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Lecture Notes

Integrated Watershed Management: Meaning, Concept, Significance and Approaches

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Concept and Meaning of Watershed

A watershed is the area that drains to a common outlet. It is the basic building block for land and water planning. A watershed is an area that supplies water by surface or subsurface flow to a given drainage system or body of water, be it a stream, river, wetland, lake, or ocean (World Bank 2001) (Figure 1, 2, 3, 4 and 2). The characteristics of the water flow and its relationship to the watershed are a product of interactions between land and water (geology, slope, rainfall pattern, land use, soils, and vegetation) and its use and management. A watershed is thus the basic unit of water storage and supply, and the basic building block for integrated planning of land and water utilization.

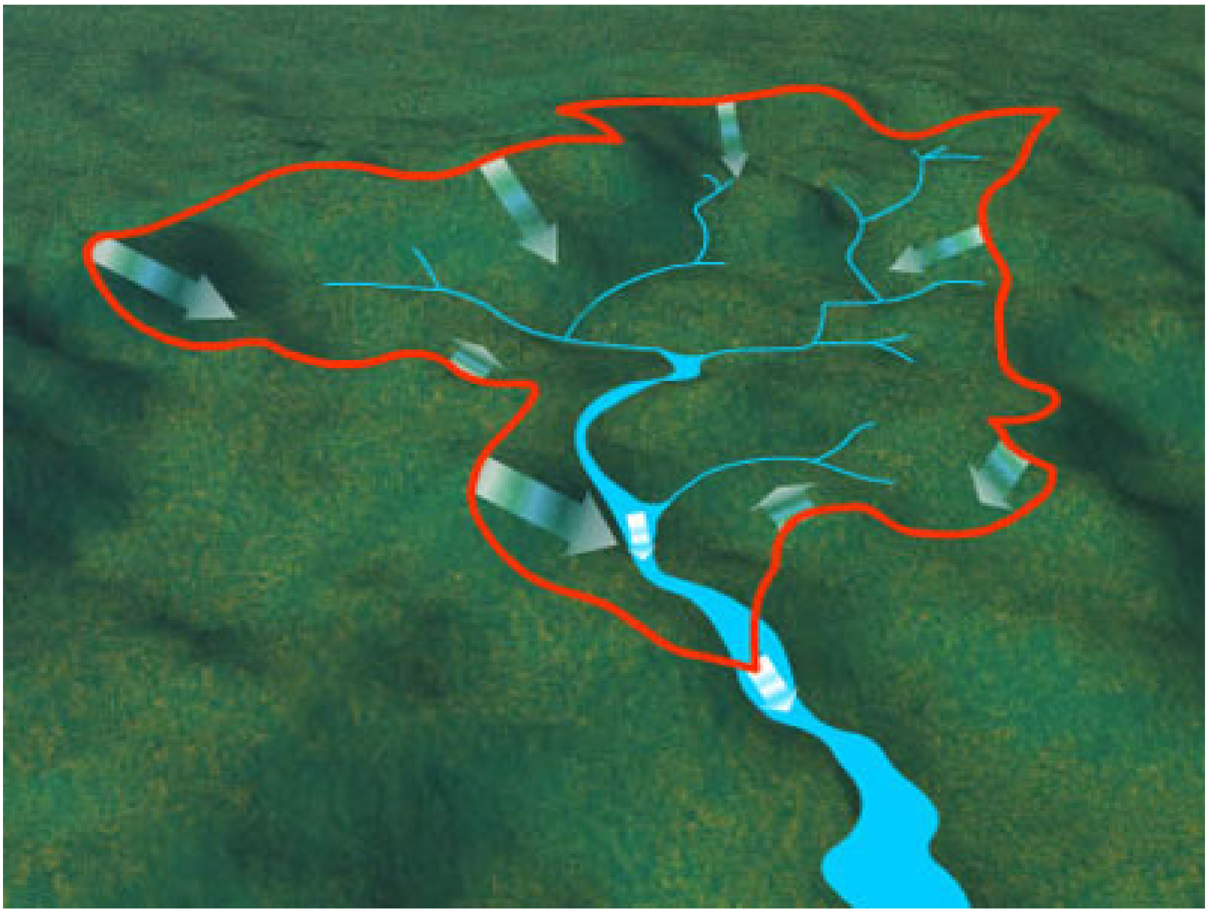

Figure 1: Watershed

Watershed includes not only the waterway itself but also the entire land area that drains to it. For example, the watershed of a lake would include not only the streams entering that lake, but also the land area that drains into those streams and eventually the lake. Drainage basins generally refer to large watersheds that encompass the watersheds of many smaller rivers and streams

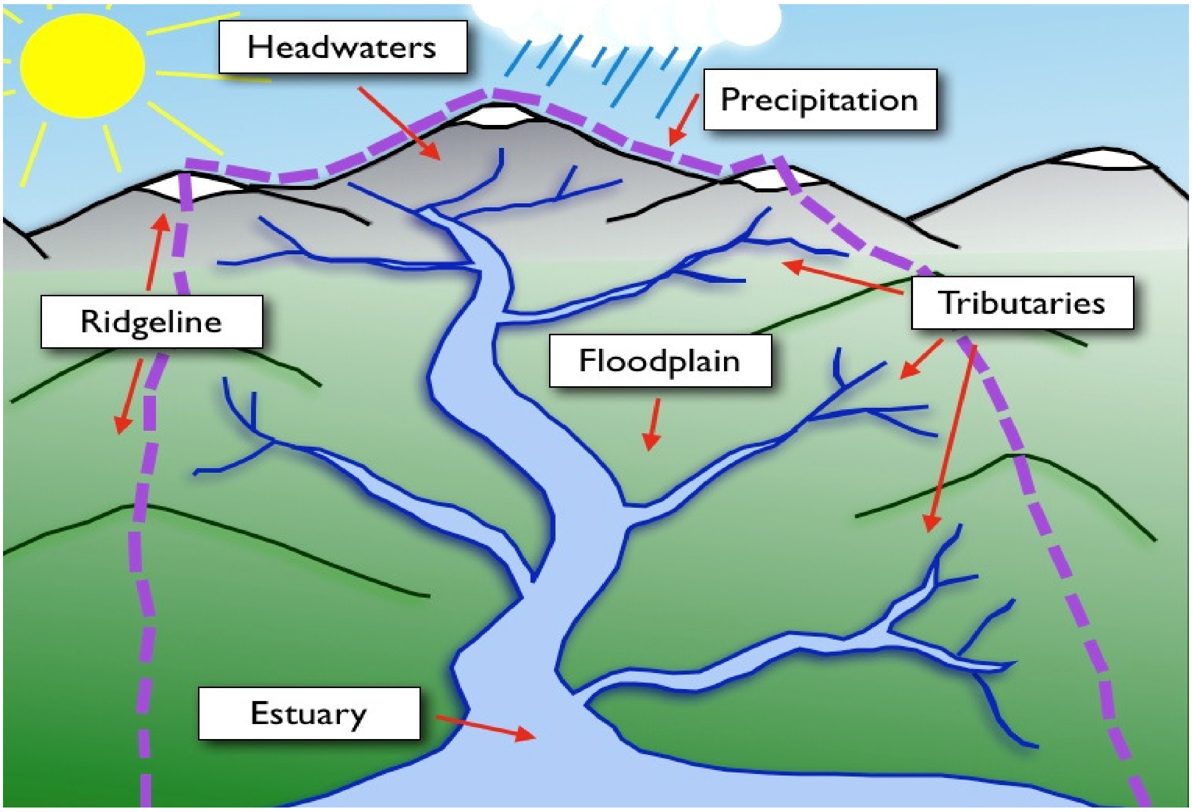

Figure 2: Watershed

Watersheds vary from a few hectares to thousands of square kilometers in area. Size is not a factor in the defining the watershed. Unless a watershed discharges directly into the ocean, it is physically a part of a larger watershed that does, and may be referred to as sub-watershed. Each watershed has its hydrological cycle, and the rainfall falling into the watershed constitutes the main source of water and hydrological cycle of a watershed. The amount of precipitation received by the watershed flows through and out of the watershed as surface or groundwater flow is incorporated into biomass, or is lost through evaporation and transpiration processes while in the watershed. The terms basin, watershed, and catchment are often used interchangeably in the literature (World Bank 2001). Basin management typically refers to macro-management at the level of the entire watershed system, sometimes across country boundaries and with a focus on institutional and policy issues. Watershed management typically refers to management at the level of the micro or sub-watershed. Catchment is generally used synonymously with watershed. The following statement would further help in understanding the meaning and concept of watershed:

- No matter where you are, you are in a watershed. Watersheds are everywhere. Watersheds are the link between our land, our water and our communities

- A watershed is a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community

- A watershed is the area of land that drains into a body of water such as a river, lake, stream or bay. It is separated from other watersheds by high points in the area such as hills or slopes. It includes not only the waterway itself but also the entire land area that drains to it.

- The precipitation that falls into a valley, and on surrounding interfluves flows downward usually creating a stream or river. The area of land that contributes water to the stream or river is called a watershed, or drainage basin

- A watershed includes both bio-physical and socio-economic units comprising all natural resources, people and their socio-economic activities within the confines of drainage divides

- Watershed is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social and economical security and provides life support services to people

Figure 3: Watershed of Nainital Lake in Uttarakhand Himalaya

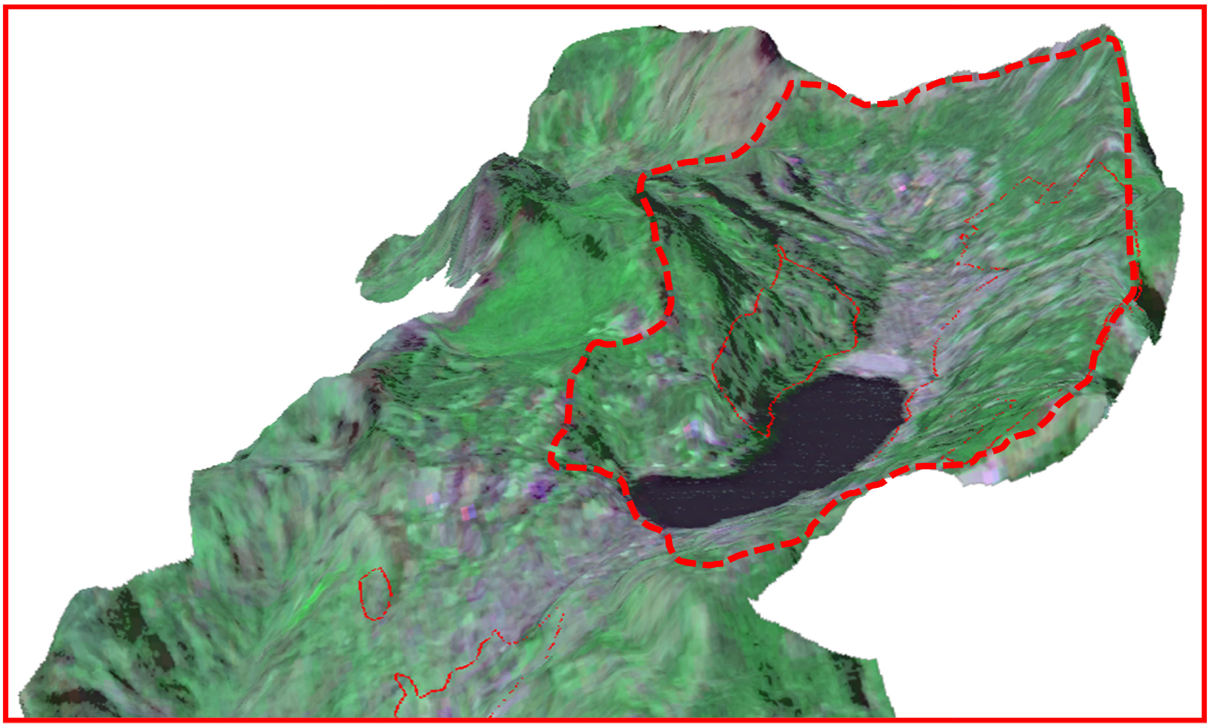

Figure 4: Watershed of Nainital Lake in Uttarakhand Himalaya, India [DEM]

