WATERSHED PLANNING AND MANAGEMENT

UNIT I

INTRODUCTION

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

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 classificationgested 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 pl. 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 sug ants 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.

1.2Scope 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.

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.

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.

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.

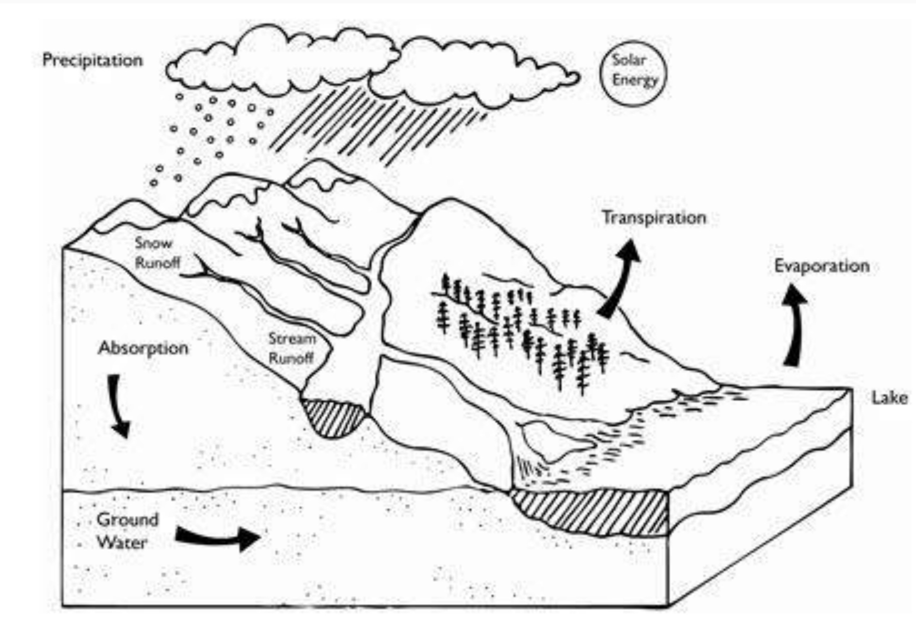


Fig. 5.1. A Watershed Illustration. (Source: Rees, 1986)

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

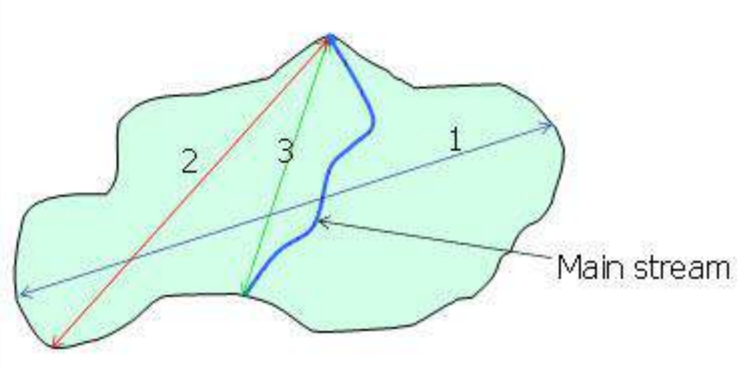


Fig. 5.2. Diagram Defining Basin Length. (Source: Zavoianu, 2011)

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)

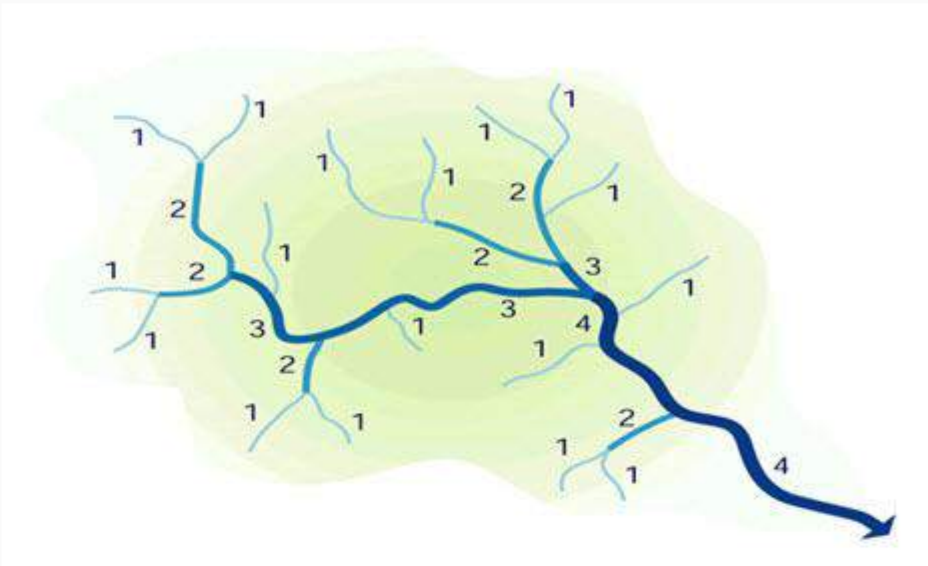


Fig. 5.3. The Horton-Strahler ordering scheme.

(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

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

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.

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.

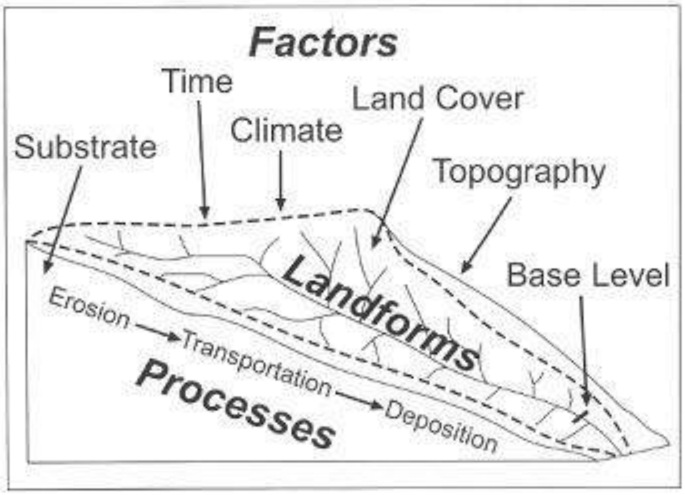


Fig. 6.1. Watershed Processes.

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.

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.

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. 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.

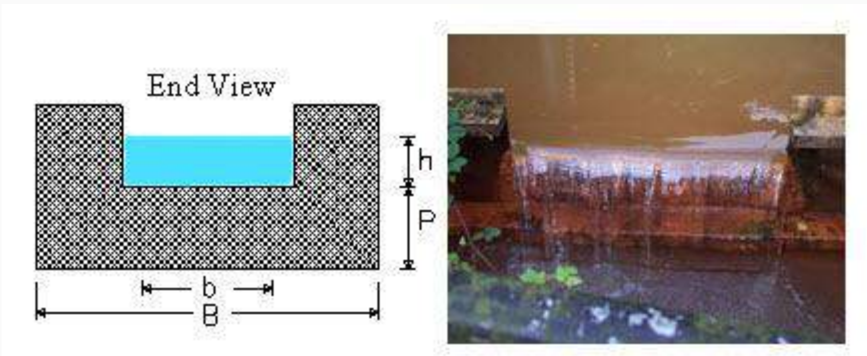


Fig. 12.1. Rectangular Weir.

(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

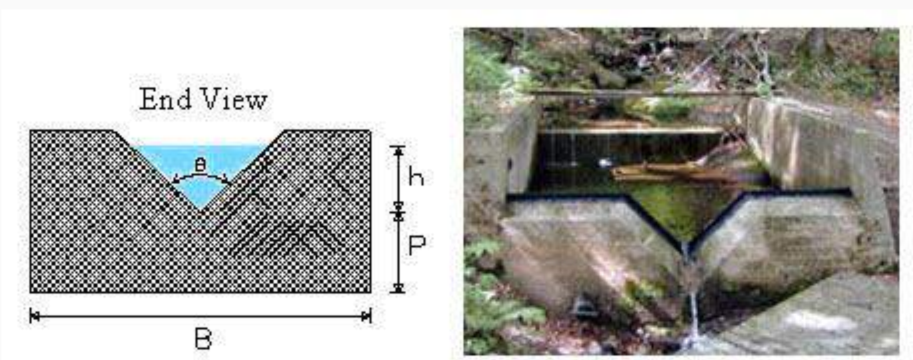


Fig. 12.2. 90° V-notch Weir.

(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.

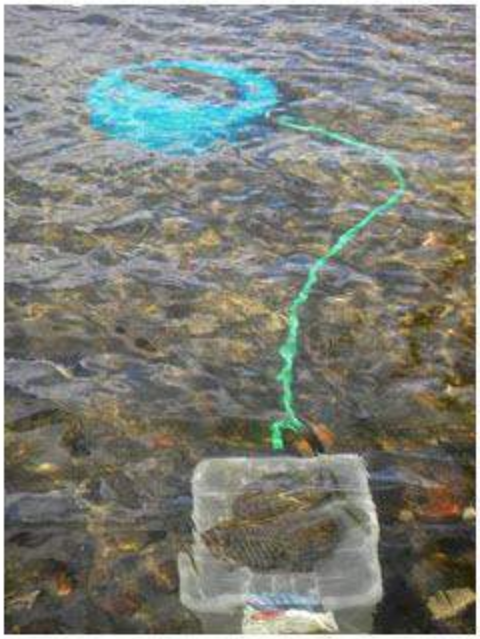


Fig. 12.3. Seepage Meter.

(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.

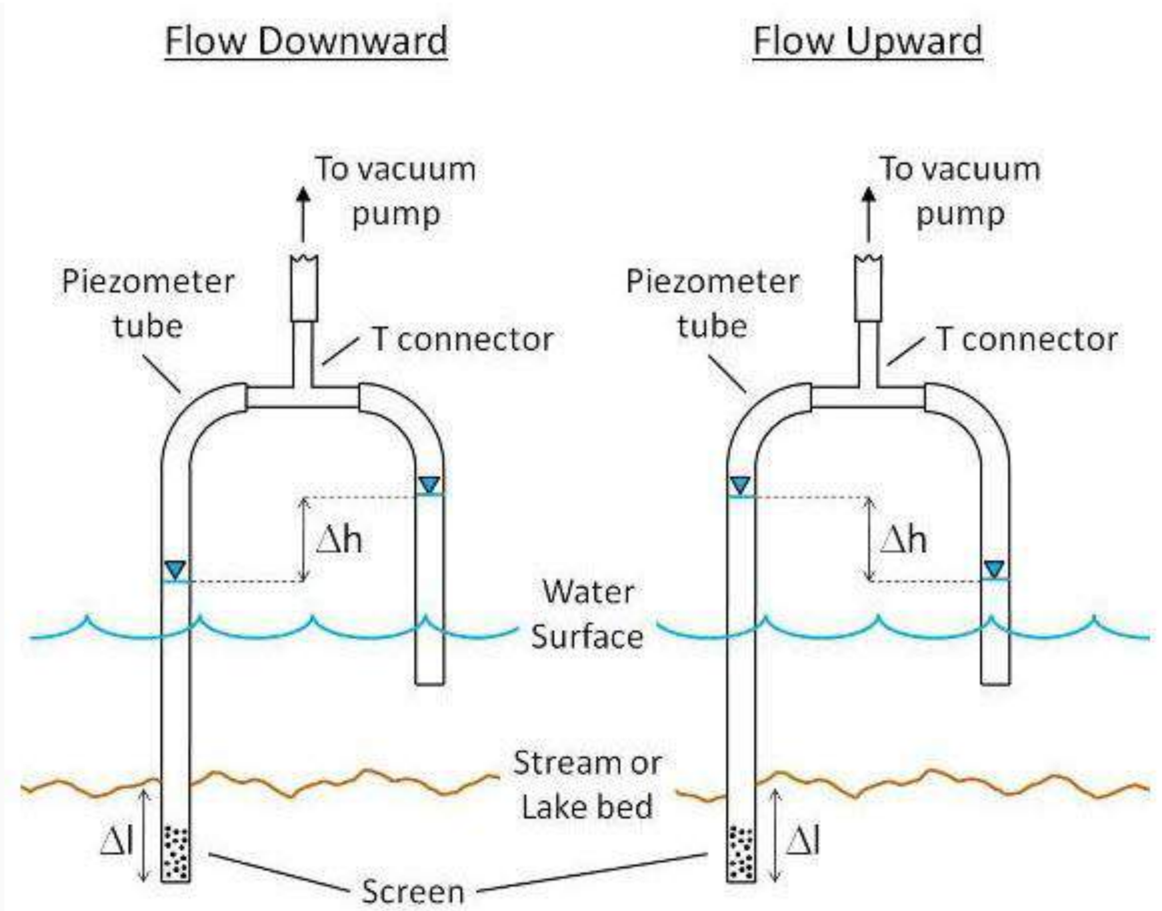


Fig. 12.4. Flow Downward (Left) Indicated by the Surface Water Level > Groundwater Level and Flow Upward (Right) Indicated by the Surface Water Level < Groundwater Level. (Source: Christopher, 2013)

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.

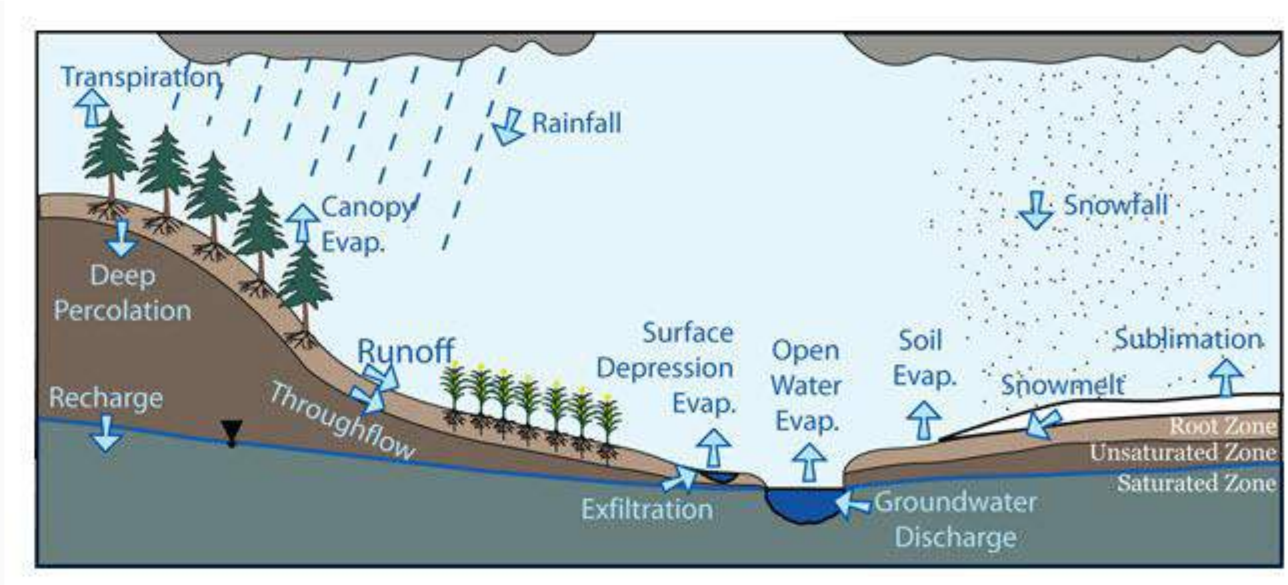


Fig. 2.5. Hydrological Cycle showing Runoff Processes.

(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).

