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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF CIVIL ENGINEERING

UNIT – I - INTRODUCTION – SCI1305

INTRODUCTION

Utilisation of available water of a region for use of a community has perhaps been practiced from the dawn of civilization. In India, since civilization flourished early, evidences of water utilization has also been found from ancient times. For example at Dholavira in Gujarat water harvesting and drainage systems have come to light which might had been constructed somewhere between 300-1500 BC that is at the time of the Indus valley civilization. In fact, the Harappa and Mohenjodaro excavations have also shown scientific developments of water utilization and disposal systems. They even developed an efficient system of irrigation using several large canals. It has also been discovered that the Harappan civilization made good use of groundwater by digging a large number of wells. Of other places around the world, the earliest dams to retain water in large quantities were constructed in Jawa (Jordan) at about 3000 BC and in WadiGarawi (Egypt) at about 2660 BC. The Roman engineers had built log water conveyance systems, many of which can still be seen today, *Qanats*or underground canals that tap an alluvial fan on mountain slopes and carry it over large distances, were one of the most ingenious of ancient hydro-technical inventions, which originated in Armenia around 1000BC and were found in India since 300 BC. Although many such developments had taken place in the field of water resources in earlier days they were mostly for satisfying drinking water and irrigation requirements. Modern day projects require a scientific planning strategy due to: 1. Gradual decrease of per capita available water on this planet and especially in our country. 2. Water being used for many purposes and the demands vary in time and space.

3. Water availability in a region – like county or state or watershed is not equally distributed. 4. The supply of water may be from rain, surface water bodies and ground water. Water resources project planning

The goals of water resources project planning may be by the use of constructed facilities, or structural measures, or by management and legal techniques that do not require constructed facilities.

The latter are called non-structural measures and may include rules to limit or control water and land use which complement or substitute for constructed facilities.

A project may consist of one or more structural or non-structural resources.

Water resources planning techniques are used to determine what measures should be employed to meet water needs and to take advantage of opportunities for water resources development, and also to preserve and enhance natural water resources and related land resources.

The scientific and technological development has been conspicuously evident during the twentieth century in major fields of engineering.

But since water resources have been practiced for many centuries, the development in this field may not have been as spectacular as, say, for computer sciences.

However, with the rapid development of substantial computational power resulting reduced computation cost, the planning strategies have seen new directions in the last century which utilises the best of the computer resources.

Further, economic considerations used to be the guiding constraint for planning a water resources project.

But during the last couple of decades of the twentieth century there has been a growing awareness for environmental sustainability.

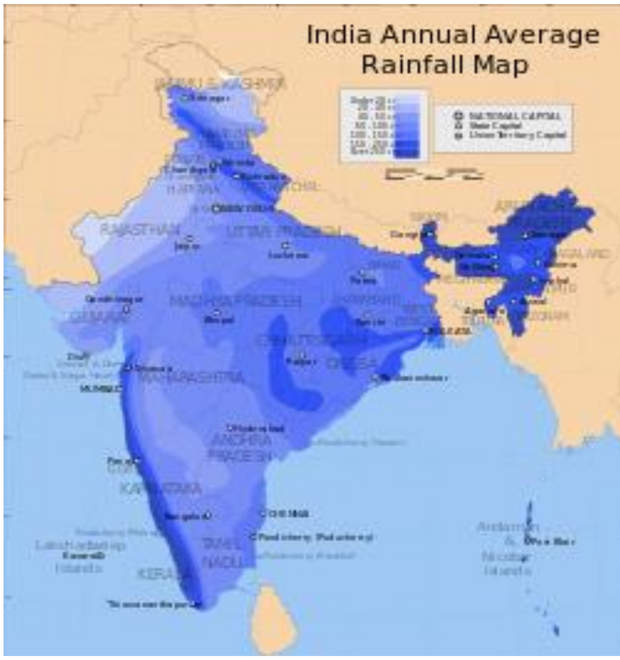
And now, environmental constrains find a significant place in the water resources project (or for that matter any developmental project) planning besides the usual economic and social constraints.