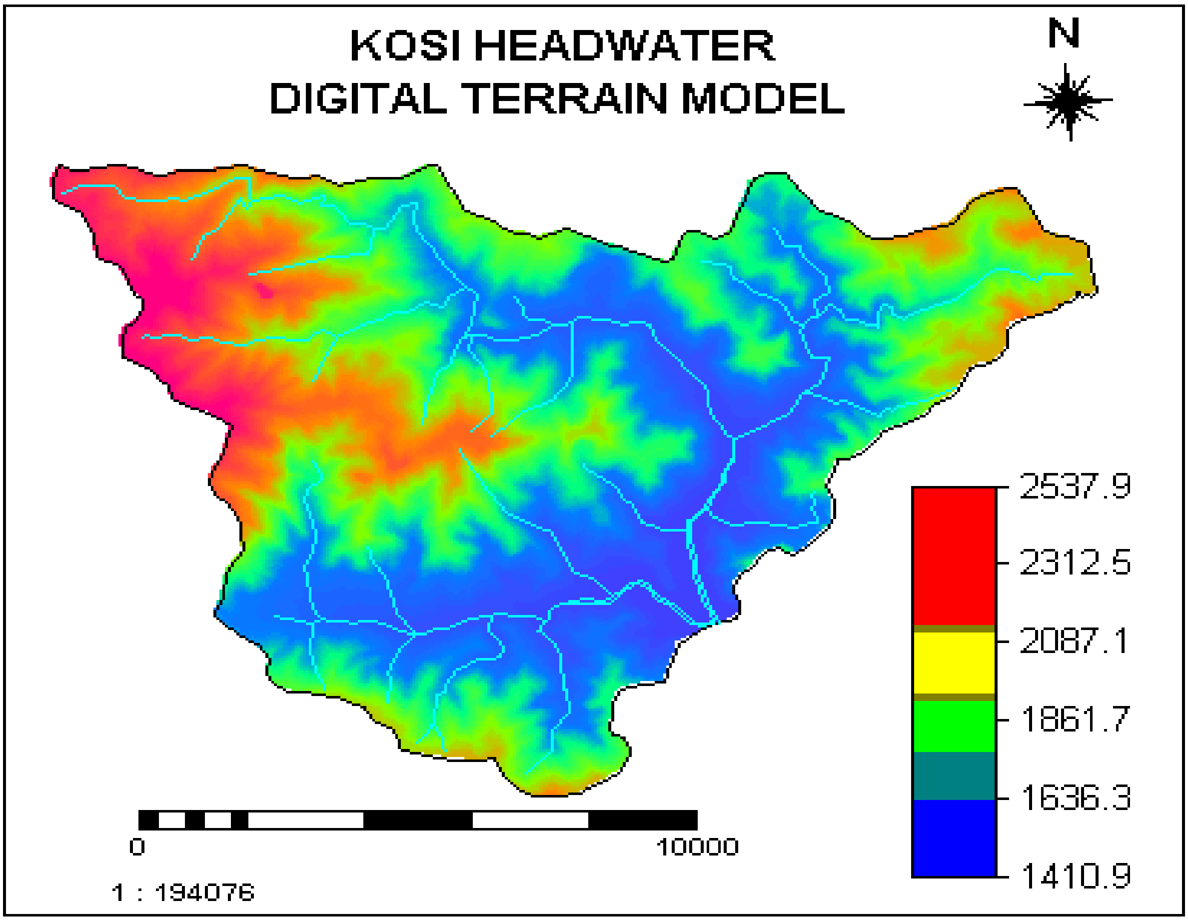

Figure 5: Headwater of Kosi River in Uttarakhand Himalaya, India [DEM]

Definition of Watershed

- A drainage basin which is also named as catchment, drainage area, catchment area and watershed is a natural unit which drains to a common stream (Leopold et al.1964)

- A drainage basin is a scientific-geographic unit having well defined topographic boundaries and forming a nested hierarchical pattern following the ordering of streams (Chorley and Haggett 1967)

- A drainage basin functions as hydrological system in which the relationship and balance between the inputs and outputs of energy is controlled and regulated by the intermediate processes of evaporation, transpiration, infiltration, run-off, soil moisture storage, sub-surface flow and groundwater storage and recharge. A watershed is a topographically delineated area that is drained by a stream system (World Bank 2001)

- A watershed is a geo-hydrological unit comprising land and water within the confines of drainage divides (Food and Agricultural Organization of the United Nation 2001)

- A watershed is a topographically delineated area that is drained by a stream system [Food and Agricultural Organization of the United Nation 2001]

- A watershed is a hydrological unit that has been described and used as a physical-biological unit and also, on many occasions, as a socio-economic-political unit for planning and management of natural resources. Catchment is often used as a synonym for watershed [Food and Agricultural Organization of the United Nation 2001]

- A watershed is differentiated from a river basin in that a river basin, with its trunk stream flowing to the sea, may encompass hundreds of watersheds and many other types of land formations [Food and Agricultural Organization of the United Nation 2001]

Stream Ordering

Stream ordering is the considered as fundamental exercise in the hydrological analysis of a watershed. The most common and widely used stream ordering method are as follows:

Horton Method: Horton (1945) originally developed the notion of stream orders in 1945. First-order streams are those which have no tributaries, second-order streams are those which receive as tributaries only streams of the first order, etc. However, the main stream is denoted by the same order number all the way to its headwaters, and hence one of the first-order streams (normally either the longest or the one which seems the most direct upstream continuation of the main stream) has to be renumbered as second order. The renumbering procedure is repeated with higher-order streams, so that the *N*th order stream extends headward to the begining of the longest tributary. Thus, as a stream-order map is prepared, one of the lower-order streams is renumbered every time two channels of equal order join one another.

Strahler method: Strahler (1957) modified the Horton's method of stream ordering to make it more pragmatic and application oriented. In Strahler method all links without any tributaries are assigned an order of 1 and are referred to as first order. The stream order increases when streams of the same order intersect. Therefore, the intersection of two first-order links will create a second-order link, the intersection of two second-order links will create a third-order link, and so on. The intersection of two links of different orders, however, will not result in an increase in order. For example, the intersection of a first-order and second-order link will not create a third-order link but will retain the order of the highest ordered link. Strahler's method is the most common and widely used stream ordering method (Figure 6 and 7).

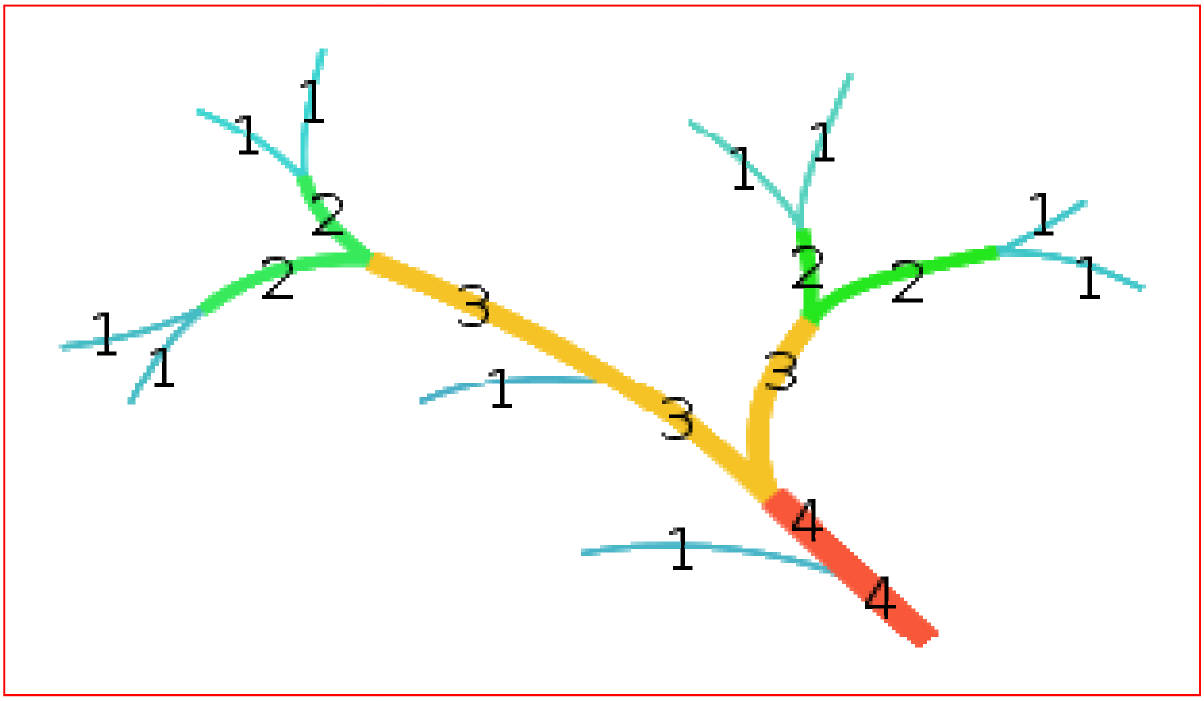

Figure 6: Stream Ordering [After Straheler]

Figure 7: Stream Ordering [After Straheler]

Delineation of Watershed

Watershed is separated from other watersheds by the water-divides which are the highest points surrounding the watershed, such as hills or slopes. The watershed is the basic unit of all hydrologic analysis and designs. Any watershed can be subdivided in to a set of smaller watersheds. Usually a watershed is defined for a given drainage point. This point is usually the location at which the analysis is being made and is referred to as the watershed “outlet”. The watershed, therefore, consists of all the land area that drains water to the outlet during a rainstorm. The boundary of a watershed therefore consists of the line drown across the contours joining the highest elevations surrounding the drainage area. Watersheds vary in size from a few hectares in urban areas to several thousand square kilometers for large river basins. Figure 8, 9 and 10 illustrate the delineation of a watershed boundary on the ground and map.

A common task in hydrology is to delineate a watershed from a topographic map. To trace the boundary, one should start at the outlet and then draw a line away on the left bank, maintaining it always at right angles to the contour lines. (The line should not cross the drainage paths) Continue the line until it is generally above the headwaters of the stream network. Return to the outlet and repeat the procedure with a line away from the right bank. The two lines should join to produce the full watershed boundary. Hydrologically, watershed is an area from which the run-off flows to a common point on the drainage system. The stream order is a measure of the degree of stream branching within a watershed. Each length of stream is indicated by its order (for example, 1rst-order, second- order, etc.). The start or headwaters of a stream, with no other streams flowing into it, is called the 1rst-order stream. First-order streams flow together to form a second-order stream. Second-order streams flow into a third-order stream and so on (Strahler and Strahler 1994). Stream order describes the relative location of the reach in the watershed.