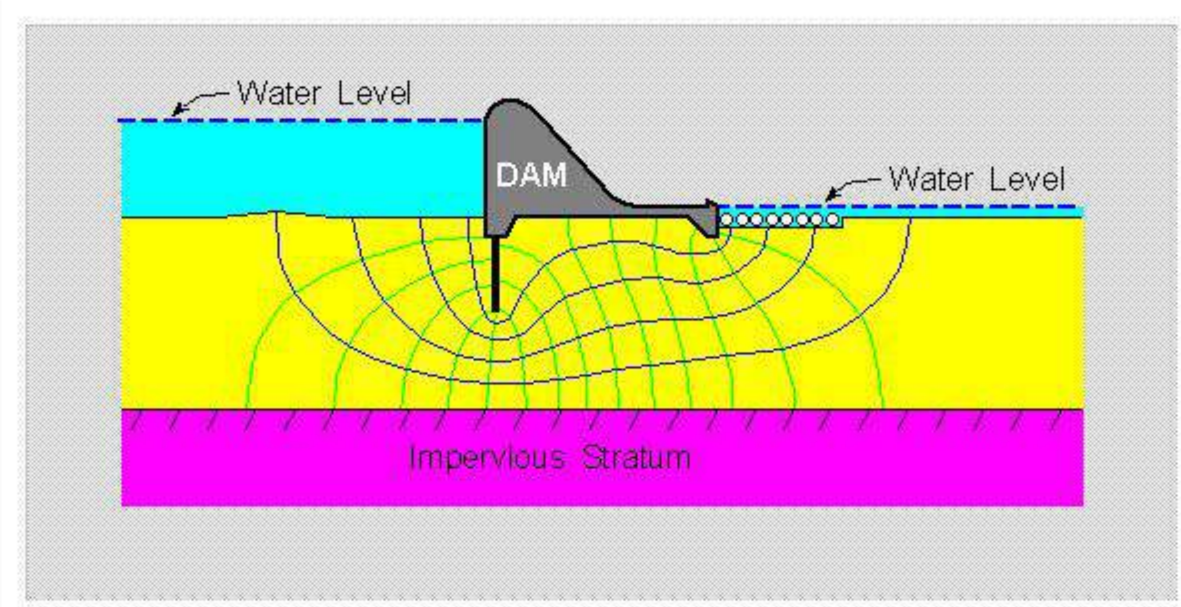


Fig. 12.6. Example of Flow Net Beneath a Dam Structure.

(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.

4.

UNIT –II

WATERSHED PLANNING

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:

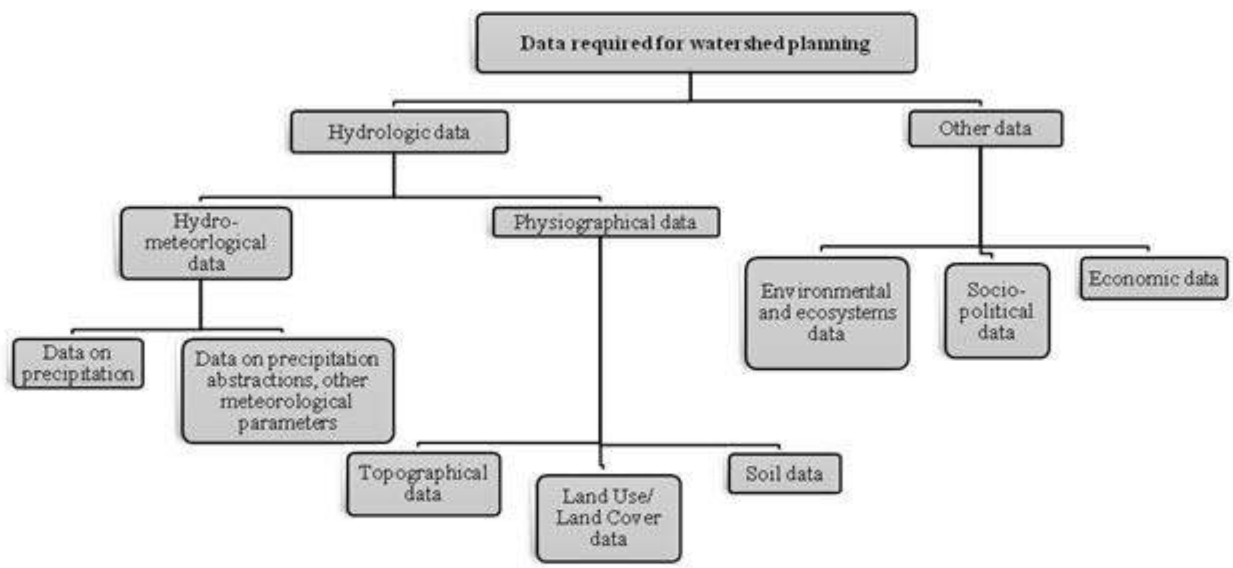


Fig. 7.1. Grouping of the data required for watershed planning.

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.

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.

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.

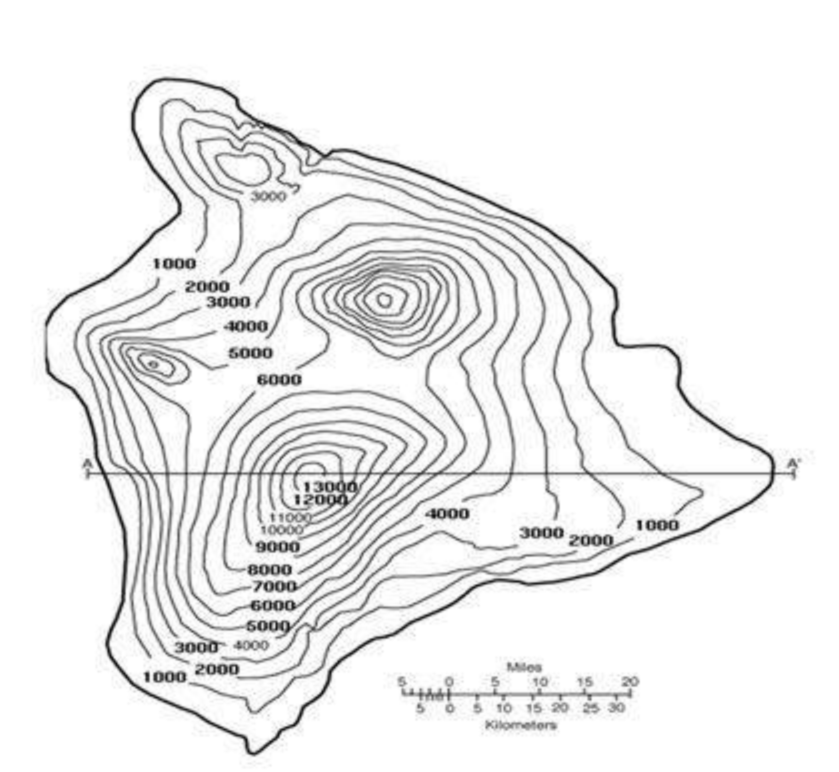


Fig. 9.1. A Typical Contour Map. (Source: http://volcano.oregonstate.edu/vwdocs/vwlessons/land_pics/a6.3.gif)

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.

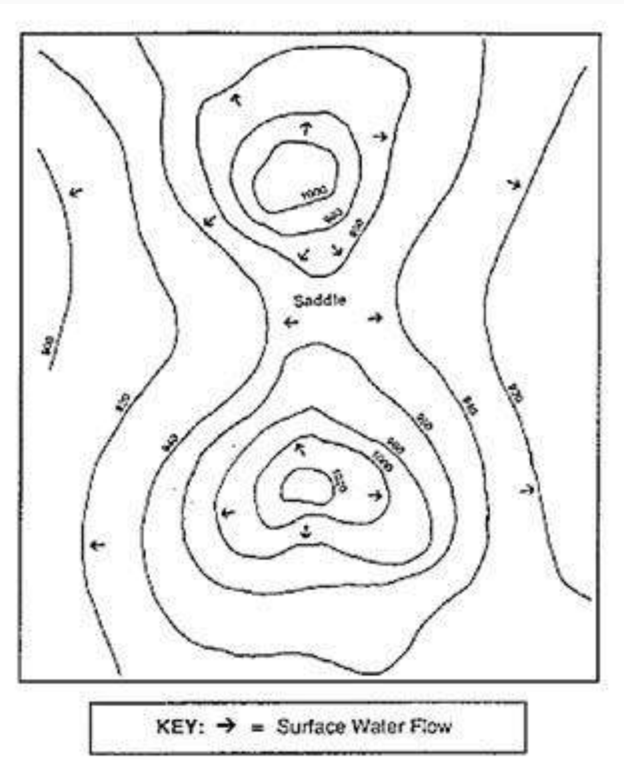


Fig. 9.2. Saddle. (Source: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nh/programs/planning/wsp/?cid=nrcs144p2_015706)

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)

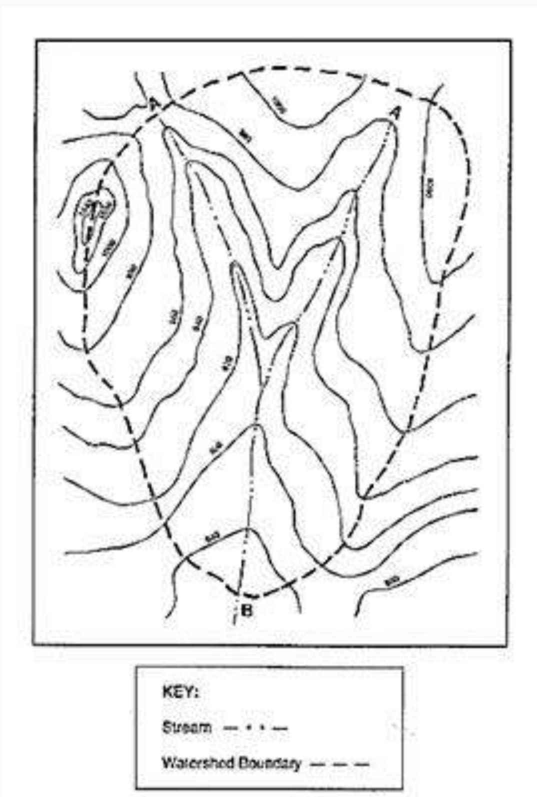


Fig. 9.3. Delineated Watershed Boundary. (Source: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nh/programs/planning/wsp/?cid=nrcs144p2_015706)

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.

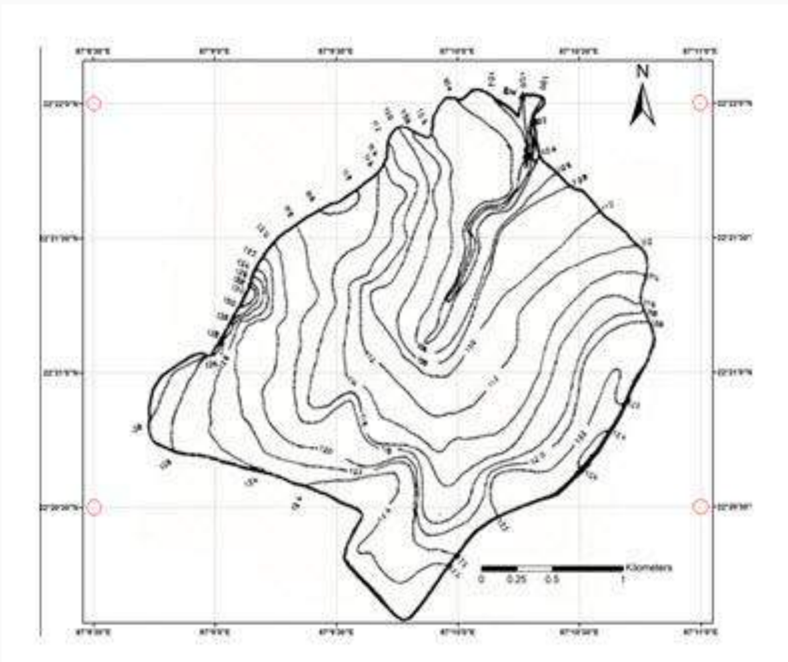
Information obtained from a GIS-based watershed analysis can include data such as watershed area, watershed climate statistics, soil/geology types, topographic statistics, hydrology, and land use.

Steps for using GIS to Delineate Watershed

9.3.1 Preparation of Digital Elevation Model (DEM)

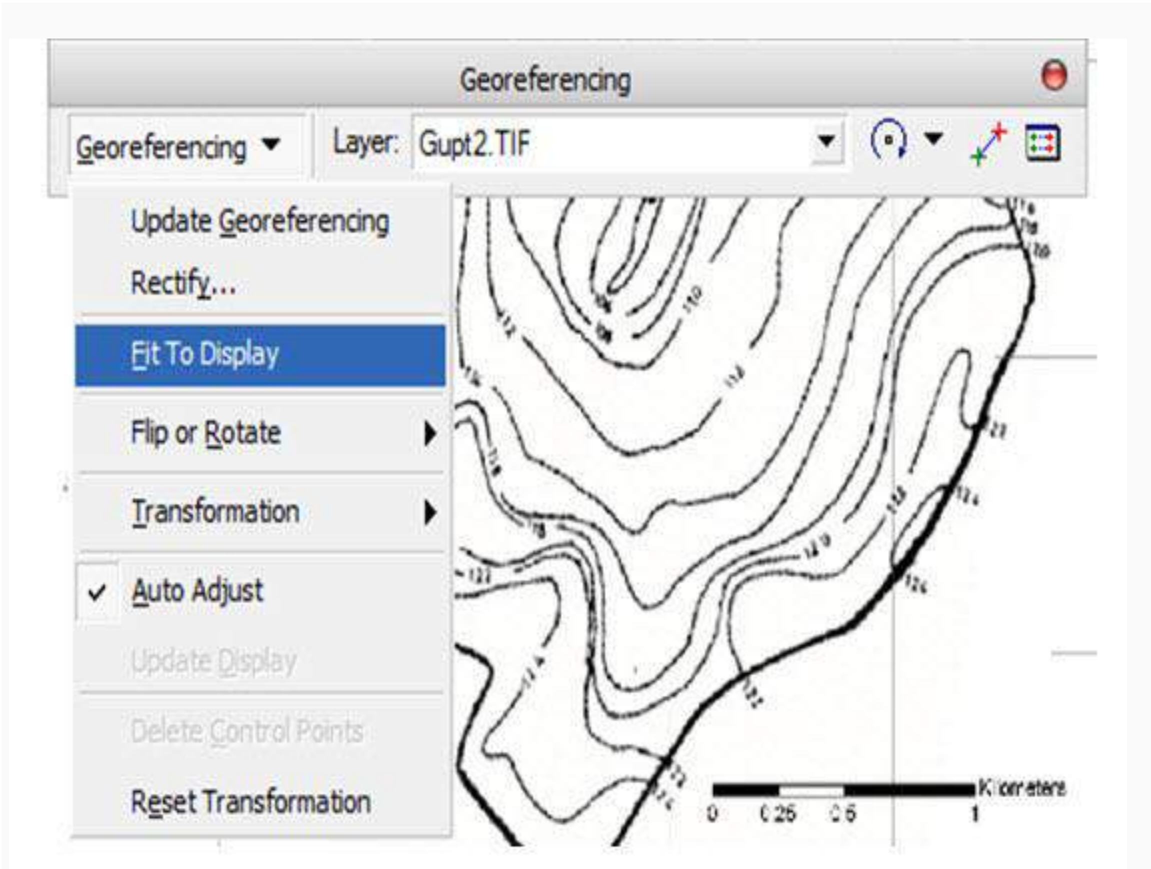
Step 1: Scanning of Topographic Map (Contour Map)