WATER RESOURCES IN INDIA

Water resources in India includes information on precipitation, surface and groundwater storage and hydropower potential. India experiences an average precipitation of 1,170 millimetres (46 in) per year, or about 4,000 cubic kilometres (960 cu mi) of rains annually or about 1,720 cubic metres (61,000 cu ft) of fresh water per person every year.[1] India accounts for 18% of the world population and about 4% of the world’s water resources. One of the solutions to solve the country’s water woes is to create Indian Rivers Inter-link.c[2] Some 80 percent of its area experiences rains of 750 millimetres (30 in) or more a year. However, this rain is not uniform in time or geography. Most of the rains occur during its monsoon seasons (June to September), with the north east and north receiving far more rains than India's west and south. Other than rains, the melting of snow over the Himalayas after winter season feeds the northern rivers to varying degrees. The southern rivers, however experience more flow variability over the year. For the Himalayan basin, this leads to flooding in some months and water scarcity in others. Despite extensive river system, safe clean drinking water as well as irrigation water supplies for sustainable agriculture are in shortage across India, in part because it has, as yet, harnessed a small fraction of its available and recoverable surface water resource. India harnessed 761 cubic kilometres (183 cu mi) (20 percent) of its water resources in 2010, part of which came from unsustainable use of groundwater.[3] Of the water it withdrew from its rivers and groundwater wells, India dedicated about 688 cubic kilometres (165 cu mi) to irrigation, 56 cubic kilometres (13 cu mi) to municipal and drinking water applications and 17 cubic kilometres (4.1 cu mi) to industry.[1]

Vast area of India is under tropical climate which is conducive throughout the year for agriculture due to favourable warm and sunny conditions provided perennial water supply is available to cater to the high rate of evapotranspiration from the cultivated land.[4] Though the overall water resources are adequate to meet all the requirements of the country, the water supply gaps due to temporal and spatial distribution of water resources are to be bridged by interlinking the rivers of India.[5] The total water resources going waste to the sea are nearly 1200 billion cubic meters after sparing moderate environmental / salt export water requirements of all rivers.[6] Food security in India is possible by achieving water security first which in turn is possible with energy security to supply the electricity for the required water pumping as part of its rivers interlinking.[7]

Instead of opting for centralised mega water transfer projects which would take long time to give results, it would be cheaper alternative to deploy extensively shade nets over the cultivated lands for using the locally available water sources efficiently to crops throughout the year.[8] Plants need less than 2% of total water for metabolism requirements and rest 98% is for cooling purpose through transpiration. Shade nets or polytunnels installed over the agriculture lands suitable for all weather conditions would reduce the potential evaporation drastically by reflecting the excessive and harmful sun light without falling on the cropped area.



ANNUAL AVERAGE RAINFALL IN INDIA. MAP SHOWING RIVERS AND FLOOD PRONE AREAS IN INDIA

FIGURE NO. 1.1 **FIGURE NO. 1.2**

The precipitation pattern in India varies dramatically across distance and over calendar months. Much of the precipitation in India, about 85%, is received during summer months through monsoons in the Himalayan catchments of the Ganges-Brahmaputra-Meghna basin. The north eastern region of the country receives heavy precipitation, in comparison with the north western, western and southern parts. The uncertainty in onset of annual monsoon, sometimes marked by prolonged dry spells and fluctuations in seasonal and annual rainfall is a serious problem for the country. Large area of the country is not put to use for agriculture due to local water scarcity or poor water quality. The nation sees cycles of drought years and flood years, with large parts of west and south experiencing more deficits and large variations, resulting in immense hardship particularly the poorest farmers and rural populations. Dependence on erratic rains and lack of irrigation water supply regionally leads to crop failures and farmer suicides. Despite abundant rains during June–September, some regions in other seasons see shortages of drinking water. Some years, the problem temporarily becomes too much rainfall, and weeks of havoc from floods.

SURFACE AND GROUND WATER STORAGE

India currently stores only 6% of its annual rainfall or 253 billion cubic metres (8.9×1012 cu ft), while developed nations strategically store 250% of the annual rainfall in arid river basins. India also relies excessively on groundwater resources, which accounts for over 50 percent of irrigated area with 20 million tube wells installed. India has built nearly 5,000 major or medium dams, barrages, etc. to store the river waters and enhance ground water recharging. The important dams (59 nos) have an aggregate gross storage capacity of 170 billion cubic metres (6.0×1012 cu ft). About 15 percent of India's food is being produced using rapidly depleting / mining groundwater resources. The end of the era of massive expansion in groundwater use is going to demand greater reliance on surface water supply systems.

India is not running out of water whereas water is running out of India without extracting its full potential benefits. Land based water reservoirs construction is very costly after meeting the land & property compensation and rehabilitation expenditures. To create adequate water storage, fresh water coastal reservoirs located on the sea area near the river deltas, is the suitable option socioeconomically without land and forest submergence problems.

HYDRO POWER POTENTIAL

Indian rivers have fairly good hydro power potential when they descend from their source mountains (Himalayas, Western Ghats, Aravali Range, Vindhya Mountains, Eastern Ghats, etc) before the water consumption or flowing to the sea. The hydro power potential keeps on varying depending on the technological developments including alternate power sources, priorities and limitations.

