) in 1977-'78. The MoA, GoI launched watershed programs in 10 catchments under the Flood Prone Rivers (FRP) Project.

During 1983, encouraged by the success in the earlier four model ORPs, CSWCRTI, Dehradun developed 47 model watersheds in the country in association with the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad. MoRD, GoI also started adopting watershed approach in 1987. The Planning Commission, GoI also started adopting integrated watershed approach in 1987-'88 for its Western Ghats Development Programme (WGDP) and Hill Area Development Programme (HADP) covering 16,000 km^2 area in Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. In 1989-'90, the Ministry of environment and Forests (MoEF) initiated National Afforestation and Eco-development Projects (NAEP) scheme following integrated watershed approach.

In the 1990s, many watershed development programs externally funded by the World Bank, European Economic council (EEC), Danish International Development agency (DANIDA), some Indo-German, Indo-Swiss and Japanese organizations were undertaken in various parts of India. Around the same time, MoA initiated a massive project on National Watershed Development Programme for Rainfed areas (NWDPRA) in 1991. In 1995, MoRD launched another big project called Integrated Wastelands Development Project (IWDP) with well formulated guidelines.

In 2001, the Planning Commission, GoI drew up an ambitious plan of treating 88.5 Mha of degraded/ rainfed lands in India, by the end of the 13th Five Year Plan in 2022 involving a huge financial investment of Rs. 72,750 crores. To strengthen the participating institutes, MoRD revised the watershed development guidelines as 'Haryali' [i.e., greenery] guidelines in 2003. The GoI established the National Rainfed Area Authority (NRAA) under the Planning Commission in 2006. MoA also started the projects on Reclamation of Alkali soils (RAS), Watershed Development Project for Shifting Cultivation Areas (WDPSCA), Indo-German Bilateral Project (IGBP) and World Bank assisted Sodic Land Reclamation Project (SLRP). MoRD has initiated watershed projects under Mahatma Gandhi National Rural employment Guarantee Act (MGNREGA), Investment Promotional Scheme (IPS) and Technology Development Extension and Training (TDET), Wastelands Development Task Force (WDTF). Till March 2005, an area of 28.53 Mha was treated at an investment of Rs. 1,457 crores by MoA, MoRD, MoEF, out of a total degraded land of 146.82 Mha –as per the estimates of the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Nagpur. From 2008, the new watershed projects are being implemented as per the latest common guidelines for watershed development projects, developed by the NRAA.

Keywords: River Basin, Watershed, Watershed management, Global watershed management perspective, Indian watershed management timeline

Lesson 2 Problems and Prospects in Watershed Management

Watershed management encounters many problems and constraints. Some of the major problems and constraints in watershed management are listed below.

2.1 Problems and Constraints in Watershed Management

(a) Land degradation in rain fed areas due to soil erosion from runoff is one of the major problems. In India it was estimated that the soil erosion in the 1990s was almost double that of soil erosion in the 1980s. Rainfall uncertainty and poor economic conditions act as a major constraint and thus prevents the farmers in rainfed areas from making investments. This leads to improper watershed management.

(b) Equitable benefit sharing of watershed management within the farming communities as well as within the different locations of watershed is a huge problem. Generally, women, marginal farmers and landless laborers gain very little or nothing at all from the watershed management activities. Several case studies in water scarce states of Gujarat and Madhya Pradesh in India have showed that overdevelopment of water harvesting structures in the upstream portion of watersheds had significantly reduced the inflows into the downstream reservoirs. On the other hand, it is also noticed that building of large reservoirs resulted in the submergence and hardship in the upstream parts and benefits for people in the downstream parts of the same watershed or a neighboring watershed generally having an urban or an industrial area.

(c) Acute shortage of water in general and drinking water especially in summer has been observed in many watersheds with inadequate watershed management which may result in severe/ recurrent droughts. It may often result in limited and temporary food productivity gains.

(d) Many a times, common lands do not get treated adequately and re-vegetation does not take place as expected in spite of the watershed management programs. As a result of this, domestic/ ecosystem water needs and livestock water/ fodder needs are either inadequately addressed or are made to suffer due to increased water withdrawals by other uses or due to overgrazing.

(e) Problems exist or new problems crop up due to improper understanding of the interaction between biophysical and socio-economic processes in watershed management.

(f) Conflict among various government ministries such as those related to agriculture [with emphasis on food production], rural development [with emphasis on employment generation & poverty alleviation], forests [with emphasis on maintaining biodiversity & wildlife], as well as conflict between government bureaucracy and elected representatives in their zeal to control funds, is a major problem in watershed management programs -which requires to be resolved on a priority basis.

(g) It is hard to conduct meaningful impact assessment studies on watershed management programs for lack of baseline data for monitoring and comparison of the current conditions. The whole exercise of watershed management is undertaken without properly estimating the water supply scenarios under drought/ normal/ surplus years as well as without proper demand management especially during drought years.

(h) Large areas inhabited with tribal population lack facilities to harvest water and to stabilize their food/ crop/ fodder production due to reduced forest yields, deterioration in land quality, lack of tribal agriculture policy and population pressure. This leads to a sustained misery, socio-political unrest and insurgency among the tribal population.

2.2 New Prospects and Opportunities Associated with Watershed Management

In spite of the above-mentioned problems and constraints as well as some other problems and constraints, watershed management is associated with new prospects and opportunities. Some of them are listed below:

(a) There is a need to produce more and better food without further undermining the environment/ ecology, especially the land, water, forests, wildlife and atmosphere. This may include adoption of best management practices (BMPs) such as organic farming, de-silting for reservoir capacity restoration as well as for crop productivity increase, sprinkler and/ or drip irrigation to avoid excess use of water, no tree felling policy, afforestation and arboriculture through high oxygen yielding & other medicinal plants etc.

(b) There is a need to ensure that gains due to groundwater recharge are not dissipated by excess groundwater extraction. To achieve this, groundwater over-extraction should be avoided through public awareness and also through regulation.

(c) There is a need to consider the downstream impacts of intensive upstream water conservation. For this, watershed associations with representations from all the stakeholders in the watershed should be made operational. These associations can take decisions in the best interest of all the people concerned.

(d) Decreasing the costs at which the gains are achieved and thereby increasing the modest benefit-cost ratio should offer new prospect and opportunity in watershed management. To realize this, low cost technologies which may involve local materials, labour at practically no cost, technologies which are traditional and time tested should be employed to generate more benefits spread over the entire watershed among all the stakeholders.

(e) Increasing all sections of people's participation beyond the project implementation stage to ensure sustainable watershed management should be a top priority. Only this can ensure progress on a sustained basis overcoming the hydro-geological, socio-political and other uncertainties.

(f) Many successful watershed management programs -especially in India, have been implemented on a small scale in a few villages by collaborated efforts among the government departments, non-governmental organizations (NGOs) and research organizations. They represent sporadic BMPs. Hence there is a need to scale up the watershed management activities over large areas which could include remote and/or difficult terrains, so that many problems affecting our agricultural, rural and forest sectors can be effectively addressed.

(g) Since there have been no or very few institutions built for research & development on collective management of watersheds, there is a need to build centers of advanced learning employing the modern tools of remote sensing, geographic information systems, decision support systems, computer based planning tools, poverty & socio-economic analysis etc.

(h) There is a need to preserve and improve common pool resources (CPRs) of land, water, fodder, forest, fisheries, wild life and agriculture which significantly contribute towards people's livelihood especially in the rural areas.

(i) There is a need to minimize migration to urban areas by creating opportunities in agriculture, natural disasters like floods/ droughts, forest/ mountain economies and by arresting fall in agricultural prices, gap in urban/ rural wages, gaps in urban/ rural employment opportunities.

Keywords: Watershed management problems, watershed management constraints, watershed management prospects, watershed management opportunities.

Module 2: Land Capability and Watershed Based Land Use Planning

Lesson 3 Land Capability and its Classification

Land capability plays a vital role in deciding the land use. In this lesson, we shall discuss on land capability and its classification.

3.1 Definition of Land Capability

Land capability may be defined as the ability of the land surface to support natural plant growth/ wildlife habitat or artificial crop growth/ human habitat. Thus, it indicates the type of land use [viz., human habitation, agriculture, pastures, forests, wildlife habitat, etc.] that is suitable over a particular type of land. Different lands have different capabilities depending on the land characteristics like slope, soil type, soil depth and erosion conditions. If certain land characteristics are not conducive for agriculture, it is desirable to utilize or ensure the continuity of that land area for other land uses as mentioned earlier.

The ultimate goal of allocation of various land capabilities over a vast land area with varied characteristics is to achieve complete soil conservation. Complete soil conservation implies perfect soil health and zero soil erosion on a sustained basis. It also facilitates total water conservation and total vegetation conservation. Thereby it results in integrated watershed management on a long term basis.

In the next section, we shall discuss the classification of land capability based on the land characteristics. This land capability classification should ensure appropriate land use for every land area for peaceful coexistence of different flora and fauna including human habitation and also a sustained productivity through human activities.

3.2 Classification of Land Capability

The Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA) has done a pioneering work on land capability classification [Klingbiel and Montgomery, 1961]. According to that, the land capability is classified broadly into two groups based on the cultivability of the land. The first group consisting of all the lands which are suitable for cultivation is referred to as 'Group 1 Lands'. The remaining group consisting of all the lands which are unsuitable for cultivation is referred to as 'Group 2 Lands'. Each of these two groups are further classified into four classes. Thus 'Group 1 Lands' comprise 'Land Classes I to IV' which are cultivable and 'Group 2 Lands' comprise 'Land Classes V to VIII' which are non-cultivable.

The following paragraphs describe each of the two groups and eight land classes in terms of their land characteristics and land use:

Group 1 Lands: Generally Suitable for Cultivation

Class I Lands: These lands are nearly level with slopes generally within 1%. The soils are deep, fertile, easily workable and are not subjected to damaging overflows. There are hardly any restrictions or limitations for their use. These lands are very good lands which can be safely cultivated by using any farming method to grow any crop, even intensively also. However, proper crop rotation and green manure use should be followed to maintain soil fertility [Mal, 1994].

Class II Lands: These lands generally have gentle slope in the range of 1 to 3%. They can be easily cultivated with some conservation practices like contour farming, strip cropping, bund construction or terracing. Therefore one or more of the following limitations exist which slightly reduce the crop choice [Murthy and Jha, 2011]:

1. Moderate susceptibility to erosion by wind or water;

2. Less than ideal soil depth;

3. Somewhat unfavourable soil structure and workability;

4. Slight to moderate salinity;

5. Occasionally damaging overflows;

6. Wetness existing permanently which can be corrected by drainage; and

7. Slight climatic limitations on land use and management.

Class III Lands: These lands generally have slopes in the range of 3 to 5% and therefore have severe limitations which further reduce the crop choice or require special conservation practices [like contour farming, strip cropping, cover cropping, bund construction or terracing] or both. Lands in this class have more restrictions than those in Class II Lands due to land characteristics. All the limitations of Class II Lands are applicable here also, but to a greater extent. Hay or pasture crops that completely cover the soil should be preferred. On wet lands of this Class -which usually have heavy and slowly permeable soils, a drainage system along with a suitable cropping plan to improve the soil structure is required.

Class IV Lands: These lands have fairly good soils [i. e., having shallow soil depth and low fertility] and generally have somewhat steep slopes in the range of 5 to 8%. Therefore they have either very severe limitations that largely restrict the crop choice or require very careful management or both. Lands may be suitable only for two to three common crops which build and maintain soil -like the fully covering pastures, with occasional grain crops which can be grown usually once in five years. These lands may have one or more of the following permanent features [Murthy and Jha, 2011]:

1. Heavy susceptibility for erosion due to wind, water with severe effects of past erosion;

2. Low moisture holding capacity;

3. Frequent overflows accompanied by severe crop damage;

4. Water logging, excessive wetness and severe salinity; and

5. Moderately adverse climate.

Land Capability Sub-Classes: Lands in Classes II, III and IV are further categorised into sub-classes based on the following limitations:

1. Risk of erosion or past erosion damage is designated by the symbol 'e';

2. Wetness damage or overflow is designated by the symbol 'w';

3. Soil root zone limitations are denoted by 's'; and

4. Climatic limitations are designated by 'c'.

Group 2 Lands: Generally Not Suitable for Cultivation

Class V Lands: These lands generally have slopes in the range of 8 to 12%. They usually have no to little erosion hazard but have other limitations which restrict their use mainly to pastures, forests, wildlife food and cover. Controlled grazing may be permitted. Some of the examples of Class V Lands are:

1. Bottom lands subject to frequent overflows that prevent the normal production of cultivated crops;

2. Stony or rocky lands;

3. Few ponded areas where soils are suitable for grasses or trees.

Class VI Lands: The lands in this Class have shallow soils and generally have quite steep slopes ranging to 18%. They have severe limitations which restrict their use to pastures with very limited grazing, woodlands, wildlife food and cover. Some of the limitations of these lands which can't be corrected are:

1. Severe erosion;

2. Stony texture with shallow rocks

3. Excessive wetness or overflow

4. Low moisture capacity

5. Severe climate.

Class VII Lands: The lands in this Class are generally eroded, rough, having shallow soil depth and steeper slopes ranging to 25%. The soils may be swampy or drought prone, with all the limitations of Class VI Lands even to a higher degree. If there is good rainfall, they may be used for forestry with fully green cover, gully control structures and severely restricted grazing.

Class VIII Lands: These lands are rough with probably the worst soil types and possibly the steepest slopes in excess of 25%. They can only be used with very sound gully control measures for forests –if conducive for tree growth, and also for wildlife habitat. However, tree felling and grazing should be strictly avoided.

Certain lands in Group 2 can be made cultivable with major earthmoving or other effective and costly reclamation operations. In India, both the Class VII Lands and Class VIII Lands are combined as Class VII Lands.

Keywords: Land capability, land capability classification, Group 1 lands, Group 2 lands.

Lesson 4 Watershed Based Land Use Planning

In this lesson, we shall discuss the impact on watershed due to land use and spatio-temporal changes in it. Then we shall move on to the planning of land use to ensure a sustainable watershed.

4.1 Impact on Watershed due to Land Use

Watershed and the land use are quite inter-dependent. Watersheds with a healthy aquatic system -in the form of adequate streams & wetlands, and an equally healthy biotic system -in the form of adequate flora and fauna, are generally sustainable systems. Once they are subjected to large scale human interventions and/ or natural calamities, the land use gets altered significantly. This in turn causes major impact in the watershed in terms of its hydrology, flora and fauna.

In many parts of the world, extensive areas of native forests and grasslands have been converted into croplands or urban areas or road/ railway systems/ networks. This has resulted in the alteration of riparian corridors, drainage of wetlands and modification of natural river systems. These changes in the land use have resulted in the hydrologic changes in the watersheds, their stream systems and surface water-groundwater linkages. Changes in water quantity and quality can affect people and ecosystems in both upstream and downstream areas of watersheds [Brooks et al, 2013].

If these changes occurring in watersheds are not managed properly, they may become unsustainable in the long run. Therefore to avoid any undesirable consequences, increased attention is being paid to maintaining or restoring natural stream channel systems, riparian communities, wetland ecosystems and floodplains which can restore the good hydrologic conditions of watersheds. Thinking on these lines, Hey (2001) called for a major program to maximize the natural storage in the wetlands and floodplains as well as to minimize conveyance in the upper Mississippi River Basin. Such a program would effectively reverse some of the impacts of the past 200 years of levee construction and other engineering practices in the basin.

If watersheds are not sustainably managed, they may show cumulative watershed effects i.e., combined environmental effects of activities in a watershed that can adversely impact beneficial uses of lands [Sidle, 2000]. Individually these environmental effects may not appear to be relevant. But collectively, they may become significant over time and space.

For example, the conversion of forest to crop lands in one part of a watershed can cause an increase in the water and sediment flow. Likewise, road construction and drainage can also have effects in a watershed similar to drainage of a wetland at some other location. Similarly, removal of dense shrubs to increase forage production may also increase water yield in some cases, benefit certain wildlife species and reduce fire hazards. However, the same shrub removal may be detrimental to other types of wildlife. Changes in vegetation composition/ density/ age structure/ continuity across the landscape can affect evapo-transpiration losses and thereby influence antecedent soil moisture conditions, water yields & their timings, stream flow volumes & their peaks, at different parts of watersheds. Overgrazing -which results in excess trampling in a watershed and excessive soil compaction, reduces infiltration capacity and increases surface runoff. Roads and trails possibly increase soil erosion due to the exposure to erodible soil and subsoil during their construction. This reduces infiltration and concentrates overland flow from precipitation excess which erodes the increased gradients in the side slopes of cuts and fills.

The increase in flooding due to the creation of finished impervious surfaces as well as due to the filling up of water bodies especially in the urbanized areas leading to a drastic reduction in infiltration or surface storage is very well known. On the other hand, forest and wild land watersheds are frequently affected by wild fires. This results in increased soil erosion due to the loss in the vegetation cover and also an increased surface runoff due to the formation of water repellent layers in the soil.

These are some of the examples wherein a change in land use has impacted the watersheds and made them ecologically unsustainable. There are many other examples of land use changes which also disturb the watersheds in terms of water quality, geomorphic and hydrologic effects. To overcome these undesirable effects, an interdisciplinary approach involving hydrology, geomorphology and ecology into watershed management and land use planning is needed to understand and appreciate the impacts of cumulative watershed effects on water yield, other stream flow characteristics and water quality. The next section will deal with the planning the land use so as to ensure sustainability in watershed management.

4.2 Planning the Land Use

There are conflicts over land use, many a times. The demands for arable land, grazing, forestry, wildlife, tourism and urban development are greater than the land resources available. In the developing countries, these demands become more acute every year. The population dependent on the land for food, fuel and employment is expected to double within the next 25 to 50 years. Even where land is still available in plenty, many people may have inadequate access to land or to the benefits from its use. In the face of scarcity, the degradation of farmland, forest or water resources are visible for all to see but individual land users lack the incentive or resources to stop it.

Land-use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options. Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding the resources for the future. The driving forces in land use planning are the needs for change, improved management or quite different patterns of land use dictated by the changing circumstances.

All kinds of rural land use like agriculture, pastoral lands, forestry, wildlife conservation and tourism are involved in land use planning. It also provides guidance in cases of conflict between rural land use and urban or industrial expansion, by indicating which areas of land are most valuable under rural use.

The following two conditions must be met if the land use planning is to be useful:

1. The need for changes in land use or the action to prevent some unwanted changes which must be accepted by the people involved;

2. There must be the political will and ability to put the plan into effect.

Wherever these two conditions are not met and the problems are pressing, it may be appropriate to mount an awareness campaign or set up demonstration areas with the aim of creating the conditions necessary for effective planning. Our basic needs of air, water, food, clothing shelter and fuel must be met from the land which is in limited supply. As population and aspirations increase, the land becomes an increasingly scarce resource.

Land must change to meet new demands which may bring new conflicts among the competing uses of the land and among the interests of individual land users and the common good. Land taken for towns and industry is no longer available for farming. Likewise, the development of new farm land may compete with forestry, water supplies and wildlife.

Planning to make the best use of land is an established idea. Over the years, farmers have made plans season after season, deciding what to grow and where to grow it. Their decisions have been made according to their own needs, knowledge of the land & the technology, labour and capital available. As the size of the area, the number of people involved and the complexity of the problems increase, the need for information and rigorous methods of analysis and planning also increase.

However, land-use planning is not just farm planning on a different scale. It has a further dimension, namely the interest of the whole community. Planning involves anticipation of the need for change as well as reactions to it. Its objectives are set by social or political requirements which take into account of the existing situation. In many places, the existing situation cannot continue because the land itself is being degraded. Examples of unwise land use include the following:

(a) The clearance of forest on steep lands or on poor soils for which sustainable systems of farming have not been developed so far

(b) Overgrazing of pastures

(c) Industrial, agricultural and urban activities that produce pollution.

Degradation of land resources may be attributed to human greed, ignorance, uncertainty or lack of an alternative but essentially, it is a consequence of using land today without investing in tomorrow. Land-use planning aims to make the best use of limited resources by the following actions:

1. Assess the present, future needs and systematically evaluating the land's ability to supply them;

2. Identify and resolve the conflicts among competing uses, the needs of individuals and those of the community, and among the needs of the present generation and those of future generations;

3. Seek sustainable options and choose those which fully meet identified needs;

4. Plan to bring about desired changes; and,

5. Learn from experience.

There can't be a blueprint for change. The whole process of planning is iterative and continuous. At every stage, as better information is obtained, a plan may have to be changed to take account of it.

i) Goals of Land Use Planning

Goals of land use planning define what is meant by the "best" use of the land. They should be specified at the outset of a particular land use planning project. Goals may be grouped under the following three headings of efficiency, equity & acceptability and sustainability.

Efficiency: Land use planned must be economically viable. Therefore, one goal of development planning is to make an efficient and productive use of the land. For any particular land use, certain areas are better suited than others. Efficiency is achieved by matching different land uses with the areas that will yield the greatest benefits at the least cost, i.e., maximum benefit cost ratio.

Efficiency might mean different things to different people. To the individual land user, it means the greatest return on capital and labour invested or the greatest benefit from the land area available. Government objectives are more complex: they may include improving the foreign exchange situation by producing for export or for import substitution.

Equity & Acceptability: Land use must be socially acceptable. It should ensure food security, employment and income security in rural areas. Land improvements and redistribution of land may be undertaken to reduce inequality or to attack absolute poverty. One way of doing this is to set a threshold standard of living to which the target groups should be raised. Living standards may include levels of income, nutrition, food security and housing. Planning to achieve these standards involves the allocation of land for specific uses as well as the allocation of financial and other resources.

An example of acceptability is given here. Following the drought of 1973-74 and the subsequent famine, the Government of Ethiopia became more aware of the serious degradation of soil in the highlands.

An ambitious soil conservation programme which concentrated on protecting steep slopes by bunding and afforestation was launched. This had made a substantial impact on soil erosion but has not contributed much to in increasing agricultural production. Large-scale afforestation was also unpopular with local people because it reduced the area available for livestock grazing while forest protection implied denying access to the public for fuel wood collection. A balance between the competing requirements of conservation and production was clearly needed if popular support for soil conservation work was to continue without inducements such as the Food-for-Work Programme.

A land-use plan to conserve steeper slopes by restoring good vegetative cover through closure, followed by controlled grazing, was found to be more acceptable to the local people than large-scale afforestation applied in isolation.

Sustainability: Sustainable land use is that which meets the needs of the present while simultaneously conserving resources for future generations. This requires a combination of production and conservation. The production of the goods required by the people now need to be combined with the conservation of natural resources on which that production depends so as to ensure a continued production in the future.

A community that destroys its land will forfeit its future. Land use has to be planned for the community as a whole because the conservation of soil, water and other land resources is often beyond the means of individual land users.

ii) Trade-offs among Conflicting Goals of Land Use Planning

Clearly, there are conflicts between these various goals of land use planning. More equity may lead to less efficiency. In the short term, it may not be possible to meet the needs of the present without consuming resources such as burning oil or clearing areas of natural forest. Decision-makers need to consider the trade-offs between different goals. But if the system as a whole is to survive, the use of natural assets must be compensated by the development of human or physical assets of equal or greater worth.

Good information such as information about the needs of the people, about land resources and about the economic, social and environmental consequences of alternative decisions is always essential. The job of the land use planner is to ensure that decisions are made on the basis of consensus or acceptable degree of disagreement.

In many cases, planning the processes like introducing appropriate new technology can reduce the costs in trade-off. It can also help in resolving the conflict by involving the community in the planning process and by revealing the rationale and information on which decisions are based.

iii) The Focus of Land Use Planning

The following points constitute the focus of land use planning.

Land Use Planning is for the People: People's needs are the driving forces in the land use planning process. Local farmers, other land users and the wider community who depend on land must accept the need for a change in land use, as they will have to live with its results.

Land use planning must be positive and needs to be for the people’s betterment. The planning team must find out about people's needs and also about the local knowledge, skills, labour and capital that they can contribute. It must study the problems of existing land use practices and seek alternatives while drawing the public attention to the hazards or inconveniences of continuing with the present practices and to the opportunities for change.

Regulations to prevent people doing what they now do for pressing reasons are most likely to fail. Local acceptability is readily achieved by local participation in land use planning. The support of local leaders is essential. At the same time, the participation of agencies that have the resources to implement the plan is also important.

Land is not the Same Everywhere: Land is the other focus of land-use planning. Capital, labour, management skills and technology can be moved to where they are needed. On the other hand, land cannot be moved, and different areas present different opportunities and different management problems. The land resources are generally changing as it is obvious in the case of climate and vegetation. But the examples such as the depletion of water resources or the loss of soil by erosion or salinity remind us that resources can be degraded, many a times irreversibly. Good information about land resources is thus essential to land use planning.

Technology: A third element in land use planning is the knowledge of technologies like agronomy, silviculture, livestock husbandry and other means by which land is used. The technologies recommended must be appropriate technologies for which the users have the capital, skills and other necessary resources. New technologies may have social and environmental implications that should be addressed by the land use planner(s).

Integration: A mistake in early attempts at land use planning was to focus too narrowly on land resources without enough thought given to their possible use. Good agricultural land is usually also suitable for other competing uses. Land use decisions are not made only on the basis of land suitability but also according to the demand for products and the extent to which the use of a particular area is critical for a particular purpose. Planning has to integrate information about the suitability of the land, the demands for alternative products or uses and also the opportunities for satisfying those demands on the available land, now as well as in the future.

Hence, land use planning is not sectoral. Even where a particular plan is focused on one sector, e.g., small holder tea development or irrigation, an integrated approach has to be carried down starting from the strategic planning at the national level to the details of the individual projects and programs at district and local levels.

iv) Land Use Planning at Different Levels

Land use planning can be applied at three broad levels: national, district and local. These are not necessarily in that order. They correspond to the levels of government at which decisions about land use are taken.

Different kinds of decisions are taken at each level, where the planning methods and plan types also differ. However at each level there is a need for a land use strategy, policies that indicate planning priorities, projects that tackle these priorities and operational planning to get the work done smoothly, swiftly and cost-effectively.

The greater the interaction between the three levels of planning, the better for all. The flow of information should be in both directions. At each successive level of planning, the degree of details needed as well as the direct participation of the local people increase.

National Level Land Use Planning: At the national level, land use planning is concerned with the national goals and the allocation of resources. In many cases, national land use planning may not involve the actual allocation of land for different uses. In place of them, it may establish the priorities for district level projects. A national land use plan may cover:

1. Land-Use Policy related to balancing the competing demands for land among different sectors of the economy such as food production, export crops, tourism, wildlife conservation, housing & public amenities, roads, industry;

2. National Development Plans and Budget consisting of project identification and the allocation of resources for development;

3. Coordination of sectoral agencies involved in land use;

4. Legislation on such subjects as land tenure, forest clearance and water rights.

National goals are complex while policy decisions, legislation and fiscal measures affect a large population and wide areas. Decision makers can't possibly be specialists in all facets of land use. So the planners' responsibility is to present the relevant information so that the decision makers can both understand and act on it.

District Level Land Use Planning: District level refers not necessarily to administrative districts but also to land areas that fall between national and local levels. Development projects are generally at this level, where planning first comes to the grips with the diversity of the land and its suitability to meet the project goals. When planning is initiated nationally, national priorities need to be translated into local plans. Conflicts between national and local interests should be resolved. The kinds of issues tackled at this stage include:

1) The siting of developments such as new settlements, forest plantations, irrigation schemes, etc.;

2) The need for improved infrastructure such as water supply, roads, marketing facilities, etc.;

3) The development of management guidelines for improved types of land use on each type of land.

Local Level Land Use Planning: The local planning unit may be the village, a group of villages or a small watershed or a catchment. At this level, it is very easy to fit the plan to the people, making use of local people's knowledge and contributions. Wherever the planning is initiated at the district level, the programme of work to implement changes in land use or management has to be carried out locally. Alternatively, this may be the first level of planning, with its priorities drawn up by the local people. Local level planning is about getting things done on particular areas of land including what shall be done where and when, and who will be responsible.

Some of the examples of local level land use planning are:

1) Layout of drainage, irrigation and soil conservation works;

2) Design of infrastructure - road alignment and the siting of crop marketing, fertilizer distribution, milk collection or veterinary facilities;

3) Siting of specific crops on suitable land.

Requests at the local level, e.g., for suitable areas to introduce tobacco or coffee, must be met with firm recommendations. Planning at these different levels needs information at different scales and levels of generalization. Much of this information may be available in maps. The most suitable map scale for national level land use planning is one by which the whole country fits on to one map sheet, which may call for a scale ranging from 1:5 million to 1:1 million or larger. District level land use planning requires details to be mapped at about 1:50000, although some information may be summarized at smaller scales ranging to 1:250000.

For local level land use planning, maps in the scales ranging between 1:20000 and 1:5000 are found to be the best. Reproductions of air photographs can be used as base maps at the local level land use planning, since field workers and experience can show that local people can recognize where they are on the photos.

v) Land Use in Relation to Sectoral and Development Planning

Land use planning is non-sectoral by definition but, unless a special planning authority is set up, a land use plan must be implemented by sectoral agencies - in agriculture, forestry, irrigation, etc. Implementation will call for help from the different extension services.

There will be no clear boundary between land use planning and other aspects of rural development. For example, a desirable change in land use may be the introduction of a cash crop. Successful management may require the use of fertilizers. This cannot be done unless there are local centres for fertilizer distribution, effective advice on its use and a system of credit for its purchase.

Local services will be of no use without an adequate national distribution system and the sufficient manufacture or allocation of foreign currency for imports. Building a fertilizer factory and organizing national distribution are definitely not part of land use planning but they may be essential for the success of planned land use. On the other hand, the siting of local distribution centres in relation to population and suitable land could well be part of the work of a land use planner.

Hence, there is a spectrum of activities ranging from focus on the interpretation of the physical qualities of the land for which the land use planner will be largely responsible to activities that need a combined input with other technical specialists. Furthermore, where matters of national policy such as adequate prices for crops are prerequisites for successful land use, the job of the planner(s) is to mention it clearly.

vi) People Involved in Land Use Planning

Land use planning involves getting many different people to work together towards common goals. The following three groups of people are directly involved:

Land Users: These are the people living in the planning area whose livelihood depends wholly or partly on the land. They include not only the farmers, herders, foresters and others who use the land directly but also those who depend on these people's products such as operators in crop or meat processing, sawmills and furniture factories. The involvement of all land users in planning is very essential. Ultimately, they have to put the plan into practice and must therefore believe in its potential benefits as well as in the fairness of the planning process.

The experience and determination of local people in dealing with their environment are generally the most neglected in spite of being the most important resource. People will grasp development opportunities that they themselves have helped to plan more readily than any other schemes that are imposed on them. Without the support of local leaders, a plan is not likely to succeed.

Achieving effective public participation in planning is a real challenge. Planners have to invest the time and resources needed to secure participation through local discussions, by broadcasting and newspaper articles, through technical workshops and extension services. Imagination, a sincere interest in people and the land as well as a willingness to experiment mark the more successful efforts by the land users.

Decision Makers: Decision makers are those responsible for putting plans into effect. At the national and district levels, they will usually be government ministers. At the local level, they will be members of the local self-government or other authorities.

Generally, the planning team provides information and expert advice. The decision makers guide the planning team on key issues and goals while also deciding whether to implement plans and if so, which of the options presented need to be chosen. Although the leader of the planning team is in charge of the day-to-day planning activities, the decision maker(s) should be involved at regular intervals. Decision makers also have a key role in encouraging public participation through their willingness to expose their decisions and the way they are reached to public scrutiny.

Land Use Planning Team: An essential feature of land use planning is the treatment of land and land use as a whole. This involves crossing boundaries between disciplines like natural resources, engineering, agriculture and social sciences. Therefore teamwork is essential. Ideally a team needs a wide range of special expertise such as a soil surveyor, a land evaluation specialist, an agronomist, a forester, a range and livestock specialist, an engineer, an economist and a sociologist.

Such a range may be available only at the national level. At the local level, a more typical planning team may consist of a land use planner and one or two assistants. Each member must tackle a wide range of jobs and will subsequently need specialist advice. Government agency staff and universities may be useful sources of such advice or assistance.

Applications of Remote Sensing and Geographical Information System (GIS) in Watershed Planning

Remote sensing and GIS two of the important modern tools which have many applications in watershed planning. In this section, the remote sensing applications in watershed planning are discussed followed by the GIS applications.

Doppler RADAR (i.e., Radio Amplification Detection and Ranging) is used in the enhanced meteorological collection of data such as wind speed and direction within weather systems. By measuring the bulges of water caused by gravity, features on the seafloor to a resolution of about a mile are mapped. By measuring the height and wavelength of ocean waves, the altimeters measure wind speeds and direction and surface ocean currents and directions. Light detection and ranging (LIDAR) is used to detect and measure the concentration of various chemicals in the atmosphere, while airborne Heights of objects and features on the ground can be measured more accurately by LIDAR than radar technology.

Remote sensing of vegetation cover is a principal application of LIDAR. Simultaneous multispectral platforms such as the images from the Landsat remote sensing satellite have been in use since the 1970s. Maps of land cover and land use from thematic mapping can be used to find minerals, detect or monitor land usage and deforestation and examine the health of indigenous plants and crops, including entire farming regions or forests.

Within the scope of the combat against desertification, remote sensing allows to follow up and monitor risk areas in the long term, to determine desertification factors, to support decision-makers in defining the relevant measures of environmental management and to assess their impact on watershed planning. After the successful launching of India's remote sensing satellites viz., Bhaskara 1 and Bhaskara 2 in 1979 and 1981, respectively, India began developing an indigenous Indian Remote Sensing (IRS) satellite program to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, watersheds, marine fisheries and coastal management.

The Indian Remote Sensing satellites are the mainstay of National Natural Resources Management System (NNRMS) for which Government of India's (GoI) Department of Space (DOS) is the nodal agency, providing operational remote sensing data services. Data from the IRS satellites are received and disseminated. With the advent of high-resolution satellites, new applications in the areas of urban sprawl, infrastructure planning and other large-scale applications for mapping have been initiated. Remote sensing applications in the country, under the umbrella of NNRMS, now cover diverse fields within the domain of watershed planning and management such as pre-harvest crop area and production estimation of major crops, drought monitoring and assessment based on vegetation condition, flood risk zone mapping etc.

GIS has been widely used in characterization and assessment studies which require a watershed-based approach. Basic physical characteristics of a watershed such as the drainage network and flow paths can be derived from readily available Digital Elevation Models (DEMs) and data such as the United States Geological Survey's (USGS) National Hydrography Dataset (NHD) Program. This, in conjunction with precipitation and other water quality monitoring data from sources such as the Environmental Protection Agency's (EPA) BASINS (i.e., Better Assessment Science Integrating Point & Non-point Sources) database and USGS, enhances development of a watershed action plan and identification of existing and potential pollution problems in the watershed.

Data gathered from Global Positioning System (GPS) surveys and from environmental remote sensing systems can be fused within a GIS for a successful characterization and assessment of watershed functions and conditions.

- **Management Planning**

When faced with challenges involving water quality and quantity due to natural as well as human-induced hazards (e.g., droughts, hazardous material spills, floods, and urbanization), planning becomes extremely important so as to mitigate their impacts and ensure optimal utilization of the available resources. Information obtained from characterization and assessment studies, primarily in the form of charts and maps, can be combined with other datasets to improve understanding of the complex relationships between natural and human systems as they relate to land and resource use within watersheds. GIS provides a common framework [i.e., spatial location] for watershed management data obtained from a variety of sources. Because watershed data and watershed biophysical processes have spatial dimensions, GIS can be a powerful tool for understanding these processes and for managing potential impacts of human activities.

The modeling and visualization capabilities of modern GIS, coupled with the explosive growth of the Internet and the World Wide Web, offer fundamentally new tools to understand the processes and dynamics that shape the physical, biological and chemical environment of watersheds. The linkage between GIS, the Internet, and environmental databases is especially helpful in planning studies where information exchange and feedback on a timely basis is very crucial and more so when there are several different agencies and stakeholders involved.

- **Watershed Restoration (Analysis of Alternative Management Strategies)**

Watershed restoration studies generally involve evaluation of various alternatives and GIS provides the perfect environment to accomplish that efficiently and accurately. GIS has been used for restoration studies ranging from relatively small rural watersheds to heavily urbanized landscapes. Coupled with hydrodynamic and spatially explicit hydrologic/water quality modeling, GIS can assist in unified source water assessment programs including the total maximum daily load (TMDL) program. As an example, alternatives for restoring a waterbody or a watershed can be studied by creating digital maps that show existing conditions and comparing them to maps that represent the alternative scenarios. GIS can also provide a platform for collaboration among researchers, watershed stakeholders, and policy makers, significantly improving consensus building and offering the opportunity for collaborative work on interdisciplinary environmental policy questions. The integrating capabilities of a GIS provide an interface to translate and emulate the complexities of a real world system within the confines of a digital world accurately and efficiently.

- **Watershed Policy Analysis and Decision Support**

The field of watershed science, particularly watershed planning, is experiencing fundamental changes that are having profound impact on the use of computer-based simulation models in resource planning and management. On one hand, the dramatically increased availability of powerful, low-cost, and easy-to-use GIS software, and more extensive spatially referenced data, are making GIS an essential tool for watershed planning and management tasks. However, with this increased use has come an increased realization that GIS alone cannot serve all the needs of planning and managing watersheds. This realization has renewed resource planners' interest in development of decision support systems that combine GIS, spatial and non-spatial data, computer-based biophysical models, knowledge-based (i.e., expert) systems, and advanced visualization techniques into integrated systems to support planning and policy analysis functions. As a component of a spatial decision support system, GIS provides very powerful visualization facilities for display and manipulation, giving immediate intuitive evaluation capabilities to which a wide range of non-technical users and decision makers can relate to.

GIS can assist the decision maker in dealing with complex management and planning problems within a watershed, providing geo-processing functions and flexible problem- solving environments to support the decision research process.

A casual look at the environmental/ecological science literature reveals intense research activities in GIS-based watershed management and planning. The explosive growth in the use of GIS for the activities listed above is testimony to its rapid evolution into a complex array of applications and implementations.

Keywords: Land use, impact on watershed, land use planning, land use goals, land use trade-offs.

Module 3: Watershed Characteristics: Physical and Geomorphologic Factors affecting Watershed Management

Lesson 5 Watershed Characteristics: Classification and Measurement

5.1 Characteristics of Watersheds

A watershed is a basic unit of hydrological behavior. On the land surface, it is a geographical unit in which the hydrological cycle and its components can be analyzed. Usually a watershed is defined as the area that appears, on the basis of topography, to contribute all the water that passes through a given point of a stream. A watershed embraces all its natural and artificial (man-made) features, including its surface and subsurface features, climate and weather patterns, geologic and topographic settings, soils and vegetation characteristics, and land use (shown in figure 5.1). A watershed carries water "shed" from the land after rain falls and snow melts. Drop by drop, water is channeled into soils, groundwater, creeks, and streams, making its way to larger rivers and eventually the sea.

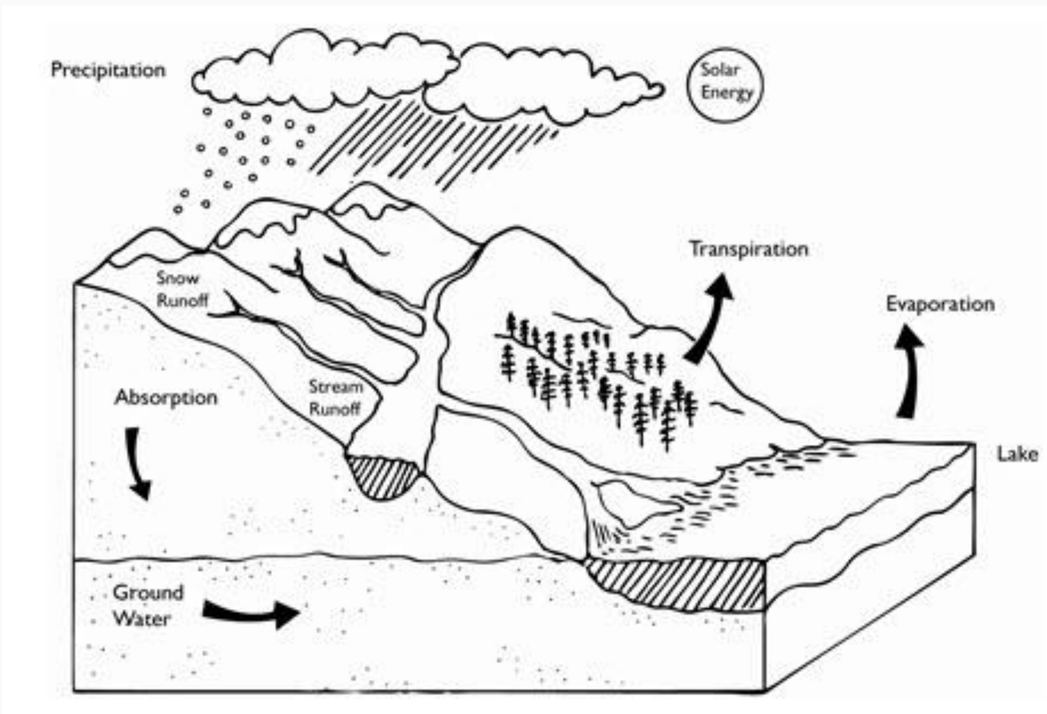


Fig. 5.1. A Watershed Illustration. (Source: Rees, 1986)

5.2 Classification of Watershed

Watersheds can be classified using any measurable characteristics in the area like- size, shape, location, ground water exploitation, and land use. However, the main classification of watershed is discussed broadly on the basis of size and land use. Two watersheds of the same size may behave very differently if they do not have similar land and channel phases. The descriptions of different watershed classifications are as below.

5.2.1 Size – The main implication of watershed size appears in terms of spatial heterogeneity of hydrological processes. The spatial variability of watershed characteristics increases with size, therefore, large watersheds are most heterogeneous. As the watershed size increases, storage increases. Based on size, the watersheds are divided into three classes.

1. Small Watersheds	< 250 km^2
2. Medium Watersheds	between 250 to 2500 km^2
3. Large Watersheds	> 2500 km^2

5.2.1.1 Small Watersheds: Small watersheds are those, where the overland flow and land phase are dominant. Channel phase is relatively less conspicuous. The watershed is highly sensitive to high-intensity and short-duration rainfalls.

5.2.1.2 Medium Watersheds: Being medium in size, the workability in these watersheds are easy due to accessible approach. Rather than size, shape of the watershed plays a dominant role. Overland flow and land phase are prominent.

5.2.1.3 Large Watersheds: These watersheds are less sensitive to high-intensity-rainfalls of short duration. The channel networks and channel phase are well-developed, and, thus, channel storage is dominant.

5.2.2 Land Use – Land use defines the exploitation (natural and human interactions) characteristics of watersheds which affect the various hydrological processes within the watershed. The watershed classification based on the land use can be given as below.

1. Agricultural
2. Urban
3. Mountainous
4. Forest
5. Desert
6. Coastal or marsh, or
7. Mixed - a combination of two or more of the previous classifications

5.2.2.1 Agricultural Watershed: Agricultural watershed is the watershed in which agricultural activities (crop cultivation) is dominant. It experiences perhaps the most dynamically significant land-use change. This usually leads to increased infiltration, increased erosion, and/or decreased runoff. Depression storage is also increased by agricultural operations. When the fields are barren, falling raindrops tend to compact the soil and infiltration is reduced. There is lesser development of streams in agricultural watersheds. The small channels formed by erosion and runoff in the area are obliterated by tillage operations. The soil structure is altered by regular application of organic and/or inorganic manure. This, in turn, leads to changed infiltration characteristics.

5.2.2.2 Urban Watershed: These are the watershed areas having maximum manipulation for the convenience of human being. These are dominated by buildings, roads, streets, pavements, and parking lots. These features reduce the infiltrating land area and increase imperviousness. As drainage systems are artificially built, the natural pattern of water flow is substantially altered. For a given rainfall event, interception and depression storage can be significant but infiltration is considerably reduced. As a result, there is pronounced increase in runoff and pronounced decrease in soil erosion. Thus, an urban watershed is more vulnerable to flooding if the drainage system is inadequate. Once a watershed is urbanized, its land use is almost fixed and its hydrologic behavior changes due to changes in precipitation.

5.2.2.3 Mountainous Watershed: Because of higher altitudes, such watersheds receive considerable snowfall. Due to steep gradient and relatively less porous soil, infiltration is less and surface runoff is dominantly high for a given rainfall event. The areas downstream of the mountains are vulnerable to flooding. Due to snow melt, water yield is significant even during spring and summer.

5.2.2.4 Forest Watershed: These are the watersheds where natural forest cover dominates other land uses. In these watersheds, interception is significant, and evapotranspiration is a dominant component of the hydrologic cycle. The ground is usually littered with leaves, stems, branches, wood, etc. Consequently, when it rains, the water is held by the trees and the ground cover provided greater opportunity to infiltrate. The subsurface flow becomes dominant and there are times when there is little to no surface runoff. Because forests resist flow of overland water, the peak discharge is reduced. Complete deforestation could increase annual water yield by 20 to 40 %.

5.2.2.5 Desert Watershed: There is little to virtually no vegetation in desert watersheds. The soil is mostly sandy and little annual rainfall occurs. Stream development is minimal. Whenever there is rainfall, most of it is absorbed by the porous soil, some of it evaporates, and the remaining runs off only to be soaked in during its journey. There is limited groundwater recharge due to occurrence of less rainfall in these watersheds.

5.2.2.6 Coastal Watershed: The watersheds in coastal areas may partly be urban and are in dynamic contact with the sea. Their hydrology is considerably influenced by backwater from wave and tidal action of the sea. Usually, these watersheds receive high rainfall, mostly of cyclonic type, do not have channel control in flow, and are vulnerable to severe local flooding. In these watersheds, the water table is high, and saltwater intrusion threatens the health of coastal aquifers, which usually are a source of the fresh water supply.

5.2.2.7 Marsh or Wetland Watershed: Such lands are almost flat and are comprised of swamps, marshes, water courses, etc. They have rich wildlife and plenty of vegetation. As water is no limiting factor to satisfy evaporative demand, evaporation is dominant. Rainfall is normally high and infiltration is minimal. Most of the rainfall becomes runoff. The flood hydrograph peaks gradually and lasts for a long time.

5.2.2.8 Mixed Watershed: These are the watersheds, where multiple land use/land cover exists either because of natural settings or due to a combination of natural and human interaction activities. In these watersheds, a combination of two or more of the previous classifications occurs and none of the single characteristics dominate the area. In India, most of the watersheds are of mixed nature of characteristics, where agriculture, forest, settlements (urban and rural) etc. land use occurs.

5.3 Watershed Characteristics: Physical and Geomorphologic Characteristics associated with Watersheds

Watershed geomorphology refers to the study of the characteristics, configuration and evolution of land forms and properties; developing physical characteristics of the watershed. It comprises of the characteristics of land surface as well as the characteristics of the channels within the watershed/basin boundary. These properties of watersheds significantly affect the characteristics of runoff and other hydrological processes. The principal watershed characteristics are:

1. Basin Area
2. Basin Slope
3. Basin Shape
4. Basin Length

Basin shape is reflected by a number of watershed parameters as are given below.

1. Form Factor
2. Shape Factor
3. Circularity Ratio
4. Elongation Ratio
5. Compactness Coefficient

Along with the surface characteristics of a watershed, the channel characteristics are important in transiting the runoff water from the overland region to channels (streams) and also from the channel of one order (primary) to the other higher order (e.g. river stream). The most common and important channel characteristics of the watersheds are:

1. Channel Order
2. Channel Length
3. Channel Slope
4. Channel Profile
5. Drainage Density

The quantification of these physical and geomorphologic properties of watershed/basin are important for estimating the watershed hydrologic processes.

5.4 Quantitative Characteristics of Watersheds

5.4.1 Physical Characteristics

Watershed geomorphology refers to the physical characteristics of the watershed. Basin area, basin length, basin slope, and basin shape are the physical characteristics of watersheds, significantly affecting the characteristics of runoff and other hydrologic processes. The quantification of these watershed/basin characteristics can be done as discussed below.

5.4.1.1 Basin Area: The area of watershed is also known as the drainage area and it is the most important watershed characteristic for hydrologic analysis. It reflects the volume of water that can be generated from a rainfall. Once the watershed has been delineated, its area can be determined by approximate map methods, planimeter or GIS.

Basin area is defined as the area contained within the vertical projection of the drainage divide on a horizontal plane. Watershed area is comprised of two sub-components; Stream areas and Inter-basin areas. The inter-basin areas are the surface elements contributing flow directly to streams of order higher than 1. Stream areas are those areas that would constitute the area draining to a predetermined point in the stream or outlet. For example, the stream area for first-order streams would be delineated by measuring the drainage area for each first-order channel. Horton (1945) inferred that mean drainage areas of progressively higher orders might form a geometric sequence. This characteristic was formulated as a law of drainage areas.

$$\bar{A}_w = \bar{A}_1 R_a^{w-1}$$

or

$$\log \bar{A}_w = \log \bar{A}_1 + (w-1)\log R_a$$

$$\log \bar{A}_w = \log\left(\frac{\bar{A}_1}{R_a}\right) + w \log R_a = a + bw$$

where A_w = mean area of basins of order w, A_1 = mean area of first-order basins, R_a = **Stream Area Ratio** and normally varies from 3 to 6

$$R_a = A_w / A_{w-1}$$

5.4.1.2 Basin Length: Length can be defined in more than one way (Fig. 5.2) -

1. The greatest straight-line distance between any two points on the perimeter
2. The greatest distance between the outlet and any point on the perimeter
3. The length of the main stream from its source (projected to the perimeter) to the outlet

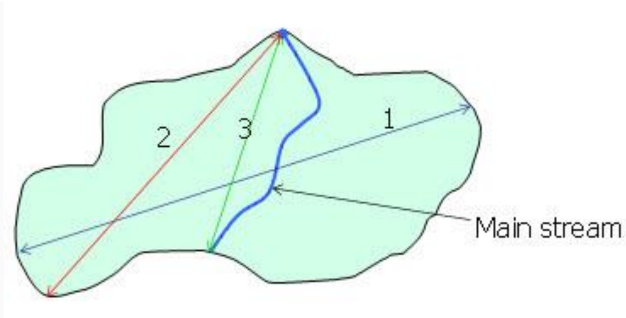


Fig. 5.2. Diagram Defining Basin Length. (Source: Zavoianu, 2011)

Conceptually the basin length is the distance traveled by the surface drainage and sometimes more appropriately labeled as hydrologic length. This length is generally used in computing a time parameter, which is a measure of the travel time of water through a watershed. The watershed length is therefore measured along the principal flow path from the watershed outlet to the basin boundary. Since the channel does not extend up to the basin boundary, it is necessary to extend a line from the end of the channel to the basin boundary. The measurement follows a path where the greatest volume of water would generally travel.

Basin length, L_b, is the longest dimension of a basin parallel to its principal drainage channel and Basin width can be measured in a direction approximately perpendicular to the length measurement. The relation between mainstream length and drainage-basin area for small watershed is given below; where L_b is in km and A in km^2.

$$L_b = 1.312\ A^{0.568}$$

5.4.1.3 Basin Slope: Watershed/basin slope affects the momentum of runoff. It reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the endpoints of the main flow path divided by the length. The elevation difference may not necessarily be the maximum elevation difference within the watershed since the point of highest elevation may occur along a side boundary of the watershed rather than at the end of the principal flow path. If there is significant variation in the slope along the main flow path, it may be preferable to consider several sub-watersheds and estimate the slope of each.

Basin slope has a profound effect on the velocity of overland flow, watershed erosion potential, and local wind systems. Basin slope S is defined as

$$S = h/L$$

where h = fall in meters, and L = horizontal distance (length) over which the fall occurs.

5.4.1.4 Basin Shape: Basin shape is not usually used directly in hydrologic design methods; however, parameters that reflect basin shape are used occasionally and have a conceptual basis. Watersheds have an infinite variety of shapes, and the shape supposedly reflects the way that runoff will "bunch up" at the outlet. A circular watershed would result in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis and having the same area as the circular watershed would cause the runoff to be spread out over time, thus producing a smaller flood peak than that of the circular watershed. A number of watershed parameters have been developed to reflect basin shape. Form factor, shape factor, circularity ratio, elongation ratio, and compactness coefficient are the typical parameters; important in defining the shape of a watershed/basin; and are discussed as below.

5.4.1.5 Form Factor: The area of the basin divided by the square of axial length of the basin; where value < 1

$$A/L^2$$

5.4.1.6 Shape Factor: The drainage area divided by the square of the main channel length; where value > 1

$$L^2/A$$

5.4.1.7 Circularity Ratio: The ratio of basin area to the area of a circle having the same perimeter as the basin; where value £ 1

$$12.57\ A/P_r^2$$

5.4.1.8 Elongation Ratio: The ratio of the diameter of a circle of the same area as the basin to maximum basin length; where value £ 1

$$1.128A^{0.5}/L$$

Compaction Coefficient: The perimeter of the basin divided by circumference of equivalent circular area; where value ^{3} 1

$$0.2821P_r/A^{0.5}$$

5.4.2 Channel Characteristics

The basin geomorphology plays an important role in the transition of water from the overland region to channels (streams) and also from the channel of one order to the other. It is easily determined by contour map and drainage map of the basin. Channel order, channel length, channel slope, channel profile, and drainage density are the most common channel characteristics, important in estimating the watershed hydrological processes and are discussed as below.

5.4.2.1 Channel Order: The first-order streams are defined as those channels that have no tributaries. The junction of two first-order channels form a second-order channel. A third-order channel is formed by the junction of two second-order channels. Thus, a stream of any order has two or more tributaries of the previous lower order. This scheme of stream ordering is referred to as the Horton-Strahler ordering scheme (Fig.5.3)

Fig. 5.3. The Horton-Strahler ordering scheme.

(Source: http://www.fgmorph.com/fg_4_8.php)

$$N_w = R_b^{W-w}$$

Or

$$\log N_w = W \log R_b - w \log R_b = a - b$$

$$(a= W \log R_b,\ b=w \log R_b)$$

where N_w = number of streams of order w; W = order of the watershed; and R_b = **Bifurcation Ratio** varies between 3 and 5. This law is an expression of topological phenomenon, and is a measure of drainage efficiency.

Bifurcation ratio is defined as the ratio between the number of streams of a particular order to the number of streams of one higher order.

$$R_b = N_w/N_{w+1}$$

5.4.2.2 Channel Length: This refers to the length of channels of each order. The average length of channels of each higher order increases as a geometric sequence. Thus, the first-order channels are the shortest of all the channels and the length increases geometrically as the order increases. This relation is called Horton's law of channel lengths and can be formulated as:

$$\bar{L}_w = \bar{L}_1 R_L^{W-1}$$

$$\bar{L}_w = \frac{L_w}{N_w}$$

where L_w = total length of all channels of order w; N_w = number of channels of order w; L_w = mean channel length of order w; L_1 = mean length of the first-order streams; R_L = **Stream-Length Ratio** generally varies between 1.5 and 3.5

$$R_L = L_w/L_{w-1}$$

5.4.2.3 Channel Slope: The channel slope is determined as the elevation difference between the endpoints of the main channel divided by the channel length.

5.4.2.4 Channel Profile: It includes the point of origin of the stream called the head, the point of termination called the mouth, and a decreasing gradient of the stream channel towards the mouth.

5.4.2.5 Drainage Density: Drainage density (D_d) is the measure of closeness of drainage spacing. It is the indication of drainage efficiency of overland flow and the length of overland flow as well as the index of relative proportions. It is defined as the length of drainage per unit area. This term was first introduced by Horton (1932) and is expressed as

$$D_d = L/A$$

or

$$D_d = \frac{\sum_{w=1}^{W} \sum_{i=1}^{N_w} L_{wi}}{A}$$

where L = Total length of all channels of all orders, A = Area; W = Basin order; N_w = No. of basin of different order.

Horton (1945) recommended using one-half the reciprocal of the drainage density to determine the average length of overland flow (L_0) for the entire drainage basin

$$L_0 = 1/(2\,D_d)$$

Where D_d basically describes the average distance between streams and L_0 approximates the average length of overland flow from the divides of the stream channels.

Keywords: Watershed Characteristics, Channel Characteristics, Watershed Classification, Morphometric Characteristics

Lesson 6 Importance of Watershed Properties for Watershed Management

6.1 Watershed Management

Watershed management is the study of the relevant characteristics of a watershed aimed at the sustainable distribution of its resources. Watershed management is an important aspect of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities within a watershed boundary.

6.1.1 Objectives of Watershed Management

The different objectives of watershed management programs are:

1. To control damaging runoff and degradation and thereby conservation of soil and water.
2. To manage and utilize the runoff water for useful purpose.
3. To protect, conserve and improve the land of watershed for more efficient and sustained production.
4. To protect and enhance the water resource originating in the watershed.
5. To check soil erosion and to reduce the effect of sediment yield in the watershed.
6. To rehabilitate the deteriorating lands.
7. To moderate the floods peaks at downstream areas.
8. To increase infiltration of rainwater.
9. To improve and increase the production of timbers, fodder and livestock resources.
10. To enhance the ground water recharge, wherever applicable.

6.2 Effect of Physical Properties on Watershed Management

Certain physical properties of watersheds significantly affect the characteristics of runoff and as such are of great interest in hydrologic analyses. The effects of each physical property on watershed management are described under the following contents.

6.2.1 Size

The size of the watershed has significant effect on its function. Size of watershed determines the quantity of rainfall received retained and disposed off (runoff). A small watershed is pronounced by overland flow which is main contributor to result a peak flow. While a large watershed has no overland flow significantly, but channel flow is the main characteristic. Large watersheds are also affected by basin storage. Watershed size plays a role here, as it interacts with the extent of land use changes, as well as factors that affect weather and climate. In smaller watersheds, the predominant interaction is between weather scale runoff-causing events and the storm hydrograph; whereas, in larger watersheds, the predominant interaction is between climate-scale runoff-causing events and the annual hydrograph. While large-scale events or land use changes may impact small watersheds and even the storm hydrograph in large watersheds, smaller, localized runoff-causing events tend to produce more intensive precipitation over restricted areas, thus having a greater impact on the storm hydrograph in small watersheds or on small tributaries to larger watersheds.

6.2.2 Shape

The common watershed may be of square, rectangular, oval, fern leaf shaped, polygon-shaped, circular or triangular type and long or narrow. Larger the watershed, higher is the time of concentration and more water will infiltrate, evaporate or get utilized by the vegetation. Reverse is the situation when watershed is shorter in length as compared to width. The shape of the land, determined by geology and weather, greatly influences drainage patterns. The density of streams and the shape of a watershed, in turn, affect the rate of overland runoff relative to infiltration. A circular watershed would result in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis and having the same area as the circular watershed would cause the runoff to be spread out over time, thus producing a smaller flood peak than that of the circular watershed.

6.2.3 Topography

Topographic configuration such as slope, length, degree and uniformity of slope affect both disposal of water and soil loss. Time of concentration and infiltration of water are thus a function of degree and length of slope of the watershed.

6.2.4 Drainage

Topography regulates drainage. Drainage density (length of drainage channels per unit area), length, width, depth of main and subsidiary channel, main outlet and its size depend on topography. Drainage pattern affect the time of concentration. A watershed with a high drainage density is characterized by quick response. Further, drainage cross section information is needed to determine the extent of flooding during high flows.

6.2.5 Area of the Watershed

The area of watershed is also known as the drainage area and it is the most important watershed characteristic for hydrologic analysis. It reflects the volume of water that can be generated from a rainfall. Determination of a workable size of watershed area is important for a successful watershed management programme.

6.2.6 Length of Watershed

Conceptually this is the distance traveled by the surface drainage and sometimes more appropriately labeled as hydrologic length. This length is usually referred for computing a time parameter, which is a measure of the travel time of water through a watershed (time of concentration). The watershed length is therefore measured along the principal flow path from the watershed outlet to the basin boundary. Since the channel does not extend up to the basin boundary, it is necessary to extend a line from the end of the channel to the basin boundary.

6.2.7 Slope of Watershed

Watershed slope affects the momentum of runoff. Both watershed and channel slope may be of interest. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the endpoints of the main flow path divided by the length. The elevation difference may not necessarily be the maximum elevation difference within the watershed since the point of highest elevation may occur along a side boundary of the watershed rather than at the end of the principal flow path. If there is significant variation in the slope along the main flow path, it may be preferable to consider several sub-watersheds and estimate the slope of each sub-watershed.

6.3 Effect of Geomorphologic Factors and Associated Processes on Watershed Management

6.3.1 Geological Rocks and Soil: Geological formation and rock types affect extent of water erosion, erodability of channels and hill faces, and finally sediment production. Rocks like shale's, phyllites erode easily whereas igneous rocks do not erode. Physical and chemical properties of soil, specially texture, and structure and soil depth influence disposition of water by way of infiltration, storage and runoff. Soil types influence the rate of water movement (lateral and vertical) in the soil. For example, finely grained soils, such as clays, have very small spaces between soil particles, inhibiting infiltration and thus promoting greater surface runoff. Conversely, coarse soils, such as sands, have larger pore spaces allowing for greater rates of infiltration and reduced runoff. Surface roughness, soil characteristics such as texture, soil structure, soil moisture and hydrologic soil groups also affect the runoff in various ways. For example; Soil properties affect the infiltration capacity. Soil particles are usually classified as clay ($d < 0.002$ mm), silt ($0.002 < d < 0.02$), or sand ($d > 0.02$ mm). A particular soil is a combination of clay, silt, and sand particles. Generally, soils with a significant portion of small particles have low infiltration capacity, whereas sandy soils have high infiltration capacity.

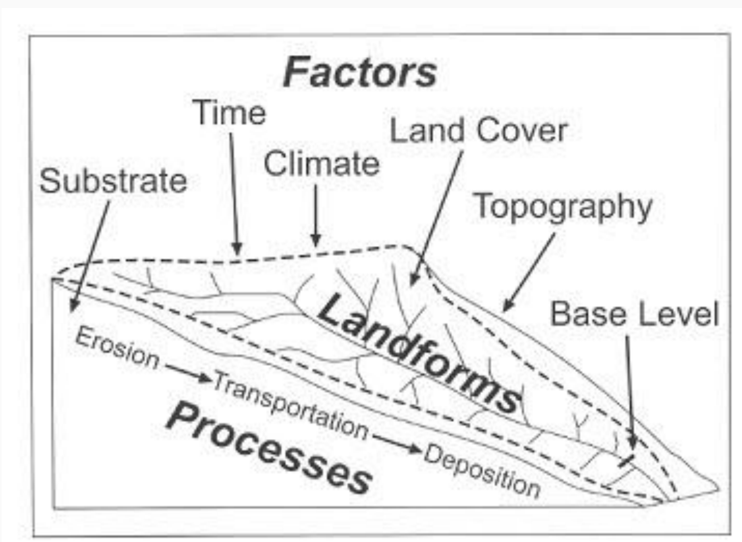


Fig. 6.1. Watershed Processes.

6.3.2 Climate: Climate parameters affect watershed functioning and its manipulation in two ways. Rain provides incoming precipitation temporally and spatially along with its various characteristic like intensity and frequency. The amount of rainfall and these parameters along with temperature, humidity, wind velocity, etc. regulates factors like soil and vegetation. Soil properties reflect the climate of the region. In the same way, the vegetation type of a region depends totally on the climate type.

6.3.3 Land Cover/ Vegetation: Depending upon the type of vegetation and its extent, this factor regulates the functioning of watershed; for eg. Infiltration, water retention, runoff production, erosion, sedimentation etc. Vegetation plays vital roles in the water cycle. It intercepts rainfall, impedes overland flow and promotes infiltration. Vegetation also uses water for growth. All of these factors reduce the quantity of runoff to streams. Vegetation binds and stabilizes soil, thereby reducing the potential for erosion. Vegetation also stabilizes stream banks and provides habitat for aquatic and terrestrial fauna. Vegetation functions to slow runoff and reduce soil compaction, allowing better percolation of rainfall into soils (infiltration) and groundwater recharge, which creates better water storage for summer base flows. In addition, the patterns, sizes, and composition of the vegetation affect reduction of soil erosion. Leaves and branches intercept the falling rain and reduce the effect of raindrop splash. Vegetative litter from dead leaves and branches builds up an organic surface that provides protection of the soil layer. Root systems also help to keep soil material stable from moving down slope.

6.3.4 Land Use: Type of land use, its extent and management are the key factors which affect watershed behavior. Judicious land use by users is of vital importance to watershed management and functioning. Change of land use within the watershed, especially within the variable source area, greatly affects the collection capacity and consequent runoff behavior of the watershed. The extent of land use change over the watershed has effects that are similar to the relationship between areal storm extent and watershed size. If the land use changes are local, then the impact of such changes is especially apparent in the storm hydrograph. The storm hydrograph is dominated by local characteristics. For land use changes that cover larger portions of the watershed, the impacts may also be observed in the annual hydrograph.

Keywords: Watershed Management, Watershed Processes, Geomorphologic Factors, Land Cover

Module 4: Hydrologic Data for Watershed Planning

Lesson 7 Importance of Watershed Planning

In this lesson, we shall discuss the definition and scope of watershed planning. Subsequently, we shall move on to the data required for watershed planning.

7.1 Definition and Scope of Watershed Planning

Planning is the process of formulation of a project consisting of practices/ strategies to achieve certain objective(s) by a definite time in future keeping the constraints in mind and considering all the available techniques. Watershed Planning pertains to the planning related to watershed(s), so as to achieve certain objective(s) related to watershed(s). Although planning is a continuous process, it is split into a time bound process to facilitate the evaluation of its impact over a time period. Like any planning, watershed planning also involves the integration of objectives, constraints, available techniques to improve the utility and effectiveness of the watershed(s) over a certain time period.

An Overview of Watershed Planning

Watershed planning involves the following three sets of factors:

1. Objectives must be established on the basis of a problem analysis;

2. Constraints to implementing a proposed management practice (i.e., project) need to be determined, including biophysical limitations, budget restrictions, and social/ cultural/ political conditions that are associated with the situation; and

3. There needs to be managerial techniques & capabilities available for implementing any proposed practice. Planning, therefore, involves the integration of objectives, constraints, and available techniques to improve the effectiveness and implementing watershed planning. The art of integration biological, physical and social sciences is emphasized here since planning is as much an art as it is a science. Each watershed related issue has its own unique set of technical characteristics and each management practice can require different technical approaches. The same does not hold for any general process of planning. A similar planning process can be used regardless of the type or number of watershed management practices being proposed. It is only the emphasis placed on each step in the process that will differ.

A basic principle in assessing both the positive and negative impact of watershed planning project is the application of what is called the 'with-and-without concept'. In other words, we want to assess the changes that occur with and without any given watershed planning project. For example, when we talk about reducing sedimentation in a downstream reservoir, we are referring to the difference in sedimentation with and without erosion-control practices. Sedimentation can still be occurring with a given erosion-control practice but at a slower rate than without the practice. Not to be neglected, however, are the effects of the project on upload productivity where soil losses are avoided (and productivity is sustained over that period without the project).

A related principle is that the losses prevented by a watershed planning practice have to be treated in a similar way as the gains obtained when applying the with-and-without concept. For example, sedimentation in the reservoir can still be increasing following implementation of the planning project but at a slower rate than without the project. This is an important principle because so many of the benefits of integrated watershed management are losses prevented rather than net gains.