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

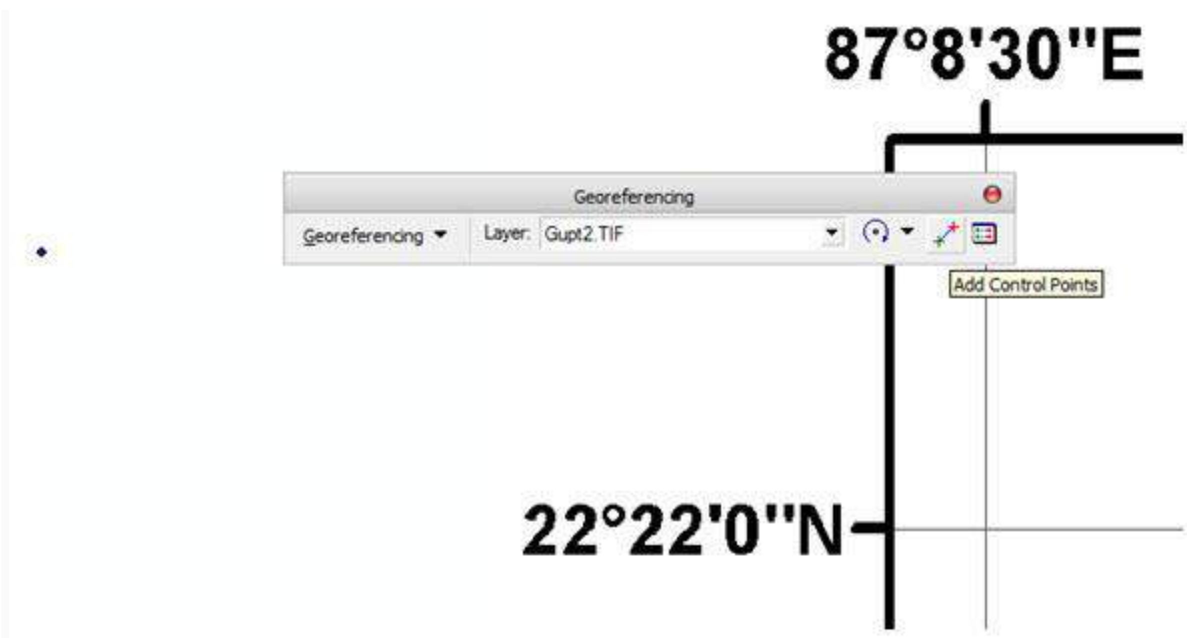


Step 2: Geo-referencing Scanned Map in ArcMap

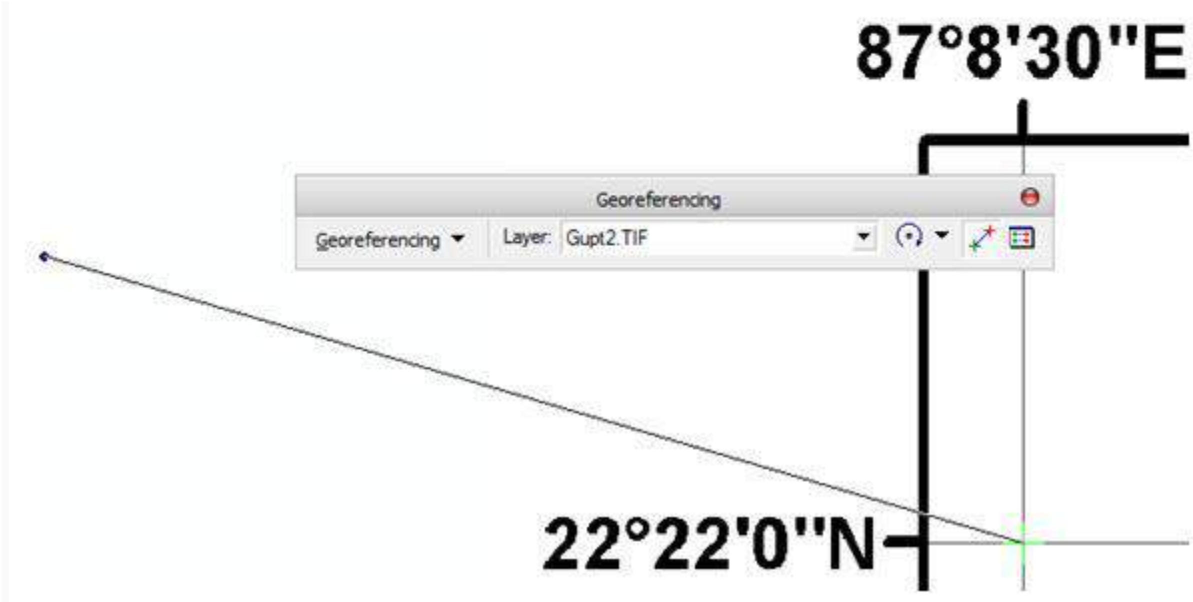
1. The process of geo-referencing a raster map requires at least four known geo-coordinates.
2. Identify four coordinates and convert them to decimal points.
3. Use Geo-referencing toolbar in ArcMap for image rectification (geo-referencing).
4. Geo-referencing - Fit To Display.



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



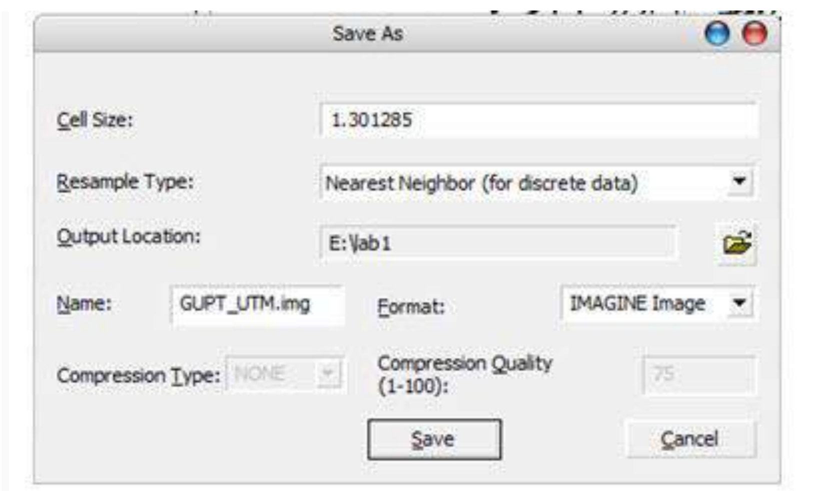
7. First click on coordinate in scanned map actual coordinate



8. Similarly complete this for other three points

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

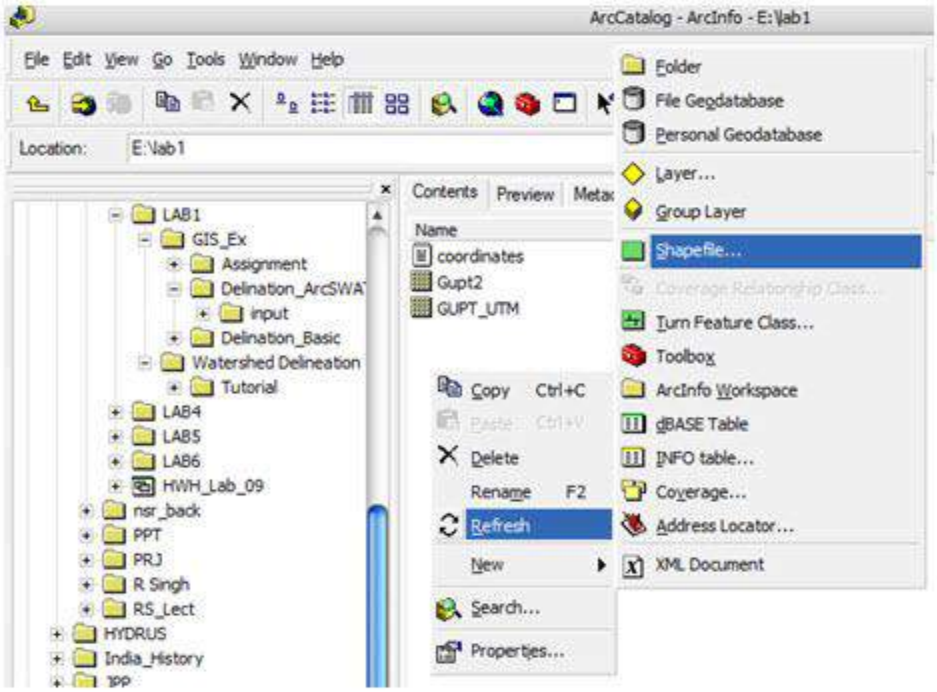
10. Geo-referencing Rectify



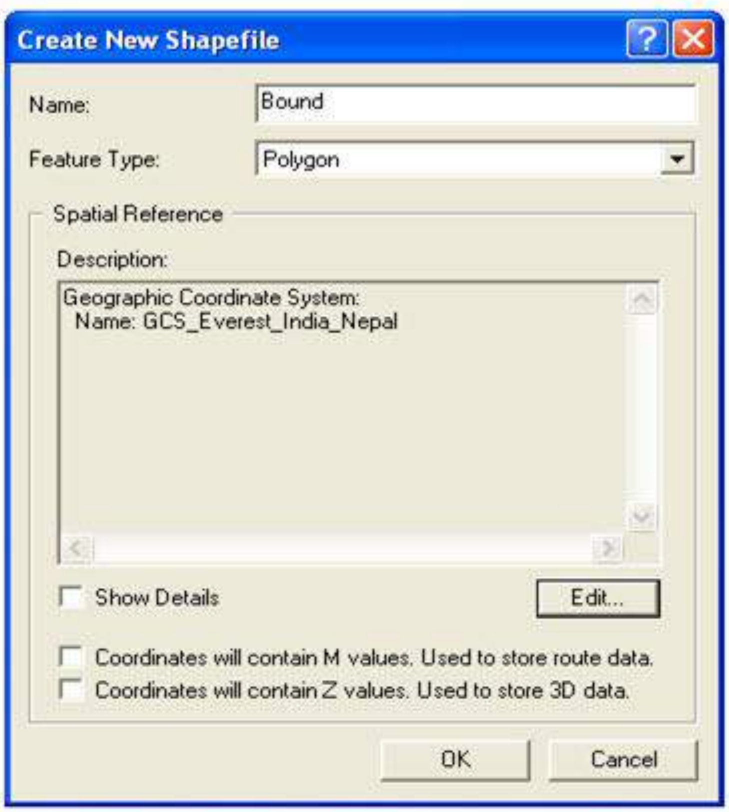
11. The rectified image can be reprojected to UTM WGS 84 system.

Step 3: Onscreen Digitization

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



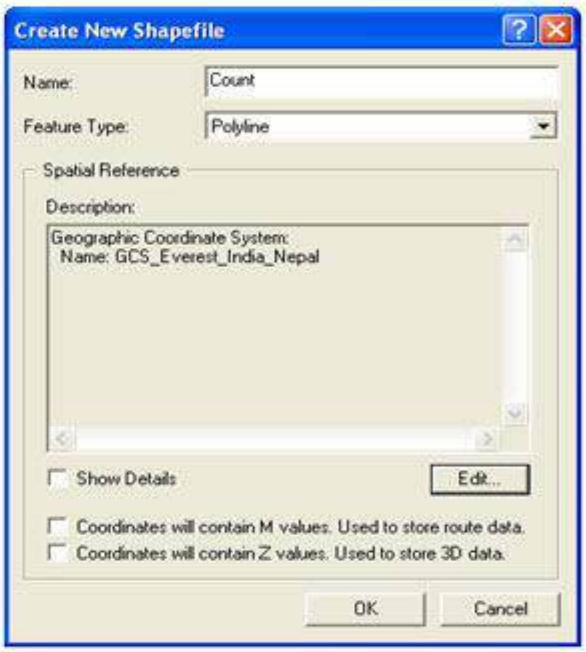
2. Select feature type as polygon and assign a spatial reference system to it.



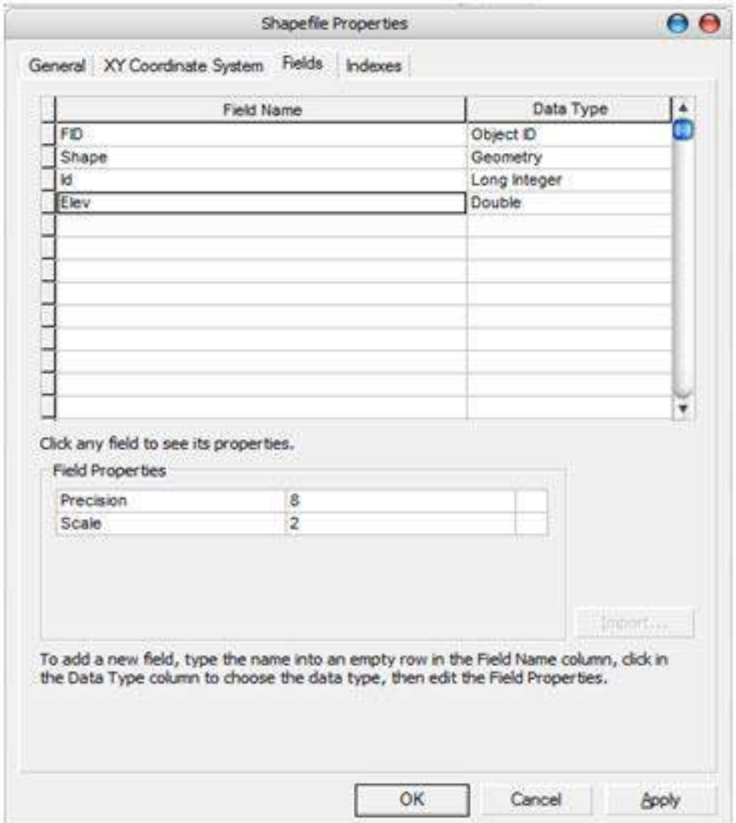
3. Now, go to ArcMap and add this layer. Open Editor Toolbar in ArcMap.

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.