WATER SUPPLY AND SANITATION

Main article: Water supply and sanitation in India

Water supply and sanitation in India continue to be inadequate, despite long-standing efforts by the various levels of government and communities at improving coverage. The level of investment in water and sanitation, albeit low by international standards, has increased during the 2000s. Access has also increased significantly. For example, in 1980 rural sanitation coverage was estimated at 1% and reached 21% in 2008. Also, the share of Indians with access to improved sources of water has increased significantly from 72% in 1990 to 88% in 2008. At the same time, local government institutions in charge of operating and maintaining the infrastructure are seen as weak and lack the financial resources to carry out their functions. In addition, no major city in India is known to have a continuous water supply and an estimated 72% of Indians still lack access to improved sanitation facilities.

In spite of adequate average rainfall in India, there is large area under the less water conditions/drought prone. There are lot of places, where the quality of groundwater is not good. Another issue lies in interstate distribution of rivers. Water supply of the 90% of India's territory is served by inter-state rivers. It has created growing number of conflicts across the states and to the whole country on water sharing issues.

A number of innovative approaches to improve water supply and sanitation have been tested in India, in particular in the early 2000s. These include demand-driven approaches in rural water supply since 1999, community-led total sanitation, a public-private partnerships to improve the continuity of urban water supply in Karnataka, and the use of micro-credit to women in order to improve access to water.

WATER QUALITY ISSUES

When sufficient salt export is not taking place from a river basin to the sea in an attempt to harness the river water fully, it leads to river basin closer and the available water in downstream area of the river basin becomes saline and/ or alkaline water. Land irrigated with saline or alkaline water becomes gradually in to saline or alkali soils. The water percolation in alkali soils is very poor leading to waterlogging problems. Proliferation of alkali soils would compel the farmers to cultivate rice or grasses only as the soil productivity is poor with other crops and tree plantations. Cotton is the preferred crop in saline soils compared to many other crops as their yield is poor. In north eastern states high acidic nature of soils due to excessive rainfall is effecting the agriculture productivity. Interlinking water surplus rivers with water deficit rivers is needed for the long term sustainable productivity of the river basins and for mitigating the anthropogenic influences on the rivers by allowing adequate salt export to the sea in the form of environmental flows. Also baseflows in rivers are to be restored by stopping excessive ground water use and augmenting surface water by canals to achieve adequate salt export to the sea and preserve the water quality.

WATER DISPUTES

MAIN ARTICLE: INTERSTATE RIVER WATER DISPUTES ACT

There is intense competition for the water available in the inter state rivers such as Kavery, Krishna, Godavari, Vamsadhara, Mandovi, Ravi-Beas-Sutlez, Narmada, Tapti, Mahanadi, etc. among the riparian states of India in the absence of water augmentation from the water surplus rivers such as Brahmaputra, Himalayan tributaries of Ganga and west flowing coastal rivers of western ghats.

WATER POLLUTION

MAIN ARTICLE: WATER POLLUTION IN INDIA

Out of India's 3,119 towns and cities, just 209 have partial treatment facilities, and only 8 have full wastewater treatment facilities (WHO 1992). 114 cities dump untreated sewage and partially cremated bodies directly into the Ganges River. Downstream, the untreated water is used for drinking, bathing, and washing.This situation is typical of many rivers in India and river Ganga is less polluted comparatively.

Open defecation is widespread even in urban areas of India.

Ganges

Main article: Pollution of the Ganges

The Ganges River is the largest river in India. The extreme pollution of the Ganges affects 600 million people who live close to the river. The river water starts getting polluted when it enters the plain. The commercial exploitation of the river has risen in proportion to the rise of population. Gangotri and Uttarkashi are good examples too. Gangotri had only a few huts of Sadhus until the 1970s and the population of Uttrakashi has swelled in recent years.

Yamuna

Main article: Yamuna

Yamuna is one of the few sacred rivers in India which is worshipped by many Indians as a goddess. However, due to the exponentially rising amounts of tourists and pilgrims with addition to the rising population of the inhabitants of its banks, Yamuna has come under extreme duress. Due to this unprecedented rise, the river has become polluted. The river has become extremely polluted such that the Indian government has launched the Yamuna Action Plan to help the cause.

Water in our planet is available in the atmosphere, the oceans, on land and within the soil and fractured rock of the earth‟s crust Water molecules from one location to another are driven by the solar energy. Moisture circulates from the earth into the atmosphere through evaporation and then back into the earth as precipitation. In going through this process, called the Hydrologic Cycle, water is conserved – that is, it is neither created nor destroyed.