Steps in the Watershed Planning Process

The watershed planning process is likely to involve the following five sequential steps:

1. Monitor and evaluate past activities and identity problems and opportunities.

2. Identity the main characteristics of the problems confronted, opportunities to resolve these problems, and establish the objectives and constraints to accomplish these objectives. This eventually leads to the formulating strategies for action.

3. Identify alternative management practices (i.e., projects) to implement the formulated strategies within the limits of the constraints.

4. Appraise and evaluate the impacts of the alternative management practices (i.e., projects) including the environmental, social, and economic effects and assess the uncertainty associated with the impacts.

5. Rank or prioritize the alternative management practices and recommend the project to be implemented when a recommendation is requested.

Evaluating Past Activities and Identifying Problems/ Opportunities in Watershed Planning

The planning process has no beginning and no certain end. A logical starting point, however, is before a problem is identified through monitoring consisting of careful observation and measurement and evaluation of resource responses to climate, management, or the lack of management. Often, no formal monitoring or evaluation system is used to obtain the information that leads to identification of a watershed issue of concern and eventual action. Instead, problems are often observed only after they have occurred such as when the scars of erosion begin to appear on a landscape, when a reservoir is silting up rapidly, or when floods and/or droughts become more frequent. Opportunities to mitigate the problems are then identified.

Regardless of how watershed related problems and opportunities are recognized, their articulation becomes one of the first steps in watershed planning. In many instances, more than one solution to a problem is possible. For example, insufficient water supplies for downstream users might be enhanced by increasing the flows of water from an upstream watershed or developing reservoirs downstream to store water for future use. In other cases, some solutions are mutually exclusive with one action precluding another. While the specific actions taken in each case might differ, the planning process remains largely the same.

Establishing Objectives, Identifying Constraints, Developing Strategies for Watershed Planning

The next stage in the watershed planning process involves establishing objectives and identifying constraints in developing strategies to solve the problems or to take advantage of the opportunities. Objectives generally evolve from the watershed problem analysis. Statements of objectives indicate that there is a need to develop an effective response for overcoming or presenting the problem. A single objective or set of multiple objectives are then translated into actions that can be constrained by the risk involved in the approaches adopted, the level of economic resources necessary, and the level of success in accomplishing other objectives.

Once objectives have been established and constraints identified, a general strategy for action needs to be developed. The important thing here is not necessarily the strategy statement itself but the process by which it was developed. If we only look at the problem statement, we likely could think of a number of alternatives to solve the problem confronted. For example, we could suggest a watershed management practice involving the conversion of tine forest type to another to increase stream flows. In other cases, the best strategy might be to leave the situation alone and spending our resources elsewhere, such as developing groundwater resources or diverting water from a water-rich to a water-scarce area.

Identifying Alternative Ways to Implement the Watershed Planning Strategy

After an acceptable strategy has been developed, the planners get down to the details of evaluating the alternative projects that could be implemented. The need here is to identify the possible watershed management practice or project that could be used to successfully implement the strategy to obtain the results desired. This is where the technical specialists, social scientists, decision makers and others dealing with socioeconomic/ cultural issues come into the picture. The task of the planner is to identity the possibilities and the array of options that are available within the constraints and circumstances surrounding the watershed management project.

Appraising Watershed Planning Strategy Alternatives

While alternatives are being developed, they are also being appraised (i.e., evaluated). In its broadest meaning, the term appraisal refers to the process of identifying, defining, and quantifying the likely impacts of the watershed management practices. The separation of these impacts into economic/ financial, environmental and social effects relates to the different types of effects that a change in the watershed management can cause.

Making Appraisals Useful

Appraisals of proposed watershed management practices and projects are useful only if they provide timely information of relevance to the planner, manager, and decision maker. A distinction often needs to be made between the technical analyst's considerations in choosing an appraisal procedure and the people's viewpoint of what characterizes an acceptable appraisal of the alternatives. A task of the planner is to bring these two perspectives together in the final appraisals.

Appraisals of watershed management practices are pursued generally in sequential levels of analysis because the resources available for these appraisals are limited in most cases. Starting with only two alternatives, for example, one management action and the other option to do nothing, is generally too restrictive. The preferable approach is to start with a number of alternative management practices and then to narrow them down systematically in stages. This approach also encourages the introduction of economics into the planning process rather than tackling it on at the end of the planning process through a feasibility study.

Risk and Uncertainty in Watershed Planning Strategy Appraisals

A planner faces a situation of uncertainty more than the risk with the appraisals of most watershed management practices. One can apply probabilities to various outcomes in the case of risk, while measures of the probability of occurrence cannot be generated in the case of uncertainty. One can also develop subjective probability estimates for different aspects of the management practices in a situation of uncertainty. However, such estimates might do more harm than good since subjectivity in the planning process should not be hidden. Hence a sensitivity analysis is suggested, using which an analysis of how the measures of worth (i.e., value) or desirability of the alternative management practices change under different assumptions concerning the values of key parameters of the practices to be appraised.

Recommending Action

In some instances, a planner's task stops when the alternatives and the implications of risk and uncertainty for the alternatives have been evaluated. In other cases, however, the planner might be asked for recommendations on which of the alternative management practices should be selected for implementation and the timing and approach to its implementation. To facilitate this selection, the appraisal results can be presented to the decision makers in different ways depending on the planning situation. Offering a ranked set of alternatives is often preferable or perhaps several rankings utilizing different appraisal criteria should be presented. Importantly, only the responsible decision maker can decide ultimately which alternative or set of alternatives need to be chosen.

Watershed Planning as a Continuous Process

Watershed Planning is a continuous process with information concerning results of the watershed management actions taken and emerging problems continuously fed back into the process. This information is then used to suggest possible changes in the ongoing watershed management practice(s). The process of collecting and disseminating information relating to ongoing management practices is part of the monitoring and evaluation effort. This Continuous process leads to valuable interactions among the planners, technical personnel and managers of watersheds and relevant decision makers.

7.2 Data Required for Watershed Planning

The data required for watershed planning can be grouped as follows:

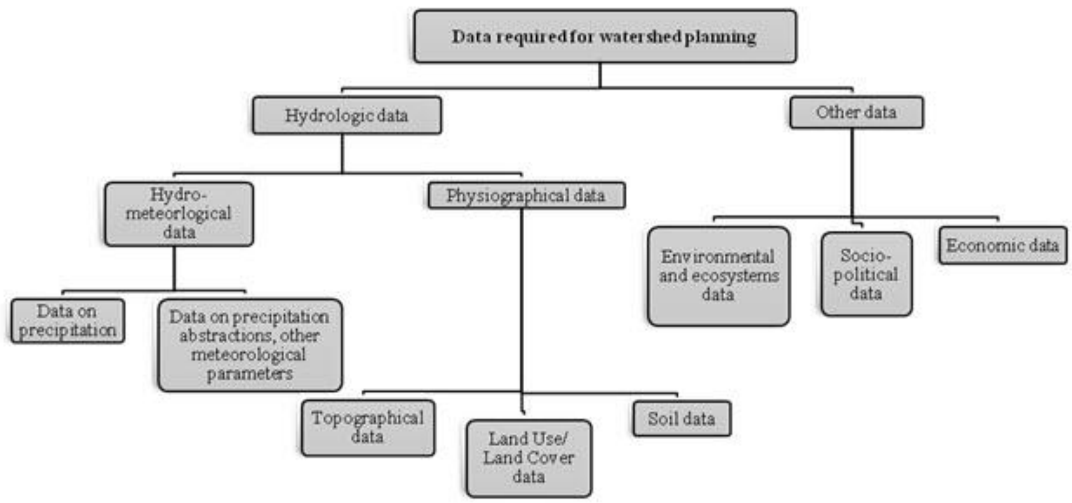


Fig. 7.1. Grouping of the data required for watershed planning.

To know what data is available and how to get district-level data or information, it is necessary to become familiar with state, district, block and city/village level agencies. It is important to understand the authority and jurisdictions of the agencies in the watershed. This understanding facilitates the search for information and also provides valuable insight into the activities which are most likely to be implemented in the watershed. For example, it is important that the watershed plan identify control actions or management practices that people or agencies in the watershed have the authority and jurisdiction to implement. This will help in selecting the management strategies that can be adopted at the local level with the existing authorities.

Other "local" Sources of watershed data include universities and environmental non-governmental organizations (NGOs). Although a university or a NGO might not be located in or near the watershed, it might be active in the watershed and hold relevant local data.

Universities can be important sources for demographic, climate, or spatial data. Many state climatology offices are associated with universities. In addition, university faculty or students regularly conduct environmental research related to their fields of study or expertise, sometimes providing data and information relevant to the local watershed planning efforts (e.g., water quality, soils, and land use changes). However, it might be difficult to identify any relevant studies and data without already knowing the specific project or contact. Universities have a variety of schools and departments, and no two are likely to be organized in the same way. Hopefully, if a university has conducted research on a watershed, one or more of the key stakeholders will be aware of it and can lead you in the right direction.

NGOs often may have information on stream condition, habitat and long-term changes in watershed characteristics (e.g., water quality). As with university information, it is difficult to identify NGOs active in the watershed and relevant data without already knowing about their existence. Typically, if a NGO has an active interest in a watershed or has collected data, the stakeholders involved will know about it.

State Sources of Information

State environmental agencies routinely collect biological, hydrological, and water quality information for the waters in the state. State environmental agencies include several divisions and offices, many of which might be useful in characterizing the watersheds and some of them might be irrelevant. Environmental agencies typically have a division or office dedicated to watershed or water quality issues. A variety of other offices deal with environmental issues (e.g., wastewater, mining, air quality) and they may have information relevant to a watershed. It is useful to visit either to the concerned state environmental agency's office physically or visit its website to learn what types of offices work in a state and identify potential sources of relevant information.

In addition to the state environmental agencies, several other state agencies might be useful in characterizing the watershed and the potential sources. For example, the Department of Agriculture can provide agricultural statistics for the districts and blocks in a state.

Union Government Sources of Information

With the various offices, divisions, and agencies in the union or central government, there are several likely sources of every type of data used in watershed characterization. The remainder of this lesson identifies these data types and their corresponding sources.

7.2.1 Hydrologic Data Required

In this section, we will be discussing the hydrologic data required in watershed planning. As indicated already in Fig. 7.1, hydrologic data includes hydro-meteorological data and physiographical data. Hydro-meteorological data includes data on precipitation, abstractions of precipitation and other meteorological parameters, which influence the watershed management. Physiographical data broadly includes topographic data, land use-land cover data and soil data.

Information on the hydrology of the watershed is necessary to visualize and document the waterbody network, including the locations of all the water bodies and how they are connected to one another. When water flows through the stream network, it carries pollutant loads, and therefore the conditions of upstream segments can significantly affect the conditions downstream. When evaluating source impacts on watershed conditions, it is crucial to understand the hydrologic network of the watershed. Not only is this information important for characterizing the watershed, evaluating sources and water body conditions, but it is also a necessary input in the watershed planning.

Climate

Local climate data are often needed in watershed planning to help understand the local water budget for the region and also for modeling purposes. Hourly or daily precipitation data, as well as temperature, evaporation and wind speed are necessary for simulating rainfall-runoff processes in watershed models. However, if weather data are being used only to generally characterize weather patterns in the watershed, daily or monthly averages are sufficient. Daily and monthly temperature and precipitation data are generally available online in the Meteorological Department website. The data are available by station through the state climate data centers and sometimes with other state departments such as agriculture department, irrigation department etc.

Physiographical Data

Rivers and streams change in direct response to climate and human activities in the watershed. Increasing impervious surfaces like pavement, clearing forests and other vegetation, compacting soils with heavy equipment, and removing bank vegetation typically result in an adjustment in the pattern, profile, or dimensions of a river or stream. Assessments of river and stream geomorphology can help determine (1) the prior or "undisturbed" morphology of the channel; (2) current channel conditions; and (3) how the stream is evolving to accommodate changes in flow volumes/ timing/ duration, channel alteration, and so forth. This information is also helpful in analyzing the movement of sediment downstream from upland sources and channel banks.

Geo-morphological studies focus on characterizing the drainage area, stream patterns (single/ multiple channels, sinuosity, meander width), the longitudinal profile (gradient), channel dimensions (e.g., width/depth ratio relative to bank full stage cross section, entrenchment), bank and channel material, riparian vegetation, channel evolution trends, and other features. Because of the fairly recent development and application of analytical tools to assess and classify rivers and streams and explore the relationships among variables affecting their physical conditions, geo-morphological data are generally not available for many river systems.

Physical and Natural Features

The information on the physical and natural features of the watershed, including the type of data are available, their importance and their locations of availability need to be collected from appropriate data sources. Information on the physical and natural characteristics of the watershed will define the watershed boundary and provide a basic understanding of the watershed features that can influence watershed sources and pollutant loading.

Watershed Boundaries

Defining the geographic boundaries of the watershed planning effort is the first step in gathering and evaluating data. Up to this point, the watershed boundary might have been a theoretical boundary. We need to know for what watershed we are planning, but we might not have documentation of its physical boundary and the water bodies contained in it. Depending on the size of the watershed, its boundary might already have been delineated by a state or a union government agency.

Floodplain Maps

This information is also relevant to water quality protection and restoration activities because floodplains, when inundated, serve many functions and provide important habitats for a variety of fish and wildlife. Floodplains are important for spawning and rearing areas. Floodplain wetlands act as nutrient and sediment sinks, which can improve water quality in streams. They also provide storage that can decrease the magnitude of floods downstream, which can benefit fish and land owners in riparian areas. In addition, streams that are actively connected to their floodplains are less prone to severe erosion. Therefore, it is important to incorporate protection of these benefits of floodplain areas into the watershed management planning.

Topography

Characterizing the topography or natural features of the watershed can help to determine possible sources of pollution. For example, steep slopes might contribute more sediment loads to the water body than flat landscapes. Topographical information is also needed in many watershed models to route movement of runoff and loading across the land and to the water body. Digital elevation models (DEMs) are grid-based Geographic Information System (GIS) coverage that represent elevation. They can be displayed in a GIS and are used for delineating watersheds and displaying topography. One DEM typically consists of thousands of grid cells that represent the topography of an area. DEMs are available with 10 m, 30 m, and 90 m cell sizes [commonly known as map resolution]. The smaller cell sizes represent smaller areas and provide more detailed and accurate topographic data. However, GIS coverage with small grid cell sizes often have large file sizes and can be difficult to work with over large areas. The 30 m and 10 m DEMs are appropriate for smaller watersheds.

Water Body and Watershed Conditions

Several sources can provide helpful information on the current condition of the water bodies in your watershed, including whether they meet water quality standards and support designated uses. This information provides a general overview of the health of the water bodies in your watershed and what uses should be supported.

Wetland Assessments

Many programs use a wetland assessment or survey to serve as a baseline for future management activities. The survey might include global positioning system (GPS) coordinates of sample plots, a general plot description and condition assessment (i.e., land use impacts), canopy information or measurements, and digital pictures of sampling areas. In addition, the survey might document flora and fauna diversity observations. These datasets can be used to help characterize the watershed and identify wetland areas. In addition, State Wetland Conservation Plans are strategies for states to achieve no net loss and other wetland management goals by integrating regulatory and non-regulatory approaches to protecting wetlands.

Watershed Related Reports

In addition to state or local water quality reports, there might be existing watershed-related studies produced for all or a portion of your watershed under various state, local, or central [i.e., union] government programs. These studies might have a narrower focus than the watershed plan (e.g., source water, specific pollutant) or be out-of-date, but they can provide information on available data, potential pollutant sources, and historical water quality and watershed conditions. This section provides a few examples of current or recent programs that might provide relevant watershed information. This is not a comprehensive list of the programs or reports that could be available for a watershed, but it does highlight commonly used plans that can provide information relevant to watershed planning.

Land Use and Land Cover Data

Evaluating the land uses of a watershed is an important step in understanding the watershed conditions and source dynamics. Land use types (together with other physical features such as soils and topography) influence the hydrologic and physical nature of the watershed. In addition, land use distribution is often related to the activities in the watershed and therefore to the pollutant sources. Sources are often specific to certain land uses, providing a logical basis for identifying or evaluating sources. For example, sources of nutrients such as grazing livestock and fertilizer application associated with agricultural land uses would likely not contribute to loading from other land uses such as urban or forest land uses. Likewise, urban land uses typically have specific pollutants of concern (e.g., metals, oil and grease) different from those associated with rural land uses. Evaluating land use distribution and associated sources also facilitates identifying future implementation efforts because some management practices are most effective when applied to a certain land use.

This section discusses some of the most common sources of land use data. Typically, land use and land cover data are obtained from aerial photographs, satellite images and ground surveys. Because in some areas land uses continually change, it is important to keep in mind the type and date of available land use data when reviewing the sources of land use data for use in developing the watershed plan.

Soils

Soils can be an important factor in determining the amount of erosion and storm water runoff that occurs in your watershed. Soils have inherent characteristics that control how much water they retain, how stable they are, or how water is transmitted through them. Understanding the types of soils in your watershed and their characteristics helps to identify areas that are prone to erosion or are more likely to experience runoff.

7.2.2 Other Relevant Data Required

In this section, we will be discussing the other relevant data required for watershed planning. As already indicated in Fig. 7.1, the other relevant data essentially includes the environmental & ecosystems data, socio-political data and economic data.

Environmental and Ecosystems Data

The environmental data includes information on habitat, silviculture sources, cropland sources, fish & wildlife, livestock sources, biological data, water quality standards and pollutant sources. The pollutant sources include point and non-point pollution sources.

Ecosystem management requires that all aspects of a watershed (e.g., land, water, air, plants, and animals) be managed as a whole, not as separate and unrelated parts. Ecosystem management plans protect the viable populations of native species and the natural rhythms of the natural range of variability of the ecosystem. They allow public use of resources at levels that do not result in the degradation of the ecosystem. Successful, effective ecosystem management requires partnerships and interdisciplinary teamwork within the watershed.

There are a number of good resources for developing an ecosystem management plan. Land uses are an important factor influencing the physical conditions of the watershed, as well as an indicator of the types of sources active in the watershed. Together with land use characteristics, population can help you to understand the potential growth of the area and possible changes in land uses and sources.

Habitat

When characterizing the watershed, it is important to gather data not only to identify potential pollutant sources but also to identify areas for conservation, protection, and restoration. Maintaining high-quality wildlife and aquatic habitat is an important goal when developing watershed plans. High-quality, contiguous habitats and their buffers as well as small pockets of critical habitat, help prevent water quality damage and provide protection for both terrestrial and aquatic organisms.

Silviculture [i.e., limited area afforestation] Sources

Silviculture can be a significant source of sediment and other pollutants to a water body. The primary silviculture activities that cause increased pollutant loads are road construction and use, timber harvesting, site preparation, prescribed burning, and chemical applications. Without adequate controls, forestry operations can cause in stream sediment concentrations and accumulation to increase because of accelerated erosion. Silviculture activities can also cause elevated nutrient concentrations as the result of prescribed burns and an increase in organic matter on the ground or in the water. Organic and inorganic chemical concentrations can increase because of harvesting and fertilizer and pesticide applications. Harvesting can also lead to in stream accumulation of organic debris, which can lead to dissolved oxygen depletion. Other water body impacts include increased temperature from the removal of riparian vegetation and increased stream flow due to increased overland flow, reduced Evapo-transpiration, and runoff channeling.

Cropland Sources

Depending on crop type and management, croplands are a potentially significant source of nutrients, sediment and pesticides to watershed streams. Cropland can experience increased erosion, delivering sediment loads and attached pollutants to receiving water bodies. Fertilizer and pesticide application to crops increases the availability of these pollutants to be delivered to water bodies through surface runoff, erosion attached to sedimentation and ground water. If cropland is an important source of pollutants in the watershed, it is useful to determine the distribution of cropland as well as the types of crops grown. Land use coverage for the watershed can identify the areas of cropland in the watershed. The number of malfunctioning Systems can also be estimated by applying an appropriate failure rate from literature.

Fish and Wildlife

Identifying the types of wildlife and their habitat requirements in the watershed can help to identify areas for protection and conservation in the watershed plan. Previous watershed reports might provide information on wildlife in the watershed. In addition, local and state fish and wildlife offices can provide information on wildlife species and distribution in their jurisdictions.

Understanding the types of wildlife in the watershed can not only identify critical habitat areas to protect but sometimes also identify pollutant sources affecting water quality. For example, birds frequenting water can be a significant source of bacteria and nutrients to reservoirs and lakes. Although wildlife is an important component of the watershed ecology and should be protected, it is important to understand their impact on water body conditions when developing watershed plan.

Livestock Sources

In watersheds with extensive agricultural operations, livestock can be a significant source of nutrients and bacteria and can increase erosion. If available, site-specific information on livestock population, distribution, and management should be used to characterize the potential effects from livestock activities.

Biological Data

Aquatic life (e.g., fish, insects, plants) are affected by all the environmental factors to which they are exposed over time and integrate the cumulative effects of pollution. Therefore, biological data provide information on disturbances and impacts that water chemistry measurements or toxicity tests might miss. This makes these data essential for determining not only the biological health but also the overall health of a water body.

Water Quality Standards

We need to obtain the current water quality standards for the water bodies in the watershed to understand for what uses the water bodies should be protected and to compare in stream monitoring data with standards to evaluate the damage. We should also document the designated uses for the water bodies and any relevant criteria for evaluating the water body conditions.

Pollutant Sources: Point Sources and Non-point Sources

Pollutants can be delivered to water bodies from various point and nonpoint sources. Identifying and characterizing sources are critical to the successful development and implementation of a watershed plan and the control of pollutant loading to a stream. Characterizing and quantifying watershed pollutant sources can provide information on the relative magnitude and influence of each source and its impact on in stream water quality conditions. Watershed-specific sources are typically identified and characterized through a combination of generation, collection, and evaluation of GIS data, in stream data, and local information. However, some common types of pollutant sources might be contributing to watershed problems, and this section discusses information available to characterize them.

The discharge of pollutants from point sources, such as pipes, outfalls, and conveyance channels is generally regulated through permits. On the other hand, nonpoint Source pollution typically comes from many diffused sources, not specific pipes or conveyances. Nonpoint source pollution is caused by rainfall or snowmelt moving over and through the ground, carrying natural and man-made pollutants and finally depositing them into surface waters. Surface water runoff represents a major nonpoint source in both urban and rural areas. Runoff from urban watersheds can deliver a variety of pollutants from roadways and grassed areas, and rural storm water runoff can transport significant pollutant loads from crop-land, pastures, and livestock operations. Natural background sources like wildlife or geology (e.g., soils high in iron) can also contribute loadings and might be particularly important in forested or less-developed areas of the watershed. Additional nonpoint sources include on-site wastewater systems (septic tanks, cesspools) that are poorly installed, faulty, improperly located, or in close proximity to a stream and illicit discharges of residential and industrial wastes as well as open defecation in developing or under-developed countries.

Socio-Political Data

Socio-political or demographic data include information on the people in the watershed, such as the number of persons or families, commuting patterns, household structure, age, gender, race, employment, and educational information. This information can be used to help design public outreach strategies, identify specific sub-populations to target during the implementation phase, or help determine future trends and needs of the populations. Local governments usually collect demographic information on their communities either through decennial census operations or through the planning or economic departments.

Economic Data

Many watersheds contain economic data such as land owned by a variety of parties, including private citizens and union/ state/ district/ block government agencies. Although information on land ownership in a watershed might not help to characterize the physical nature of the area, it can provide insight into sources of information for characterizing the watershed or identifying pollutant sources. It can also be very useful in identifying watershed planning implementation opportunities.

Local Ordinances

Local ordinances that establish construction-phase erosion and sediment control requirements, river corridors and wetland buffers, and other watershed protection provisions are often included as part of a watershed plan implementation strategy. We need to check and see what current ordinances are in place for the communities involved through the planning or pollution control departments.

Land Management Practices

Information on how the land is managed in a watershed is helpful to identify both current control practices and potential targets for future management. This information will not only support the characterization of the watershed but also will be important in identifying current watershed sources, future management efforts, and areas for additional management efforts.

Lesson 8 Utility of Hydrologic Data in Watershed Planning

As already mentioned in Lesson 7, relevant data related to various fields is required for watershed planning. Since the hydrological data is the most significant among all the required data, in this lesson we shall focus on it by initially discussing the utility of hydro-meteorological data in watershed planning. Subsequently, we shall move on to the utility of physiographical data in watershed planning.

8.1 Use of Hydro-meteorological Data in Watershed Planning

Hydro-meteorological data is an important hydrologic data. It includes data on precipitation, abstractions of precipitation and other meteorological parameters which influence the watershed management. Depending on the objectives of watershed planning, the hydro-meteorological data requirement will be different. The watershed planning and management may generally have any one or more of the following objectives along with any one of the following listed features [as given in Table 8.1]:

Table 8.1. Watershed planning objectives and the features associated with them

Watershed planning objective	Associated features
1. Hydrological characterization:	a) Watershed planning, b) General water balance;
2. Flood management and control:	a) Structures [i.e., dams, river training etc.], b) Flood forecasting & warning, c) Flood plain zoning & flood frequency estimation, d) Coastal inundation;
3. Irrigation and drainage:	a) Supply, b) Demand scheduling;
4. Groundwater planning:	a) Recharge, b) Flooding management;
5. Water quality management:	a) Pollution control, b) Dilution, c) Salinity & sedimentation management;

6. Fisheries and eco-conservation: a) Hydro-ecology,

b) Hydro-morphology;

According to the purpose as well as the associated feature, the hydro-meteorological data requirement will be as listed in Table 8.2:

Table 8.2. Watershed planning objective, feature(s) and relevant hydro-meteorological data required

Watershed planning Objective & feature as given in Table 8.1	Hydro-meteorological data requirement
1 a. and 1 b.	Precipitation, temperature, humidity, wind speed.
2 a.	Precipitation, temperature, humidity, wind speed & direction.
2 b.	Precipitation, temperature, evapo-transpiration, synoptic information, forecasts & alerts, medium & long range forecasts.
2 c.	Precipitation, temperature, evapo-transpiration, synoptic information.
2 d.	Wind speed & direction, synoptic information, forecasts & alerts.
3 a. and 3 b.	Precipitation, temperature, humidity, wind speed, medium & long range forecasts.
4 a and 4 b.	Precipitation, temperature, humidity, wind speed, medium & long range forecasts.
5 a., 5 b. and 5 c.	Precipitation, temperature, humidity, wind speed, forecasts & alerts.
6 a. and 6 b.	Precipitation, temperature, humidity, wind speed, medium & long range forecasts.

Use of Hydro-Meteorological Data in Hydrological Characterization

The primary concern of a water management agency is with rainfall, river flow and groundwater, and the focus of their activity will be the measurement and analysis of these variables. Historically the main climate variable collected by a water management agency is rainfall, as this, even in the absence of water management or catchment models, will provide an intuitive, subjective or qualitative assessment of the interaction between rainfall, river and groundwater. For the most part, rainfall data are widely available on a daily basis, and can be agglomerated into 10-day, monthly, seasonal values, etc.

The climate data items used are: precipitation, temperature and evaporation, either in conjunction with, or drivers for, hydrological and hydro-geological variables. Evaporation data are produced by measurement using evaporation pans or evaporimeters, or estimated as evapo-transpiration. The most widely used method for the latter is by the Penman-Monteith Equation, which requires measurement of air temperature, humidity (as vapour pressure), solar radiation or duration of sunshine, wind speed and length of day.

The most basic level of providing data for catchment planning is through a "catalogue" approach, where statistics related to locations and areas are presented. However, there are few instances outside of the more developed countries, e.g. USA, Australia, New Zealand, of comprehensive visualization of data-sets. Their establishment requires a lead agency to host the site and have the responsibility for a range of decisions on what the system will provide, including:

- Maintenance of the website
- Regularity of updating
- Content and format of presentation
- Control of access, e.g. user controlled, open public access
- Management of queries.

In the tactical role, a water balance or catchment model needs to be periodically updated on a scale of weeks to consider such requirements as releases for irrigation and power scheduling, and thus the component data has to be regularly updated. Updated data in these applications are often part of a more complex decision support framework, which may involve critical actions outside the immediate brief of the collection agency. The time frame for accessing data may well be at different time intervals than regular processing and publication procedures employed by data collection agencies, which are mostly monthly. The present widespread use of data-logging instruments allows data access and processing to be flexible.

In the operational role data feeds for similar applications as those of a tactical nature may be necessary at short intervals, of a few days or daily. It is more common for water management agencies to collect climate data for their own requirements, than for climate agencies to collect their own hydrological data.

A significant data item in water balance activities is the estimation of evapo-transpiration (ET) as a major component of losses on a range of spatial and temporal scales. Estimation of ET in practical terms has always been a problematic topic. ET requires the measurement of:

- air temperature,
- atmospheric humidity,
- radiation balance,
- wind speed,

All of which require integration over a daily period.

Use of Hydro-Meteorological Data in Flood Management and Control

The responsibilities for planning and design of flood management can fall within the brief of planning and infrastructure agencies, whereas operations for major flood defence, which includes such measures as flood forecasting and warning may be the responsibility of water management or meteorological agencies. Catchment management covers dams, diversion structures, river bank and infrastructure protection. Apart from the usual data mentioned in Table 8.2, the following data is also needed:

- Daily rainfall,
- Sub-daily rainfall, at least hourly,
- Wind velocity and direction.

Daily and sometimes sub-daily rainfall are variables collected by both climate and water management agencies, and the greater density of rain gauges in networks used by water management agencies may reduce the need for data from climate agencies.

Wind velocity and direction are most important for dam design, where wind set-up for wave protection is required, but may apply to exposed sections of river embankments. Wind set-up requires information on mean wind speed, duration of winds above certain thresholds, persistent direction and maximum gust velocity.

For flood forecasting and warning, radar measurement of rainfall, weather satellite information, numerical weather prediction and quantitative precipitation forecasting are required. In flood frequency estimation, maximum river levels and discharges are required as part of the extrapolation of the more extreme events. The effects of catchment structure, antecedent conditions and statistical methods may assume that a flood of a given probability is produce by a rainfall of lesser probability. The estimation of probable maximum precipitation (PMP) is a special aspect of flood frequency analysis.

The aim of flood plain zoning is to identify parts of the flood plain, with different categories of risk for planning and development purposes, broadly to define which parts are subject to more frequent flooding. Therefore it has to be avoided for domestic habitation and critical infrastructure.

Coastal flooding, which may also include flooding in estuary areas, can be caused by range of conditions relating to tide, wind speed and direction and atmospheric pressure. Areas showing particular physical structures, including narrowing coastal bays and shelving sea-bed, can be particularly susceptible to a combination of meteorological conditions, defined as a storm surge. The principal observations involved, wind speed and direction, atmospheric pressure and tides, are generally the responsibility of meteorological services, but coastal flood warning operations are often shared between the meteorological and water management agencies.

Use of Hydro-meteorological Data in Irrigation and Drainage

At the highest, strategic, level irrigation and drainage require consideration in terms of long-term national planning, and involve many more bureaucratic operators than just the meteorological and water management agencies. However, as data providers, these two rank in importance alongside the agricultural agency. Tables of daily data are published that include the full range of variables for the calculation of potential evapo-transpiration and a 24-hour measurement of evaporation is included for most stations.

The supply sources for irrigation and drainage can come from surface water and groundwater, and the overall management of these are the responsibility of a water management agency. However, the day-to-day operations will be done by the irrigation managers, based on resource availability, demand and constraints put in place by general water and environmental management. Managing the supply on a small, individual abstraction, or for a major system, requires some information on meteorological forecasts, mostly in the medium term (days and months) and in the longer term, (years or longer) where planning and strategy have to be considered.

Meteorological services could perhaps provide enhanced information for demand scheduling by making available observations from a national or regional network of automatic weather stations (AWS). The latest versions of AWS have sophisticated software for the estimation of evapo-transpiration.

Use of Hydro-meteorological Data in Groundwater Planning

In arid and semi-arid climates, given suitable geological conditions, it can provide the only reliable, large volume source. Its management is a sub-division of the overall brief for water management, and in many countries is done on a departmental basis within the water management agency.

Groundwater is usually characterized by an annual cycle of drawdown and recharge, and its use as a water supply depends on its management within this cycle. There are also cases, due either to the configuration or type of aquifer, or major cyclical climate patterns, e.g. El Nino-La Nina, that cycles over more than one year can occur. Confined aquifers, where recharge is delayed, can show response to rainfall conditions weeks or even months later. Large artesian basins, such as those in the interior eastern areas of Australia and the eastern Sahara, can have responses to seasonal rainfall patterns in peripheral mountains, lagged by several years.

Groundwater recharge takes place during rainy seasons, e.g. monsoon seasons in the tropics, winter in temperate latitudes. When rainy conditions begin to predominate, it is first necessary for the soil moisture deficit (SMD) to be replenished. The magnitude of SMD prior to recharge is a function of evapo-transpiration, vegetation and soil type. Groundwater management is done by reference to known trigger levels, which may be particular aquifer water or storage level, or demand criteria.

Groundwater flooding chiefly occurs when aquifer water levels (water table) rise to above ground level, a situation brought about by high rainfall quantities over extended periods. Because of the delayed response in vertical and horizontal flow in aquifers, flooding often takes place sometime after the causative rainfall events, and may persist for some time (days, weeks), as outflow is also controlled by the aquifer characteristics.

Use of Hydro-meteorological Data in Water Quality Management

The catchment management to maintain water quality in rivers, lakes and groundwater is primarily a function of the water management agency. The maintenance of quality is implemented through complex legislation covering chemical, biological and physical characteristics, and a broad range of users, e.g. agriculture, industry, municipalities all have controls under which they must operate. The need for quality maintenance is becoming more stringent, as national and international targets for ecological and conservation measures are put into place.

Incidents of water pollution arise for several reasons, and response to these incidents can often have a dependence on meteorological conditions for their management and restoration of normalcy. A particular issue for the short-term management of sewage is the risk of combined sewer overflows (CSOs). Combined sewers, where foul water and surface water are carried in the same system are widespread in many countries, and when heavy rainfall occurs, rapid surcharge of the system will result in spillage of untreated sewage. It is important for sewer management to be able to identify the types of conditions that cause CSOs.

Dilution is a key method for permitting the discharge of waste which may, even after treatment, still contain some impurities. Depending on the regime of the receiving water, usually a river or a lake, there are obviously advantages to the management and control from a forecast or projection of meteorological conditions, either incidence of rain, or the duration of dry weather. Information on immediate or protracted elevated temperatures is also important, as these can affect the status of the receiving waters.

Problems of salinity and sedimentation are most directly the result of droughts, and in markedly seasonal climates are of greater or lesser significance in most dry seasons. Thus meteorological information on the extent of dry conditions is of considerable importance. Salinity build up in the soils of irrigated areas results from excessive evaporation from water in the top surface of the soil, which brings up salts that have been previously leached, often by over-application of water, or maintaining drainage water levels to high.

Use of Hydro-meteorological Data for Fisheries and Eco-Conservation

Fisheries within rivers and lakes are highly dependent on the maintenance of the required water quality to support the whole of the aquatic environment. The hydro-meteorological information requirements for temperature monitoring and drought forecasting are equally relevant here. In addition, high temperatures can be critical for some fishes. In combination with water quality especially under low flow conditions, they can produce stress or death of fish stocks.

Conservation is a very complex topic, and in the water sector concerns complex physical and biological relationships in water-bodies and wetlands. Water management may be affected by catchment-wide initiatives, or by site-specific interventions. Conservation agencies can operate on a range of levels, from international bodies such IUCN (the International Union for the Conservation of Nature), WWF (World Wildlife Fund), to national and local conservation bodies. These two organizations have become increasingly involved in decision-making on water resources on several levels.

8.2 Use of Physiographical Data in Watershed Planning

Physiographical data broadly includes topographic data, land use-land cover data and soil data. In this section, we shall discuss its utility in watershed planning.

Utility of Topographical Data in Watershed Planning

Topographical data involves data on physical/ natural features of the watershed, watershed boundaries, floodplains in the watershed, wetlands and water bodies etc. Depending upon the purpose and the features of watershed planning as listed in Table 8.1, the utility of the topographical data will vary. In many cases, the data on either the spatial variation or the spatio-temporal variation of the topographical data parameters listed below are required.

For hydrological characterization, the data on slope, permeability of the ground surface, roughness of the ground surface, obstructions like buildings or other manmade infrastructure or hills or depressions is required. For flood management and control, the data on wetlands and water bodies, channel cross sections, other natural and artificial flood mitigation structures is required. For irrigation and drainage, data on optimum water table depth, canal linings, canal flow capacity, crop type, crop area are necessary.

For groundwater management, the data on annual changes in water table depth, crop root zone depths, wetlands and water bodies is needed. For water quality management, the locations of point and non-point pollution sources, total maximum daily loads (TMDLs), spatio-temporal variations in pH, turbidity, total suspended solids, total dissolved solids, biochemical oxygen demand (BOD) etc. may be needed. For fisheries and eco-conservation, the data on dissolved oxygen, spatio-temporal variations in aquatic plants and animals having eco-conservation capabilities is required.

Utility of Land Use/ Land Cover (LULC) Data in Watershed Planning

LULC data consists of data on forests, grass/ range lands, cultivated lands, orchards, wildlife reservations, recreation areas, urban/ rural areas, water bodies, eroded areas etc. Depending upon the purpose and the features of watershed planning as listed in Table 8.1, the utility of the LULC data in watershed planning varies. In most of the cases, the data on either the spatial variation or the spatio-temporal variation of the LULC data is required to carry out watershed planning.

LULC influences practically all the processes of hydrologic cycle like interception, infiltration, surface runoff, surface storage, groundwater runoff, groundwater storage, evapo-transpiration (ET). LULC also influences meteorological parameters such as temperature, humidity and wind velocity, which in turn impact the estimation of ET. Therefore especially the purposes of watershed planning like hydrological characterization, flood management and control, groundwater planning in a watershed get affected significantly. Thus LULC data has a great utility in watershed planning.

An improved model performance plays a vital role in achieving the watershed planning objectives. Hence, appropriate values of the lumped and/or distributed model parameters need to be assigned in the model, based on the accurate analysis by experts of the spatio-temporal variations in the watershed LULC data.

Utility of Soil Data in Watershed Planning

Soil data can be an important factor in determining the amount of erosion and storm water runoff that occurs in the watershed of interest. It can enable the estimation of water retained within the soil, analyze the slope stability or the flow of groundwater through the soil pores. Data on the types of soils in the watershed and their characteristics helps us to identify the areas that are prone to erosion or sedimentation as well as the areas which are more likely to experience runoff.

Keywords: Hydro-meteorological data utility, Physiographical data utility, Precipitation data utility, Topographical data utility, Land use land cover data utility, Soil data utility.

Module 5: Watershed Delineation and Prioritization

Lesson 9 Watershed Delineation

9.1 Concept of Topographic or Contour Map

A topographic map is a two-dimensional representation of a portion of the three-dimensional surface of the earth. Topography is the shape of the land surface, and topographic maps exist to represent the land surface.

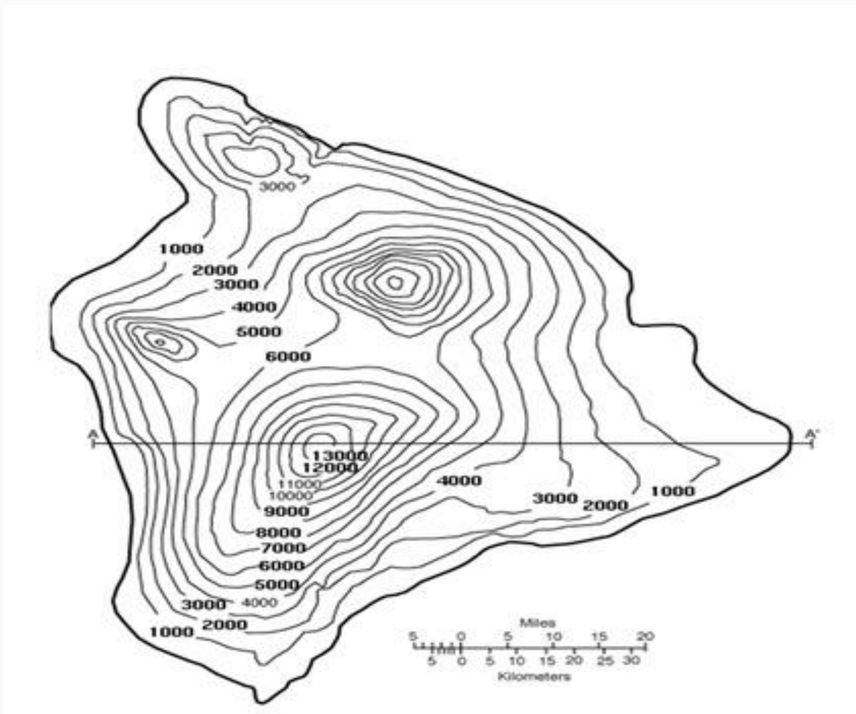


Fig. 9.1. A Typical Contour Map.
(Source: http://volcano.oregonstate.edu/vwdocs/vwlessons/land_pics/a6.3.gif)

Cartographers solve the problem of representing the three-dimensional land surface on a flat piece of paper by using contour lines, thus horizontal distances and vertical elevations can both be measured from a topographic map (Fig. 9.1).

The terms used to indicate what information is contained on a topographic map are given below:

9.1.1 Map Scale: Maps come in a variety of scales, covering areas ranging from the entire earth to a city block (or less).

9.1.2 Vertical Scale (Contour Interval): All maps have a horizontal scale. Topographic maps also have a vertical scale to allow the determination of a point in three dimensional spaces.

9.1.3 Contour Lines: Contour lines are used to determine elevations and are lines on a map that are produced from connecting points of equal elevation (elevation refers to height in feet, or meters above sea level). The following are general characteristics of contour lines:

1. Contour lines do not cross each other, divide or split.
2. Closely spaced contour lines represent steep slopes, conversely, contour lines that are spaced far apart represent gentle slopes.
3. Contour lines trend up valleys and form a "V" or a "U" where they cross a stream.
4. Contour lines can not merge or cross one another on the map, except in the case of an overhanging cliff.
5. Contour lines can not end anywhere, but close on themselves either within or outside the limits of the map.

On most topographic maps, index contour lines are generally darker and are marked with their elevations. Lighter contour lines do not have elevations, but can be determined by counting up or down from the nearest index contour line and multiplying by the contour interval. The contour interval is stated on every topographic map and is usually located below the scale.

9.2 Watershed Boundary Delineation from Contour/Topographic Maps

Topographic maps; for example, have a scale of 1:24,000 (which means that one inch measured on the map represents 24,000 inches (2000 feet) on the ground). They also have contour lines that are usually shown in increments of ten or twenty feet. Contour lines represent lines of equal elevation, which typically is expressed in terms of feet above mean sea level. As you imagine water flowing downhill, imagine it crossing the contour lines perpendicularly.

9.2.1 Watershed Boundary Delineation from Contour/Topographic Maps

The water flow is perpendicular to contour lines. In the case of the isolated hill, water flows down on all sides of the hill. Water flows from the top of the saddle or ridge, down each side Fig. 9.2. As the water continues downhill, it flows into progressively larger watercourses and ultimately into the ocean. Any point on a watercourse can be used to define a watershed.

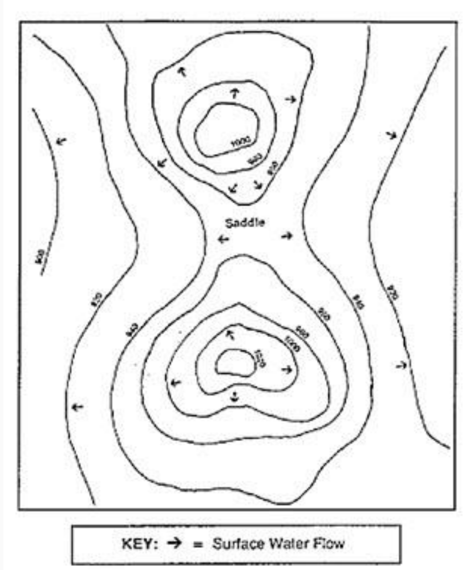


Fig. 9.2. Saddle.
(Source: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nh/programs/planning/wsp/?cid=nrcs144p2_015706)

As one proceeds upstream, successively higher and higher contour lines first parallel then cross the stream. This is because the floor of a river valley rises as you go upstream. Likewise the valley slopes upward on each side of the stream. A general rule of thumb is that topographic lines always point upstream. In Fig. 9.3, for example, the direction of stream flow is from point A to point B. Ultimately, the highest point upstream is obtained. This is the head of the watershed, beyond which the land slopes away into another watershed. At each point on the stream the land slopes up on each side to some high point then down into another watershed. Join all of these high points around the stream to have the watershed boundary. (High points are generally hill tops, ridge lines, or saddles)

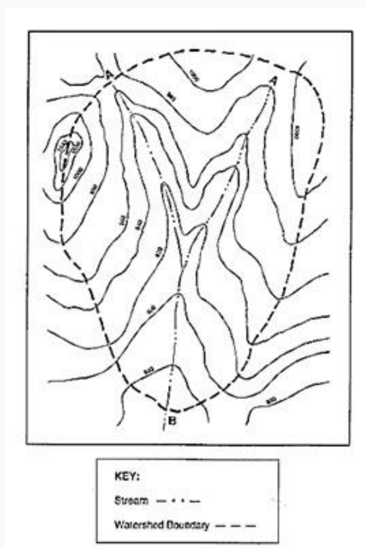


Fig. 9.3. Delineated Watershed Boundary.
(Source: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nh/programs/planning/wsp/?cid=nrcs144p2_015706)

9.3 Geographic Information System (GIS) for Watershed Delineation

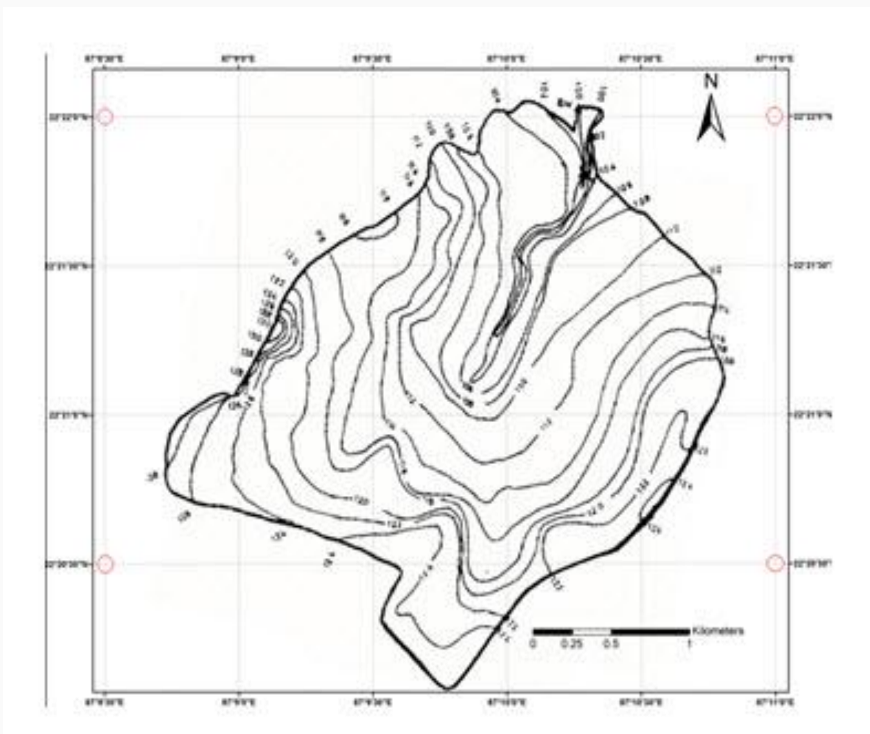
Aquatic resource managers increasingly require information about the characteristics of watersheds that drain to stream reaches of interest. Furthermore, they need this information for multiple watersheds within states or larger regions. Geographic information systems (GIS), coupled with increased spatial data availability, allow researchers to obtain this information. Information obtained from a GIS-based watershed analysis can include data such as watershed area, watershed climate statistics, soil/geology types, topographic statistics, hydrology, and land use.

Steps for using GIS to Delineate Watershed

9.3.1 Preparation of Digital Elevation Model (DEM)

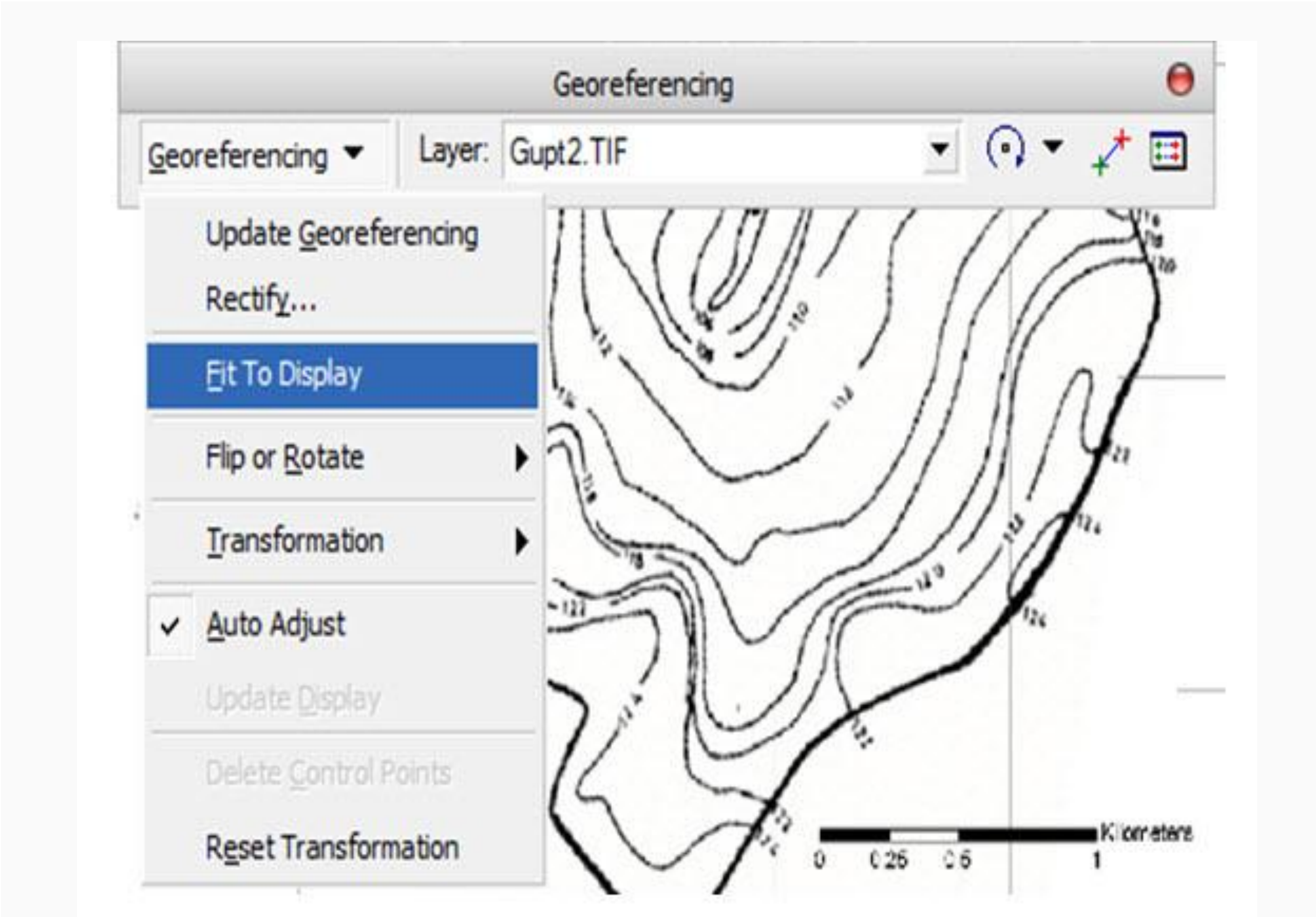
Step 1: Scanning of Topographic Map (Contour Map)

Scan the contour map in high resolution and save it preferably in a *.TIFF file.

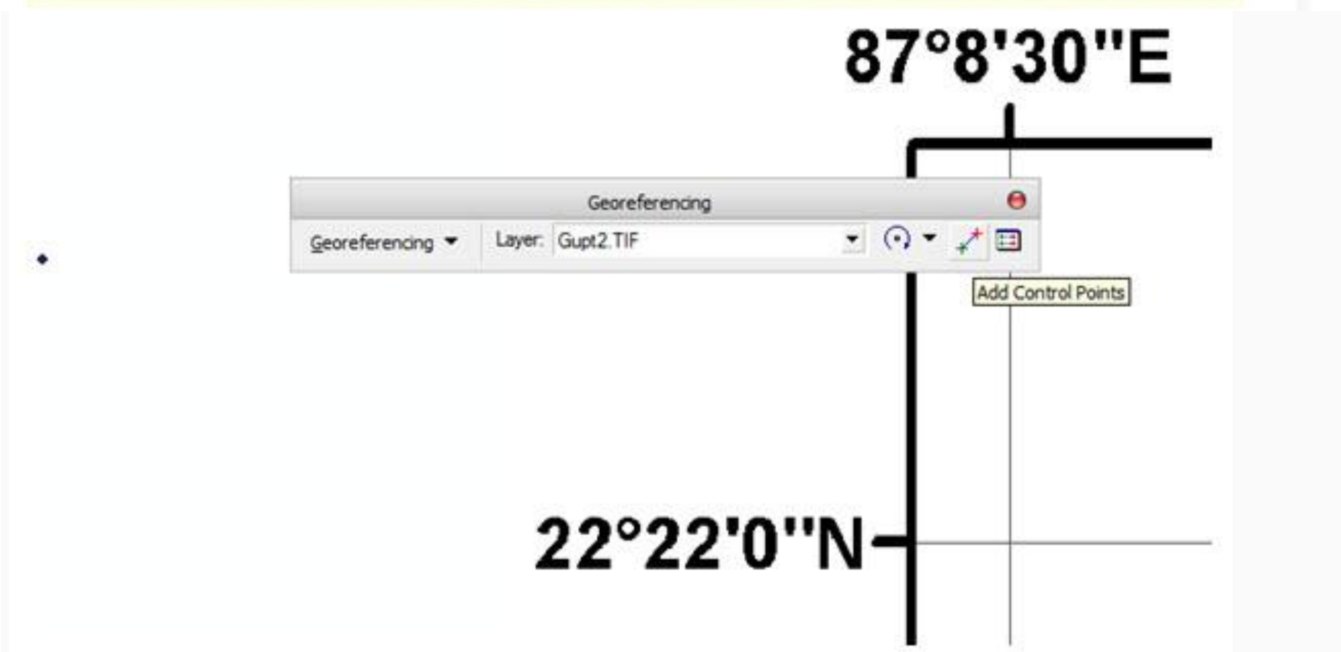


Step 2: Geo-referencing Scanned Map in ArcMap

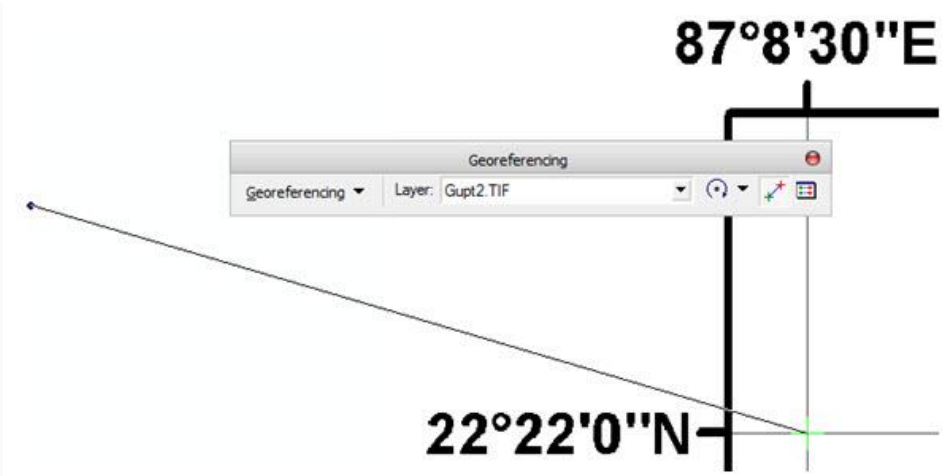
1. The process of geo-referencing a raster map requires at least four known geo-coordinates.
2. Identify four coordinates and convert them to decimal points.
3. Use Geo-referencing toolbar in ArcMap for image rectification (geo-referencing).
4. Geo-referencing - Fit To Display.



5. Zoom to first coordinate
6. Select Add Control points



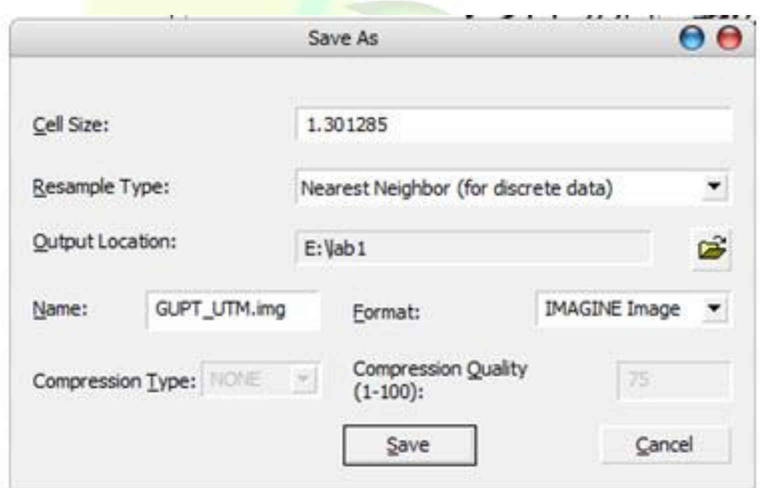
7. First click on coordinate in scanned map actual coordinate



8. Similarly complete this for other three points

9. Save the rectified image in a different file (*.TIFF / *.IMG).

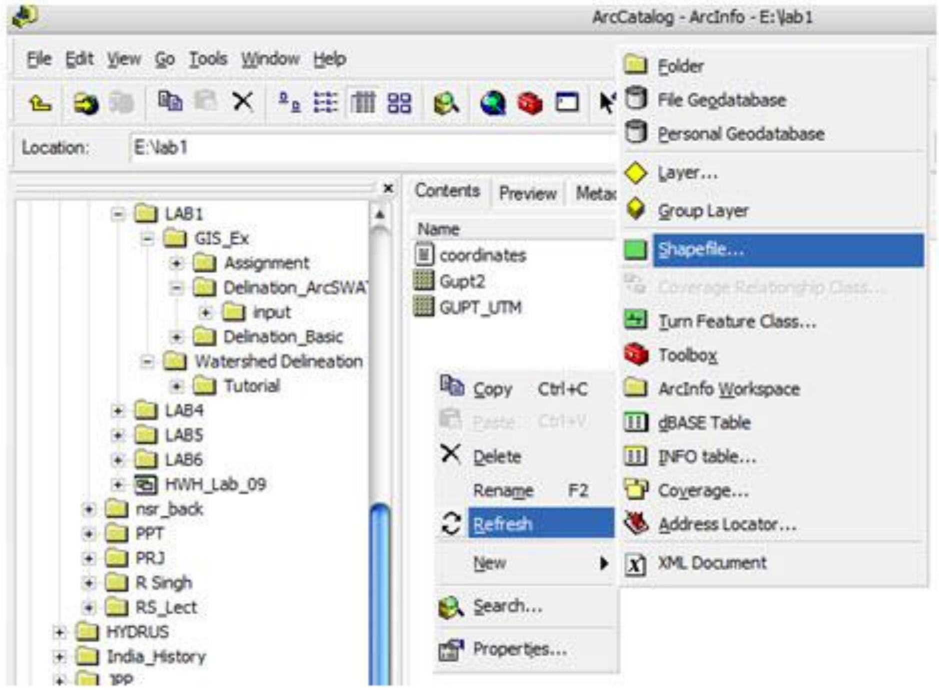
10. Geo-referencing Rectify



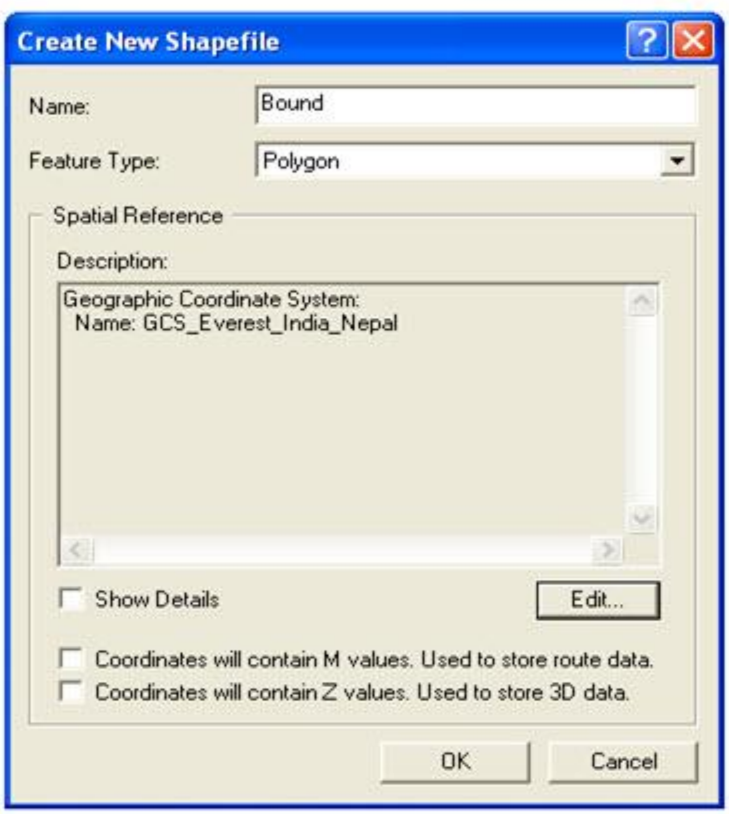
11. The rectified image can be reprojected to UTM WGS 84 system.

Step 3: Onscreen Digitization

1. Boundary: Create a new shape file using ArcCatalog (say bound)



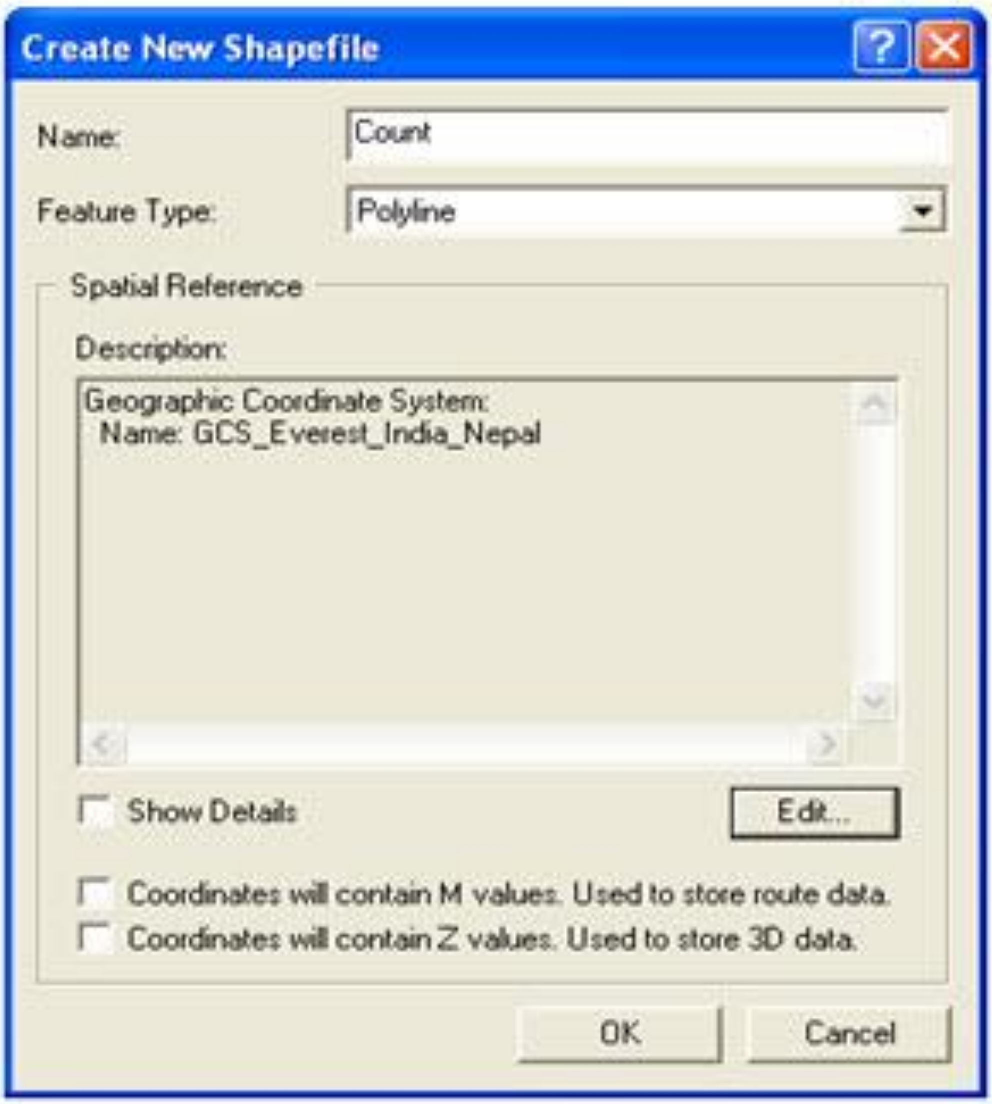
2. Select feature type as polygon and assign a spatial reference system to it.



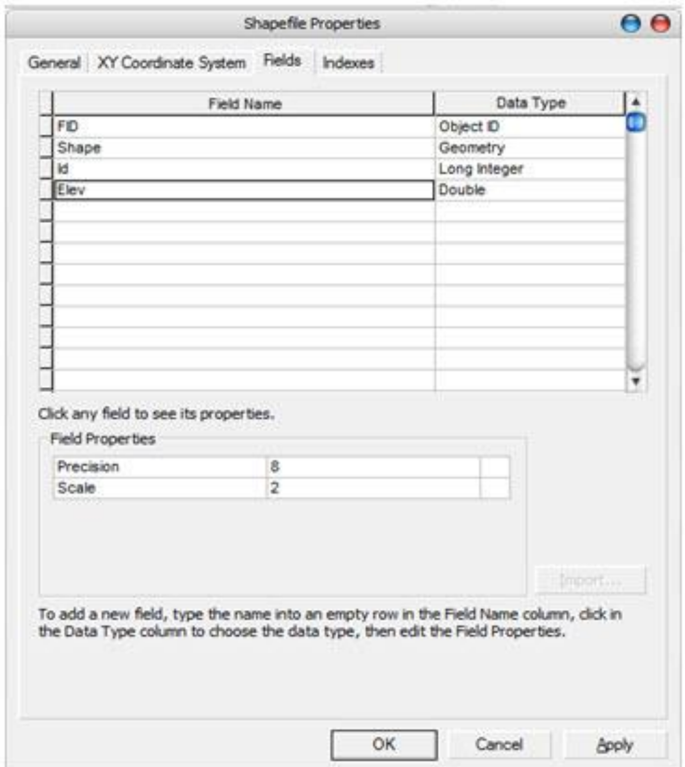
3. Now, go to ArcMap and add this layer. Open Editor Toolbar in ArcMap.

4. Select the bound layer in TOC and click start editing. Now, digitize the boundary and save it. Then to stop editing, click stop editing.