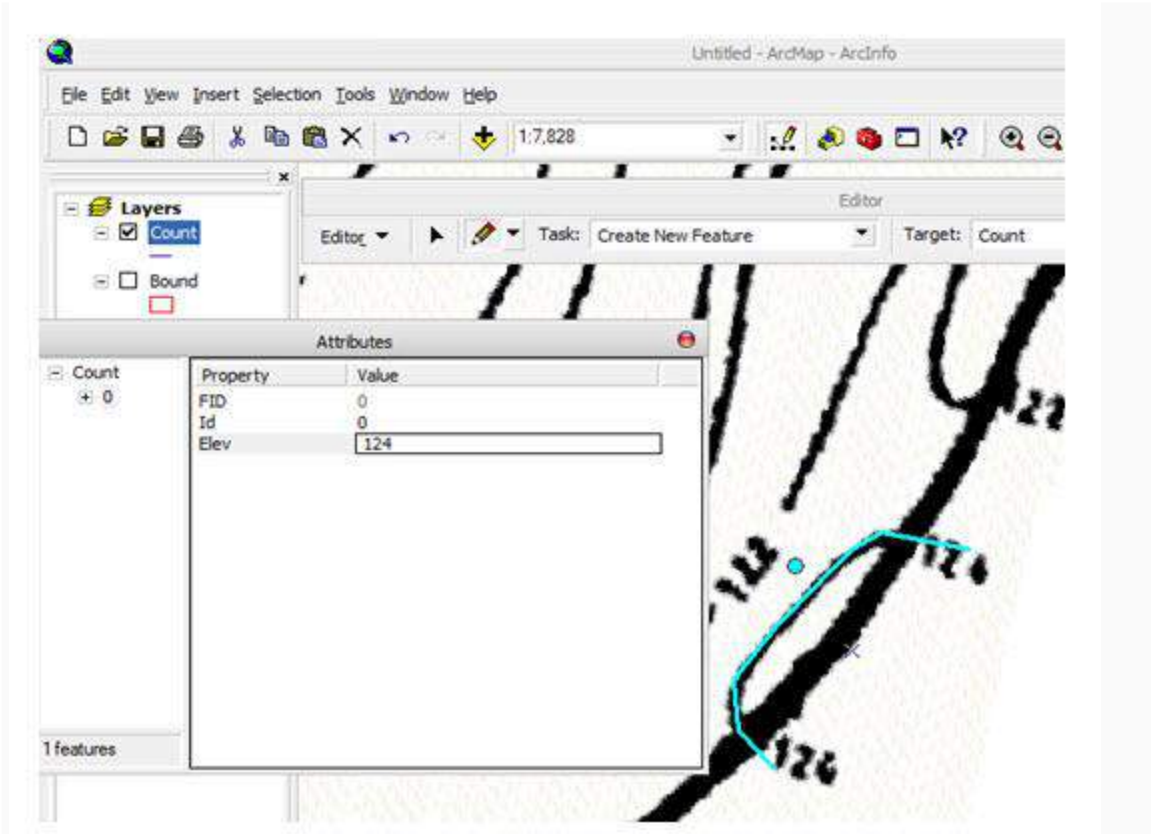
5. Contour line: Create another shape file (say count). This will be a polyline feature and assign a spatial reference system.



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

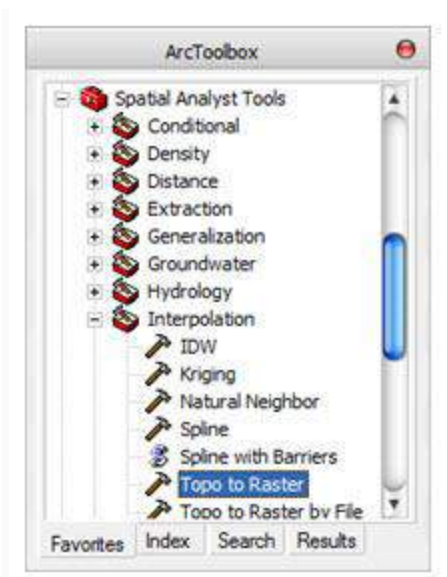


7. Now, digitize all the contours as mentioned above and enter elevation value to each contour in the elev field. Save it and to stop editing, click stop editing.



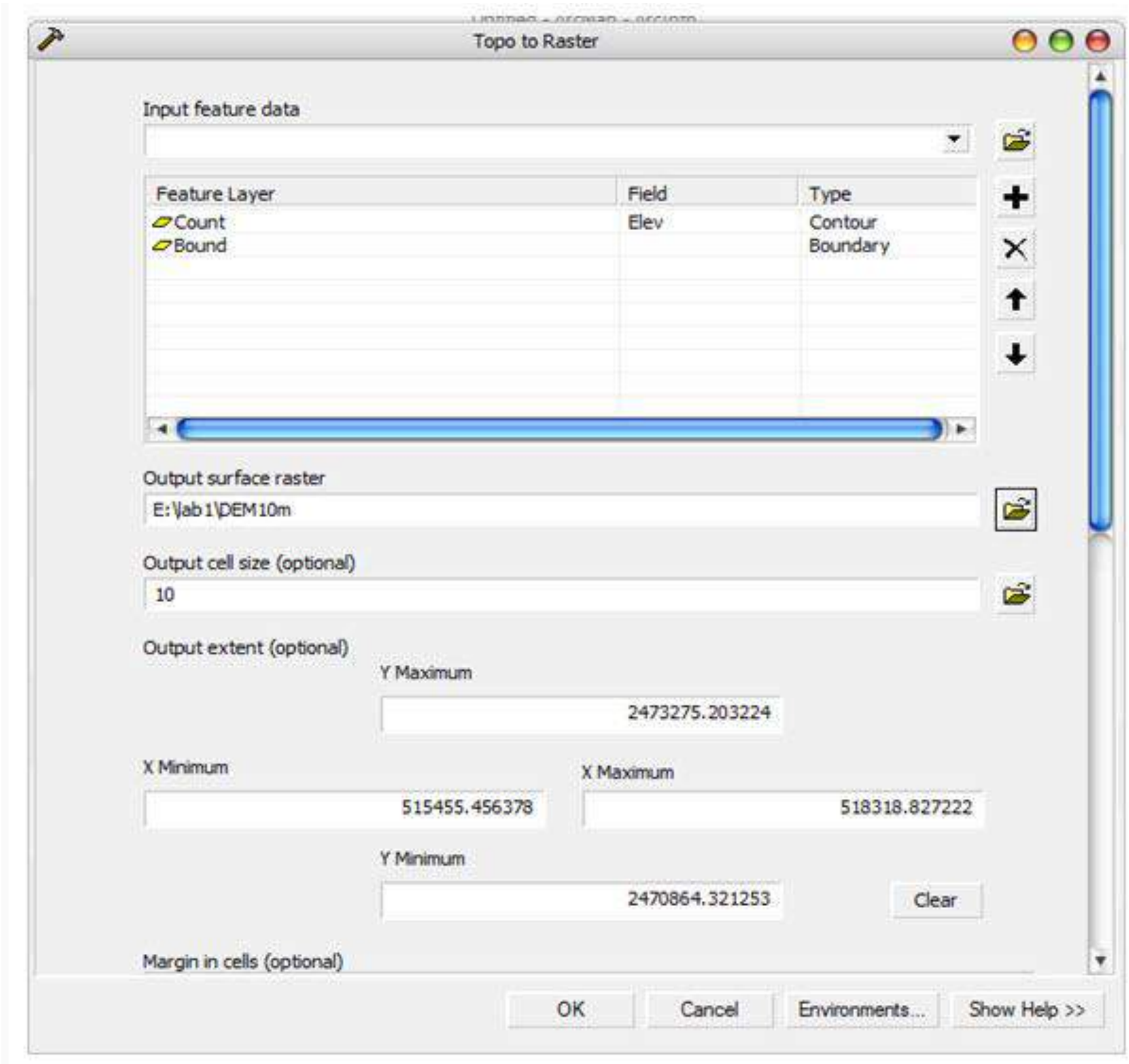
Step 4: DEM Creation (Interpolate to Raster)

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

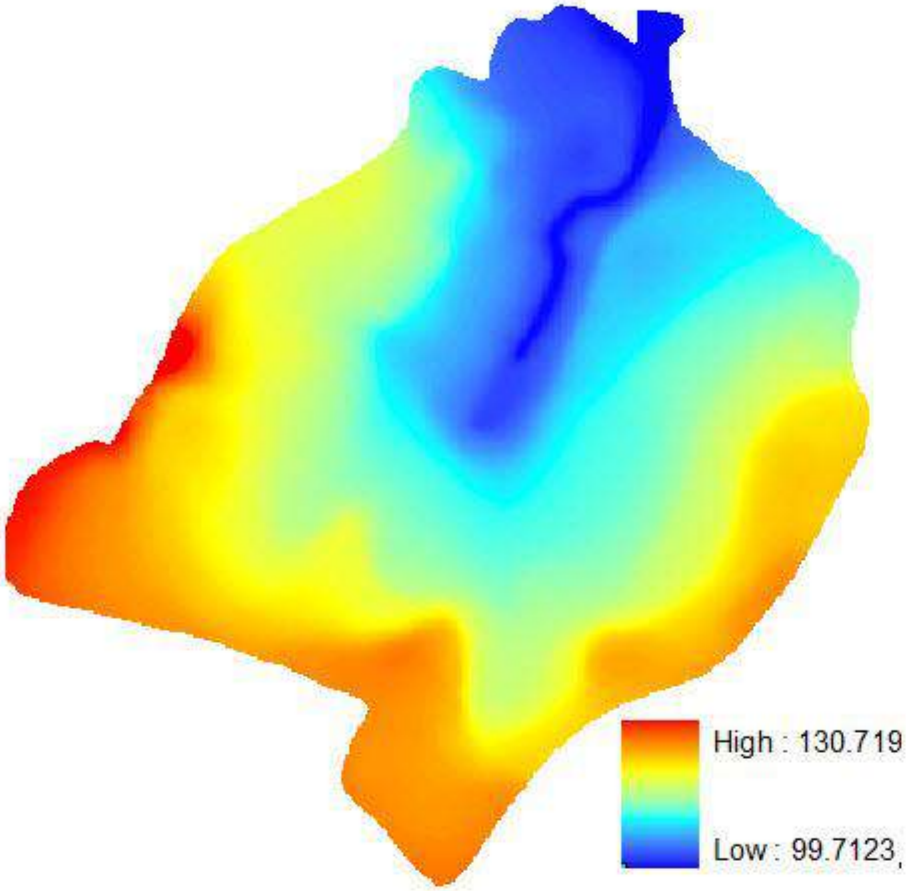


2. In the input feature data, provide both the shape files (count and bound).

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.

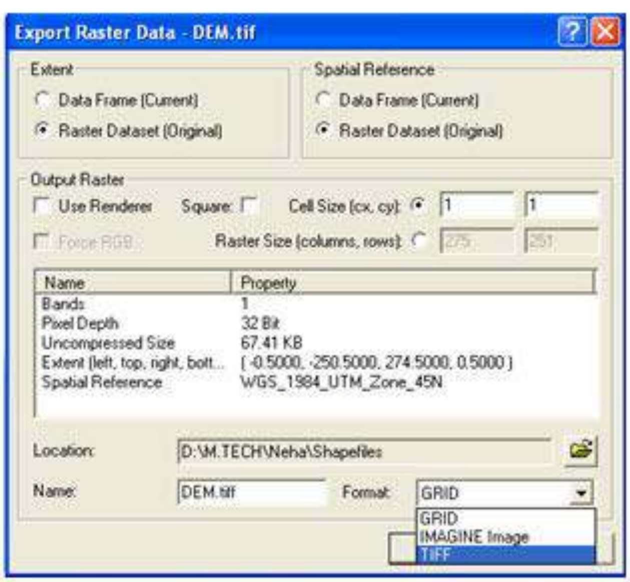


6. Final DEM may look like this

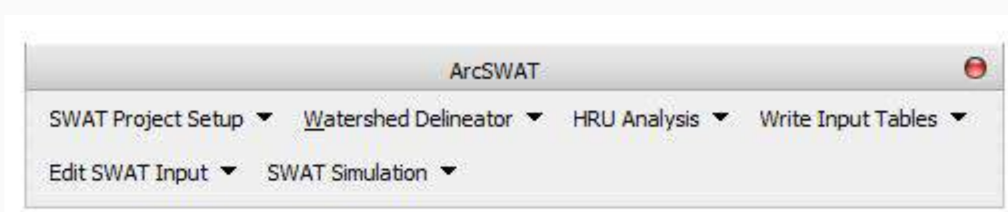


9.3.2 Steps for Delineating a Watershed using GIS based Model - ArcSWAT

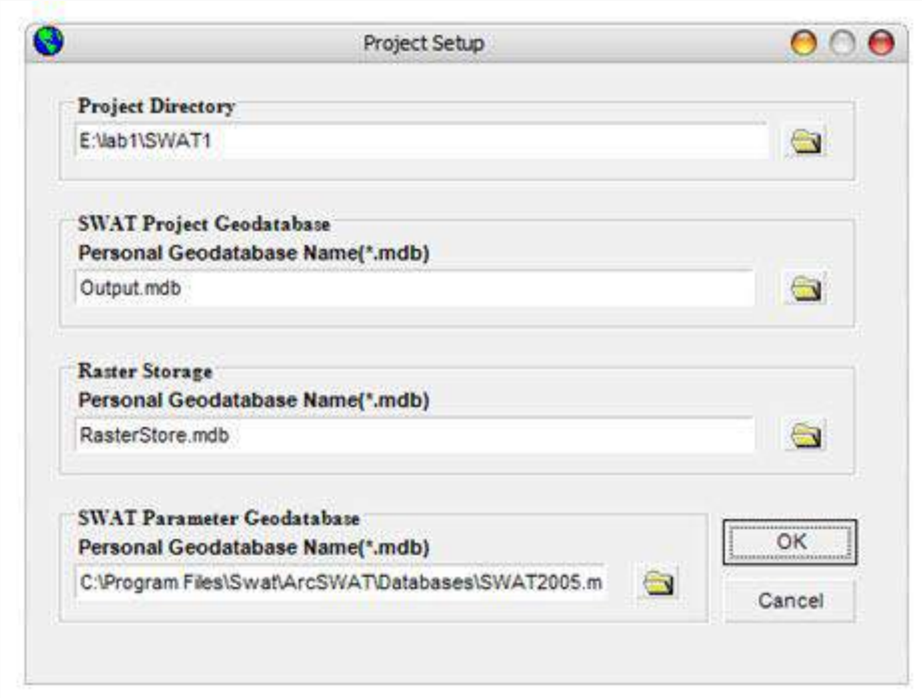
Step 1: Export the DEM from image (img.) file to TIFF file and save it again.



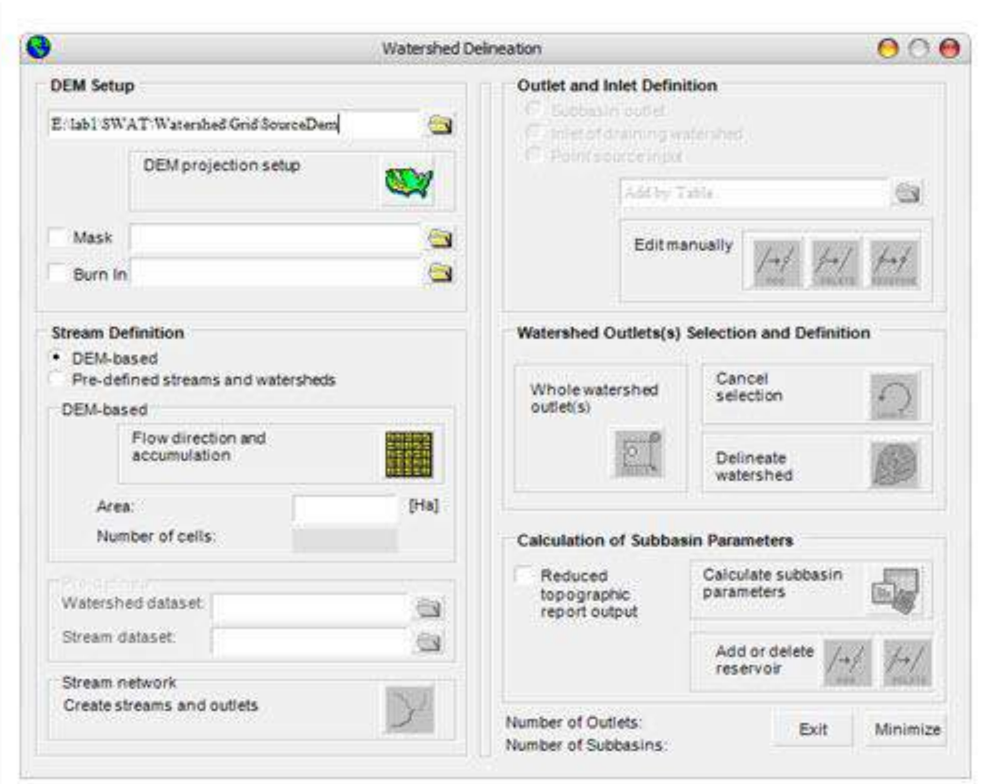
Step 2: Open the ArcSWAT toolbar



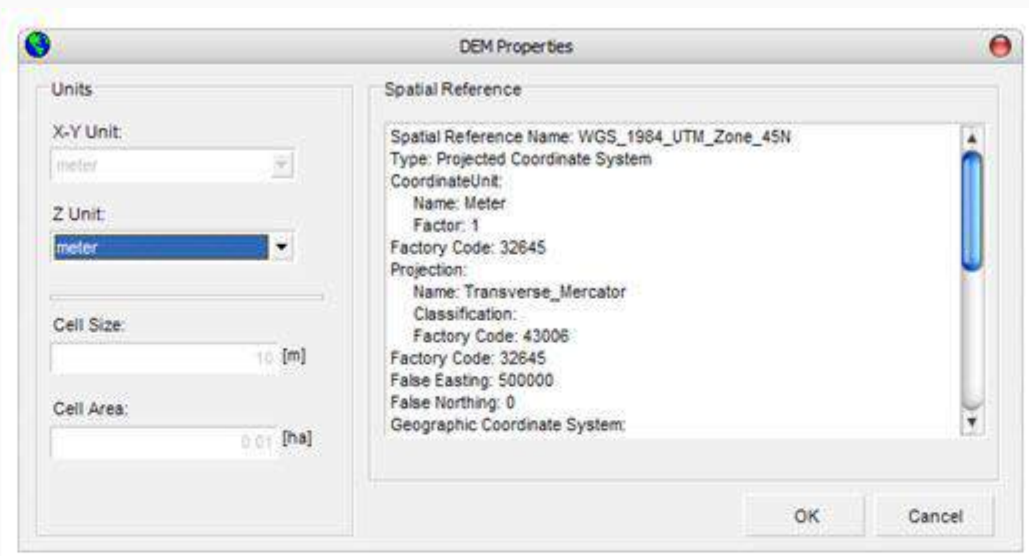
Step 3: Go to SWAT Project Setup, choose New SWAT Project to open the dialog below. Select a suitable project directory.