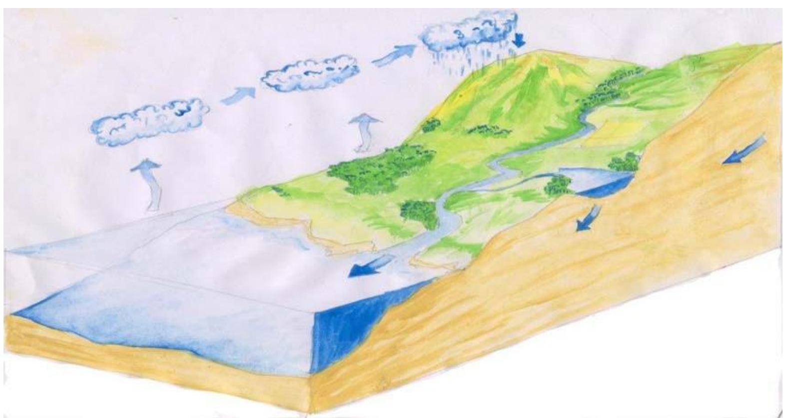


FIGURE NO. 3. HYDROLOGIC CYCLE

It would perhaps be interesting to note that the knowledge of the hydrologic cycle was known at least by about 1000 BC by the people of the Indian Subcontinent. This is reflected by the fact that one verse of Chhandogya Upanishad (the Philosophical reflections of the Vedas) points to the following:

"The rivers… all discharge their waters into the sea. They lead from sea to sea, the clouds raise them to the sky as vapour and release them in the form of rain…"

The earth"s total water content in the hydrologic cycle is not equally distributed.

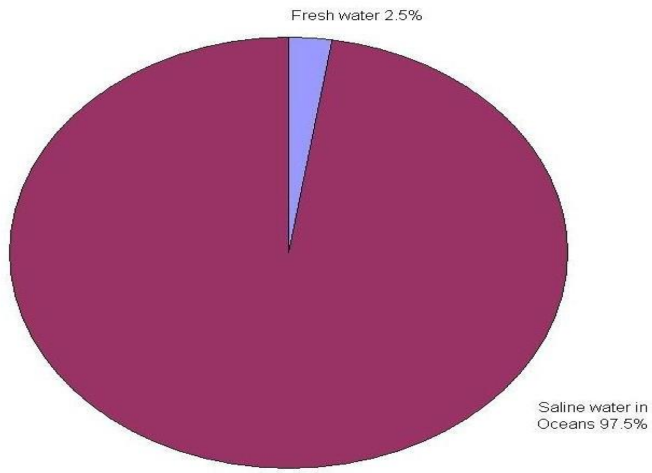


FIGURE NO. 4. TOTAL GLOBAL WATER

The oceans are the largest reservoirs of water, but since it is saline it is not readily usable for requirements of human survival. The freshwater content is just a fraction of the total water available.

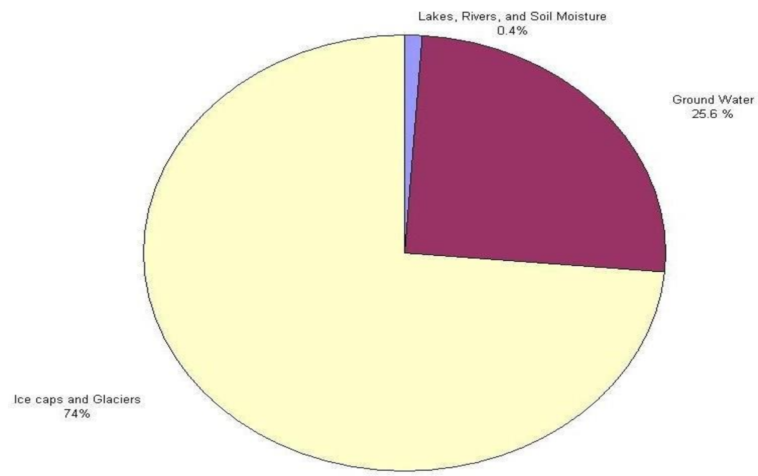


FIGURE NO. 5. GLOBAL FRESH WATER DISTRIBUTION

Again, the fresh water distribution is highly uneven, with most of the water locked in frozen polar ice caps.

The hydrologic cycle consists of four key components

1. Precipitation
2. Runoff
3. Storage
4. Evapotranspiration

1. Precipitation

Precipitation occurs when atmospheric moisture becomes too great to remain suspended in clouds. It denotes all forms of water that reach the earth from the atmosphere, the usual forms being rainfall, snowfall, hail, frost and dew. Once it reaches the earth‟s surface, precipitation can become surface water runoff, surface water storage, glacial ice, water for plants, groundwater, or may evaporate and return immediately to the atmosphere. Ocean evaporation is the greatest source (about 90%) of precipitation.