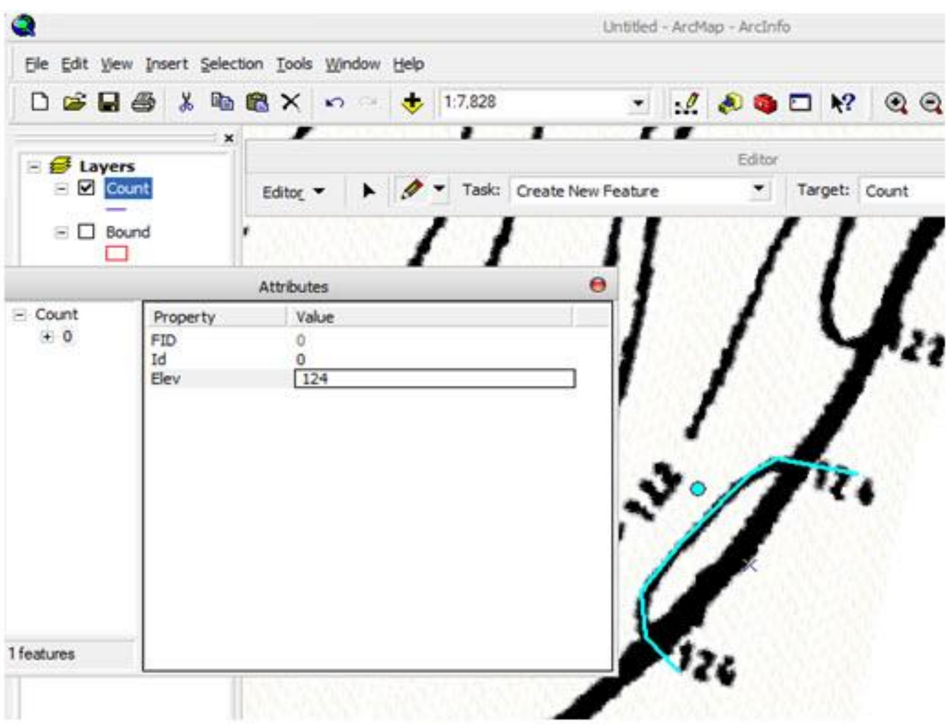
5. Contour line: Create another shape file (say count). This will be a polyline feature and assign a spatial reference system.



6. In ArcCatalog right click on the shape file, go to properties and add a new field (say elev) to provide contour elevation.

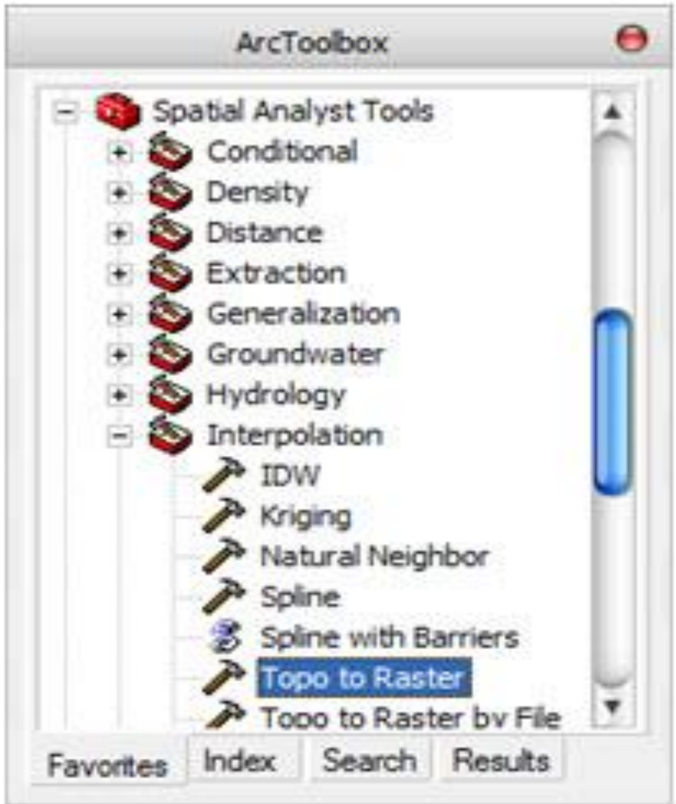


7. Now, digitize all the contours as mentioned above and enter elevation value to each contour in the elev field. Save it and to stop editing, click stop editing.



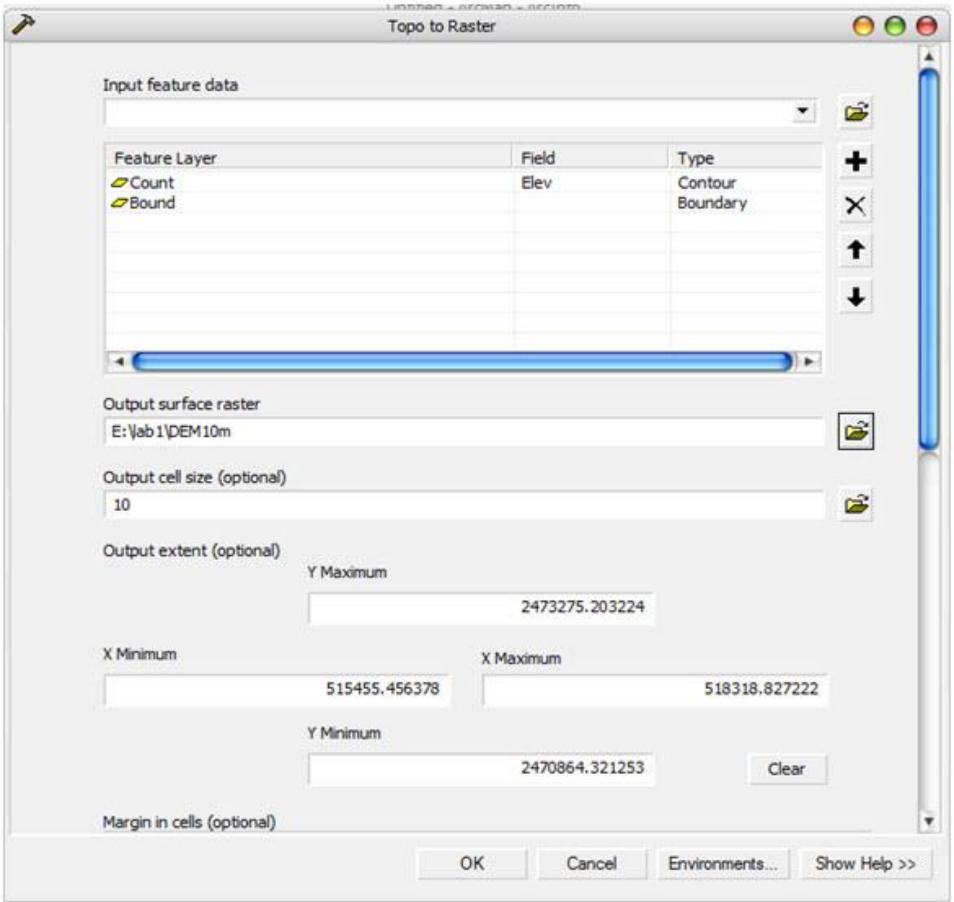
Step 4: DEM Creation (Interpolate to Raster)

1. Use Topo to Raster tool in ArcToolbox. This creates a hierologically correct raster of elevation.

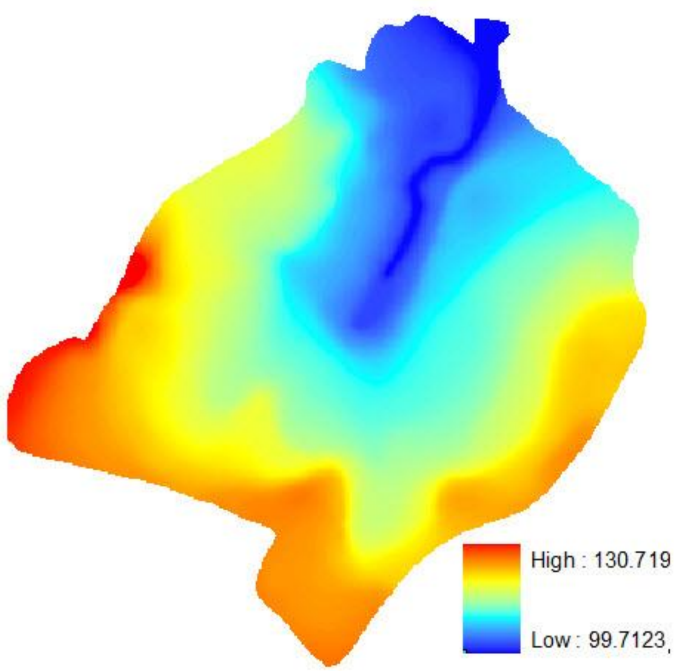


2. In the input feature data, provide both the shape files (count and bound).
3. For count in the field change it to elev, and for bound change the type to boundary.
4. Locate the folder where output will be saved and provide required cell size in Output cell size option.

5. Press OK to create the DEM.

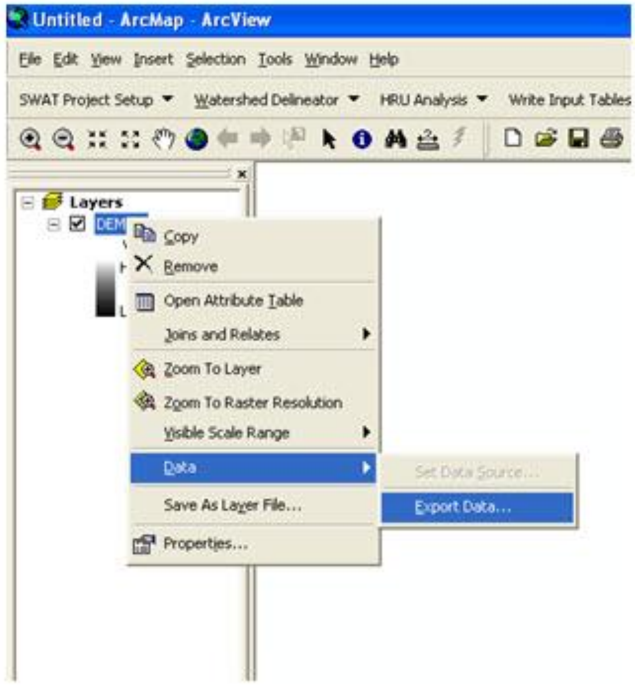


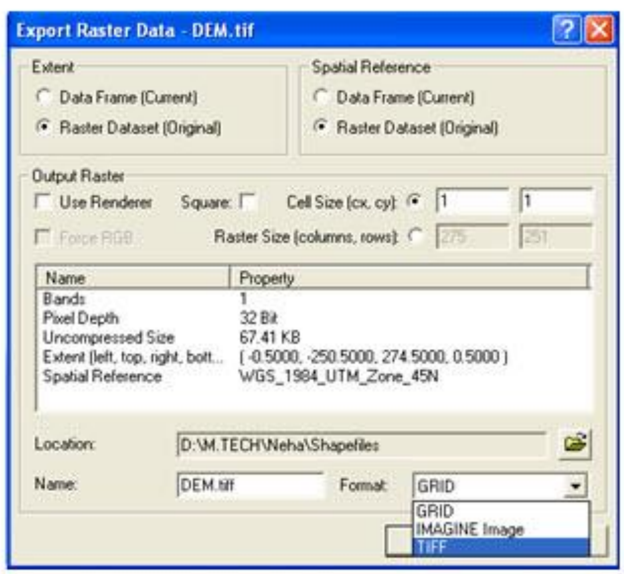
6. Final DEM may look like this



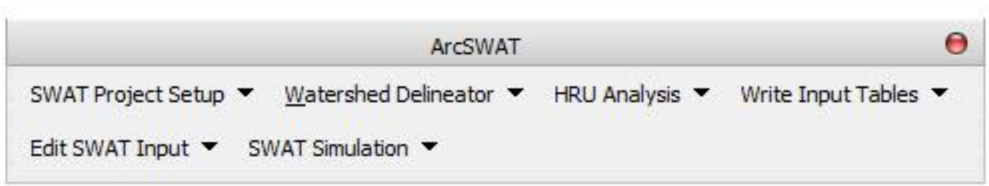
9.3.2 Steps for Delineating a Watershed using GIS based Model - ArcSWAT

Step 1: Export the DEM from image (img.) file to TIFF file and save it again.

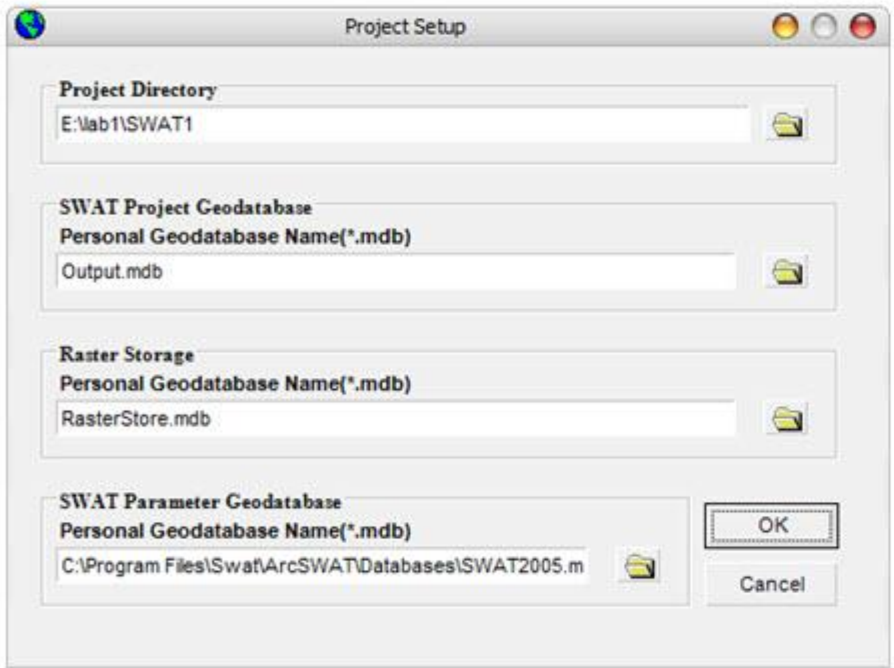




Step 2: Open the ArcSWAT toolbar

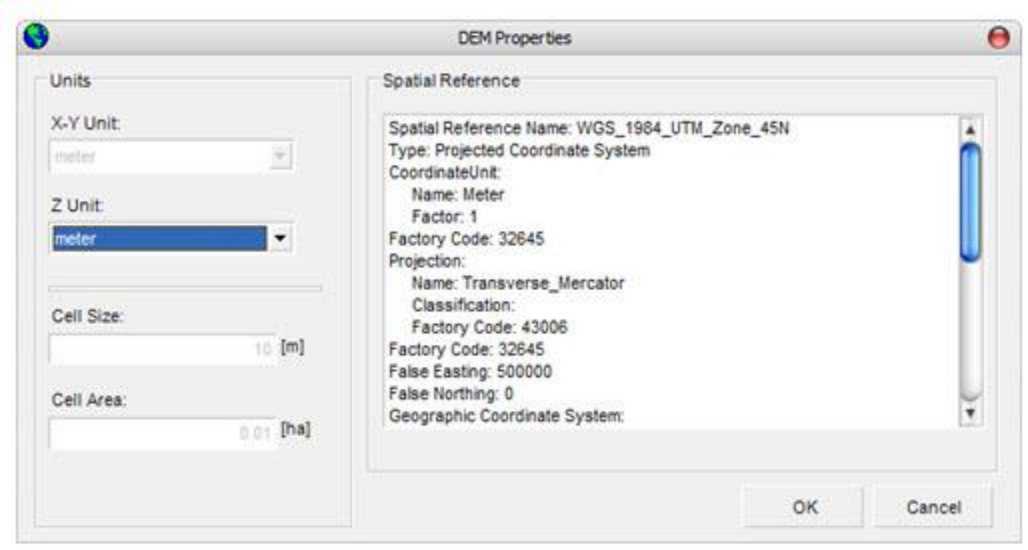


Step 3: Go to SWAT Project Setup, choose New SWAT Project to open the dialog below. Select a suitable project directory.

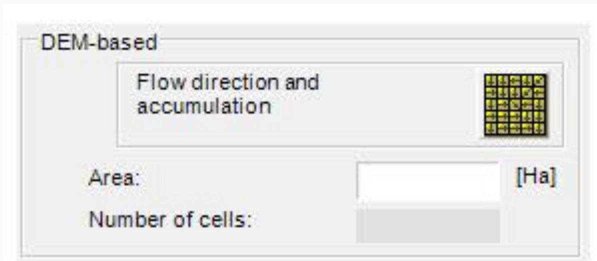


Step 4: Go to Watershed Delineator choose Automatic watershed delineator to bring the watershed delineation window. Load the DEM.tiff.

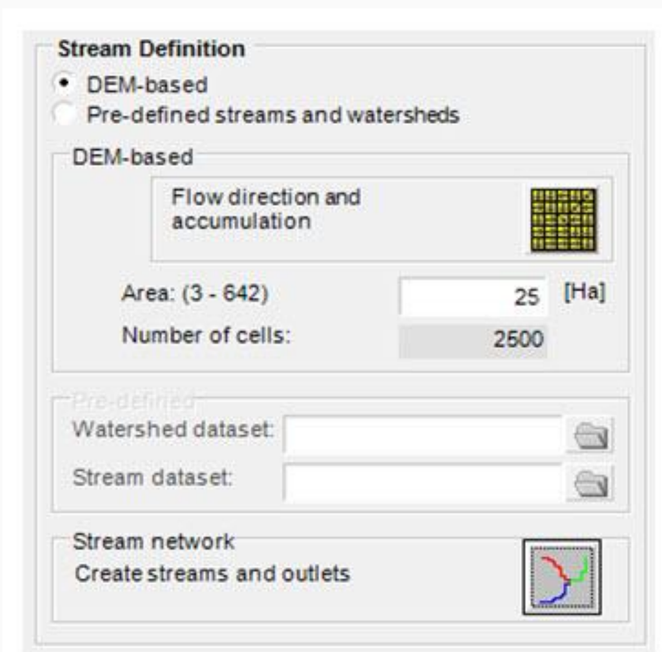
Step 5: In DEM projection setup set Z Unit to meter.



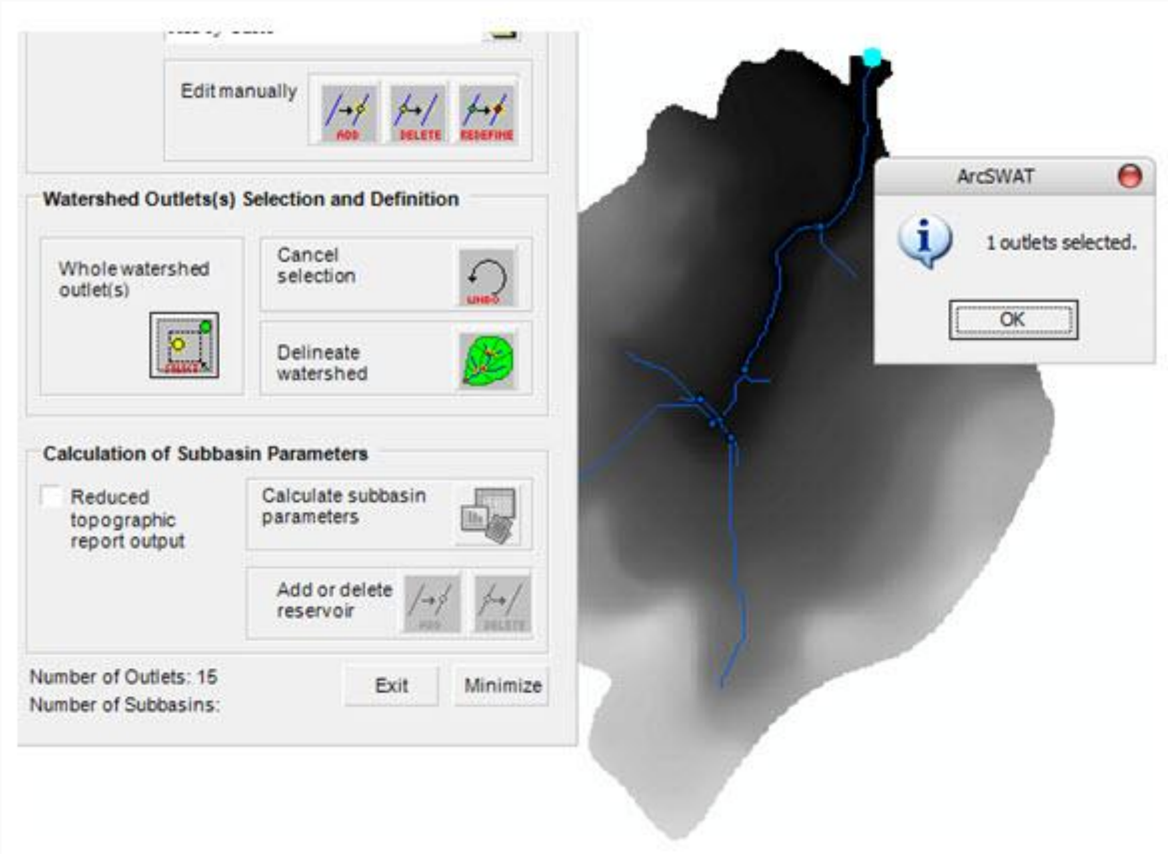
Step 6: Click on the flow direction and accumulation.



Step 7: Set min. area to 25 ha. (Greater than the threshold value) and create streams and outlets.



Step 8: If required change any outlet and Inlet definition. Then select the whole watershed outlets and choose Delineate watershed option.



9.4. Accuracy in Watershed Delineation

9.4.1 Spatial Data Accuracy

Do we simply get better results when using finer resolution source data e.g. DEM? At first, it may seem so, but consider high-resolution (let's say 1m) LiDAR derived DEM. If we have a big road crossing a river in our watershed, it may appear as an elevated surface high enough to change watershed delineation result. Therefore it is sometimes necessary to burn-in existing streams. This process alters DEM such that no bumps on the river appear. While this feature is missing in Spatial Analyst/Hydrology tool, one can find it in more specialized hydrology extensions for GIS like ArcHydro and TauDEM.

9.4.2 Raster Data Resampling

During the work with GIS, one will often have to re-project the data in different coordinate systems. To get rid of unnecessary details in case when all other data has much lower resolution and excessive details just take space or vice versa, one may have just a single raster file with no-so-good resolution and certain GIS extension/plug-in would require equalizing spatial resolution. In all these procedures re-sampling is involved. That is interpolation of existing data. There are several re-sampling techniques available in most GIS. One should be aware of what kind of data is dealt with. If it is a land use data, that is when each grid cell is assigned an integer code, the new intermediate cells may be filled using nearest neighbor approach instead of calculating some average. However it is vice versa in case of DEM. One may not want to interpolate the DEM using nearest neighbor approach which is usually default but linear or cubic could become good choices. Unless categorical data (like land use) is used, make sure of using real values and not integers and apply smooth re-sampling.

9.4.3 Slope & Flow direction

Several algorithms exists to define flow direction and to choose single one with the steepest slope when each inner cell is surrounded by 8 adjacent cells.

- D8? that simply chooses single cell among 8 adjacent cells. As a result, concentration to distinct lines happens. This is the only available algorithm in Spatial Analyst/Hydrology toolbox in ArcGIS.
- D∞? calculates hypothetical flow direction and then splits flow between 1 or 2 adjacent cells based on how close directions to these cells are close to the hypothetical one. Still only single flow direction is chosen each time.
- MD∞ ? similar to previous one, but allows flow in multiple directions, but as a result it all gets distributed between same 8 adjacent cells.
- There are other algorithms, but they are not as widely spread as aforementioned. Some of them, like proportioning flow according to slope, generate unrealistic spread pattern.

Keywords: Watershed Delineation, Contour Map, Digital Elevation Model, Geographic Information System

Lesson 10 Prioritization of Watersheds

10.1 Concept of Priority Watersheds

In a watershed management programme, particularly in case of large watersheds, it may not be possible to treat the entire area of the watershed with land treatment measures. Identification and selection of few areas or sub-watersheds having relatively more degradation problem, for development planning and implementation of conservation activities according to level of need and status of degradation, are required. These few selected areas or sub-watersheds within a large watershed are called the priority watersheds. In this process, collection of sufficient bio-physical and socio-economic information is required for integrated watershed management planning. After effectively prioritization of watersheds (sub-watersheds), a sub-watershed management plan for each priority sub-watershed is prepared in order to minimize natural and human-induced hazards and to conserve valuable resources (soil, water, biodiversity and socio-cultural aspects). And finally, various integrated watershed management activities in the selected priority watershed (sub-watershed) is implemented.

10.2 Factors Influencing Prioritizing Watersheds

In the face of enormity of degradation problems and constraint of financial resources coupled with limitation of expertise, a scientific approach to land resource management calls for an evolution of suitable methodology for clear identification of critical areas for treatment. Prioritization of areas into very high, high, medium, low and very low vulnerability helps in addressing the conservation and management efforts to secure maximum benefit.

Watershed prioritization is a prerequisite to operationalize any major scheme as it allows the planners and policy makers to adopt a selective approach considering the vastness of the catchment area, severity of the problems, constraints of funds and man power demands of the local and political system. The prioritization of watersheds varies with the objectives of different schemes but the basic framework of watershed remains the same.

10.3 Basics and Methods of Watershed Prioritization

It is not feasible to take the whole watershed area at once for its management. Thus the whole basin is divided into several smaller units, as sub watersheds or micro watersheds, by considering its drainage system. Two different methods are listed in this section for prioritization of sub watersheds from a large watershed:

10.3.1 Sediment Yield Index (SYI) and Runoff Potential Index (RPI) Models

The methods used for determining the priority of the sub-watersheds for treatment from soil erosion and sediment yield point of view are; (i) reconnaissance surveys, (ii) soil and land use surveys, (iii) sediment observations, and (iv) Remote Sensing methods.

1. A **reconnaissance survey** of the entire watershed gives an idea of the relative erosion status of the sub-watersheds. This procedure is approximate and is to be used when no other method is available.

2. Detailed **soil and land use surveys** include the erosion information of the sub-watersheds. A careful interpretation of these reports could provide information on the relative erosion status of the various sub-watersheds.

3. Actual **measurement of the silt load** contributed by each of the sub-watersheds will give a clear picture of the extent of erosion in the sub-watersheds. Observations in respect of silt loads recorded over a period of three to five years will indicate the sub-watersheds which are contributing higher silt loads. The main difficulty with this procedure is that the data has to be collected over a period of years so that reliable conclusions can be drawn.

4. **Remote Sensing Techniques** consisting of satellite imagery and its interpretation offer a good scope for determining the priority areas in large watersheds.

Study of the Survey of India topographical map on 1:50,000 scale helps to have an idea of the catchment area and identification of the major landscape and land use. The methodology of Priority Delineation Survey comprises the following steps.

1. Preparation of framework of micro-watershed through systematic delineation.

2. Codification of different stages of delineation by using Alpha-numeric symbolic code.

3. Rapid Reconnaissance Survey on 1:50,000 scale base (SOI Toposheets, aerial photographs and other base material) leading to the generation of a map indicating Erosion Intensity Mapping Units (EIMU).

4. Assignment of delivery ratio to various Erosion Intensity Mapping Units.

5. Computation of Silt Yield Index (SYI)/Run-off Potential Index (RPI) for individual micro-watersheds.

6. Based on the descending values of SYI/RPI grading of micro-watersheds into very high, high, medium, low and very low priority categories is assigned.

7. Assignment of weightage values to various Erosion Intensity Mapping Units based on their relative sediment yield/run-off potential.

EIMU is an assemblage of land and soil characteristics, viz., physiography, slope, land use and land cover with density, surface condition, soil depth, texture and structure of surface and sub-soils, colour, drainage condition, salinity and alkalinity, stoniness and rockiness, erosion condition and existing management practices.

The delivery ratio of an erosion intensity mapping unit indicates the transportability of the soil material detached from the area enclosed by the unit to the site of the dam/reservoir. The maximum values of delivery ratio adjudged for individual EIM unit are based on factors influencing the suspension and mobility of suspended material like texture, mineralogy and pH of the soil, land use/land cover conditions, terrain slope, surface stoniness/rockiness and soil conservation measure adopted. The adjustment delivery ratios are also dependent on the watershed attributes such as drainage pattern/drainage density, watershed gradient, and proximity to active stream resources. The maximum delivery ratio value, assigned to various EIMU ranges from 0.40 to 0.95.

The Following Literature may be considered.

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.

$IE = T_w * 100/T_a$,

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 below. 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 suitable priority classes such as: very high, high, medium, low and very low.

Table 10. 1. Proposed Weights as per Distance from the Reservoir

Distance from reservoirs (Miles/Kms)	Weights
<5 / < 8.0	50
6-10 / 9.7-16	40
11-25 / 17.7-40.2	30
26-50 / 41.8-80.5	20
51-100 / 82.1-161	10
>100 / > 161	5

10.3.2 Morphometric Analysis

Morphometric analysis could be used for prioritization of micro-watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps.

Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation is done in GIS environment using Digital Elevation Model (DEM) either prepared from contour map or directly taking DEM from reliable sources, eg. ASTER 30 m DEM. The various morphometric parameters such as area, perimeter, stream order, stream length, stream number, bifurcation ratio, drainage density, stream frequency, drainage texture, length of basin, form factor, circulatory ratio, elongation ratio, length of overland flow, compactness coefficient, shape factor, texture ratio are computed. The linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility. Higher the value, more is the erodibility. Hence for prioritization of sub-watersheds, the highest value of linear parameters is rated as rank 1, second highest value is rated as rank 2 and so on, and the least value is rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor have an inverse relationship with erodibility. Lower the value, more is the erodibility. Thus the lowest value of shape parameters is rated as rank 1, next lower value was rated as rank 2 and so on and the highest value is rated last in rank. Hence, the ranking of the micro watersheds is determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters.

The prioritization is carried out by assigning ranks to the individual indicators and a compound value (Cp) is calculated. Watersheds with highest Cp are of low priority while those with lowest Cp are of high priority. Thus an index of high, medium and low priority is produced.

10.4 Purpose and Benefits of Watershed Prioritizations

The purpose to identify priority basins are to identify focus watersheds to complete a series of restoration activities. Those can address the critical needs in that watershed and allow for natural recovery.

Benefits of Prioritization

1. This approach is simple to adapt and useful for managers, as it combines the best available information from scientific investigations with the knowledge and intentions of local stakeholders.

2. While comparing among watersheds or varying condition within the same cluster type or across cluster types, this approach generates a relevant list of prioritized watersheds.

3. It assists the users in developing a profile of watersheds of interest, by graphically locating a watershed and obtaining relevant information about its vulnerability.

4. The contemplative process used to locate multiple watersheds is helpful in deciding upon a course of action with regard to prioritizing watershed protection and restoration.

Keywords: Watershed Prioritization, Sediment Yield Index, Runoff Potential Index, Morphometric Analysis.

Module 6: Water Yield Assessment and Measurement

Lesson 11 Water Yield

11.1 Concept of Water Yield

The water yield is defined as the amount of freshwater derived from unregulated flow (m^3s^{-1}) measurements for a given geographic area over a defined period of time. The freshwater flow (yield) is generated from a combination of base flow, interflow and overland flow originating from groundwater, precipitation and/or snowpack. The flow rate encompasses the hydrologic processes (for example, interception, infiltration and evapotranspiration), the state of water storage (for example, lakes, aquifers, snowpack and soil moisture) within a drainage basin, and is influenced by climatic (for example, temperature) and physiographic (for example, topography) variables of the watershed or basin. Flow is exclusively used to estimate water yield because it can be measured with a known level of accuracy compared to other parts of the water cycle such as precipitation and evapotranspiration, which can contain higher levels of uncertainty.

11.2 Water Yield Assessment

The water yield of a watershed may either be measured directly on a single outlet on the main stream or be calculated through empirical equations based on important physical properties of a particular watershed. Using the directly measured runoff values is, of course, the best way, but since it takes a long time and investments, the empirical method is preferred in applications. The methods of water yield assessment are discussed as below.

11.2.1 Direct Measurement Method: Water Yield can be roughly calculated by dividing the mean annual volume of stream flow (expressed in cubic meters per year) that is produced in a nested watershed (expressed in square kilometers). The area of a nested watershed can be determined using the following approach:

For example, (Fig. 11.1) the watershed associated with Station 1 has a nested area of 15 km^2 and a gross area of 15 km^2 (they are the same, as no further upstream watershed exists). The watershed associated with Station 2 has a nested area of 10 km^2 and a gross area of 25 km^2.

The water yield can also be expressed in mm (depth of water spread uniformly over the watershed area), as both precipitation and evaporation are typically expressed in mm. For example, a watershed with 1,000 mm annual precipitation, and an annual 40% (i.e. 400 mm), water loss due to evaporation, would have a water yield of 600 mm per year.

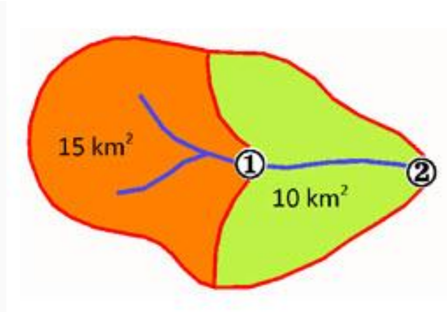


Fig. 11.1. Direct Measurement Method for Water Yield Estimation. (Source: Alberta Water Portal, 2013)

11.2.2 Water Budget Approach: Water yield from watersheds with deep soils and high infiltration capacities can be estimated with a water budget approach. Soil moisture storage characteristics govern the relationship between precipitation and water yield. Monthly values of precipitation and potential evapotranspiration (PET) are the only data required in this method. Soil moisture storage characteristics can be estimated from soil textural properties and the effective rooting depth of vegetation. The difference in precipitation and PET is considered roughly as the water yield from the watershed.

11.2.3 Upstream-Downstream Consideration: Increasing water yield from upland watersheds does not necessarily result in a significant increase in water yield at downstream reservoir sites or locations where water is extracted from the channel. As the distance increases between treated watersheds and the storage reservoir, opportunities for water losses from surface and channels (lateral and vertical losses of water from channels' sections) increase as well. Riparian or phreatophyte vegetation along stream courses can result in large losses of water by transpiration. Likewise, transmission losses (leakage) within the channel can exceed any water yield increases from upstream areas, particularly in the case of ephemeral streams. Transmission losses can be approximated by –

1. Estimating the hydraulic conductivity of stream bottom material
2. Applying the hydraulic conductivity to the total area that is wetted by flow, and
3. Applying the above for the time duration of flow

Water yield improvement schemes should also take into account the evaporative losses from the reservoir pool. In more arid regions, reservoir evaporation can represent a large percentage of annual stream flow at the site. The relationship between incremental increase in storage and corresponding increase in surface area of the reservoir pool determine to a large extent, whether increased water at the reservoir will be available for the later use.

Once evaporation and seepage losses are estimated, the net water yield can be approximated at location of interest. The net water yield with and without watershed practices can then be examined over time, preferably using historical records that represent periods of water shortages or droughts. It is during such periods that additional water supplies represent the greatest benefit in terms of irrigation, municipal industrial supplies, fisheries production, etc.

11.3 Benefits of Water Yield Assessment

The benefits of water yield assessment can be listed as below

1. The assessment of water yield provides reliable information on availability of water resources (surface and ground water) to plan their extraction and uses.

2. It integrates the land processes affecting the water movement above and below the ground surface and thus reflects the management of watershed physical properties required to improve the water yield.

3. It provides information of interactions between head watershed to the tail watershed and thus provides a view on whether to develop conservation measures at head watershed to the tail watershed.

4. It provides information on water availability at a particular location of watershed as annual, seasonal and at even smaller time scale. This can be well used for planning the water use activities.

5. Provides an idea on surface and ground water interaction in the watershed.

11.4 Water Assessment and Management Perspectives

The first step in evaluating water yield benefits or cost is to quantify the relationship between land use and management practices that affect vegetative cover and the corresponding change in water yield. Watershed experiments indicate that water yield often increase when:

1. Forest are cleared or thinned

2. Vegetation is converted from deep rooted to shallow rooted species, and

3. Vegetation cover is changed from species from high to low interception capacities

The magnitude in change in water yield depends on the soils, climatic conditions and percentage of the watershed affected. The largest changes in water yield tend to follow complete forest removal. The length of time that water yield exceeds pre-cutting conditions depends on the type of vegetation that replaces the forest and the regrowth of vegetation on the site.

11.4.1 Land Use, Vegetation Cover and Water Production

The links between land use and water production, and the contribution of a particular vegetation cover to runoff and groundwater supplies, have been studied worldwide. Studies have confirmed that different land covers usually deliver different water yields, seasonally and annually, as well as in times of high and low flows. Achieving an understanding of catchment hydrodynamics and the inter-relationship with vegetation type is therefore essential to develop an integrated approach to land-use planning aimed at maximizing water yield at the watershed level. Influences of changing land use and vegetation cover on water yield are particularly important in the upper source areas, where environmental changes may result in reduced downstream flows and groundwater availability.

11.4.2 Impact of Afforestation

The impact of afforestation on the timing and seasonality of water yield is more ambiguous. The regulating capacity of the vegetation is generally very small compared to the soil and thus soil physical properties play a major role. Forests are generally known for a high soil infiltration capacities, enhancing base flow. However, soil destruction during the afforestation process, e.g. by heavy machinery, may hinder infiltration and stimulate surface runoff and further decrease low flows. On the long term, forest soils may regenerate, even up to a point where infiltration is higher than before afforestation. The afforestation reduces both dry and wet season flow. While the absolute flow reduction is largest during the wet season, the dry season experiences a larger proportional reduction, which may have important consequences for downstream water supply.

11.4.3 Groundwater / Base Flow Changes

Some pressure for upland watershed projects comes from downstream interests, which must cope with inadequate amounts of water in the stream channel during the normal dry season or low flow months. When precipitation is lacking, groundwater and reservoir storage can supplement water supplies. Small reservoir in the upland may indeed perform this function to some extent if there are releases during times of shortage. The constructions of numerous ponds in the headwaters is often not only a water conservation and development activity of benefit to the land owners, but in aggregate these may contribute to base flow through underground aquifers and thereby maintaining flows in streams longer in the dry season.

Keywords: Water Yield, Watershed, Water Budget, Afforestation.

References

Lesson 12 Measurement of Water Yield from Watersheds

12.1 Measurement of Water Yield

The water yield of a watershed is the amount of freshwater generated from a combination of base flow, interflow and overland flow originating from groundwater, precipitation and/or snowpack. It is quantified by measuring or estimating the flow in various processes (surface flow, groundwater flow, lateral flow, seepage flow, and intra boundary water movement) using suitable methods. In order to quantify the water yield from watershed, the measurement and estimation of these water are discussed as below.

12.1.1 Surface Water

Stream gauging in a stream is a technique used to measure the discharge, or the volume of water moving through a channel per unit time. The depth of water in the stream channel, known as a stage or gauge height can be used to determine the discharge in a stream. When used in conjunction with velocity and cross-sectional area measurements, stage height can be related to discharge. If a weir or flume (devices, generally made of concrete, located in a stream channel that have a constant known shape and size) is used, based on the weir or flume shape, mathematical equations can be helpful for velocity measurements. Stream gauging can be done by measuring the stage height and velocity at a series of points in a cross-section of a stream or by constructing a flume or weir and recording stage height. Different methods of measuring stream flow are as below.

12.1.1.1 Stage and Velocity or Velocity-Area Method

Discharge, or the volume of water flowing in a stream over a set interval of time, can be determined with the equation:

$$Q = AV$$

where, Q is discharge (volume/unit time - e.g. m^3/s, also called cumecs), A is the cross-sectional area of the stream (e.g. m^2), and V is the average velocity (e.g. m/s).

Stream water velocity is typically measured using a current meter. Current meters generally consist of a propeller or a horizontal wheel with small, cone-shaped cups attached to it which fill with water and turn the wheel when placed in flowing water. The number of rotations of the propeller or wheel-cup mechanism corresponds with the velocity of the water flowing in the stream. Water flowing within a stream is subject to friction from both the stream bed and the air above the stream. Thus, when taking water velocity measurements, it is conventional to measure flow at 0.6 times the total depth, which typically represents the average flow velocity in the stream. This is achieved by attaching the current meter to a height-calibrated rod. The rod can also be used to measure stream stage height. If a current meter is not available, another technique known as the float method can be used to measure velocity. While less accurate, this method requires limited and easy to obtain equipment. To measure velocity via the float method, one simply measures the time a floating object (such as a piece of wood) takes to travel a measured distance. This is done in a relatively straight channel section length of 30 m. Velocity is then calculated by dividing the distance traveled by the float in observed time.

Velocity also varies within the cross-section of a stream, where stream banks are associated with greater friction, and hence slower moving water. Thus, it is necessary to take velocity measurements along a cross-section of a stream. Since stream channels are rarely straight, it is helpful to measure velocity across an "average" reach of the stream (e.g. average width and depth) with a single channel, a relatively flat stream bed with little vegetation and rocks, and few back-eddies that hinder current meter movement.

Discharge is measured by integrating the area and velocity of each point across the stream; that is, the stream is divided into sections. By multiplying the cross-sectional area (width of section x stage height) by the velocity, one can calculate the discharge for that section of stream. The discharge from each section can be added to determine the total discharge of water from the stream.

Discharge and stage height are often found to be empirically related and this relationship can be elucidated using a rating curve. A rating curve is constructed by graphing several manually derived discharge measurements with a corresponding stage height. A best-fit curve is fit to these data points and the equation of the line corresponds to the relationship between stage and discharge. The greater the number of measurements, the more reliable the rating curve will be to determine discharge based on stage data.

12.1.1.2 Measuring Discharge Using a Weir

Discharge in small streams can be conveniently measured using a weir. A weir is a small dam with a spillway of a specific shape, usually made of erosion-resistant material such as concrete. Two common weir shapes are a 90° V-notch or a simple rectangular cutout. This method for measuring discharge involves creating a dam just downstream of the weir. This dam impounds in the weir, resulting in a more or less consistent stage height (e.g. a pool of more stagnant water without complications determining height due to waves or ripples). Using the height of water over the weir crust, discharge is determined using empirically-derived equations, as below.

Rectangular Weir (Fig. 12.1):

$Q = 3.33\ (L-0.2H)\ H^{3/2}$, in feet;

$Q= 1.84\ (L-0.2H)\ H^{2/3}$, in meters.

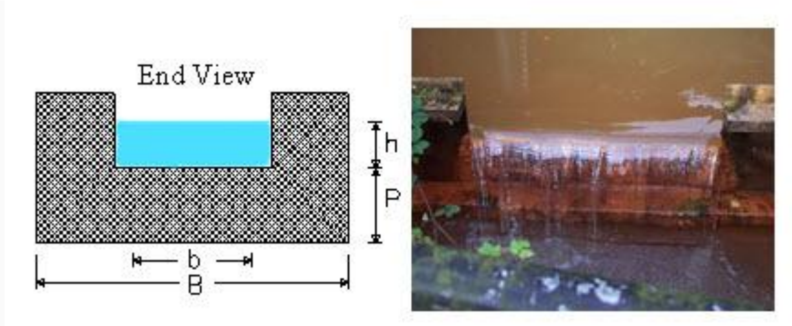


Fig. 12.1. Rectangular Weir.

(Source: http://www.ussi.co.uk/Weirs_and_Flumes.html)

90° V-notch weir (Fig. 12.2):

$Q = 2.5H^{5/2}$, in feet;

$Q = 1.379H^{5/2}$, in meters

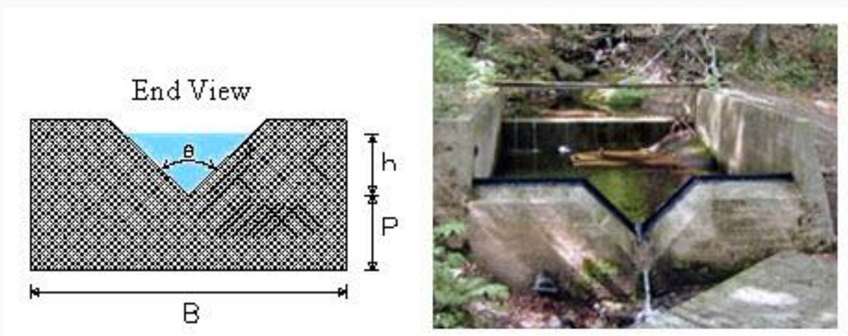


Fig. 12.2. 90° V-notch Weir.

(Source: http://www.lmnoeng.com/Weirs/vweir.htm)

Q represents discharge (ft^3/s or m^3/s), L is the length of the weir crest (ft or m), and H is the height of the water in the backwaters/weir (ft or m). These equations negate the need for measuring point velocities and are generally more reliable since the concrete construction of the weir resists change in channel shape, which is a confounding factor when using the velocity-area method to determine discharge.

12.1.1.3 Discharge Measurement by Tracer Methods

Velocity-Area Tracer Discharge Equation: The discharge using velocity-area method is computed by –

$$Q = AL/T$$

Where, Q = discharge in cubic feet per second (ft^3/s), A = average cross-sectional area of reach length in square feet (ft^2), L = reach length between detection stations in feet (ft), T = recorded time required for the tracer solution to travel between the detection stations at each end of the measurement reach in seconds (s)

Tracer-Dilution Discharge Equation: The dilution method equation for discharge is –

$$QC_0+qC_1 = (Q+q)\ C_2$$

$$Q = q\ (C_1-C_2)/(C_2-C_0)$$

Where, C_0 = the natural or background concentration of the tracer of the flow, C_1 = the concentration of the strong injected tracer solution, C_2 = the concentration of tracer after full mixing at the sampling station, including the background concentration of the stream, Q = the discharge being measured, q = the discharge of the strong solution injected into the flow.

The discharge of the channel flow, Q, is measured by determining C_0, C_1, C_2, and the injection rate, q. Only the final plateau value or C_2, the downstream concentration, must be recorded rather than a complete record of the passing cloud that is needed with the salt-velocity-area method.

12.1.2 Measurement of Ground Water Yield

12.1.2.1 Seepage Meters for Measuring Groundwater

Seepage meters (Fig. 12.3) measure the quantity of water moving into or out of the river through the streambed sediments. Such measurements help quantify ground water/surface water interchange. Seepage meter methods determine the variability of ground-water discharge and recharge at specific locations in the streambed which provides local-scale stream bed heterogeneity. This method uses an open-ended drum pushed into the streambed to measures the amount of water that is lost or gained in the bag connected to the seepage meter over time. Seepage from the bottom sediment is collected in a plastic bag to estimate specific discharge q (m/s).

$$q = Q/A$$

Where, Q (m^3/s) is the flow rate and A (m^2) is the area covered by the seepage meter.

Fig. 12.3. Seepage Meter.

(Source: http://astro.temple.edu/~ltoran/docs/gw_sw.htm)

Working of Seepage Meter

The basic concept of a seepage meter is to enclose and isolate an area of the sediment–surface water interface with a cylinder that is open at its base and vented at the top to a plastic collection bag. The change in the volume of water in the collection bag over a measured time interval is used to determine the direction and rate of flow between surface water and groundwater. A gain in water volume in the collection bag indicates that flow is occurring from groundwater to surface water, while a loss in water volume indicates that flow is occurring from surface water to groundwater. Seepage meters have an advantage over other methods of measuring groundwater–surface water exchange since flow measurements can be made without measurement of the hydraulic conductivity of the sediment. Seepage meters are particularly useful when many measurements are needed in order to characterize groundwater–surface water exchange in different segments of a water body.

12.1.2.2 Mini-piezometers

Mini-piezometers are simple instruments for measuring the direction of water flow between groundwater and a surface water body such as a lake or stream (Fig. 12.4). Often temporarily installed, mini-piezometers are essentially scaled-down versions of piezometers, which are routinely used to make groundwater level measurements. When combined with surface water level measurements, this can be used to determine the direction of water flow. When flow measurements from seepage meters are combined with hydraulic head measurements from mini-piezometers, the hydraulic conductivity of the bottom sediment can be calculated.

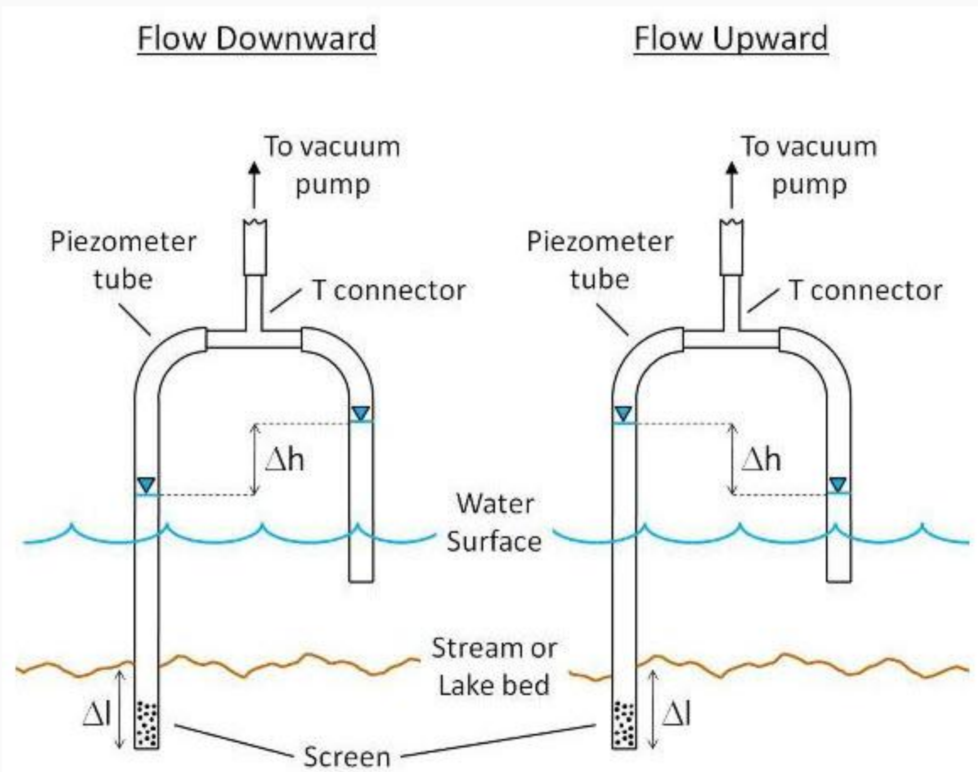


Fig. 12.4. Flow Downward (Left) Indicated by the Surface Water Level > Groundwater Level and Flow Upward (Right) Indicated by the Surface Water Level < Groundwater Level. (Source: Christopher, 2013)

12.1.3 Measurement of Lateral Flow or Interflow

Interflow is the portion of the stream flow contributed by infiltrated water that moves laterally in the subsurface until it reaches a channel. Interflow is a slower process than surface runoff. Components of interflow are quick interflow; which contributes to direct runoff; and delayed interflow, which contributes to base flow (Fig. 12.5). Interflow velocities are measured with different measuring devices (TDR-waveguides, FD-probes, geoelectrics, changes of conductivity in antecedent water courses, and others) for the assessment of bandwidths of lateral and vertical conductivity during and after long-lasting rainfall.

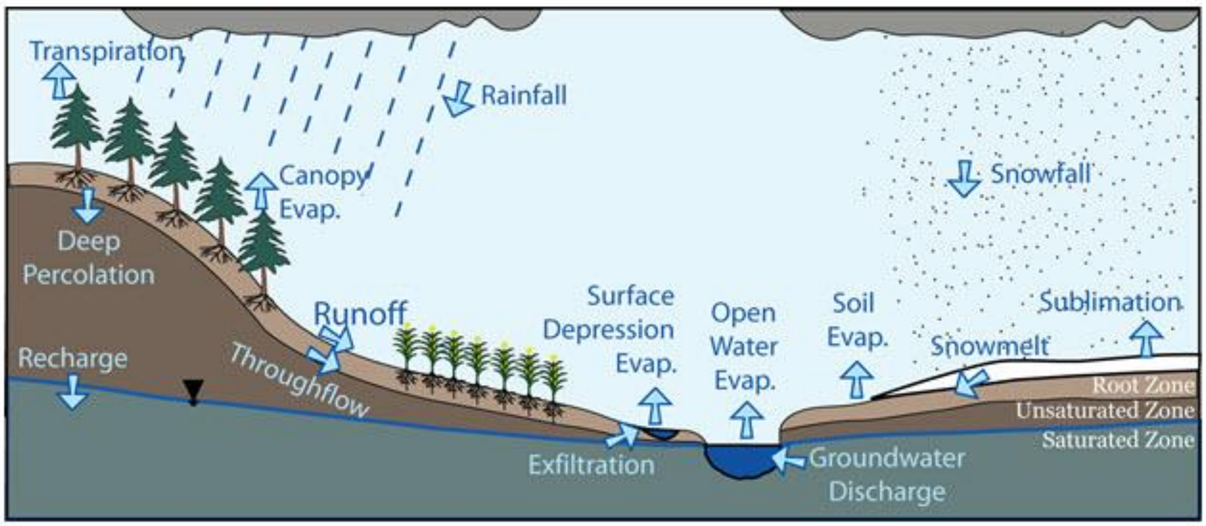


Fig. 2.5. Hydrological Cycle showing Runoff Processes.

(Source: http://hydrogeology.glg.msu.edu/research/active/modeling-and-monitoring-hydrologic-processes-in-large-watersheds)

Infiltrated water is initially referred as the Upper Zone Storage (UZS). Water within this layer percolates downward or is exfiltrated to nearby water courses, and is called interflow. Interflow is represented by a simple storage-discharge relation;

$$DUZ = REC * (UZS-RETN) *Si$$

where: DUZ = the depth of upper zone storage released as interflow in mm, REC = a dimensionless coefficient (optimized), UZS = water accumulation in the upper zone region in mm, RETN = retention and Si = internal slope (land surface slope). REC is a coefficient, which cannot be predicted, and is therefore estimated through optimization. Values of REC are expressed as the depletion fraction per hour of the Upper Zone storage and range from 0.001 to 0.005 i.e., from 0.1 to 0.5 percent of the water stored in the upper zone is drained off each hour. DUZ is calculated simultaneously with Upper Zone to Lower Zone drainage.

12.1.4 Measurement of Seepage Flow

Seepage occurs in all three dimensions and Darcy's law is applicable when flow of water is in one direction. Solution for 3D problems is complicated and needs advanced mathematical calculations. In many cases, 3D problems are simplified to 2D and seepage flow is calculated accordingly using Laplace Equation.

Laplace graphical solution (Flow Net) requires 2 families of curves that meet at right angle. One is called flow line and the other is called equi-potential line. The network of these lines is called "Flow Net" (Fig. 12.6). Properties of flow net are; same flow quantity through each flow channel and same head drop between each adjacent pair of equi-potential lines (except for partial drop).

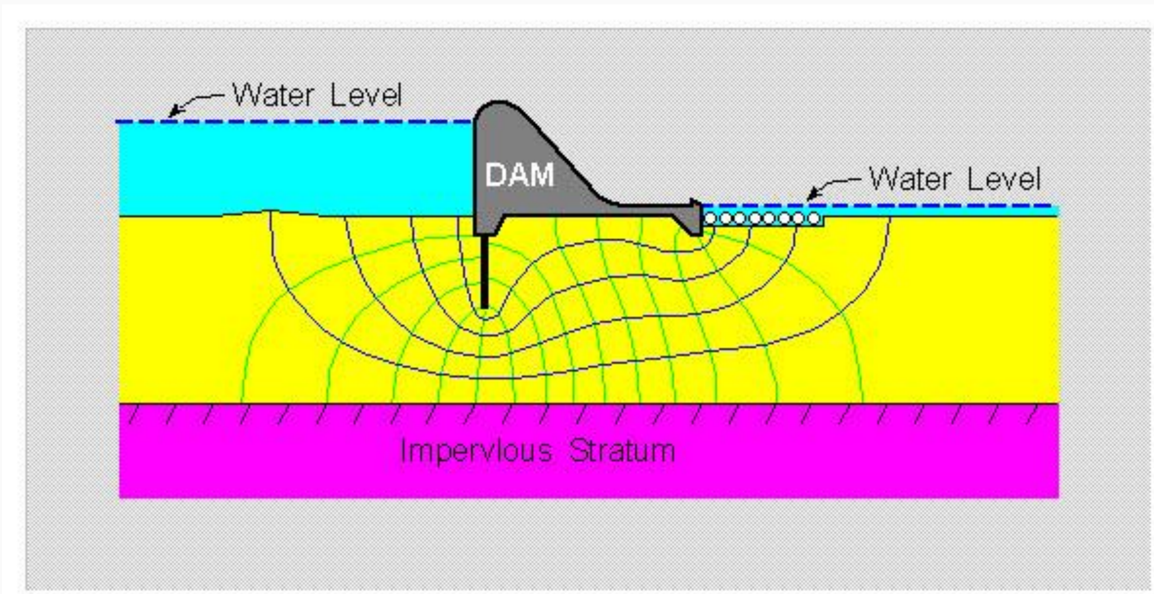


Fig. 12.6. Example of Flow Net Beneath a Dam Structure.

(Source: Fung, 2008)

12.1.5 Water from Outside Watershed Boundary

The flowing water above or below the ground does not follow any local and political boundaries. However, it moves with natural gradient. Due to this property, water flows to and from neighboring watersheds. Accurate measurement of this incoming or outgoing water from the watershed, in consideration, is quite difficult. To quantify and assess this water, modeling serves as a better tool when using the process and interaction information characteristics of the watersheds.

12.2 Modeling and Assessment of Water Resources in Watersheds

Measurement of water yield in a watershed is a time taking, tedious and difficult process. It involves several instrumental as well as human error possibilities. To reduce these negative aspects and to get quick information, modeling is often used as tool to assess the water yield of a watershed. The detail of modeling of watershed water resources is discussed as below.

12.2.1 Purpose and Scope of Watershed Modeling

A watershed model simulates hydrologic processes in a more holistic approach compared to many other models which primarily focus on individual processes or multiple processes at relatively small- or field-scale without full incorporation of a watershed area. Watershed-scale modeling has emerged as an important scientific research and management tool, particularly in efforts to understand and control water pollution. Watershed modeling involves a holistic approach that involves not only examining surface hydrology, groundwater hydrology, or their interface as whole systems, but attempting to imitate the three regions as one system. One limitation is the availability of precipitation, flow, land cover, etc. data for the entire region. Another consideration is the limited understanding of the interactions between smaller hydrologic entities.

12.2.2 Models Used for Watershed Modeling

Watershed models can be grouped into various categories based upon the modeling approaches used. The primary features for distinguishing watershed-scale modeling approaches include the nature of the employed algorithms (empirical, conceptual, or physically-based), whether a stochastic or deterministic approach is used for model input or parameter specification, and whether the spatial representation is lumped or distributed. Various watershed models developed and used for assessing the watershed water yield can be categorized based on their characteristics, and time and spatial scale of use as below.

12.2.2.1 Based on Nature of Input and Uncertainty

Watershed models can be categorized as deterministic or stochastic depending on the techniques involved in the modeling process. Deterministic models are mathematical models in which outcomes are obtained through known relationships among states and events. Stochastic models will have most, if not all, of their inputs or parameters represented by statistical distributions which determine a range of outputs.

12.2.2.2 Based on Nature of the Algorithms

Physically-based models are based on the understanding of the physics associated with the hydrological processes which control catchment response and utilize physically based equations to describe these processes. Empirical models consist of functions used to approximate or fit available data. Such models span to a range of complexity, from simple regression models to hydro informatics based models which utilize Artificial Neural Networks (ANNs), Fuzzy Logic, Genetic, and other algorithms.

12.2.2.3 Based on Nature of Spatial Representation

Watershed-scale models can further be categorized on a spatial basis as lumped, semi-distributed, or distributed models. The lumped modeling approach considers a watershed as a single unit for computations and the watershed parameters and variables are averaged over this unit. Compared to lumped models, semi-distributed and distributed models account for the spatial variability of hydrologic processes, input, boundary conditions, and watershed characteristics. For semi-distributed models, the aforementioned quantities are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins, which in turn are treated as a single unit. These models describe mathematically the relation between rainfall and surface runoff without describing the physical process by which they are related eg. Unit Hydrograph approach. Spatial heterogeneity in distributed models is represented with a resolution typically defined by the modeler.

12.2.2.4 Based on Type of Storm Event

Watershed-scale models can be further subdivided into event-based or continuous-process models. Event-based models simulate individual precipitation-runoff events with a focus on infiltration and surface runoff, while continuous process models explicitly account for all runoff components while considering soil moisture redistribution between storm events.

Keywords: Surface Water, Groundwater, Lateral Flow, Seepage, Watershed Modelling.

Module 7: Hydrologic and Hydraulic Design of Watershed Structures

Lesson 13 Hydrologic and Hydraulic Design of Recharge Structures

Recharge structures play a very important role in watershed management through artificial groundwater recharge. In most of the cases, recharge structures also result in surface water conservation –discussed in detail in Lesson 19 and Lesson 20 of Module 10. The design of these structures is based on the sound principles of hydrology and hydraulics. In this lesson, we shall discuss the hydrologic and hydraulic design of recharge structures falling under direct methods and surface methods.

13.1 Hydrologic Design as Applied to Recharge Structures

There are three main methods of artificial groundwater recharge as listed below.

1. Direct methods.
2. Indirect methods.
3. Incidental methods.

(A) Direct Methods: Direct methods of recharge can further be subdivided into two main categories as surface methods and sub-surface methods.

(B) Surface Methods: In this method of recharge, water is applied on the permeable ground surface wherein it infiltrates into the unsaturated zone to reach slowly the underground water table. Surface techniques, especially spreading techniques of artificial recharge are most widely used because of their economy and easiness in operation. Various types of spreading techniques are as follows:

- Recharge basins
- Furrows and ditches
- Regulated stream channels

(C) Recharge Basins:

Excavation or building dikes or levees constitute basins [Refer to Fig 13.1]. The shape and size of the basin depends upon topography and availability of land. To reduce deposition of sediments, the water released to the basin should have minimum sediment. This can be achieved by the following measures:

1. By water diversion to the basin during the non-flood periods, when the suspended sediment is low;
2. By adding certain chemicals in the water to remove sediments;

3. By providing Sedimentation basins to hold water before releasing it into the recharge basin.

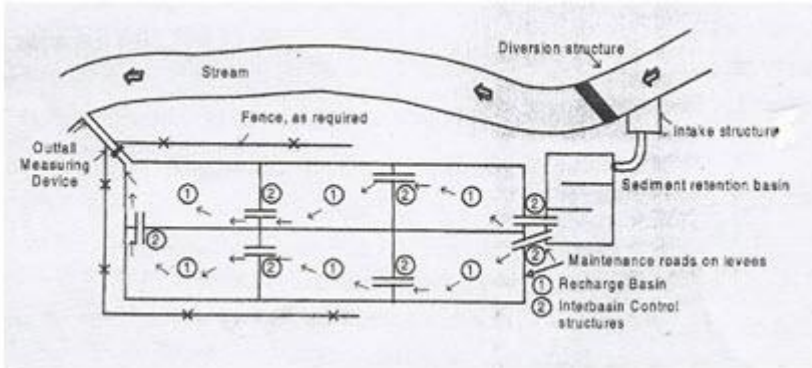


Fig. 13.1. Layout of a typical recharge basin. (Source: Patel & Shah, 2008)

Requirements of Recharge Basin Sites

1. Knowledge of surface geology downward in the basin and laterally away from the basin;
2. Considerable knowledge of permeable soil in the basin which permits adequate infiltration rate;
3. Sufficient knowledge of the unsaturated zone between ground surface and water table.

Furrows and Ditches

This method of recharge is very useful for irregular terrain. Furrows and ditches should be shallow, flat bottomed, and closely spread to obtain maximum water contact area. Gradient of major ditches should be sufficient to carry suspended material through the system so that surface openings are not clogged due to deposition of fine-grained material. The design of furrows and ditches system depends upon the topography and the size of the area. A downstream collecting ditch is necessary to return excess water to the main channel. [Refer to Fig. 13.2].

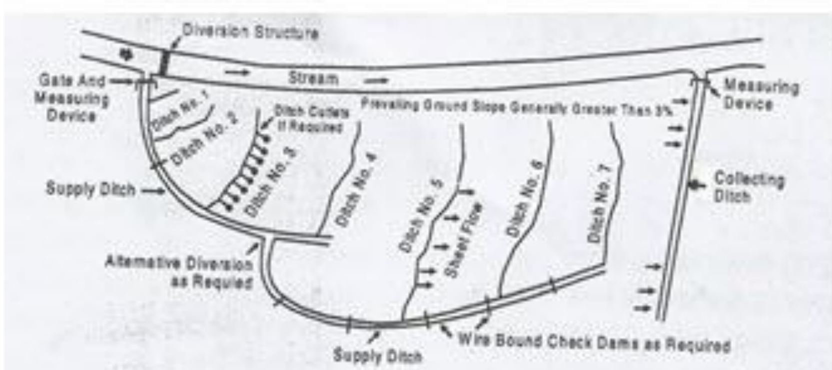


Fig. 13.2. Furrows and ditches for groundwater recharge. (Source: Patel & Shah, 2008)

Regulated Stream Channels

The objective of this method is to extend the time and area over which water is recharged from a natural influent stream channel. It requires upstream storage facilities to regulate stream flows and to enhance infiltration. The flow rate of water should be such that it should not exceed the absorptive capacity of downstream channels. Different types of stream channel regulations include:

- Widening, leveling or scarifying a stream channel bed;
- Constructing permanent low check dams;
- Constructing temporary low check dams of stream bed materials;
- Constructing L - shaped finger bikes in straight stream channels and L-shaped hook levees in curved stream channels.

13.2 Hydraulic Design Applied to Recharge Structures

In this section, we shall discuss the theory of artificial groundwater recharge. It will be followed by a discussion on spreading in shallow/ deep phreatic aquifers.

Theory of Artificial Recharge by Spreading

As a variant of induced recharge, the most likely set-up of an artificial recharge scheme consists of a series of spreading ditches and infiltration galleries arranged alternately at equal intervals. For unconfined aquifers which are pervious up to the ground surface, this set-up offers few difficulties. With slight modifications, it may also be applied for artesian aquifers when the confining layer on the top is thin. For confined aquifers covered by thick deposits of less pervious material, recharge must be accomplished by injection wells, having their own problem and possibilities. The simplest construction of parallel spreading ditches and infiltration galleries is shown in Fig. 13.3, where the coefficients of transmissivity (kH) of the aquifer as well as the maximum allowable drawdown (S_0) are determined by the local hydro-geological conditions. The other factors indicated in this figure viz., q_0, L and w, must be chosen such that the purposes of the recharge scheme are fulfilled.