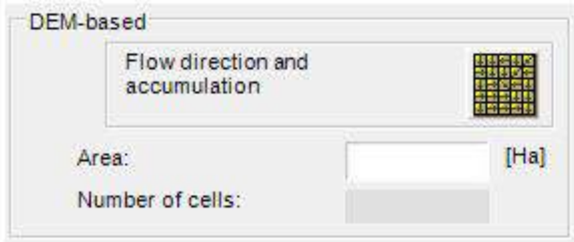
Step 4: Go to Watershed Delineator choose Automatic watershed delineator to bring the watershed delineation window. Load the DEM.tiff.



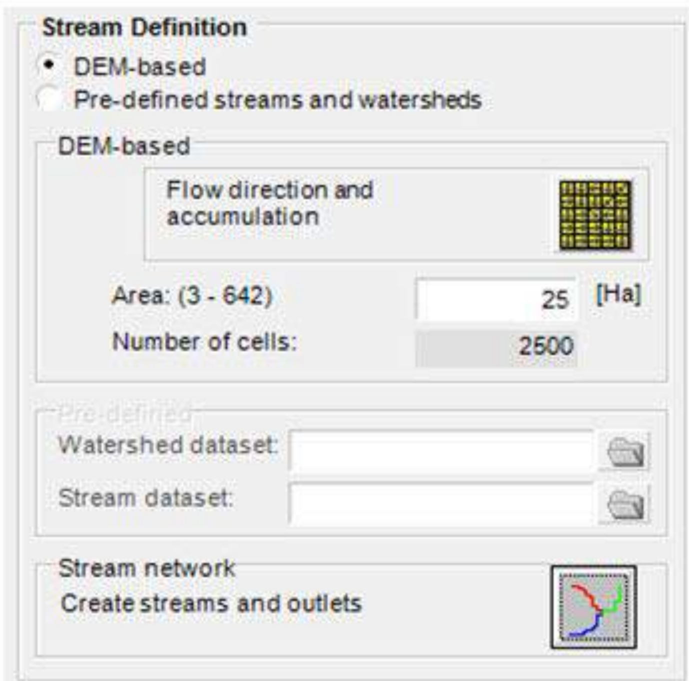
Step 5: In DEM projection setup set Z Unit to meter.



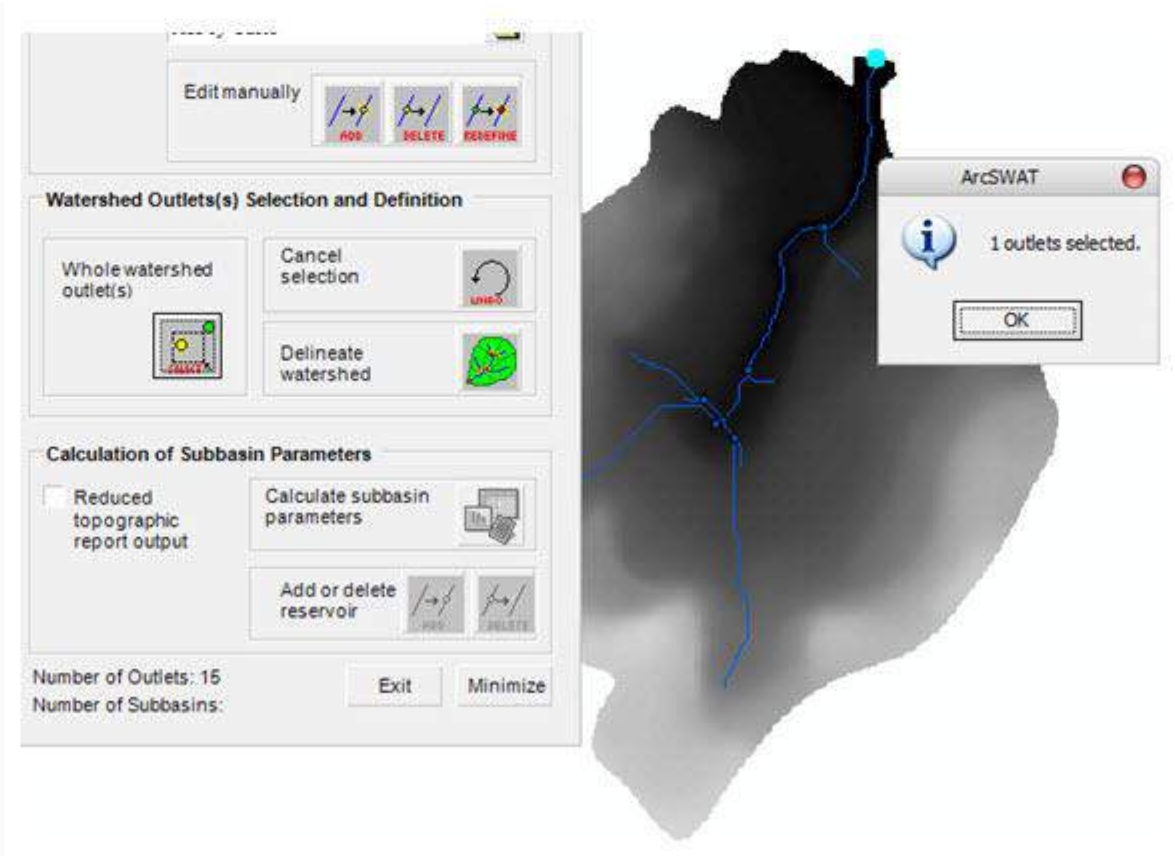
Step 6: Click on the flow direction and accumulation.



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.

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

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.

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.

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).

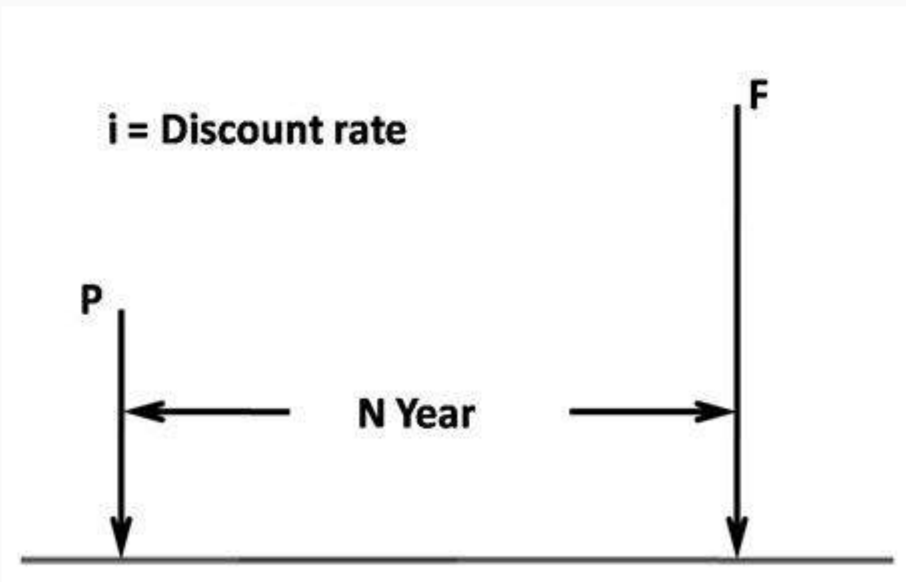


Fig. 30.1. Single-payment factors (a) Single-payment compound amount factor = F/P, (b) Single payment present worth factor = P/F.

(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

$$A = F\frac{\mathbf{i}}{(\mathbf{1}+i)^N - \mathbf{1}} \qquad (15.3)$$

Where, $\frac{\mathbf{i}}{(\mathbf{1}+i)^N - \mathbf{1}}$ 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,

$$A = P\,\frac{i(1+i)^N}{(1+i)^N - \mathbf{1}} \qquad (15.4)$$

Where, $\frac{i(1+i)^N}{(1+i)^N - \mathbf{1}}$ 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.

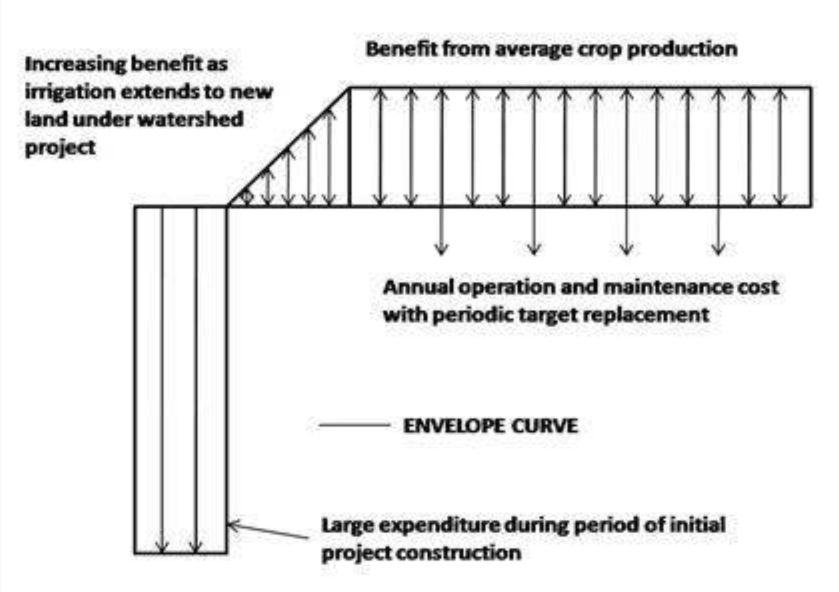


Fig. 30.2. Cash flow diagram for hypothetical irrigation project.

(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

UNIT III

WATERSHED MANAGEMENT

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.

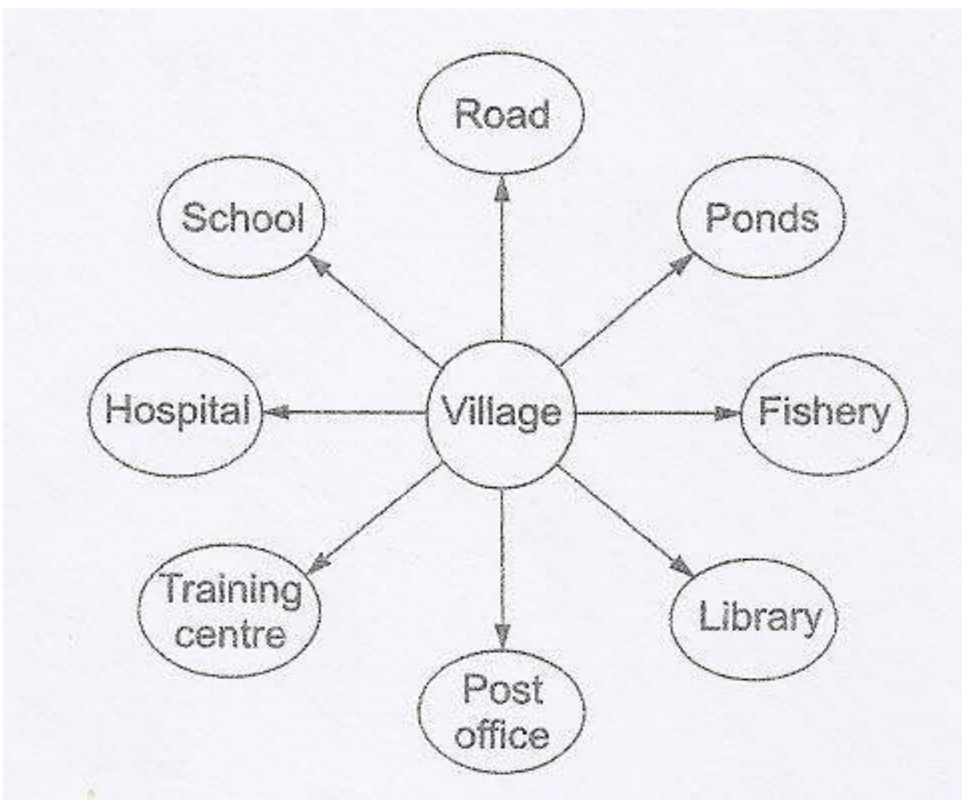


Fig. 25.1. A typical Venn diagram used in participatory rural appraisal (PRA). (Source: Das and Saikia, 2013)

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.

Runoff

10.1 Introduction

There are a number of definitions of runoff that have been used either explicitly or implicitly in hydrological analyses over the years. Runoff is the part of the rainfall over a catchment area that eventually leaves the catchment as a surface stream flow, whatever is the flow pathway that the water has followed on its way to the stream channel. Thus this definition includes both surface and subsurface runoff pathways.

10.1.1 Runoff Processes in Rural Areas

In arid and semi-arid regions with scarce vegetation and those disturbed by humans (urbanization, etc.), infiltration capacity is a limiting factor and Hortonian overland flow is the dominant process. This also happens when the top soil is frozen. In most humid regions, subsurface flow and saturation overland flow are dominant processes. Where the soils are well-drained, deep and very permeable, the water table is deep and the saturated zone is confined to the valley floor. Saturated overland flow is less important than subsurface flow in this situation. Where the soils are thin, only moderately permeable, and slope is gentle and concave shaped, the water table is shallow and the saturated zone expand readily, the saturated overland flow dominates in this situation.