Rainfall is the predominant form of precipitation and its distribution over the world and within a country.

India has a typical monsoon climate. At this time, the surface winds undergo a complete reversal from January to July, and cause two types of monsoon. In winter dry and cold air from land in the northern latitudes flows southwest (northeast monsoon), while in summer warm and humid air originates over the ocean and flows in the opposite direction (southwest monsoon), accounting for some 70 to 95 percent of the annual rainfall. The average annual rainfall is estimated as 1170 mm over the country, but varies significantly from place to place. In the northwest desert of Rajasthan, the average annual rainfall is lower than 150 mm/year. In the broad belt extending from Madhya Pradesh up to Tamil Nadu, through Maharastra, parts of Andhra Pradesh and Karnataka, the average annual rainfall is generally lower than 500 mm/year. At the other extreme, more than 10000 mm of rainfall occurs in some portion of the Khasi Hills in the northeast of the country in a short period of four months. In other parts of the northeast (Assam, Arunachal Pradesh, Mizoram, etc.,) west coast and in sub-

Himalayan West Bengal the average annual rainfall is about 2500 mm.

Except in the northwest of India, inter annual variability of rainfall in relatively low. The main areas affected by severe droughts are Rajasthan, Gujarat (Kutch and Saurashtra).

The year can be divided into four seasons:

- The winter or northeast monsoon season from January to February.
- The hot season from March to May.
- The summer or south west monsoon from June to September.
- The post – monsoon season from October to December.

The monsoon winds advance over the country either from the Arabian Sea or from the Bay of Bengal. In India, the south-west monsoon is the principal rainy season, which contributes over 75% of the annual rainfall received over a major portion of the country.

2. Runoff

Runoff is the water that flows across the land surface after a storm event. As rain falls over land, part of that gets infiltrated the surface as overland flow. As the flow bears down, it notches out rills and gullies which combine to form channels. These combine further to form streams and rivers. The geographical area which contributes to the flow of a river is called a river or a watershed. The following are the major river basins of our country, and the corresponding figures, as obtained from the web-site of the Ministry of Water Resources, Government of India (http://www.wrmin.nic.in) is mentioned alongside each.

1. Indus
2. Ganges
3. Brahmaputra
4. Krishna
5. Godavari
6. Mahanandi

7. Sabarmati
8. Tapti
9. Brahmani-Baitarani
10. Narmada
11. Pennar
12. Mahi

3. Storage

Portion of the precipitation falling on land surface which does not flow out as runoff gets stored as either as surface water bodies like Lakes, Reservoirs and Wetlands or as sub-surface water body, usually called Ground water.

Ground water storage is the water infiltrating through the soil cover of a land surface and traveling further to reach the huge body of water underground. As mentioned earlier, the amount of ground water storage is much greater than that of lakes and rivers. However, it is not possible to extract the entire groundwater by practicable means. It is interesting to note that the groundwater also is in a state of continuous movement – flowing from regions of higher potential to lower. The rate of movement, however, is exceptionally small compared to the surface water movement.

The following definitions may be useful:

Lakes: Large, naturally occurring inland body of water

Reservoirs: Artificial or natural inland body of water used to store water to meet various demands.

Wet Lands: Natural or artificial areas of shallow water or saturated soils that contain or could support water–loving plants.

4. Evapotranspiration

Evapotranspiration is actually the combination of two terms – evaporation and transpiration. The first of these, that is, evaporation is the process of liquid converting into vapour, through wind action and solar radiation and returning to the atmosphere. Evaporation is the cause of loss of water from open bodies of water, such as lakes, rivers, the oceans and the land surface. It is interesting to note that ocean evaporation provides approximately 90 percent of the earth‟s precipitation. However, living near an ocean does not necessarily imply more rainfall as can be noted from the great difference in the amount of rain received between the east and west coasts of India.

Transpiration is the process by which water molecules leaves the body of a living plant and escapes to the atmosphere. The water is drawn up by the plant root system and part of that is lost through the tissues of plant leaf (through the stomata). In areas of abundant rainfall, transpiration is fairly constant with variations occurring primarily in the length of each plants growing season. However, transpiration in dry areas varies greatly with the root depth.

Evapotranspiration, therefore, includes all evaporation from water and land surfaces, as well as transpiration from plants.