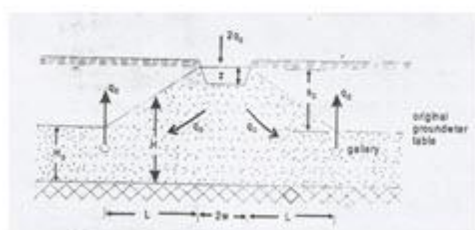


Fig. 13.3. Artificial groundwater recharge with parallel ditches and infiltration galleries (Source: Patel & Shah, 2008)

It means an adequate detention time of the recharge water in the sub-soil and no rapid clogging of the spreading basins. When it is provisionally assumed that both the spreading basin and the gallery for groundwater recovery fully penetrate the saturated thickness of the aquifer, these requirements may be formulated mathematically as:

a) Detention time (t)

$t = pHL/q_0$ (13.1)

Or, $q_0 = pHL/t$ (13.2)

Here, p is the soil porosity.

b) Maximum allowable drawdown (S_0)

$S_0 = [q_0 / (kH)]\, L$ (13.3)

Or, $q_0 = kHS_0/L$ (13.4)

c) Entry rate (v_e)

$v_e = q_0 / w$ (13.5)

or, $q_0 = v_e\, w$ (13.6)

The entry rate requirement can always be satisfied by increasing the width of the spreading basin, while the requirements for t and S_0 give us the length and flow rate.

$$L = \sqrt{kS_0 t/p} \qquad (13.7)$$

$$q_0 = (H / t)\sqrt{kS_0 pt} = H\sqrt{kS_0 p/t} \qquad (13.8)$$

With shallow aquifers composed of fine sand, H and k will be small, calling for a short length and a low flow rate, which can best be accomplished using a number of parallel ditches. With deep aquifers built up of coarse sand and high values of aquifer thickness H and hydraulic conductivity k, the length and flow rate may be much greater. The scheme having a number of parallel ditches may again be used, but in plan it tends to be rather square, leading more or less automatically to the recharge scheme of Fig. 13.4. Here a spreading pond is surrounded by a circular battery of wells for recovery of groundwater.

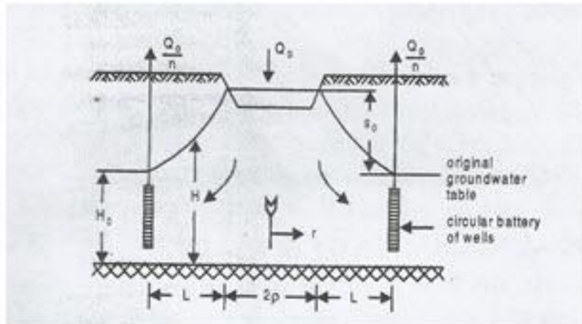


Fig. 13.4. Artificial recharge with a spreading pond surrounded by a circular battery of wells. (Source: Patel & Shah, 2008)

Spreading in Shallow Phreatic Aquifer

The design procedures to be used in this case can best be demonstrated with an example [Huisman and Olsthorm, 1983]. Consider an aquifer composed of fine sand with a coefficient of permeability (k) = 0.12×10^{-3} m/s, a porosity (p) = 0.38, a saturated aquifer thickness before spreading (H_0) of 15 m, a maximum allowable rise of water table (S_0) = 2 m, giving together an average saturated aquifer thickness during spreading (H) = 16 m. A capacity (Q_0) = 30×10^6 m^3/y or 0.951 m^3/s is sought, with a detention time (t) = 8 weeks or 4.84×10^6 s and a maximum allowable entry rate (v_e) = 0.4 m/d or 4.63×10^{-6} m/s. This gives as length and flow rate [Refer to Fig. 13 .3].

$$L = \sqrt{\frac{0.12\times10^{-3}\times2\times4.84\times10^{6}}{0.38}} = 55.3 \text{ m}$$

$$q_0 = 16\sqrt{\frac{0.12\times10^{-3}\times2\times0.38}{4.84\times10^{6}}} = 69.5 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}.$$

The width of the spreading basin (2w) thus equals

$$2w = \frac{2\times69.5\times10^{-6}}{4.63\times10^{-6}} = 30.0 \text{ m}$$

and the combined length of the spreading basins (B) is given by,

$$B = \frac{0.951}{2\times69.5\times10^{-6}} = 6841.7 \text{ m}.$$

The total area between the infiltration galleries (A) equals

$$A = 6841.7 \times [30.0 + (2 \times 55.3)] = 0.962 \times 10^6 \text{ m}^2.$$

The amount of water in dynamic storage in the pores of the formation between the original and the present water table (V) is given by

$$V = p\, S_0\, (L + 2w)\, B \qquad (13.9)$$

Out of this volume, a fraction corresponding to the degree of saturation (m/p) can be used. Here μ is the fraction of water voids. With m = 0.25 and the other factors as assumed before,

$V = 0.25 \times 2 \times (55.3 + 30.0) \times 6841.7 = 0.292 \times 10^6\ m^3$, allowing an interruption in the spreading operations for a period, $t = V/Q_0 = (0.292 \times 10^6)/0.951 = 0.307 \times 10^6$ s or 3.55 days.

This period will seldom be adequate to let a wave of polluted river water pass the point of intake. The calculations given above have the attraction of being simple and straight forward, but they have strongly simplified the reality, demanding at this point a number of corrections. The first simplification is the assumption of a constant saturated aquifer thickness (H) in the calculation of the drawdown (S_0) given by,

$$S_0 = [q_0 / (kH)]\, L = 2.0 \text{ m}$$

Taking into account the variation in water table elevation as well as the recharge by available rainfall (P) [assumed to be temporally uniform at the rate of 400 mm/year or 12.7×10^{-9} m/s]. For the case of India and other monsoon climates, this assumption has to be suitably modified. With the commonly used notations, the following is the correct estimation:

$$(H_0 + S_0')^2 - H_0^2 = \frac{2q_0L}{k} - \frac{PL^2}{k} \qquad (13.10)$$

For the case under consideration, the computed maximum drawdown (S_0') = 1.99 m, which has a negligible difference compared to the value of 2.0 m originally assumed.

The second simplification concerns the assumption that the spreading ditch fully penetrates the saturated thickness of the aquifer and does so over a width of 2w. To correct this, the spreading ditch is first replaced by a fully penetrating one of zero width, increasing the flow length by an amount w and giving the first additional drawdown (ΔS_1) as:

$$\Delta S_1 = \frac{q_0}{k(H_0 + S_0)}\, w = 0.51 \text{ m.}$$

Replacing this ditch by the real one gives the second additional drawdown (ΔS_2) as:

$$\Delta S_2 = \frac{2q_0}{\pi k} \ln\left(\frac{H_0 + S_0}{2w}\right) = -0.21 \text{ m.}$$

Together, we get the total drawdown (ΣS_0) as:

$$\sum S_0 = 1.99 + 0.51 - 0.21 = 2.29 \text{ m.}$$

The third simplification involves the finite length of the spreading ditch. When the area available has a more or less square shape in the top view, the total length of the spreading ditches calculated as 6841.7 m, must be broken up into 6 units, each of a length B = 1140.3 m. This gives a ratio B/L = 1140.3/55.3 = 20.6.

The piezometric level inside the gallery is less than that which corresponds with H_0 = 15 m, but this does not affect the water table outside the recharge area. With a number of spreading ditches parallel to one another, the capacity of the gallery (q_0) equals 2 ´ 69.5 ´ 10^{-6} = 139 ´ 10^{-6} m^2s^{-1}, giving for a circular drain of 0.5 m outside diameter (Ω) an additional drawdown due to partial penetration (ΔS) as follows:

$$\Delta S = \frac{q_0}{\pi k} \ln\left(\frac{H}{\Omega}\right) = \frac{139\times10^{-6}}{\pi(0.12\times10^{-3})} \ln\left(\frac{15}{\pi\times0.5}\right) = 0.83 \text{ m}$$

To this value, we must add the entrance resistance caused by clogging. Finally, it should be noted that a spreading ditch fully penetrating the saturated thickness of the aquifer over a width of 2w has been assumed. Replacing this ditch by a real one slightly lowers the minimum detention time. But with regard to the improvement in water quality during underground flow, this decrease is compensated by an increase in the average detention time, roughly by a factor of (L + w)/L=1.27 to 6.15 ´ 10^6 s or 10 weeks.

Spreading in Deep Phreatic Aquifer

The difference in spreading operations for deep and shallow aquifers is not a major one, but it only concerns the layout of the spreading area. Again, this can best be clarified with an example, assuming in this case capacity (Q_0) = 30 ´ 10^6 m^3/y = 0.951 m^3/s, permeability (k) = 0.4 ´ 10^{-3} m/s, porosity (p) = 0.38, fraction of water voids (m) = 0.32, maximum allowable entry rate (v_e) = 5 cm/h = 13.9 ´ 10^{-6} m/s, saturated aquifer thickness before spreading (H_0) = 60 m, the maximum allowable rise of water table (S_0) = 5 m, average saturated aquifer thickness during spreading (H) = 62.5 m, average detention time (t) = 8 months = 21.0 ´ 10^6 s, to allow when a linear spread in detention time is desired varying between 2 and 14 months. This gives, in the same way as described in the preceding section,

$$L = \sqrt{kS_0t/p} = 332.5 \text{ m}$$

$$q_0 = H\sqrt{kS_0p/t} = 376.0 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$$

$$w = q_0/v_e = 27.1 \text{ m}$$

$$B = Q_0/2q_0 = 1264.6 \text{ m}$$

$$A = 2B(L + w) = 0.910 \times 10^6 \text{ m}^2$$

$$V = \mu S_0 (L + 2w) B = 0.782 \times 10^6 \text{ m}^2$$

Here we are allowing an interruption in spreading of 9.5 days. The corrected drawdown follows from a uniformly assumed rainfall rate (P) = 400 mm/year = 12.7 ´ 10^{-9} m/s). For monsoon conditions such as in India, this assumption needs to be suitably modified taking the normal annual rainfall pattern into consideration.

Using Eq. 13.10, the computed maximum drawdown (S_0¢) = 4.97 m, which is quite close to the maximum allowable rise of water table (S_0) = 5 m.

$$\Delta S_1 = \frac{q_0}{k(H_0 + S_0)} w = 0.39 \text{ m}$$

$$\Delta S_2 = \frac{2q_0}{\pi k} \ln\left(\frac{H_0 + S_0}{2w}\right) = 0.11 \text{ m}$$

$$\sum S_0 = 4.97 + 0.39 + 0.11 = 5.47 \text{ m}$$

For a single spreading ditch, bounded at both sides by parallel infiltration galleries has reduction factors for additional flows around the far ends. This reduces $_0$ to 4.69 m, or well below the maximum allowable value of 5 m.

In the case considered above, the recharge area has a width of 719 m and a length of 1256 m, thus approaching a square area. This indicates a possibility of circular battery of wells. With the usual notation, the design criteria become

(a) Detention time (t), neglecting the soil mass below the spreading pond of dia. (r) at the surface level:

$$t = pH\Pi\,[(\rho + L)^2 - \rho^2]/Q_0 \qquad (13.11)$$

(b) Drawdown, composed of two terms: $S_0 = S_1 + S_2$. Here S_1 is the flow resistance from the rim of the spreading pond to the concentric battery of wells, calculated from the following Equation

$$(H_0 + S_1)^2 - H_0^2 = \frac{Q_0}{\pi k} \ln\left(\frac{\rho + L}{L}\right) \qquad (13.12)$$

S_2 is the flow resistance from the rim of the spreading pond calculated from the following Equation:

$$S_2 = \frac{Q_0}{2\pi k H} \alpha \qquad (13.13)$$

Here, α is tabulated as follows:

2ρ/H	0.01	0.1	1	10	100
α	308	27.6	1.58	0.088	0.0088

With sufficient accuracy, α may also be calculated from the equation:

$$\alpha = e^{(0.415 - 1.29x + 0.004x^2 + 0.0073 x^3)} \qquad (13.14)$$

where, x = ln (2ρ/H).

(c) *Entry rate*

$$v_e = Q_0/(\Pi\rho^2) \qquad (13.15)$$

With the same data as in the example above, the following values are obtained:

ρ = 147.6 m [From Eq. 13.15];

L = 390.4 m [From Eq. 13.11];

S_1 = 1.99 m [From Eq. 13.12];

S_2 = l.28 m [From Eq.s 13.13 and 13.14];

Therefore, $S_0 = S_1 + S_2$ = 3.27 m.

This value for S_0 is much smaller than the maximum allowable value of rise in water table of 5.0 m. To remedy this situation, the value of r is to be suitably modified. Accordingly L, S_1 and S_2 need to be re-calculated so that $S_0 = S_1 + S_2$ will be very to the maximum allowable value of rise in water table of 5.0 m.

The amount of water in dynamic storage (V) is given by,

$$V = \mu S_0 \pi \rho^2 \int_{\rho}^{\rho+L} \mu S_2 \pi r dr \qquad (13.16)$$

Since S is approximated as,

$$S = S_0 \frac{\ln[\frac{L+\rho}{r}]}{\ln[\frac{L+\rho}{\rho}]} \qquad (13.17)$$

This gives,

$$V = \mu S_0 \pi \frac{(L+\rho)^2 - \rho^2}{2\ \ln[\frac{L+\rho}{\rho}]} \qquad (13.18)$$

As regard to the pumping equipment of wells for groundwater recovery, the additional drawdown due to point abstraction (ΔS_{pa}) and additional drawdown due to partial penetration (ΔS_{pp}) should be accounted for. Say with 40 wells at an interval of 99m between two wells, the individual capacity = $Q_0/40 = 23.8[10^{-3}]$ m^3/s. With a screen length of 20 m [i.e., porosity (p) = $20/H_0 = 20/60 = 0.333$] and an outside dia. of gravel pack [$2r_0$] of 0.60 m, we get

$$\Delta S_{pa} = \frac{23.8 \times 10^{-3}}{2\pi \times 0.4 \times 10^{-3} \times 60}\, ln \frac{99}{2\pi \times 0.3} = 0.62\, m$$

$$\Delta S_{pp} = \frac{23.8 \times 10^{-3}}{2\pi \times 0.4 \times 10^{-3} \times 60} \frac{1 - 0.333}{0.333}\, ln \frac{[1 - 0.333] \times 20}{0.3} = 1.20\, m$$

To these values, we must add the additional resistance caused by clogging of well screen and gravel pack.

Keywords: Artificial groundwater recharge, Artificial recharge by spreading, Hydrologic design of recharge structures, Hydraulic design of recharge structures, Groundwater recharge structures.

Lesson 14 Design of Earthen Embankments and Diversion Structures

14.1 Hydrologic and Hydraulic Design of Earthen Embankments

Earthen embankments play a major role in watershed planning and management. In this section, the design of small earthen embankments viz., tank bunds -which are very useful in watershed management, is discussed.

14.1.1 Tank Bunds

Tank bund is an embankment of low height. Generally it is made of earth. Since earth of various types is available, tank bunds may be constructed using principles adopted for construction of earth dams. Generally three types of tank bunds are constructed. They are:

(a) Homogeneous Tank Bund (Type A): Uniform and homogeneous materials are used in the construction of these type of earthen embankments. It is constructed with relatively flat side slopes from the consideration of stability. Most of the bunds belong to this type [Fig. 14.1].

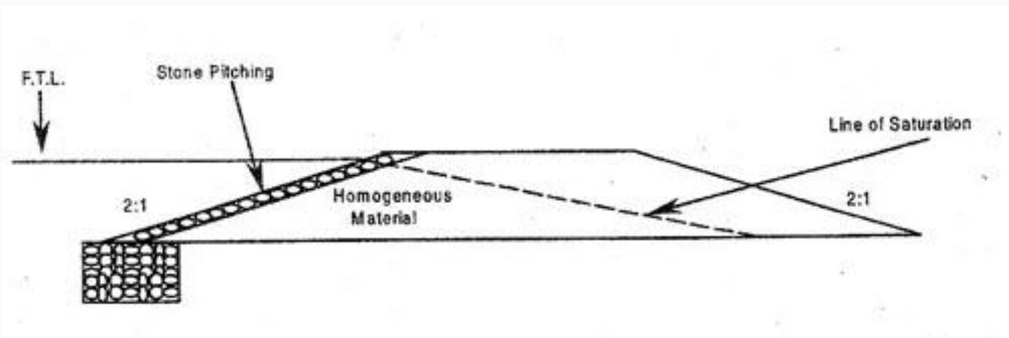


Fig. 14.1. Homogeneous Tank Bund (Type A).

(Source: Patel and Shah; 2008)

When the height of tank bund is more than 5 m, the section is modified suitability with seepage checking trenches, blankets, toe drains etc. s need to be applied

(b) Zoned Tank Bund (Type B): When earth of different types is locally available the bund may be constructed by dividing the section in different zones [Fig. 14.2].

Outer zone is generally made of pervious material indicated as ‘P’ in Fig. 14.2. The inner zone is made of impervious material. It is indicated as ‘I’ in the same figure.

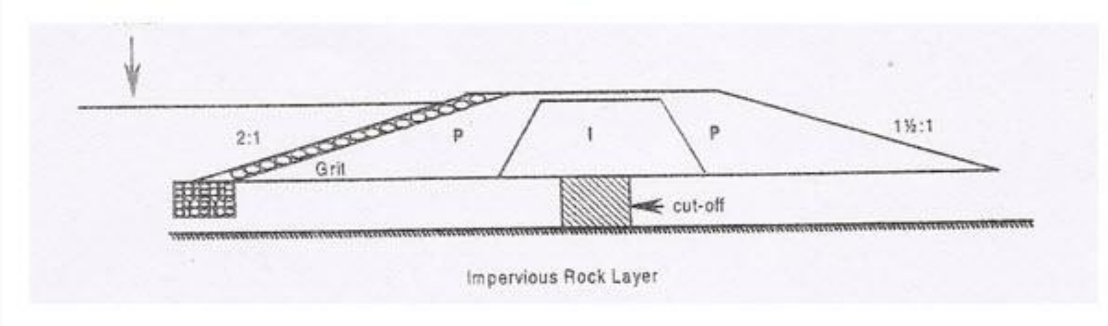


Fig. 14.2. Zoned Tank Bund (Type B). (Source: Patel and Shah; 20080

(c) Diaphragm Type Tank bund (Type C): Many times zoning is done by providing a central core wall, called diaphragm. It is generally constructed with masonry or concrete [Fig. 14.3].

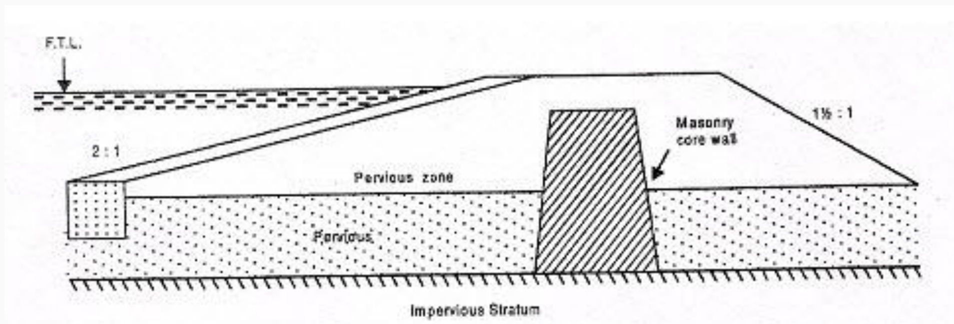


Fig. 14.3. Diaphragm Type Tank Bund (Type C).

(Source: Patel and Shah; 2008)

In such types of tank bunds, the diaphragm is taken quite deep into the foundation preferably up to the impervious stratum.

Design of Tank Bunds

Although high tank bunds are designed on the principles similar to design of earth dams, low tank bunds are constructed using empirical dimension. Commonly adopted bund dimensions are given in Table 14.1.

Table 14.1. Empirical Dimensions for Tank Bund Design (Source: Patel and Shah; 2008)

Height of the Tank Bund above the Deepest Bed (m)	Freeboard (m)	Top Width (m)
More than 7.5	1.8	2.7
6.0 to 7.5	1.5	1.8
4.5 to 6.0	1.2	1.5
2.5 to 4.5	0.9	1.2

The side slopes of the tank bund are kept quite mild. A slope of 2:1 (Horizontal: Vertical) is commonly used. However, for lesser heights steeper slopes may be adopted.

Like earth dams, the upstream face of the tank bund is generally given stone pitching, also called revetment. Thickness of the pitching may vary from 0.3 to 0.6 m. A toe is also provided to support the sloping face. General arrangement is already shown in Fig.s 14.1 to 14.3.

Storage Capacity of a Tank: Storage capacity of a tank can be calculated using trapezoidal formula. It is stated as:

$$V = H/3\ \left(A_1 + A_2 + \sqrt{A_1 * A_2}\right) \qquad (14.1)$$

Here,

V is volume enclosed between two adjacent contours.

A_1 & A_2 are the areas enclosed in two contours.

H is the contour interval.

This method is useful in finding capacity between two successive contours only. But since tank bunds are of small heights, the method is quite useful. The effective storage in a tank is the volume between level of the sill of the outlet or the lowest sluice and full tank level.

14.2 Hydrologic and Hydraulic Design of Diversion Structures

It is already mentioned that tanks are small storage structures constructed to meet local requirements. Obviously attempt is not made to store full runoff from the catchment area. It is therefore necessary to make suitable arrangement of diversion structures to pass excess water above Full Tank Level (FTL) safely to the downstream. Diversion structures constructed to provide passage to excess water are called escape weirs or tank surplus weirs.

The water starts spilling over the weir as soon as tank is filled up to its crest. However, due to rush of incoming water the level in the tank rises temporarily above FTL. This new level reached is called Maximum Water Level (MWL). It depends on the extent of flood. For design purposes, MWL is calculated taking into account maximum flood discharge likely to occur and the waterway available at the site of the escape weir. The spilling water is carried down through a channel, which is generally a natural drainage and has enough discharge carrying capacity.

Selection of Site for a Tank Surplus Weir: Following points may be taken into consideration while selecting a site for a tank weir:

(i) Tank surplus weir performs the function of passing excess flow. Therefore it is preferable to locate the weir in a natural saddle away from the tank bund.

(ii) The saddle i.e. the Natural Surface Level (NSL) is approximately at the same level as the FTL. It should be given first preference.

(iii) Hard foundation -if available at the site, reduces the cost of construction of bed protection works.

(iv) When a site away from tank bund is not available, as far as possible weir may be located on one end of the tank bund.

(v) Surplus weir may be housed in the body of the tank bund, only as a last resort.

(vi) Care should be taken to see that escape channel carrying surplus water is not likely to damage the cultivated areas.

Types of Weirs: Escape weirs constructed in tank irrigation system is similar to a diversion weir or an anicut constructed across the river channel. It may be constructed with either masonry or rock fill or concrete depending upon the availability of construction material and site conditions.

Masonry Weirs: This type of weir is most commonly used in a tank irrigation system. Masonry weirs are generally constructed as vertical drop weirs and are designed as gravity weirs. Self-weight of the body wall is the only restoring external force and it resists all destabilizing forces like water pressure, uplift etc. On the body of the weir, dam stones may be erected to enable extra storage. Depending upon the site conditions, masonry weirs may be constructed in three ways as given below.

Masonry Weir with Horizontal Floor: a drop is provided as shown in Fig. 14.4. This weir type is suitable when hard rock is available in the foundation and the height of the weir is less than 1 m or so.

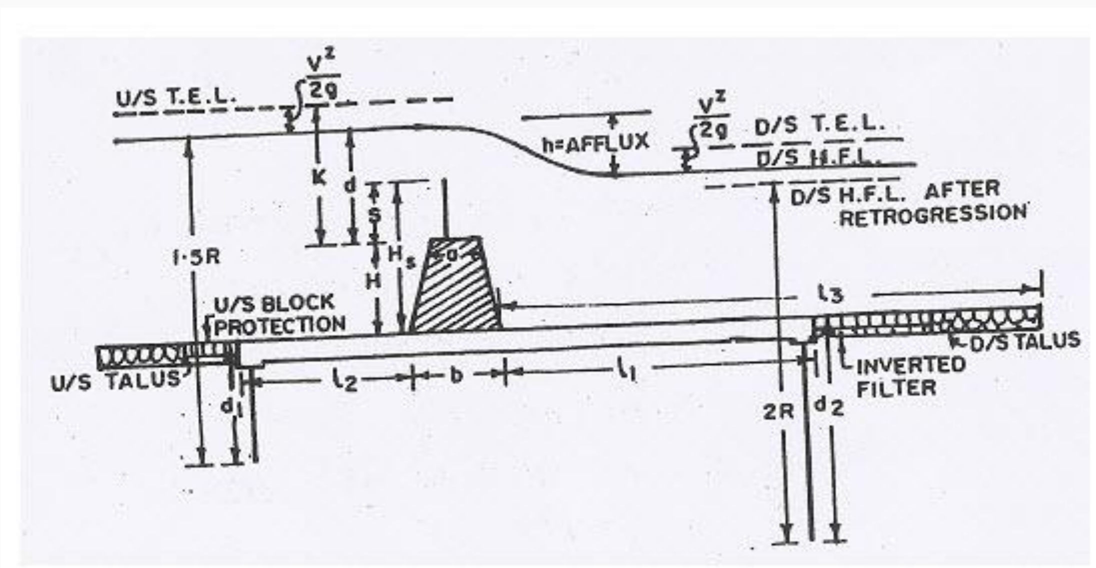


Fig. 14.4. Masonry weir with horizontal floor.

(Source: Punmia and Pande, 1992)

Masonry Weir with Depressed Floor: This type of weir is similar to one explained above except that the downstream apron is depressed below the ground level as shown in Fig. 14.5. By depressing the apron below ground level a sort of stilling pond is formed. It helps in dissipating the energy of water spilling over the crest of the weir. This type of arrangement is generally used for weirs with greater heights of more than 2.5 m. They are designed like a canal fall with the inclined floor generally having a slope of 4 H: 1 V.

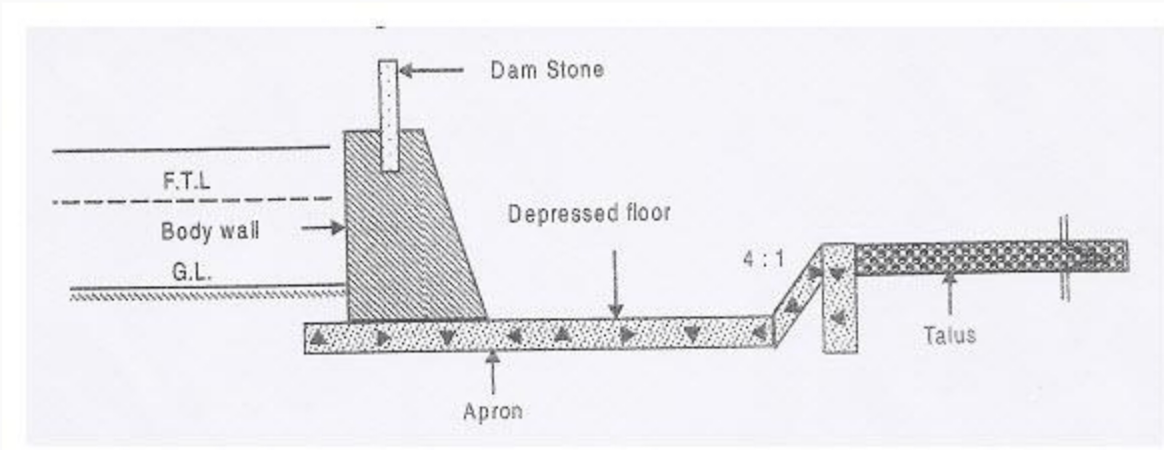


Fig. 14.5. Masonry weir with depressed floor.

(Source: Patel and Shah, 2008)

Masonry Weir with Stepped Floor: When the topography is such that there is no space for constructing either horizontal or depressed floor apron, weir with a stepped apron may be constructed as shown in Fig. 14.6. It is generally having a step and is suitable for low heights of body wall.

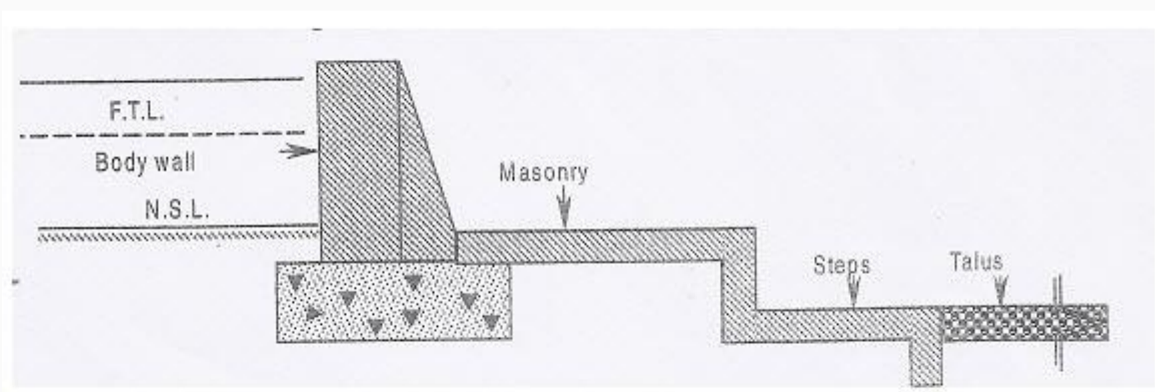


Fig. 14.6. Masonry weir with stepped apron. (Source: Patel and Shah, 2008)

Rockfill Weir: They are constructed as shown in with locally available dry rockfill, if such material is available in sufficient quantity. To support the rockfill masonry, retaining walls are constructed as shown in Fig. 14.7. Top surface of the weir is plastered. This type of weir acquires a very wide cross section because the slopes are quite flat [i.e., 1 V: 4H on the upstream side and 1 V: 20 H on the downstream side, generally].

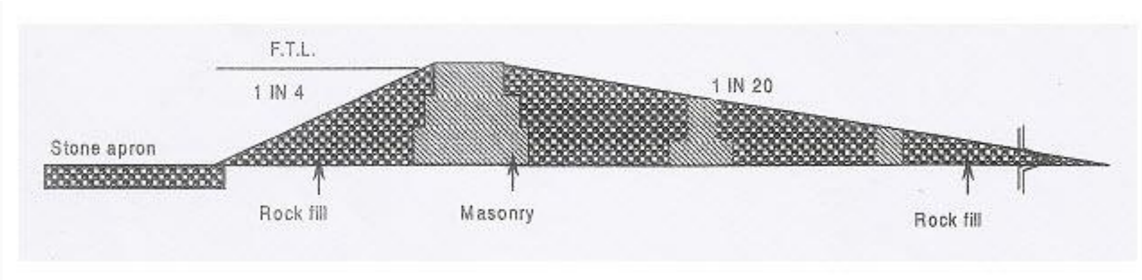


Fig. 14.7. Rockfill weir. (Source: Patel and Shah, 2008)

Concrete Weir: A typical profile of concrete weir is shown in Fig. 14.8. This type of weir is constructed with reinforced concrete to make the section monolithic. weir is constructed mostly where foundations are pervious.

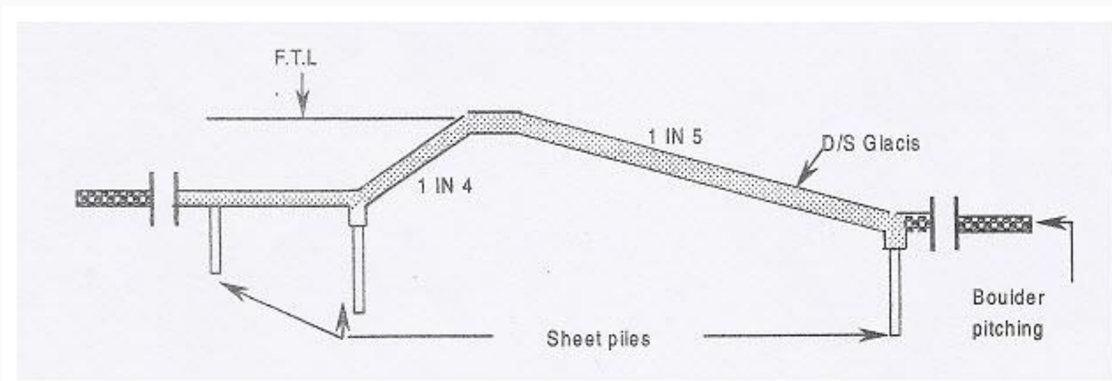


Fig. 14.8. Concrete weir. (Source: Patel and Shah, 2008)

In this type of weir, a sloping glacis is generally provided on the downstream side. It helps in creating a hydraulic jump on the sloping face. When hydraulic jump is created, excessive supercritical energy gets dissipated. Thus the bed below the weir is protected.

Design of Tank Weirs

Maximum Flood Discharge of Tank: Since the weir has to safely pass the excess flow downstream, estimation of peak flow becomes the first step in design of tank weirs. Catchment area of tank is generally small and fan shaped it is difficult to measure the discharge. Therefore it is estimated using empirical formulae. In North India, Dicken's formula is used while in South India, Ryve's formula is used. Dicken's formula is as given below:

$$Q = C.A^{3/4} \qquad (14.2)$$

where,

Q is peak flow in cumec,

A is catchment area in km^2 and

C is a constant.

The values of C are as given below:

C=11.4 for North India; C=13.9 to 19.5 for Central India and C = 22.2 to 25 for Western India

Ryve's formula for peak discharge (Q) is stated as below:

$$Q = C.\ A^{2/3} \qquad (14.3)$$

where,

Q is peak flow in cumec,

A is catchment area in km^2,

C is a constant, as given below.

C = 6.75 for areas within 24 km from the coast.

C = 8.45 for areas within 24-161 km from the coast.

C = 10.1 for limited hilly areas.

This formula can be applied for a free catchment. Fortanks in series or interconnected tanks the formula needs correction. Modified formula for discharge (Q_m) is:

$$Q_m = C.A^{2/3} - C_m.\ A_m^{2/3} \qquad (14.4)$$

where A_m is the catchment area in km^2 intercepted by upstream tank;

C_m is the new coefficient, whose value varies from 0.2 to 0.33.

Waterway of the Weir

The weirs constructed are generally broad crested weirs and the formula which gives discharge (Q) over broad crested weir can be used. Generally, the velocity of approach is neglected. The discharge formula is in the following form:

$$Q = C.L.H^{3/2} \qquad (14.5)$$

where,

L is the weir length in m;

H is the design head over weir given by (MWL - FTL) in m;

C is a coefficient, as given below.

C = 1.84 for weir crest up to 0.9 m width.

C = 1.66 for weir crests more than 0.9 m width.

C = 1.66 for crests with dam stones.

C = 1.47 for crests with d/s sloping face.

Length of Apron: Usually the length of the horizontal downstream apron is kept as 2(D + H) from the toe of body wall, where D is the height of the body wall above floor and H is the maximum water head over the crest of the wall. An additional factor of safety of 1.5 is provided when important areas lie below the surplus weir. Then horizontal downstream apron length becomes 3(D + H).

Length of Stone Pitching: Generally 3(D + H) to 5(D + H) length of stone pitching is provided on the downstream side of apron in continuation of the horizontal downstream apron. Greater length is provided, when there is a weaker foundation material.

Keywords: Earthen embankments, Diversion structures, Tank bunds, Escape weirs, Masonry weirs, Rockfill weirs, Tank Weirs.

Module 8: Soil Erosion and its Control Measures

Lesson 15 Problem /Types of Water Induced Soil Erosion & Measures for its Control

15.1 Problem of Water Induced Soil Erosion

Detachment of soil from its original location and transportation to a new location is known as soil erosion. Mainly water is responsible for this erosion although in many locations wind, glaciers etc. are also the agents causing soil erosion. Unless otherwise stated, erosion will refer to only water erosion in this lesson. The natural erosion under a balanced condition of forest and vegetative cover is responsible for the creation of earth's crust over millions of years. Weathered and disintegrated rocks mixed with decomposed organic matter got deposited on the surface during this slow process of soil formation. This top soil surface supports all the plant life and consequently animal and human life also. With the beginning of human civilization, harmful soil erosion process started. Man felled trees to create land for farming, construction of houses, roads etc. The soil was tilled in any manner for farming and any type of crop was grown anywhere. Coupled with this, overgrazing by animals created favourable conditions for soil erosion. By the time man could realize this ill effect, it was too late and required very expensive protection measures.

History of Soil Erosion

Although man could realize the ill effects of erosion much later, he has been unconsciously struggling with the problem since farming started. Man constructed bunds around the cropped plots to conserve water and soil. Farming started about 7000 years ago when man began to settle and leave nomadic life. It is reported that the first civilization started in the plains of Mesopotamia located in the valley of Tigris and Euphrates rivers. It gradually developed into the world's best civilization during the time of the Babylonians, Assyrians etc. The downfall of this civilization can be attributed more to the unwise utilization of the fertile land resources rather than the successive invasion by different regimes.

The Nile Valley consisting of Egypt, Uganda, Sudan and Ethiopia are also considered to be an area of the oldest civilizations of the world. Egypt is called the gift of River Nile. The neighbouring countries of Israel, Syria, Jordan, Greece, Turkey etc. were equally prosperous once upon a time. The rainfall being scanty, farmers started irrigation of the crops through canals. Scientific design of canals was unknown to the man and silting started soon. Mesopotamia has been known as the place of the Garden of Eden and the Tower of Babel. There were high density of population and big cities. This land has seen the rise and fall of at least eleven empires. The debris caused due to erosion for centuries left a deep blanket over these big cities and now the ruins of the cities, some scattered villages can be seen here.

Tigris and Euphrates rivers originate from the mountains that have been made devoid of tree cover by felling and flow through overgrazed hill lands. Runoff water that flew from the catchment into these rivers carried huge silt with it. The silt was deposited in the canal below and it was a difficult task to maintain the canal system. With the growth in population, the canal system was further expanded and maintenance became more difficult. Also there has been repeated invasion of the country and it became almost impossible to fight the invaders and to maintain the canals. As a result the canal system and finally the agriculture failed. With a small agricultural production, only a small population could be supported and the great civilization disappeared.

There are innumerable examples of how soil erosion destroyed civilizations. The Jordan River washed off most of the fertile soils from the slopes and bed rocks can be seen there. High lands of Judea have been severely eroded and a very poor yield obtained. The famous Nabatean civilization of about 2000 years ago along with its capital Petra is in ruins now. This can also be attributed to the breakdown of agriculture system due to severe soil erosion. Shanxi, a province of China faced severe soil erosion after the denudation of forests. Many cultivated areas have turned into gullies.

Classic examples of disappearance of human civilization in India due to the mismanagement of soil resources are Mohenjo-Daro and Harappa. Vast tracts of hilly areas of north eastern states have been made barren by jhuming (i.e., shifting cultivation). Siwalik range of the Himalayas suffered a severe soil loss due to denudation and overgrazing by cattle. The eroded soil silted up the river beds. The Kosi River originating from Nepal got silted up due to erosion problems in the upper catchment. Most of the years, it inundates vast areas in North Bihar. River Damodar has been a river of sorrow for the alluvial plains of West Bengal due to erosion problems in Chota Nagpur region of Jharkhand. Again, by construction of reservoirs and treatment of the upper catchment the problem has been largely overcome.

15.2 Types of Water Induced Soil Erosion

Soil erosion is broadly classified into natural type called geological erosion and manmade type called accelerated erosion. Geological erosion takes place under natural undisturbed conditions when a balance is maintained between the soil, climate and vegetative cover. It is a very slow process and responsible for soil formation as well as soil loss. Both together maintain a balance for favourable growth of the plants. Most of the present topographical features of the world such as natural channels, valleys, canyons etc. are results of the geological erosion. As far, as agricultural lands are concerned, geological erosion is not of much consequence.

Different activities of man such as cutting of forest, felling of trees, cultivation of land, overgrazing etc. have disturbed the natural balance between the soil, climate and vegetative cover. Under this condition, soil erosion is taking place at a much faster rate and this is called accelerated erosion. It. is destructive in nature and caused much land degradation. Only accelerated erosion is a matter of concern for the agricultural land and henceforth it will be referred to erosion only. The erosion can be classified as: (i) water erosion, (ii) wind erosion, (iii) coastal erosion.

Depending upon the degree of erosion and its location, water erosion is further classified as: (a) raindrop erosion, (b) sheet erosion, (c) rill erosion, (d) gully erosion, (e) stream channel erosion. These are discussed in details in the subsequent sections.

Raindrop Erosion

Raindrop erosion is the result of direct impact of raindrops on bare soil or in thin film of water. If the soil surface is covered with good vegetation, much harmful effects do not occur as the drops break into finer sprays and much of it infiltrates into the ground. However, if the raindrop strikes the bare soil, considerable raindrop erosion takes place. The raindrops sometimes fall at high speed of 50 kmph and the soil particles may be splashed to a height of 60 cm and move laterally to a distance of 150 cm.

The same soil particles are generally splashed more than once. Thus they are detached from the main soil body and easily carried with the runoff water. In a level surface much serious problem may not occur as the soil is just shifted from one place to another. But in sloping lands they are easily transported down the slope and may join a rill or a gully from where further downward movement becomes easier. Apart from soil particles, the plant nutrients are also removed and transported from the productive land.

A part of the rainfall with clay and silt suspension infiltrates into the ground. In this process the fine particles are removed due to sedimentation phenomena. These fine particles block the soil pores and the infiltration capacity of the soil is greatly reduced. As a result, the runoff rate increases and more soil particles are transported. Thus raindrops striking bare soils on sloping ground, causes severe damage which intensifies as the duration increases.

Factors affecting raindrop erosion are (i) vegetative cover and mulches, (ii) rainfall, (iii) wind velocity and direction, (iv) soil texture and structure, (v) topography, particularly degree and length of slope. Raindrops falling on plants, crop residue or other mulches lose their energy before striking the soil. High wind velocity in the direction of slope causes higher splash. The wind velocity and air resistance also affects the raindrop velocity. The raindrop velocity depends upon the height of fall up to a height of about 10.5 m after which it attains the terminal velocity. Soil loss increases with the increase of this terminal velocity which may vary from 4.5 to 9 m/s depending upon the drop size. Surface roughness and obstructions reduce the soil loss due to splashing.

Sheet Erosion

Sheet erosion has been defined as the uniform removal of soil in thin layers from sloping land which results from sheet or overland flow occurring in thin layers. The top fertile layer of the soil is slowly skimmed off every year and it flows down as muddy water. The field appears to be the same as it was before the rainy season. But huge amount of soil gets lost every year. Initially the reduction in the crop yield may not be significant. But over the years the yield declines till it reaches a minimum. Sometimes, the lower layers of soil and finally the bed rock may be exposed rendering the soil unfit for any crop production. Therefore, although sheet erosion occurs slowly but it is very harmful as it cannot be detected easily in the initial stage.

Recent studies on the mechanisms of erosion using remote sensing and other photographic techniques indicate that the type of sheet erosion mentioned above rarely occurs. Along with the detachment and transport of soil particles, the second phase of erosion called rill erosion also takes place. High speed photographs clearly indicate the change of position of the microscopic rills. In case loose topsoil is located above a comparatively light subsoil, combination of sheet and rill erosion easily occurs. For a given soil surface with a fixed size, shape and density of soil particles, the eroding and transporting power of sheet flow is greatly influenced by the depth and velocity of runoff.

Rill Erosion

Rill erosion is called the second erosion in which the removal of soil by rain water from small but well demarcated semi-permanent channels or streamlets takes place due to overland flow. Rill erosion starts simultaneously with sheet erosion. But conventionally rill erosion is said to have started when channels are large enough to be visible.

Like sheet erosion, rill erosion is also often overlooked although detachability and transportability of soil are much higher due to higher surface velocity. If care is taken, channels formed due to rill erosion can easily be smoothed out by farming operations. If proper care is not taken, rill develops both in depth and width. Ultimately movement of small farm implements becomes difficult and cropped area reduces. Finally the rills may develop into gullies.

Gully Erosion

If the rills are not attended for a long time they develop further in their depths and widths and finally form gullies. Gullies are therefore an advanced stage of rill erosion, which is an advanced stage of sheet erosion. Once the gully has been formed, it cannot be smoothed out by normal cultivation practices. It requires costly and effective structures/ practices to control the further advancement of gully.

The advancement of gully depends upon watershed characteristics, rainfall characteristics, soil characteristics, shape of the gully, slope of the channel and cultivation practices in the watershed. Following four different processes are involved in the development of the gully:

(i) **Waterfall erosion at the gully head**: Water falling at the gully head cuts the edge and caving of banks takes place. This detached mass of soil is carried away by runoff water. If the subsoil is loose, undermining proceeds at a faster rate. The depth and width of the gully thus increase. More land area is covered by gullies and gradually gully branches spread all over the area.

(ii) **Channel erosion**: It is caused by the water flowing through the gully or by raindrop splash on unprotected soil. As much of the water passes through the gully head, lengthening of the gully takes place.

(iii) In cold regions, alternate freezing and melting of snow occurs on the exposed soil banks and causes erosion.

(iv) Due to undercutting, slides or mass movement of the soil takes and huge quantity of soil is lost at a much faster rate.

Generally, the following 4 stages are involved in the development of gullies:

Stage 1: Formation Stage

Channel erosion takes place by downward scour of the topsoil. If the topsoil can provide resistance, this stage proceeds slowly.

Stage 2: Development Stage

Upstream movement of the gully head and simultaneous enlargement of width and depth take place. The weak parent material is rapidly removed.

Stage 3: Healing Stage

Vegetation begins to grow in the channel and further erosion stops.

Stage 4: Stabilization Stage

The gully bed and sides reach a stable slope and sufficient vegetation grows to anchor the soil and to trap soil flowing from upstream. New topsoil develops and vegetative cover grows.

Classification of Gullies: There are several systems of gully classification. According to one system gullies are classified as per their cross-sections. Depending upon soil, climatic conditions, age of the gully and type of erosion it may be either V-shaped or U-shaped. V-shaped gullies are formed due to scouring of soil by concentrated runoff in unprotected depressions. If both the surface and subsurface soil are easily erodible, then U-shaped gullies are formed. Vertical walls are formed due to undermining and collapse of the banks. Both the types of gullies may be visible in the same channel.

Another commonly used method of classification of gullies is based on drainage areas and gully sizes. Based on their works in the ravine lands of Gujarat in 1961, Tejwani and Dhruvanarayana classified gullies into four classes. According to this classification, very small gullies have depths and widths within 3 m and 18 m respectively. Small gullies have depth within 3 m, but width is greater than 18 m and side slopes may be a between 8 to 15 per cent. Medium gullies have depth between 3 to 9 m, bed width 18 m or more. Deep and narrow gullies generally have depths 3 to 9 m and bed width less than 18 m.

Stream Channel Erosion

Stream channel erosion is the removal of soil either from stream bank or from channel bed. The flowing water gradually erodes the river bank(s) or the bed below the water surface. Sometimes, the streams and rivers change their course during the periods of peak flows. This is a very serious problem as the river gets widened every year. The widening of the river destroys huge cultivated lands, villages, cities, railway lines, bridges, other structures etc. Very costly and effective protection measures are required to prevent this type of erosion.

Stream channel erosion consists of two parts namely, bank erosion and scour erosion caused by undercutting. The later is more serious as it can cause huge landslides. The stream bank erosion is caused by removal of vegetation, by overgrazing or by tilling very close to the river bank. The velocity and soil texture etc. influence the scour erosion. Stream channel erosion differs from gully erosion in the following aspects:

(i) Stream channel erosion occurs at the lower end of the headwater tributaries, whereas, gully erosion occurs near the upper ends of headwater tributaries.

(ii) Stream channel erosion occurs in streams that have almost continuous flow, whereas, gully erosion occurs in streams with intermittent flow.

15.3 Measures for Water Induced Soil Erosion Control

15.3.1 Contour Cultivation

Contour cultivation consists of performing all farm operations like ploughing, seeding etc., approximately along contours. Ploughing produces small ridges across the slope. These ridges along with crops arrest the movement of soil and water. In low rainfall areas, contour cultivation helps in moisture conservation. In high rainfall areas, significant amount of soil and a part of water is conserved. The furrows formed due to contour cultivation store large amount of rainwater and allow it more time to infiltrate. Due to uniform soil moisture distribution during entire crop period, the crop yield increases.

Contour cultivation is also an important step in upstream flood control. However, in steep slopes under high rainfall conditions, contour cultivation may cause more harms than benefits. There could be breaking of ridges followed by increased cumulative flow and gully formation. Under such conditions, contour cultivation needs to be supplemented by measures like terracing and bunding. In contour cultivation, gradual surface sealing takes place due to deposition of fine particles and subsequent decrease in infiltration capacity. This should be avoided by suitable desilting measures.

15.3.2 Contour Bunding

Bunding or construction of small embankment is carried out to reduce the length of slope, to reduce the velocity of runoff water and to hold the water in the catchment for a longer period. Thus more water infiltrates into the ground and less run-off and soil erosion take place. Different types of bunds are used for erosion control and moisture conservation.

When the bunds are constructed along the contours with some minor deviation to adapt to practical situations, they are known as contour bunds. If the bunds are constructed with some slope, they are known as graded bunds, Side bunds are constructed along the slope at the two sides of the contour bund. Lateral bunds are constructed along the slope in between two side bunds to reduce the length of the contour bund. This reduces the concentration of runoff water along one side. Supplemental bunds are constructed between two contour bunds to limit the horizontal spacing of the contour bunds. Peripheral bunds are constructed along the field boundaries and may not conform to the contours.

In India, contour bunding or simply bunding has been practiced for a long time and the Indian farmers have very good knowledge about it. First thing that is done to control a rill or a gully is to do bunding. The former state of Bombay did notable works in contour bunding and in other states like Andhra Pradesh, Tamil Nadu and Karnataka vast areas were put under contour bunds. From the experience gained through these constructions, it was known that bunds could stand well only in shallow, medium and medium deep soils. Deep black soils show cracks in dry conditions and the bunds fail. Through these cracks water continues to flow and big breaches are caused. This results in severe damage to the fields. Although various erosion problems exist in black cotton soils, contour bunding cannot be taken up in such soils successfully.

Design of Contour Bunds

The design of contour bund includes determination of spacing, both horizontal and vertical and bund cross-section. The bund cross-section includes base width, side slope and bund height. The bund height should be sufficient to store the expected runoff from a rainfall of 10 years recurrence interval. Over this depth, extra depth should be provided for the design depth of water over the weir and the free board. The base width, side slope and top width are decided by the nature of soil.

Spacing of Contour Bunds

As the water flows through a sloping land, it attains erosive velocity. The bund should be spaced in such a way so as to intercept the erosive velocity. Again, the spacing should not be too close to interfere with the farming operations. Different relationships have been developed for the spacing of bunds.

Ramser's Formula

Ramser conducted experiments in sub-humid areas with good infiltration rates and developed the following relationship for vertical, interval of contour bunds.

$$V.I = 0.3\left(\frac{s}{3} + 2\right) \qquad (15.1)$$

Where V.I = vertical interval between consecutive bunds [m], and s = land slope [in per cent].

The above formula does not take into account soil and rainfall characteristics and its applicability cannot be genera1ized. When the above formula is used for soils with high infiltration rate and good conservation practices such as contour farming, growing of cover crops etc., then 25% extra spacing can be used. On the other hand, in soils of low infiltration capacity arid unfavoub1e conservation measures, the spacing should be reduced by 15%. Similar adjustments are required for rainfall variation. For high rainfall areas, the interval should be reduced and vice-versa. In fact, a general relationship of the following form may be used and the constants should be evaluated for the specific site.

$$V.I = \left(\frac{s}{a} + b\right) \qquad (15.2)$$

Where V.I = vertical interval between consecutive bunds [m], and s = land slope [in per cent]. The constants a and b should be evaluated for the specific soil and rainfall characteristics.

Cox's Formula

M.P. Cox, a water management specialist of United States Agency for International Development (USAID) gave the following formula for spacing of contour bunds.

$$V.I. = (xs + y) \times 0.3 \qquad (15.3)$$

Where V.I = vertical interval between consecutive bunds [m], and s = land slope [in per cent].

y = infiltration and crop cover factor.

The values of x and y are given in Tables 15.1 and 15.2 respectively.

Table 15.1. Values of the Rainfall Factor (x) (Source: Mal, 1995)

Rainfall condition	Value of x	Annual Rainfall, cm
Scanty	0.8	64
Moderate	0.6	64-90
Heavy	0.4	over 90

Table 15.2. Values of the Infiltration and Crop Cover Factor

(Source: Mal, 1995)

Intake rate	Crop cover during critical period	Value of y
Below average	Low average	1.0
average or above	Good average	2.0
One of the above two factors is		
favourable and the other is unfavourable		1.5

For the purpose of moisture conservation mainly, the spacing of the bunds can be selected as given in Table 15.3. The recommendation is based on the works carried out by Gadkary in the former Bombay State.

Table 15.3. Spacing of Contour Bunds, (Source: Mal, 1995)

land slope, %	Vertical interval, m	Approx. horizontal distance, m
0 to 1	1.05	105
1 to 1.5	1.20	97
1.5 to 2	1.35	76
2 to 3	1.50	61
3 to 4	1.65	52
4 to 5	1.80	39
5 to 6	1.95	36

Alignment and Construction of Contour Bunds

For the purpose of alignment and construction of contour bunds, a map showing the plan of the area is necessary. The map should either be available or prepared using any standard method like plane table survey. All natural features like streams, gullies, field boundaries etc., should be shown in the map. The area is then divided into blocks of suitable size (say 50 ha) in which soil conservation programmes can be taken up at a time. Detailed map of each block with a larger scale should be prepared. On these maps, the locations of the contour bunds are marked.

For drawing the position of the contour bonds on the map, at first lever survey is conducted by taking a suitable grid distance so that contours can be drawn on the map at an interval of 30 cm. From the contour map, average slope of the land is calculated. Knowing the slope, infiltration and rainfall characteristics, the vertical and horizontal intervals are calculated for the bunds. Planning is started from the top of the watershed. Contour bunds are located on the map as per the calculated horizontal interval. The positions are then transferred to the field. Slight modification is made to eliminate the sharp curvatures and changing of existing field boundaries. Another method in which the contours are directly located in the field can be used for alignment of contour bunds. This is known as *direct contour method*.

While using direct contour method, the slope of the land is determined approximately by taking flying levels. The vertical and horizontal intervals are calculated as describe earlier. Locating of the bunds is started from the top of the watershed. The dumpy level is set up at a convenient position. Leveling staff is held at one corner of the proposed location of the first bund and the reading is taken. The staff is shifted to different positions from where the same level readings are obtained. These positions are marked with pegs. Thus the position of the first contour bund is obtained. This procedure is repeated to obtain the positions of all the remaining contour bunds.

15.3.3 Graded Bunding

In areas of the high rainfall (annual rainfall greater than 800 mm) and fine textured soil, the entire runoff cannot be easily and economically stored in the catchment through contour bunding. The excess runoff may not safely be disposed of through the surplussing arrangement. Under such situations, graded bunds can be used to dispose of the excess runoff safely. Graded bunds have generally wide and shallow channels and earthen bunds laid along a pre-determined longitudinal grade. For a comparatively flatter slope of land, simply an earthen bund is constructed along a grade and water flows behind the bund. Therefore, contour bunds are mostly used for conservation of moisture in low rainfall areas with permeable soils. On the other hand, graded bunds are used partly for conservation of moisture and partly for safe disposal of the excess water in high rainfall areas and/or in tight soils.

Design Considerations

The design of graded bund includes determination of vertical interval (V.I.), grade and cross-section. Also a decision should be taken whether only the bund or a bund in combination with channel will be constructed. Only a bund is preferable as the problem of channel maintenance is eliminated.

Vertical Interval

The same principle as used for determination of the vertical interval and horizontal spacing of contour bund may also be used for graded bund. In case the soil is very permeable with high infiltration capacity and good biological control measures are practiced, the spacing of bunds can be increased by 25%. On the other hand for a fine textured soil without proper biological controls, the spacing may be reduced by about 15% from the calculated value.

Grade

Either a uniform or a variable grade is used for graded bunds. For short bunds of 100 to 150 m length uniform grade is used and for longer bunds variable grade is recommended. For most of the soils, grade can be in the range of 0.2 to 0.4%. In case of long bunds of 400 m or so in a permeable soil, the grade can be 0% at the beginning and increases to maximum 0.5% at the tail end. For impervious soil the grade at the beginning should be about 0.2% and increases to 0.4% at the tail end. The concept is to provide sufficient velocity of water so that an economical cross-section of channel can be obtained and at the same time the velocity should be non-erosive. The grade should generally change in every 100 m length. Short bunds of 100 to 200 m with channels (terrace) reduce the maintenance problems.

Cross-Section

The cross-section of the bund should be sufficient for stability, highest flood level should be below the top of the bund and the seepage line should lie below the toe of the bund on the downstream side. Generally a top width of 50 cm is used although it may vary from 30 to 90 cm for various heights of the bund. The height can be from 50 to 80 cm. Table 15.4 provides the dimensions of a typical trapezoidal shaped graded bund. The stable side slope depends upon the type of soil. For clayey soil it may be as steep as 1 : 1, for loamy soil 1.5H : 1V and for sandy soil it is increased to 2H : 1V. The seepage line has a horizontal to vertical slope of 3:1, 5:1 and 6:1 for clayey, sandy loam and sandy soils respectively. The base width of the bund should, therefore, be designed using this criteria and the depth of flow.

Table 15.4. Typical Dimensions of Trapezoidal Shaped Grade Bunds (Source: Mal, 1995)

Height, cm	Top width, cm	Bottom width, m	Cross-section, m^2
55	50	2.25	0.75
80	50	2.50	1.00
80	50	2.60	1.25
80	50	3.50	1.50

In case a channel is constructed in combination with the bund, the channel should have sufficient capacity to carry the excess runoff with non-erosive velocity. The non-erosive velocity ranges from 50 to 75 cm/s for soils varying from sandy to clayey type. The velocity also depends on the channel grade. Manning's formula should be used to calculate the velocity of flow and the channel capacity. Generally, a cross-section of 1 m^2 with a depth of about 45 cm serves the purpose in most of the cases. The channel may be designed for parabolic shape as it finally assumes that shape although originally it is constructed as a trapezoidal channel.

Alignment and Construction of Graded Bunds

The alignment of the graded bund can be done in a manner similar to that of the contour bund. As in contour bunds, the alignment can first be made on a contour map and then transferred to the field. They can also be aligned directly in the field. Before deciding the alignment of graded bunds, the location of the outlet and the grassed waterway should be finalized.

The reduced level (R.L.) of the outlet point of the topmost bund is determined. The distance along the contour is measured in a step of about 25 m and the elevation of the alignment is increased to provide the necessary grade. In case a variable grade has to be provided, the same procedure will work except that the rise in level at different steps will be proportional the grade. The outlet elevation of the second bund is obtained by deducting the vertical interval from the R.L. of the outlet of the first bund. Other points of the second and subsequent bunds are obtained in the similar manner as in case of the first bund. The alignment of a graded bund is shown in Fig. 15.1. The bund length in this case is only 100 m and a uniform grade of 0.3% has been provided. The vertical interval has been assumed to be 0.6 m.

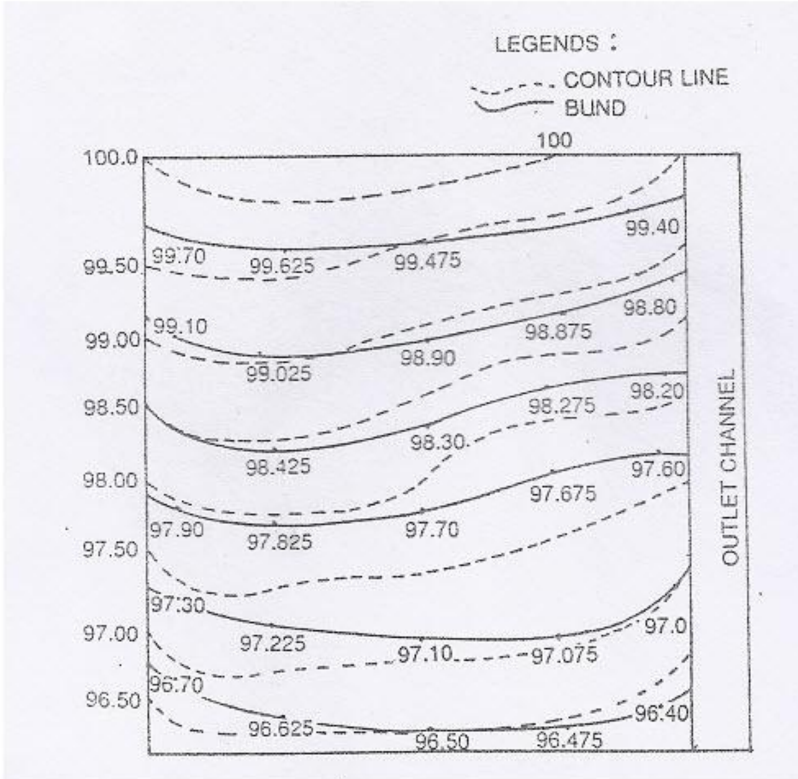


Fig. 15.1. Alignment of a Graded Bund. (Source: Mal, 1995)

The construction method of graded bund is same as that of contour bund. If manual labour is easily available, it can be used for making the bund precisely. Bullock drawn buck scraper can be used for scraping and filling the soil on the bund. Before that the soil should be loosened by ploughing. For large scale bunding, grade terracer pulled by wheel tractor, bulldozer, motor grade etc., are used. If a channel-cum-bund is constructed then the soil for bund should be obtained from the channel. Otherwise, the soil should be scraped from both sides of the bund for its formation.

15.3.4 Bench Terracing

Bench terraces are constructed to divide a steeply-sloped hilly land into a series of level or nearly level strips or benches running across the slope. The benches are separated by almost vertical risers retained by rocks or thick growth of vegetation. In India, bench terracing -although not very scientifically designed, has been very widely used for centuries. In the hilly regions of the north eastern states, Himachal Pradesh, Kerala, Tamil Nadu, Bihar, etc. farmers have been using bench terraces for growing crops.

Bench terraces are constructed on steep slopes greater than 6 to 7%, although recent recommendations favour their construction on slopes greater than 15%. Therefore, the cost of construction is very high and the construction is justified only when land available for cultivation is very scarce. The depth of soil should be adequate so that even after cut sufficient depth is available for crop growth.

Components of Bench Terrace

The bench terrace essentially consists of the four components namely, (i) riser, (ii outlet channel, (iii) platform and (iv) shoulder bund. Fig. 15.2 shows the components of a bench terrace. The riser is a vertical wall at the upstream end of the strip of land converted to bench terrace. The outlet channel can be located either at the upstream or at the downstream end depending upon the rainfall and soil conditions. Platform is the level or nearly level strip obtained by terracing and crop is grown in this zone. Shoulder bund helps to retain the rainfall in the terraced area.

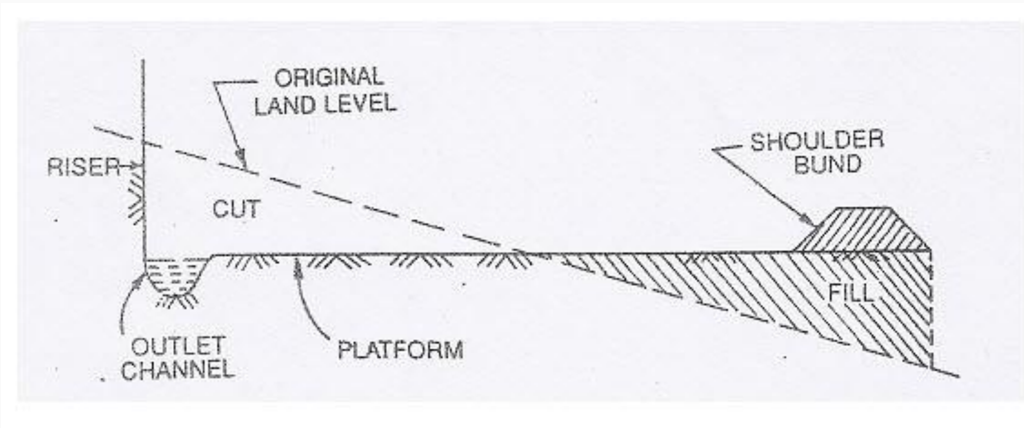


Fig. 15.2. Components of a Bench Terrace. (Source: Mal, 1995)

Types of Bench Terraces

Depending upon slopes, bench terraces are classified as (i) level bench terrace, (ii) outward sloping bench terrace and (iii) inward sloping bench terrace. Fig. 15.3 shows these types. There are other types such as California type terrace, Tati terrace, conservation bench terrace etc.

Level Bench Terrace: They are also known as table top or paddy terraces. They are generally used in paddy cultivation as paddy requires some ponded water. On a land of very mi1d slope such as 1% also level bench terrace is constructed to facilitate paddy cultivation. The level type is suitable in area with medium rainfall and permeable soils.

Outward Sloping Bench Terrace: In areas of low rainfall or shallow soil depth this type is suitable. The existing steep slope can be reduced to a mild slope to reduce soil erosion, conserve soil moisture and grow crops other than transplanted paddy. In case leveling is done in phases, this may be considered to be a step towards achieving a level or inward sloping terrace. The surplus runoff water should be safely disposed of through the provision of a graded channel.

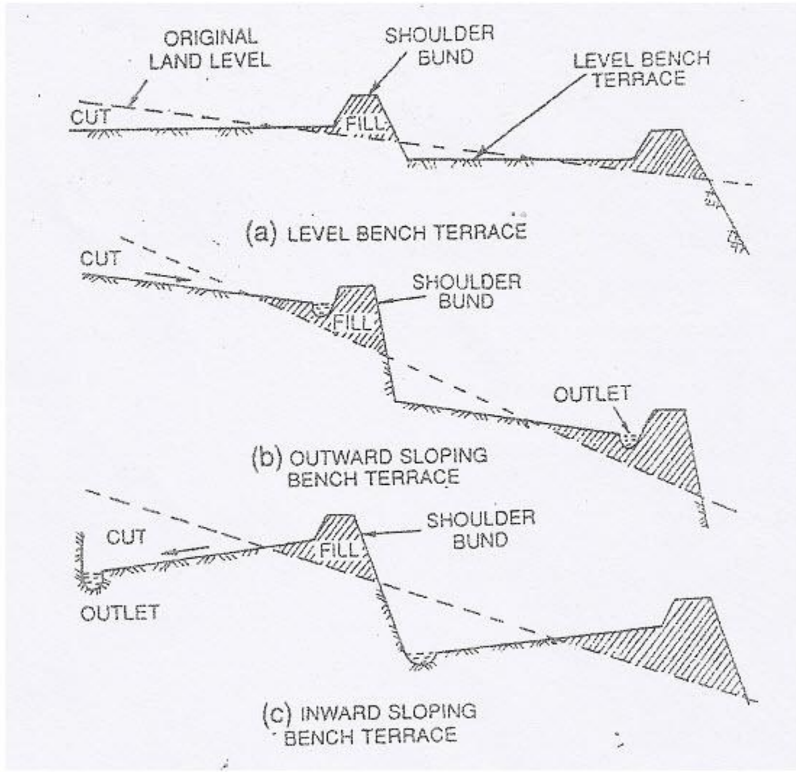


Fig. 15.3. Different Types of Bench Terraces. (Source: Mal, 1995)

Inward Sloping Bench Terrace: In high rainfall areas with steep slopes these types of terraces may be used. They have a drain on the inner side which is provided with a suitable grade along the length to convey the excess water to one side. Vegetated waterway is used to dispose of the water from such drains.

California Type Terrace: This is also known as Puerto Rican type terrace. At first, a vegetative or a mechanical barrier is established along the contour. Then the soil is ploughed and pushed downward gradually during tillage operations every year. Thus the terrace is developed slowly over a number of years.

Tati Terrace: The Tati terrace was first adopted in Tati village near Chandwa in Palamau district of Bihar by the Soil Conservation Department of the Damodar Valley Corporation (DVC). On lands having slope up to 3% and where contour bunds are not possible due to existing field boundaries, rectangular retention terraces known as Tati terraces are found to be more useful. Bunds are constructed on all or at least three sides following the revenue boundary so that water is stored and some leveling is done. Outlet is provided at one end and a vertical interval of about 60 cm is maintained.