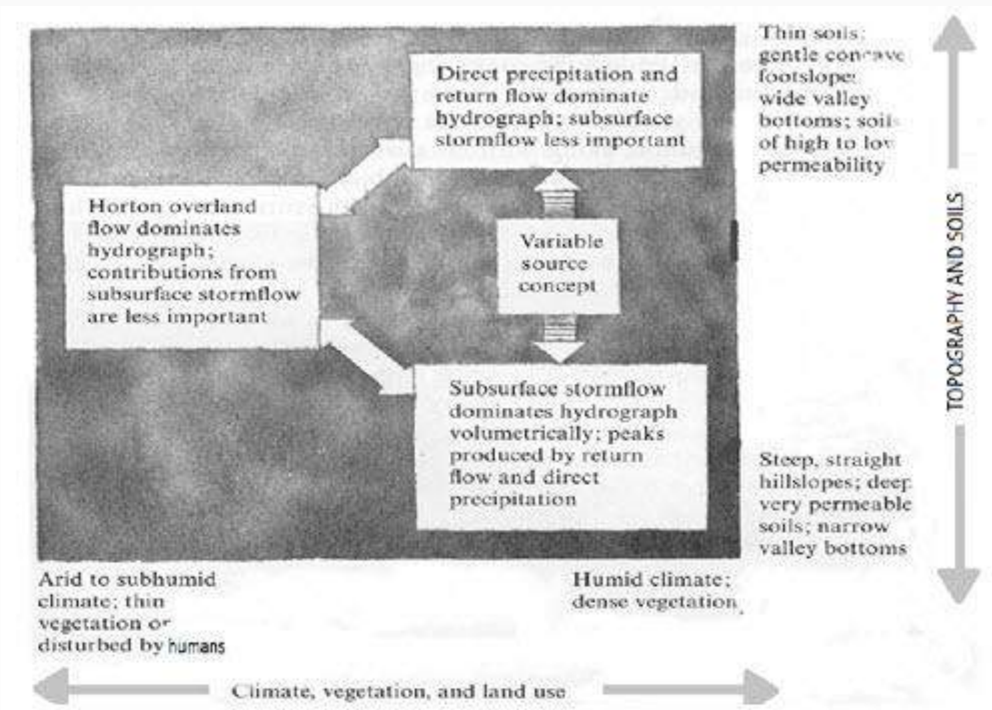


Fig. 10.1. Runoff process for different soils, vegetation and land use. (Source: http://people.ucalgary.ca/~hayashi/geog515/lectures/515_0607.pdf)

10.1.2 Runoff Processes in Urban Areas

Modification of the land surface during urbanization changes the type and magnitude of runoff processes. Covering parts of the catchment with impervious roofs and concrete lots increases the volume and rate of Horton overland flow. Planners have to design detention ponds to accommodate increased runoff. Gutters and storm sewers convey runoff rapidly to stream channels. The channels are straightened and lined with concrete to increase the efficiency, so that they transmit the flood wave downstream more quickly. A storm hydrograph after urbanization has larger peak flow and shorter lag time than before. The capacity of culverts and bridges are overtaxed and residential areas become flooded during large storms.

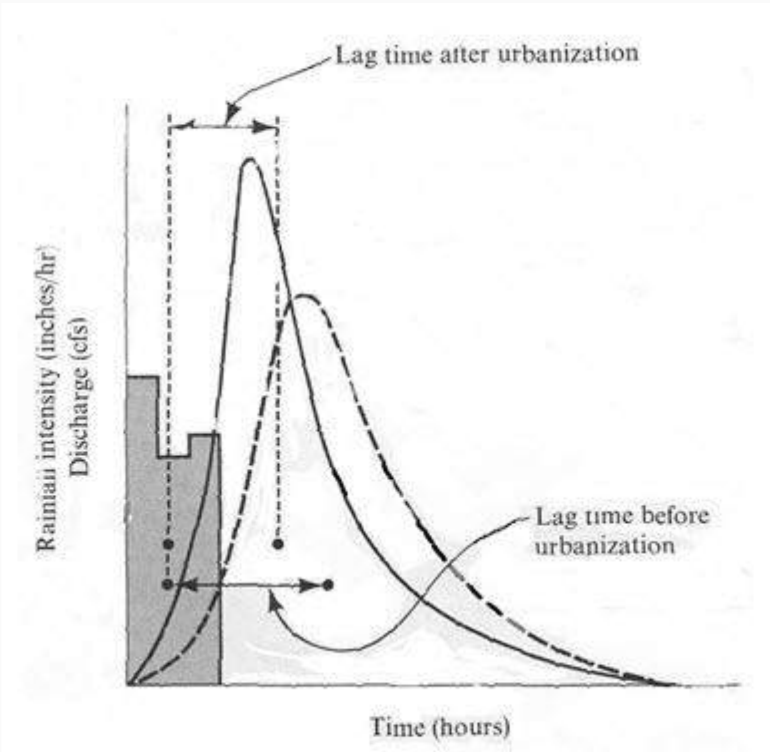


Fig. 10.2. Effects of urbanization on storm hydrographs. (Source: http://people.ucalgary.ca/~hayashi/geog515/lectures/515_0607.pdf)

10.1.3 Human Activities Affecting Runoff

As population grows and as more development and urbanization occur, more of the natural and pervious landscape is replaced by impervious surfaces, such as roads, houses, parking lots and buildings that reduce infiltration of water into the ground and accelerate runoff to ditches and streams. In addition to increasing imperviousness, deforestation, grading of land surface, construction of drainage networks increase runoff volumes and shorten runoff time into streams from rainfall and snowmelt. As a result, the peak discharge, volume, and frequency of floods increase in streams.

10.1.4 Runoff Cycle

It is that part of hydrological cycle which falls between the phase of precipitation and its subsequent discharge in the stream channels or direct return to the atmosphere through evaporation and evapotranspiration.

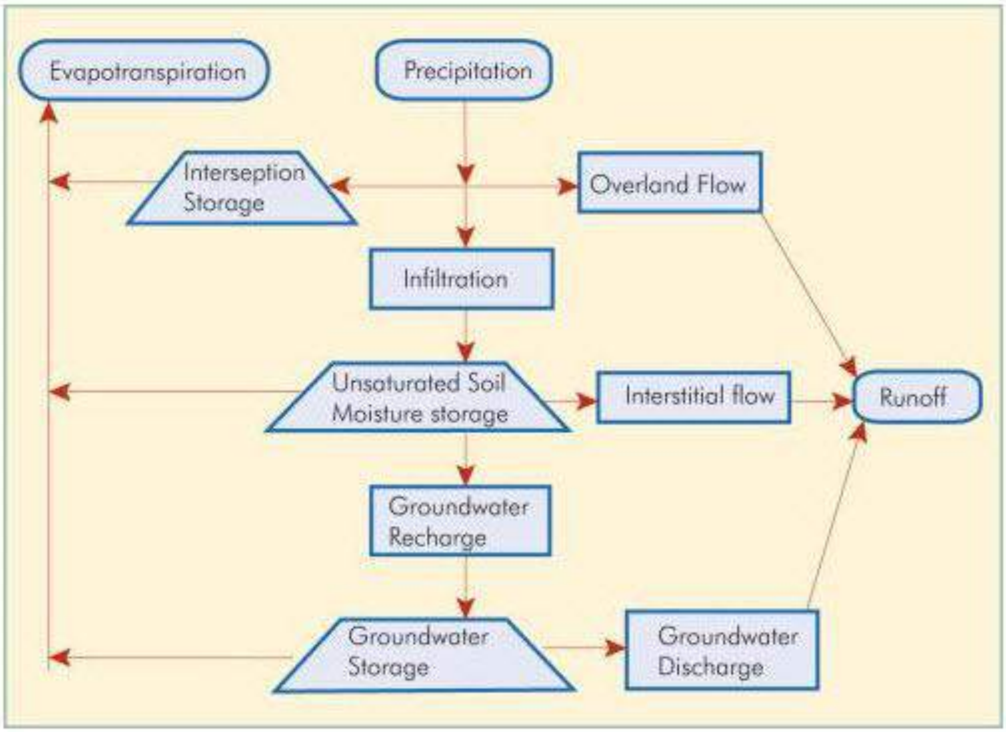


Fig. 10.3. Runoff cycle. (Source: http://texeresilk.com/jquery/14/runoff-cycle)

10.1.5 Conditions Associated With Runoff Cycle

1. As a result of occurrence of a storm rainfall event, from the water that reaches the land surface after satisfying in interception by the vegetation, temporary surface and channel storage build up. The water then starts flowing governed by gravity force when the localized depressions are filled up by water.

2. This process continues simultaneously with infiltration and the channel flow component increases, flowing towards larger streams, tributaries and rivers. The infiltrated water first fills up soil pores in the upper soil layers after which the excess water joins the groundwater table.

3. After this stage and when the rainfall stops, there is no further supply of water and the channel flows start depleting. Meanwhile, the larger surface depressions, ponds, lakes and reservoirs gradually get replenished.

4. The flow that continues thereafter through the rivers flow towards the seas and the oceans.

10.2 Types of Runoff

Based on the time lag between rainfall and runoff, it may be classified in to the following three types:

1. Surface runoff.
2. Sub - surface runoff, and
3. Base flow.

1. Surface Runoff

It is the portion of rainfall which enters the stream immediately after the rainfall when the localized depressions are filled up and the top soil layer is saturated. The short journey of this water flowing over the land as a sheet of water is also called overland flow. This overland flow soon finds paths of lesser resistance such as rills, streams, tributaries, rivers, etc., which all combined is termed as surface runoff.

Fig. 10.3. Surface runoff. (Source: http://milford.nserl.purdue.edu/weppdocs/overview/runoff.html)

2. Sub-surface Runoff

The portion of rainfall, which first infiltrates into the soil and moves laterally without joining the water-table to the streams, rivers or oceans is known as sub- surface runoff. The sub-surface runoff is usually referred to as interflow.

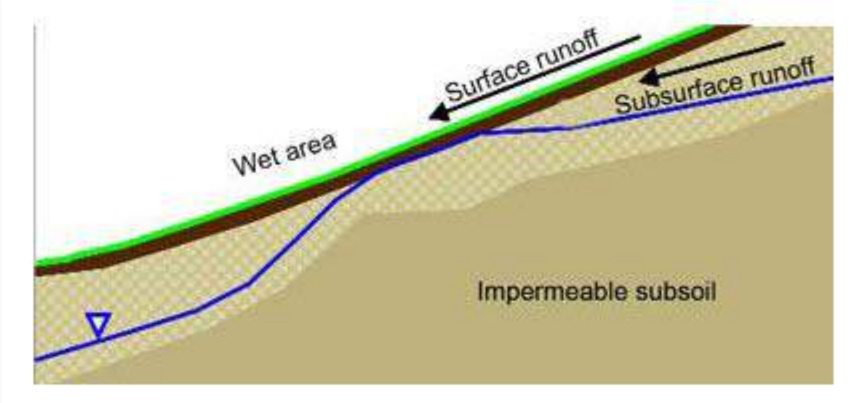


Fig. 10.4. Sub-surface runoff. (Source: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1294678601507)

3. Base flow

It is the delayed flow, defined as that part of rainfall which after falling on the ground surface infiltrates into the soil and meets the water table and flow towards the streams, rivers, oceans etc. The movement of water in this type of runoff is very slow; that is why it is also referred to as delayed runoff. It takes a long time to join the rivers or oceans. Sometimes base flow is also known as ground water flow. Base flow is not directly contributed by rainfall and continues much after the rainfall has ceased. In very large catchments and also for snow covered catchments, base flow continues throughout the year giving rise to perennial rivers, as against seasonal rivers, which dry up during the summer. Thus,

Total Runoff = Surface runoff + Base flow (Including sub - surface runoff)

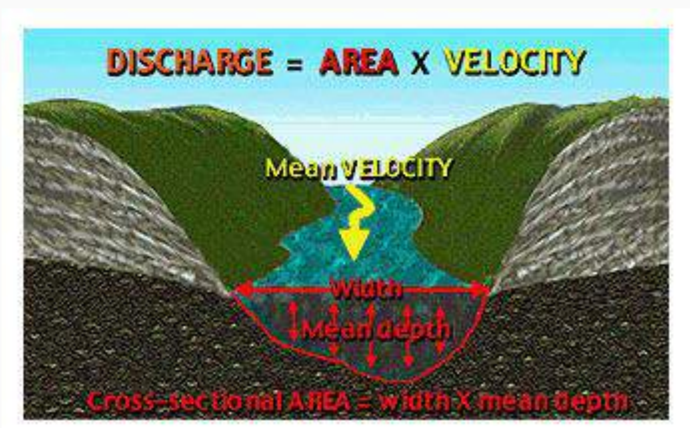


Fig. 10.5. Base flow. (Source: http://www.bigelow.org/virtual/water_sub2.html)

Special Case of Runoff Generation by Snowmelt

Many hydrological regimes, particularly mountain regimes, are dominated by the spring snowmelt component. Snowmelt has particular characteristics in generating the snowmelt hydrograph. It tends to have only low intensities since even after the snowpack is "ripe" and ready for melt, rates of melt are limited on a daily basis by the energy available to supply the latent heat necessary to convert ice and snow to liquid water. Initially, routing through the snowpack may also diffuse the daily melt signal, and there may be some refreezing of water at night. Another interesting feature of the melt process is that it will have a characteristic spatial pattern since, in general, south facing slopes will melt before north facing slopes (in the Northern Hemisphere) and a low elevation snowpack before a high elevation pack. There may also be spatial variations in melt associated with differences in the storage of snow as a result of drifting during the winter period. The response of a catchment during the snowmelt period may depend very much on the state of the soil. If the soil is frozen, then it is likely that infiltration rates may be limited and there is a greater chance of the melt generating a downslope surface runoff through the base of the pack. If the soil is unfrozen, then the low intensity of the melt will usually mean that the bulk of the melt will infiltrate into the soil profile. Depending on the weather conditions prior to a pack being established, it is quite possible that in some years the soil surface remains frozen all winter, while in other years the surface is unfrozen at the start of the melt season.

10.3 Factors Affecting Runoff

Runoff rate and volume from an area are mainly influenced by following four factors:

A. Climatic factors.

B. Physiographical Factors.

C. Metrological factors

D. Storage Characteristics

(A) Climate Factors

It is associated with characteristics of precipitation which includes:

1. Types of Precipitation

It has great effect on the runoff. Precipitation which occurs in the form of rainfall starts immediately as surface runoff depending upon rainfall intensity while precipitation in the form of snow does not immediately result in surface runoff. It does so only after the snow is melted.

2. Rainfall Intensity

If the rainfall intensity is greater than infiltration rate of soil then runoff starts immediately after rainfall. While in case of low rainfall intensity, runoff starts later. Thus high intensities of rainfall yield higher runoff. Under a monsoon climate, as over India, rainfall intensities are generally higher than the infiltration rate and it is quite common to find runoff occurring even when the lower soil layers remain unsaturated.

3. Duration of Rainfall

It is directly related to the volume of runoff because infiltration rate of soil decreases with duration of rainfall. Therefore medium intensity rainfall even results in considerable amount of runoff if duration is longer.

4. Rainfall Distribution

Runoff from a watershed depends very much on the distribution of rainfall. It is related to the direction of storm movement: from outlet of the catchment upstream and vice-versa. It is also expressed as "distribution coefficient" mean ratio of maximum rainfall at a point to the mean rainfall of watershed. Therefore, near outlet of watershed runoff will be more.

5. Direction of Prevailing Wind

If the direction of prevailing wind is same as drainage system, it results in low peak. A storm moving in the direction of stream slope produces a higher peak in shorter period of time than a storm moving in opposite direction.

6. Other Climate Factor

Other factors such as temperature, wind velocity, relative humidity, annual rainfall etc., affect the water losses from watershed area.

(B) Physiographic Factors

These include both watershed and channel characteristics, which are as follows:

1. Size of Watershed

A large watershed takes longer time for draining the runoff to outlet than a smaller watershed and vice-versa.