WATER RESOURCES POTENTIAL

Surface water potential

The average annual surface water flows in India has been estimated as 1869 cubic km. This is the utilizable surface water potential in India. But the amount of water that can be actually put to beneficial use is much less due to severe limitations posed by Physiography, topography, inter-state issues and the present state of technology to harness water resources economically. The recent estimates made by the Central Water Commission, indicate that the water resources is utilizable through construction of structures is about 690 cubic km (about 36% of the total). One reason for this vast difference is that not only does the whole rainfall occur in about four months a year but the spatial and temporal distribution of rainfall is too uneven due to which the annual average has very little significance for all practical purposes.

Monsoon rain is the main source of fresh water with 76% of the rainfall occurring between June and September under the influence of the southwest monsoon. The average annual precipitation in volumetric terms is 4000 cubic km. The average annual surface flow out of this is 1869 cubic km, the rest being lost in infiltration and evaporation.

Ground water potential

The potential of dynamic or rechargeable ground water resources of our country has been estimated by the Central Ground Water Board to be about 432 cubic km.

Ground water recharge is principally governed by the intensity of rainfall as also the soil and aquifer conditions. This is a dynamic resource and is replenished every year from natural precipitation, seepage from surface water bodies and conveyance systems return flow from irrigation water, etc.

The highlighted terms are defined or explained as under:

Utilizable surface water potential This is the amount of water that can be purpose fully used, without any wastage to the sea, if water storage and conveyance structures like dams, barrages, canals, etc. are suitably built at requisite sites.

Central Water Commission Central Water Commission is an attached office of Ministry of Water Resources with Head Quarters at New Delhi. It is a premier technical organization in the country in the field of water resources since 1945.

The commission is charged with the general responsibility of initiating, coordinating and furthering, in consultation with the State Governments concerned, schemes for control, conservation and utilization of water resources throughout the country, for purpose of flood control, irrigation, navigation, drinking water supply and water power development.

Central Ground Water Board It is responsible for carrying out nation-wide surveys and assessment of groundwater resources and guiding the states appropriately in scientific and technical matters relating to groundwater. The Central Ground Water Board has generated valuable scientific and technical data through regional hydro geological surveys, groundwater exploration, resource and water quality monitoring and research and development. It assists the States in developing broad policy guidelines for development and management of groundwater resources including their conservation, augmentation and protection from pollution, regulation of extraction and conjunctive use of surface water and ground water resources. The Central Ground Water Board organizes Mass Awareness Programmes to create awareness on various aspects of groundwater investigation, exploration, development and management.

Ground water recharge Some of the water that precipitates, flows on ground surface or seeps through soil first, then flows laterally and some continues to percolate deeper into the soil. This body of water will eventually reach a saturated zone and replenish or recharge groundwater supply. In other words, the recuperation of groundwater is called the groundwater recharge which is done to increase the groundwater table elevation. This can be done by many artificial techniques, say, by constructing a detention dam called a water spreading dam or a dike, to store the flood waters and allow for subsequent seepage of water into the soil, so as to increase the groundwater table. It can also be done by the method of rainwater harvesting in small scale, even at individual houses. The all India figure for groundwater recharge volume is 418.5 cubic km and the per capita annual volume of groundwater recharge is 412.9 cubic m per person.

LAND AND WATER RESOURCES OF INDIA

The two main sources of water in India are rainfall and the snowmelt of glaciers in the Himalayas. Although reliable data on snow cover in India are not available, it is estimated that some 5000 glaciers cover about 43000 km2 in the Himalayas with a total volume of locked water estimated at 3870 km3. considering that about 10000 km2 of the Himalayan glacier is located within India, the total water yield from snowmelt contributing to the river runoff in India may be of the order of 200 km3/year. Although snow and glaciers are poor producers of fresh water, they are good distributors as they yield at the time of need, in the hot season.

The total surface flow, including regenerating flow from ground water and the flow from neighbouring countries is estimated at 1869 km3/year, of which only 690 km3 are considered as utilizable in view of the constraints of the present technology for water storage and inter – state issues. A significant part (647.2 km3/year) of these estimated water resources comes from neighbouring countries; 210.2 km3/year from Nepal, 347 km3/year from China and 90 km3/year from Bhutan. An important part of the surface water resources leaves the country before it reaches the sea: 20 km3/year to Myanmar,

181.37 km3/year to Pakistan and 1105.6 km3/year to Bangladesh ("Irrigation in Aisa in Figures", Food and Agricultural Organisation of the United Nations, Rome, 1999; http://www.fao.org/ag/agL/public.stm). For further information, one may also check the web-site "Earth Trends" http://elearthtrends.wri.org.

The land and water resources of India may be summarized as follows.