Figure 8: Delineation of Watershed on the Ground

Identifying stream order is useful to understand amount of water availability in reach and its quality; and also used as criteria to divide larger watershed into smaller unit. Moreover, criteria for selecting watershed size also depend on the objectives of the development and terrain slope. A large watershed can be managed in plain valley areas or where forest or pasture development is the main objective. In hilly areas or where intensive agriculture development is planned, the size of watershed relatively preferred is small. In recent years the use of Geographic Information System (GIS) has become increasingly popular and has facilitated much of the work of hydrologists. The use of Digital Elevation Models (DEMs) in particular has made watershed delineation a relatively smooth procedure.

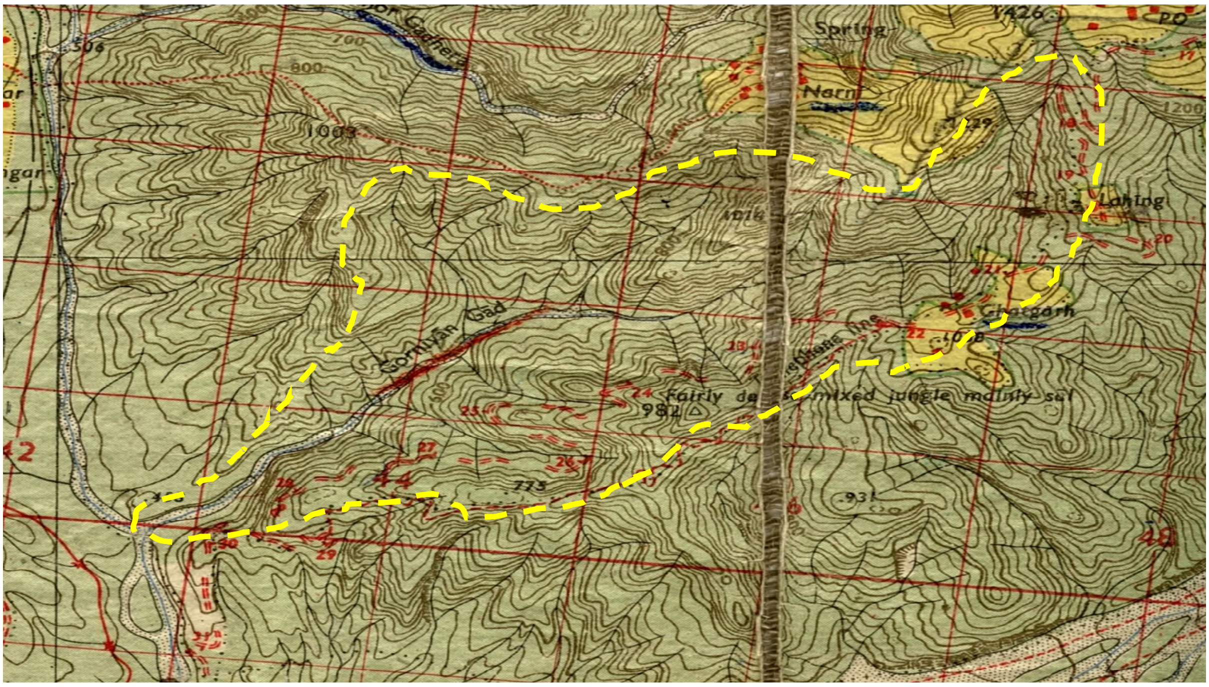

Figure 9: Delineation of Watershed on Topographical Map

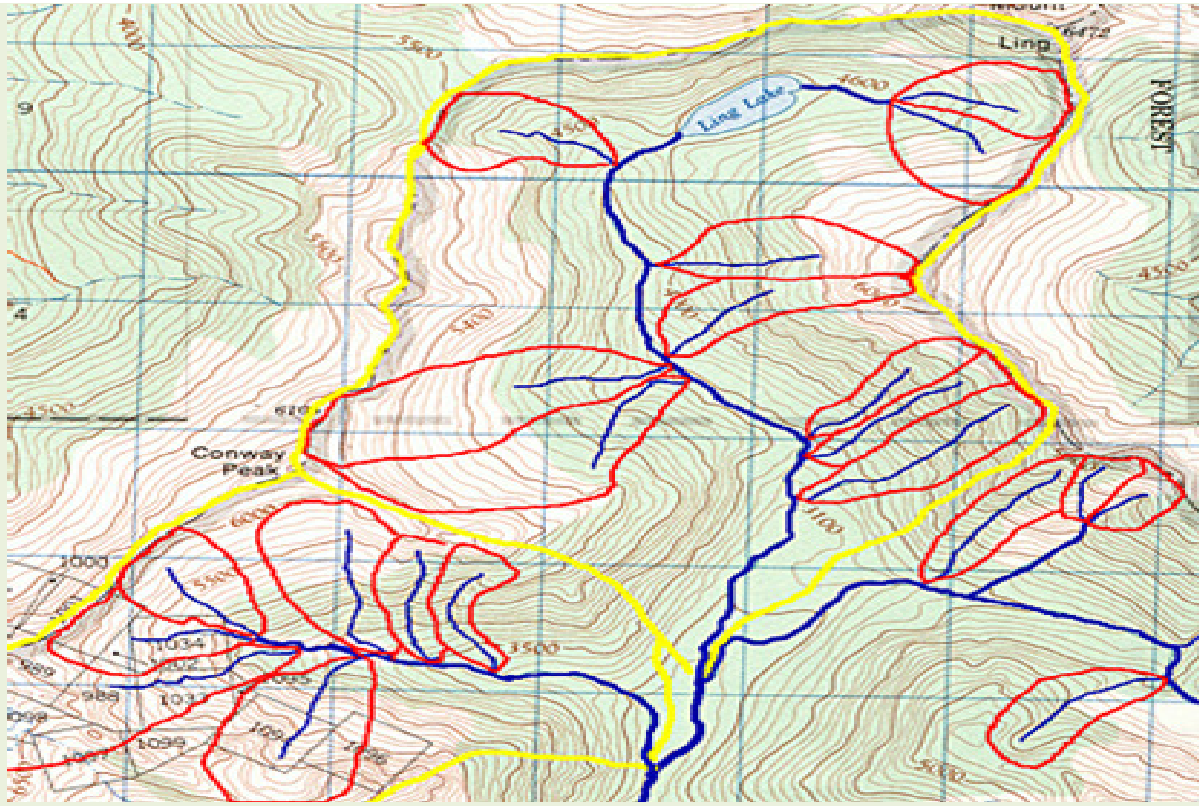

Figure 10: Delineation of Boundaries of Watersheds of Different Orders

Hierarchy of Watershed

Every stream, tributary, or river has an associated watershed, and small watersheds aggregate together to become larger watersheds. Water travels from headwater to the downward location and meets with similar strength of stream, then it forms one order higher stream (Strahler 1957; Strahler and Strahler 1994). The watershed are delineated following the stream order, for example first order watershed, second order watershed, third order watershed and so on. The first order watershed is delineated joining the water-divides around the first order stream, and following the same principle the watersheds of varying orders can be delineated. The first order watershed is part of the second order watershed, and a third order watershed is formed by more than one second order watershed. Thus the watersheds of lower to higher order follow a perfect heretical order (Figure 10).

The Headwater and its Significance

The headwater is defined as a zero or first order catchment and the land where the water flow lines originate. It is the land that is closest to the water divides (Haigh, 2002). The essential characteristic of headwater is that it is both a margin and a point of origin. Headwater provides the recharge zone for both surface and ground water. The headwater regions lie as close to the margin of the socio-economic system as to the hydrological systems. Thus, the headwaters are very critical for the conservation of land, water and forests resources and for the sustainability of highland-lowland interactive ecosystems, and therefore need adequate protection of environment and sustainable management of natural resources. But the headwaters are now emerging as frontiers of environmental conservation and resource exploitation conflicts under the impact of socio-economic and political pressures, particularly in developing and less developed countries of the world.

The exploitation of headwater resources has not only threatened the livelihood security of communities through the rapid depletion and erosion of land, water and forest resources in the headwater regions, but also affected the economy of densely populated downstream ecosystems through silting of river beds, increased incidence of floods, decreased water flow in rivers. The downstream impacts of changes in the headwater regions are now clearly discernible in Indo-Gangetic Plains, Pacific coast of British Columbia, in Canada, Great Plains of China etc. (Haigh, 2002). In order to address the problem of the management of headwater resources, the Headwater Control Movement (HCM) that attempts to integrate the land and livelihoods in the headwater regions and downstream areas, came into being in 1989. It was established on the principle that the Headwater environments are threatened by man induced environmental changes, and direct interventions that demand the practical application of coordinated and integrated environmental management can secure the environment as well as the livelihood of the headwater communities. The main objective of the Headwater Control is to develop an integrated approach to the management of headwater regions that is capable of addressing the needs of headwater communities for self-sustainability in environmental, economic and cultural terms.

With the excessive demand of land and other natural resources the headwaters of Himalaya have come under increased biotic stress during the recent years. This has resulted not only in the rapid geo-hydrological imbalances and environmental changes, but also in creation of vast patches of waste and degraded lands in the headwater areas leading to ecological as well as economic un-sustainability. In view of this, it is therefore essential to delineate the critical headwaters in the entire region and take necessary measures for the rehabilitation and management of wastelands in the headwater regions on priority basis. The salient features of headwater are as follows:

- Headwater is a zero to first order catchment
- Headwaters constitute recharge zone of surface and groundwater
- Headwaters are situated as close to the margin of socio-economic system as to hydrological
- Headwaters are now emerging as frontiers of resource developmental activities leading to hydrological disruptions
- Land use intensification in headwaters is effecting ecological and socio-economic sustainability of both upstream and downstream areas.

Watershed Parameters and Geomorphology

Watershed geomorphology refers to the physical characteristics of the watershed. Certain physical properties of watersheds significantly affect the characteristics of runoff and as such are of great interest in hydrologic analyses. The principal watershed characteristics has been explained below and shown in Tables 1 and 2.

Table 1: Watershed Characteristics

Parameters	Characteristics
Climate	Temperature, Precipitation, Moisture
Size	Micro Watershed, Watershed, Basin
Shape	How it Looks
Drainage	Pattern, Stream Ordering, Stream Frequency, Stream Density, Bifurcation Ratio, Stream Length
Hierarchy	Ordering of Watershed
Geology	Rocks, Structure, Lineaments etc.
Slope and Aspect	Surface Gradients and its Aspects
Soils	Soils Texture and Types
Hydrology	Water Behaviour and Response
Land Use	Land Utilization Processes
Socio-economic	Human Interferences

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 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.

Area of the watershed: As mentioned earlier, there is no definite size for a watershed; it may be as large as several thousand square kilometres or as small as only a few square kilometres (Figure 11). 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. Thus the drainage area is required as input to models ranging from simple linear prediction equations to complex computer models. Once the watershed has been delineated, its area can be determined, either by approximate map methods or by GIS.