2. Shape of Watershed

Runoff is greatly affected by shape of watershed. Shape of watershed is generally expressed by the term "form factor" and "compactness coefficient".

- **Form Factor** is ratio of average width to axial length of watershed

$$F = B/L$$

F, dimensionally equal to $A/\{(L).(L)\} = A/L^2$

- **Compactness Coefficient**

Ratio of perimeter of watershed to circumference of circle whose area is equal to area of watershed

- **Two types of shapes**

a. Fan shape [tends to produce higher runoff very early]

b. Fern shape [tend to produce less runoff].

3. Slope of Watershed

It has complex effect. It controls the time of overland flow and time of concentration of rainfall. For example, a sloppy watershed results in greater runoff due to greater runoff velocity and vice-versa.

4. Orientation of Watershed

This affects the evaporation and transpiration losses from the area. The north or south orientation, affects the time of melting of collected snow.

5. Land Use

Land use and land management practices have great effect on the runoff yield. For example, an area with forest cover or thick layer of mulch of leaves and grasses contribute less runoff because water is absorbed more into soil.

6. Soil moisture

Magnitude of runoff yield depends upon the initial moisture present in soil at the time of rainfall. If the rain occurs after a long dry spell then infiltration rate is more, hence it contributes less runoff.

7. Soil type

Infiltration rate vary with type of soil. So runoff is greatly affected by soil type.

8. Topographic characteristics

It includes those topographic features which affects the runoff. Undulated land has greater runoff than flat land because runoff water gets additional energy [velocity] due to slope and less time to infiltrate.

9. Drainage Density:

It is defined as the ratio of the total channel length [L] in the watershed to total watershed area [A]. Greater drainage density gives more runoff

Drainage density = L/A

(C) Metrological factors

a. Temperature,

b. Humidity

c. Wind velocity

d. Pressure difference

(D) Storage Characteristics

a. Depressions

b. Ponds, lakes and pools.

c. Stream

d. Channels.

e. Check dams in gullies

f. Upstream reservoirs or tanks.

g. Ground water storage in deposits/aquifers

13. Design Requirements of Gully Control Structures

A structure installed across an active gully to stabilize the gully through control of erosion of gully bottom and banks is called gully control structure.

13.1 Design Requirements of Gully Control Structure

The gully control structures primarily designed for safe disposal of excess runoff generated from the watershed. While designing gully control structures three major points are considered, namely, (i) structure must have sufficient provision for safe discharge, (ii) the structure should have sufficient strength to withstand the pressure exerted by flowing water and (iii) the structure should be protected from erosion due to the flow passing over it. These points refer to hydrologic design, structural design and hydraulic design of structures. However, the design vigor depends on the type of gully control structures such as permanent structures require more vigorous design than temporary structures.

13.2 Functions or Purpose

The primary function of gully control structures is to provide safe passage to the flow through intervening into the prevailing slope of natural channel. The other purpose or function of gully control structures are listed below.

1. To reduce runoff erosive forces by stacking off the gradient of a gully and by controlling the course of flow to minimize ill effect on the banks.
2. To store water in the upstream as channel storage for irrigation.
3. To block sediment to keep it from damaging the downstream environment.

4. To maintain the stability of soil when vegetative cover is being established.

13.3 Causes of Failures

The structure failure caused mainly due to faulty hydrologic, hydraulic or structural design either alone or combination of these. However, there are cases when structures failed because of

· Insufficient capacity of structure

· Insufficient provision for dissipation of kinetic energy within the confine of structure

· Unprotected banks near to upstream of structures,

· Improper foundation causing uplift pressure to prevail over the body of the structure.

13.4 Types of Structures

Gully control structures can be grouped into two categories, namely, temporary gully control structures and permanent gully control structures. Temporary gully control structures are made up of locally available material and are designed for 3-10 years. Most of the check dams come under the category of temporary gully control structures. On the other hand, permanent gully control structures are designed for 25 to 50 years period.

13.4.1 Temporary Structures

All temporary structures should be practiced in G-1 type gullies. The purpose of this kind of dam is to temporarily maintain the stability of a gully and to make possible the establishment of vegetative cover. These are not durable and need frequent maintenance, though these are inexpensive and easy to build. These structures are constructed using the locally available material. The life of temporary structure is limited to 3-8 years.

Design Criteria of Temporary Structures

1. The overall height of a temporary check should not ordinarily be more than 75 cm. An effective height of about 30 cm is usually considered sufficient. Minimum 15 cm freeboard is necessary.

2. Life of the check dams under ordinary conditions should be 3-8 years and hence should be design for rainfall of 10 years return period.

3. Since the purpose of check dams in gully control is to eliminate grade in the channel, check dams theoretically should be spaced in such a way that the crest elevation of one will be same as the bottom elevation of the adjacent dam up-stream. Hence horizontal interval depends on the channel slope and height of check dam. Check dams of lesser height in higher slope will require more frequent check dams down the stream.

4. Suitable apron should be provided to avoid the souring due to the flow passing over these check dams. For this purpose, rip-rap is provided in the length of 1 to 1.5 meter downstream of the check dams. The gap between the rip-rap can be seeded with grass.

13.4.1.1 Woven Wire Dams

These dams are used in gullies of moderate slope and small drainage area. They help in the establishment of vegetation for permanent control of erosion. To construct a woven-wire dam a row of posts is set along the curve of the proposed dam at about 1.2 m intervals and 60-90 cm deep. Heavy gauge woven wire is placed against the post with the lower part set in a trench (15-20 cm deep) so that 25-30 cm projects above the ground surface along the spillway interval. Rock, brush or sod may be placed for approximately up to a length of 1.2 m to form the apron. For sealing the structure, straw, fine brush or similar material should be placed against the wire on the upstream side to the height of spillway crest. Fig.13.1 shows woven wire dam.

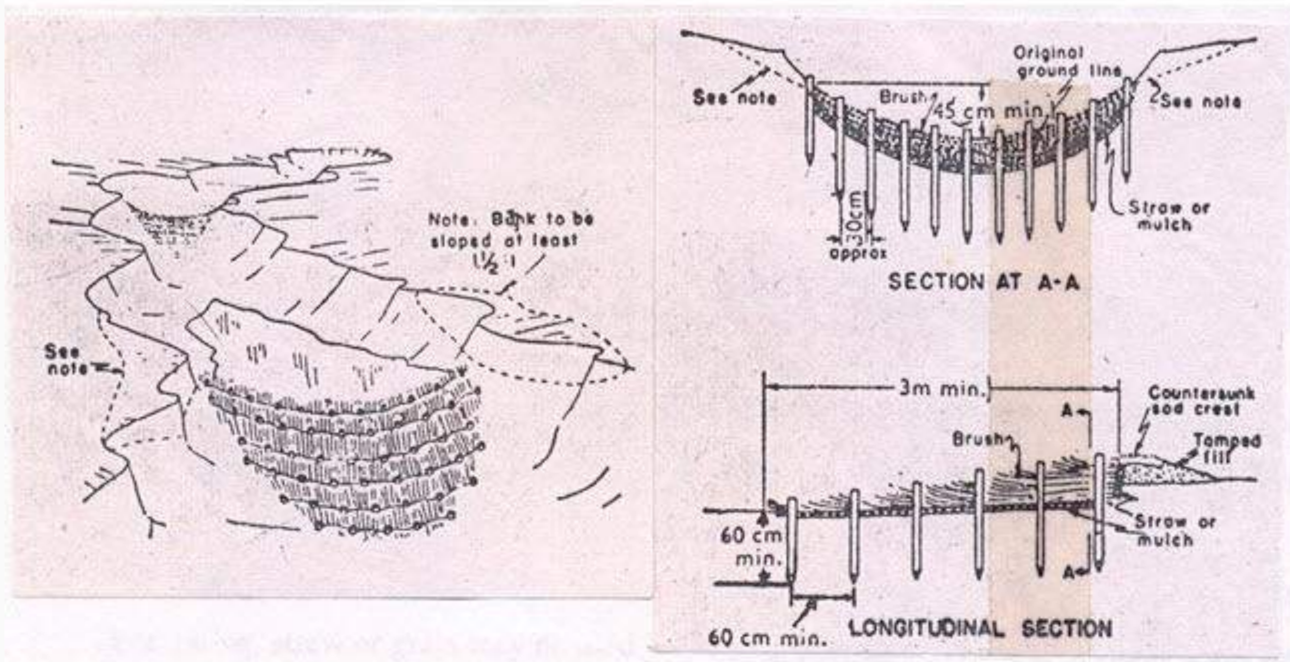


Fig. 13.1. Woven wire dam. (Source: Michael and Ojha, 1978)

13.4.1.2 Brush Dams

They are cheap and easy to build, but least stable of all types of check dams. They are best suited for gullies with small drainage area. The center of the dam is kept lower than the ends to allow water to flow over the dam rather than around it. For a distance of 3-4.5 m along the site of structure, sides and bottom of the gully are covered with thin layer of straw or similar fine mulch. Brushes are then packed closely together over the mulch to about one half of the proposed height of dam. Several rows of stakes are then driven crosswise in the gully, with rows 60 cm apart, and stakes 30-60 cm apart in the rows. Heavy galvanized wire is used to fasten the stakes in a row, as well as to firmly compress the brushes in places. Sometimes large stones are also placed on top of brush to keep it compressed and in close contact with the bottom of the gully. The major weakness is the difficulty of preventing the leaks and constant attention is required to plug openings of appropriate size with straw as they develop. Fig.13. 2 shows brush dam.

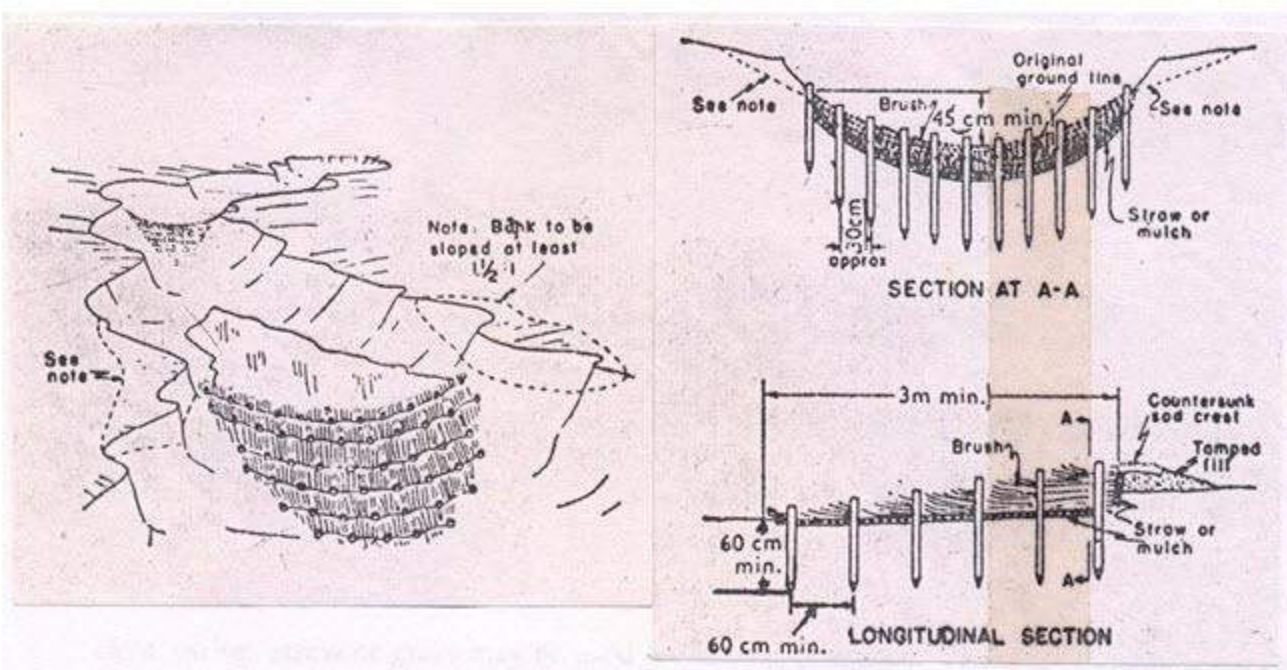


Fig. 13.2. Brush dam. (Source: Michael and Ojha, 1978)

13.4.1.3 Loose Rock Dam

Loose rock dams are suitable for gullies have small to medium size drainage area. They are used in areas where stones or rocks of appreciable size and suitable quality are available. Flat stones are the best choice for dam making as they can be laid in such a way that the entire structure is keyed together. If round or irregular shed stones are used, structure is generally encased in woven-wire so as to prevent outside stones from being washed away. If the rocks are small, they should be enclosed in a cage of woven-wire. To construct the dam, a trench is first made across the gully to a depth of about 30 cm. This forms the base of the dam on which the stones are laid in rows and are brought to the required height. The center of the dam is kept lower than the sides to form spillway. To serve as an apron, several large flat rocks may be countersunk below the spillway, extending about 1 m down-stream from the base of the dam. Fig.13.3 shows loose rock dam.

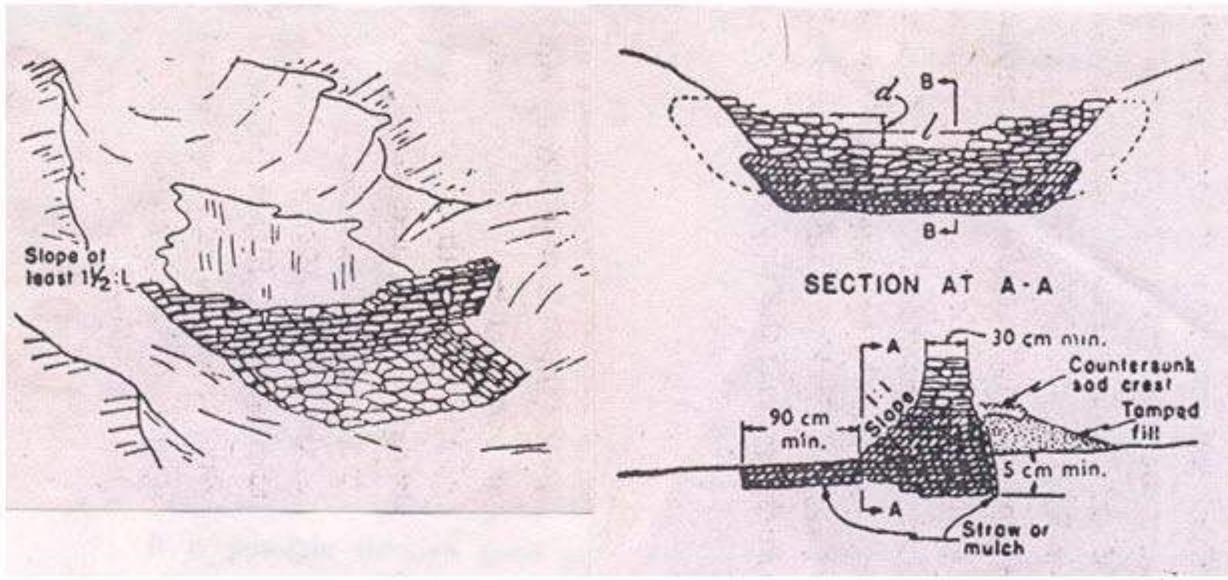


Fig. 13.3. Loose rock dam. (Source: Michael and Ojha, 1978)

13.5 Permanent Structures

Permanent structures are constructed when the benefits from such structures are justifiable compared to the cost of construction. General requirements of the permanent structures for gully control are: (1) they should be constructed with permanent materials, (2) they should have adequate capacity to handle the runoff, and (3) they should help in stabilizing the gully and store water wherever necessary. For the purpose of gully control, following types of structures are adopted.