Design Principle for Bench Terrace

Terrace design is influenced by the conditions of soil depth, slope, rainfall, farming practices etc. The design includes (i) terrace spacing, (ii) terrace grade and length, and (iii) terrace cross-section.

Terrace Spacing: The spacing is expressed in terms of the vertical interval (V.I.) and for this the following formula is generally used.

$$\text{V.I.} = 0.3\left(\frac{S}{2} + 2\right) \qquad (15.4)$$

Here S = slope (%). But this formula cannot give a precise relationship for all conditions as the spacing depend upon slope, soil depth and surface condition and agricultural practices.

The depth of cut is influenced by the V.I. and depth of soil limits the maximum depth of cut. At the same time the width of terrace should permit economic agricultural operation.

Conservation Bench Terrace

In the conservation bench terrace (CBT), the terrace width is divided into two parts namely, the runoff part and the bench part. The upper part is the runoff part which is left undisturbed and contributes runoff water. The lower part is the bench part which receives the runoff water. The bench part is leveled by cut and fills method and generally a maximum depth of cut of 25 cm is used. A part of the excavated soil is used construct the two edge bunds and the laterals. The top soil is spread in the runoff part to smoothen the land surface to a uniform slope. At the junction of the runoff and bench part, a transition with a slope of 1.5H: 1V is provided. Grass turfing is provided to prevent scouring of this part.

Depending upon the land slope, the CBT is divided into different width ratios. For a slope range of 0.25 to 1%, the ratio of widths of runoff part and bench part is 3:1. For slope range of 1 to 2%, it is changed to 2.5: 1. For a slope range of 2 to 4% the ratio may be 2: 1. The vertical interval (V.I.) of CBT is calculated in terms of slope [S, %] by using the formula.

$$\text{V.I.} = \frac{S}{4} + 2 \qquad (15.5)$$

The conservation bench terrace was developed and applied successfully as long back as in 1959 in semi-arid areas of USA by Zingg and Hanser. In different periods they have been applied in the arid tracts of Texas, Kansas, Eastern Colorado, Montana and North Dakota for various slopes ranging from 1 to 5%. The width ratio of runoff part to bench part is varied in the range of 1: 1 to 3 : 1 and the crop yield improved in the range of 18 to 36%. In India, CBTs have been successfully used in Bellary, Karnataka; Kota, Rajasthan; Hazaribagh, Jharkhand; Doon Valley, Uttarakhand and Midnapore, West Bengal. Red laterite soil of Midnapore with a slope of 1.5% and bunding at a spacing of 40 m, produced a maximum of 72% runoff in bare soil. Inter-cropping with maize and kalai (2: 5) reduced the runoff to 27%. In CBT system this runoff could be impounded in the bench part for growing paddy.

15.3.5 Grassed Waterways

Vegetated or grassed waterways are used for safe disposal of runoff from field, traced areas, diversion channels, spillways or other structures. They either naturally exist or are constructed to particular shapes and dimensions. In case of construction, the vegetation in the waterway should be first established before any water is allowed to flow through it.

Functions: The grassed waterway may serve any of the following functions:

1. As outlets for diversions and terraces,
2. As outlets for farm ponds,
3. As outlets for emergency spillways,
4. To dispose of water collected by road ditches or discharge through culverts, and
5. To carry runoff from natural drains and prevent formation of gullies.

Location of Waterways and its Development

The waterways can be developed at a minimum cost by locating them in the existing depressions as minimum earthwork will be required. Moreover, runoff water can flow from all sides without much modification of the topography. Also a minimum a disturbance of the existing field boundaries should be caused while deciding the location.

The grassed waterway is developed by first constructing it to a proper shape and dimensions. Fertility is built up for growth of vegetation. Then the grass is planted either by transplanting sods or by seeding at suitable moisture content. During establishment of vegetation proper care is required to protect the waterway. Animals should be kept away during this period. Either the waterway should be constructed in advance of the channel that will discharge into it or the flow should be diverted during the period of stabilization. 1f any soil is washed away during the rains, it should be filled up and reseeded. After complete establishment of vegetation, only controlled grazing should be allowed. It should not be used as a Cart track.

Design Principles for Grassed Waterway

The grassed waterway is generally designed for expected runoff from a rainfall of 10 years recurrence interval. The design includes the shape, grade, design velocity and the cross-section of the waterway.

Shape: Generally parabo1ic triangular and trapezoidal shapes are used for waterways. Natural waterways have a shape very close to parabolic shape. Trapezoidal channels after a long use gradually approximate to the shape of a parabola. When a V-ditcher is used for construction, triangular shaped waterways are constructed. V-ditcher in combination with a buck scraper can construct a trapezoidal shaped waterway.

Channel Grade and Velocity: The topography of the land largely influences the channel grade. If the land slope is very high, channels should not run down the general slope to produce erosive velocity. The maximum grade should not exceed 10% and preferably it should be within 5%. The grade should be checked with maximum non-erosive velocity for various conditions by using Manning's formula. The following values of non-erosive velocity should be used.

Table 15.5. Permissible Flow Velocities for Different Cover Conditions (Source: Mal, 1995)

Cover condition	Permissible velocity
1. sparse cover	0.9 m/s
2. Vegetation to be established by seeding	0.9 to 1.2 m/s
3. Dense, vigorous sod established quickly	1.2 to 1.5 m/s
4. Well established sod of excellent quality	1.5 to 1.8 m/s
5. Well established quality and conditions under which flow cannot be handled at lower velocity	1.8 to 2.5 m/s

Cross-Section: As explain earlier, the shape can be parabolic, triangular or trapezoidal for different shapes. The channel cross sections are designed as most economical sections.

Keywords: Water induced soil erosion, Contour cultivation, Contour bunding, Graded bunding, Bench terracing, Grassed waterways.

Lesson 16 Problem/ Types of Wind Induced Soil Erosion & Measures for Control

16.1 Problem of Wind Induced Soil Erosion

Wind erosion has been active in shifting soil materials since prehistoric days. In the earlier days wind erosion has not just created problems but also helped in soil formation in many regions. The activity of man accelerated the wind erosion process and it became more destructive. Deforestation, faulty method of land use, overgrazing, burning etc. are the human activities that accelerated the process of wind erosion. Along the Missouri and Mississippi rivers of the USA huge shifting of soil due to wind erosion took place. In India, wind erosion is said to be responsible for creation of the vast desert area of Rajasthan.

Wind erosion is a most serious problem in arid and semi-arid regions of the world. The normal annual rainfall in these regions is very low (5 to 15 cm), soil is dry and vegetation is very limited. Contrary to the general belief, wind erosion also takes place in many humid areas. The sandy soils along the rivers, lake, and coastal plains and the organic soils are removed by wind erosion. The wind erosion in such cases is more harmful as the value of the land affected is higher. Wind erosion causes several damages. It not only removes the top fertile soil but also damages crops, buildings, highways, railways, fences etc. As the finer particles are easily transported, they are removed along with organic matter and nutrients. Finally coarse textured sand particles are left and they can be more easily detached. No vegetation grows on this and the water holding capacity of soil reduces. Thus the problem multiplies. If the particles carried by the wind strike the young seedlings, they get damaged. Maintenance of channels, railways and highways become costly. Sometimes, the fertile land merges with the desert and the whole village or town may be affected due to the ingress of desert.

16.2 Types of Wind Induced Soil Erosion

Wind induced soil erosion can be classified as per the following types of soil movement.

Types of Soil Movement

Wind erosion takes place with the help of three types of soil movement. They are: (i) suspension, (ii) saltation and (iii) surface creep. All these types of movements generally take place simultaneously. The phenomenon of wind erosion is most important near the surface and major portion of the soil movement takes place within a height of about 1 m.

Suspension: Fine dust particles with diameters less than 0.05 mm are submerged in the laminar zone of air flow and therefore, they cannot be moved by direct action of the wind. The movement of these particles is generally initiated by the impact of the particles in saltation [described a little later in this Section]. Thus without saltation, the movement of the fine dust particles cannot take place. Once lifted up in the air-stream, the particles move in suspension by the turbulence of the wind.

Soils made up of very fine particles specially with diameters less than 0.01 mm are very resistant to movement. Apart from remaining submerged below the turbulent zone of wind flow, cohesive and adhesive forces are much greater for fine particles. Specially cohesive force is high at high moisture content end when dried, the adhesive force helps them to bind together. Therefore, without saltation the movement of fine textured soil generally cannot take place. However, if some objects move over the dried surface then formation of dust particles takes place in fine textured soil and it becomes susceptible to erosion by direct action of wind.

Once the particles are lifted, their movement in suspension depends on the pattern of the wind movement. Generally they are lifted to great heights and carried to long distances. Thus they are carried away to far off distances from the place of the eroding area and are complete loss to the area. In contrast, soil moved in saltation and surface creep [also described later in this Section] gets deposited in the nearby area. Particles carried in suspension are deposited only when the wind velocity completely subsides or rainwater wets them.

Saltation: The direct action of the wind on the soil particles and their collision with other particles create somersaulting soil movement known as saltation. Major portion of the soil movement takes by saltation. The particles are pushed along the ground surface due to the wind velocity in the initial stage [Fig. 16.1]. The movement continues for some time and then descends almost in a straight line with an angle of descent in the range of 6 to 12° with the horizontal After they strike the ground, they may rebound and continue their movement by the saltation process. When the particles lose their energy by repeated striking, they may sink into the ground to form part of movement through surface creep.

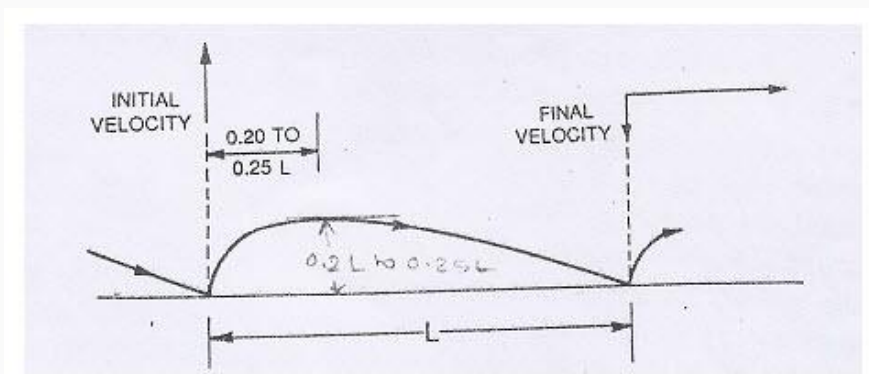


Fig. 16.1. Movement of Soil Particles by Saltation. (Source: Mal, 1995)

The initial angle of ascent of the particles in saltation is vertical but the final velocity is in horizontal direction. The particles rise to different heights and then descend at accelerated speed as a result of gravity. The vertical distance through which a particle rises in saltation is about one fifth to one forth the horizontal length of movement in a single leap. Fine grains of diameters ranging from 0.1 to 0.5 mm are mainly moved by the saltation process. The fraction of soil particles that most easily move has diameters between 0.1 and 0.15 mm. Particles of different diameters generally move at different heights.

The movement of soil by wind is not only dependent on the force of the wind acting on the particles but also on the velocity distribution of the wind to the height of saltation. The height of movement is limited and therefore the wind velocity above certain height has no influence on the soil movement. Soil structure, surface residues, stability of structure, crusting, puddling, grading of the materials on the surface by raindrops etc., influence the soil movement.

Surface Creep: Coarser soil particles having a diameter range of 0.5 to 2 mm are too heavy and cannot be lifted up by wind action. Therefore, they can move neither by saltation nor by suspension. When the particles moving due to saltation strike them, they are pushed along the ground surface. This type of rolling or sliding of heavy particles along the ground surface is known as surface creep. Particles in saltation receive their impact energy from the direct action of the wind pressure, whereas, in surface creep the particles derive the kinetic energy from the impact of other particles moving in saltation.

Major portion of the soil erosion by wind takes place in saltation. It may vary between 50 to 75 per cent of the total weight of the soil eroded depending upon the relative size of the particles, wind velocity etc. Suspension may erode between 3 and 40 per cent; whereas, the percentage for surface creep may be between 5 to 25. Also it may be noted that suspension and surface creep are mainly initiated by saltation. Therefore, if it is possible to prevent soil movement by saltation, the other two will automatically be controlled.

16.3 Measurement for Wind Induced Soil Erosion Control

Any practice or measure that reduces the wind velocity or improves the soil characteristics is helpful to control wind erosion. Improved soil characteristics should have better structure, improved cohesive property and good moisture holding capacity. Some of the measures may provide both the requirements. Vegetation improves the soil structure and at the same time retards the surface wind velocity. In general the following practices may be adopted to control the wind erosion:

1. The soil should be covered with vegetation or crop residues as far as possible.
2. Limited cultivation should be done.
3. Dry soils should not be tilled.
4. Permanent vegetation may be established on unproductive soils.
5. After the rains, the soil may be tilled so that clod formation takes place.
6. Tillage implements should be selected in such a manner that rough surface is formed and crop residue is not buried.
7. Overgrazing should be avoided.

Principal methods of reducing surface wind velocity are vegetative control, tillage practices and mechanical methods. Vegetative control consists of cultivated crops, field and strip cropping, stubble mulching. Shrubs and trees although form part of the vegetation act as mechanical barrier to wind. Other mechanical barriers or windbreaks also may he used.

Cultivated Crops

Among the cultivated crops, close growing crops provide better protection when compared to the row of crops. Their effectiveness depends upon (i) type of crop grown, (ii) stage of growth, (iii) density of cover, (iv) row direction, (v) climatic condition etc. Vegetation also helps to deposit the soil that is eroded from the neighboring areas. Specially, during the dry months when the soil is most susceptible to erosion, the field should be covered with vegetation.

Row crops such as maize, cotton, jowar, bajra etc., provide only partial protection. Seeding should be done in a way to provide crop rows normal to the direction of general wind direction. Crop rotation should be suitably decided to improve the soil structure and conserve the moisture. Crops suitable for such soil and climatic conditions and also capable of providing protection should be selected.

16.3.1 Stubble Mulching

When row crops like maize, bajra etc. are grown at the time of harvesting the stubble –i.e., lower portion of the stem, should be left to a certain height and the whole crop should not be harvested from the bottom. At least 10% of the rows shou1d be left standing. In case the crops are used for pasturing, the stock should be removed leaving enough stalks along with leaves to provide the necessary protection. Thus stubble mulching is the practice of maintaining crop residues at the ground surface during harvesting to resist the soil erosion. The benefits derived are:

(i) Wind velocity is retarded.

(ii) Soil blowing is physically obstructed.

(iii) Raindrops lose their energy before striking the soil.

(iv) Better absorption of rainfall takes place due to longer retention period and permeable soil structure.

(v) Evaporation loss is reduced.

(vi) Crop yield increases.

(vii) By reducing wind velocity, they can trap eroding soil from neighbouring areas.

However, the benefits accrued from stubble mulching depend upon the size of the field, velocity and relative direction of wind, quality and quantity of stubble mulching left in the field Narrow fields separated by windbreaks will be more easily protected compared to a large open field. If the crop residues can be left in vertical position, better protection can be provided. Most erodible soil may require about 10 tonnes of stubble per hectare for protection and this much crop residue may not be available from one hectare of land. During the period of fallowing, stubble mulching is most effective to provide a cover to the soil.

16.3.2 Field Strip Cropping and Contour Strip Cropping

Field and contour strip cropping consists of alternate strips of row (i.e., erosion-susceptible) crops and close growing (i.e., erosion-resistant) crops in the same field. The strip cropping is laid out generally parallel to the field boundary or perpendicular to the erosive wind direction. The main benefits of strip cropping are:

(i) Vegetation provides physical protection against blowing of soil.

(ii) Soil erosion is limited to a distance equal to the width of the erosion susceptible crop.

(iii) Better conservation of moisture takes place.

(iv) Particles carried in saltation are trapped.

Main problems in strip cropping are:

(i) In a mechanized farm, movement of machinery becomes difficult due to narrow strips.

(ii) In case of attack by insects, there is more number of edges for protection.

The width of the strips should be selected in a way such that the farming operation is not hampered and at the same time much erosion does not take place. For example, in a sandy soil the width of the erosion susceptible crop should be limited to 6 m. But for movement of farm machinery, the width may have to be increased. In a sandy loam soil the width can be increased up to 30 m. Among the erosion resistant crops groundnut, legumes, grasses, berseem etc., that cover the ground are preferred. Row crops that permit erosion are maize, cotton, potato, bajra, jowar,.etc. Fig. 16.2 shows the field and contour strip cropping for protection of a field from wind erosion.

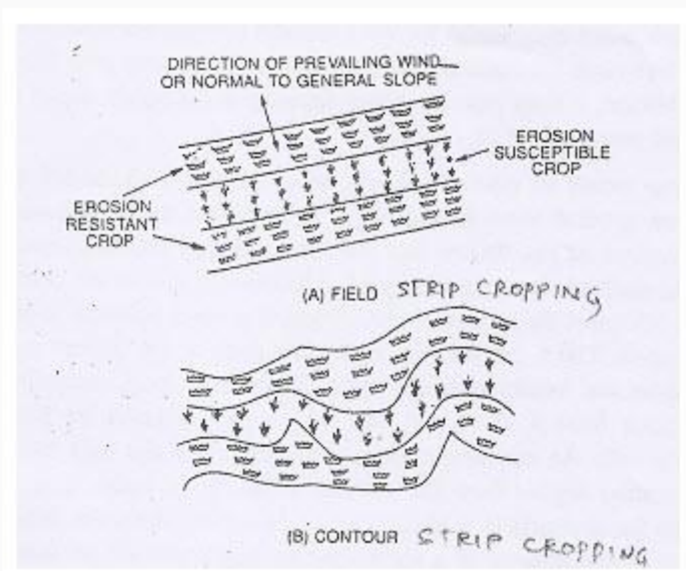


Fig. 16.2. Field and Contour Strip Cropping. (Source: Mal, 1995)

16.3.3 Windbreaks

A windbreak is defined as any type of barrier for protection from winds and refers to any mechanical or vegetative barriers consisting of buildings, gardens, orchards and feed lots. Windbreaks made up of just mechanical barriers are not very useful for field crops. However, they are frequently used for the protection of farm sheds and small areas. The mechanical barriers include brush fences, board walls, vertical burlap or paper strips. Brush matting, rock or gravel barriers are also used as windbreaks. Some of these barriers are impermeable and others are semi-impermeable. Generally the semi-impermeable barrier are more useful as they provide better diffusion and eddying effects on the leeward side of the barrier. When vegetable crops in organic soils are required to be protected, vertical burlap or paper strips are often used. Brush matting, debris, rock, gravel etc., are more useful for stabilizing sand dune areas.

Studies of wind tunnel on the flow pattern of wind over model barriers and windbreaks indicate that the sharper barrier provides better protection compared to other shapes. The zone of influence of a rounded shape is much less than the narrow vertical shapes. The porosity of the barrier helps to extend its zone of influence downwards but may decrease the degree of protection. The wind velocity at the ground is much lower than the standard open velocity; their ratio is of the order of 0.07. Even the standard velocity may be about twice as higher compared to the surface velocity over mowed grasses. Thus the frictional drag on even vegetation reduces the wind velocity. The pull of free moving winds that pass the ends of the windbreak, can act on the sides of the stilled air mass. Thus the protection provided by the windbreak is not of rectangular shape but tends to be narrowed towards the outer limit. In addition to providing protection to the soil from wind, windbreaks have other commercial values. The tree bunches and leaves may be used as fodder and fuel.

16.3.4 Shelterbelts

A shelterbelt, usually consisting of shrubs and trees is a longer barrier than a windbreak. It is primarily used for protection of field crops, soils and conservation of soil moisture. The shelterbelt is not only useful for wind erosion control, but also saves fuel like windbreak, increases livestock production, reduces evaporation, prevents firing of crops from hot winds. In addition, it may provide better fruiting in orchards, make spraying of trees for insect control more effective.

To achieve better result in controlling the wind velocity, shelterbelts should be moderately dense from ground level to tree tops. A study on the distribution of wind velocity around the shelterbelt has shown that the wind velocity reduces significantly on the leeward side of the shelterbelt immediately after the barrier and at the central portion. At a distance of 15 to 20 times the height of shelterbelt, the wind velocity is almost equal to the velocity in the open. The wind velocity at the two ends of the barrier may be about 20 per cent greater than the velocity in the open. Therefore, long shelterbelts always provide better protection than a short one and no opening should be provided in a continuous long shelterbelt. An opening shortens the length of the belt and near it the velocity as usual becomes higher than the normal velocity. In case, it is essential to provide a road through the shelterbelt, it should be made curved. Another important point to be remembered for establishment of a shelterbelt is that it should be made as far as possible perpendicular to the direction of the most erosive wind.

Woodruff and Zingg (1952) conducted wind tunnel studies for estimation of the distance of full protection from a windbreak or shelterbelt and gave the following formula.

$$d = 17h\left(\frac{V_m}{V}\right)\cos 6 \qquad (16.1)$$

where d = distance of full protection, m

h = height of the barrier, m

V_m = actual wind velocity at 15 m height, m/s, and

q = the angle of deviation of prevailing wind direction from the perpendicular to the barrier.

From the wind erodibility of farm fields, Chepil (1959) concluded that the velocity (V_m) at 15 m height required to move the most erodible soil fraction was about 9.6 m/s. This is valid for a smooth bare surface after the initiation of erosion and before formation of surface crust by rainfall. In fact, Equation 16.1 is valid for wind velocities up to 65 km/h. While deciding the width of crop strips, the same equation may be used by substituting crop height as the height of barrier.

A shelterbelt will be more effective if a combination of low, medium and, tall trees is used as shown in Fig. 16.3. This helps to provide a compact and dense barrier. Generally shrubs of low height should be grown on the windward side. Tree species of low branches may be placed at the middle and tall trees with high branches on the leeward side. But such a multiple row shelterbelt occupies large land area. Suitable varieties of trees should be selected for the specific location. For the desert areas of Rajasthan trees like Neem (Azadirachta Indica), Anacardium Occidentale, shrubs like Sisal (Agave Americana) etc. are commonly used.

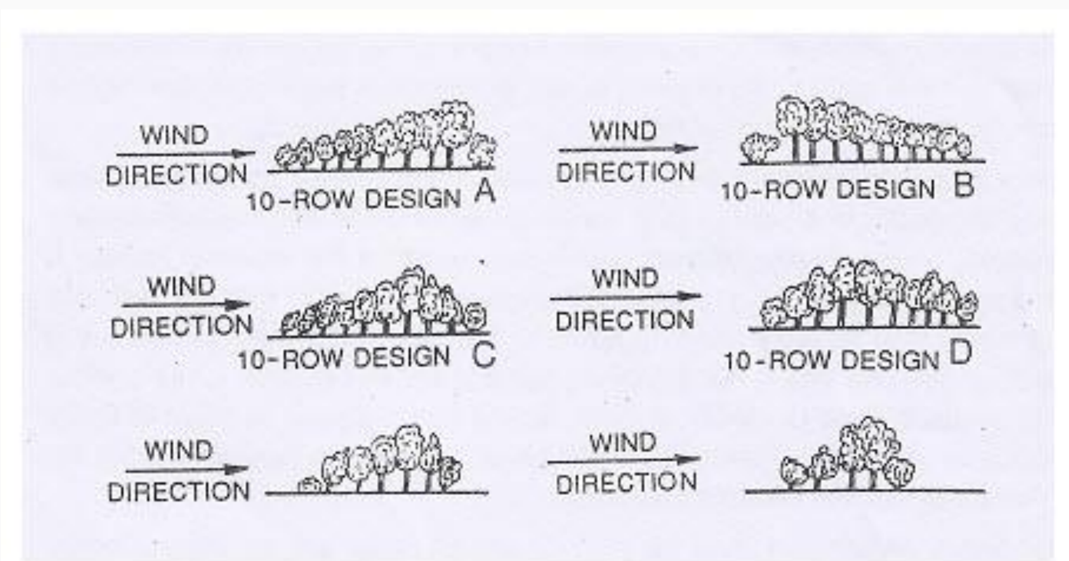


Fig. 16.3. Side View of Tree Arrangement in Shelterbelts.

(Source: Mal, 1995)

16.3.5 Other Tillage Practices

Other tillage practices -if properly adopted, can reduce the wind induced soil blowing to a great extent. Similarly, faulty tillage operations increase the soil erosion by wind. If the soil is pulverized and the crop residues are buried due to tillage operations, erosion problem increases. The effective way of prevention of wind erosion is by producing a rough, cloddy surface and exposing the crop residues on the surface. If the land is ploughed at optimum moisture content after the rains, big clod and large aggregate formation takes place.

If by tillage practices, small ridges perpendicular to the direction of the wind can be formed then significant control is possible. In case the surface soil consists of mainly sandy soil underlain by fine textured clayey soil, tillage may give some immediate benefit. The sand being more erodible should be buried and resistant clayey soil be brought to the surface. Efforts should be made to grow vegetation at the earliest. Otherwise this may not be effective for a long period. The clay may also provide cloddy structure on the surface. Generally, these types of tillage operations are Very costly and should be taken up only when other better alternatives are not immediately available. If vegetation is grown, the organic matter produced in the soil by the vegetal cover can serve the same purpose in addition to providing other benefits.

As discussed earlier, stubble mulching provides a good control for wind erosion. This is specially important in a year of crop failure or when sufficient vegetative cover cannot be produced. Sweep furrow openers which can cut under the material, leaving it in almost standing position are very effective implements. One-way disc plough also leaves the crop residues in partially standing position. Mould board plough turns the soil and buries the crop residues and is not therefore, suitable for this purpose. Again when it is required to produce a rough cloddy surface, mould board plough is suitable under an optimum moisture condition. Vertical disc plough or harrows are suitable neither for retaining crop residues nor for creating cloddiness.

Other important implements used for ridging and clodding are the lister plough, shovel or sweep cultivator, deep-furrow drill, spring-tooth harrow etc. Mould board plough, subsoiler, lister, disc plough and grading machines can bring the subsoil to the surface. When straight or V-shaped blades or rods are used as subsurface tillage implements, they can undercut without disturbing the surface or the residues. Obviously, the clods cannot be formed on the surface by these tillage implements.

It should however, he remembered that tillage practices offer only temporary and urgent controls and may have to be repeated. They are quite costly and should not be used as a general practice. They cannot act as substitutes for the vegetative covers which provide long term and multiple benefits. Therefore, other tillage practices should be used only as emergency measures when no other method is immediately effective.

Keywords: Wind induced soil erosion, Stubble mulching, Field strip cropping, Contour strip cropping, Windbreaks, Shelterbelts.

Module 9: Sediment Yield Estimation/Measurement from a Watershed and Sediment Yield Models

Lesson 17 Measurements of Sediment Yield

Sediment is a naturally occurring material that is formed by processes of weathering and erosion, and is subsequently transported by the action of wind, water or ice and/or by the force of gravity acting on the particle itself. Sediments are most often transported by water (fluvial processes), wind and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition, though sediment also often settles out of slow-moving or standing water in lakes and ocean. Sand dunes are examples of wind transport and deposition.

17.1 Sediment Generation and Transport Mechanism in Watersheds

Sediment is primarily generated because of fluvial (water) and Aeolian (wind) processes. The forces which are involved in this are: a) attacking forces, which remove and transport the soil particles, b) resisting forces, which retard the erosion.

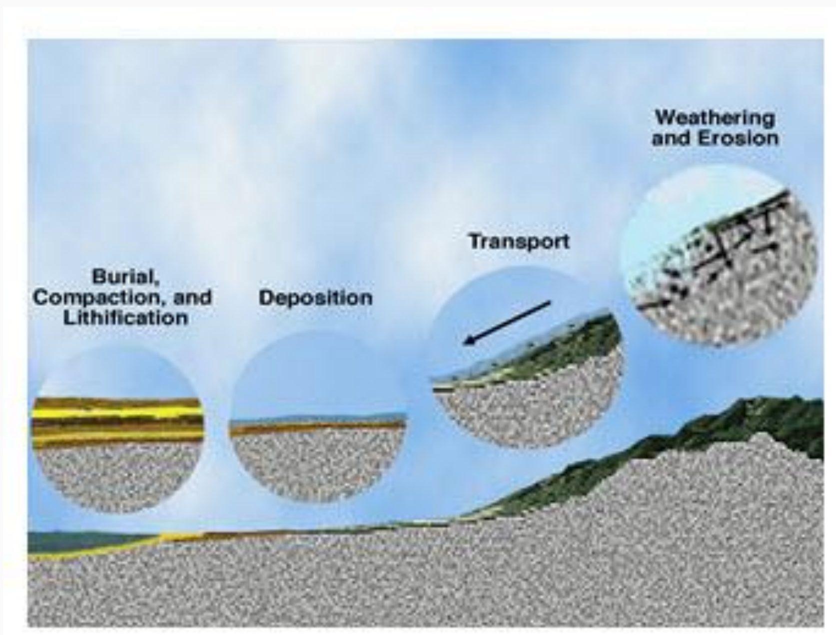


Fig. 17.1. Effect of Weathering and Gravity on Sediment Generation.

(Source:http://www.indiana.edu/~g103/theinteractiveearth/5Sedimentary%20Rocks/module5.html)

Sediment generation in a landscape is a factor of multiple natural and anthropogenic influences. Selby (1993) identifies climate and geology as the predominant factors of erosion with a close interdependency of soil type and vegetation. Out of all the sediment generating agents, the role of water in detachment, transportation and deposition is indeed very significant (Fig. 17.1). Since recent past, human activities favoring more to it because of increased land degradation.

Sources of Sediment Generation are:

1. Sheet erosion from agricultural, forest and waste land.
2. Mass movements of soil from landslides and soil creeps.
3. Gullying by concentrated runoff.
4. Stream channel erosion including bank cutting and bed degradation.
5. Erosion caused by floods.
6. Erosion incident to activities like roads, rail roads, clearing for housing and industries etc.
7. Mining and dump left as wastes.

Transport Mechanism

Sediment transport is the movement of solid particles (sediment), typically due to a combination of the force of gravity acting on the sediment, and/or the movement of the fluid in which the sediment is entrained. Sediment transport due to fluid motion occurs in rivers, the oceans, lakes, seas, and other bodies of water, due to currents and tides, in glaciers as they flow, and on terrestrial surfaces under the influence of wind. Sediment transport due to gravity can occur on sloping surfaces in general, including hill slopes, cliffs, and the continental shelf-continental slope boundary. Flow and sediment transport are important in relation to several engineering topics, e.g. erosion around structures, back filling of dredged channels and near shore morphological change.

Estimation of the sediment flow rates by a stream is necessary to understand the extent of erosion in the stream's catchment and for estimating the reservoir life if one is planned to be constructed on the stream.

There are three main processes through which sediment is transported in the streams. These processes are:

1. Suspension
2. Saltation
3. Surface creep

Suspension: Suspended sediment is that which remains in suspension in the flowing water for a considerable period of time without contact with the stream bed.

Saltation: Movement of sediment along the stream bed because of bounce and skip on the bed.

Surface Creep: It is the movement of sediment almost in continuous contact with the stream bed.

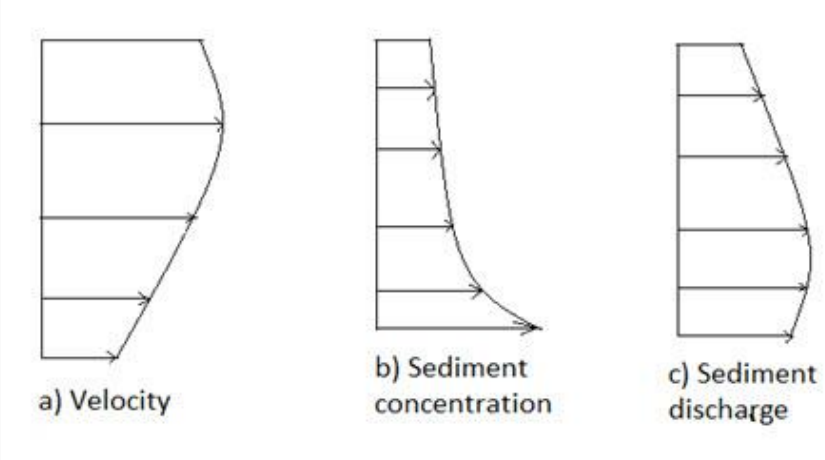


Fig. 17.2. Velocity and Sediment Distribution in a Straight Natural Stream.
(Source: http://www.tulane.edu/~sanelson/eens1110/streams.htm)

The Figure 17.2 (a, b and C) shows how the velocity, sediment concentration and sediment discharge varies with the depth of flow. In first case i.e a) which is showing variation of velocity of flow with the depth, from the profile it is analyzed that maximum velocity is not at the top surface but lies somewhere below that (0.2 depth). From b) it is analyzed that as the depth of flow increases sediment concentration increases in the flow and transportation of sediment increases. In case c), the sediment discharge profile is showing that as depth increases it is increases up to some depth and later on starts decreasing.

17.2 Types of Sediments Transported along with Streams

A channel flowing in watershed transports the runoff along with the sediment. The total sediment load that is transported out of the watershed by a stream is classified into components depending upon their origin as:

1. Wash Load
2. Suspended Load
3. Bed Material Load comprises of bed and sediment load.

17.2.1 Wash Load is the sediment originating from the land surface of the watershed and is transported to the stream channel by means of splash, sheet, rill and gully erosion. Wash load is generally composed of fine-grained soils of very small velocity.

17.2.2 Suspended Load is relatively finer bed material that is kept in suspension in the flow through turbulence eddies and transported in suspension mode by the flowing water. These particles move considerably long distances before settling on the bed and sides. The suspended load is further divided into the wash load which is generally considered to be the silt+clay sized material (< 62 μm particle diameter) and is often referred to as "fine-grained sediment". The wash load is mainly controlled by the supply of this material (usually by means of erosion) to the river. The amount of sand (> 62 μm particle size) in the suspended load is directly proportional to the turbulence and mainly originates from erosion of the bed and banks of the river. In many rivers, suspended sediment (i.e. the mineral fraction) forms most of the transported load. Suspended load can also be classified into three grades as:

1. Coarse sediment: Particles diameter > 0.20 mm
2. Medium sediment: Particles diameter between 0.20 to 0.075mm
3. Fine sediment: Particle diameter < 0.075mm

17.2.3 Bed Material Load is sediment load composed of grain sizes originating in the channel bed and sides of the stream channel.

Bed Load is relatively coarse bed material load that is moved at the bed surface through sliding, rolling and saltation. Bed load is stony material, such as gravel and cobbles that moves by rolling along the bed of a river because it is too heavy to be lifted into suspension by the current of the river. Bed load is especially important during periods of extremely high discharge and in landscapes of large topographical relief. It is rarely important in low-lying areas.

17.3 Methods of Stream Sediment Measurement/Sampling

In order to prevent environmental and associated engineering issues, it is very necessary to measure total sediment load. Many methods are designed and available to measure the sediment load. A few of these methods are discussed as below.

17.3.1 Location of Measurement/Sampling

To reduce the errors in sediment measurements, site selection is required with careful observation and precautions. Sampled sediment data can be influenced by several sources of variability, including spatial which is defined by the sample location relative to the investigated activity (MacDonald, 1992) i.e, near the stream bed sediment concentration is more, in the middle relatively less while at the top surface it is too less. Thus it is difficult to select the sampling point. To avoid or possibly reduce these errors, following points should be taken in to care for the site selection.

1. If the sampling is to be done only at one point, then sample should be collected at a depth of 0.6 times depth of stream (d), measured from top.
2. In case of double point sampling, one sample should be collected at a depth of 0.2d while other at 0.8d and then the resultant concentration should be averaged.
3. For three points sampling one sample should be taken near the top of water surface, second from mid depth of stream and third near the stream bed and weighted equally.
4. In case of multiple sampling, several samples from several points of vertical section of the stream are taken, which helps to get more accurate result.

17.3.2 Frequency of Sampling

Frequency of sampling depends on the sediment concentration in the stream flow. It is well known that sediment concentration increases rapidly on rising phase of hydrograph. This happens due to the action of rain drops on the soil which displaces the soil from their position resulting in sediment formation. Therefore, sediment samples should be collected more frequently at the beginning of runoff and it should be continued up to peak. The sample should be taken at every 15 minutes interval.

17.3.3 Number of Sediment Monitoring Stations

In case of watershed, from where total runoff is disposed off through the outlet, the collection of sample is carried out as it is the most ideal point in the whole watershed for sample collection. While in case of drainage system, gauging station should be provided at every outlet and samples are collected.

17.3.4 Observation and Collection of Sediment Samples

17.3.4.1 Location of Observation Post

Silt observation posts should be located on the basis of the following points:

1. Wherever possible, the site of stream gauging should be utilized for installation of silt observation post because it represents the yield of sediment rate from the entire watershed.

2. The observation sites should be free from any disturbing points such as change in site configuration and back water effect etc.

3. A silt observation site should be located at that point of stream, from where the constant soil erosion is taking place due to turbulence.

4. The site should be easily accessible (facility of transportation).

5. Wherever available, the sediment monitoring station with overhead platform like arrangement should be used. It helps in collection of sediment sample from the entire width of the stream.

6. In the hilly regions, where torrential flow exists, cable bridge may be used for taking the observations.

7. The site should have straight stream length of about 150m, both towards upstream and downstream face.

17.3.4.2 Collection of Sediment Samples

a) Suspended Load Sampling

The concentration of suspended load varies in the stream cross-section both horizontally and vertically. For the sampling of this suspended sediment for calculation of the overall quantity of sediment carried by the water, various samplers are available. Different types of suspended load samplers are:

1. Vertical Pipe
2. Instantaneous Vertical Sampler
3. Instantaneous Horizontal Sampler
4. Bottle Type Sampler
5. Integrating Sampler

1. **Vertical Pipe:** A vertical pipe sampler as its name indicates consists of a vertical pipe which is lowered to desired depth. The water sediment mixture flows upwards and when filled, valves at either end of the pipe are closed.
2. **Instantaneous Vertical Sampler:** The instantaneous vertical sampler obtains specimen from a smaller part of the vertical depth after the sampler is lowered to the sampling point.
3. **Instantaneous Horizontal Sampler:** It consists of horizontal cylinder equipped with end valves which can be closed suddenly to trap sample at any desired depth. This sampler can operate close to the stream bed. It is designed to minimize the disturbance losses.
4. **Bottle Type Sampler:** Bottle type sampler resembles similar to the milk bottle with the necessary provision for lowering the bottle to the sampling point (depth) and opening the bottle at the desired depth. Air within the bottle is displaced by the incoming sample, which escapes through the intake opening causing disturbances at the intake end.
5. **Integrating Sampler:** Modified form of bottle type sampler is integrating sampler, which takes representative sample from the entire depth. No disturbance to the flow is there as entrance and exit are different. An example of this sampler is Delft bottle type sampler, practically used in sediment sampling of rivers and channels.

Delft bottle type sampler is used to measure suspended sediment transport in rivers and other water courses from the surface down to 0.1 m above the river bottom. The sediment containing water flows through a bottle shaped sampler. The shape of this sampling body induces a low pressure at the rear face in such a way that the water enters the nozzle of the sampler with almost the same velocity as the undisturbed flow. The sharp decrease of the velocity in the wide sampling chambers causes the sediment material to settle there.

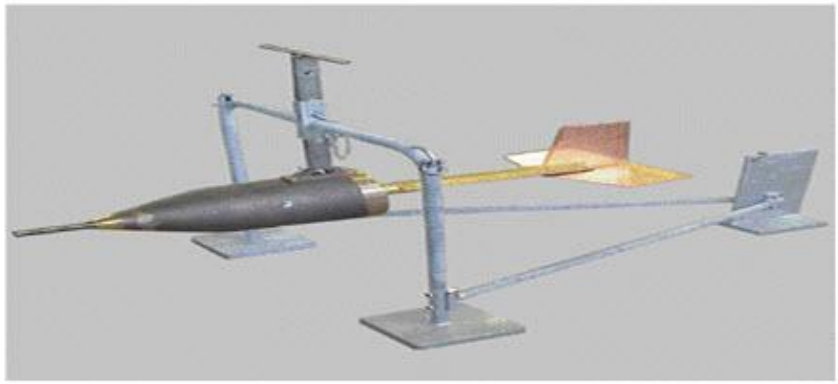


Fig. 17.3. Suspended Load Sampler Delft Bottle Type.

(Source:http://pkd.eijkelkamp.com/PKD/PKDPages/05bFlowingsedimentdepthsensingturbidity/tabid/618/Default.aspx?language=zh-CN)

b) Bed Load Sampling

The rate of bed load movement is determined by placing the sampler on the stream bed and measuring the amount of material collected in a given time. The bed load sampler is usually held in position by a rod if the stream is shallow, or by a cable boat or by trolley etc.

Bed load samplers are of different types according to their construction and principle involved. Three main types of bed load sampler are in maximum use:

1. Basket Type
2. Tray or Pan Type
3. Pressure Difference Type

1. **Basket Type:** Basket type sampler consists of a box or basket, generally made of meshed material. The sampler is lowered to rest on the stream bed with the open end on the upstream to catch a sample of moving material/sediment. The introduction of the sampler into the stream causes an inward resistance to flow and a resultant lowering of the stream velocity. Hence the entrance velocity is decreased from that of the undisturbed stream, causing some of the material to drop out before entering the sampler. Thus, the efficiency, i.e., the percentage of the material moving towards the sampler, which is actually caught by it is less than 100%.

2. **Tray Type Sampler:** It consists of flat pan or tray-shaped device with baffles or slots to check the moving material. It has the same disadvantage as that of basket type sampler.

3. **Pressure Difference Type:** It is designed to overcome the objection of decreased velocity at the entrance to the sampler. A pressure drop at the exit just sufficient to overcome the energy losses is formed, thus giving the same entrance velocity as in the undisturbed stream.

17.3.5 Estimation of different Loads from Samples

The collected samples from different locations and depths of streams are brought back to laboratory, where the sediment particles are filtered out from the solution. The filtered particles are dried up for 24 hours at 104 °C in the lab and then weighted up. This weight represents the sediment concentration in the sampled water. By estimating the total water flowing off from that point in stream per unit time (second, hour or day) the total sediment flow in the same unit of time can be calculated. In practical, the “parts per million” (ppm) equivalent to mg/l is used as unit of sediment concentration in water, where the concentration sediment in mg is shown as available in per liter of flowing water in channel or river. For an example, let in a one liter bottle sampler, the sediment concentration has been measures as 315 gm after filtering the drying up the sample. In this way the sediment concentration measures in the river is 315 mg/l (or 0.315 g/l).

Keywords: Sediment Yield, Stream Sediment, Sediment Transport, Sediment Measurement

Lesson 18 Estimation and Modeling of Sediment Yield

18.1 Estimation of Different Load from Watersheds

Sediment carried along with the flow of a river is known as sediment load. The quantity of sediment suspended in a river can provide valuable information about the river and its watershed, including geology and ecology, as well as the impact of human activities like development (agricultural, settlement etc) and agro-chemical use. The sediment load of a river is transported in various ways, shown in Fig. 18.1, although these distinctions are to some extent arbitrary and not always very practical in the sense that not all of the components can be separated in practice:

1. Dissolved Load
2. Suspended Load
3. Intermittent Suspension (Saltation) Load
4. Wash Load
5. Bed Load

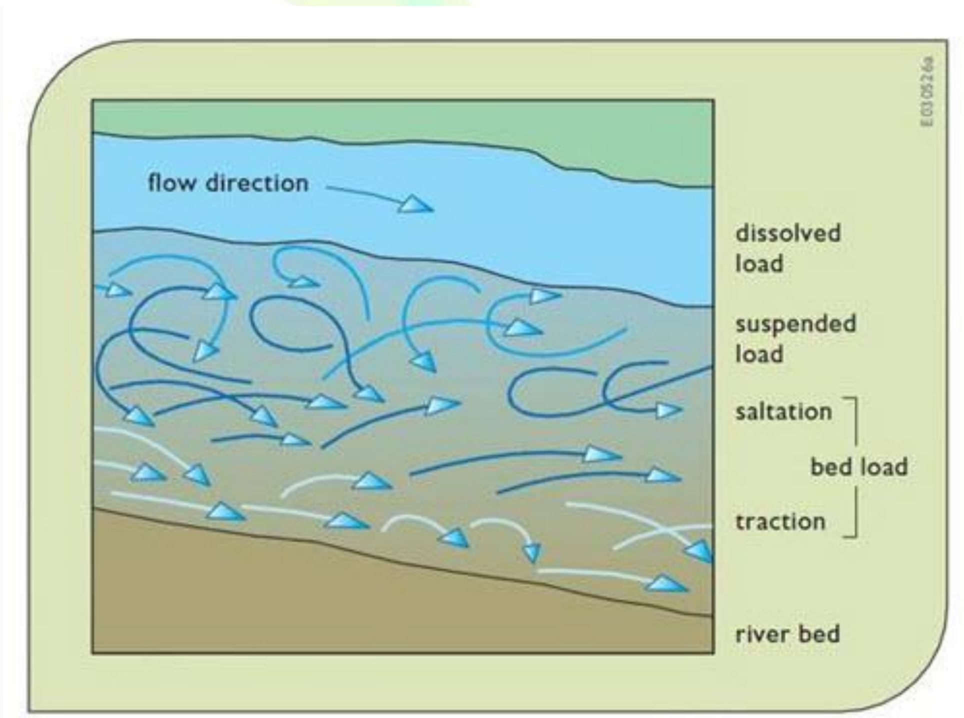


Fig. 18.1. Illustration of Different Types of Sediment Loads.

(Source: http://riverrestoration.wikispaces.com/Sediment+transport+models)

1. Dissolved Load: Dissolved load is material that has gone into solution and is part of the fluid moving through the channel. Since it is dissolved, it does not depend on forces in the flow to keep it in the water column. The amount of material in solution depends on supply of a solute and the saturation point for the fluid. For example, in limestone areas, calcium carbonate may be at saturation level in river water and the dissolved load may be close to the total sediment load of the river. In contrast, rivers draining through insoluble rocks, such as in granitic terrains, may be well below saturation levels for most elements and dissolved load may be relatively small. The dissolved load is also very sensitive to water temperature and due to this reason, tropical rivers carry larger dissolved loads than those in temperate environments. Total dissolved-material transport, $Q_s(d)$ (kg/s), depends on the dissolved load concentration C_0 (kg/m^3), and the stream discharge, Q (m^3/s)

$$Q_s(d) = C_0Q$$

2. Suspended Load: Suspended load comprises sand+silt+clay sized particles that are held in suspension because of the turbulence of the water. The suspended load is further divided into the wash load, which is generally considered to be the silt+clay sized material (< 62 μm particle diameter) and is often referred to as "fine-grained sediment". Suspended load moves at the same velocity as the flow. The upward currents must equal or exceed the particle fall-velocity (Fig. 18.2) for suspended sediment load to be sustained.

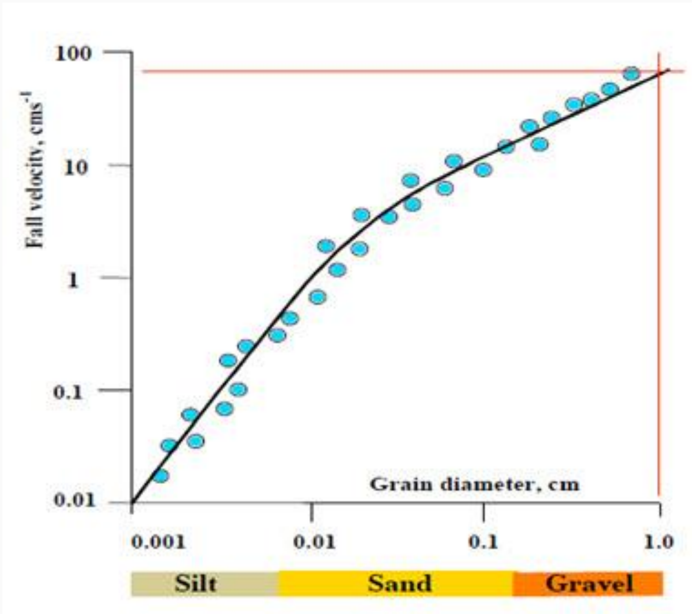


Fig. 18.2. Fall Velocity in Relation to Diameter of a Spherical Grain of Quartz.

(Source:http://www.sfu.ca/~hickin/RIVERS/Rivers4(Sediment%20transport).pdf)

3. Intermittently Suspension or Saltation Load: Saltation load is a term used by sedimentologists to describe material that is transitional between bed load and suspended load. Saltation means "bouncing" and refers to particles that are light enough to be picked off the river bed by turbulence but too heavy to remain in suspension and, therefore, sink back to the river bed. These are particles that bounce along the channel, partly supported by the turbulence in the flow and partly by the bed. They follow a distinctively asymmetric trajectory.

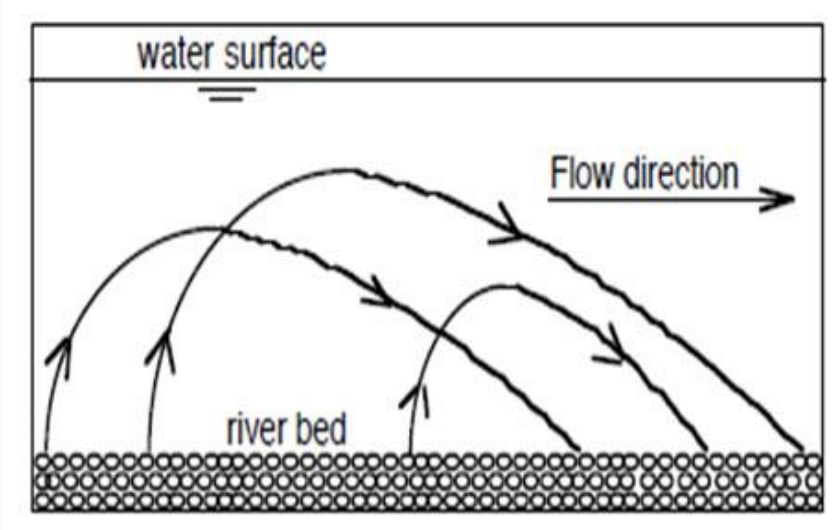


Fig. 18.3. The Trajectory of Sediment Saltation (Intermittently Suspended)

Grains Moving in the Flow.
(Source:http://www.sfu.ca/~hickin/RIVERS/Rivers4(Sediment%20transport).pdf)

4. Wash Load: Analysis of suspended load and the corresponding bed materials of various streams for their size analysis have shown that the suspended load can be divided into two parts depending on the sizes of material in suspension vis-à-vis the size analysis of the bed material. One part of the suspended load is composed of these sizes of sediment found in abundance in the bed. The second part of the load is composed of those fine sizes not available in appreciable quantities in the bed. These particles, termed as the ***wash load***, actually originate from the channel bank and the upslope area. Wash load grains tend to be very small (clays and silts) and, hence have a very small settling velocity. Once introduced into the channel, wash-load grains are kept in suspension by the flow turbulence and essentially pass straight through the stream with negligible deposition or interaction with the bed.

5. Bed Load: Bed load is the clastic (particulate) material that moves through the channel fully supported by the channel bed itself. These materials, mainly sand and gravel, are kept in motion (rolling and sliding) by the shear stress acting at the boundary. A distinction is often made between the bed-material load and the bed load. Bed-material load is that part of the sediment load found in appreciable quantities in the bed (generally > 0.062 mm in diameter) and is collected in a bed-load sampler. It includes particles that slide and roll along the bed (in bed-load transport) but also those near the bed transported in saltation or suspension. Bed load, strictly defined, is just that component of the moving sediment that is supported by the bed (and not by the flow). That is, the term "bed load" refers to a mode of transport and not to a source.

After successful measurements of different sediment loads flowing along with river/channel water, the estimation of watershed sediment load is performed to find out total soil/sediment loss from the watershed. In this process, bed load and suspended load are separately estimated for the desired time (second, day, month, year) and then summed up to find out total sediment load from the watershed. The methods of estimating these loads of watershed are discussed as below.

Suspended Load

The amount of suspended load transported in a day (for an example here) is given by:

$$S = \frac{p\,x\,q\,x\,86400}{1000}$$

Where, S = amount of material transported in tonnes/day; = amount of material in 1 cu.m. of water in kg; = rate of stream flow in m^3/s.

Bed Load

The bed load which is collected in the sampler is dried and weight. The dry weight when divided by time taken for the measurement and the width of the sampler, gives the rate of bed load movement per unit width of the river bed per unit time at the point of measurement. For design purpose bed load is generally taken as certain percentage of suspended load as:

Table 18.1. Maddock's classification for estimation of the bedload (Maddock, 1975)

Concentration of Suspended Load (ppm)	Type of Material forming the Stream Channel	Texture of Suspended Material	% of Measured Suspended Load that could be taken as Bed Load
Less than 1000	Sand	Similar to bed material	25 to 150
Less than 1000	Gravel, rock or consolidate clay	Small amount of sand	5 to 12
1000 to 7500	Sand	Similar to bed material	10 to 35
1000 to 7500	Gravel, rock or consolidate clay	25% sand or less	5 to 15
Over 7500	Sand	Similar to bed material	5 to 15
Over 7500	Gravel, rock or consolidate clay	25% sand or less	2 to 8

(Source: http://www.fao.org/docrep/t0848e/t0848e-10.htm)

Once the bed and suspended loads are calculated the total sediment load for each day or for any required period can be easily calculated.

18.2 Modeling of Sediment Yield from Watersheds

Modeling is a useful tool for erosion scenario assessment that enables the adequate selection of erosion control measures (Moehansyah et al, 2004). Sediment models are to link the on-site rates of erosion and soil loss within the watershed to the outlet sediment yield. Erosion and sediment yield can be predicted by using two main types of models- empirical and physically based models. The first group is based on the identification of relationships between different watershed property parameters with the sediment generated from watershed when a robust data base exists. These relationships must be statistically significant. Physically based models consist of the description of processes (involved in sediment initiation, generation and transport etc.) with the help of mathematical equations dealing with the laws of conservation of energy and mass (Morgan, 2005). They integrate both the detachment and transport processes for upstream locations and channels.

The first developed and widely used empirical model for sediment yield estimation is USLE (Universal Soil Loss Equation). Due to some practical limitation it has been modified MUSLE (Modified Universal Soil Loss Equation). The description about these empirical models is as below.

18.2.1 Universal Soil Loss Equation (USLE): The Universal Soil Loss Equation (USLE) predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. This erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites. The USLE can be used to compare soil losses from a particular field with a specific crop and management system to "tolerable soil loss" rates. Alternative management and crop systems may also be evaluated to determine the adequacy of conservation measures in farm planning.

Five major factors are used to calculate the soil loss for a given site. Each factor is the numerical estimate of a specific condition that affects (represent) the severity of soil erosion at a particular location. The erosion values reflected by these factors can vary considerably due to varying weather conditions. Therefore, the values obtained from the USLE more accurately represent long-term averages. The USLE is expressed as:

$$A = R \times K \times L \times S \times C \times P$$

Where, A = Gross amount of soil erosion (tonnes.ha^{-1}.yr^{-1}.) and represents the potential long term average annual soil loss in tons per hectare per year. R = Rainfall factor related to rainfall-runoff erosion (MJ.mm.$ha^{-1}h^{-1}$); *K* = Soil erodibility factor related to soil erosion (t.ha.h.MJ^{-1} mm^{-1}); L = Slope length factor (dimensionless); *S* = Slope steepness factor (dimensionless); *C* = Factor related to cover management (dimensionless); *P* = Factor representing the supporting practices applied (dimensionless)

Procedure for Using the USLE

1. Determine the R Factor
2. Based on the soil texture, determine the K value. If there is more than one soil type in a field and the soil textures are not very different, use the soil type that represents the majority of the field. Repeat for other soil types as necessary
3. Divide the field into sections of uniform slope gradient and length. Assign an L value to each section
4. Choose the crop type factor and tillage method factor for the crop to be grown. Multiply these two factors together to obtain the C factor
5. Select the P factor based on the support practice used
6. Multiply the 5 factors together to obtain the soil loss per hectare (acre)

18.2.2 Modified USLE: The MUSLE equation is applicable to the points, where overland flow enters the streams and then all those points are summed up to give the total amount of sediment delivered to the stream network within a watershed. Williams (1975) developed the MUSLE by replacing the rainfall energy factor in the USLE with a runoff energy factor. In general, MUSLE is expressed as follows (Williams, 1975):

$$Y = 11.8 \times (Q \times q_p)0.56 \times K \times LS \times C \times P$$

Where, Y is the sediment yield to the stream network in metric tons, Q is the runoff volume from a given rainfall event in m^3, q_p is the peak flow rate in m^3/sec., K is the soil erodibility factor, LS is the slope length and gradient factor, C is the cover management factor and can be derived from land cover data, and P is the erosion control practice factor which is a field specific value. The Q, q_p, and LS parameters can be derived from Digital Elevation Model (DEM), land cover, soil, and rainfall data.

18.3 Watershed Hydrologic Models used in Sediment Yield Estimation

Sediment transport models are being developed to assist state and local resource agencies for the purpose of developing appropriate management plans to reduce/control sedimentation problems in the watersheds. Use of models in identifying areas with high sediment yield that can be of dredging concern. Controlling sediment loads requires knowledge and quantitative assessment of soil erosion and the sediment transport process. A number of factors such as drainage area size, basin slope, climate, land use/land cover affect sediment delivery processes.

Under hydrologic models for sediment yield estimation, models can be called parametric, deterministic, or physically based models. These models are developed based on the fundamental hydrological and sedimentological processes. They may provide detailed temporal and spatial simulation but usually require extensive data input. Below are the few models and their parameters required to estimate sediments from the watersheds used extensively for the purpose.

1. **AGNPS (Agricultural Non Point Source Pollution, 1985)**: It requires 22 parameters for each grid cell (area unit) and there is a limitation for the number of cells in running the model.

2. **CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems, 1980):** It evaluates non point source pollution (sediment and agro-chemicals) from field plots.

3. **SPUR (Simulation of Production and Utilization of Rangelands, 1983):** The process oriented model used to replace the USLE for routine assessment of watershed characteristics.

4. Hydrologic models such as **GSSHA** (Gridded Surface/Subsurface Hydrologic Analysis), **SWAT (**Soil and Water Assessment Tool**)**: They require even larger quantity of input data. Hourly/daily input values of meteorological and radiation variables are required for continuous simulations.

5. Other models include

    1. EUROSEM (European Soil Erosion Model)
    2. KINEROS (Kinematic runoff and erosion model)
    3. LISEM (LImburg Soil Erosion Model)
    4. WEPP (Water Erosion Prediction Project)
    5. ANSWERS (Areal Non point Source Watershed Environment Response Simulation)
    6. GLEAMS (Groundwater Loading Effects of Agricultural Management Systems)
    7. EPIC

Keywords: Sediment Load, Sediment Yield, Sediment Yield Modeling, Universal Soil Loss Equation

Module 10: Rainwater Conservation Technologies and Water Harvesting Structures

Lesson 19 Rainwater Conservation Technologies

19.1 In-Situ Rainwater Conservation Techniques

In this Section, in-situ rainwater conservation techniques are described. They can provide lasting solution to the drinking water problem, when adopted on a sustained basis. Now let us briefly discuss the rural drinking water problem in India.

According to the National Drinking Water Mission of India, a village is classified as a problem village if:

- The source of water i.e., a well or a hand pump is located at a distance of more than 1.4 km from the habitat.
- The source dries up during the summer months.
- The source has inadequate supply. The Government of India norm for adequate supply in rural areas is 40 liters/capita/day (lpcd) and 30 liters/cattle/day.
- The source contains total dissolved solids/arsenic/fluoride/iron in concentrations above their permissible limit.

According to Agarwal (2000), the number of such problem villages identified in 1972 was 150,000 and out of these, 94,000 were provided a source of drinking water by 1980, as per Government of India (GoI) records. The number of remaining problem villages should then have become 56,000. However, a separate inventory showed that the total number of problem villages had now become 231,000 in the same year 1980. Again according to Government of India reports, 192,000 villages were provided a source by 1985, but 140,975 villages remained without a source. Out of these, by 1997 the problems of 110,371 villages were apparently addressed, but still the number of remaining problem villages was 61,747 instead of 30,604 which one can obtain through simple subtraction.

This bewildering and confusing statistical jugglery is a sad reflection on the failure of the methodology used till now in solving the acute water problems, which have also increased manifold over the years. It also means that:

- The solutions found to problem villages were not sustainable.
- Some new villages which were earlier having an adequate source have turned ‘problematic’, possibly because of over-exploitation and
- The increasing practice of tapping deeper aquifers has led to problems of drinking water quality.

One important point to be noted is that in all the Government machinery approaches so far, the methodology adopted was to locate what was already provided for by nature if possible, at the problem village itself, or otherwise provided through expensive pipelines from elsewhere, where the natural source was available at that point in time.

There was hardly any attempt made at creating a new source at the problem village itself through harvesting and conserving the precipitation endowment received annually. The second reason was that the Government efforts failed at the operation and maintenance level. This happened because the people were not involved in the process of solving the problem. The people were neglected and in turn they neglected the upkeep of the sources made available by the Government departments. Rainwater roof catchment systems (RRCS) as existing in many individual homes of the states mentioned were also surveyed and studied. Among the north-eastern states of India viz., Arunachal Pradesh, Nagaland, Mizoram, Manipur, Meghalaya, Assam and Sikkim, RRCS are accepted particularly in those places where the homes are scattered and the piped water supply tem could not reach individual homes. In contrast, the RRCS cannot be readily applied in densely populated areas, where there are many industries/factories or excessive traffic load is causing to precipitate acid rains. In all the states mentioned above, the average annual rainfall is of the order of 1500 - 3000 mm and there is no concentration of industries.

Rain Water Harvesting

The term rainwater harvesting (RWH) refers to direct collection of precipitation falling on the roof or onto the ground without passing through the stage of surface runoff on land. It is sometimes used to describe the entire gamut of water harvesting. We shall use it here only in the specific sense. There are two types of rainwater harvesting viz., roof water harvesting and 'In situ' water harvesting. In this lesson, rainwater harvesting methods are described.

Basically, there are two types of rainwater harvesting schemes - those designed for agricultural use and those designed for human use. Rainwater catchment schemes intended for agricultural use require large catchment areas. In this case, use of the ground surface is the obvious choice. However, water for human use should be more convenient and cleaner than water for agriculture use. Roofs are an obvious choice for a catchment surface as their elevation protects them from contamination and damage which are common to ground surface catchments.

The advantages of rainwater roof catchment system are:

- The quality of rainwater is high, if collected and stored in a hygienic manner. The system is independent, and therefore suitable for scattered settlements.
- Local materials and craftsmanship can be used in rainwater system construction.
- No energy costs are needed to run the system.
- Ease of maintenance by the owner/user.

The disadvantages of rainwater roof catchment system are:

- The high initial cost.
- The water available is limited by rainfall and roof area. For long dry seasons, the required storage volume may be too high, which is very expensive.
- Mineral free water has no taste while people may prefer the taste of mineral rich water.
- Mineral free water may cause nutrition deficiencies in people who are already on mineral deficient diets.

Roof Water Harvesting

Traditionally, rain water harvesting comprises collection of the precipitation falling onto the roof or terrace of a building and storing it in a waterproof sump at ground level for use year round or in periods of scarcity of supply from other sources such as a pond or a well. Roof water harvesting was practiced, as a matter of necessity, mostly in the low rainfall areas of the country, having annual rainfall less than 500 mm per year. Roof water harvesting and storage systems are common features of all old buildings in North Gujarat, Saurashtra and Western Rajasthan. Roof water harvesting was also practiced in some coastal areas where the groundwater was brackish. Modern construction during the last 50 years, especially in urban areas, has no provision for the collection and storage of roof water. The increase of population and inefficient system of distribution of municipal water supply has led to seasonal scarcity of domestic water supply in practically all the urban agglomerates. The utility of roof water harvesting is now being realized and the movement of roof water harvesting is slowly gathering momentum in urban areas. In prevailing situations of uncertain supply, having a captive source of potable water is a main source of water security for a dweller. The rainwater stored over the ground in a sump or recharged into a dug well or an open well, provides much-needed succour during the summer months. Traditionally, the rainwater collected from roofs was always stored in sumps. In modern days, the roof water is stored in a sump and/or recharged into the local aquifer. The practice of using rainwater for directly recharging the local aquifer is becoming popular in urban areas.

Roof water harvesting has also become necessary now in hilly areas having high rainfall. The traditional perennial sources of water in such areas are springs. However, the yield of these springs has either dwindled over the years due to deforestation or the total amount supplied by them has become inadequate because of increase in population.

In some parts of Andhra Pradesh, Madhya Pradesh, Gujarat and Rajasthan, the level of fluoride in groundwater is above the permissible limit, (i.e., 1.5 mg/1). In parts of West Bengal and Bangladesh, the groundwater also contains arsenic above the permissible limit of 50 µg/l. In these situations also, roof water harvesting is desirable although there may be no shortage of groundwater. Rainwater is practically free of dissolved solids and also does not have substances such as arsenic and fluoride.

There are areas where there is no problem with groundwater quality, or where the water table in the monsoon season does not rise up to ground level. In such areas, it is desirable and cheaper to recharge the collected precipitation into the groundwater reservoir through a percolation pit in the ground or through an existing open well or a tube well. However in areas where the groundwater quality is poor due to excess occurrence of dissolved salts/fluoride/arsenic or due to anthropogenic pollution, surface storing in sumps or other storage structures becomes a necessity. Sumps are also the only option for storing the roof harvested water in the case of a hilly terrain, having slopes or a laterite cover. Generally in such areas, aquifers having adequate storage capacity are generally absent.

If roof water harvesting is practiced on a large scale in an urban area, then it also helps in reducing the severity of floods, which follow a heavy downpour. Similarly if it is used for spot recharging by large number of households, then it helps in restoring the water table and also in improving the quality of water. Another benefit accruing from roof water harvesting in an urban area is that it reduces the demand on the municipal water supply system -that in general is inadequate to meet the needs of each and every household.

19.2 Rainwater Conservation through Storage

The Storage Tank: A satisfactory storage tank is the most important part of the roof water harvesting System. It is difficult to construct and must be a durable device; hence it is the most expensive component of the system. The materials used are masonry, concrete, ferro-cement, plastics, metal sheets etc. The design stage of the project involves sizing the storage tank. There are a number of methods that can be used to determine the tank volume.

Dry Season Demand versus Supply: This approach considers the length of the dry period as a design constraint. The tank is designed so that it accommodates the household demand during the dry season. For this reason, the method is most appropriate where there is a definite wet/dry period during the year. The length of the dry period can be estimated by:

- Asking farmers and residents about the longest drought they remember.
- By estimating from official weather analysis data the number of consecutive dry months per year. The dry season demand versus supply method should also consider the maximum drought length in the light of its probability of occurrence.

The dry season demand versus supply gives only a rough estimate of supply and demand. However, it does not take into account variations in annual rainfall patterns. A better method of tank sizing involves the Mass Curve Analysis technique.

Mass Curve Analysis: A more accurate method of sizing a tank involves an analysis of data using the mass curve technique. Successful use of the technique requires approximately 10 years of data.