Geographical area 329 million hectare

Natural runoff (Surface water and ground water) 1869 cubic km/year

Estimated utilizable surface water potential 690 cubic km/year Ground

water resources 432 cubic km/year

Available ground water resource for irrigation 361 cubic km/year Net

utilizable ground water resource for irrigation 325 cubic

WATER RESOURCES PLANNING

The main sources of water supply are surface and ground water which have been used for a variety of purposes such as drinking, irrigation, hydroelectric energy, transport, recreation etc. Often, human activities are based on the „usual or normal‟ range of river flow conditions. However, flows and storage vary spatially and temporally; and also they are finite (limited) in nature i.e., there is a limit to the services that can be expected from these resources. Rare or „extreme‟ flows or water quality conditions outside the normal ranges will result in losses to river-dependent, human activities. Therefore, planning is needed to increase the benefits from the available water sources.

The purpose of water resources planning and management activities is to determine

(i) How can the renewable yet finite resources best be managed and used?

(ii) How can this be accomplished in an environment of uncertain supplies and uncertain and increasing demands, and consequently of increasing conflicts among individuals having different interests in the management of a river and its basin?

DEVELOPMENT OF WATER RESOURCES

Due to its multiple benefits and the problems created by its excesses, shortages and quality deterioration, water as a resource requires special attention. Requirement of technological/engineering intervention for development of water resources to meet the varied requirements of man or the human demand for water, which are also unevenly distributed, is hence essential.

The development of water resources, though a necessity, is now pertinent to be made sustainable. The concept of sustainable development implies that development meets the needs of the present life, without compromising on the ability of the future generation to meet their own needs. This is all the more important for a resource like water. Sustainable development would ensure minimum adverse impacts on the quality of air, water and terrestrial environment. The long term impacts of global climatic change on various components of hydrologic cycle are also important.

India has sizeable resources of water and a large cultivable land but also a large and growing population to feed. Erratic distribution of rainfall in time and space leads to conditions of floods and droughts which may sometimes occur in the same region in the same year. India has about 16% of the world population as compared to only 4% of the average annual runoff in the rivers.

With the present population of more than 1000 million, the per capita water availability comes to about 1170 m3 per person per year. Here, the average does not reflect the large disparities from region to region in different parts of the country. Against this background, the problems relating to water resources development and management have been receiving critical attention of the Government of India. The country has prepared and adopted a comprehensive National Water Policy in the year 1987, revised in 2002 with a view to have a systematic and scientific development of it water resources. This has been dealt with in Lesson 1.3, "Policies for water resources development".

Some of the salient features of the National Water Policy (2002) are as follows:

- Since the distribution of water is spatially uneven, for water scarce areas, local technologies like rain water harvesting in the domestic or community .

- Technology for/Artificial recharge of water has also to be bettered.
- Desalination methods may be considered for water supply to coastal towns.

PRESENT WATER UTILIZATION IN INDIA

Irrigation constitutes the main use of water and is thus focal issue in water resources development. As of now, irrigation use is 84 percent of total water use. This is much higher than the world"s average, which is about 65 percent. For advanced nations, the figure is much lower. For example, the irrigation use of water in USA is around 33 percent. In India, therefore, the remaining 16 percent of the total water use accounts for Rural domestic and livestock use, Municipal domestic and public use, Thermal-electric power plants and other industrial uses.

The term irrigation is defined as the artificial method of applying water to crops. Irrigation increases crop yield and the amount of land that can be productively farmed, stabilizes productivity, facilitates a greater diversity of crops, increases farm income and employment, helps alleviate poverty and contributes to regional development.

NEED FOR FUTURE DEVELOPMENT OF WATER RESOURCES

The population of India has been estimated to stabilize by about 2050 A.D. By that time, the present population of about 1000 million has been projected to be about 1800 million (considering the low, medium and high estimates of 1349 million 1640 million and 1980 million respectively). The present food grain availability of around 525 grams per capita per day is also presumed to rise to about 650 grams, considering better socio-economic lifestyle (which is much less than the present figures of 980 grams and 2850 grams per capita per day for China and U.S.A., respectively). Thus, the annual food grain requirement for India is estimated to be about 430 MT. Since the present food grain production is just sufficient for the present population, it is imperative that additional area needs to be brought under cultivation. This has been estimated to be 130 Mha for food crop alone and 160 Mha for all crops to meet the demands of the country by 2050 A.D.