1) **Drop structures**: The drop structures are recommended for G-2 type of gully where the downstream fall of water is limited to 3.0 meter. The drop structures are used along the gully bed to act as control points so that the gully bed is not eroded below the crest level of the structure. Fig. 4 shows drop spillway.

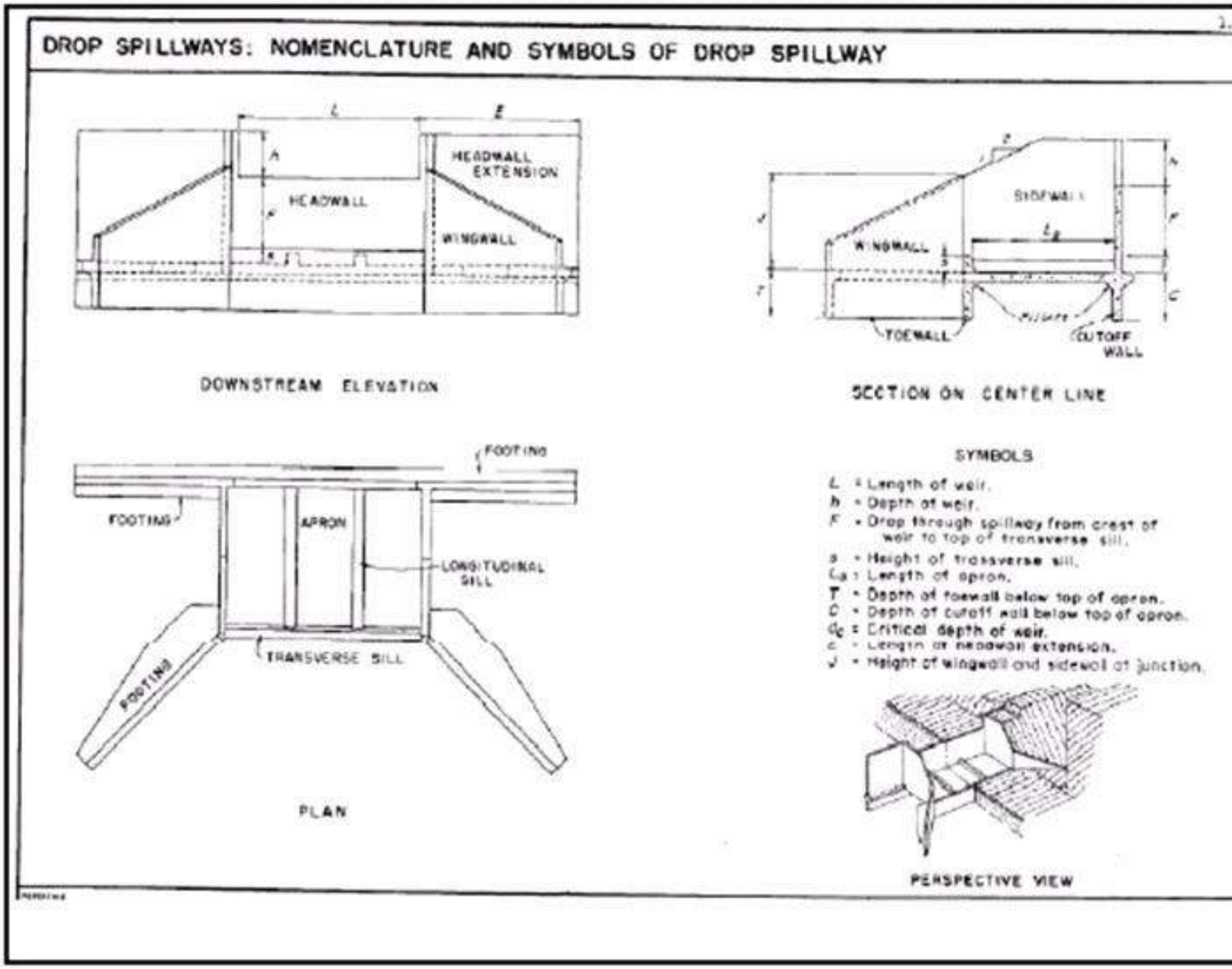


Fig. 13.4. Drop structure. (Source: Singh et al. 1978)

2) Chute structure: It is permanent type gully control structures in which the excess runoff are passed through chute spillway. This type of structure is recommended for G-3 type of gully where the gully depth is more than 3 meter. Fig. 5 shows chute spillway.

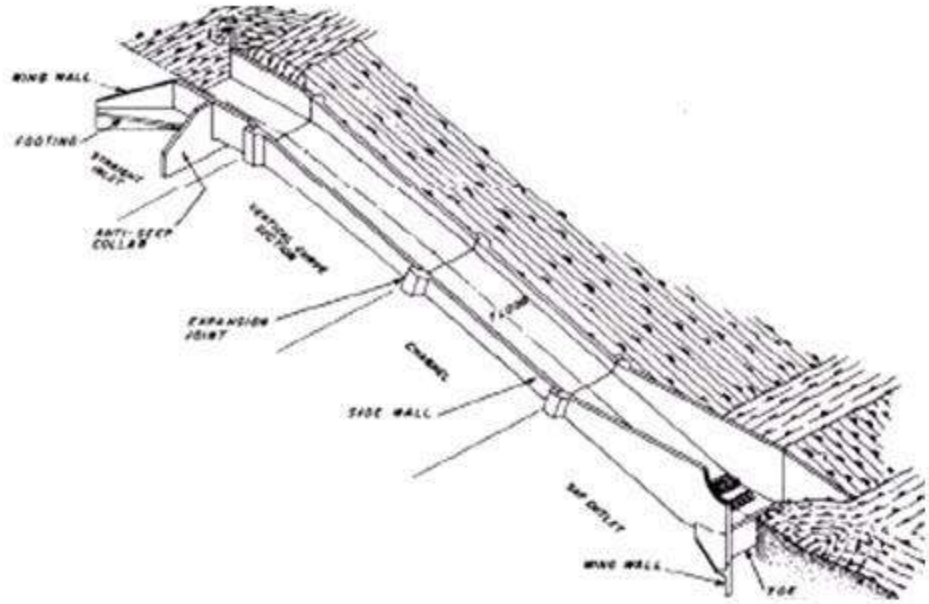


Fig. 13.5. Chute structures. (Source: SCS, 1984)

3) **Drop inlet structures:** These structures should be practiced in G-4 type of gullies where the depth is more than 9 meters and steep side slope exist. In this conditions the drop structures and chute structures are difficult to construct and practically not feasible. In this type of structures the runoff is guided through under lying pipe towards downstream. Fig. 6 shows drop inlet structure.

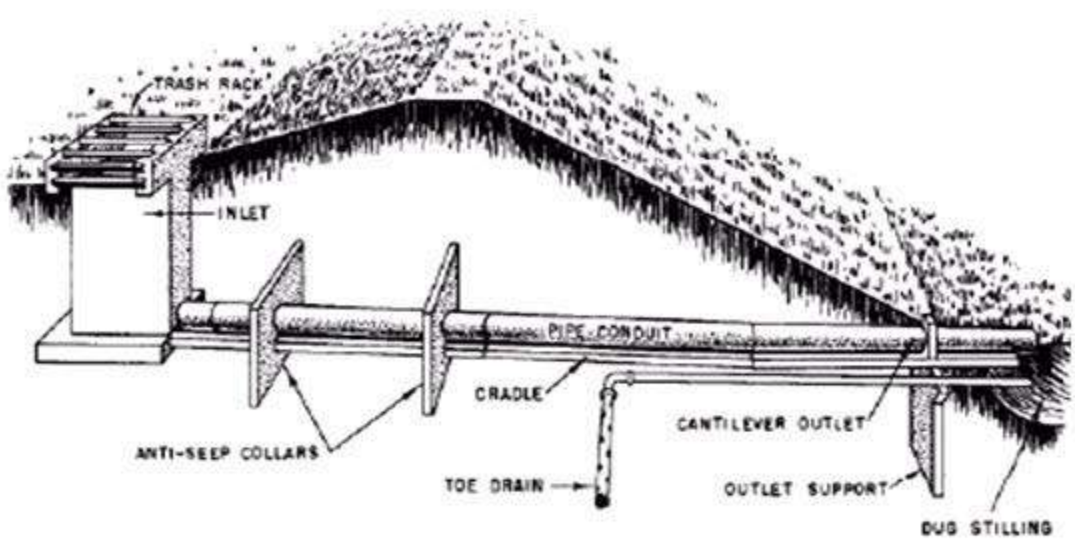


Fig. 13.6. Drop inlet spillway. (Source: SCS, 1984)

13.6 Planning for Gully Control

Control of gully erosion is done both by taking appropriate measures in the gully beds as well as in the catchment area. The first step in planning the gully control programme is to plan to control the runoff from the catchment area. This may be done by using good land and crop management practices, such as contouring, strip cropping and terracing. Gully control measures should be considered when the plan for the entire watershed is prepared.

Control of gullies may be an extensive operation and the cost of the gully control must be balanced by the benefits. Benefits include the protection of the adjoining areas, reduction of sediment load to the river system, storage of water and sometimes reclamation of the gully beds for cultivation purposes.

DRYLAND TECHNOLOGIES

TECHNIQUES TO REDUCE EVAPORATION AND TRANSPIRATION LOSS

REDUCING EVAPORATION LOSSES

Soil moisture is the most limiting factor in dryland agriculture. It is lost as evaporation from the soil surface and as transpiration from the plant surfaces. Evaporation has to be arrested as it is not directly related to productivity whereas transpiration can be reduced to some extent without affecting productivity of plants. The evaporation losses can be reduced by:

1. Mulches
2. Antitranspirants
3. Wind breaks
4. Weed control

Mulches

About 60 to 75 per cent of the rainfall is lost through evaporation. These evaporation losses can be reduced by applying mulches. Mulch is any material applied on the soil surface to check evaporation and improve soil water. Application of mulches results in additional benefits like soil conservation, moderation of temperature, reduction in soil salinity, weed control and improvement of soil structure.

Types of mulches
Soil mulch or dust mulch:

If the surface of the soil is loosened, it acts as a mulch for reducing evaporation. This loose surface soil is called soil mulch or dust mulch. Intercultivation creates soil mulch in a growing crop.

Stubble mulch

Crop residues like wheat straw or cotton stalks etc., are left on the soil surface as a stubble mulch. The advantages of stubble mulch farming are protection of soil from erosion and reduction of evaporation losses.

Straw mulch

If straw is used as mulch, it is called as straw mulch.

Plastic mulch

Plastic materials like polyethylene, polyvinyl chloride are also used as mulching materials.

Vertical mulching

To improve infiltration and storage of rainwater in these soils, vertical mulches are formed. It consists of digging narrow trenches across the slope at intervals and placing the straw or crop residues in these trenches. The pruned plant material is placed in contour trenches formed between rows or in trenches around the plants in concentric circles each year in one circle.

REDUCING TRANSPIRATION LOSSES

Antitranspirants

About 99 per cent of the water absorbed by the plants is lost in transpiration. If transpiration is controlled, it may help in maintenance of favourable water balance.

Antitranspirant is any material applied to transpiring plant surfaces for reducing water loss from the plant. These are of four types:

1. Stomatal Closing
2. Film forming
3. Reflective
4. Growth retardant

Stomatal Closing type

Most of the transpiration occurs through the stomata on the leaf surface.

1. Fungicides like phenyl mercuric acetate (PMA) and herbicides like atrazine in low concentrations serve as antitranspirants by inducing stomatal closing.

These might reduce the photosynthesis also simultaneously. PMA was found to decrease transpiration to a greater degree than photosynthesis in a number of plants.

Film Forming Type

Plastic and waxy materials which form a thin film on the leaf surface retard the escape of water due to formation of physical barrier.
Mobileaf, hexadeconol, silicone are some of the film forming type of antitranspirants. The success of these chemicals is limited since they also reduce photosynthesis.

1. The desirable characteristics of film forming type of antitranspirants are:
2. They should form a thin layer,
3. They should be more resistant to the passage of water vapour than carbon dioxide and the film should maintain continuity and should not break

Reflectant Type

These are white materials which form a coating on the leaves and increase the leaf reflectance (albedo). By reflecting the radiation, they reduce leaf temperatures and vapour pressure gradient from leaf to atmosphere and thus reduce transpiration.

1. Application of 5 per cent kaolin spray reduces transpiration losses.
2. A diatomaceous earth product (celite) also increases reflection of solar radiation from crop canopy

Growth Retardant

These chemicals reduce shoot growth and increase root growth and thus enable the plants to resist drought. They may also, induce stomatal closure.

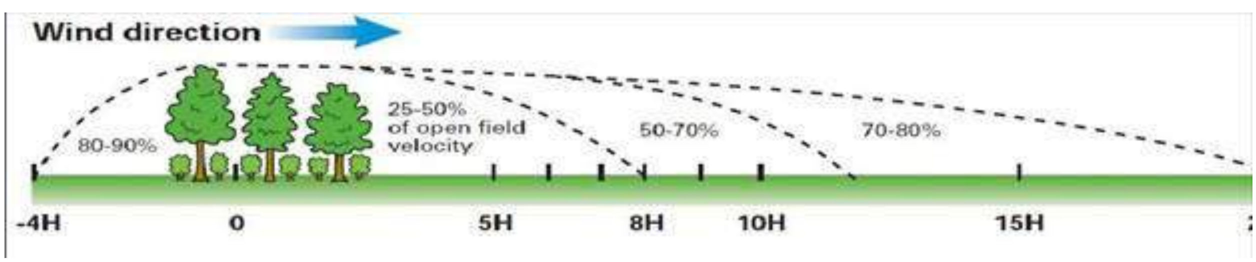
1. Cycocel is one such chemical useful for improving water status of the plant

Antitranspirants generally reduce photosynthesis. Therefore, their use is limited to save the crop from death under severe moisture stress. If crop survives, it can utilise the rainfall that is received subsequently. Antitranspirants are also useful for reducing the transplantation shock of nursery plants. They have some practical use in nurseries and horticultural crops.

WIND BREAKS AND SHELTERBELTS

Wind breaks are any structures that obstruct wind flow and reduce wind speed while shelterbelts are rows of trees planted for protection of crops against wind. The direction from which wind is blowing is called windward side and direction to which wind is blowing is called leeward side.

Shelterbelts are planted across the direction of wind. They do not obstruct the wind flow completely. Depending upon their porosity, certain amount of wind passes through the shelterbelts while the rest deflects and crosses over the shelterbelts. It thus reduces wind speed without causing turbulence. The protection offered by the shelterbelts is dependent on the height of central tree row in the shelterbelts. Generally, shelterbelts give protection from desiccating winds to the extent of 5 to 10 times their height on windward side and up to 30 times on leeward side. Due to reduction in wind speed, evaporation losses are reduced and more water is available for plants. The beneficial effect of shelterbelts is seen more clearly in drought years. In addition, shelterbelts reduce wind erosion.



WEED CONTROL

1. Promptweed control eliminates the competition of weeds with crops for limited soil moisture.
2. Transpiration rate from weeds is more compared to crops.

3. Effective weed control in dryland agriculture leads to increasing availability of soil moisture to crops.

This is the most useful measure to reduce transpiration losses.

Spraying nutrient solution

Nutrient solution spray is recommended in the event of revival of rain and release of moisture stress.

- Urea or DAP spray (2% solution) is useful for quicker regeneration of crops like legumes and castor after rain.

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