First, an approximation of the runoff coefficient [i.e., ratio of runoff to rainfall] is required. Some rainwater will be lost during collection. This amount is accounted in the runoff coefficient. This is not a precise value but is estimated on the basis of the type of roof, the condition of gutters and piping, and the evaporation expected from the roof and tank. Approximate runoff coefficient values are given in Table 19.1 as follows:

Table 19.1. Runoff Coefficients (Source: Patel and Shah, 2008)

Type of Roof	Good Gutters	Poor Gutters
Metals	0.9	0.8
Other roofs	0.8	0.7

The Filter: Whenever it is apprehended that water may contain dust or other organic matter from the roof, simple filtration device using crushed charcoal, sand and gravel or coconut fibers or some combinations thereof as media may be installed over the storage tank.

Operation and Maintenance

Rooftop catchment Surfaces collect dust, organic matter and bird droppings, which can clog channe1s, cause sediment buildup on the tank bottom apart from contamination of the stored water. During periods of no rain, these materials are accumulated on the roof and they are washed off with the first rain.

The following steps are necessary for proper maintenance of various components:

Roof: (i) Roof must be periodically cleaned out of dust, branches of trees, leaves, bird droppings etc. (ii) Corrugated metal sheet requires to be painted preferably before each monsoon. (iii) Clay tiles are to be checked from time to time and broken tiles are to be replaced. (iv) Support Structure of the roof is to be checked time to time.

Gutter System: (i) The gutter must be cleaned frequently to prevent overflowing during heavy rains. (ii) The joints of the gutter should be checked periodically and made correct if there is a likelihood of leakage. The joints can be sealed with tar or rubber and the jointing compound should not contaminate water. (iii) The slope of the gutter should also be checked from time to time. (iv) Metal gutters are required to be painted when required. The support of the gutter should also be checked. This can be accomplished by tying wire around the gutter and fastening it to the roof [Fig. 19.1].

Storage Tank: The maintenance requirements of the tank will eventually depend on the effectiveness of the first flush system and the frequency of roof and gutter cleaning. Contamination can be avoided by diverting the first 10 - 20 liters of rain from the tank. Flush traps can be used to prevent the first flush from reaching the tank. In this case, the plastic pipe over the reservoir collects the first flush water from the roof and the removable end allows discharge after each rainstorm.

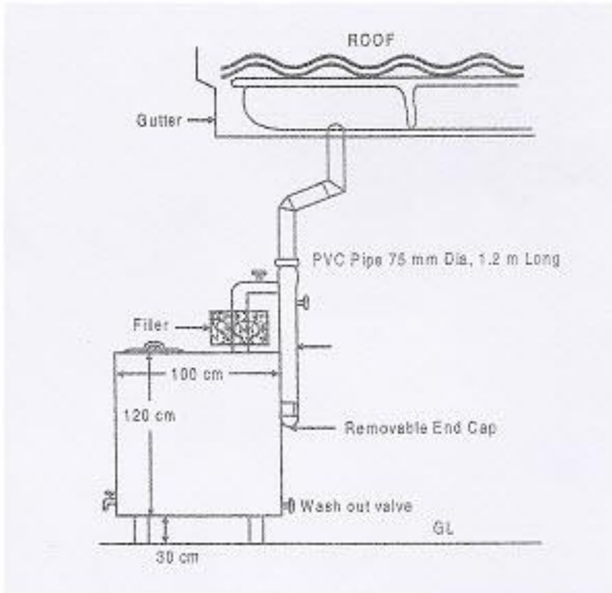


Fig. 19.1. A Typical Roof Water Harvesting System. (Source: Patel and Shah, 2008)

Another important factor is the quality of the tank cover and screening in the inlet and outlet. Sunlight reaching the water will promote algae growth. Unprotected openings will also encourage mosquito breeding. So, the following steps are necessary: (i) The inside of all tanks require periodic cleaning. The tank walls should be scraped annually. Vinegar, baking soda or bleaching powder solutions are commonly used as cleaning agents. (ii) Sediments should be removed annually. (iii) Care must be taken not to contaminate the next volume of incoming storage water. (iv) If cracks in the tank wall are observed, they should be re-plastered after each cleaning of the tank surface. (v) Only after cleaning and disinfection, the water should be allowed to enter. (vi) The tank cover should be checked for tightness so that mosquito and other insects cannot find entry into the tank. (vii) The entry pipe and the overflow pipe should be checked for proper screening arrangements to prevent entry of flies etc. (viii) Sheet metal tanks require to be painted periodically to prevent formation of rust.

Filter: Wherever filters are fitted over storage tank, they require frequent inspection, cleaning of the media and periodical flushing to prevent bacterial builds up on the filter medium. However, in most instances the use of a filter is impractical due to the frequent maintenance required.

Instead of disinfecting all the water stored in the storage tank, it is desirable to disinfect only that portion of water, which will be consumed for drinking and cooking. So, covering of the storage vessels inside the house is always required.

Keywords: Rainwater conservation, Roof water harvesting, Water harvesting structures, First flush devices, Gutter system.

Lesson 20 Design of Water Harvesting Structures

20.1 Need for Water Harvesting Structures

Although we generally get a lot of rain in India, we do not have adequate water at all the times and at all the places. The reason for this is the lack of the realization of the value of each rain drop. The average annual rainfall in India is 1,170 mm, which is higher than all the continents except South America as well as the global annual average of around 850 mm. However, the rainfall in India occurs during short spells of high intensity. Because of such high intensities and short durations of heavy rain, most of the rainfall in India tends to flow away rapidly leaving very little amount for groundwater recharge. This results in most parts of India experiencing water scarcity even for domestic uses.

Ironically, Cherrapunji in Meghalaya –historically regarded as the wettest place on earth with a normal annual rainfall of over 11,000 mm, also suffers from acute drinking water shortage. This is because rainwater is not conserved adequately and is allowed to drain away. Thus it does not matter how much rain we get, if we don't harvest or capture it.

This highlights the need to implement water harvesting through appropriate structures, to ensure that the rain falling over a region is conserved as fully as possible. This can be done by either storing it for direct use on/below/above ground or recharging it into the groundwater.

20.2 Design of Tanks and Ponds for Water Harvesting

Percolation Tank

A percolation tank is generally constructed in low level wasteland or a small drain. It has well defined catchment and the water spilling over is diverted to a nearby natural drain. It consists of earthen embankment and an overflow type masonry waste weir. Permeable formation in the reservoir bed is an essential requirement of percolation tank. The tank acts as storage of intercepted runoff, which percolates down to phreatic aquifer creating a recharge mound. The percolation time depends upon the permeability of bed formation. Normally it is expected that between two consecutive rain spells, most of the storage percolates down. Thus, during 2 to 3 rainfall cycles, the actual recharge gain is two to three times the storage capacity of the tank. The shape and size of the recharge mound depends on the nature of phreatic aquifer underlying the surface. This type of recharge structure is useful in area having sandstone and limestone formation underlying [Refer to Fig. 20.1].

Tank is a general term used for surface water storage of moderate size. The storage may have come into being due to interception of rainwater in a natural depression or a manmade excavation. Such water bodies are popularly called ponds. Alternatively water storage may be done by closing the openings of a natural saucer shaped landform by constructing bund sized embankments. The storage so created is called a tank. The tank bunds are mostly constructed with earth to keep cost of construction low and are commensurate with the benefits envisaged.

Water storages of large size are not called tanks, but they are referred to as reservoirs. Such reservoirs are formed in the river valleys by constructing a barrier or a dam using masonry, concrete or earth depending upon site conditions. Technically, bund is a miniature form of a dam.

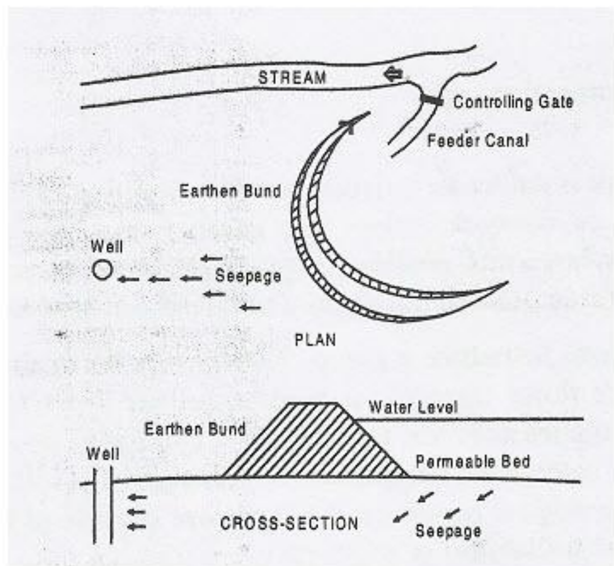


Fig. 20.1. Schematic Diagram of a Percolation Tank. (Source: Patel and Shah, 2008)

Due to simplicity in construction it was a very popular mode of conserving rainwater. In South India where rivers are monsoon fed, tanks assume special importance. In the plains of Uttar Pradesh, West Bengal and Orissa as also in the plateaus of Madhya Pradesh, Chhattisgarh tanks have been extensively practiced.

Classification of Tanks

Bunds which are generally less than 12 m high, results in tanks. From the consideration of height of bunds, up to 4.5 m high bunds generate a small tank. Medium sized tanks are formed by bunds up to 9 m height. It may however be noted that, this classification is very approximate because the shape and size of the tank is not dependent on the height of the bund alone. It is equally influenced by the topographical features of the region.

Network of Tanks

The tank system may exist with each tank as a separate entity or in the form of a group of tanks in a series or tanks with inter-connection. In a tank system, following types of network exist:

(i) Isolated tanks;

(ii) Tanks with inter-connections; and

(iii) Tanks in series.

Isolated Tanks: When a tank is fed by an independent free draining catchment and also when the surplus flows do not form network inflow into another tank, the tank system is called an isolated tank system. Mostly large and medium sized tanks are constructed as isolated tanks with independent catchment area. Also in the plains and on plateau lands, tanks exist in isolation.

Tanks with Inter-Connections: Sometimes a group of tanks may be so situated that they could be inter-connected to receive flows through, as well as deliver flows to other tanks in the group severally. It thereby implies that the tanks have a combined catchment. Any surplus water received by a tank from the catchment lying above it is transferred to other tanks. Depending upon the prevailing hydro-meteorological conditions, the tanks are capable of feeding either each other or one another. Thus, optimum water utilization and storage is achieved.

Tank in Series: Such tanks are located alongside the river drainage channels. They are fed by inflow drains and serviced by escape or outflow drains. The tanks in upper reaches get their supplies from the catchment through inflowing drains. It then lets its surplus flow down through an escape or outflow drain, which contributes to the inflow of the tank lower down in the series. Thus while the uppermost tanks have substantially free catchment, the tanks lower down have limited free catchment falling between two tanks. The tanks lower down in the series get inflows immediately after rainfall from their free draining catchments. But supplies from already intercepted catchments are received only after the upper tanks get filled. The advantage of this system is that, surplus water from the upper tank is picked up by the lower tanks rather than allowing any wastage.

However, there is a safety related disadvantage. In case of breach in the upper tank, lower tanks also become prone to severe flooding endangering the safety of the tank bunds. To avoid this, breaching sections are provided at appropriate locations in each tank.

Water Harvesting by Ponds

The traditional practice of collection rainwater in village ponds suffers from following limitations:

1. Large open surface is subjected to high evaporation losses.

2. Large bed area is subjected to high seepage losses.

In Spite of these limitations in the village ponds, the bulk water requirement for about half the year is met from them. Small groundwater recharge mound formed under the pond bed used to partially supply through wells dug in the pond bed. This traditionally practiced rainwater harvesting structures have served water supply requirements since ages. During the scarcity years, some deepening of ponds is made through de-silting. But if it is done in a haphazard manner, it does not help much and rather it may lead to other problems like water logging, mosquito breeding, etc.

Pond Lining

The limitations of traditional ponds, especially the quality deterioration and seepage losses could be completely stopped by using plastic lining. This simple technique has proved to be effective. The evaporation loss could be checked by use of chemical retardants and adopting system of multiple ponds system (i.e., compartments). Limitation of the depth factor has to be accepted and required storage could be built by increasing the length and breadth of the pond. Of course, in places where salty water is available is at greater depths, the pond storage can be increased even with less open surface and thereby reducing the evaporation losses. Such favorable locations may not be provided with plastic lining, provided the rate of salt contamination from the sediments is within the limits. Plastic lining is a rather costly proposition, however, it envisages better use of local water resources and regular maintenance is almost negligible.

This technology involves lining of the walls and floor of the pond, tank reservoir with tough, wide-width low-density polyethylene (LDPE) film. These LDPE films are available in widths of 4 to 12 m and thickness of 100 to 250 microns. These films meet specifications as per the Bureau of Indian Standards Code IS: 2508 - 1984. This film has excellent water barrier properties, very good blend of physical properties such as tensile impact strength coupled with good weathering capability and chemical resistance properties. These films also prevent the inherent salinity of the soils and saline groundwater from seeping into the pond or tank and start contamination.

The construction of plastic lined pond includes excavation work, screening work for removing big boulders and sharp edged gravels which could damage the plastic film, dressing of sides and beds so that lining is not punctured, laying plastic film on beds and sides, brick lining on the sidewalls, soil filling on the floor, inlet system and distribution system. By 2008, 19 villages of Bhal area of Gujarat, India had 20 such plastic lined ponds [Refer to Fig. 20.2].

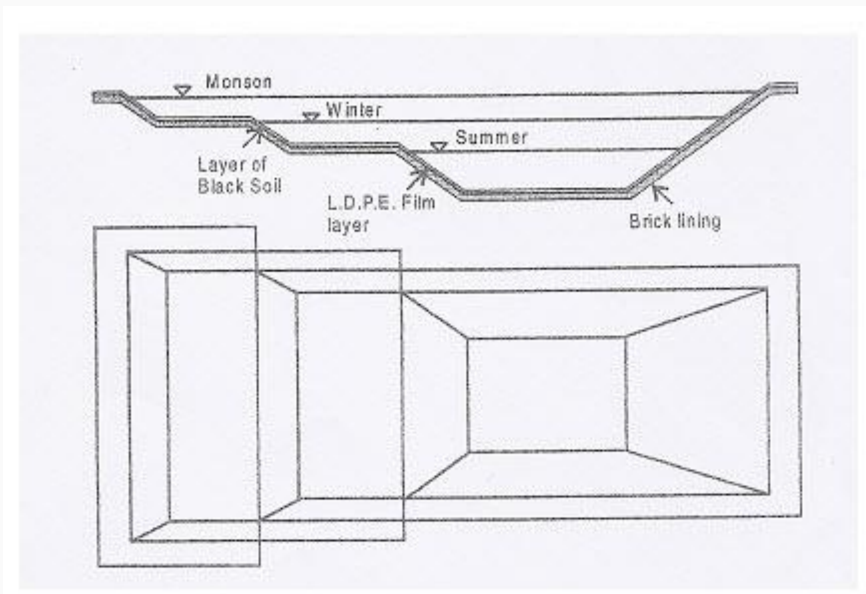


Fig. 20.2. Water Harvesting by Plastic Lined Ponds. (Source: Patel and Shah, 2008)

Keywords: Water harvesting structures, Percolation tank, Tank networks, Water harvesting by ponds, Plastic lined water ponds.

Module 11: Water Budgeting in a Watershed

Lesson 21 Water Budget

21.1 What is Water Budget?

A water budget is a measure of the amount of water entering and the amount of water leaving a system. It is a way to evaluate all the sources of supply and the corresponding discharges with respect to a basin or aquifer. It is a basic tool that can be used to evaluate the occurrence and movement of water through the natural environment. To maintain a balance in the ecological system, one must account for the incoming (source of water) and outgoing (water losses in the system) water resources. A water budget may be used to manage development of water resources within a region, and to ensure a sustainable supply of water over time.

Water budget commonly provides knowledge about how much water is available, where is it available with detailed understanding of the flow dynamics. These flow dynamics include the origin and movement of groundwater and surface water as well as the interaction between the two systems. Water budget studies consider the volumes of water within the various reservoirs of the hydrologic cycle and the flow paths from recharge to discharge. The water budget takes into account the water cycle, evapo-transpiration, groundwater and surface water supplies, and inter basin (import and export) transfers of the water. Thus, a water budget is important to understand since it provides crucial information regarding the carrying capacity of the land with regard to water resources. Figure 1 shows the conceptual model of water budget.

21.2 Components of Water Budget

The most basic equation for water budgets is based on the hydrologic cycle, where water moves from the atmosphere to the Earth's surface to various destinations, and finally back to the atmosphere:

$$P = I + ET + R \qquad (1)$$

Where; P = precipitation, I = infiltration, ET = evapo-transpiration, R= runoff

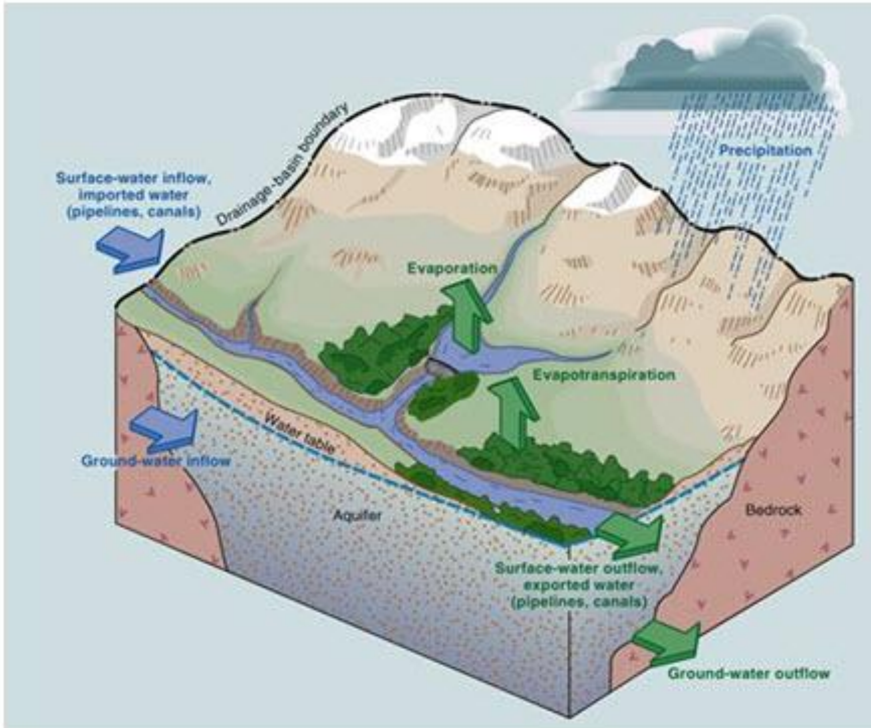


Fig. 21.1. A Conceptual Water Budget.

(Source: http://water.usgs.gov/watercensus/water-budgets.html)

21.2.1 Precipitation

Precipitation is the sole input to the water budget under natural conditions. Precipitation comes in various forms.

21.2.2 Infiltration/Recharge

Infiltration of water into the land surface is a critical component of a water budget. Without infiltration, all water would either evaporate from the land surface or runoff to surface waters. The term "infiltration" means that the water moves downward from the land surface into the soil. Some infiltration water moves toward streams just below the land surface. This water is not used for potable water supplies, generally, but is invaluable for ecosystem health. Other infiltrated water penetrates more deeply in to soil layers and can recharge aquifers. Under natural conditions, water from aquifers is transmitted to surface waters after periods ranging from years to millennia. Infiltration is highly dependent on the amount, intensity and season of precipitation. A lower percentage of precipitation infiltrates to become ground water during periods, where soils are very dry (e.g., summer), brief storms, high-intensity storms, and when the ground is frozen.

21.2.3 Evapo-Transpiration

Evapo-transpiration is a combination of two terms evaporation and transpiration. Evaporation involves the transformation of surface water to atmospheric water. Transpiration occurs when water in plants moves from shallow soils to the root system to the leaves, transporting nutrients and energy, and then evaporates from the leaves. The two terms are usually considered together in water budget calculations. Both evaporation and transpiration tend to be higher during periods of hot weather, low humidity and high wind. Of course, nearly all transpiration occurs during the growing season in case of agricultural crops and round the years for natural vegetation like forest.

21.2.4 Runoff

Runoff occurs when precipitation falls onto the land surface and moves toward surface waters. Runoff is affected by a wide variety of factors, such as:

1. soil type and depth
2. the presence or absence of vegetation
3. the presence or absence of impervious surfaces such as pavement or buildings
4. general topography
5. the extent to which water is trapped in puddles and never gets to major surface waters,
6. the intensity of the precipitation
7. the form of the precipitation (such as snow or rain), and
8. the amount of moisture in the soil just before the precipitation.

In simple terms a water budget for a given area (watershed or basin) can be looked at as water inputs, outputs and changes in storage. The inputs into the area of investigation (precipitation, groundwater or surface water inflows, anthropogenic inputs such as waste effluent) must be equal to the outputs (evapo-transpiration, water supply removals or abstractions, surface or groundwater outflows) as well as any changes in storage within the area of interest.

In the simplest form this can be expressed as:

Inputs = Outputs + Change in storage

$$\mathbf{P + SWSW_{in} + GW_{in} + ANTH_{in} = ET + SW_{out} + ANTH_{out} + \Delta S} \qquad (2)$$

Where; P = precipitation, SW_{in} = surface water flow in, GW_{in} = groundwater flow, $ANTH_{in}$ = anthropogenic or human inputs such as waste discharges, ET = evaporation and transpiration (evapo-transpiration), SW_{out} = surface water flow out, GW_{out} = groundwater flow out, $ANTH_{out}$ = anthropogenic or human removals or abstractions, ΔS = change in storage (surface water, soil moisture, groundwater)

More detail is incorporated into the water budget to account for additional physical aspects. Essentially, three compartments are considered in the water budget determination i.e. the ground surface; the unsaturated zone and the saturated zone.

Precipitation falls onto the ground surface and then can either:

1. evapo-transpirate back to the atmosphere
2. runoff from the surface to surface water bodies (e.g. streams, lakes and wetlands)
3. move downward to the unsaturated zone, or
4. be removed for human water supply purposes

In turn, water that moves to the unsaturated zone can either:

1. evapo-transpirate back to the atmosphere;
2. move laterally as interflow to discharge to local surface water bodies; or
3. move downward to the saturated zone

Similarly, water that moves to the saturated zone can:

1. evapo-transpirate back to the atmosphere (e.g. via plants whose roots extend to near the water table)
2. move in the groundwater system and eventually discharge into a surface water body; or
3. be removed for human water supply purposes

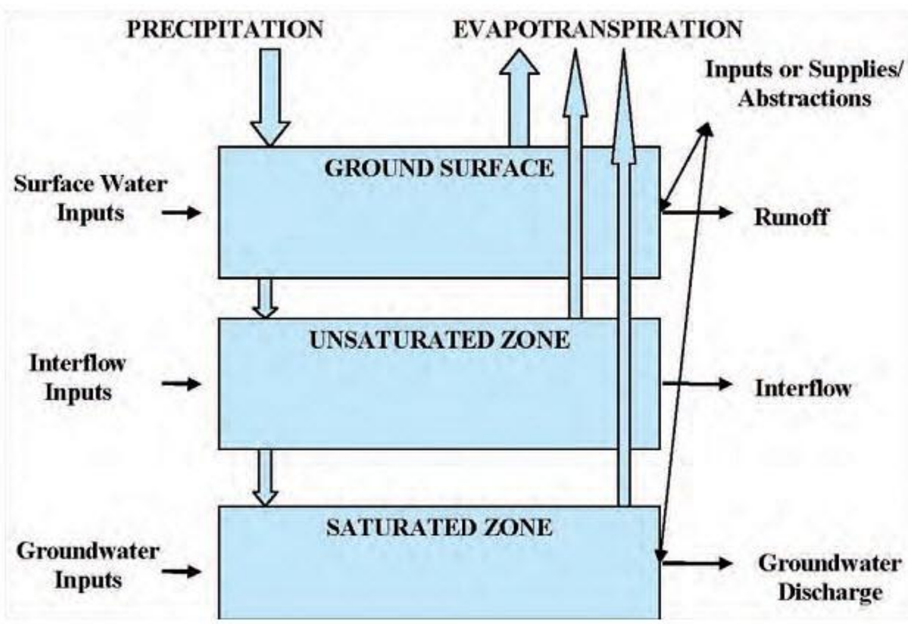


Fig. 21.2. The Water Budget Components.

(Source: http://www.conservation-ontario.on.ca/watershed_management/reports/IWM_WaterBudgetOverview_Final_Jun2.pdf)

Figure 21.2 illustrates that evapo-transpiration can occur from any of the three compartments (ground surface, unsaturated and saturated zones). This figure also shows anthropogenic inputs and/or abstractions. These are both related to human intervention in the water cycle. Inputs would occur in an instance, where water external to a watershed was being brought into and disposed of within the watershed, thereby increasing the water volume in the watershed. Supplies or abstractions would occur, where water was being withdrawn from either a surface water body or the groundwater system and was being removed from the watershed. It is important to note that these human interventions are often difficult to account for in a water budget owing to the fact that a certain portion of the withdrawn water is likely re-circulated back within the same watershed (e.g. through irrigation or through leakage from municipal infrastructure, etc.). Figure 21.2 also shows inputs into the three compartments (i.e. surface water inputs, interflow inputs and groundwater inputs). Water budgets are generally carried out on a watershed or sub-watershed scale and the surface water inputs and interflow inputs tend to be negligible.

Mathematically, the water budget can be expressed as follows:

$$P = RO + AET + I + D + A \pm \Delta I \pm \Delta s \pm \Delta g \qquad (3)$$

Where; P = precipitation, RO = surface runoff, AET = actual evapo-transpiration, I = interflow, D = groundwater discharge, A = anthropogenic inputs (septic systems) and/or supplies/abstractions, ΔI = change in land surface storage, Δs = change in soil moisture storage, Δg = change in groundwater storage

Following the above water budgeting equation:

$$\text{Stream Flow Discharge (SFD)} = I + D + RO \qquad (4)$$

$$\text{Infiltration} = P - AET - RO - \Delta S - \Delta I \qquad (5)$$

$$\text{Aquifer Recharge} = P - AET - RO - \Delta S - \Delta I - I \qquad (6)$$

Over long periods of time in an unstressed, natural state basin (no groundwater pumping or other anthropogenic influences), the natural inputs will balance the natural outputs so that the change in storage will be zero. Soil moisture storage may vary considerably on a daily basis but the net change (Δs) over an annual cycle will be negligible compared to other water budget components. Similarly, groundwater storage and land surface storage may fluctuate on a monthly or annual basis, but Δg and ΔI will approach zero (steady state) over an extended period of time provided other water budget components remain essentially constant. If Δs, ΔI and Δg equal zero, then substitution of equation (6) into equation (3) reveals that

$$\text{Aquifer recharge, } R = D + A \qquad (7)$$

Substitution of equation (3) into (2) gives us

$$\text{Stream flow discharge, } SFD = P - AET - A \qquad (8)$$

If groundwater pumping is small, (i.e., A~0), then annual recharge can be equated to groundwater discharge and stream flow discharge will be the difference between precipitation and actual evapo-transpiration.

$$R = D \tag{9}$$

The preceding quantification assumes the groundwater divides would have to correspond to a large degree to the surface water divides in a 3-dimensional sense and this depends on the size of the study area and the nature of the groundwater flow system. It is important to understand the relationship between the groundwater and surface water divides. Where these divides are not coincidental, groundwater inputs within the surface watershed may not be reflected in the groundwater discharge within the surface watershed.

21.3 Factors affecting Water Budget of a Watershed

The natural "water budget" accounts for all the water entering the watershed, how it travels through the watershed or is stored, and all the water leaving the watershed. The natural factors affecting water budget of a watershed are as below:

1. rainfall and snowfall
2. temperature and wind
3. vegetation
4. soil properties (surface and subsurface)
5. stream and channel characteristics (vegetated or clear channels)

In addition to these natural factors, human activities and alterations of the watershed greatly affect the water budget. These factors include:

1. How much water is pumped out of the ground or the river and where that water ends up ?
2. How much water is stored in reservoirs and later pumped out ?
3. How much water is "imported" from other watersheds ?
4. How much water is "exported" to other watersheds or lost from the watershed (via water pipes, sewers, or through increased evaporation) ?

Keywords: Water Budget, Precipitation, Infiltration, Evapo-Transpiration, Runoff.

Lesson 22 Budgeting of Water in a Watershed

22.1 Methods of Water Budgeting of Watershed

We have a finite supply of water and it moves within the hydrologic cycle, or water cycle within a watershed. In order to ensure a sustainable supply of water within the water cycle, we need to pay attention to what is happening on the land and how that impacts our natural environment. Precipitation reaching the land surface is impacted and distributed in numerous ways. Any precipitation that falls within the watershed is influenced by physical characteristics of the land, air pollution, and land uses. By developing a schematic of the physical watershed, we can determine where water sources are located, how much water is being used, how much is being stored, and where the important recharge areas are located (where surface water and groundwater interact). The way water moves in a watershed relies on the typography of the land, types of soils, etc. Excess water can be stored in a watershed in low areas or below ground – slowly being released over time during drier periods. However, overuse or contamination of these sources of water significantly impacts the quality and amount of the available water. The amount of water available in a watershed is not infinite and it is susceptible to stress.

A water budget is a basic tool that can be used to evaluate the occurrence and movement of water through the natural environment. Water budgets provide a foundation for evaluating its use in relationship to other important influencing conditions such as ecological systems and features and social and economic components. The water budget process can encompass various levels of assessment, which start simple and grow more complex if there are concerns about how much water is available at any level. The higher the 'tier', or level, the more complex the science involved and the narrower the geographic focus. Water budgets commonly go well beyond how much water is available and where it is. It also includes a detailed understanding of the flow dynamics. These flow dynamics include the origin and movement of groundwater and surface water, as well as the interaction between the two systems. This overall interdependent understanding is necessary for sound water management. Water budget studies consider the volumes of water within the various reservoirs of the hydrologic cycle and the flow paths from recharge to discharge. Water budgets need to consider this information on a variety of spatial and temporal scales.

For an understanding of the hydrology of areas with little available data, a better insight into the distribution of the physical characteristics of the catchments is provided by image processing techniques. Some of the new measurement methods (photographic systems, active radar systems etc.) could yield assessment of areal distribution or at least to some extent reliable areal totals or averages of hydrologic variable such as precipitation, evapo-transpiration and soil moisture. Some of the main hydrological application fields of remote sensing are:

1. Topography
2. Water bodies

3. Vegetation
4. Spatial rainfall patterns
5. Evaporation and soil moisture
6. Snow cover extent
7. Groundwater assessment

Geographical Information System (GIS) is often utilized in hydrological studies by coupling it with hydrological models. Two types of approaches are possible for this purpose. In the model driven approach, a model or set of models is defined and thus the spatial (GIS) input for the preparation of the input data and output maps are required. The other approach is the data driven approach. It limits the input spatial data to parameters which can be obtained from generally available maps, such as topographic maps, soil maps etc. The possibility of rapidly combining data of different types in a GIS has led to significant increase in its use in hydrological applications. It also provides the opportunities to combine different data types from different sources. One of the typical applications is use of a Digital Terrain Model (DTM) for extraction of hydrologic catchment properties such as elevation matrix, flow direction matrix, ranked elevation matrix, and flow accumulation matrix.

In a natural state an unstressed basin experiences negligible long term changes in land surface, soil moisture and groundwater storage. However, this is not always the case. Also, groundwater flows as well as impacts of human activities can result in water moving between watersheds (i.e. inter-basin flow) and may be difficult to adequately quantify.

22.2 Measurements

In simple terms a water budget for a given area can be looked at as water inputs, outputs and changes in storage. The inputs into the area of investigation (precipitation, groundwater or surface water inflows, anthropogenic inputs such as waste effluent) must be equal to the outputs (evapo-transpiration, water supply removals or abstractions, surface or groundwater outflows) as well as any changes in storage within the area of interest.

In the simplest form this can be expressed as:

Inputs = Outputs + Change in Storage

$$\mathbf{P + SWSW_{in} + GW_{in} + ANTH_{in} = ET + SW_{out} + ANTH_{out} + \Delta S}$$

Where;

P = Precipitation

SW_{in} = Surface Water Flow in

GW_{in} = Ground Water Flow in

$ANTH_{in}$ = Anthropogenic or Human Inputs such as Waste Discharges

ET = Evaporation and Transpiration

SW_{out} = Surface Water Flow out

GW_{out} = Ground Water Flow out

$ANTH_{out}$ = Anthropogenic or Human Removals or Abstractions

ΔS = Change in Storage (Surface Water, Soil Moisture, Ground Water)

22.3 Modeling Approach

A conceptual water budget model is first developed to obtain a basic understanding of the physical flow system. An initial synthesizing of the available data can be used to gain an appreciation of the various fluxes in the watershed. This initial work may indicate, where critical data gaps exist. The use of numerical modeling can provide a more refined understanding of the flow system including both surface and groundwater. Numerical models are tools used to simplify the representation of these processes and enable quantification and evaluation of the hydrologic system at various levels – watershed, sub-watershed and site scale. Although these models can provide hard quantitative values, it is important to recognize the uncertainty in numerical modeling and use the models appropriately in making water management decisions.

The most appropriate model for water budget analysis will depend primarily on the dominant flow processes (surface water or groundwater). If changes in the groundwater discharge will significantly affect the flow of a river, then the model used should simulate the complexities of the groundwater system. If flow in the river is most affected by surface runoff and through flow during and following storm events, then the model must be able to simulate the complexities of the surface water processes.

The three basic types of numerical models that are built and used for water budget analysis are:

1. Surface Water Models
2. Ground Water Models
3. Conjunctive or Integrated Continuum Models

Commonly an integrated approach is used, where output from both a surface water model and a groundwater flow model is iteratively compared. Traditionally, assumptions are made about all processes in a model. The processes of greatest interest are those that are explicitly represented in the model equations. The processes considered least important are treated as lumped processes and are specified as inputs or outputs to the model. They may be spatially variable but are not explicitly derived by equations in the particular model. In a groundwater flow model the recharge is input directly and is derived from field values or output from a surface water model.

Effective Application of a Numerical Model for Water Budget Analysis Requires:

1. definition of specific objectives of the analysis at the start
2. identifying the characteristics of the hydrologic system through development of a conceptual model (review existing reports: size, spatial variations, land use variability, topography, geologic structure, etc.)
3. determination of the scale of the problem or the level of detail that needs to be included (e.g. micro-watershed versus large river basin)
4. determination of the appropriate time scale
5. collection or compilation of sufficient data to evaluate each process
6. suitability for linkage to GIS
7. effective calibration and validation
8. recognition and minimization of the uncertainty in the analysis
9. re-evaluation of the applicability of the analysis prior to addressing new objectives.

Secondary Considerations Include:

1. available resources (e.g. training for model application)
2. model availability, preferably from an organization that provides regular updates and technical assistance.

Keywords: Watershed, Water Budget, Numerical Models, Flow Processes.

Module 12: Effect of Cropping System, Land Management and Cultural Practices on Watershed Hydrology

Lesson 23 Watershed Land Use/Land Cover

23.1 Land Use and Land Cover (LULC)

Land use and land cover are often related, but they have different meanings. Land use involves an element of human activity and reflects human decisions about how land will be used. Land cover refers to the vegetative characteristics or manmade constructions on the land's surface. For example, after a timber harvest land cover has changed, but the land use of that area will not have changed if seedlings were planted or natural regeneration is occurring and it will continue to be used for timber production. Often, different methods are used to develop land use and land cover estimates. Land use is generally determined by surveys based on field observations or enumeration, while land cover is generally determined using remote sensing techniques or aerial photography interpretation. In short, while land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it, land cover is the observed biophysical cover on the earth's surface.

23.2 Agricultural Practices and LU/LC

Since the invention of agriculture, ~10,000 years ago, humans have modified or transformed the land surface. Agricultural production has caused greater environmental change to the biosphere than any other land use. It is estimated that 50% of the world's land is used for agriculture and animal production while only 5% is unmanaged lands, parks and preserves. The major mode of human land transformation has been through agriculture. It is estimated that over the last 300 years, globally, 20% of forests and woodlands, 1% of grasslands and pastures (although most grasslands were converted to pastures) were lost while croplands expanded by 466%. Figure 23.1 illustrates these changes at a global scale. Although land-use practices vary greatly across the world, their ultimate outcome is generally the same: the acquisition of natural resources for immediate human needs, often at the expense of degrading environmental conditions.

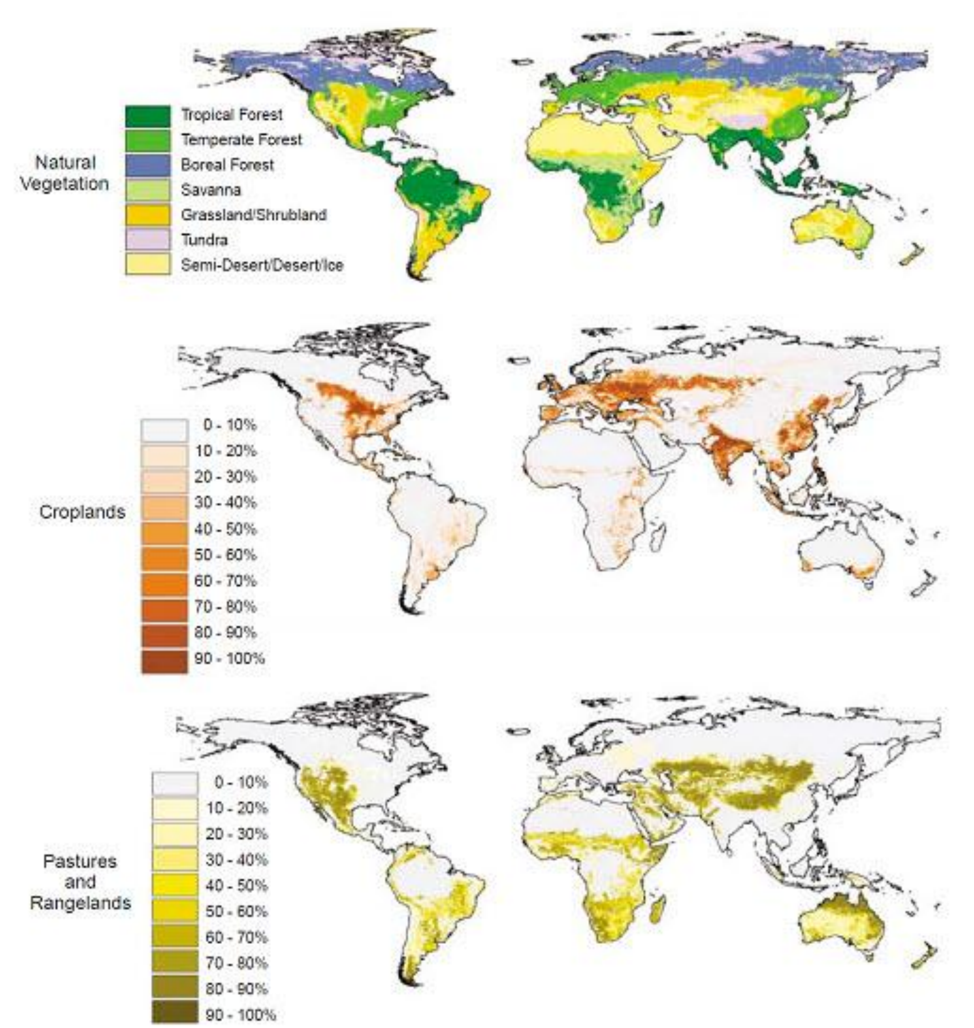


Fig. 23.1. World Wide Extent of Human Land Use and Land Cover Change. (Source: Foley, Jonathan A., et al. "Global consequences of land use." Science 309.5734 (2005): 570-574)

Land-cover changes also affect regional climates through changes in surface energy and water balance. Humans have also transformed the hydrologic cycle to provide freshwater for irrigation, industry, and domestic consumption. Furthermore, anthropogenic nutrient inputs to the biosphere from fertilizers and atmospheric pollutants now exceed natural sources and have widespread effects on water quality and coastal and freshwater ecosystems. Land use has also caused declines in biodiversity through the loss, modification, and fragmentation of habitats; degradation of soil and water; and overexploitation of native species. Although modern agriculture has been successful in increasing food production, it has also caused extensive environmental damage. For example, increasing fertilizer use has led to the degradation of water quality in many regions. In addition, some irrigated lands have become heavily salinized, causing the worldwide loss of ~1.5 million hectares of arable land per year, along with an estimated $11 billion in lost production. Up to ~40% of global croplands may also be experiencing some degree of soil erosion, reduced fertility, or overgrazing. The loss of native habitats also affects agricultural production by degrading the services of pollinators, especially bees. In short, modern agricultural land use practices may be trading short-term increases in food production for long term losses in ecosystem services, including many those are important to agriculture.

23.3 LU/LC Management of Watersheds

Land use can disrupt the surface water balance and the partitioning of precipitation into evapotranspiration, runoff, and groundwater flow. Surface runoff and river discharge generally increase when natural vegetation (especially forest) is cleared. Water demands associated with land-use practices, especially irrigation, directly affect freshwater supplies through water withdrawals and diversions. Agriculture alone accounts for ~85% of global consumptive use. As a result, many large rivers, especially in semiarid regions, have greatly reduced flows, and some routinely dry up. In addition, the extraction of groundwater reserves is almost universally unsustainable and has resulted in declining water tables in many regions.

Water quality is often degraded by land use. Intensive agriculture increases erosion and sediment load, and leaches nutrients and agricultural chemicals to groundwater, streams, and rivers. In fact, agriculture has become the largest source of excess nitrogen and phosphorus to waterways and coastal zones. Urbanization also substantially degrades water quality, especially where wastewater treatment is absent. The resulting degradation of inland and coastal waters impairs water supplies, causes oxygen depletion and fish kills, increases blooms of cyanobacteria (including toxic varieties), and contributes to waterborne disease.

Integrated watershed management, involves the adoption of a coherent management system for land, water and vegetation which can help to achieve the sustainable use of the natural resources within a watershed. This approach recognizes that such factors as urban and agricultural development, the loss of wetlands, land drainage schemes, forest clearance and other activities carried out in the watershed, even though well away from river channels can increase the volume and rate of run-off and worsen flood conditions. The watershed is the logical unit for coordinated land-use planning and management and effective and sustainable resource and environmental management. There is a clear association between land-use decision-making, natural resources utilization and the quality of the watershed environment - with a systems approach, the likely adverse consequences of mismanagement can be anticipated and appropriate precautions taken to minimize or avoid their effects.

The principles adopted for land-use planning at the watershed level may include the following components:

1. Integrated Utilization of Natural Resources
2. Sustainable Farming Systems
3. Interactive and Pro-active Community Farming Systems
4. Community Participation
5. Conservation Measures
6. Development of Models for Sustainable Land-use Systems

A sustainable farming system needs to focus on the social conditions, especially poverty alleviation, and may include the following components:

1. Food Component
2. Fodder Component
3. Fuel Component
4. Income Generation Component

23.4 Role of Cultural Practices as Land Management

Cultural land management practices can be classified into following basic categories.

1. Shifting Cultivation
2. Nomadic Pastoralism
3. Continuous Cultivation
4. Mixed Subsistence Farming

The insite about these cultural practices and their effect can be discussed as below.

23.4.1 Shifting Cultivation

Shifting cultivation, swidden or slash and burn agriculture is a common means of food production in the tropics. It is well suited to nutrient poor soils in areas of low population density. The natural vegetation is cut and burned, followed by up to five seasons of growing then several years of fallow. Once the area is allowed to go fallow, another area is chosen and the process repeated. The fallow usually lasts 20 years in humid areas and as few as 10 years in dryer areas. During the fallow period soil nutrients are regenerated and given long enough fallow, the cycle can be repeated indefinitely. Burning the natural vegetation makes nutrients stored in forest biomass more available in the form of inorganic ash. These nutrients usually decline rapidly with each successive crop and weeds and pests soon invade. Thus, crops can only be grown for a few seasons. Often the area is not completely abandoned, useful perennial plants (fruits plant) are left to mature and the area is revisited frequently to harvest the crop. This system gives very high yields per unit of cultural energy input. Unfortunately, with increasing population pressures and less available land, the fallow period has decreased. This leads to increased soil erosion and decreased species diversity. The shorter fallow associated with modern swidden agriculture makes the practice unsustainable.

23.4.2 Nomadic Pastoralism

Nomadic pastoralists raise domesticated relatives of wild undulates such as goats, cattle, camels and sheep. They live almost exclusively off animal product such as milk, meat and blood, though diets are often supplemented with plant products gathered in incidental foraging. The people tend to migrate extensively in search of water and pasture. This system allows humans to occupy areas unsuitable for rain-fed agriculture, although usually at low population densities. The animals are able to convert low quality plant food (grass), which are unusable by humans, into high quality foods such as milk and meat. The population of the animals varies considerably depending on rainfall. The populations are generally higher than those of wild relatives and can therefore feed more people than can otherwise be supported in these environments. Nomadic pastoralism is usually practiced in savannnas or areas otherwise unsuited for permanent rainfed agriculture. This form of subsistence is therefore most common in Africa, Northern Asia and Arabia. The Massai of Kenya is a well known group of nomadic pastoralists.

23.4.3 Continuous Cultivation

Under continuous cultivation, fields are used year after year with only brief fallow periods. Weeds, pests and losses of soil nutrients are frequent problems. Thus, a higher level of cultural energy input is required. Frequently, such areas are dependent on nutrient inputs from seasonal flooding or alluvial sediments in paddy water. In paddy fields, nitrogen can also be added by N_2-fixing cyanobacteria. The net energy gain for continuous cultivation is less than in shifting cultivation. This system can be very sustainable, much of the traditional farming, in India and Southeast Asia is based on continuous cultivation.

23.4.4 Mixed Subsistence Farming

The majority of farmers employ a combination of farming techniques. Mixed agriculture, with livestock and crops integrated into a single ecosystem, is very common in Asia, Africa and the Americas. Farmers are often highly dependent on animals as a key component of the farming system. The animals provide meat, milk, fuel, fertilizer, draft power, transportation and can be fed largely with agricultural waste products. Additionally, farmers are frequently engaged in a combination of agricultural and economic pursuits. They can barter for food or labor, sell agricultural products or work for others. The choice of cropping system can be based on several factors; climate, soil types, local economies, markets, availability of labor and land, knowledge base and traditions all influence the decision.

Common Characteristics

The following characteristics can be considered common and important features of traditional agricultural systems.

1. Focus on risk reduction
2. Year round vegetative cover of soils
3. System diversity: farm systems based on several cropping systems, cropping systems based on a mixture of crops, and crops with varietal and other genetic variability
4. Trophic complexity approaching natural systems. Multiple interactions between plants, weeds, pathogens and insects
5. High net energy yields because energy inputs are relatively low

6. Low levels of inputs and high degree of self-sufficiency

One of the key features of traditional farming systems is the interaction between domesticated varieties and their wild relatives. The promotion of natural hybridization and introgression has, over time, increased the genetic diversity available to farmers. Traditional farmers also experiment with new varieties and breed plants purposefully to create new strains. They generally plant experimental plots first and only integrate new varieties into their main crops once a variety has proven itself to be of value. This constant experimentation and breeding has created the diversity of crops upon which we now depend. Traditional farming systems also promote genetic diversity. The landscape in a traditionally farmed area is a patchwork of different vegetation types created by the farming methods. The result is a variety of ecological niches that encouraged biological diversity. The landscape, even in intensively managed areas, is a mosaic of cultivated, grazed, uncultivated, and successional areas. Evidence from tropical forests as well as desert areas in the Americas has shown that certain traditional agricultural activities increased the number of species present rather than decreased them. Some of the areas with the richest species diversity, such as tropical forests, have been managed by humans for centuries.

Keywords: Land Use Land Cover, Land Management, Watershed Management, Cultural Practices.

Lesson 24 Effect of Land Use Land Cover on Watershed Hydrology

24.1 Methods of Watershed LU/LC Estimation

Land use land cover information has been of interest for planning resources as well as to understand the condition of the area since long. Earlier it was used to develop by surveying the area at regular interval of time. However, with the development of technology and growing need of getting reliable/accurate information within less time, new techniques have been developed and being employed. Nowadays, two technologically efficient methods are generally adopted for estimating land use/land cover of a watershed:

i) Using Aerial Photographs

Aerial photographs have been used in the mapping of vegetation since 1920, but their development as a major tool in forestry and related fields has come in use since 1940. Modern techniques involving the use of aerial photographs have been made possible by the availability of high-grade photographs at a low cost, coupled with the development of simple photogrammetric instruments, and of photo-mensurational techniques. The principal advantage of aerial photographs in vegetation and land-use surveys lies in the fact that they provide a permanent record of conditions which is available in the office for detailed analysis. When studied with the aid of the stereoscope, they present a three-dimensional picture of the terrain seen directly from above. Maps can quickly and accurately be prepared from photographs. Units of vegetation and of land use can be delineated from the photographs and their areas determined with greater accuracy than is possible in the field in any reasonable amount of time.

ii) Using Remote Sensing Imagery (RS)

Land cover mapping is one of the most important and typical applications of remote sensing data. Generally land cover does not coincide with land use. A land use class is composed of several land covers. Remote sensing data can better provide land cover information rather than land use information. Initially the land cover classification system should be established, which is usually defined as levels and classes. The level and class should be designed in consideration of the purpose of use (national, regional or local), the spatial and spectral resolution of the remotely sensing data, user's request and so on. Table 1 shows a classification typically used with remotely sensed data.

Table 24.1. Land Use and Land Cover Classification System Typically Used with Remotely Sensed Data

Category	Sub-categories
Urban or Built-up Land	Residential, commercial, services, transportation, communications utilities, industrial and commercial complexes, mixed urban or built-up land, other urban or

	built-up land
Agricultural Land	Cropland and pasture orchards, groves, vineyards, nurseries, and ornamental horticultural areas, confined feeding operations, other agricultural land
Rangeland	Herbaceous rangeland, shrub and brush rangeland, mixed rangeland
Forest Land	Deciduous forest land, evergreen forest land, mixed forest land
Water	Streams and canals, lakes, reservoirs, bays and estuaries
Wetland	Forested wetland, non-forested wetland
Barren Land	Dry salt flats, beaches, sandy areas, bare exposed rock, strip mines quarries, and gravel pits, transitional areas mixed barren land
Tundra	Shrub and brush tundra, herbaceous tundra, bare ground tundra, wet tundra, mixed tundra
Perennial Snow/Ice	Perennial snowfields, glaciers

24.2 Use of Remote Sensing in LU/LC Estimation

Land use land cover classification can be carried out by using remote sensing images of required (available) resolution through the following process/steps.

i) Pre-processing

This includes data operations which normally precedes further manipulation and analysis of the image data to extract specific information. These operations aim to correct distorted or degraded image data to create a more faithful representation of the original scene. These preprocessing procedures are essential for ensuring high-quality information from remote sensors and are performed on satellite image data prior to the retrieval of land, atmosphere, and ocean information. Pre-processing functions are generally grouped as Radiometric or Geometric corrections.

Radiometric correction is important to ensure that terrestrial variables retrieved from optical satellite sensor systems are calibrated to a common physical scale. Radiometric correction ensures that measurements and methods yield self-consistent and accurate geophysical and biophysical data, even though the measurements are made with a variety of different satellite sensors under different observational conditions and the parameter retrieval methodologies. Radiometric corrections include correcting the data for Sensor Irregularities and Unwanted Sensor or Atmospheric Noise, and converting the data so that they accurately represent the reflected or emitted radiation measured by the sensor.

The images acquired by Earth observation systems cannot be transferred to maps as is, because they are geometrically distorted (spherical nature of land surface representation of 2D rectangular shape). These distortions are due to errors in the satellite's positioning on its orbit, the fact that the Earth is turning on its axis as the image is being recorded, eg. the effects of relief. They are amplified even more by the fact that some satellites take oblique images. Some distortions, such as the effects of the Earth's rotation and camera angles, are predictable. They thus can be calculated and correction values applied systematically. Satellites also have sophisticated on-board systems to record very slight movements affecting the satellite. This information is used mainly to correct the satellite's position (when this is necessary), but can also be used to correct the images geometrically. The producers of satellite images generally propose applying the most elementary corrections based on the satellite's known information.

ii) Collection of the Ground Truth Data

In order to "anchor" the satellite measurements, we need to compare them with something we have observed and measured. Ground truthing is one part of the calibration process where a person on the ground makes a measurement of the same thing the satellite is trying to measure, at the same time the satellite is measuring it. The two answers are then compared to help evaluate how well the satellite instrument is performing. Usually we believe the ground truth more than the satellite, because we have more experience making measurements on the ground and sometimes we can see what we are measuring with the naked eye.

iii) Image Classification

Objects of similar natures have similar spectral properties. That means that the electromagnetic radiation reflected by objects of the same nature is similar overall and these objects will thus have similar spectral signatures. Since the spectral signatures of the objects observed by satellites are converted into different colours in digital images, objects of the same kind will appear in closely related colours. This property has been used for years to interpret aerial photographs and the images supplied by Earth-observing satellites. The interpreter places in the same category all the objects in an image that seem to have the same or closely related colour. Since the colours in a digital image are merely a conventional transposition of numerical values, it is also possible to exploit the computer's computational power to classify the pixels by their numerical values, which is to say, in the final analysis, by the corresponding objects' spectral properties. This is the basic principle of image classification.

There are two types of image classification.

a) Unsupervised Classification

In unsupervised classification, the computer is allowed to analyze all of the spectral signatures of all of the image's pixels and to determine their natural groupings, that is to say, to group the pixels on the basis of their similar spectral signatures. In some cases the user may impose the number of categories that he wants to have at the end of the classification process and in some programs can also force certain classes to appear. The classification algorithms usually involve several passes during which the proposed solutions are refined so as to create increasingly homogeneous and well-differentiated groups. The main advantage of this method is its great speed, for it requires practically no intervention from the user. Its main flaw is to be based exclusively on spectral differences, which do not always correspond to natural land cover categories. For example, unsupervised classification often yields several classes corresponding to grassy vegetation but only one class encompassing the entire urban fabric, roadways, and tilled fields, which does not usually meet the interpreter's needs.

b) Supervised Classifications

Supervised classification is the procedure most often used for quantitative analysis of remote sensing image data. It rests upon using suitable algorithms to label the pixels in an image as representing particular ground cover types, or classes. A variety of algorithms is available for this, ranging from those based upon probability distribution models for the classes of interest to those in which the multi-spectral space is partitioned into class-specific regions using optimally located surfaces. Irrespective of the particular method chosen, the essential practical steps usually include:

1. Decide the set of ground cover types into which the image is to be segmented (possible number of classes). These are the information classes and could, for example, be water, urban regions, croplands, rangelands, etc.

2. Choose representative or prototype pixels from each of the desired set of classes. These pixels are said to form training data. Training sets for each class can be established using site visits, maps, air photographs or even photo-interpretation of a colour composite product formed from the image data. Often the training pixels for a given class will lie in a common region enclosed by a border. That region is then often called a training field.

3. Use the training data to estimate the parameters of the particular classifier algorithm to be used; these parameters will be the properties of the probability model used or will be equations that define partitions in the multispectral space. The set of parameters for a given class is sometimes called the signature of that class.

4. Using the trained classifier, label or classify every pixel in the image into one of the desired ground cover types (information classes). Here the whole image segment of interest is typically classified. Whereas training in Step 2 may have required the user to identify perhaps 1% of the image pixels by other means, the computer will label the rest by classification.

5. Produce tabular summaries or thematic (class) maps which summarize the results of the classification.

6. Assess the accuracy of the final product using a labeled testing data set.

24.3 Effects of LU/LC on Watershed Hydrology

Land cover plays a key role in controlling the hydrologic response of watersheds in a number of important ways. Changes in land cover can lead to significant changes in leaf area index, evapotranspiration, soil moisture content and infiltration capacity, surface and subsurface flow regimes including base flow contributions to streams and recharge, surface roughness, runoff, as well as soil erosion through complex interactions among vegetation, soils, geology, terrain and climate processes. Furthermore, land use modifications can also affect flood frequency and magnitude. Physiography and land cover determine the hydrologic response of watersheds to climatic events. However, vast differences in climate regimes and variation of landscape attributes among watersheds (including size) have prevented the establishment of general relationships between land cover and runoff patterns across broad scales.

24.3.1 Effect on Runoff/Stream Flow

1. Urban Watersheds

Urban watersheds are dominated by buildings, roads, streets, pavements, and parking lots. These features reduce the infiltrating land area and increase imperviousness. Because drainage systems are artificially built, the natural pattern of water flow is substantially altered. For a given rainfall event, interception and depression storage can be significant but infiltration is considerably reduced As a result, there is pronounced increase in runoff. Thus, an urban watershed is more vulnerable to flooding if the drainage system is inadequate. Once a watershed is urbanized, its land use is almost fixed and its hydrologic behavior changes due to changes in precipitation.

2. Agricultural Watersheds

An agricultural watershed experiences perhaps the most dynamically significant land-use change. Changing land use and the treatment usually lead to increased infiltration, increased erosion, and/or decreased runoff. Depression storage also is increased by agricultural operations. When the fields are barren, falling raindrops tend to compact the soil and infiltration is reduced. There is lesser development of streams in agricultural watersheds because small channels formed by erosion and runoff are obliterated by tillage operations.

3. Forest Watersheds

Interception is significant, and evapotranspiration is a dominant component of the hydrologic cycle. The ground is usually littered with leaves, stems, branches, wood, etc. The subsurface flow becomes dominant and there are times when there is little to no surface runoff. There is greater recharge of groundwater. Because forests resist flow of water, the peak discharge is reduced, although inundation of the ground may be increased. Complete deforestation could increase annual water yield by 20 to 40 %.

4. Mountainous Watersheds

The landscape of these watersheds is predominantly mountainous. Because of higher altitudes, such watersheds receive considerable snowfall. And such watersheds have substantial vegetation and thus interception is significant. Due to steep gradient and relatively less porous soil, infiltration is less and surface runoff is dominantly high for a given rainfall event. Flash floods are a common occurrence. The areas, downstream of the mountains, are vulnerable to flooding. Due to snow melt, water yield is significant even during spring and summer.

5. Desert Watersheds

There is little to virtually no vegetation in desert watersheds. The soil is mostly sandy and little annual rainfall occurs. Sand dunes and sand mounds are formed by blowing winds. Stream development is minimal. Whenever there is little rainfall, most of it is absorbed by the porous soil, some of it evaporates, and the remaining runs off only to be soaked in during its journey. There is limited opportunity for ground water recharge due to limited rainfall.

6. Coastal Watersheds

The watersheds in coastal areas may partly be urban and are in dynamic contact with the sea. Their hydrology is considerably influenced by backwater from wave and tidal action. Usually, these watersheds receive high rainfall, mostly of cyclonic type, do not have channel control in flow, and are vulnerable to severe local flooding. The water table is high, and salt water intrusion threatens the health of coastal aquifers, which usually are a source of fresh water supply. The land gradient is small, drainage is slow, and the soil along the coast has a considerable sand component.

7. Marsh or Wetland Watersheds

Such lands are almost flat and are comprised of swamps, marshes, water courses, etc. They have rich wildlife and plenty of vegetation. Evaporation is dominant, for water is no limiting factor to satisfy evaporative demand. Rainfall is normally high and infiltration is minimal. Most of the rainfall becomes runoff. Erosion is also minimal, except along the coast. The flood hydrograph peaks progress gradually and lasts for a long time.

24.3.2 Effect on Sediment Generation and Transport

Sedimentation can adversely affect reservoirs, waterways, irrigation systems and coastal zones. A change in the sedimentation load of a river can also affect the river's biology and have implications in terms of fish production or biodiversity. Factors controlling sediment generation and export from a watershed include geologic structure, soil properties, topography, vegetation, land use, temporal and spatial distribution of precipitation and streamflow generation mechanisms. It is however, difficult to combine these factors into one reliable expression for estimating sediment discharge from a watershed or to isolate the individual effects of these factors. It is generally admitted that the bulk of sediment load of rivers originates from specific locations within the watershed, and that most of the sediments are brought into the river during extreme climatic events. There is clear evidence that changes in land-use practices can have a significant impact on the rate of erosion. Changes in land cover, from forest to agriculture for instance, usually induce an increase in soil erosion. On the other hand, good agricultural practices can substantially reduce the erosion hazard.

Keywords: Land Use Land Cover, Watershed Hydrology, Remote Sensing, Image Classification.

Module 13: People's Participation in Watershed Management

Lesson 25 Need for People's Participation in Watershed Management

25.1 Participatory Rural Appraisal (PRA) Method of People's Participation

Introduction

A close relationship exists between resources such as land, water, forest and mineral and the community, particularly living in the rural areas of the watershed. Therefore, participation and awareness of the community about the development and management program of the watershed are very important. Two participatory and learning action techniques are adopted for community. These are rapid rural appraisal (RRA) and participatory rural appraisal (PRA). These techniques have enabled local people to express, share, emphasize and examine their knowledge. RRA had been in practice till late 1970s and 1980s. Some limitations and flaws have been observed in participation of village community in RRA. This is due to some outsiders who used to enter the village area to obtain data from the village people and thus they finally become the central executing members. In the late 1980s, PRA technique was evolved. In PRA, investigators or members are all villagers. They control the whole project. They are learners, catalysts and facilitators. They do all the works of mapping, diagramming, viewing and analyzing. They identify the priorities and give shape to their information, knowledge, attitudes and aptitudes. Thus, their efforts become a creative approach to information sharing and a challenge to prevailing preconceptions about the rural people. Mukherjee (1993, 1995, and 1997) presented ideas on participatory rural appraisal methodology, PRA analysis through questionnaire survey and PRA on national resources.

Participatory Rural Appraisal and Peoples Participation

Participatory rural appraisal is already defined in the Introduction Section earlier. The people who participate in watershed management are villagers, farmers and common people. They are the participants, beneficiaries and promoters of any development works in the watershed. Their full cooperation and participation is at the root of success of any project. They may participate in different modes. According to Pretty (1988), these participation modes are as follows:

(i). Passive Participation: It is the indirect participation of people in the event which is going to happen or has already happened.

(ii). Participation to Supply Information: This is the people's participation to supply information by answering questions through questionnaire, survey(s) or other methods.

(iii). Participation through Consultation: People participate through consultation and the agencies who hear the people's views may modify the program as per the views of the people.

(iv). Participation for the Material Incentive: This is the participation of people by providing resources such as labour in return of food, money and other material benefits.

(v). Functional Participation: People participate by forming groups to meet the pre-determined objectives related to a project.

(vi). Participation through Interaction: People participate with the implementing agency through interaction.

(vii). Participation by Self-Mobilization: People participate by self-initiated mobilizations and corrective actions.

The project implementing agency should keep in mind the community's participation for the successful completion of the watershed management project(s).

Basic Principles and Fundamentals of PRA

Basic Principles

PRA is a reversal of learning. It is an informal way of learning from the local, physical, technical, social and psychological knowledge of the people. PRA is a way to understand and analyze the peoples' living conditions, to share the outcomes and to plan for their activities.

PRA is conducted to establish rapport with the people. It also aims to identify and define their problems for prioritization in the village itself. PRA is the technique of immediate analysis and survey of village resources, based on principle of listening and progressive learning. Thus, the main principle is to gather information about the villagers, their willingness to participate and resources of the area through patient listening and interaction.

Fundamentals of Participatory Rural Appraisal

(i) Sharing: It is the sharing of information, ideas, knowledge and experience between facilitators (i.e., policy makers) and villagers (i.e., stake-holder population).

(ii) Villagers as Performers: The facilitators should initiate a process so that villagers can work as performers, taking up the task of facilitating investigation, analysis, presentation and learning.

(iii) Self-Critical Awareness: Facilitators examine critically and continuously their own behavior.

(iv) Personal Responsibility: Personal responsibility should be taken up by the facilitators for what is done rather than relying on the authority or authorities for the rigid set of rules.

(v) Maximizing Diversity: By ensuring maximum diversity, the information is enriched. It is essential to notice and investigate the differences, contradictions and anomalies. The objective should be to seek variability rather than objectives.

(vi) Triangulation: It is the process of cross-checking and progressive approximation of truth. Here, investigators assess from findings from different methods, places, times and disciplines.

Assumptions and Basics of Participatory Rural Appraisal

PRA is based on the following assumptions.

(i) It is assumed that it is quite possible and desirable to involve local community in the development projects of the watershed.

(ii) It is also assumed that active participation of the local people can be increased with time in the ongoing works.

(iii) It is assumed that learning from the local people is possible.

(iv) It is assumed that informal approaches and discussions with local people are more effective as the projects progress.

(v) In the execution of the project, multidisciplinary teams are more effective in completing the works in time smoothly.

(vi) The issues that may be involved in the developmental works should be investigated from different perspectives with the help of different approaches.

(vii) The circumstances and systems can be explored instead of adhering to statistical findings.

The PRA need to include the following basic approaches:

(i) Due respect for behavior, attitudes, aptitude and knowledge of the village people should be given.

(ii) Facilitators should have full confidence on the ability of the community to do things.

(iii) There exists a lot of scope for learning from the community.

(iv) Facilitation to the community should be recommended to encourage them to do all the investigations, planning and analysis.

(v) The community should be empowered to own the outcome as an incentive.

(vi) Information and field experience are to be collected and shared by both the facilitators and the community.

Thus, in the basic approaches of PRA, more emphasis is given to the establishment of a cordial relationship between the community and the facilitators. It is also attempted to let the community feel more empowered during the whole process. Local people should be involved as active agents.

25.2 Effective Linkage between People and Policy Makers in Watershed Management

To ensure an effective linkage between the people and policy makers in watershed management, the tips listed below should be followed by the PRA practitioners. At the same time, the myths of PRA listed below need to be properly understood.

Tips for PRA Practitioners

1. For the successful completion of the watershed projects, project implementation agency (PIA) and the community should act as a unified team to handle all areas.
2. A checklist should be made every day before going to the field. This may help in encompassing techniques and progress of the work.
3. The facilitators should keep time for the use of PRA processes and techniques in the field.
4. Participatory rural appraisal techniques should be applied to different parts of the watershed. This may facilitate cross-checking and triangulation. This will further help in rapport building among different sections of society.
5. It is better to explain the objective(s) and methodology in detail to the group before starting the PRA techniques.
6. Participatory rural appraisal is a continuous process. Hence, its techniques should be in the first 4 years of the watershed development.
7. There are various participatory rural appraisal techniques and tools. A judicious selection of the technique and tool for a particular project helps to produce better results of the work.
8. PIA members and community should be accommodative and innovative in handling the available, suitable and adoptable techniques and tools.
9. The team building culture in the community is to be promoted. Identification of self-help groups (SHGs) and user groups (UGs) should be an automatic outcome.
10. Approach to a project should be flexible so as to suit the needs and demands of the community.
11. The community should control the techniques and tools so that they can modify, rectify, evolve and include relevant aspects of their own.
12. The community members may be allowed to start the work in the morning hours at their convenience.
13. Community should not feel left out or ignored. Regular consultation and facilitation should be made with them.
14. It is advisable to select a permanent and spacious place in the village for discussion / meeting between villagers and PIA members.

Myths of PRA Techniques

Participatory rural appraisal is a simple process, yet the facilitators should be aware of the myths of the following PRA techniques.

(i) "It is quick" means all stakeholders need to devote time on each technique.

(ii) It is easy when skills of communication, facilitation, conflict and negotiation is imparted.

(iii) "Anyone can do it" when one gives insight into various organizational management methods.

(iv) It is a fancy if one is aware of the complicated and unnecessary innovations and makes procedure, process and outcomes very simple.

(v) It has no theoretical basis. Participatory rural appraisal is based on action and research approach.