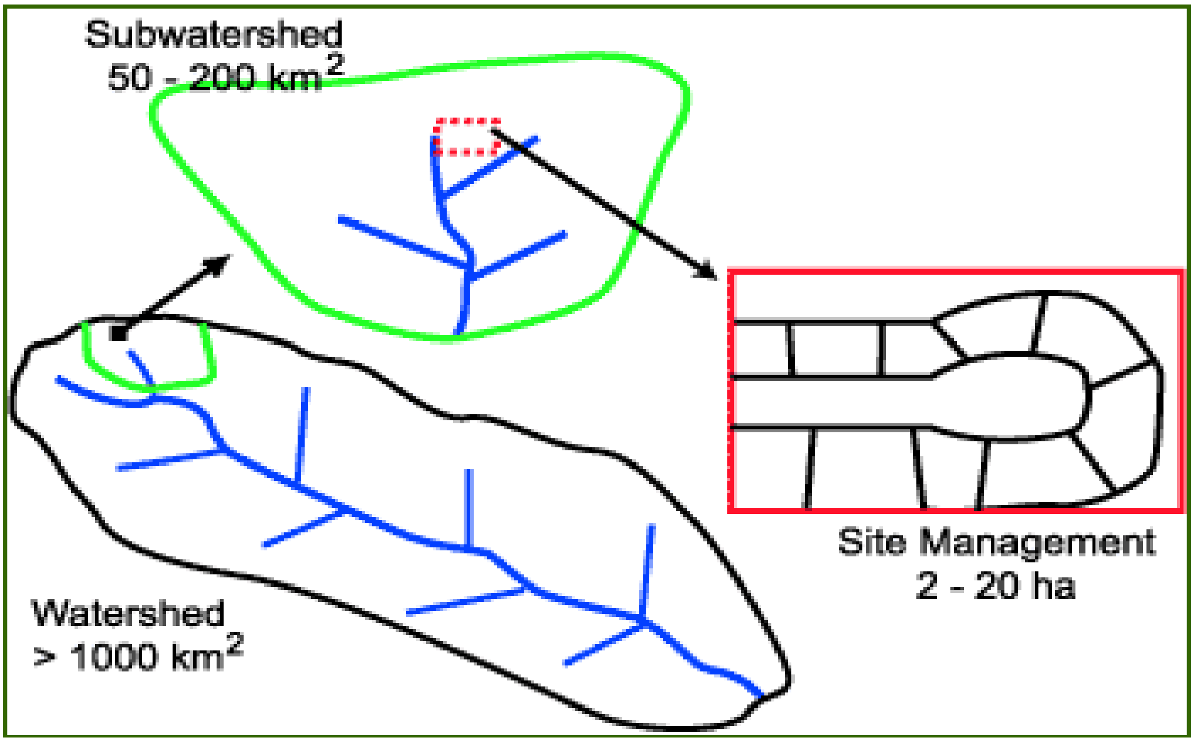

Table 11: Watershed Size

Table 2: Watershed Size

Watershed Management Unit	Area (in km^2)
Micro-watershed	0.05 – 0.50
Sub-watershed	01 – 10
Watershed	10 – 100
Sub-basin	100 – 1000
Basin	1000 – 10000

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.

Shape of Watershed: Watersheds develop in different shapes (Figure 12). They cross county, state, and national boundaries. 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

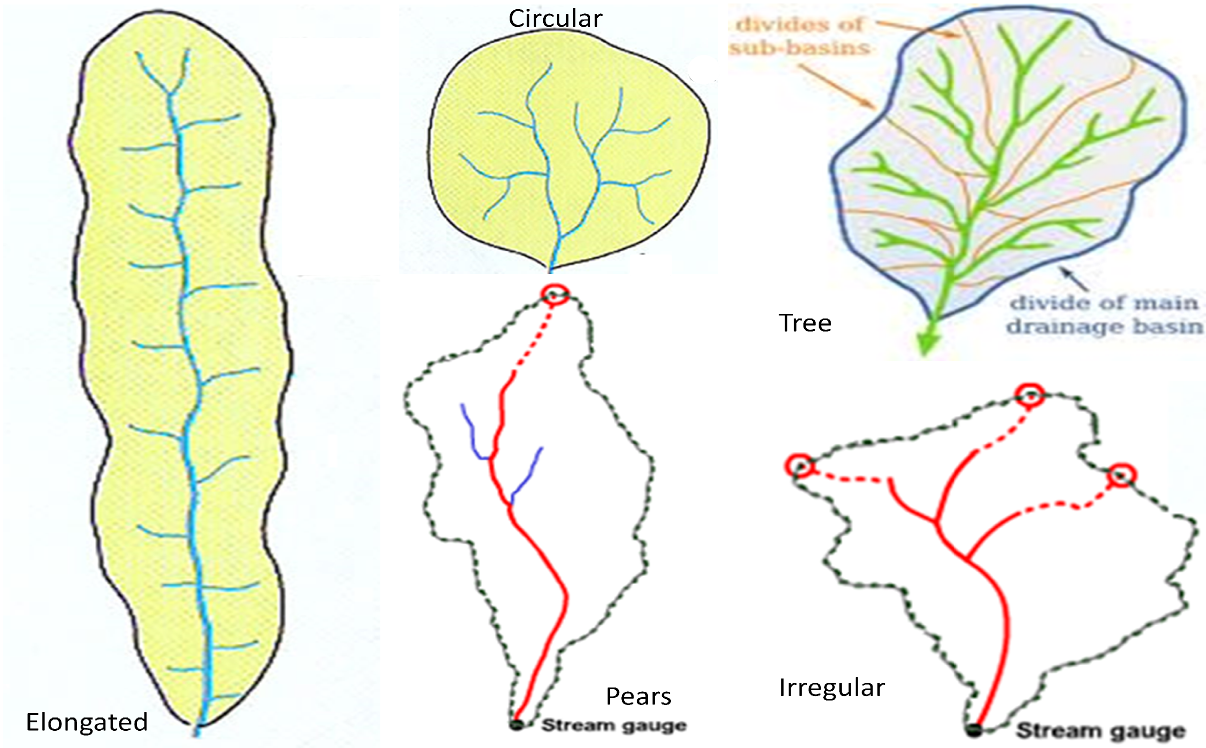

Table 12: Watershed Shapes

Land use and soil characteristics of watershed: Land use and soil characteristics affect both the volume and timing of runoff. During a rainstorm, flow from an impervious, steeply sloped, and smooth, surface make a little retardation and no loss to the flow. In comparison, flow along a pervious grassy hill of the same size will produce retardation and significant loss to the flow due to infiltration (Figure 13).

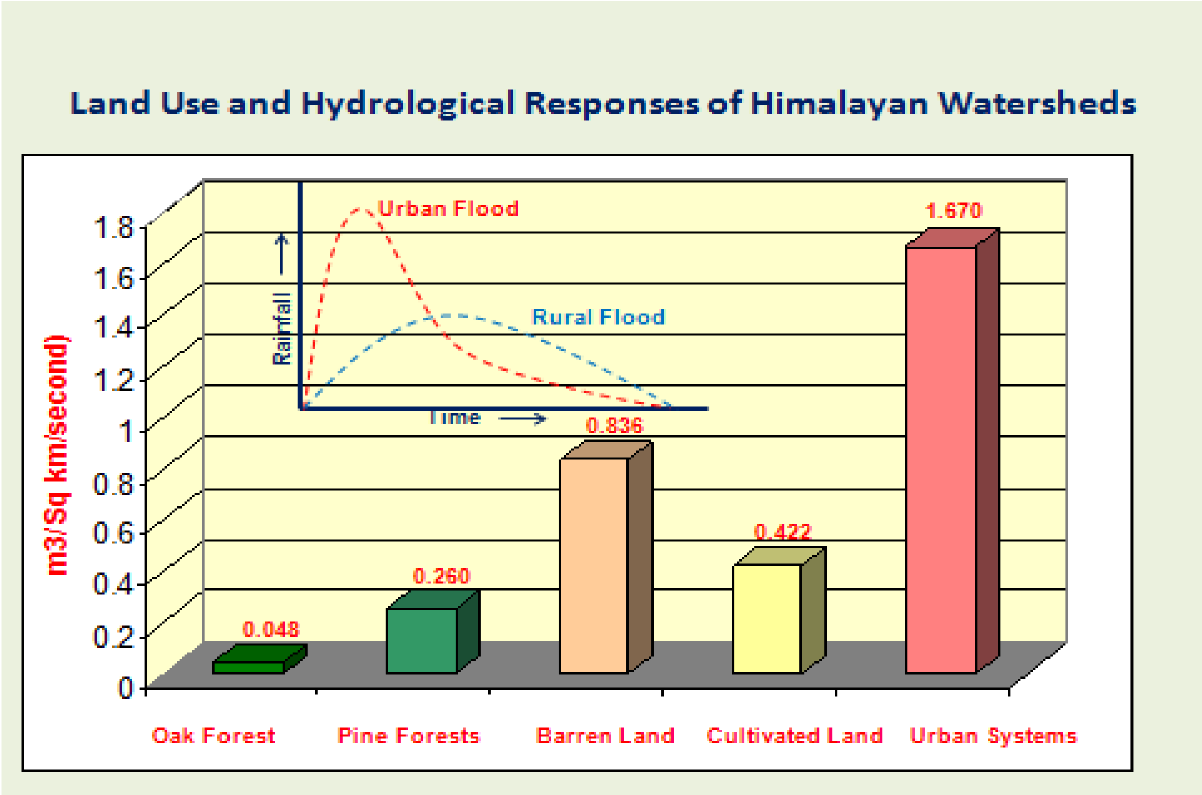

Table 13: Hydrological Responses of the Himalayan Watersheds

Functions of Watershed

A watershed performs the following crucial functions:

Water Capture: Watershed is an hydrological unit. Water capture is process of water's transfer from atmosphere into the soil. All precipitation received from the atmosphere should have the maximum opportunity to enter into the ground where it falls. Land management can affect the extent of water capture by making it easier for water to infiltrate to soil surface and percolate down to greater depth. *Infiltration* is the movement of moisture into and through soil surface, and *percolation* is the downward movement of water through soil (Figure 14).

Water Storage: The captured water is stored in soil particles. The amount of moisture a soil can hold depends on soil depth, texture and its structure, and on the type of vegetation. After the soil is saturated additional water will either run-off through the surface, or percolate into rocks. The moisture retained by soils lost in three ways: (i) through transpiration by plants, (ii) percolation of excess water, and (iii) direct evaporation from bare surface (Figure 14).

Water Release: In the process water moves through soil profile to seeps, springs, and ultimately into the streams and rivers that are the water conduits for the upland. The amount and rate of water released depends on: (i) Subsurface Flow - the water already in the uplands, stream- banks and riparian areas in excess of soil capacity, and (ii) Precipitation that exceeds the soil's infiltration's capacity and flows over the soil surface (Figure 14).

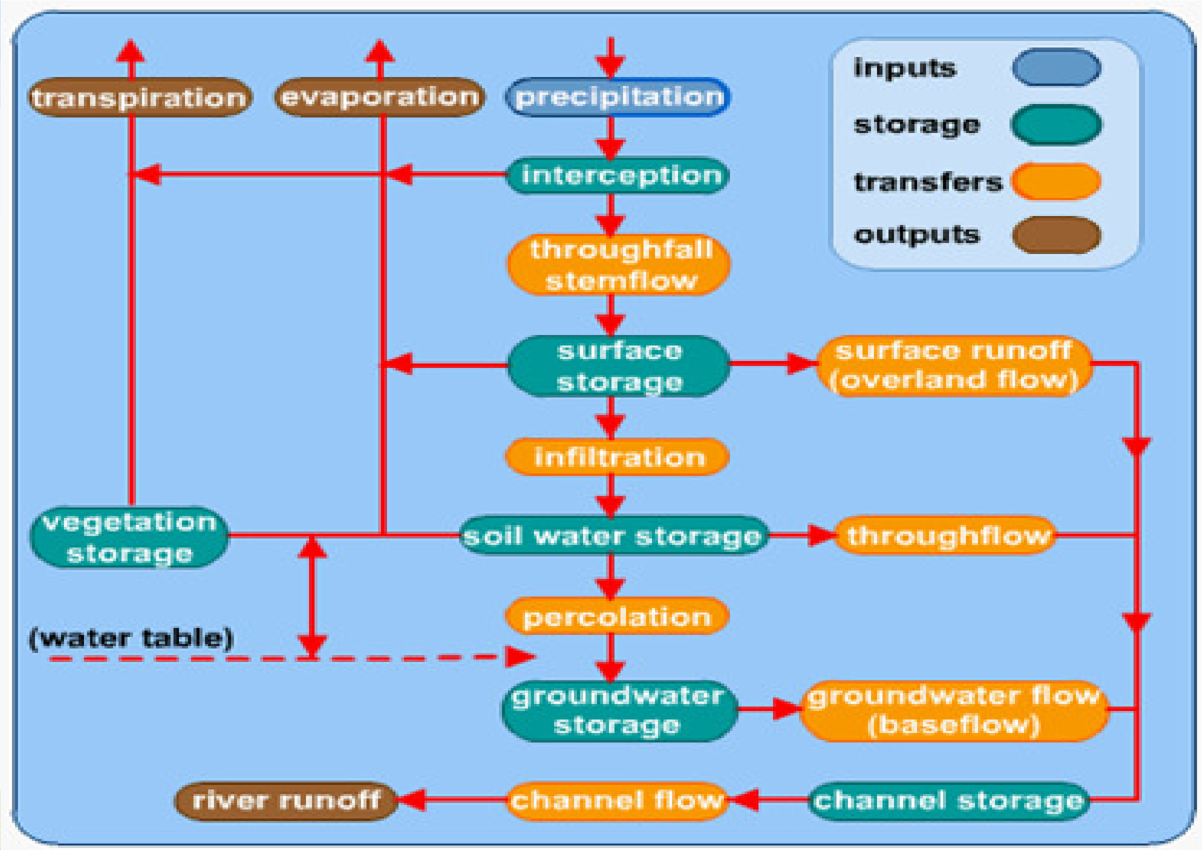

Table 14: Hydrological Processes and Functions of Watershed

Watershed Hydrological Cycle

The hydrological cycle refers to the process beginning with the water falling on the surface in either liquid or in solid form. The captured water is then taken up by vegetation, retained by soil or percolate through the soil. The water may enter into springs streams, rivers, lakes groundwater reservoirs or into the sea. It can then return to the atmosphere by evaporating and then start the cycle again. The simple hydrological cycle has been shown in Figure 14 and 15.

For millions of years, water has been used. It is constantly being recycled and reused. It is important to understand how water moves through the Earth's water cycle, which is defined as the movement of water from the Earth's surface into the atmosphere and back to the Earth's surface again. When it rains, the rainwater flows over land into waterways or is absorbed by the ground or plants. Water evaporates from land and water bodies becoming water vapor in the atmosphere. Water is also released from trees and other plants through transpiration. The water vapour from evaporation and transpiration forms clouds in the atmosphere which in turn provide precipitation (rain, hail, snow, sleet) to start the cycle over again. This process of water recycling, known as the water cycle, repeats itself continuously.

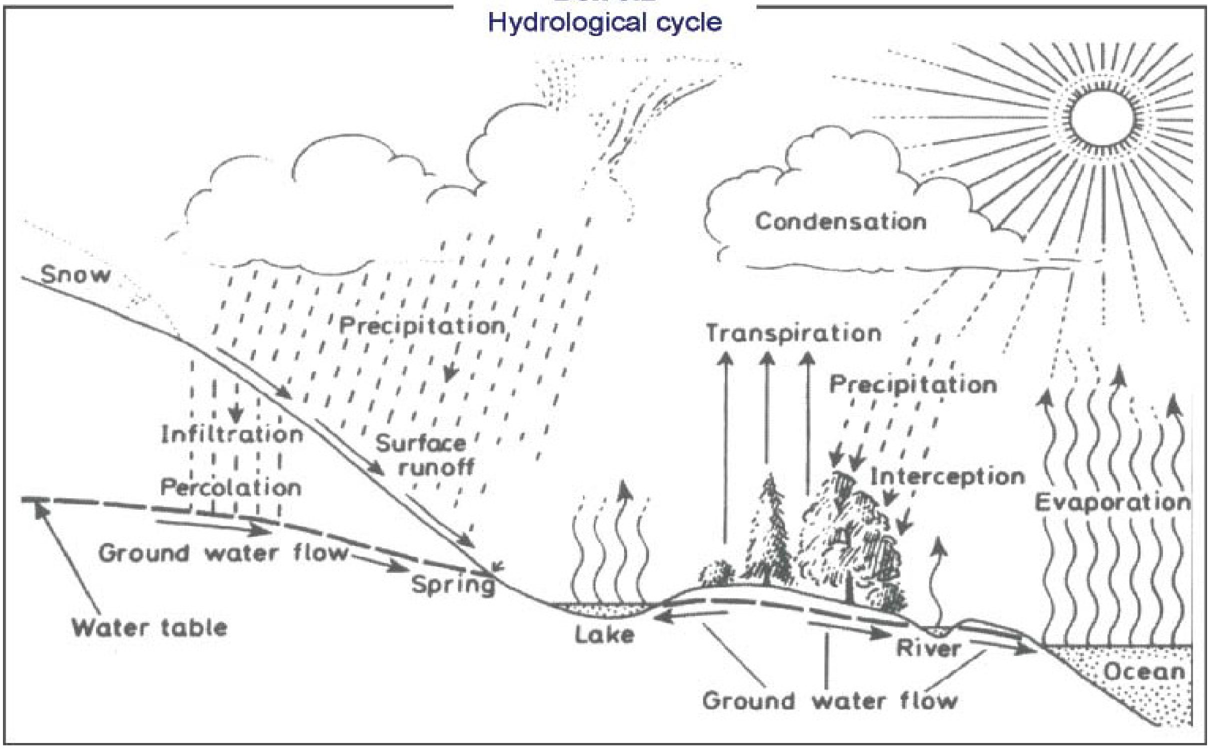

Table 15: General Hydrological Cycle

Watershed Terminology

- **Surface Water:** Water found in rivers, streams, lakes and reservoirs.

- **Base Flow:** The volume of flow in a stream that is not derived from surface run-off, hence, base flow is contributed by ground water discharging to a stream.

- **Aquifer:** Any water-bearing soil or rock formation that is capable of yielding sufficient water to a well.

- **Ground Water:** Water that infiltrates into the soil and is stored in slowly flowing and renewed underground reservoirs (aquifers).

- **Water Table:** The top of the saturated zone when referring to ground water.

- **Erosion:** The detachment and movement of soil material from the land surface by wind or water.

- **Sediment:** Material carried and/or deposited by wind, water or glaciers.

- **Sedimentation:** Insoluble particles of soil and other inorganic and organic materials that become suspended in water and eventually fall to the bottom.

- **Hydrograph:** A graphic of changes in water flow or water level plotted against time. A hydrograph shows stage, flow, velocity, or other properties of water with respect to time.

The Physical Properties of Watershed

The physical properties of watershed include drainage characteristics, geological setting, terrain and geomorphic features, climatic complexities, hydrological system and soil quality of watershed. These physical characteristics not only influence and control the hydrological response and behaviour of watershed, but also determine to large extent the productivity of natural resources and their carrying capacity, conservation needs as well as and opportunities of socio-economic development in the watershed

Trans-boundary River Basins

Generally, the trans-boundary river basin are large watershed encompassing geographical area of several thousand km^2 . Many of these river systems are shared by two or more nations, and these trans-boundary resources are linked by a complex web of environmental, political, economic and security interdependencies. The interdependencies extend not only across national borders, but also between the different water systems, underlining the need for integrated management of these resources (see how these inter-linkages are explored under the 'Indicators' section of this page). The trans-boundary river basins of the world provide vital resources for nearly half of the world's population. This assessment shows existing and increasing risks in the majority of these basins. The world's trans-boundary river basins span 151 countries, include more than 2.8 billion people (around 42 % of the world's population), cover 62 million km2 (42 % of the total land area of the Earth), and produce around 22 000 km3 of river discharge each year (roughly 54 % of the global river discharge).

While ecosystem services provided by these systems support the socio-economic development and wellbeing of much of the world's population, these basins continue to be impacted and degraded by multiple and complex human-induced and natural factors.. Further, management of trans-boundary waters is becoming increasingly important under changing climate and climate change natural disasters. However, this is being constrained by limited availability of funds, resulting in the need for better prioritization of the allocations of limited financial resources. One of the major constraints to the effective management of trans-boundary waters is the lack of a systematic, periodic global comparative assessment of their changing conditions in response to changing stresses. Nevertheless, establishing political will and trans-boundary cooperation frameworks, as well as improving economic and technical capacity at both the national and trans-boundary level, will be crucial in managing these risks and maintaining healthy rivers and deltas for the future. The trans-boundary river basins of the world has been shown in Figure 16:

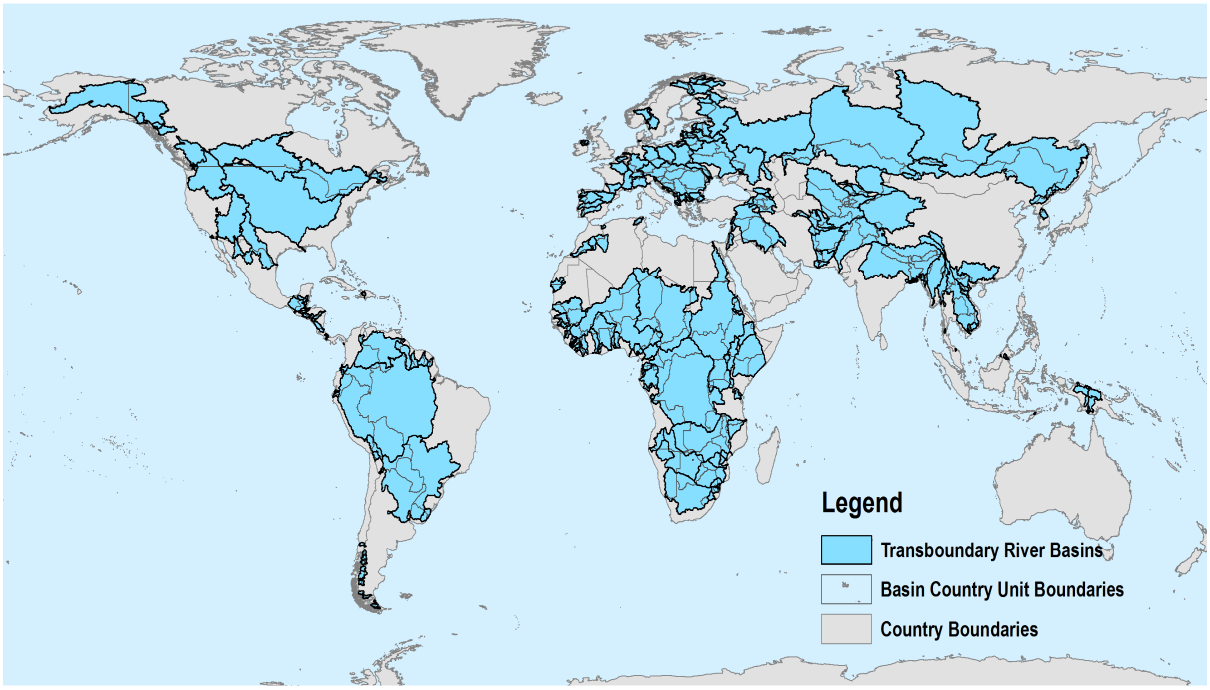

Table 16: Trans-boundary River Basins of Our Planet

Himalayan Trans-boundary River Basins

Hindu Kush Himalaya constitutes headwaters of some of the largest trans-boundary basins of planet that sustain one-fourth global population dependent primarily on subsistence agriculture in Pakistan, India, Nepal, Bhutan, China and Bangladesh. Climate change has stressed hydrological regimes of Himalayan headwaters through higher mean annual temperatures, melting of glaciers, altered precipitation patterns and more frequent and extreme weather events causing substantial decrease in water availability and increasing frequency and severity of hydrological hazards. This may increase proportion of health, food and livelihood insecure population in South Asia which includes some of the poorest people of the world with access to less than 5% of planet's freshwater resources. This will have enormous regional implications for fundamental human endeavours ranging from poverty alleviation to environmental sustainability and climate change adaptation, and even to human security and peace in the region.

A regional geo-political cooperation framework among riparian countries is therefore highly imperative not only for adaptation to long-term impacts of climate change; but also for socio-economic sustainability and political stability in South Asia. It was observed that political transition, threats of internal and external security, weak leadership, and long standing conflictual inter-state dynamics are important reasons for missing regional cooperation in trans-boundary water management and for freezing hydro-diplomacy in the region. However, there is growing realization, demand and recommendations by scientific community, intellectuals, NGOs and civil society organizations for trans-boundary water governance which would help in initiating regional cooperation for adaptive headwater governance across the Hindu Kush Himalaya. A number of regional and local institutions working in South Asia can play an effective role in initiating regional water cooperation in South Asia (Figure 17).

Table 17: Major Trans-boundary River Basins of Hindu Kush Himalaya

The important Trans-boundary river basins of South Asia Are:

Indus Basin: Tibetan Plateau in China constitutes headwater of Indus System, flowing across north-western India and eastern Pakistan it drains into Arabian Sea. Indus system is fed by six rivers including Indus, Ravi, Chenab, Jhelum, Beas and Sutlej which critical resource for both India and Pakistan

Ganges-Brahmputra-Meghna (GBM): This is the largest catchment covering an area of nearly 1.7 million $km^{2.}$ Principal rivers include Ganges, Brahmputra, Meghna, Mahananada, Tista, Yamuna and Kosi

Watershed Management and Sustainable Mountain Sustainable Development

In the 1970s, people all over the world started to notice the environmental threats affecting the planet. Following a warning from the scientific community, the UN called the Conference on Human Environment in 1972, urging Member States to pay more attention to the management and conservation of natural resources in their development efforts. In the following years, environmental concerns became an essential ingredient of political rhetoric, mass communications and the thinking of the general public. Green movements mushroomed in the North and South, and new "ecologically sound" rules and behaviours were promoted. However, economic development and nature conservation continued to be perceived as two different and diverging goals. Environmental protection was seen as a luxury that only rich countries could afford; un-industrialized countries were expected to concentrate more on fighting poverty, disease and illiteracy.

The Report of UN Brundtland Commission (1987) titled '*Our Common Future'* changed the above-mentioned view of human ecology. The report emphasized that the economic significance of natural capital endowments and demonstrated their rational and judicious utilization, which satisfies the current needs of human populations without compromising the chances of future generations. The document refers to this concept as 'Sustainable Development'. The report played a significant role in the sustainable development of mountain regions of the world, particularly in developing and low developed countries through watershed management based on the following scientific rationales:

- A drainage basin is the primary unit for water and matter circulation, analysis and planning

- Since watersheds are defined by natural topography and hydrology, they represent a logical basis for managing water and other natural resources

- When watersheds become the focal point, managers, stakeholders and others are able to gain a more complete understanding of overall conditions in an area

- Watersheds catch and store precipitation, releasing the stored water to stream channels and ground water

- These functions are influenced by climate, geology, topography, land use, soil and vegetation, slope and its aspect and size of the watershed

- While climate determines the amount and type of precipitation entering the watershed, people can significantly influence how these watersheds function

- Land management activities, such as mining, forestry, recreation, grazing, fires, agriculture, and urbanization can impact the vegetation and soil that in turn affects the quantity and timing of water moving through the watershed

- All life depends on soil and water falling on that soil. The entire societies have disappeared because they did not properly understand and care for their soil and water resources. Without productive soils and water, diversity of plants and animals would decline and current human population cannot be maintained

History of Watershed Management

Even though watershed management has become an increasingly important aspect of water resources development in recent years in both developed and developing countries. However, it should be noted that its importance has been realized for at least some 3000 years. Ever since agriculture began, humans have been manipulating water and slopes in order to benefit cultivation and control floods and drought. By 3000 BC, early attempts to control water flow had evolved into sophisticated extended irrigation systems.

Irrigation was discovered in China, on the banks of the Yellow River, and in the Fertile Crescent, which roughly corresponds to the watersheds of three major Near East rivers: the Nile, the Euphrates and the Tigris. From these cradles, irrigation diffused rapidly throughout Asia. By 2500 BC, irrigated agriculture was being practised in the Indus valley, and between 500 and 1 000 years later it had spread to peninsular India and southeast Asia. By 1500 BC, it had been reinvented in the American continent. In china and India watershed management was a common practice 3000 to 5000 years back, in Yellow and Indus river basins. The Indus Civilization collapsed due to inappropriate management of land and water resources

The Greeks, Romans and other Mediterranean people were familiar with water engineering, but they applied the technology more to urban water supply than to irrigation. Nevertheless, Mediterranean hillside terracing and tree planting on slopes - which still characterize the regional landscape - were the forerunners of modern watershed management techniques. Ancient hydraulic technology and land husbandry expertise were further refined during the Middle Ages. Well-fed irrigation systems that still function in oases on the edge of the Sahara testify to the precision and effectiveness of Arab water engineering.

Major hydraulic civil - military works carried out by Italian Renaissance towns, such as Florence, demonstrate what technology was achieving in Europe by the end of the sixteenth century. The capacity to control water flow also increased in Asian, American and African societies: by 1000 AD, the Incas had refined a sophisticated watershed management model, based on the vertical integration of different ecotypes existing in Andean watersheds. Similar approaches were developed by other upland people in Europe and Asia.

In Europe, the potential of watershed technology started to be fully exploited at the beginning of the modern era. Between the sixteenth and seventeenth centuries, the introduction of New World crops such as maize, potato and tomato, the diffusion of non-fallow cultivation techniques based on slow drainage and abundant fertilization, the suppression of the commons and privatization of agricultural lands, and the rapid improvement of machinery led to ever-increasing agricultural yields. Surpluses were essential for sustaining the growing population employed in industry, trade and services, but they also required major public investment in irrigation, land reclamation and watershed management works.

Scientific Watershed Management

- After the Second World War, watershed management became an important element of development policies, as advocated by the Bretton Wood institutions and the United Nations (UN) system. Between 1950 and 1970, big irrigation schemes and hydropower dams were constructed in Asia, Africa and Latin America to promote agricultural development and economic growth while ensuring water and electricity supply. The environmental and social costs of these large-scale watershed works were often underestimated.

- By the 1960s, problems with protecting artificial basins and channels from runoff and sedimentation helped to increase practitioners' and policy-makers' awareness of the importance of upstream–downstream linkages in watersheds. Watershed planning started to consider more thoroughly such processes as seasonal torrents, erosion, rapid basin saturation and downstream floods. The integrated development approach encouraged decision-makers to pay more attention also to the economic and social implications of watershed management, which became "integrated watershed management.

- In the 1970s, it was noticed that environmental threats were affecting the planet. Following a warning from the scientific community, the UN called the Conference on Human Environment in 1972, urging Member States to pay more attention to the management and conservation of natural resources in their development efforts.

- In the following years, green movements mushroomed in the North and South, and new 'ecologically sound' rules and behaviours were promoted. However, economic development and nature conservation continued to be perceived as two different and diverging goals. Environmental protection was seen as a luxury that only rich countries could afford; unindustrialized countries were expected to concentrate more on fighting poverty, disease and illiteracy.

- As mentioned in the preceding section that UN report on *Our Common Future* in 1987 emphasized the economic significance of natural capital endowments and demonstrated the important role that sound development practice can play in environmental protection. The report promoted a new type of development, which satisfies the current needs of human populations without compromising the chances of future generations. The document refers to this as 'Sustainable Development'.

UNCESD 1992 and Watershed Management

- The UN Conference on Environment and Development (UNCED), in Rio de Janeiro, Brazil in 1992, approved Agenda 21, that provides essential guidelines for sustainable development policy and practice ever since. Among Agenda 21's statements on watershed management issues, the most extensive are in Chapter 13 on "Sustainable mountain development", which suggests promoting integrated watershed development and alternative livelihood opportunities. This establishes a framework for linking: (i) Development of appropriate land-use planning and management for both arable and non-arable land in order to prevent soil erosion, (ii) increase biomass production and maintain the ecological balance; (iii) the promotion of alternative income-generating activities, such as sustainable tourism and fisheries and environmentally sound mining; (iv) the improvement of infrastructure and social services in mountain areas, in order to protect the livelihoods of local communities and indigenous people; (v) mitigation of the effects of natural disasters related to poor watershed management through hazard prevention measures, risk zoning, early warning systems, evacuation plans and emergency supplies.

- Agenda 21 also stresses that successful watershed management must be based on local stakeholders' informed participation in natural resource management, economic growth and social change.

- Agenda 21 played an important role in adoption of an integrated and participatory approach to conservation and development. It incorporated the views of economists and social scientists in watershed management; helped ecologists and foresters to understand local livelihood systems and recognize the validity of some indigenous solutions to site-specific problems; improved communications and collaboration among planners and local people; and encouraged participatory watershed management. Watershed management institutions were increasingly involved in the global events that followed the Rio Conference – the World Summit on Sustainable Development (2002), the International Years of Mountains (2002) and Freshwater Year (2003), etc.

- It incorporated the views of economists and social scientists in watershed management; helped ecologists and foresters to understand local livelihood systems and recognize the validity of some indigenous solutions to site specific problems; improved communications and collaboration among planners and local people; and encouraged participatory watershed management. A large number of watershed management projects and programmes were implemented all over the world by different organizations and stakeholders, many of them using integrated and participatory approaches.