(vi) It is just an old wine in a new bottle. PRA techniques are flexible and hence their innovations and modifications may be promoted.

(vii) The training is necessary. But complex training to the members of PIA and the community should be avoided.

(viii) People involved are neutral. People involved should be free from the influences of political and social biases.

(ix) It is useful only for the need assessment. PRA is used for all-round need assessment of the watershed.

(x) It is universal. To respect heterogeneity, it is preferable to use and apply PRA techniques in different groups.

Benefits of Participatory Rural Appraisal

PRA offers lots of benefits to the community. The poor and weaker section of the community is empowered through PRA techniques. This section of the people can take actions on the need-based proposals. PRA plays an important role in improving the outlook of the community when they are allowed to involve in diverse fields of watershed management. PRA helps both the community and the PIA members in appraisal, identification, planning, implementation, monitoring and evaluation of all types of management works. Research priorities and initiation of participatory research are identified through PRA. PRA helps in indicating changes and modifications in the organization, and thus it becomes closer to community's aspirations. Policy reviews in the watershed programmes and management are possible in PRA.

Different Tools Employed in PRA

There are many tools and techniques employed under PRA. A few of the important tools are discussed here.

Social and Resource Mapping

In this tool, local people are involved in preparing the map of the village areas to show the village resources and different parts of the villages such as their living areas, wastelands, agricultural lands, grazing fields, forests, ponds, wells, fisheries, rivulets, streams or rivers, flood- and erosion-prone areas, schools, village libraries, development clubs, other public institutions, village roads, side drains, railway lines if any near the village and irrigation canal system in the agricultural fields. Village people draw the map to solicit their knowledge and participation. This is done by the villagers, and thus they gain confidence to participate in other development activities. Their map helps to explore and analyze the spatial information, particularly to study the problems and opportunities. The map can give a quick impression about the existing village setup.

Soil and Hydrology Mapping

This map is also prepared by the villagers in addition to the social and resource mapping. In this map, detailed data on soil and hydrology of the village such as types of soil in different areas of the map and hydrological information showing stream, rivulets and drains to carry the runoff produced by rainfall are shown.

Essential Data Collection in a Tabular Form

The village people collect all the essential data and present them in different tabular forms. These data are the most important tools to plan the watershed development project in the community as they give vivid pictures of the status of development. The data collected and presented by the villagers in different tabular forms include the population of the village, distribution of families on caste/class basis, family distribution according to land holdings, total employed persons in the village and categories of employment such as public/private etc., the number of qualified persons, total population of villagers and the number of cattle, goats, sheeps, etc. A table on the information about the miscellaneous items in the village such as its connectivity with pitched road, electrical lines, banks, telephone lines, mobile telephone towers, water supply lines, cable TV connections, and cooperative milk collection centres is also presented.

Ranking Matrix

Ranking matrix of preference is performed by villagers to know about their attitude, valuation, etc. to a particular item of daily livelihood. For example, rabi crop wheat is placed in the first rank in terms of its use as food, taste, market value, etc., and so wheat occupies the matrix ranking of 1. Similarly, if mustard is placed in the second highest position, it will be shown in the matrix as ranking of 2. This ranking matrix analysis is normally presented in a tabular form.

Historical Time Line

This is another tool to collect the information on community or village about their stages and trends of development with a historical time line. In other words, it is the information about the sequence of changes in the village with respect to social, economical, educational, agricultural and other aspects of living standards. It reveals the trends of periodical development. The older people are witness of this development by virtue of their age. These sections of elderly people may be contacted to know about the past history of the village, indicating systematically the period when those changes took place. The time line for agriculture has indicated occurrence of floods, droughts, adaptation of new crop varieties, use of fertilizers and years of major crop production and crop failure. Similarly, timeline will indicate the year of irrigation facilities, years of major water harvesting tanks and ponds, years of major soil erosion in the rivers and hills, land degradation by landslides, water logging, etc.

Transect or Group Walk

The group walk is a process of participatory rural appraisal that involves travelling across the village from one corner to other along with villagers for verification of items supplied for the social and resource mapping. This travel or walk has a lot of purposes such as to have a clear concept on the farm practices, tree plantation, forest cover, wasteland, water table, ponds, water holding capacity of the soil, slope of land, common lands and land use, grassland, grazing fields, recreational grounds, available water resources and other resources. Thus, full picture of the village with existing facilities could be gathered and accordingly this tool paves the way for future planning.

Seasonal Analysis

Seasonal analysis is a tool to provide insight into rainfall pattern, average rainfall, extent of cultivated kharif and rabi crops, income of farmers in each season, seasonal functions in the village, seed sowing and harvesting periods, seasonal human and animal disease, etc. All these items and the time required to complete are indicated by the villagers in a simple table.

Venn Diagram

A typical Venn diagram is shown in Fig. 25.1. It gives an approximate idea about some existing infrastructure of the village and their relevance to the village community. The size and distance of the circle from the centre indicates the importance of facilities to the village. The item in the biggest circle indicates the highest need. Thus, the Venn diagram is another tool to learn the existing infrastructure and their need for the community.

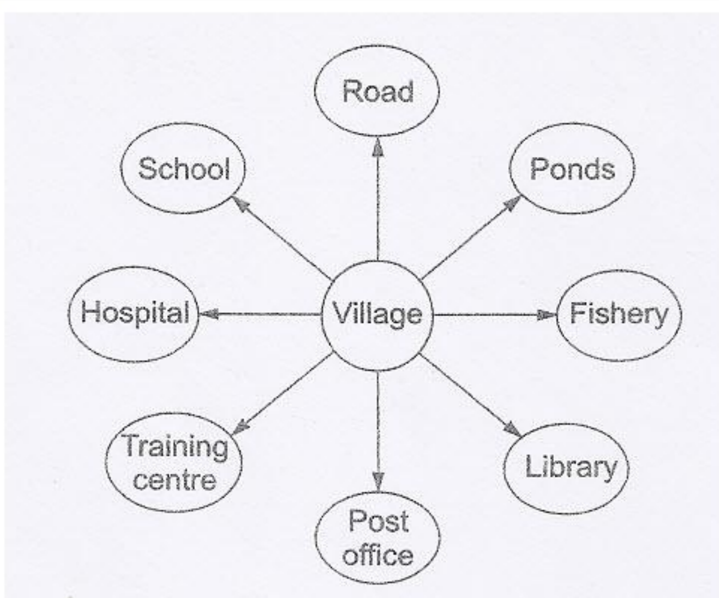


Fig. 25.1. A typical Venn diagram used in participatory rural appraisal (PRA). (Source: Das and Saikia, 2013)

Indigenous Technical Knowledge

Indigenous technical knowledge (ITK) available in rural areas is one of the main tools in PRA exercise. Villagers are the storehouse of ITK. These people are the rich sources of traditional wisdom/practices/skills, beliefs and local resources. The villagers can express their proverbs idioms, drama, dance, local history, etc. through traditional wisdom. ITK tool helps them to express their views. ITK can also be gathered for sharing the views with the community.

Women's Participation

Women's participation in the development of watershed management is considered as one of the major tools. Women in the villages take part in various activities such as agricultural production in the field, collection of fuel wood, fetching drinking water, preservation of seeds, milk processing, sharing the knowledge on traditional foods/medicines, besides their exclusive role in housekeeping. Women's committees may be formed in the village to contribute in a systematic way to the PRA activities.

Participation of NGO

Non-governmental organizations (NGOs) can be actively involved in the developmental works of watershed. NGOs can create awareness of watershed development education in the rural masses. They can also arrange field training for the villagers. They can evaluate and monitor the project activities. NGQs can act as facilitators towards watershed management efforts.

Conclusion

A close relationship exists between resources and the community living in the rural areas of the watershed. Therefore, participation of the community in the development and management of the watershed is very important. The two techniques viz., rapid rural appraisal (RRA) and participatory rural appraisal (PRA), help the local people to express, share, emphasize and examine their knowledge. The RRA has become almost obsolete owing to some of its major drawbacks. In late 1980s, participatory rural appraisal technique was evolved. In the PRA, villagers monitor the whole project. The participants in PRA are villagers, farmers and common people. They are the beneficiaries and promoters of any developmental works in the watershed. The principle of PRA is based on listening and progressive learning. So it is the technique of immediate analysis and survey of village resources. For the successful completion of the watershed project, a project implementation agency (PIA) is formed. This PIA and the community should act as a unified team to handle all areas. Both PRA and PIA can offer lots of benefits to different sections of the community. Various tools and techniques have been brought under PRA. Some of the important tools are social and resource mapping, soil and hydrology mapping, essential data collection in the tabular form, ranking matrix, historical timeline, seasonal analysis, transect or group walk, Venn diagram to show an approximate idea about the existing infrastructures, indigenous technical knowledge (ITK), women's participation in watershed project and participation of NGOs.

Keywords: Rapid rural appraisal, Participatory rural appraisal, Self help groups, Indigenous technical knowledge, Non-govermental organizations.

Lesson 26 Case Studies in People's Participation in Watershed Management

26.1 People's Participation Case Study within India

The regeneration of Jhabua- a poor tribal district of Madhya Pradesh, situated on the border with Gujarat- is an outstanding effort by a state government to involve the people on a large-scale in integrated land and water management, probably the first of its kind in India. The state-wide programme was initiated in 1998 by Digvijay Singh, the then Chief Minister of Madhya Pradesh, after he was inspired by the work of social activist Anna Hazare in his village Ralegan Siddhi in Maharashtra.

In 1985, Jhabua was just a moonscape. Thirteen years later, the land was being nursed back to life with care. The programme, entitled the Rajiv Gandhi Mission for Watershed Development (RGMWD), started in 1994. Already, satellite imagery was showing changes in the number of water bodies and the extent of the green cover. Trees were beginning to grow and there was grass. Dug wells had water and were often overflowing. All these were in a place that was chronically drought-prone in the 1980s. It was the result of political will combined with eager participation of local communities.

Jhabua down the Ages

Jhabua is an upland region of western Madhya Pradesh. Once a heavily forested area, Jhabua lost its natural wealth over the last 45-50 years. Almost 80 per cent of its forest is severely degraded. Of this, more than 30 per cent of forest land was without any tree cover. The reasons are many and range from government-aided plunders by contractors to clearing up for agricultural activities and population pressure.

As the uplands were used for cultivation without terracing, the humus and fertile layer of soil was lost and soil erosion accelerated. Free grazing further affected the vegetative cover of the land. The district was dotted with rock-exposed hillocks. The intensive cultivation on uplands led to an ecological disaster, resulting in loss of land productivity, decline in employment opportunities, and distress outmigration of people.

Jhabua's topography is undulating. There is rapid runoff in the district, which has an annual average rainfall of 830 mm. As such, post-monsoon water was almost non-existent. Moreover, there is wide variation in annual rainfall from year to year. This had resulted in extensive hill, gully and ravine soil erosion.

Both Jhabua and its adjoining areas in Dhar district were, thus, on the threshold of an ecological disaster, which spelt doom for the populace. The impact was greater on the tribal people as 83 per cent of the district's populations were tribals, mostly Bhils, whose survival was closely linked to forests.

During 1966-68, Jhabua witnessed its first famine since independence. There was another severe drought in 1985 when Jhabua recorded only 308 mm of annual rainfall, the lowest since 1911. It also witnessed the first food riots after the 1947 Indian Independence. Migration out of Jhabua for jobs continued into the 1990s, ranging between 57-66 per cent. In almost all landholding categories, except large farmers, more than one-third of the household was migrating.

Rescue Mission

The situation changed in the mid-1990s, when the Madhya Pradesh government launched the RGMWD programme, in October 1994. A decentralized and time-bound mission, it started with the objective of improving 1.2 million hectares (mha) of the land stretched over several watersheds, by the year 2000, with each watershed project finishing within four years. It envisaged greening more than 2.9 mha — approximately one per cent of the country's total land area — spanning 6,691 villages, through 5,024 watersheds [see Table 26.1].

Table 26.1. Mission Extensive (Source: Mahapatra, 2001)

No. of villages (i.e., vill.s) in undivided Madhya Pradesh under the Rajiv Gandhi Mission for Watershed Development

	1996-97			**1997-98**			**1998-99**			**1999-2000**		
	EAS	**DPAP**	**Tot.**	**EAS**	**DPAP**	**Tot.**	**EAS**	**DPAP**	**Tot.**	**EAS**	**DPAP**	**Tot.**
Dist.s	42	25	NA	45	25	NA	61	25	61	61	31	61
Blocks	354	134	NA	419	134	NA	459	134	459	459	134	459
mWSs	488	165	653	585	165	750	624	173	797	624	173	797
µWSs	3,220	1,151	4,371	3,863	1,176	5,039	4,461	1,253	5,714	4,461	1,253	5,714
Vill.s	4,817	1,874	6,691	5,864	1,963	7,827	6,182	2,016	8,198	6,182	2,016	8,198

Note: EAS: Employment Assurance Scheme; DPAP: Drought-Prone Area Programme; mWS: Milli-watershed [5,000 to 10,000 ha.]; µWS: Micro-watershed [500 to 1,000 ha.]

1. Total Blocks & Districts covered under EAS and DPAP could not be ascertained as in some places the programmes were overlapping.

2. The figures for 1997-98 were upto Nov. 1998, since the Govt. changed the documentation process at that time.

By 2001, Jhabua had become a model district in watershed management. The mission had broken all rules. The people, instead of bureaucrats, were the decision-makers. The mission, introduced in the undivided state's 61 districts, had also transformed the local economy. Approximately 14 million human-days of employment were created in Jhabua alone. Some 218 micro-waiersheds covered 124,000 hectares (ha) at an estimated cost of Rs 44.47 crore.

The mission's guidelines, keeping in view its objectives, for selecting a watershed were:

- Acute shortage of drinking water;
- Soil erosion and poor water resources, causing a decrease in agricultural and biomass productivity;
- Preponderance of wastelands;
- Extensive land degradation;
- Large population of Scheduled Castes and Scheduled Tribes dependent on watershed resources;
- Actual wages lower than minimum wages; and,
- A watershed that is contiguous to an earlier developed watershed.

Making All the Difference

What was different in this programme was the mode of implementation [see Table 26.2:]. In the 1ast 50 years, most programmes and schemes meant for the people had not included them. When the end-users were involved, the system simply did not work. In this watershed mission, attempts were made to put all the responsibility on the people, with the government working only as a facilitator it was time for the villagers to take over. Other factors that contributed to the success of the programme included coordination of the programme at all levels, financial systems that reached out to the people, and the integration of forest management into land and water management.

Table 26.2. Changing Times (Source: Mahapatra, 2001)

Conceptual change in watershed management

Lacunae in previous watershed management programmes	How Rajiv Gandhi Mission for Watershed Development (RGMWD) tried to mend them
Projects were implemented in an isolated and segmental manner by different departments.	All watershed activities were put under RGMWD for a coordinated approach.

Relief operations were ad hoc and did not include soil & water conservation (S&WC) –the region's most important problem.	All employment generating schemes focus on S&WC and seek to make them sustainable.
There were no proper guidelines for implementing agencies on watershed design and planning.	RGMWD decides the plans, designs with an area-specific approach and gives priority for indigenous knowledge.
People were not consulted for their own needs and to determine what suits their land the most.	People are the focal point of solving problems.

Putting People First

The first and most important aim of the mission was to make the programme a totally people-oriented one. The people were involved in the concept, planning, implementation and maintenance of land and water conservation activities in their watershed areas.

For instance, the villagers play an active role in managing the funds provided for the watershed programme. Nearly 80 per cent of the funds for the programme were put in a bank account managed by watershed development committees made up of village people.

The mission experimented by greening the anti-poverty programmes, to regenerate the lost environment and also create jobs. It had its leadership in R Gopalakrishnan, a bureaucrat, who was the then coordinator of the Rajiv Gandhi Missions of the Madhya Pradesh government. His experience in Jhabua in the drought-stricken mid-1980s inspired him to look for a green anti-poverty system. In the late 1980s, he had read *Towards Green Villages: A Strategy for Environmentally- Sound and Participatory Rural Development*, a study prepared by the Centre for Science and Environment. The study had argued that the large investments that the country was making under rural employment programmes could greatly benefit the poor and improve the local economy if it was directed towards ecological regeneration activities under people's control.

All watershed activities under various departments were pulled into one body in a major effort to convert community demand into action entailed:

- Establishing multi-disciplinary coordinating structures at watershed, district and state levels to act as facilitators for community organizations;
- Capacity building, planning and implementation and promoting community action processes;
- Making rural people, the actors in the programme from planning and implementation to maintenance, monitoring and management for which necessary community institution at the village level were evolved;

- Harnessing all available techno-scientific resources to support the decision-making process of the people;
- Developing a 'cascade' approach to the idea of land and water conservation, whereby it was seen as a completely integrated group of soil conservation & water impounding structures, each drawing upon and adding to the other; and,
- Involving people's representatives and members of Panchayati Raj (i.e., local self-government) institutions.

Coordination at Various Levels

The institutional complexity of the programme was extraordinary. The programme created several tiers of institutions to promote a people's movement for watershed management at the state, district and village level ¾ at the state level, for policy coordination; at district and mille-watershed level, for implementation and co-ordination; and, at the village level, to ensure that all villagers acquire an interest in the effort. These institutions helped deal with the lack of inter-departmental co-ordination and intra-village community tensions that mark all watershed programmes. Significantly, not one new bureaucrat was recruited or a new department created.

With the then Chief Minister's secretary as the coordinator of the mission, RGMWD was given high executive status. This was indicative of the state government's will in the mission, and was also a clever move to make all officials accountable to the Chief Minister's Office.

At the district level, the collector was the mission leader, which again put all the officials under the highest authority at the local level. So the mission had introduced a single-command system from the top, while giving flexible powers to the commanding authority at the operational level. It was the political will at the highest level that has made possible a single-command structure at the government level, thus skirting bureaucratic turf battles before bestowing power on the people. Serious efforts were made to give local communities powers of decision-making and control over resources.

Integration with Joint Forest Management (JFM)

Combining the principles of joint forest management (JFM) and watershed treatment was a new approach that was adopted in Jhabua. The JFM-watershed treatment started in 1994, with the formation of 20 village forest committees, the executive body under JFM that was mandated to protect forests with the help of the forest department. An intensive JFM awareness programme was initiated in villages.

With the adoption of the JFM-watershed treatment combination, tree felling had reduced drastically. In 1992-93, 1,412 tribals were arrested for tree-felling. In 1994-95, it came down to 676 and, according to forest officials, it had declined even further. People believed that forest degradation is the root cause of their misery. While JFM had protected the forest, the watershed programme made land fertile and helped recharge groundwater. In November 1997, 22 *gram panchayats* (i.e., village governments) handed over 4,000 ha of village land to be declared as forest area for afforestation.

Of Jhabua's total forest area, 60 per cent (i.e., 100,950 ha) was brought under JFM by the year 2000 and the 344 village forest committees covered 420 villages. The committees had 72,656 members, of which 43,953 were males and 29,703 were females. Ironically, more villagers were guarding the forests than forest guards - one forest guard and two villagers for every 1,000 ha.

Financial Arrangements

Rajiv Gandhi Mission for Watershed Development (RGMWD) was funded by both the state and the Central Government. According to Central government guidelines, all funds under the drought-prone area programme (DPAP), funded by both the state and Central government, and the Integrated Watershed Development Programme (IWDP), funded entirely by the Central government, were to be spent on watershed treatment. Similarly, 50 per cent of the funds from the employment assurance scheme (EAS) were earmarked for it, apart from sectoral funds at the district level, and Jawahar Rozgar Yojana (JRY) funds at the *panchayat* level [see Table 26.3: Financing the Future].

Table 26.3. Financing the Future (Source: Mahapatra, 2001)

Source of money received by the district government for watershed development

Employment Assurance Scheme		**Drought-Prone Area Prog.**		**Integr. Watershed Dev. Prog.**	
Central Govt.	State Govt.	Central Govt.	State Govt.	Central Govt.	State Govt.
80 %	20 %	50 %	50 %	100 %	0 %

According to the guidelines for watershed committees prepared by RGMWD, once watershed plan prepared by the watershed committee was sanctioned, the District Rural Development Authority (DRDA) would release 75 % of the total money to the committee. The rest is kept for administrative expenses of the project's implementing agencies (PIA). The money was transferred into the account of the watershed committee and its secretary was the statutory operator. Every fortnight, the watershed committee would meet to take decisions about various watershed activities, with the consent of other villagers, who were also invited to the meetings. The committee would report on the progress of the activities to the PIA at the watershed level which in turn would report it to the mission leader at the district level. Expenses incurred on the activities were put before the gramsabha [i.e., village body] for its scrutiny.

The watershed committee maintained two accounts viz., the project account and the development fund account. The first was meant for the money released by DRDA, and it would provide the daily expenditure of the project. The second was a fixed deposit account, for which 10 per cent of the total project cost was set aside. This was for post-project maintenance of all assets created during the implementation of the project. When villagers volunteer labour, a part of the respective wage was also kept in this account.

Both the Central and state governments would send their share of the money to the *zilla parishad* (i.e., district council). The *zilla parishad* then would disburse the money in the following way for a standard project period of four years:

- 0.2 % was kept by the *zilla parishad* for its own administrative expenses and for training of PIAs;
- 20 per cent was given to PIAs (five per cent for training of watershed development committees, users' groups, etc.; five per cent for community organization; five per cent for entry point activities; and, five per cent for administrative expenses of PIAs) and,
- 79.8 per cent was given to watershed development committees (WDCs), of which 75 per cent was for watershed treatment works and 4.8 per cent was for administrative expenses of WDCs with which they could engage a full-time secretary and two paid volunteers. In Jhabua, the total expenditure till mid-1998 was Rs 16.48 crore, which means a total expenditure of just Rs 1,104 per hectare. Of the Rs 16.48 crore, Rs 4.53 crore (about 30 per cent) was spent by the project implementing agencies. A substantial amount of Rs 4.53 crore - about 60 per cent was spent on what is called entry point activity, i.e., activities that help to build up the credibility of the government, community organization and on training and capacity building, all of which was necessary for good institution building and social mobilization at the village level. About Rs 11.95 crore was handled by the village watershed development committees, and went as direct investment into the watershed development work, a large part of which was spent as wages for the employment generated (see Fig. 26.2: Investment to prosperity – a ground reality).

Saving Schemes

The programme encouraged villagers to save a part of their wages as a Watershed Development Fund (WDF), for future use for the management of the watershed. This was a mandatory fund developed through 5 per cent contribution of the cost of all works on community land by all users, 10 per cent contribution of the cost of all works on private lands owned by non-Scheduled Caste and non-Scheduled Tribe villagers, and 5 per cent contribution of the cost of all works on private lands owned by Scheduled Caste and Scheduled Tribe villagers.

WDF was thus a fund that was developed from contributions from all members of all user groups of landowning people). Self-help groups (that is, groups of landless people) were not expected to contribute to this fund. WDF was to be used for the repair and maintenance of the soil and water conservation structures created under the programme after the project came to an end in four years. The fund was entirely controlled by the community and neither the *panchayat* nor the officials of the rural development department had any control over it. Withdrawals from the fund were jointly signed by the chairperson of the village watershed committee and a representative of the *panchayat*.

Savings were also encouraged through a *gram kosh* (i.e., village fund) for use by the village for collective activities as per the wishes of the community, and *bairani kuldis* (i.e., women's thrift and credit groups), which women can use to help each other with soft loans. All WDFs of Jhabua together had Rs 0.48 crore (some 35 per cent of the total expenditure on the programme), all village funds together had Rs 0.42 crore (about 3 per cent of the total) and all *bairani kuldis,* with 17,297 members, had a total deposit of about Rs 2.44 crore (about Rs 1,400 per member or about 18 per cent of the total expenditure). In other words, the programme had not just resulted in an improvement of the local ecology, but also in an improvement of the collective and individual financial security of the local villagers.

Economic Gains from Ecological Wealth

Watershed development in Jhabua had greened the environment and improved the economic status of the people. Dramatic changes were seen in water availability, afforestation, agricultural production, food security, and fodder availability and migration rates. It had also empowered women.

Water Availability

The foundation of any watershed programme is water and soil conservation. In the case of Jhabua it meant arresting the water that would fall on the hill slopes instead of allowing it to carry away the precious topsoil. The water is collected in a way that it percolates into the land and recharges the groundwater. Wherever necessary, small tanks were made. Some 143 new tanks were built and the water table had risen by 0.64 m on an average in 19 micro-watersheds [see Fig. 26.1]. The irrigated area increased to 1,115 ha in 18 micro-watersheds studied, which was nearly double the irrigated area of 1994-95.

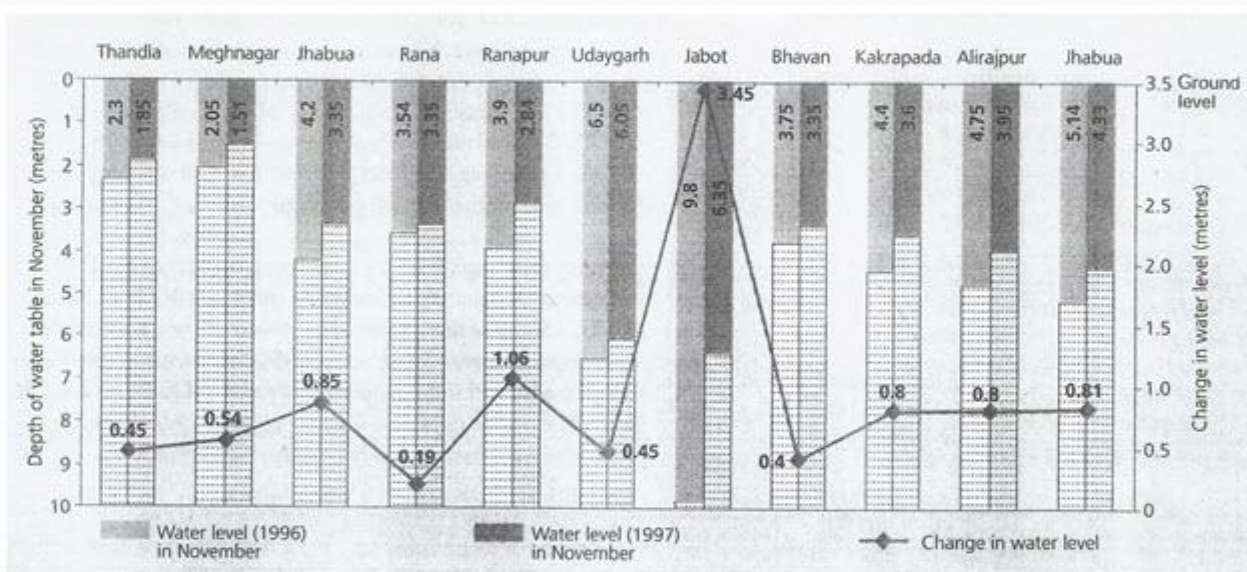


Fig. 26.1. Water Table Rise in Jhabua Dist., Madhya Pradesh. (Source: Mahapatra, 2001)

Afforestation

The protection of land in the watershed and planting of various species of benefit to the local people (like *bamboo, amla* and *neem)* had shown a 66 per cent reduction in wasteland area in 11 micro-watersheds. District officials estimated that over two million trees were regenerated. The regeneration rate was far more rapid as compared to lands where only joint forest management (JFM) programmes were implemented because the water conservation efforts increase soil moisture and, therefore, plant growth. In turn, there was a more rapid increase in economic return to the poor people involved in watershed management.

Agricultural Production

With increased irrigation, agricultural productivity was rising. In seven micro-watersheds studied, the cropped area had increased by seven per cent and the cropping intensity of the cultivated land was also rising. The *rabi* (winter crop) area had increased.

Food Security

Food availability had increased by one to about four months. Some 313 village-level grain banks were established to ensure timely availability of food grains on easy credit.

Fodder Availability

Possibly, the earliest benefit had come from rapid regeneration of grass and thus it increased fodder availability. Some estimates suggested a 5-6 times increase in grass from the regenerated lands. This change could be seen with the data from the Hathipahwa watershed, where work started in 1995-96. The watershed covered 231.26 ha area in Ambakhoda and Badkua villages. It covered village agricultural land, government forest land and government revenue land. Before the work started, the land had no vegetation. The six tanks in the watershed would rarely fill up. Villagers had to buy grass from markets in neighboring Gujarat. There was a regular seasonal stream of distress migration. But by the year 2000, with watershed management and stall-feeding of cattle, the people of the watershed could sell grass every year and seasonal migration had almost disappeared. The change had come in just three years simply from the economic benefits due to increased grass production. Apart from earning money from selling grass, villagers had started keeping better breeds. Villagers had got 14 high quality cows and buffaloes by the year 2000. Increased water availability had increased vegetable productions which are sold in the local market.

Money Lending and Migration

The watershed development programme was already having a substantial social impact. Dependence on local moneylenders had gone down. A study of select micro-watersheds revealed that loans from moneylenders had gone down by 22 per cent. Distress migration has reduced considerably.

Looking Ahead

Some of the main issues that arose in the context of Jhalbua's success were:

- What would happen after the government withdraws the Mission along with its funding?
- What about power conflicts among bureaucrats of government departments/ programmes and elected representatives?
- What would happen when the forest grows enough to affect grass production?
- Is Jhabua replicable?
- Does watershed development stand the test of drought?

One of the main concerns was what would happen after the mission withdraws and the community takes over the job of maintaining the watersheds. Past experience had shown that many successful programmes had failed once they were totally entrusted to the people, because of inherent flaws in making them sustainable. Will the past repeat itself in Jhabua? Once the officials and the PIAs withdraw, the age-old problem of linkage between government and people would likely to crop up.By the year 2000, people would seek the Project Implementation Authority (PIA) officials' help for sanctioning money or checking technicalities. As many as 17 account books were to be maintained in a single watershed unit by the local people, most of whom were illiterate. It would not be practical to maintain so many account books. However till the year 2000, the government had ensured that the success would continue. Grassroot organizations that were non-political and thus had credibility among the villagers were formed. These would serve as pillars of watershed activities. When the government was planning a national programme on watersheds, this institution building was given priority and as Madhya Pradesh has shown, the institutions had proved to be effective.

The *panchayat* (i.e., local government) institutions were facing parallel power centres. To avoid conflict, district authorities had made many *gram panchayat* (i.e., village government body) members as watershed committee secretaries. However, the usual conflict between the two power centres would be expected there regarding the ownership.

As fodder had been given importance as an economic and area-specific need, doubts arose about what would happen when the forest grows enough to affect grass production and whether this would not affect the cattle. Officials said it would not because, with the availability of fodder the people would prefer more productive cattle than many non-yielding animals. It would bring down the demand for fodder and compensate for the decline in grass production.

The 1999 monsoon failure was a good testing ground to evaluate watershed programmes in the face of drought. Jhabua proved that good watershed programmes can withstand monsoon failures.

The people involved in making Jhabua a success were confident that this programme would be sustainable. This confidence stemmed from the fact that the mission had made sure that the institution of the watershed committee and other supplementary organizations such as women's banks became new power centres for people at the lowest level. Once people saw the benefits, it would be very hard to see the programme failing.

By the year 2001, Jhabua towered over other efforts and it was up to the people if they want to continue to reap benefits of good land and water management. And it was up to other states, if they want to follow the example of Madhya Pradesh.

26.2 People's Participation Case Study outside India

Redeeming Negev's Heritage in Israel

The Negev desert in Israel was uncultivated for 1,300 years from the 7th century AD onwards, until Israeli scientists reconstructed the ancient agricultural farms during the 1950's harvesting the area's meagre annual average rainfall of 100 mm. Trees and plants that used to be raised in the Negev in the past were once again raised successfully.

The Negev is situated in the south of the country and covers an area of 1.25 Mha. Summers are hot and dry, extending over 7-8 months from March to October, while the winters are cool. Rainfall is sporadic and irregular, varying from 25 mm in a drought year to over 200 mm in a good year.

The Negev was densely settled by the Israelites under Solomon and the Judean kings in 1000 BC, marking the beginning of a period when desert agriculture flourished. It came to an end in the 6th century BC. The Negev was deserted until the 3rd century BC when the semi-nomadic Nabateans came from southern Arabia and settled there. They brought merchandise from India, Greece, Rome and built fortresses and cities at Avdat, Shivta and other places in the Negev to protect their trade routes. They practised agriculture around these cities to supply food to passing caravans, reusing the remains of old Israelite farms. In 106 AD, the Romans occupied the Nabatean empire, but agriculture in Negev continued to flourish.

Maximizing Meager Resources

Farmers in ancient times used a technique called runoff farming which made it possible for them to cultivate the desert with only 100 mm of rainfall. The soil of the Negev has the property of clogging and forming a thin crust on the surface as soon as it gets wet, turning impermeable to water almost immediately. As a result, the initial infiltration rate of 17-18 mm/h soon drops to 2-3 mm/h. When the precipitation is more than 3 mm/h, the excess water flows over the soil surface as runoff, which is then used for irrigating the crops.

The intensity of rain is more important than the amount of rain to create a runoff. A cultivated plot needs a catchment area 20-30 times its own size to get enough runoff for growing one crop. For example, consider the annual rainfall to be 100 mm and the catch ment is 20 times larger than the cultivated plot. If 75 per cent rainfall is lost due to infiltration and evaporation and only 25 per cent runoff is actually generated, then the plot receives 20 x 25 = 500 mm of runoff, in addition to 100 mm of direct rain. This quantity of water is enough for one cropping season.

Depending upon prevailing conditions, three different water harvesting systems were constructed on dry river beds known as *wadis.* In its simplest form, the *wadi* was divided into a series of terraces by building horizontal stone walls across it. These terraces retained part of the flood water and the excess amount flowed into successive fields below [see Fig. 26.2].

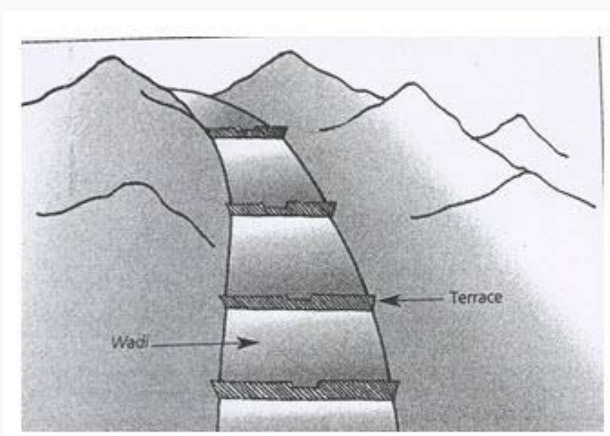


Fig. 26.2. Terraces for Harvesting in Negev Desert, Israel. (Source: Gogte, 2001)

In the second system, where terraces were unable to withstand the strong river currents, diversion dams were built across the river bed to raise the water level high enough to enter adjoining channels, leading to terraced fields built on adjacent floodplains.

The third and the most common method of rainwater harvesting was the conduit channel system, linking a group of terraced, cultivated fields to their catchment areas located on the slopes of surrounding hills. The terraced fields were normally located on the beds of small tributaries, dispersions or floodplains. The slopes had channels which ran diagonally along the hillsides and emptied the runoff into the fields [see F ig. 26.3].

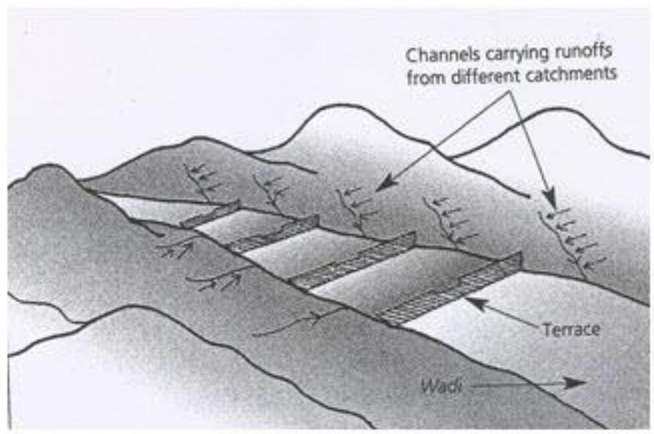


Fig. 26.3. Channel Networks and Terraces in Negev Desert, Israel.

(Source: Gogte, 2001)

Terrace walls were 300-500 mm high and built with 2-3 rows of stones. The distance of one wall from another was about 15 m, which also defined the size of the terrace. The stone walls had spillways to carry excess water downstream. The spillways had stone staircases which led the water to the lower terraces without causing erosion.

The depth of soil in the fields was 2-3 m. When the fields were flooded, water stood at 300 mm over the surface and then infiltrated into the soil within 2-3 days. Experiments have shown that 1mm of water is able to wet up to 8-10 mm depth of soil. Thus, a 300 mm of water column would suffice to saturate 2-3 m of soil in terraced fields which is sufficient to grow crops.

Traces of the old agricultural practices can still be seen in the Negev. The hills here were covered with stones and prevented the formation of a complete crust when it rained. Besides, the stones retained some water which then infiltrated into the soil. These stones were deliberately collected together to either strengthen the channels or heap them into mounds which are still visible in some areas. This also helped to increase the runoff once the catchment area was cleared of stones.

Inhabitants of the Negev built several cisterns to store drinking water for themselves and their livestock. One or more channels from the neighbouring hills would lead the runoff water into each cistern. Before entering a cistern the channels would open into a basin which collected part of the silt and dirt carried by the water. The cisterns were covered to protect them from pollution and evaporation. These cisterns are still recognizable in the desert, identified by the high mounds with loose white silt along their sides that give evidence of past cleaning operations of the cisterns.

Restoring a Shattered Visage

Israeli scientists, led by Michael Evenari, botanist and desert ecologist at the Hebrew University in Jerusalem, reconstructed two ancient farms at Shivta and Avdat in 1960, to understand the ancient systems of agriculture and how these could be adapted to suit present needs.

The farm at Shivta was reconstructed using the layout and water distribution system of the original Nabatean farm . Only those trees were planted which were grown by farmers in ancient times, as mentioned in the documents dated between 7th century AD and 8th century AD. These included almonds, pistachios, figs, grapes, carobs, apricots, peaches and plums.

Avdat, on the other hand, was an experimental farm with the objective of testing new crops, increasing yield and widening the application of runoff farming. As the water entering the fields was to be accurately measured and controlled, a modern floodwater distribution system was superimposed over the ancient system. In Avdat, trees were selected on the basis of their resistance to drought. Besides the trees grown at Shivta, cherries, apples and loganberries were also cultivated. The trees grown in the 7th and 8th centuries in the area fared better. The field crops that were tested in Avdat included wheat, barley, peas for seed production, sunflower and onion bulbs. Among the fodder plants, best results were obtained from alfalfa *(Medicago sativa),* Harding grass *(Phalaris tuberosa)* and Smilo grass *(Oryzopsis miliacea).* The perennial salt bush *(Atriplex halimus)* was also found to be well suited to runoff farming.

Small is Better

During the experiments at Avdat, it was discovered that smaller the catchment area, larger would be the runoff collected per m^2 of catchment area. During one of the floods, measurements showed that a catchment of 340 ha produced 1,238 m^3 of runoff or 3.6 m^3/ha, whereas a 3ha catchment produced 156 m^3 of runoff or 52 m^3/ ha.

This is because in a large area where the runoff has to travel over long distances, more water was lost due to depressions, stones and other irregularities, resulting in increased infiltration and evaporation losses. This gave the scientists the idea that each tree or bush could have its own independent catchment called micro-catchment [see Fig. 26.4].

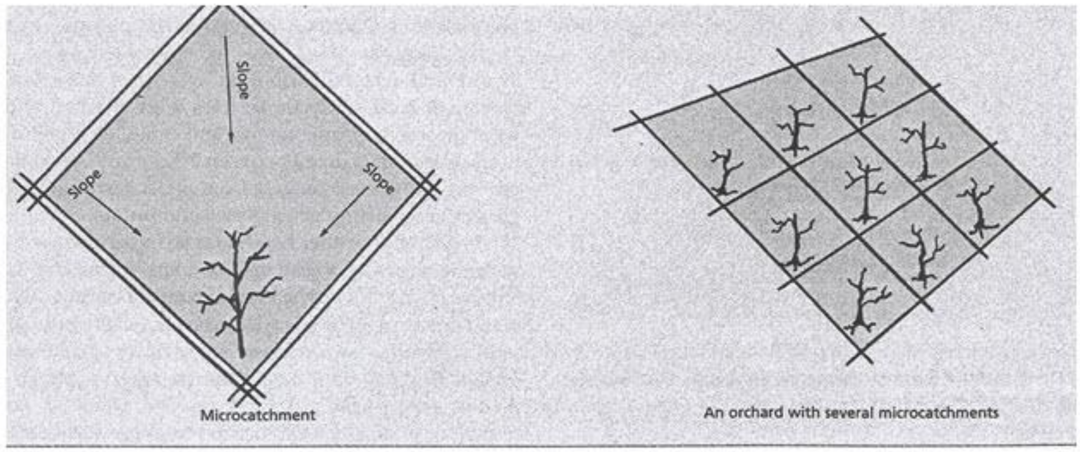


Fig. 26.4. Micro-catchments developed for macro-yields in Negev Desert, Israel. (Source: Gogte, 2001)

Micro-catchments between 15.6-1,000 m² in size were constructed with an earthen border 200 mm in height. A square basin was dug at the lowermost point to collect the runoff from the micro-catchment where a tree or a bush was planted. The basin had to be dug up after every flood for aeration. The optimal microcatchment size [in m²] for fruit trees, grape vines and salt bush was 250, 62 and 32 respectively.

Micro-catchments offer many advantages. Being small in size, they do not suffer from water loss due to evaporation and uncontrolled percolation that larger catchments witness. The amount of water collected in micro-catchments can account for up to 62 per cent of the total rainfall. Even low intensity rains generate runoff in micro-catchments and while large catchments have only one runoff, these can generate up to eight runoffs. The cost of installing and maintaining a micro-catchment is also very low as no channels, terraces or stone fences are required. Even flat areas can have micro-catchments. These can also help to bring saline soil under cultivation, as runoffs are large enough to leach the soil in 1 to 2 years. Though the micro-catchment technique was developed independently in Israel, it was a surprise for Israeli scientists to discover later that farmers in southern Tunisia were traditionally growing olives in micro catchments, a technique probably introduced there by Phoenicians who had built the Carthage in 814 BC.

Keywords: Milli-watersheds, Micro-watersheds, Joint forest management, Ecological wealth, Migration from rural areas.

Module 14: Monitoring & Evaluation of Watershed Programs

Lesson 27 Monitoring of Watershed Programs

27.1 Background to Watershed Program Monitoring

Monitoring is an important component for planning, implementation and completion of an integrated watershed development project. Monitoring is inherently related to project activities. It is a diagnostic study that helps in decision-making and policy changes of the ongoing project. Both monitoring and evaluation of a project are important for funding authorities of the project.

Monitoring is a process of continuous assessment of project activities in the context of implementing schedules. Monitoring takes care of day-to-day progress and management of the project. It is the regular observation and recording of activities taking place in the watershed project and also a process of routinely gathering information or data on all aspects of the project. Monitoring involves checking on how the project activities are progressing. It also involves giving feedback about the progress of the project to the donors/sponsors and beneficiaries of the project. The gathered data are used in making decisions for improving project performance.

Watershed development committee (WDC), Project implementation agency (PIA) and District rural development agency (DRDA) have special monitoring tools, system and tables for recording the monitored data. Thus, monitoring setup involves defining the objectives · of monitoring system to design a program to systematically look after the achievements, to select the indicators, location, ·metho.ds and frequency of observation and to organize, motivate and train people.

Evaluation gathers information .from the observed data on monitoring .and these are presented in a form which is easy to understand. Evaluation may require some additional studies to obtain data which are available for monitoring. Different investigators have worked on monitoring and evaluation of the watershed project.

Purpose of Monitoring

The purposes of monitoring watershed programs are as follows:

1. To carry out the analysis of the situation in the village community and the project and to determine whether the inputs in the project are well utilized.

2. To study the problems faced by the community in carrying out the project are identified to find a solution. And thereby it ensures that all activities are carried out properly by the right people and in time.

3. To determine whether project plan is suitable for solving the problem at hand.

Monitoring Tools

Numerous monitoring tools are available to determine the values of indicators over time. Some of the commonly used tools are as follows:

(a) Community workshops are arranged to evaluate the extent of performance and achievement.

(b) Farmers can record their simple and easily observable changes in their farms in logbooks. These records produce information in detail.

(c) Community may evaluate some technical indicators such as sediment yield, fodder productivity, change in quality of the living standard, crop productivity, inv9lvement of self-help groups (SHGs) or user groups (UGs) etc.

(d) Geographical information system (GIS) is another monitoring tool which can provide lot of information

(e) Field indicators such as soil denudation, advance or reduction in gullies, land use

- Pattern and changes, channel scouring etc. are observed and measured.

(f) Remote sensing satellite imaginaries and aerial photographs are to be taken at the beginning of the project and it should be repeated periodically

(g) Video monitoring

(h) Hydro-meteorological data measurements

(i) Watershed modeling

27.2 Scheduled and Unscheduled Monitoring of Watershed Programs

As part of developing the watershed plan, one should develop a monitoring component to track and evaluate the effectiveness of the implementation efforts using the criteria developed in the previous section.

This phase of the watershed planning process should result in element *i* of the nine elements for awarding grants. Element *i* is *"A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established to determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards."*

Monitoring programs can be designed to track progress in meeting load reduction goals and attaining water quality standards, but there are significant challenges to overcome. Clear communication between program and monitoring managers is important to specify monitoring objectives that, if achieved, will provide the data necessary to satisfy all relevant management objectives. The selection of monitoring designs, sites, parameters, and sampling frequencies should be driven by the agreed-upon monitoring objectives, although some compromises are usually necessary because of factors like site accessibility, sample preservation concerns, staffing, logistics, and costs. If compromises are made because of constraints, it's important to determine whether the monitoring objectives will still be met with the modified plan. There is always some uncertainty in monitoring efforts, but to knowingly implement a monitoring plan that is fairly certain to fail is a complete waste of time, effort, and resources. Because statistical analysis is usually critical to the interpretation of monitoring results, it's usually wise to consult a statistician during the design of a monitoring program.

Measurable progress is critical to ensuring continued support of watershed projects, and progress is best demonstrated with the use of monitoring data that accurately reflect water quality conditions relevant to the identified problems. All too frequently watershed managers rely on modeling projections or other indirect measures of success (e.g., implementation of management measures) to document achievement, and in some cases this approach can result in a backlash later when monitoring data show that actual progress does not match the projections based on surrogate information.

There is no doubt that good monitoring can be complex and expensive. Monitoring can be done at numerous levels; the most important criterion is that the monitoring component should be designed in concert with your objectives. If documenting the performance of particular manage practices under seasonal conditions is important, a detailed and intensive water quality monitoring regime might be included. If your objective is to restore Swimming at a beach previously closed, you might monitor progress by keeping track of the number of days the beach is open or the number of swimmers visiting the beach. If restoration of life in a stream is the objective, annual sampling of benthic invertebrates and fish might be included, or a count of anglers and a creel census could be useful. If another agency is already conducting monitoring (e.g., making annual measurements of phosphorus load or regulating shellfish beds based on bacteria counts), you might be able to use such ongoing monitoring to track your project's progress. Regardless of the specific objective, keep in mind that documental measures your water quality goals are important.

Because of natural variability, one of the challenges in water quality monitoring is to be able to demonstrate a link between the implementation of management measures and water quality improvements. To facilitate being able to make this connection, the following elements should be considered when developing a monitoring program.

The monitoring component, which will be used to assess the effectiveness of implementation strategies, can also be used to address other important information needs in the watershed with minimal changes or additional resources. We should consider a range of objectives like the following when developing your monitoring program:

- Analyze long-term trends.
- Document changes in management and pollutant source activities in the watershed.
- Measure performance of specific management practices or implementation sites.
- Calibrate or validate models.
- Fill data gaps in watershed characterization.

- Track compliance and enforcement in point sources.
- Provide data for educating and informing stakeholders.

When developing a monitoring design to meet our objectives, it is important to understand bow the monitoring data will be used. We need to ask ourselves the following questions:

- What questions are we trying to answer?
- What assessment techniques will be used?
- What statistical tools and precision are needed?
- Can we control for the effects of weather and other sources of variation?
- Will our monitoring design allow us to attribute changes in water quality to the implementation program?

The answers to these questions will help to determine the data quality objectives (DQOs),that are critical to ensuring that the right data are collected. These DQOs also take into consideration practical constraints like budget, time, personnel, and reporting requirements and capabilities. Parameters measured, sampling locations, sampling and analysis methods, and sample frequency are determined accordingly. It's helpful to know the degree of measurement variability you might encounter for a given parameter method and watershed. If variability in a parameter concentration or value is relatively high because of natural or methodological causes, it will be difficult to identify actual improvements over time. You might need to collect more samples, consider different methods, make more careful site selections, select different parameters or indicators, or use a combination of approaches.

Monitor Land Use Changes in Conjunction with Water Quality Monitoring

The monitoring component of the watershed plan should include not only water quality monitoring but also monitoring on the land, including the land treatments being implemented and the land use activities that contribute to nonpoint source loads. Land treatment tracking is important to determine whether the plan is being implemented appropriately and in a timely manner. At a minimum, we should track where and when practices were installed and became operational. But we should look beyond money spent or points on a map and consider how the measures are working. Structural practices like waste storage lagoons or sediment basins might be easy to see and count, but their associated management activities are more difficult to monitor. How have nitrogen and phosphorus applications changed under nutrient management? Are riparian buffers filtering sheet flow or is runoff channelized through the buffer area? Are contractors following erosion and sediment control plans?

Sometimes such questions can be answered only by asking the landowners. Some agricultural watershed projects have had success in asking farmers to keep records of tillage, manure and fertilizer application, harvest, and other management activities. Several projects used log books and regular interviews by local crop management consultants to gather such information. In urban settings, public works staff can be valuable sources of information. Aerial photography and windshield or foot surveys are also useful. We should remember to monitor not just where implementation is occurring but in all areas in the watershed that might contribute to nonpoint source loads.

A good land treatment/land use monitoring program will help us to:

- Know when and where measures are implemented and operational
- Determine whether measures are working as planned and how much they have accomplished
- Assess contributions of non-implementation areas to watershed nonpoint loads
- Prevent surprises

Surprises can derail the best watershed plan. An accidental release from a waste storage facility, a truck spill, land use changes, technology adoption, or the isolated actions of a single bad actor can have serious water quality consequences and, if the source is not documented, can cause you to question the effectiveness of your plan.

The result of a good land use/land treatment monitoring program is a database of independent variables that will help you explain changes in water quality down the road. The ability to attribute water quality changes to your implementation program or to other factors will be critical as you evaluate the effectiveness of the implementation effort and make midcourse plan corrections.

27.3 Post Monitoring Suggestions in Watershed Programs

Monitoring for Several Years before and after Implementation

To increase our chances of documenting water quality changes, we should conduct multiple years of monitoring both before and after implementing management measures. Year to year variability is often so large that at least 2 to 3 years each of pre- and post-management practice implementation monitoring might be necessary to document a significant water quality change following management practice implementation. Also, longer-duration monitoring might be necessary where water quality changes are likely to occur gradually. Sampling frequency and collection should be consistent across years.

Keywords: Watershed program monitoring, Water quality monitoring, Long term watershed monitoring, Land use change monitoring.

Lesson 28 Evaluation of Watershed Programs

28.1 Scope of Watershed Program Evaluation

Evaluation is an important aspect of watershed programs. It is a multi-dimensional task which is generally performed at different times during the implementation of watershed programs. Until recently watershed program evaluators tended to favor either a quantitative or a qualitative evaluation. Typically, quantitative evaluations reflect a simplistic view that reality takes a single form that can be perceived and measured objectively. On the other hand, qualitative evaluations reflect a more constructive view, implying that reality can have multiple versions.

There is a rising interest in mixing both the qualitative and quantitative methods of watershed program evaluation. This comes from the fact that purely quantitative and purely qualitative approaches to watershed program evaluation both have limitations. The strengths of each evaluation often compensates for the weaknesses of the other evaluation.

Quantitative Evaluation of Watershed Programs

The quantitative evaluation of watershed programs attempts to attribute changes in various outcome variables to a project intervention (i.e., 'treatment') and determine whether such effects are statistically significant. An experimental approach is often considered as an acceptable standard for quantitative evaluation of watershed programs. Yet, in many cases the results of such a study may not extrapolate beyond the watershed projects examined.

There are many situations wherein an experimental approach to quantitative watershed program evaluation may not be possible. In such situations, various approaches have been used, each with their own strengths and limitations.

The first approach is called a "before/after" study. The evaluator measures the levels of outcome indicators in a watershed area before and after a watershed treatment. This is a fairly weak but feasible approach that involves an unlikely assumption that there have been no other significant changes during the study period.

A second approach consisting of a "with/without" study, is useful when no baseline data are available. This is often the case when an evaluation is commissioned after a watershed project has been implemented.

Cost-benefit analysis has long been the method of choice in economic appraisal of agricultural development and irrigation projects. Cost-effectiveness analysis is similar but it estimates only the costs of alternate approaches of achieving a given objective. Cost-benefit analysis aims to evaluate costs and benefits that occur with a project and compare them to what would happen without the project. Even if all costs and benefits could be identified and valued, cost-benefit and cost-effectiveness analysis would give only a single assessment of overall project performance. However, watersheds consist of multiple users who are affected differently by the project. A favorable benefit-cost ratio could temporarily mask uneven distribution of benefits, yet those who do not benefit may be in a position to undermine the project.

Thus there are clearly multiple challenges associated with using quantitative evaluation methods for evaluation of watershed projects. Most challenges are introduced by the fact that watershed projects are not amenable to the same controlled conditions as in the experiments which provide the data for a simplistic analysis.

Qualitative Evaluation of Watershed Programs

In contrast to quantitative evaluation, qualitative evaluators typically place less emphasis on measurement and more on context and on understanding the subtle manifestations. In general, a qualitative approach tends to be flexibly structured and uses open-ended questions in an inductive fashion. The objective is not to obtain a numerical estimate of some phenomenon, but to develop an in-depth understanding of an issue by probing, clarifying, and listening to stakeholders talk about a topic in own words. The in-depth nature of the qualitative approach means that a study's scale is usually smaller than that found in quantitative research.

As with quantitative evaluation of watershed programs, sampling issues in qualitative evaluation also raise questions about biases in data. While quantitative researchers use random sampling whenever possible, qualitative researchers use several strategies to increase the internal validity of their findings. In qualitative evaluation, data collection and analysis become inseparable; as such researchers collect much of the data themselves, rather than relegating this task to field assistants.

Mixed Evaluation of Watershed Programs

Researchers use mixed evaluation of watershed programs for various reasons. Here, qualitative and quantitative components may be used either sequentially or in parallel or in an integrated fashion. When qualitative and quantitative components in a mixed evaluation are used in an integrated manner, the information and data collected from one activity is used for the other activities of the evaluation process also.

28.2 Indicators and Stages for Watershed Program Evaluation

Watershed program evaluation can be quantified in terms of certain indicators. These indicators are the measures of targets or goals of the watershed project implementation, which facilitate the expected positive change in the watershed projects. They also give an insight into and quantify the process of evaluation. The various indicators generally used for watershed program evaluation are discussed in the following sections:

i) Technical Indicators

Technical indicators in Watershed Program Evaluation include the extent of soil loss and runoff, amount of discharge in the stream and amount of sediments in flowing water at the outlet point, increase in the yield of wells and rise in water table, average annual water flow and flood peak, changes in soil moisture, concentration of suspended sediments, annual sediment yield, turbidity of water, biological and chemical properties of water, pH, annual reservoir sedimentation, pesticide concentration, etc.

ii) Common Property Resources (CPR) Use Indicators

Common property resources (CPR) use indicators are productivity of crop, fodder, fuel wood, pasture land, community forest land and milk. Further information to be collected are areas of managed agro-forestry, protected degraded forest land by social fencing, unprofitable cropland and grazing land, unused area with agro-forestry and areas of common property resources.

iii) Institutional Building and Community Organization Indicators

These indicators include the number of rural development institutions in the watershed and the coordination among them, financial independence of the institutions, their capacity building to solve managerial, administrative and financial problems, the number of trained professionals assigned to the project, the number of welfare and development programs performed by the institutions, the number of farmers trained in soil conservation and modern agriculture techniques, the percentage of population willing to adopt appropriate technology to improve crop, livestock, water harvesting, etc., and the performance of self-help groups, user groups and watershed development committees (WDCs).

iv) Ecological Improvement Indicators

Ecological improvement indicators include the biodiversity and biomass indices, severely eroded, overgrazed and over-utilized lands, wastelands, lands under shifting cultivation, stabilized slopes, areas of treated ·gullies, number and depth of gullies, soil fertility and organic matter content of soil.

v) Economic and Social Indicators

These indicators quantify the change in the living standards, .household savings, household expenditure and household income, number of families living above poverty line (APL) or below poverty line (BPL), extent of migration to urban areas in search of .employment and indebtedness in cash or kind, prevailing wage rate in agriculture and non-farm sectors, changes in crop production, double cropped areas, agricultural and non-agricultural land values, number of annual man days generated, number of working women and young people per year, time spent in fetching and collecting drinking water, annual request for technical assistance and skill up gradation of rural artisans.

vi) Essential Service Indicators

These indicators include the literary rate, number of schools in operation, percentage of school attending children and their age, number of primary school dropouts, percentage of houses having electricity connection and drinking water facilities, number of dispensaries in operation per year and the families receiving medical care, annual mortality, percentage of population of age group 0-16 years receiving immunization, couples protected under family planning, annual birth rate, number of annual sterilizations, length of motorable road added per year in kilometers, level of child malnutrition below 1 year age group and availability of essential commodities.

Stages of Watershed Program Evaluation

It is a common practice to carry out the watershed program evaluation in four stages with the help of the six indicators mentioned earlier. These four stages are discussed here:

i) Baseline Evaluation

This is the evaluation in the initial planning stage. The data on the indicators are used as benchmark for evaluation. A reliable baseline data on hydro-meteorological, economical, social, physical and biological parameters are provided for this evaluation.

ii) Mid-term Evaluation

This evaluation is done in the middle of the watershed program implementation. In this stage of evaluation, initial problems in the planning are overcome and the flow of inputs to the target population is commenced and their response can be observed. The purpose of such mid-term evaluation is to check on the effectiveness of each individual activity. This evaluation quantifies the short and mid-term benefits of the project.

iii) Terminal Evaluation

This evaluation is done at the end of the project economic life. It indicates the efficiency of project implementation, accuracy of the project estimates, etc.

iv) Post-Terminal Evaluation

This evaluation is carried out after 5 to 15 years of watershed program period. Long-term effects and impacts become visible in this post-terminal evaluation.

Impact of Evaluation on Watershed Management

The evaluation of watershed management during a normal year and a year under stress conditions is very difficult and complex. Developmental works in a year under stress decline significantly. Therefore, the aim of the watershed management should be to focus on utilization and harnessing of existing resources for the maximum production and benefits. One of the main thrusts of watershed management programs should be to minimize the differences in the benefits during a normal year and a year under stress, as far as possible.

Keywords: Watershed program evaluation, quantitative watershed program evaluation, qualitative watershed program evaluation, watershed evaluation indicators, watershed evaluation stages.

Module 15: Planning and Formulation of Project Proposal, Cost Benefit Analysis of Watershed Programmes

Lesson 29 Watershed Planning and Project Formulation

29.1 Scope of Watershed Planning

The watershed planning implies, the judicious use of all the watershed resources to achieve maximum benefit with minimum loss/hazard to the natural resources i.e. land, vegetation and water for the well being of people. The planning should be carried out on the individual watershed basis. The task of watershed planning includes the treatment of land by using most suitable biological and engineering measures in such a manner that, the work must be economical and socially acceptable.

29.2 Objective and Benefits of Watershed Planning

Objectives: The different probable objectives for watershed management planning may be cited as under:

- To control damaging runoff and degradation and thereby conservation of soil and water.
- To manage and utilize the runoff for useful purposes of watershed development concern.
- To protect, conserve and improve the land of watershed for more efficient and sustained production.
- To protect and enhance the water resources originating in the watershed.
- To check the soil erosion and reduce the effect of sediment yield on the watershed.
- To rehabilitate the deteriorating lands.
- To moderate the flood peaks at the downstream area.
- To establish watershed management practices and measures.
- To enhance the groundwater recharge, wherever applicable.
- To improve and increase the production of timbers, ranges, and wild life resources.
- To intensify agricultural extension activities.

Benefits: The benefits of watershed planning can be categorized in three aspects- environmental, social and financial.

1. Environmental Benefits:

- Improves quality of water for drinking and recreational use.
- Enhances water supply.
- Protects wildlife habitat and improves natural resources.
- Controls flooding by restoring riparian and wetland areas

2. Community/Societal Benefits:

- Directly involves community members in developing a vision for the future of the watershed.
- Provides opportunities to educate citizens on protecting and fixing the environment that do not conflict with current and future development.
- Gives citizens an active voice in protecting and restoring natural resources that are important to them.
- Provides opportunities to cooperate with neighboring communities.

3. Financial Benefits:

- Reduces costs for meeting regulations and fixing damage that would happen if sensitive areas are developed.
- Reduces costs for drinking water treatment.
- Improves availability of water for improving cropping intensity and thus the production.
- Provides a new organization through which to get grants to improve the environment.

29.3 Developing Steps of Watershed Planning

In order to achieve the different objectives selected for watershed planning, it is necessary to go through the distinct steps:

- Recognition of problems.
- Analysis to determine the causes of watershed problem.
- Development of alternative solutions for the objectives formulated to solve the problem.
- Selection of best solution.

- Application of selected solution.
- Protection and improvement of works, which have already been implemented.

The above steps can further be grouped in following four phases; i.e. recognition phase, restoration phase, protection phase and improvement phase.

1. Recognition Phase

Under this phase, the recognition of watershed problems, their probable causes and development of alternatives for them, are described, which is carried out by conducting several surveys such as:

a) Soil survey

b) Land capability survey

c) Agronomic survey

d) Forest lands under permanent vegetation survey

e) Engineering survey

f) Socio-economic survey

These surveys are made to ascertain the watershed's problems, qualitatively and quantitatively, to constitute a guide line for deciding the land treatment measures. Furthermore, the compilation of these surveys and collected information are analyzed to determine the nature of watershed's problem, causes of problem and effect of the problems on land unit as human beings, too. All these information obtained so make a basis to select alternatives for rectification of problems and fulfillment of management objectives.

2. Restoration Phase

This phase covers the task of selection of best solutions and their applications for watershed management. In other way, this phase comes after recognized problems, in which treatment measures are applied to critical areas for the recognized problems, identified earlier during recognized phase, so that these critical areas can be restored to the pre-deterioration stages. In forthcoming phase, the proper treatment measures, which will include the biological and engineering measures, are implemented to all types of land falling under watershed.

3. Protection Phase

It is third phase of watershed management, in which general health of watershed is taken care of to ensure normal working. In addition to this, the protection of watershed against all those factors which cause deterioration is also carried out. The protection is preferably made on the critical areas, which are restored in the phase of restoration.

4. Improvement Phase

This is the last phase, has precedential importance in watershed management work. Under this phase, the overall improvements made during management of watershed are evaluated for all the lands covered. In addition, attention should be given to make improvement on agricultural land, forest land, forage production, pasture land and socio-economic status of the people.

29.4 Formulation of Watershed Project

Formulation of watershed projects involve careful analysis of available resources, defining the problem, formulation of objectives, steps wise work plan to achieve the objectives within defined time and optimum available budget. Detail of these aspects are presented in brief as below.

29.4.1 Definition/Description of Problem

The problems such as: flood, drought, erosion and sediment damage and other problems related to the conservation, development, utilization, disposal of water originating in the watershed etc are considered under this section. Major problems are outlined as under:

Flood Damage: The following points are considered to evaluate the flood damage occurred in a watershed

1. Amount and value of land improvements and other properties exposed to the flood hazards in the watershed.
2. Frequency of flood occurrence.
3. Significance of small frequent floods or large infrequent floods in total flood problems.
4. Limitations

Sediment Damage: The problems exposed by sediment deposition are considered in following cases:

1. Problems of reservoir sedimentation
2. Problems of channel silting
3. Drainage problem
4. Irrigation development
5. Loss of agricultural land

Erosion Damage: The problems of erosion damage are studied under the following contents:

1. Extent of sheet, gully and channel erosion.
2. Downstream damage due to sediment deposition.

3. Effect on agricultural production due to erosion.

4. General effects on watershed's economy.

Water Management Problem: It includes the detail on irrigation needs, drainage, water supply required for agriculture and non-agricultural uses and other management needs.

Special Problems: The problems such as: land slip, land slide, highway erosion, mines etc. are counted for preparation of watershed work plan.

29.4.2 Stepwise Work Plan

Main proposal is divided in different sections.

Section-I

In this section, a brief report about project area is cited, which includes following details:

1. General features
2. Demography
3. Economy
4. Geology
5. Climate
6. Water resources: surface and subsurface water rights and laws.
7. Land resources: soil types, chemical and physical properties of soil and land use capability classification.

Section-II

In this section, the present status and development potential of the area are explained, which are outlined with the help of following details:

a) Present Status

1. Power supply
2. Land use
3. Agricultural production and availability of inputs such as, seeds, fertilizers, money etc.
4. Government policy

a. Incentives

b. Financial institutions

5. Marketing facility

6. Infrastructure for transport

7. Growth rate of traditional agriculture

b) Future Requirement

1. Land preparation
2. Irrigation and drainage requirement
3. Reclamation of saline and alkali soils
4. Farm equipments and supply
5. Land reforms required

c) Development potential

1. Potential according to land use
2. Aerial photograph for project planning
3. Land use capability
4. Economics of alternative farming methods.

Section-III

a) Preparation of Development Plan

1. Justification
2. Guide line and concept
3. Objectives and scope of the plan
4. Priorities
5. Economic constraints
6. Stage of development

b) Main Programme

1. Land Development
2. Irrigation and drainage

3. Soil conservation measures

c) Step to be Recommended for Socially Acceptance of Proposal

d) Evaluation

1. Putting of hydrologic measurement stations
2. Analysis of data

e) Monitoring of Infrastructures

f) Development Schedule

Section-IV

Cost Estimation: Capital cost, annual cost, foreign exchange requirement and equivalent annual cost are considered.

Section-V

In this section, the benefits are computed from following sources:

1. Improvement in water quantity and quality
2. Increment in agricultural production
3. Environmental control and recreation
4. Enhancement of economy of area

Section-VI

Economic Analysis

1. Criteria
2. Project cost
3. Tangible and intangible benefits
4. Agricultural and other benefits
5. Benefits-cost analysis
6. Equivalent annual benefit
7. International rate of return

Section-VII

Financial Analysis

1. Cost allocation
2. Payment capacity

Section VIII

Programme Implement technique

Section IX

Conclusion and Recommendation

Keywords: Watershed Planning, Watershed Project Formulation, Surveys, Watershed Planning Work Plan

Lesson 30 Economics of Watershed Projects

30.1 Economic Evaluation of Watershed Projects

Economic evaluation of watershed projects is essential to determine their consequential effects on social welfare needs and environmental enhancements. Watershed projects also generate productive, protective, social and employment generation benefits. A watershed project is considered economically feasible if the total benefits that result from the project exceed those which would accrue without the project by an amount in excess of the project cost. Economic feasibility is contingent on technical feasibility because a project incapable of producing the desired output is not going to produce the benefit needed for its justification. The test of social feasibility is equally important components of overall economic evaluation of the project. Social feasibility of watershed projects is determined by assessing the change in daily lives of the beneficiaries and evaluating the willingness of the stakeholders. Project evaluation requires a comparison between the events predicted to occur if the project is built and those predicted to occur if the project is not built. Cost and benefits of actual events are considered for economic evaluation.