Watershed Management: FAO View Point

- Watershed management is primarily a matter of gravity. Gravity makes rainwater flow at a speed – and with a power - that is directly proportional to the slope gradient. Rocks, soil, vegetation cover and human-made artefacts can slow the flow and divert part of it to the subsoil. Gravity makes it possible to distribute highland rainfall over downstream areas, create and renew surface and underground water resources, irrigate plants, water animals, enrich land with mineral and organic sediments, and transport biological materials such as seeds.

- Watershed ecology is very important to humankind. The world's supply of freshwater depends largely on people's capacity to manage upstream - downstream flows. Food security also largely depends on upland water and sediments

Watershed Management in India

About 60 per cent of total arable land (142 million ha) in India is rain-fed, characterized by low productivity, low income, low employment with high incidence of poverty and a bulk of fragile and marginal land . Rainfall pattern in these areas are highly variable both in terms of total amount and its distribution, which lead to moisture stress during critical stages of crop production and makes agriculture production vulnerable to pre and post production risk. Watershed development projects in the country has been sponsored and implemented by Government of India from early 1970s onwards. Various watershed development programs like Drought Prone Area Program (DPAP), Desert Development Program (DDP), River Valley Project (RVP), National Watershed Development Project for Rain-fed Areas (NWDPRA) and Integrated Wasteland Development Program (IWDP) were launched subsequently in various hydro-ecological regions, those were consistently being affected by water stress and draught like situations. Entire watershed development program was primarily focused on structural-driven compartmental approach of soil conservation and rainwater harvesting during 1980s and before. In spite of putting e/orts for maintaining soil conservation practices (example, contour bunding, pits excavations etc.), farmers used to plow out these practices from their 1elds. It was felt that a straightjacket top-down approach cannot make desired impact in watersheds and mix up of individual and community based interventions are essential.

The integrated watershed development program with participatory approach was emphasized during mid 1980s and in early 1990s. This approach had focused on raising crop productivity and livelihood improvement in watersheds (Wani et al. 2006) along with soil and water conservation measures. The Government of India appointed a committee in 1994 under the chairmanship of Prof. C. H. Hanumantha Rao. The committee thoroughly reviewed existing strategies of watershed program and strongly felt a need for moving away from the conventional approach of the government department to the bureaucratic planning without involving local communities. The new guideline was recommended in year 1995, which emphasized on collective action and community participation, including participation of primary stakeholders through community-based organizations, non-governmental organizations and *Panchayati Raj* Institutions.

Watershed development guidelines were again revised in year 2001 (called Hariyali guidelines) to make further simpli1cation and involvement of PRIs more meaningful in planning, implementation and evaluation and community empowerment and guidelines were issued in year 2003. Subsequently, Neeranchal Committee (in year 2005) evaluated the entire government-sponsored, NGO and donor implemented watershed development programs in India and suggested a shift in focus 'away from a purely engineering and structural focus to a deeper concern with livelihood issues'. Major objectives of the watershed management program are: (i) conservation, up-gradation and utilization of natural endowments such as land, water, plant, animal and human resources in a harmonious and integrated manner with low-cost, simple, e/ective and replicable technology; (ii) generation of massive employment; (iii) reduction of inequalities between irrigated and rain-fed areas and poverty alleviation.

Watershed Management: Himalayan Experience

Keeping this in view, the Planning Commission of India has clearly underlined, recommended and emphasized the need of watershed approach for the development of mountain areas. Defining the need and objectives of watershed approach for the mountain environment the Seventh Five Year Plan states, 'In view of the need to balance the indispensability of economic development with the imperatives of environmental conservation and ecological security, the strategy for hill areas would be to formulate realistic and manageable programmes for tackling the interlinked problems involved in the eco-development of the Himalayan region'.

The major thrust for the integrated development of hill areas would be on the basis of critical watershed, sub-watershed and micro-watershed for the conservation of environment and ecological regeneration and productive approach for optimum utilization of land, water and human resources in a scientific manner and integrating various developmental activities having a bearing on the environment and ecological balance in the hill areas on micro-watershed basis with multidisciplinary approach under one umbrella to ensure optimum utilization of land, water and plant resources on the one hand and man and animal resources on the other' (Seventh Five Year Plan, 1985). Realizing the needs of watershed approach, the Government of Uttaranchal has set a Directorate of Watershed Management under the Ministry of Rural Development, which is responsible for the coordination of all development programs at watershed and micro-watershed levels.

In Uttarakhand Himalaya various watershed development programmes, particularly Integrated Wasteland Development Program (IWDP) were launched subsequently in various hydro-ecological regions of the State. The integrated watershed management project is spread over an area of about 2348 Km^2 in 76 micro-watersheds in the densely populated rain-fed middle Himalayan ranges. As many as 468 identified *Gram Panchayats* (Village Councils) in 18 Development Blocks of 11 Districts are participating in this project. An estimated 258000 population of the project area is likely to be benefited from the project outcomes. As in other Himalayan States of India, Integrated Watershed Management projects in Uttarakhand Himalaya has been sponsored and implemented by Government of India. The main objectives of the integrated watershed management programmes in Uttarakhand Himalaya are: (i) conservation, and optimal utilization of natural assets such as, land, soil, water, plant, animal and human resources in a harmonious and integrated manner with low-cost, simple, effective and replicable technology and through community participation and involvement; (ii) improvement of rural livelihood and generation of viable means of employment in villages; (iii) reduction of inequalities between irrigated and rain-fed areas; (v) poverty alleviation; (vi) promoting women's empowerment and gender equality.

The Up-stream and Down-stream Linkage in Watershed: An Himalayan Perspective

Himalaya support a variety of ecosystems and provide key resources and environmental services to the densely populated lowland far away from mountains. The Himalayan highland and lowland ecosystems are thus highly interactive and inter-dependent in terms of ecology and economy as well as in social and political perspectives. The mountain population have contributed significantly to the conservation and protection of these ecosystem goods and services with their rich local indigenous knowledge and traditional resource management practices . The most important provisioning service provided by the Himalayan mountain ecosystem to lowland is freshwater, and therefore Himalaya is known as ‘water tower’ (Viviroli 2007; UNEP-WCMC 2002). The freshwater of Hindu Kush Himalayan (HKH) mountain ranges is used by more than 200 million people living in the region and by 1.3 billion people living in the densely populated downstream in South and East Asia (Viviroli et al. 2007; ICIMOD 2009).

The Himalayan headwaters regulate the hydrological regimes both in upland and lowland and contribute significantly towards maintaining the hydrological cycle through purification and retention of rainwater in the forms of groundwater, ice, and snow, as well as in lakes and streams (ICIMOD 2009).

However, climate change has stressed hydrological regimes of Himalayan headwaters through higher mean annual temperatures, melting of glaciers and altered precipitation patterns which are not only increasing the frequencies and magnitudes of extreme weather events, particularly high intensity rainfall, flash floods, floods and droughts, but also causing substantial decrease in water availability through changes in volume and discharge of water in streams and rivers both in mountains and their adjoining plains (ICIMOD 2009). During recent years, the high intensity precipitation have triggered flash floods, slope failure and landslides in mountainous terrain having severe impacts on the natural and socio-economic sustainability both in up-streams and down-streams ecosystems (ICIMOD 2009). These changes are exuberating the impacts of other drivers of change, particularly land use changes and rapid urbanization in Himalaya.

Upland-lowland linkages in the watershed not only related with hydrological processes and supply of freshwater and soils, but being part the same physical contiguous system the up-stream and down-stream areas are interlinked through diverse social and economic linkages. The availability of freshwater in Himalayan headwaters is under severe threat both from natural processes and anthropogenic stressors. The increasing population pressure and urbanization in Himalaya is not only stressing water resources in terms of demand, utilization patterns and management practices, but also disrupting the hydrological regime of the rain-fed headwaters. The change in headwater system is affecting river flows, agriculture, forests, biodiversity and health besides creating hydrological hazards and disasters both in upland and lowlands.

Watershed Management: A dynamic Approach

The First Generation Watershed Management

The first generation of watershed management operations in developing countries in the 1970s and 1980s gave priority to protection of forests, water resources, downstream assets, particularly reservoirs, and tended to adopt engineering solutions. This programme did not consider including the socio-economic aspects of watershed into the conservation process of natural resources. The emphasis of these watershed management projects was on the conservation of soil, forests and water resources mainly using structural techniques and measures. These watershed management projects have been designated as first generation of watershed management programmes. The outcome of the first generation watershed management have not been encouraging particularly in developing countries as these completely lack human dimension of natural resource management. As a result, the first generation watershed management was replaced with a new or second generation watershed management approach supported by the international community in developing countries in 1990s. The conventional and Integrated approaches of Watershed Management have been shown in Figures 18 and19.

The Second or New Generation Watershed Management

In the 1990s, a new generation watershed management operations focused more on the problems of natural resource management and poverty reduction in upland areas, using farming systems and participatory approaches and livelihood improvement based on the integration of natural, economic and socio-economic parameters within the watershed particularly in developing countries. The second generation watershed management operations focused more on the participatory natural resource management, poverty reduction, livelihood improvement through sustainable farming systems in upland areas, based on the integration of natural, economic and socio-economic parameters within the watershed. However, this approach could not evolve a framework for the desired integration of natural and social and economic components of watershed management.

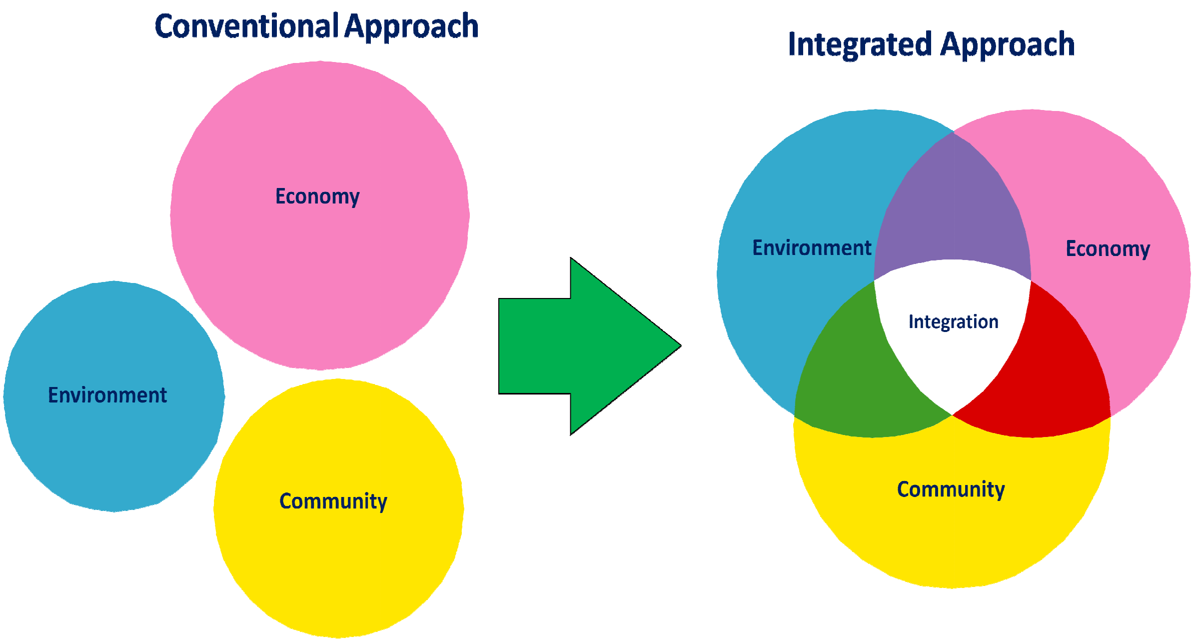

Table 18: Watershed Management Approaches

Watershed Management

- Watershed management is the integrated use of land, vegetation and water in a geographically discrete drainage area for the benefit of its inhabitants, with the objective of protecting or conserving the hydrological services that the watershed provides and of reducing or avoiding negative downstream or groundwater impacts

- Watershed management is the analysis, protection, repair and utilization of drainage basins for optimum control and conservation of water with due regard to other natural resources

- Watershed management is basically concerned with the development and application of land use practices in order to utilize the resources of the region in such a manner that the soil and water resources are protected and conserved

- The key characteristics of a watershed that drive management approaches are the integration of land and water resources, the causal link between upstream land and water use and downstream impacts, the typical nexus in upland areas of developing countries between resource depletion and poverty, and the multiplicity of stakeholders (world Bank 2001)

Integrated Watershed Management

- Integrated Watershed management is the process of formulating and carrying out a course of action involving the manipulation of resources in a watershed to provide goods and services without adversely affecting the soil and water base. Usually, watershed management must consider the social, economic and institutional factors operating within and outside the watershed

- All watersheds contain many kinds of natural resources - soil, water, forest, rangeland, wildlife, minerals, etc. In developing and managing a watershed, the use of some natural resources will be complementary while others will be competitive. For instance, logging may affect water resources and recreation. Changing intensive land use to less intensive ones may benefit soil and water resources

- Integrated Watershed management involves decision-making about use of resources for many purposes, a multi-disciplinary approach is essential. It should include government institutions from various disciplines, and also involve people from different parts of society

- Integrated Watershed management is a continuous process. New elements, both man-made (road building, mining, logging, and cultivation) and natural occurrences (landslides, wildfire, floods) may become a factor at any time. It is important to remember that when new challenges arise, the original management plan must be revised. It is the watershed manager's or planner's responsibility to make the government authorities aware that watershed management is a continuous and flexible process.

Watershed Management Approaches

Watershed management is the integrated use of land, vegetation, and water in a geographically discrete drainage area for the benefit of its residents, with the objective of protecting or conserving the hydrologic services the watershed provides and reducing or avoiding negative downstream or groundwater impacts. The following watershed management approaches have evolved to respond to the complex challenges of natural resource management using the watershed as a practical unit of implementation:

Integrated Approach: This approach suggest the integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and plant resources to meet the basic needs of people and animals in a sustainable manner. This approach aims to improve the standard of living of common people by increasing his earning capacity by offering all facilities required for optimum production (Singh, 2000). In order to achieve its objective, integrated watershed management suggests to adopt land and water conservation practices, water harvesting in ponds and recharging of groundwater for increasing water resources potential and stress on crop diversi1cation, use of improved variety of seeds, integrated nutrient management and integrated pest management practices, etc.

The integrated approach emphasizes on collective action and community participation including of primary stakeholders, government and non-government organizations, and other institutions. Watershed management requires multidisciplinary skills and competencies. Easy access and timely advice to farmers are important drivers for the observed impressive impacts in the watershed. These lead to enhance awareness of the farmers and their ability to consult with the right people when problems arise. It requires multidisciplinary pro1ciency in 1eld of engineering, agronomy, forestry, horticulture, animal husbandry, entomology, social science, economics and marketing. It is not always possible to get all the required support and skills-set in one organization. Thus, consortium approach brings together the expertise of different areas to expand the effectiveness of the various watershed initiatives and interventions

Watershed management programs typically adopt integrated natural resource management approaches with a focus on upland areas where they target the twin objectives of resource conservation and poverty reduction. They also target improvements in downstream environmental services. Because of the multiplicity of stakeholders, watershed management programs tend to be complex and "institution intensive." Because of the public good aspects of watershed management - the prevalence of externalities and the poverty reduction imperative watershed management programs typically involve government actions and subsidies and/or market based mechanisms. A typical watershed management program is thus likely to aim at the following: Improving the management of land and water, and their interactions and externalities. Increasing the intensity and productivity of resource use in the upland area with the objective of reducing poverty and improving livelihoods. Improving environmental services and reducing negative externalities for downstream areas. Addressing technical, institutional, and policy issues needed to ensure equitable. Figure 19 illustrate the integration of climate change adaptation into integrated watershed management.

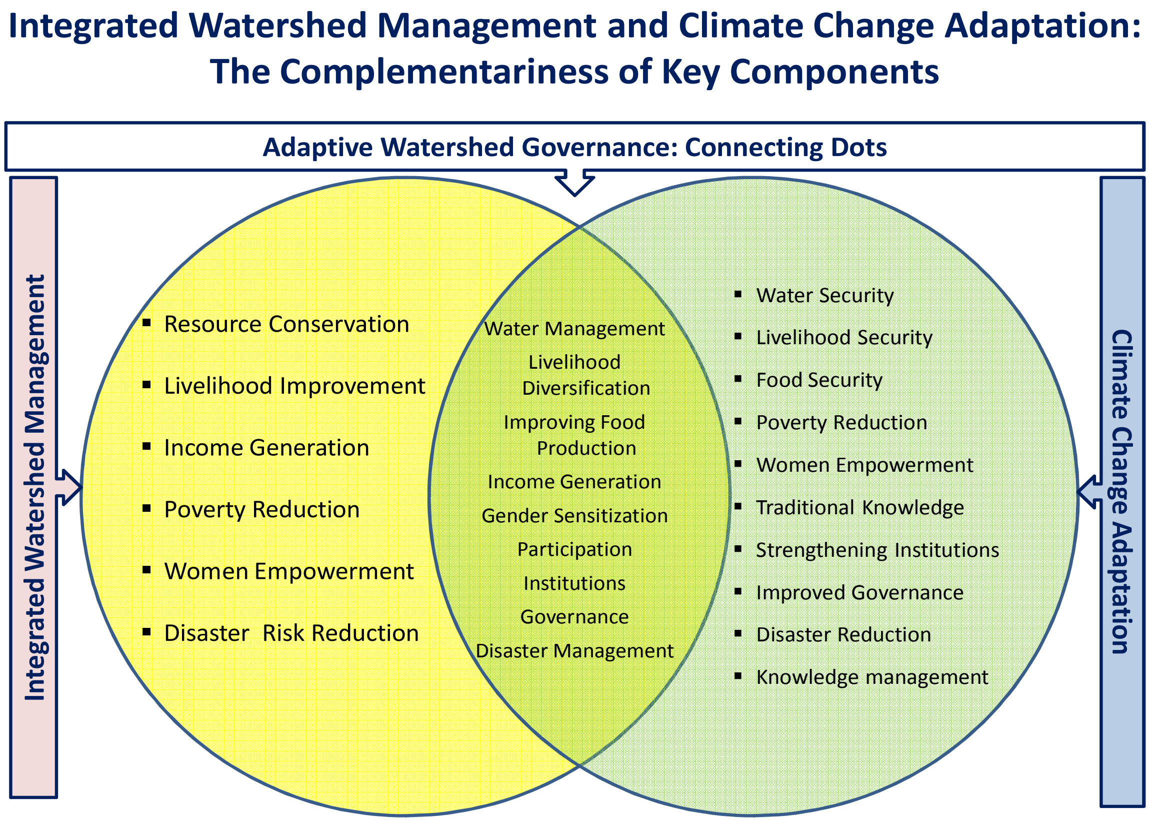

Table 19: Integrating Climate Change Adaptation into Watershed Management

Participatory Approach: The 1990s represented a new departure for watershed management programs supported by the international community in developing countries. Although engineering solutions were not excluded where appropriate, the emphasis was placed more on farming systems and on participatory and demand-driven approaches implemented at the decentralized level. Impetus was given to this new departure by the renewed emphasis on rural poverty reduction in development programs. The temporal status of people's participation in integrated watershed management has been shown in Figure 20.

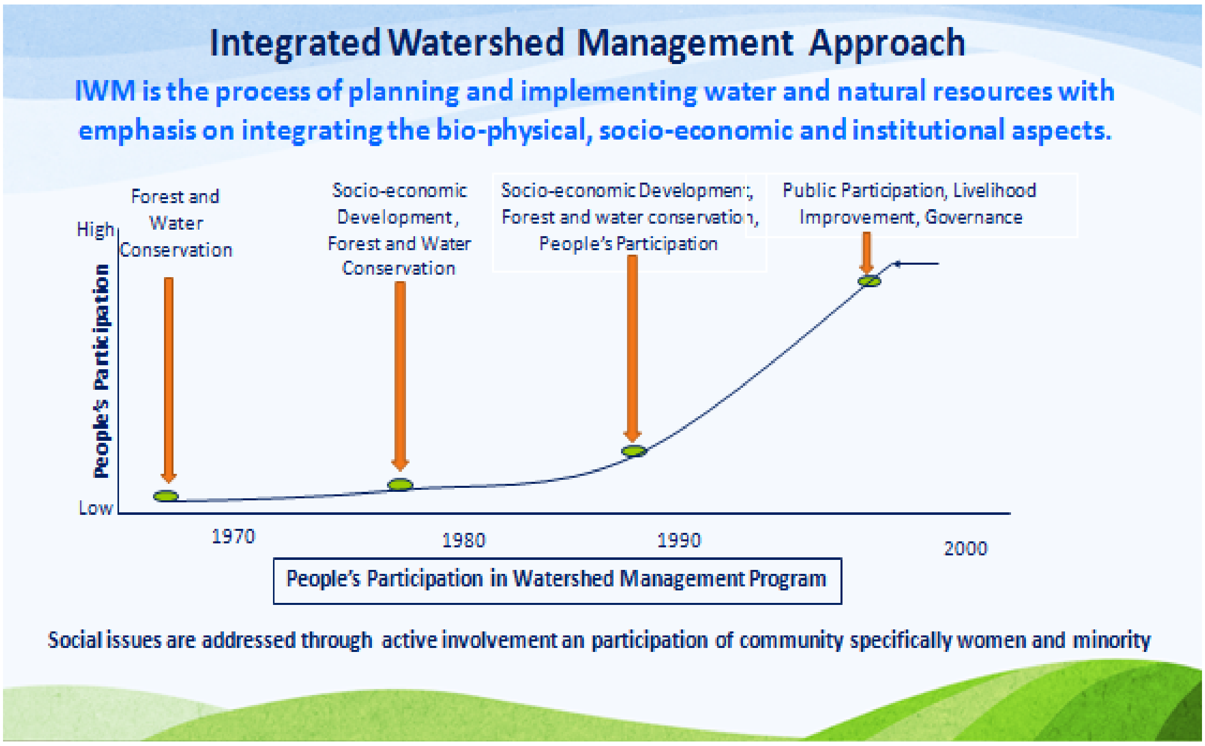

Table 20: People's Participation in Integrated Watershed Management

The move away from planned investments toward farming systems and participatory approaches was designed to seek synergies and to limit the need for tradeoffs. However, it posed two considerable challenges. First, it was not clear under what circumstances the new watershed management approach could achieve both conservation objectives *and* income increases. Second, it remained to be demonstrated whether investments made upstream under a demand driven watershed management program could have a positive effect on downstream conditions by improving hydrological services or reducing negative externalities.

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