30.1.1 Benefits

Benefits of watershed projects vary from many kinds of effects, a systematic procedure is required to make sure that each effect is considered and evaluated. A variety of terminologies have been used by planners and economists to describe individual project consequences. Measurement of cost is relatively easier than the complex benefit consequences resulting from a watershed project. Broadly, the benefits are classified into tangible and intangible benefits.

1. Tangible benefits results from the consequences to private parties, which can be assigned a monetary value. The benefits obtained from project-produced goods and services denote primary benefits and these could be of different kinds (direct, indirect, land-enhancement, protective etc.) Direct benefits accrue by putting project output to its intended use. They may consist of increase in farm income resulting from application of irrigation water, reduction in physical damage as a result of flood protection and sand casting on fertile lands etc. Indirect benefits result as individuals realize the economic consequence of technological external effects. The effects may result either from the production of project output or from its use by others. For example, output intended for one purpose (storage of harvested rainwater for irrigation) may also provide other beneficial effects (fish production). Protection of uplands from irreversible losses through erosion may benefit community of extra revenue and fodder from protected uplands. Land enhancement benefits result, where more productive land uses is made possible by the watershed project and are distinguished from direct benefits to the land use, which would prevail without the project.

Benefits that may accrue from watershed projects are,

1. Protection to the eroding uplands

2. Protection to the downstream fertile lands from silt flow, floods and sand casting.
3. Land development in the command area.
4. Flood moderation and drought alleviation.
5. Irrigation in kharif and rabi seasons.
6. Increased biomass production from erstwhile degraded or wasted common lands.
7. Improved environment and communication, etc.

2. Intangible benefits describe consequences, which cannot be assigned a monetary value but should be considered while evaluating a project. Examples of such benefits of water harvesting structures may consist of environmental restoration, ecological diversity etc.

30.1.2 Costs

Costs of the project generally include cost of construction, operation and maintenance of activities associated with watershed projects like cost of storage (dam, spillway, pond, etc.), cost of soil conservation structures (contour bunding, terraces, half moon terraces), cost of water distribution system, etc.

30.1.3 Mathematics of Economic Analysis

Economic analysis consists of following steps:

1. Estimate or predict physical consequences (i.e. benefits and costs) resulting from each alternative (i.e. watershed activities) including that of doing nothing.
2. Assign a monetary value on each physical consequences based on market price.
3. Select a discount rate to convert the prediction time of monetary values into an equivalent single number.
4. Select an appropriate time horizon of the project.
5. Compare the alternatives for selecting a feasible project and in case of post project evaluation compare the cost and benefits with the bench mark data.

30.2 Concept of Time and Money

A rupee in hand is more valuable than a rupee to be received a year from now. The process of finding the present worth of future income is called discounting. It is the present value of future payments discounted at some rate, called discount rate. The interest rate assumed for discounting is the discount rate. The discount rate is generally the same as prevailing interest rate in the market. The interest rate looks backwards from the future to the present.

30.2.1 Discounting Factors

1) Single Payment Factors

a) Single Payment Compound Amount Factor (SPCAF):

This indicates the number of rupees, which have accumulated after N years for every rupee initially invested at a rate of return of i percent (Fig. 30.1). For P as a present and F as a future amount, the formula is given as:

$$F = P(1+i)^N$$

Where,

$(1+ i)^N$ is called discount factor for single payment compound amount and abbreviated as (F/P, i%, N).

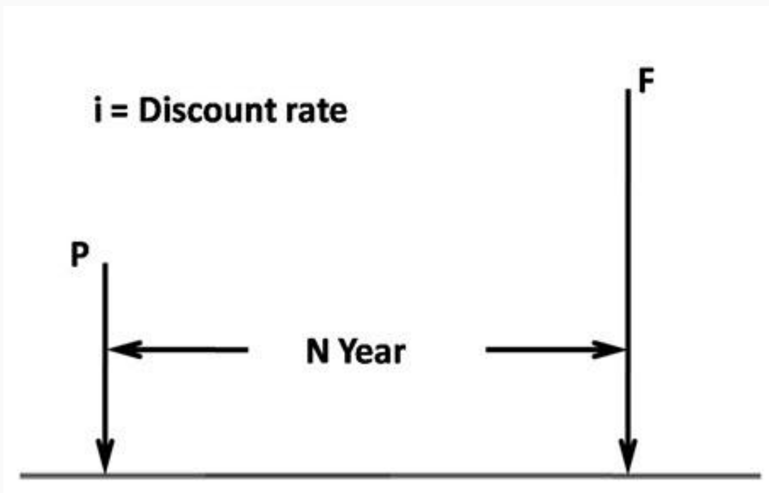


Fig. 30.1. Single-payment factors (a) Single-payment compound amount factor = F/P, (b) Single payment present worth factor = P/F.

(Source: Samra et. al.,2002)

b) Single Payment Present Worth Factor (SPPWF):

This indicates the number of rupees (P) one must initially invest at i % discounting rate to have F rupee after N years. It is inverse of SPCAF;

$$P = F\left(\frac{1}{i+i}\right)_N \qquad (15.2)$$

Where,

$\frac{1}{i+i^{N}}$ is discount factor for single payment present worth and abbreviated as (P/F, i %, N).

2) Uniform Annual Series Factors

a) Sinking Fund Factor

This indicates the number of rupees one must invest in uniform amounts at i percent interest rate at the end of each of N years to accumulate one rupee. If A is equal amount at the end of each year and F is accumulated amount, then

$$A = F\,\frac{\mathbf{i}}{(1+i)^{N}-1} \qquad (15.3)$$

Where, $\frac{\mathbf{i}}{(1+i)^{N}-1}$ is the sinking fund factor abbreviated as (A/F, %, N)

b) Capital Recovery Factor (CRF)

This indicates the number of rupees one can withdraw in equal amounts at the end of each of N years if one rupee is initially deposited at i percent interest. Hence,

$$A = P\,\frac{i(1+i)^{N}}{(1+i)^{N}-1} \qquad (15.4)$$

Where, $\frac{i(1+i)^{N}}{(1+i)^{N}-1}$ is the capital factor and abbreviated as (A/F, %, N).

c) Uniform Series Compound Amount Factor (USCAF)

This indicates the number of rupees, which will accumulate if one rupee is invested at i percent rate at the end of each of N years. It is inverse of sinking fund factor.

$$F = A\,\frac{(1+i)^{N}-1}{i} \qquad (15.5)$$

Where, $\frac{(1+i)^{N}-1}{i}$ is the USCAF and abbreviated as (F/A, %, N)

d) Uniform Series Present Worth Factor (USPWF)

This indicates the number of rupees one must initially invest at i percent rate to withdraw one rupee at the end of each of N years. This is the inverse of the capital recovery factor.

$$P = A\,\frac{A(1+i)^{N}-1}{i(1+i)^{N}} \qquad (15.6)$$

Where, $\frac{(1+i)^{N}-1}{i}$ is the discount factor (P/A, %, N) for USPWF

30.3 Cash Flow

Cash flow is the movement of money into or out of a business, project, or financial product. It is usually measured during a specified, finite period of time. Measurement of cash flow can be used for calculating other parameters that give information on a project's value and situation. Cash flow can be used, for example, for calculating parameters:

- To determine a project's rate of return or value. The time of cash flows into and out of projects are used as inputs in financial models such as internal rate of return and net present value.
- Cash flow can be used to evaluate the 'quality' of income generated by accrual accounting. When net income is composed of large non-cash items it is considered low quality.
- To evaluate the risks within a financial product, e.g., matching cash requirements, evaluating default risk, re-investment requirements, etc.

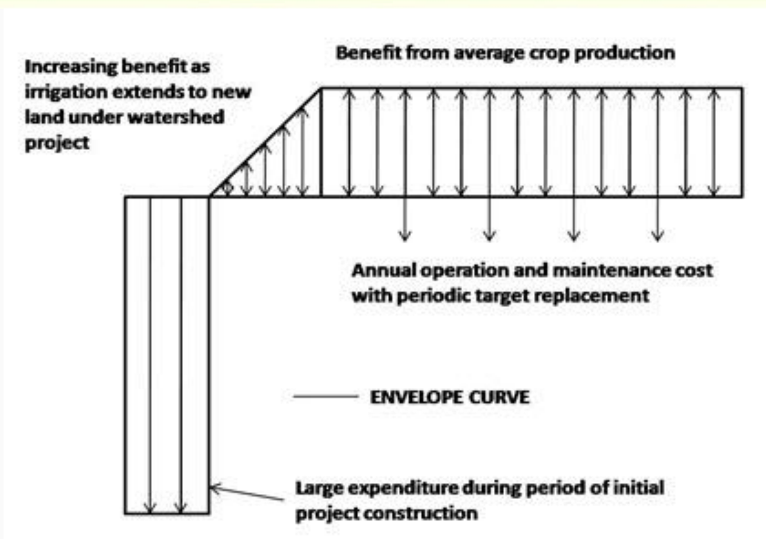


Fig. 30.2. Cash flow diagram for hypothetical irrigation project.

(Source: Samra et. al. , 2002)

Cash flow can be diagrammatically represented in the form of graphical presentation of each monetary value (costs and benefits) on vertical axis and time on horizontal axis (Fig. 30.2). Receipts or benefits are represented by arrows pointing upwards, while costs are represented by arrow pointing downwards. The length of the arrow is made proportional to the cost or benefit. Cash flow diagram provides a conceptualized picture of project value at different stages to help in carrying out benefit-cost analysis. Annual benefits and cost will not in fact be constant every year but vary around average values in an almost random fashion with crop production and other operation and maintenance needs.

30.4 Discounting Techniques

The procedure in which discounting factors may be systematically applied to compare alternatives is a discounting technique. There are three discounting techniques: (i) present worth method (ii) benefits-cost ratio method, and (iii) rate of return method. Each method, if used correctly, leads to the same evaluation of the relative merit. However, each has advantages and disadvantages.

(1) Present Worth Method

The present worth (PW) of the net benefits of the project is the difference between the discounted value of all the benefits and cost of the project over its life.

$$PW = \sum_{t=1}^{N}\left(\frac{P}{F}, i\%, T\right)(B_t - C_t)$$

$$= \sum_{t=1}^{N}\left[\frac{1}{(1+i)^t}(B_t - C_t)\right]$$

Where C_t is the cost, and B_t is the benefit in year (t), N is the period of analysis in year and i is discount rate.

Following rules are applied to make correct choices:

1. Figure all present worth to the same time base.
2. Determine all present worth by using the same discount rate.
3. Accept the project when PW > 0, otherwise reject. Higher the PW, better is the project.
4. Choose the alternative with greatest present worth in a set of mutually exclusive alternatives.
5. If benefits cannot be qualified but are approximately equal, or the budget is limited, choose the alternative having least cost.

(2) Benefit-Cost Ratio Method

The befit-cost ratio (BCR) is the present worth of benefits (PWb) divided by the present worth of cost (PWc)

$$BCR = \frac{\sum_{t=1}^{N}\left[\frac{P}{F},\ i\%, t\right] B_t}{\sum_{t=1}^{N}\left[\frac{P}{F},\ i\%, t\right] C_t} = \frac{\sum_{t=1}^{N}\frac{B_t}{(1+i)^t}}{\sum_{t=1}^{N}\frac{C_t}{(1+i)^t}}$$

The following rules are followed:

1. Figure all present worth to the same time base.
2. Project is worth considering if BCR > 1, otherwise reject it. If set of mutually exclusive alternatives (or projects) are involved for comparison, proceed to next rule.
3. Rank the alternatives in the set of mutually exclusive alternatives in order of increasing cost. Choose the more costly alternative if the incremental BCR exceeds unity, otherwise, choose the less costly alternative.
4. Determine all present worth by using the same discount rate.

3) Rate of Return Method

The rate of return (ROR), also called internal rate of return (IRR), is the discount rate, which makes the net present value or present worth (PW) of net benefits equal to zero. It represents the average earning power of the money in the project over its life. It is found by trial and error in successive approximation to find the ROR, which will make the sum zero.

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

Choose a discount rate and compute PW of net benefits. If this sum (i.e. PW) is zero, the chosen discount rate will be the ROR. If the PW is positive, repeat the exercise with a higher discount rate. If it is negative, find out a lower discount rate, until the PW value is reached nearest to zero. When the value changes from positive to negative (or vice versa), interpolate to arrive at the estimated ROR.

Project is considered economically worthy, when ROR is higher than the interest rate payable on invested money or any minimum acceptable value. If set of mutually exclusive alternatives are involved, rank them in order of increasing cost. Choose the more costly project if the incremental ROR exceeds the minimum acceptable interest rate, otherwise choose the less costly alternative.

30.5 Costs-Benefit Analysis

Cost–benefit analysis (CBA), sometimes called benefit–cost analysis (BCA), is a systematic process for calculating and comparing benefits and costs of a project, decision or government policy (hereafter, "project"). CBA has two purposes:

1. To determine if it is a sound investment/decision (justification/feasibility).
2. To provide a basis for comparing projects. It involves comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

CBA is related to, but distinct from cost-effectiveness analysis. In CBA, benefits and costs are expressed in monetary terms, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their "net present value." Closely related, but slightly different, formal techniques include cost-effectiveness analysis, cost–utility analysis, economic impact analysis, fiscal impact analysis and social return on investment (SROI) analysis.

Cost–benefit analysis is often used by governments and other organizations, such as private sector businesses, to evaluate the desirability of a given policy. It is an analysis of the expected balance of benefits and costs, including an account of foregone alternatives and the *status quo*. CBA helps predict whether the benefits of a policy outweigh its costs, and by how much relative to other alternatives (i.e. one can rank alternate policies in terms of the cost-benefit ratio). Generally, accurate cost-benefit analysis identifies choices that increase welfare from a utilitarian perspective. Assuming an accurate CBA, changing the status quo by implementing the alternative with the lowest cost-benefit ratio can improve Pareto efficiency. An analyst using CBA should recognize that perfect evaluation of all present and future costs and benefits is difficult, and while CBA can offer a well-educated estimate of the best alternative, perfection in terms of economic efficiency and social welfare are not guaranteed.

The following is a list of steps that comprise a generic cost-benefit analysis.

1. List alternative projects/programs.
2. List stakeholders.
3. Select measurement(s) and measure all cost/benefit elements.
4. Predict outcome of cost and benefits over relevant time period.
5. Convert all costs and benefits into a common currency.
6. Apply discount rate.
7. Calculate net present value of project options.

8. Perform sensitivity analysis.
9. Adopt recommended choice.

30.5.1 Principles of Cost Benefit Analysis

One of the problems of CBA is that the computation of many components of benefits and costs is intuitively obvious but that there are others for which intuition fails to suggest methods of measurement. Therefore some basic principles are needed as a guide.

1. There must be a Common Unit of Measurement

In order to reach a conclusion as to the desirability of a project, all aspects of the project, positive and negative must be expressed in terms of a common unit; i.e., there must be a "bottom line." The most convenient common unit is money. This means that all benefits and costs of a project should be measured in terms of their equivalent money value. A program may provide benefits which are not directly expressed in terms of rupees but there is some amount of money the recipients of the benefits would consider just as good as the project's benefits.

2. CBA Valuations should Represent Consumers or Producers Valuations as revealed by their actual behavior

The valuation of benefits and costs should reflect preferences revealed by choices which have been made. For example, improvements in transportation frequently involve saving time. The question is how to measure the money value of that time saved. The value should not be merely what transportation planners think time should be worth or even what people say their time is worth. The value of time should be that which the public reveals their time is worth through choices involving tradeoffs between time and money.

3. Benefits are Usually Measured by Market Choices

When consumers make purchases at market prices they reveal that the things they buy are at least as beneficial to them as the money they relinquish. Consumers will increase their consumption of any commodity up to the point, where the benefit of an additional unit (marginal benefit) is equal to the marginal cost to them of that unit, the market price. Therefore for any consumer buying some of a commodity, the marginal benefit is equal to the market price. The marginal benefit will decline with the amount consumed just as the market price has to decline to get consumers to consume a greater quantity of the commodity. The relationship between the market price and the quantity consumed is called the demand schedule. Thus the demand schedule provides the information about marginal benefit that is needed to place a money value on an increase in consumption.

4. Gross Benefits of an Increase in Consumption is an Area under the Demand Curve

The increase in benefits resulting from an increase in consumption is the sum of the marginal benefit times each incremental increase in consumption. As the incremental increases considered are taken as smaller and smaller the sum goes to the area under the marginal benefit curve. But the marginal benefit curve is the same as the demand curve so the increase in benefits is the area under the demand curve.

5. Decision Criteria for Projects

If the discounted present value of the benefits exceeds the discounted present value of the costs then the project is worthwhile. This is equivalent to the condition that the net benefit must be positive. Another equivalent condition is that the ratio of the present value of the benefits to the present value of the costs must be greater than one. If there are more than one mutually exclusive project that have positive net present value then there has to be further analysis. From the set of mutually exclusive projects the one that should be selected is the one with the highest net present value.

Example 1: How much will be the worth of irrigation benefit of Rs. 50,000.00 and Rs. 90,000.00 of net benefits resulting from water harvesting project 5 and 20 years after the start of construction, respectively, at interest rate of 12%.

Solution:

Present worth of Rs. 50,000 after 5 years

P = 50,000.00 (P/F, 12.5%, 5)

From the interest table for i =12%, discount factor for N = 5 = 0.5674

Therefore, P = 50,000.00 X 0.5674= Rs. 28370.00

Present worth of Rs. 90,000 after 20 years

P = 90,000.00 (P/F, 12%, 20)

From the interest table for i =12%, discount factor for N = 20 = 0.1037

Therefore, P = 90,000.00 X 0.1037 = Rs. 9333.00

Example 2: How much will be the worth of irrigation benefit of Rs. 5000.00 in 15 years at the interest rate of 12%?

Solution:

Present worth (P) = Rs.5000.00, N = 15 years and i = 12%

Therefore, future worth (F) after 15 years will be F = 5000.00 (F/P, 12%, 15)

= 5000.00 X 5.4736 = Rs. 27,368.00 (F/P value obtained from table)

Discount factor, F/P can also be calculated (F/P, 12%, 15) = $(1+ 0.12)^{15}$ = 5.4736

Keywords: Watershed Projects, Economic Evaluation, Cost Benefit Analysis, Discounting Techniques

Module 16: Optimal Land Use Models

Lesson 31 Optimal Land Use

Introduction

Inappropriate and uncontrolled use of natural resources can downgrade their quality and destroy them. Sustainable development and optimized use of natural resources involves effective utilization of the existing resources without damaging the assets and preserves these valuable resources for the future generation. Soil loss or erosion is the most important problem developing due to disturbances of natural resources setting and needs to be considered for sustainability. There are many factors affecting the type and extent of erosion in a watershed. One of the factors is how the lands are used. Over the past years, this issue has played an important role in erosion, as a result of technological advancements introduced in nature. Therefore, the kind of use of lands is an important factor in erosion and production of sediments in watersheds. There are many other constraints like limited availability of water, availability of budget etc which enforces to use land in optimal way.

31.1 Objectives of Optimal Land Use

It takes 300 years for 1 cm of soil (depth) to be formed. Therefore, in order to preserve it as a natural asset along with maximization of income, it is vital to prevent soil erosion.

31.2 Methods and Possibilities in Optimal Land Use

At present, scientific and optimized management of agriculture and natural resources are considered to be important items in sustainable development. In order to achieve sustainability and optimized land allocation, we can use linear programming, multi-objective linear programming, and Geographic Information System (GIS) approaches.

Different researches show that by using linear programming the area of land uses may be modified in such a way that maximum profit and minimum erosion can be resulted. Although finalizing superb economic choices should be accompanied by taking into account biological considerations, ecosystems' sustainability and social issues. The application of different optimization methods have been developed in recent years in such a way that most of administrative and logical measures have been based on relevant research.

Many researchers have already applied the above techniques for the optimization of land use. Benli and Kodal (2003) in their study on the optimization of land use in southeast of Antalya, Turkey, highlighted programming for the purpose of maximizing profit obtained from agricultural lands, in spite of shortage of water. Nguyen and Egashira (2004) emphasized the increase in the use of agricultural and forest lands in Tran Yen, Japan, through appropriate land allocation for different uses. Singh and Singh (1999) investigated the multi-objective linear programming model for optimizing land use in the north of China. The results show that if the resources are used properly, the preservation of soil and provision of food and income for rural inhabitants will be continuously improved. Nikkami et al. (2002) utilized the optimization model to decrease environmental and economic effects of soil erosion caused by mismanagement of land use activities in one of the sub-basins of Damavand watershed, Iran. Nikkami et al. (2009) used multi-objective linear programming in a study on the basin Kharestan watershed which is situated north-west of Iqlid, in the province of Fars, Iran. They determined the optimal land use level to decrease erosion and increase the income of the inhabitants of the basin, concluding that the current land use levels were not appropriate for decreasing erosion and increasing the income of the inhabitants. The results showed that if land use is optimized, the degree of soil erosion and the profitability of the entire watershed under standard land use circumstances will respectively decrease 53.2% and increase 207.98%. The modelling of spatial use distribution of agricultural lands to maximize profit in two regions in England. Multi-objective linear programming was utilized to enhance income and decrease soil erosion in the basin of Brim and watershed, in Iran. The findings indicate that the application of optimization of land use can contribute to total income up to 18.62% and decrease soil erosion about 7.87%.

31.3 Use of Remote Sensing and GIS Techniques in Achieving Optimal Land Use

Traditional data gathering methods ranging from sample surveys to systematic land use surveys are generally too expensive and time consuming to obtain optimal land use. The timely accurate agricultural information using remote sensing techniques are of strategic importance for determining the food policy and management of the food crisis in case of crop damage due to disasters like severe drought, flood etc. Remote sensing allows the spatio-temporal analysis of land use and land cover changes. It supplies the needed geo database to build informative and rich understanding of natural resources. The role of GIS is in storing, managing a great deal of data about the images and all the related attributes to allow their manipulation, analysis and finally presentation according to choice. The ability of GIS in spatially accurate representation facilitates the analysis, computations, prediction, retrieving through many types of processing, especially overlaying of different layers extracted from multi date remotely sensed data.

31.4 Models for Watershed Processes Simulation

Watersheds are modeled to facilitate well-studied designs and informed management decisions. In engineering and management practices, it is important to understand complex interactions occurring today as well as predict impacts years, perhaps even decades, into the future. In recent years, watershed management practices that were once praised for their broad benefits to society have become the focus of harsh criticisms for their adverse and unexpected environmental or socio-economic impacts. Watershed models help us predict future impacts of projects and management policies, which in turn contributes to improved water resources system design, planning, and operation, and thus more sustainable water resources management. The watershed has been widely acknowledged to be the appropriate unit of analysis for water and natural resources planning and management problems. However, many of the environmental processes and socio-economic activities occurring within a watershed are simply too complex, dynamic, and spatially variable to be precisely monitored and thoroughly understood. As population grows, continued human encroachment into natural systems seems inevitable, with expanding communities needing increased water supplies to carry on various development activities in the watershed. Paradoxically, both water shortage (drought) and overabundance (flooding) will become even more problematic for many communities. Expectations will remain high for using water as a means of socio-economic development and ecosystem conservation and enhancement. It is unlikely that these expectations can be met without the aid of analytical tools such as computer watershed models. Watershed models are mathematical representations of watershed processes and affected socio-economic and environmental systems. They have become a fundamental and integrated element of any engineering project or management practice that is deemed to alter diverse natural processes. Models help us gain insights into hydrological, ecological, biological, environmental, hydro-geochemical, and socio-economic aspects of watersheds, and thus contribute to systematized understanding of how watershed sub-systems function, which is essential to integrated water resources management and decision making. There are numerous watershed models, having various levels of sophistication and providing diverse types of information, but all watershed models share one common characteristic, that is, they are all simplifications of actual watershed processes. Another common characteristic of all models is that they require data, or observations, in order for their parameters (i.e., equation coefficients) to be estimated accurately. The process of adjusting model parameters to obtain a good match between model output and real-world observations is called calibration. Additionally, an independent set of observations should be used to test, or verify, the calibrated model in order to evaluate the expected accuracy of model results. If the expected accuracy is not acceptable, additional data should be gathered, or a simpler model may be warranted. Although these steps of calibration and verification may be costly and time-consuming, they are critical to ensuring accurate results and fostering confidence in predicted outcomes. A chronological synthesis of watershed modeling provides an overview of how modeling goals have evolved from describing only physical processes to the integration of social, economic, and environmental objectives in support of decision making.

Keywords: Optimal Land Use, Watershed Processes Simulation, Remote Sensing, GIS Techniques.

Lesson 32 Case Studies on Optimal Land Use

32.1 Case Study on Optimal Land Use within India

A variety of techniques can be used to minimize the impact of various agricultural and other activities on total soil loss from a large area. Evaluating alternate resource management strategies through experiments at each site within a large area is generally not feasible. In this context, to obtain the effectiveness of existing resource management systems or hypothetical solutions, more quantitative system tools such as Spatial Decision Support Systems (SDSS), including simulation models and Geographic Information Systems (GIS) are of great use. For developing a SDSS for assessing the impact of existing and proposed (optimized) resource-management plans on regional soil and water conservation, it is essential that the selected (regional) hydrologic model is not site-specific and subjective bias. It should have the ability to assess the impact of land use and other resource-management strategies on water quantity, sediment production and transport, and crop growth. ; Further, the SDSS has the ability for an easy methodology and is based on readily available input data to link to GIS. Although the contribution of GIS in decision support systems (comprising simulation models) is largely as a method for gathering data and visualizing results, yet the two approaches can be fully integrated with an optimization tool to provide a powerful combined package for spatial decision support. Linear programming (LP) is a type of optimization technique (Greenberg, 1978) in which both objective function and constraints are linear and additive. Linear programming and related optimization techniques have proved to be among the most flexible tools for generating various decision-making scenarios and for analysing the complex relationships between decision variables and constraints. The present study was thus a showcase of developing a SDSS, comprising a watershed-scale hydrologic model and a linear programming tool for estimating sediment yields from a (test) Nagwan watershed in Damodar–Barakar catchment under existing resource management systems. It further proposes an optimized land-use plan and assesses the impact of this LP-optimized land-use plan on the test watershed's total sediment yield.

Study Area

Encompassing a total area of nearly 9576 ha, the test Nagwan watershed (Fig. 32.1) is located at the upper part of the Sewani river between 23° 59′– 24° 05′ N and 85° 18′– 85° 23′ E within the Damodar–Barakar catchment in India, the second most seriously eroded area in the world (EI-swaify et al., 1982). The soils of the area are mainly of the clay loam type. The maximum and minimum elevations of the area are 637m and 564 m, respectively. About 86% of area is under a slope range of 1–6%. The area experiences a sub-humid subtropical monsoon climate, characterized by hot summers (40 °C) and mild winters (4 °C). The total annual average precipitation of 1206 mm is distributed mainly between June and September, with about 15 rainy days per month. The average storm intensity, considering storms of more than 30 min duration, is about 10 cm/h. Out of the total watershed area of 9576 ha, about 55.00% is under agriculture, 17.22% is under forest, and about 21.77% is wasteland. The watershed comprises of 42 villages with about 5976 families making up a total population of about 49,508. Most of the farmers in the area are either small (17009 with 1–2 ha land holding size) or marginal (13955 with a land holding size less than 1 ha) with an average land holding size of about 0.16 ha. The main agricultural crops grown during Kharif season (June–October) are paddy and corn, and in the Rabi season (November–April) are wheat, gram, and mustard. Paddy–mustard, paddy–wheat, and corn–mustard are the main crop rotations. The majority of the watershed is mostly single-cropped with paddy as the major crop and corn as the second most common crop. Agriculture is mostly rainfed, as only 20% of irrigation available in the area is from sources other than rain, and the cropping intensity is also quite low at 98%.

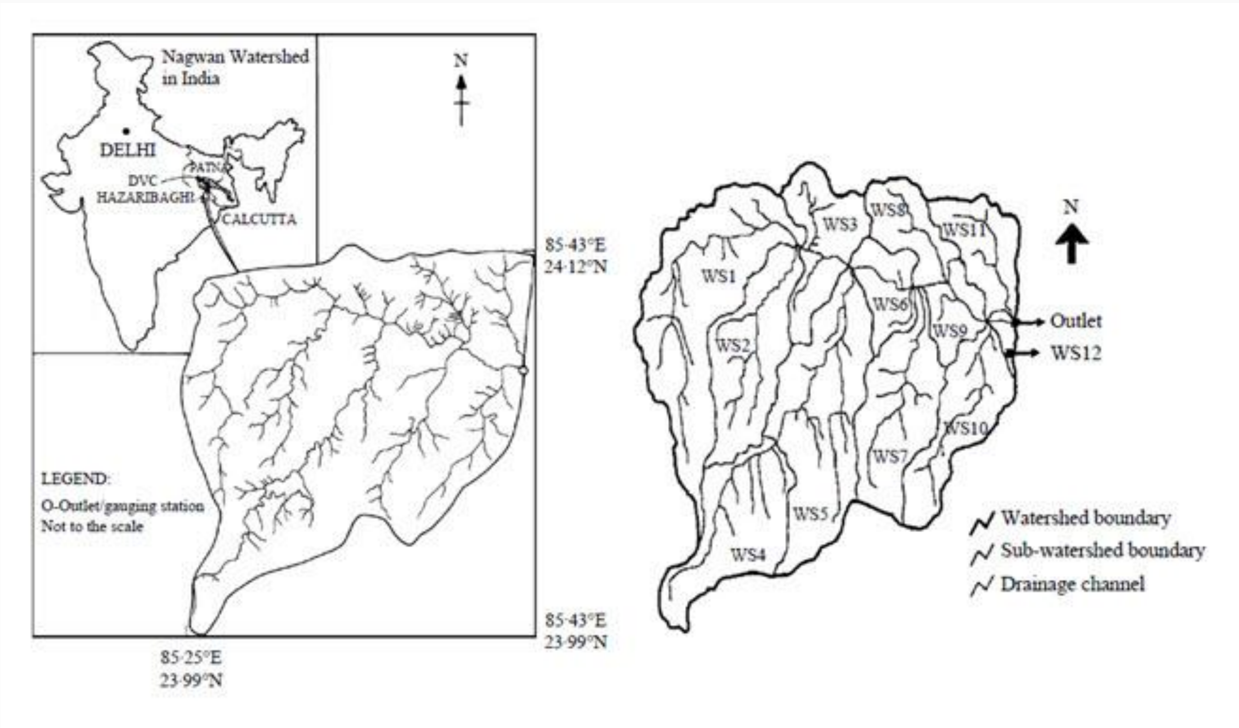


Fig. 32.1. Location and Sub-watersheds Delineated Nagwan watershed in India. (Source: Kaur et al., 2004)

The proposed SDSS comprises of a hydrological model- Soil and Water Assessment Tool (SWAT). The SWAT Arc-View system consists of three key components:

1. Generating sub-basin topographic parameters and model input parameters
2. Editing input data set and executing simulations
3. Viewing graphical and tabular results.

The delineation of the watershed and the development of the watershed and sub-watershed database were the first set of fundamental steps performed by the proposed SDSS. The watershed and its sub-watershed boundaries were delineated from the DEM of the test area (Kaur and Dutta, 2002) by setting a threshold value of 300 ha or 834 cells for starting the stream delineation. This led to the delineation of 12 sub-watersheds within the watershed (Fig. 32.1). This was followed by determination of all the geometric parameters of sub-basins and stream reach by means of the raster-grid functions of the GIS. These were stored as attributes of derived vector themes. Next, the land use and soil grids and the related data files were loaded and clipped in the watershed area followed by their re-classification and re-sampling at the DEM cell size. In order to capture the heterogeneity in soil and land-use of the watershed, each sub-watershed within it was further divided into one or more Hydrologic Response Units (HRU), representing a unique combination of the land use and soil types. For example, sub-watershed 1 had 3 HRUs with upland paddy on silty loam soil, upland paddy on loamy sand soil, and long-duration paddy on clay loam soil, while sub-watershed 3 had just 1 HRU with upland paddy on silty loam soil, and sub-watershed 11 had 4 HRUs with corn on sandy loam soil, poor canopy forest on wasteland, upland paddy on loamy soil, and upland paddy on silty loam soil. This resulted in a total of 44 HRUs for the whole test watershed. Precipitation, temperature, and weather-generator data were defined by loading the station location and data files. All the SDSS-required input files were generated sequentially through the interface, and the SDSS was run for the calibration and the validation periods, after setting the initial soil moisture storage and base-flow factor values as 1 and using the Pristley–Taylor method for evapotranspiration estimations. Formulation of an LP model for the optimized land-use plan, a Linear Programming (LP) technique, which has been used since the late 1950s in a wide variety of planning situations (Dantzig, 1963), was used to design a model to propose an optimum land-use plan for the watershed.

Defining Decision Variables

Any LP analysis starts by defining 'decision variables', which are the different alternatives stated by the problem; for example, in a land-use planning situation, the decision variables may be the different land-use types (LUTs) to be allocated. Strictly speaking, LP is not a spatial technique, because it does not take into account the spatial distribution of the decision variables. However, it can be tailored to deal with spatial problems, if previous regionalization is performed by means of any GIS tool in a SDSS. In the present investigation, in order to capture the soil, land-use, topography, and climate heterogeneity (the four important variables controlling soil and water loss) in a watershed, the delineated watershed was divided into 15 sub-watersheds and 44 HRUs using the Arc-View GIS and the Arc-View Spatial Analyst packages. In the proposed LP algorithm, these individual HRUs were treated as decision variables, representing specific land use types under a specific soil type in a particular sub-watershed in the test watershed. By doing so, it was possible not only to take into account the spatially distributed character of constraints, to obtain more practical and realistic plans for reduced total soil and water losses from the watershed, but also to spatially distribute the LP-optimized resource plan (i.e. different land-use types) for better planning and decision-making.

Establishing objectives is in fact the most important step of any LP analysis, as it is the definition of the objectives that guides the decisions to be taken for solving the problem. Often, these objectives are mutually contradictory, so they can be conceived as either objectives or constraints. In the present exercise, the main objective of planning new land uses was to reduce the total soil loss from the watershed. Thus, the objective here, in a way, was to maximize the most soil loss reducing land-use type(s). This objective function (Z); i.e. minimization of total soil loss (in tonnes) from the watershed was hence expressed as:

$$Z = \sum_{j=1}^{m} c_j x_j$$

where: the x_j values are the decision variables, each representing the total (optimized) area (ha) under a given LUT in a jth (with j=1, 2,… m; m=44) HRU within the watershed, and the c_j values refer to the (known) soil loss rates (t/ha) from each of these HRUs under a given LUT (and soil and topography). These c_j values can be either the actual plot-experiment-based soil-loss values under each LUT or the values simulated through a well-tested and validated hydrologic model. Under real-world conditions, it is not practical to obtain actual soil-loss values, under varying soil, climate, and topographic conditions, for each LUT through field/plot experiments. Hence, in the present exercise (case study), these c_j values represented the proposed SDSS-estimated, 9-year (validation period) averaged (Kharif season), soil-loss values for each HRU within the watershed under existing resource-management conditions.

Identifying Key Constraints

The above objectives are constrained by economic, resources, and environmental limitations as well as by a set of secondary objectives. For this exercise, three sets of constraints were considered. These constraints were ecological (soil loss constraints), technical (paddy-yield, corn-yield, labour, affinity for forest and total area constraints), and financial (benefit from paddy and corn cultivation). Since the proposed land-use (LU) planning model was designed only for the Kharif season (i.e. the season with maximum soil and water loss from the region), the major LUTs considered in the proposed LU-optimization problem for the area were forests, paddy, and corn. These constraints, for the proposed land-use planning LP model, were mathematically expressed as detailed in the following subsections.

Sub-Watershed Area Constraints

In general, soil losses are minimal from areas under forest covers. Hence, designing a single area constraint for the whole watershed, with 44 decision variables, each representing an HRU with either (long-duration Kharif or upland) paddy, upland corn or forest (open or closed) would have led to a vast allocation of forested area in the test watershed, thereby leading to a infeasible land-use plan for the area. To take care of this problem, each sub-watershed was considered to be a compact and self-sufficient unit as far as the selection of LUTs was concerned. By doing so, land-use allocations within a watershed were restricted to only the LUTs found within each sub-watershed. This was expressed in the form of the following 15 sub-watershed area constraints in the proposed land-use LP model:

$$\sum_{j} x_j \leqslant TA_k$$

where: TA_k=total (known) area of the kth (with k=1, 2,…. 15) sub-watershed (in ha), as obtained from the SWAT-Arc View interface of the proposed SDSS; and x_j = (optimized) area under a given LUT in (one or more) jth HRU(s) in a kth sub-watershed.

Sub-Watershed Soil-loss Constraints

Soil loss rate (s_j) is a function of land topography, physiography, climate, and hydrology. Hence, it was considered to be an important (integrated) index constraining suitability of a land under a particular land-use type. The total soil loss from a watershed is a function of soil loss from each HRU in a sub-watershed. Thus, to minimize the total soil loss from the watershed, following 15 sub-watershed soil loss constraints were designed so as to constrain the total soil loss per HRU (or a decision variable or a LUT), within a particular sub-watershed, to either less than or equal to the total (current) soil loss from that sub-watershed. These 15 soil-loss constraints were expressed as:

$$\sum_{j} s_j x_j \leqslant TS_k$$

where: TS_k=total (known) current soil loss (in tonnes, during the Kharif season) from the kth (with k=1, 2, … 15) sub-watersheds, as obtained through the hydrologic component of the proposed SDSS; $x_{j=}$(optimized) area under a given LUT in a jth HRU (ha) in the kth sub-watershed; and $s_{j=}$the current soil loss rate (t/ha) under a given LUT in a jth HRU in the kth sub-watershed.

Yield Constraint for Paddy

$$\sum_{j} y_{p_j} x_{p_j} \geqslant TP_p$$

where: x_{pj}=(optimized) area (ha) under a paddy in a (presently paddy producing) jth HRU in the test-watershed, and y_{pj}=current paddy yield (t/ha) in a (presently paddy producing) jth HRU in a test watershed under existing resource-management practices. These y_{pj} values can be either the actual plot-experiment-based paddy yield values under each soil type and climatic and management conditions or the values simulated through a well-tested and validated crop model. In real-world conditions, it is not practical to obtain actual paddy-yield values, under varying soil, climate, and topographic conditions through actual field/plot experiments. Hence, in the present exercise, these y_{pj} values represented the proposed SDSS estimated, 9-year (validation period) averaged (Kharif season), paddy-yield values for each HRU in the test watershed under the existing resource-management practices. These (simulated) paddy-yield values estimated through the proposed SDSS for each HRU within the test area were observed to be ranging between 0.74 and 0.94, with an average of about 0.901 t/ha for the whole test area. Thus, in the above expression, TP_p=total (current) paddy productivity (in tonnes) in the watershed was equated to 0.901 t/ha x 5898 ha (i.e. total current area under paddy cultivation) = 5299.8 tonnes.

Yield Constraint for Corn

$$\sum_{j} y_{c_j} x_{c_j} \geqslant TP_c$$

where: x_{cj}=(optimized) area (ha) under corn in a (presently corn producing) jth HRU in the test watershed, and y_{cj}=current corn yield (t/ha) in a (presently corn producing) jth HRU in the watershed under existing resource-management practices. Like paddy yields, these were also estimated through the proposed SDSS for each HRU within the watershed. It has been observed that these ranged from

0.189 to 1.904, with an average of about 0.907 t/ha for the whole test area. Thus, in the above expression, TP_c = total (current) corn productivity (in tonnes) in the watershed was equated to 0.907 t/ha x 725.7 ha (i.e. total current area under corn cultivation) = 658.21 tonnes.

Benefit Constraint for Paddy

$$\sum_j b_{p_j} x_{p_j} \geqslant TB_p$$

where: x_{pj}=(optimized) area (ha) under paddy cultivation in a (presently paddy producing) jth HRU in the watershed, and b_{pj}=current benefit (of Rs 1010.28 per ha, obtained as per the collected economics of the area through PRA exercise) with paddy cultivation in a (presently paddy producing) jth HRU in the watershed. Based on this, TB_p=total (current) benefit with paddy cultivation in the watershed was equated to 1010.28 (Rs per ha) x 5898 ha = Rs 5958631.4, as shown in Table 32.1.

Input (rate)	Input cost (Rs)
Seed (70 kg ha^{-1} @ Rs 7 kg^{-1})	490.00
Human labour (60 man days ha^{-1} @ Rs 45 man-day^{-1})	2700.00
Fertilizer: Urea (15 kg ha^{-1} @ Rs 4 kg^{-1})	60.00
DAP (25 kg ha^{-1} @ Rs 10 kg^{-1})	250.00
FYM (1.5 t ha^{-1} @ Rs 200 t^{-1})	300.00
Irrigation (12 cm ha^{-1} @ Rs 50 ha-cm^{-1})	600.00
Land revenue	20.00
Overheads (@ 10% of working capital)	442.00
Interest on the working capital (@ 12% for 6 months: Kharif season)	291.72
Total cost of cultivation (Rs ha^{-1})	5153.72
Output (yield)	**Return (Rs)**
Grain (9 q ha^{-1} @ Rs 500 q^{-1})	4500.00
Straw (28 q ha^{-1} @ Rs 60 q^{-1})	1664.00
Gross return (Rs ha^{-1})	6164.00
Net return (Rs ha^{-1})	1010.28

Table 32.1. Cost Benefit Analysis of Paddy Cultivation in the Watershed

(Source: Kaur et al., 2004)

Benefit Constraint for Corn

$$\sum_j b_{c_j} x_{c_j} \geqslant TB_c$$

where: x_{cj} = (optimized) area (ha) under corn (or corn) cultivation in a (presently corn producing) j^{th} HRU in the watershed, and b_{cj}=current benefit (of Rs 3639.34 per ha, obtained as per the collected economics of the area through PRA exercise) with corn cultivation in a (presently corn producing) j^{th} HRU in the watershed. Based on this, TBm=total (current) benefit with corn cultivation in the watershed was equated to 3639.34 (Rs per ha) x 725.7 ha = Rs 2,641,069, as shown in Table 32.2.

Input (rate)	Input cost (Rs)
Seed (25 kg ha^{-1} @ Rs 10 kg^{-1})	250.00
Human labour (20 man days ha^{-1} @ Rs 45 man-day^{-1})	900.00
Fertilizer: Urea (10 kg ha^{-1} @ Rs 4 kg^{-1})	40.00
FYM (1.5 t ha^{-1} @ Rs 200 t^{-1})	300.00
Land revenue	20.00
Overheads (@ 10% of working capital)	151.00
Interest on the working capital (@ 12% for 6 months: Kharif season)	99.66
Total cost of cultivation (Rs ha^{-1})	1760.66
Output (yield)	**Return (Rs)**
Grain (9 q ha^{-1} @ Rs 400 q^{-1})	3600.00
Straw (36 q ha^{-1} @ Rs 50 q^{-1})	1800.00
Gross return (Rs ha^{-1})	5400.00
Net return (Rs ha^{-1})	3639.34

Table 32.2. Cost Benefit Analysis of Corn (Maize) Cultivation in Nagwan Watershed(Source: Kaur et al., 2004)

Labour Constraint

$$\sum_j l_j x_j \leqslant TL$$

where: x_j=(optimized) area under paddy or corn cultivation in a j^{th} HRU (ha) in the test watershed; l_j=labour required for paddy (=60 man-days/ha) or corn (=20 man-days/ha) cultivation in a j^{th} HRU with paddy or corn cultivation, respectively, in the watershed; and TL=total labour (man-days) available in the watershed (i.e. total agricultural labour-number of days in the 5-month growing season=10034 x 5 x 30 = 1505100), as per the collected economics of the area through PRA exercise.

Affinity Constraint for Forest

This was designed to maintain at least the current level of forested area (i.e. 30% of the total area) in the watershed:

$$\sum_j x_{f_j} \geqslant TA_f$$

where: TA_f = current total area under forest cover in the watershed (=2850 ha), and xf_j~(optimized) area (ha) under forest cover in a (presently forested) j^{th} HRU in the watershed.

Total Watershed Area Constraint

This was designed to ensure that the sum of areas allocated, by the proposed LP model, to all HRUs within watershed is never more than the total watershed area.

$$\sum_{j=1}^{m} x_j \leqslant TA$$

where: TA~actual total area (ha) of the watershed (~9576 ha), and x_j~(optimized) Area (ha) under each land-use type in a j^{th} HRU in the watershed.

Implementation of the LP Model

After obtaining the necessary coefficients as detailed in the previous section, the objective function and the constraints for the proposed LP model were designed and implemented on a standard MS-DOS personal computer and public-domain software, QSB (Quantitative Systems for Business V 2.0; Chang and Sullivan 1986). The input matrix for the proposed land-use LP model was solved in 32 iterations.

Results and Discussion

SDSS proposed sediment yields under the existing land-use plan, the calibrated available soil water capacity and curve number values. The proposed SDSS yielded a moderately good correlation coefficient and model efficiency coefficient values of 0.54 and 20.67, respectively for the observed versus predicted total sediment yields for the calibration years. The observed data for the validation period indicated an annual average total sediment yield of 25.35 t/ha from the Nagwan watershed during the Kharif seasons. In comparison with this, the proposed SDSS predicted an annual average total sediment yield of 21.28 t/ha, with a correlation coefficient of 0.65, model efficiency of 0.70, relative error of 217.97%, and root mean square prediction error of 9.63 t/ha for the same validation period. The above results clearly showed that, even under Indian conditions, with data sets of poor spatial resolutions, the proposed SDSS could simulate the annual dynamics of the total sediment yield at the watershed outlet reasonably well. Hence, it was assumed that the proposed SDSS was capable of mimicking even HRU and sub-watershed-scaled sediment yields realistically.

LP Model Proposed Sediment Yields Under the Optimized Land-use Plan

On comparing the total sediment yield values under the LP-optimized alternate land-use plan (18.11 t/ha) with those under existing land use (21.28 t/ha), it can be seen that the LP-optimized land-use plan could lower the total sediment yield from the watershed by about 14.89%. SDSS proposed sediment yields under the LP model proposed optimized land-use plan. Incorporation of the LP model proposed land-use plan in the proposed SDSS resulted in an average annual total (Kharif season) sediment yield of 18.17 t/ha, as compared with the 21.28 t/ha under the existing land-use plan, for the 9-year validation period. It could be clearly seen that even the proposed SDSS predicted an annual average reduction of 14.61% in the total watershed sediment yield under the LP-optimized land-use plan. This decrease could also be seen at the sub-basin level from the annual average spatial distribution map of the test watershed. Besides this, the proposed land-use plan resulted in an increase in the paddy (0.926 t/ha) and the corn (1.523 t/ha) crop yields in the watershed by 2.80 and 68.14% over the present paddy (0.901 t/ha) and corn (0.907 t/ha) crop yields, respectively.

Conclusions

The present investigation could thus quite realistically demonstrate the potential of the proposed SDSS for assessing the impact of on-going resource management practices on the sediment yields from the Nagwan watershed simply meaning the value of land use land cover optimization benefit. Besides this, it also demonstrated the immense application potential of such spatial decision support systems in designing an LP-optimized regional soil conserving-land-use plan and assessing its impact on the total sediment yield from the watershed.

32.2 Case Study on Optimal Land Use Outside India

Study Area

The Brimvand watershed is located in upstream of agricultural canal of Brimvand dam and 4 km from north of Sarpole Zahab City in Kermanshah Province, Iran. It comprises 9572 ha area distributed within 15 sub-watersheds as shown in Figure 32.2.

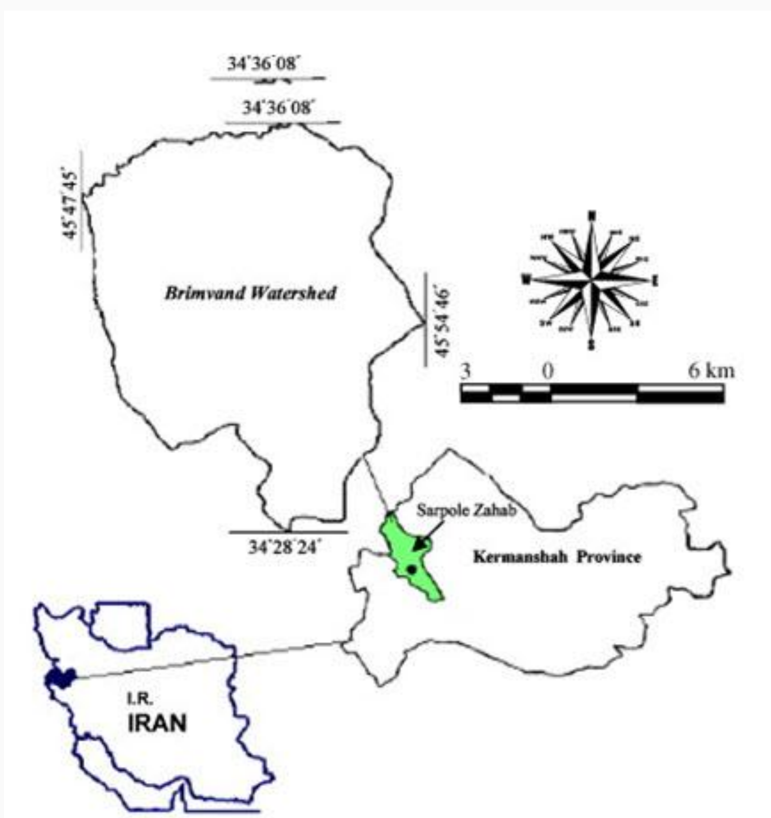


Fig. 32.2. Study Area Location. (Source: Sadeghi et al., 2009)

Data Acquisition and Problem Formulation

The problem was structured in the study area to maximize economic return and minimize soil loss. The information and data required for defining constants and coefficients of objective functions and constraints, viz. land availability, water availability/supply, soil characteristics, slope steepness and aspect, present land use, soil erosion and sediment yield, socio-economical conditions were extracted from the available comprehensive studies (Kermanshah Watershed Management Office, 2000) conducted for the area. The geographical characteristics of the study area are given in Table 32.3.

Table 32.3. The Important Geographical Characteristics of the Brimvand Watershed in Iran (Source: Sadeghi et al., 2009)

Characteristics	Value
Total area (ha)	9572
Orchard	38.32
Rangeland	4001.27
Irrigated farming	4049.27
Dry farming	952.97
Residential and outcrops	530.17
Maximum elevation (m amsl)	1310
Minimum elevation (m amsl)	510
Average elevation (m amsl)	651
Average slope (%)	10.6
Annual precipitation (mm)	485.4

In addition to the above-mentioned information, some other field studies and land surveys were also conducted for checking, and further details and information. The general benefit maximization problem was formulated as below:

$$\text{Max}(Z_1) = \sum_{i=1}^{n} C_{Bi} X_i$$

Where, Z_1 is the total annual income in million Iranian Rails (mIR), C_{Bi} is annual income for each land use (mIR/ha), Xi is the area of each land use in ha and n stands for numbers of land uses. If the annual gross benefit, production cost and soil erosion destruction cost per hectare of different land uses is given by A_{i1}, A_{i2} and A_{i3}, the above equation can be rewritten as below.

$$\text{Max}(Z_1) = \sum_{i=1}^{n} [A_{i1} - (A_{i2} + A_{i3})] X_i$$

where, A_{i1} is the gross profit for every land use, A_{i2} is the production costs spent for each land use and A_{i3} represents the costs wasted on soil caused by erosion in every land use.

The second objective was to minimize soil erosion as represented in the following equation:

$$\text{Min}(Z_2) = \sum_{i=1}^{n} C_{Ei} X_i$$

where, Z_2 = total soil erosion (t year^{-1}), C_{Ei} = annual soil erosion for every land use (t ha^{-1} year^{-1}), X_i = the area of each land use (ha), i = the land use number and n = the total number of land uses. Within the watershed, following were the considered land capability constraints:

X1 ≤ B1

X3 ≤ B2

X4 ≤ B3

X1 + X3 ≤ B4

The land availability constraints were considered as below:

X1 + X2 + X3 + X4 ≤ B5

The considered social and legislation constraints were like below:

X1 ≥ B6

X2 ≥ B7

Non-negativity constraints to solve the LP model were as below:

X1, X2, X3 and X4 ≥0

Where, B1 to B4 are the maximum allowable area to orchard (X1), irrigated farming (X3), dry farming (X4), and summation of orchard and irrigated farming. B5 denotes the maximum arable land resources. B6 and B7 represent the minimum area of orchard and rangeland (X2) in ha respectively. Since there are sufficient and accessible water supply systems in Brimvand watershed, no constraint was defined for water availability. There are 10 springs with discharges from 2 to 453 l/s (16.9 Mm^3/year) and 128 wells with the total discharge capacity of 11.2 m^3/year in the study watershed. The main irrigation canal of Brimvand Dam with the average discharge of 5 m^3/s also passes along the entire watershed. The above objective functions and constraints were quantified in coordination with site-specific information, which directly or indirectly obtained for the study area. Since the economic losses resulting from soil erosion have also to be considered in the first objective function, the soil erosion estimation in different land uses was conducted on the first onset. The estimation of soil erosion was made using Pacific South-West Interagency Committee method for 15 hydrologic units after applying the concept of sediment delivery ratio. The model consisted of nine factors, viz. surface geology, soil erodibility, climate, runoff, topography, vegetation cover, land use, upland erosion and gully erosion which were totally determined for the entire sub-watersheds. The erosion estimates were then incorporated to the land uses existed either thoroughly or partially in each hydrologic unit (sub-watershed) and the soil erosion rate associated with each land use was ultimately found out. The possible land use modification was then incorporated in order to minimize soil erosion rate based on land capability criteria and cultural, social and legal constraints.

The annual gross benefit, production cost and soil erosion destruction cost per each hectare of different land uses were estimated according to Kermanshah Watershed Management Office studies and interviews made with the inhabitants. Based on the collected data and information, grape is the main orchard product planted in terraced lands. There is no interest among the watershed inhabitants to invest on gardening for long term period return. Meanwhile, the farmers are not convinced to have commercial gardening through which they can be benefited. The low level economic conditions of the watershed inhabitants make them to scare large investments with high risk. The individual contracts between almost two thirds of the farmers and the landowners to guarantee the low but reliable income are one of the evident of such unreliable benefit to the farmers. The irrigated areas are mainly used for wheat, corn, melon, alfalfa, cotton, and bean plantation. Wheat, barley and peas are cultivated in dry farming areas as well under low tillage precaution. They usually prefer dry farming land use, since according to them, it needs low attention and tillage activities through which they also ascertain their ownership. The rangeland areas are also mostly being utilized for sheep and goat grazing purposes and the rates of benefits were then calculated based on the forage productions and the total digestible nutrients (TDN), which feeds a particular number of animal units. The dry forage production amounts of less than 50, 50–120 and more than 120 kg/ha were considered for rangeland classification in three categories of light, moderate and heavy grazing. Erosion destruction cost was estimated by calculating the area lost to erosion in each land use considering rooting depth and soil bulk density. The coefficients of maximization objective function were ultimately calculated using net benefit obtained through subtracting total cost from gross benefit. The right hand side values of the constraint equations were then determined based on land capability standards defined according to slope steepness, soil depth and water availability as well as cultural and legal constraints with the help of geographic information system. The benefit maximization and soil erosion minimization in the Brimvand watershed were solved with the help of ADBASE model which is capable to solve multi-objective problems using the simplex method. In order to obtain the most effective constraint as well as land use on changing objective functions, which facilitates decision makers/managers to address various alternatives (Chang et al., 1995), the sensitivity analysis was also performed through subjecting the objective functions to a particular change of input resources within the permissible range of variation. The permissible ranges were approximately assigned with respect to the potential of change of the variables under consideration. The percentiles of changes were then depicted against each other's and the most sensitive land use was ultimately distinguished in both objective functions.

Application of the Model to Brimvand Watershed

As already explained, only two broad planning objectives of economic development and soil erosion reduction were considered to be optimized in the Brimvand watershed. The soil erosion rates were estimated to be 7.39, 8.14, 7.39 and 21.11 t/ha/year for orchard, rangeland, irrigated farming and dry farming land uses, respectively. Since, the rooting depth and soil bulk density in orchard, rangeland, irrigated farming and dry farming land uses based on field studies and lab experiments were measured to be 1.00±0.2, 0.15±0.05, 0.50±0.1 and 0.15±0.06m, and 1.08±0.04, 1.11±0.06, 1.08±0.07 and

1.09±0.05 t/m^3, respectively, the area depleted owing to soil erosion found to be 6.84±1.7, 48.91±7.0, 13.68±3.2 and 129.13±16.6 m^2/year per each unit area (ha) of land uses at sequence. The mean net benefit of orchard, rangeland, irrigated farming and dry farming land uses were therefore calculated as 8.50, 0.16, 4.88 and 0.32 mIR/ha, respectively. So that, the objective functions of the benefit maximization and the soil erosion minimization problems in the Brimvand watershed were formulated as follows:

$$\text{Max } (Z_1) = 8.5042X1 + 0.1562X2 + 4.8758X3 + 0.3215X4$$

$$\text{Min } (Z_2) = 7.389X1 + 8.144X2 + 7.389X3 + 21.112X4$$

The above two objective functions were then subjected to the following constraints. Considering no limitation for water availability for all land uses, the maximum allocation of area of 518.81 with slope below 12% and soil depth beyond 0.65 m was contemplated for orchard as,

$$X1 \leq 518.81$$

Almost 59% of the area lies between altitude ranges of 500–600 m above mean sea level (msl). Most of the watershed appears as hilly, plateaus and alluvial fan land types. The slope of some 38% of the area is below 2%. The maximum area of 4044.64 ha could therefore be designated for irrigated agriculture with slope below 5% and very deep soil (>100 cm). Thus the constraint was formulated as below:

$$X3 \leq 4044.64$$

The upper slope limit of 12% based on the existing standards and government regulation was applied for determining the maximum allocation of land for dry farming agriculture as given below:

$$X4 \leq 1464.34$$

Based on the similarities between recommended standards for irrigated and orchard land uses and easiness of having access to water resources, the following constraint was also formulated for the study area.

$$X1 + X3 \leq 4563.37$$

It was not possible to change the utility of inhabitant, roads and outcrops areas and these areas had to be therefore subtracted from the entire watershed area and the rest area was used for optimization. In the other words, the total land available for development in the watershed was 9041.83 ha. That was

$$X1 + X2 + X3 + X4 \leq 9041.83$$

According to the current cultural tendency of the people in this region toward household gardening mainly for self-sufficiency and amusement, the area under orchards could be limited at least at the level of existing area of 38.32 ha.

$$X1 \geq 38.32$$

Government regulation, Iran Forest and Rangeland Nationalization Act of 56 required that the rangeland area should be legitimately no less than 4001.27 ha in this watershed for the purpose of natural resources conservation. Therefore,

$$X2 \geq 4001.27$$

The corresponding simplex method table was therefore extracted according to the formulated problem for the study watershed as given in Table 32.4.

Table 32.4. Simplex Table for Land Use Optimization in Brimvand Watershed, Iran (Source: Sadeghi et al., 2009)

Functions	X_1	X_2	X_3	X_4	Modality	Right hand side
Objectives						
1	8.5042	0.1562	4.8758	0.3215	Max	0.00
2	−7.389	−8.144	−7.389	−21.112	Max	0.00
Constraints						
1	1	0	0	0	≤	518.81
2	0	0	1	0	≤	4044.64
3	0	0	0	0	≤	1464.37
4	1	0	1	0	≤	4663.37
5	1	1	1	1	≤	9041.83
6	1	0	0	0	≥	38.32
7	0	1	0	0	≥	4001.27

Optimization Results and Analysis

From Tables 32.3 and 32.4, it can be seen that there is no serious change in irrigated farming and rangeland areas, whereas the orchard area with a very small quantity of land occupancy has been increased by 13.5 times and the dry farming area has been declined by 50%. All these possible changes can be made within the areas qualified for each land use as depicted in Fig. 32.1. It is environmentally as well as economically preferred that some uses, mostly dry farming land use, to be changed to orchards, since the steep slope areas with high erosion rate and less production is traditionally converted to level terraces by the farmers when they develop orchards. Further, prior to change, the land needs to be precisely surveyed to avoid any hazardous unexpected problem. The linear optimization problem was successfully solved using the multipurpose ADBASE software program. The results also showed the successful linkage between economic aspects and environmental outcomes at a watershed scale. Because of changes considered in land use areas through optimization, the annual benefit enhanced from 21,001 to 24,911 mIR (i.e. 18.62% growth), whereas the annual soil erosion would decrease from 82,910 to 76,380 t (i.e. about 7.87% reduction). Such type of land use allocation not only satisfied all governing constraints exist in the study watershed but also ascertained socio-economic improvement, legitimate fulfillment and environmental sustainability.

Sensitivity Analysis

The sensitivity analysis was also performed for the benefit maximization as well as soil erosion minimization objective functions and the corresponding results have been depicted in Figs. 32.3 and 32.4, respectively. Scrutinizing the results of sensitivity analyses (Figs. 32.3 and 32.4) verify that the changes in objective functions in both cases are linear and they are mostly controlled by reduction in rather than increasing the resources. It can also be verified here that the change of some specific allocations would create much more impact on the final optimal solutions generated by the optimization programming in connection with variations of parameter values versus the relative changes of decision variables. It could also be implied from Fig. 32.3 that reduction in benefit has the highest sensitivity to the reduction of orchard and irrigated farming areas, whereas benefit increment is only sensitive to increase in orchard area. It is seen in Fig. 32.4 that the reduction of irrigated farming and orchard areas increased soil erosion drastically. On the other hand, reduction in rangeland area leads to increase soil erosion. In over all, the changes in benefit and soil erosion in Brimvand watershed is mainly controlled by variation in orchard and irrigated land uses.

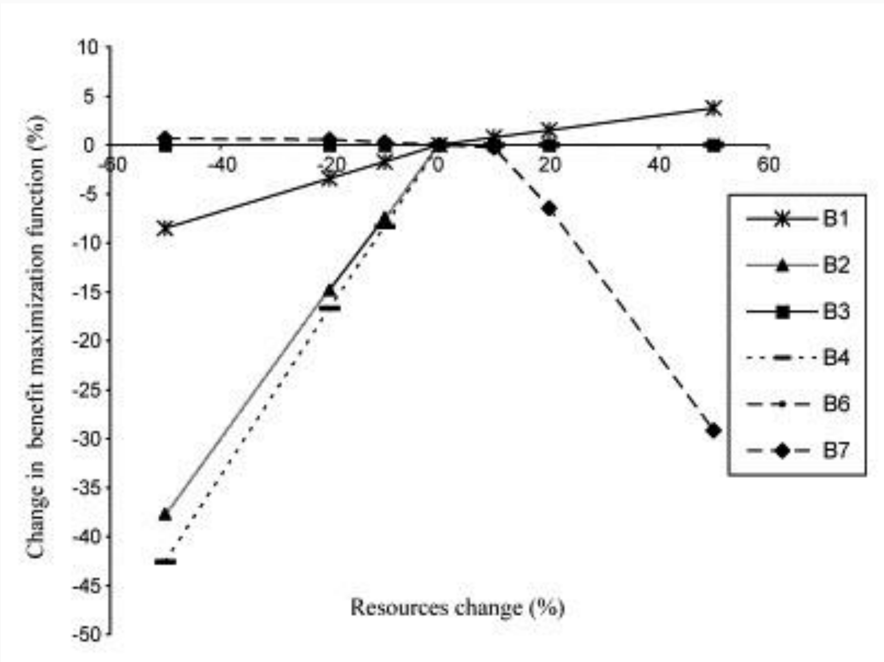


Fig. 32.3. Sensitivity Analysis of Benefit Maximization Function in Brimvand Watershed, Iran (B1, B2, B3, B4, B6 and B7 are Maximum Allowable Area to Orchard, Irrigated Farming, Dry Farming, Summation of Orchard and Irrigated Farming, Minimum Area of Orchard and Rangeland, Respectively). (Source: Sadeghi et al., 2009)

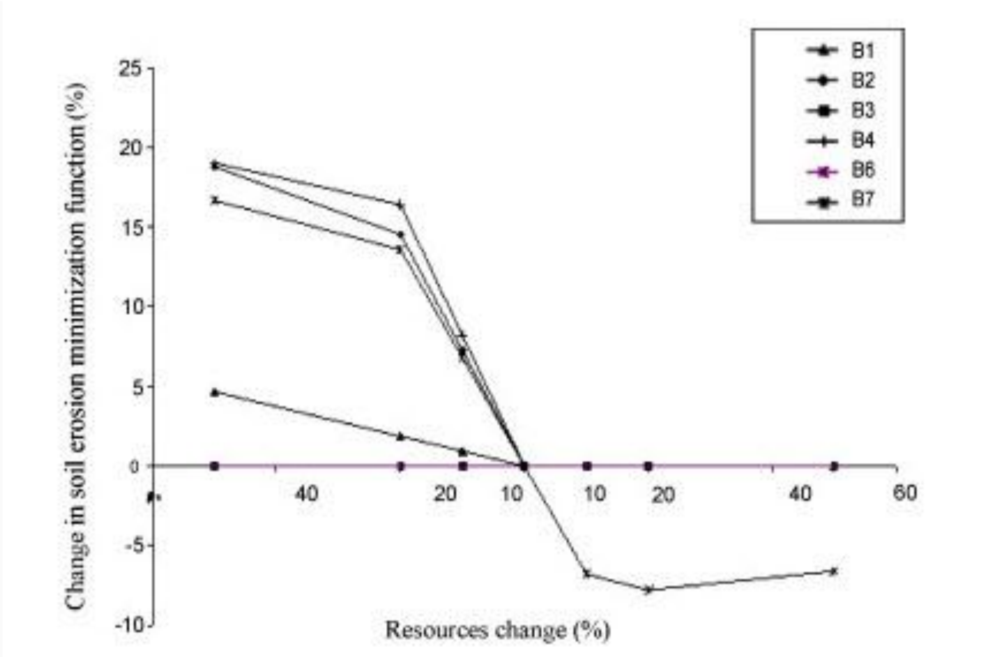


Fig. 32.4. Sensitivity Analysis of Soil Erosion Minimization Function in Brimvand Watershed, Iran (B1, B2, B3, B4, B6 and B7 are Maximum Allowable Area to Orchard, Irrigated Farming, Dry Farming, Summation of Orchard and Irrigated Farming, Minimum Area of Orchard and Rangeland, Respectively). (Source: Sadeghi et al., 2009)

Conclusion

A benefit and soil erosion problem was formulated and solved to minimize soil erosion and maximize benefits using optimization of allocation of land resources to orchard, range, irrigated and dry farming land uses within the Birmvand watershed in Kermanshah province, Iran. The ADBASE optimization software program was successfully applied and led to determine appropriate areas allotted to different land uses. The results obtained during the study approved the applicability of optimization model in solving problems, which sometimes conflicting each other. It can also be concluded that contrary to single objective classical land use planning models, the multi-objective linear programming can be used to tractably search for optimum land use scenarios with respect to different governing constraints existing within a watershed. On the study watershed there appears a significant reduction in soil erosion and augmentation in profit from allocating the optimal land uses.

Keywords: Optimal Land Use, Watershed Processes Simulation, Case Studies, India.