Along with the inevitable need to raise food production, substantial thrust should be directed towards water requirement for domestic use. The national agenda for governance aims to ensure provision of potable water supply to every individual in about five years time. The National Water Policy (2002) has accorded topmost water allocation priority to drinking water. Hence, a lot of technological intervention has to be made in order to implement the decision. But this does not mean that unlimited funds would be allocated for the drinking water sector. Only 20% of urban demand is meant for consumptive use . A major concern will therefore be the treatment of urban domestic effluents.

Major industrial thrust to steer the economy is only a matter of time. By 2050, India expects to be a major industrial power in the world. Industry needs water fresh or recycled. Processing industries depend on abundance of water. It is estimated that 64 cubic km of water will be needed by 2050 A.D. to sustain the industries. Thermal power generation needs water including a small part that is consumptive. Taking into account the electric power scenario in 2050 A.D., energy related requirement (evaporation and consumptive use) is estimated at 150 cubic km.

Consumptive use: Consumptive use is the amount of water lost in evapo- transpiration from vegetation and its surrounding land to the atmosphere, inclusive of the water used by the plants for building their tissues and to carry on with their metabolic processes. Evapo-transpiration is the total water lost to the atmosphere from the vegetative cover on the land, along with the water lost from the surrounding water body or land mass.

NEED FOR PLANNING AND MANAGEMENT

Planning and management of water resources systems are essential due to following factors:

(1) Severity of the adverse consequences of droughts, floods and excessive pollution.

These can lead to

a. Too little water due to growing urbanization, additional water requirements, instream flow requirements etc. Measures should be taken to reduce the demand during scarcity times

b. Too much water due to increased flood frequencies and also increase in water requirements due to increased economic development on river floodplains

c. Polluted water due to both industrial and household discharges

(2) Degradation of aquatic and riparian systems due to river training and reclamation of floodplains for urban and industrial development, poor water quality due to discharges of pesticides, fertilizers and wastewater effluents etc.

(3) While port development requires deeper rivers, narrowing the river for shipping purposes will increase the flood level

(4) River bank erosion and degradation of river bed upstream of the reservoirs may increase the flooding risks

(5) Sediment accumulation in the reservoir due to poor water quality

Considering all these factors, the identification and evaluation of alternative measures that may increase the quantitative and qualitative system performance is the primary goal of planning and management policies.

SYSTEM COMPONENTS

Water resources management involves the interaction of three interdependent subsystems:

1. **Natural river subsystem** in which the physical, chemical and biological processes takes place

2. **Socio-economic subsystem**, which includes the human activities related to the use of the natural river system

3. **Administrative and institutional subsystem** of administration, legislation and regulation, where the decision, planning and management processes take place

Inadequate attention to one subsystem can reduce the effect of any work done to improve the performance of the others.

PLANNING AND MANAGEMENT – APPROACHES

Two approaches which lead to an integrated plan and management policy are

From the top down or the command and control approach
From the bottom up or the grassroots approach

Top down approach: Water resources professionals prepare integrated, multipurpose

„master" development plans with alternative structural and non-structural management options. There is dominance of professionals and little participation of stakeholders. In this approach, one or more institutions have the ability and authority to develop and implement the plan. However, nowadays, since public have active participation in planning and management activities , top-down approaches are becoming less desirable or acceptable.

Bottom up approach:

In this approach there is active participation of interested stakeholders – those affected by the management of the water and land resources. Plans are being created from the bottom up Water rather than top down. Top down approach plans do not take into consideration the concerns of affected local stakeholders. Bottom up approach ensures cooperation and commitment from stakeholders The goals and priorities will be common among all stakeholders by taking care of laws and regulations and by identifying multiple alternatives and performance criteria. Tradeoffs are made between conflicting goals or measures of performance.

I**NTEGRATED WATER RESOURCES MANAGEMENT (IWRM)** According to Global

Water Partnership (GWP, 2000), IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of the vital ecosystems. An integrated water management model develop solutions by involving all the essential components into an optimization scheme. The resources are used in relation to social and economic activities and functions. There is a need for laws and regulations for the sustainable use of the water resources.

Dublin principles for a good water resources management as described by the United Nations Water Conference in 1977 are:
The “ecological principle”– to treat water as a unitary resource within river basins, with particular attention to ecosystems.

The “institutional principle”– to respect the principle of subsidiarity through the involvement of government, civil society and the private sector.

The “instrument principle”– to recognize water as a scarce economic community by imposing various penalties for excessive usage.

A management policy must be developed only after considering the factors such as cost effectiveness, economic efficiency, environmental impact, ecological and health considerations etc.

PLANNING AND MANAGEMENT ASPECTS

Technical aspects It is first necessary to identify the characteristics of resources in the basin, including the land, the rainfall, the runoff, the stream and river flows and the groundwater Technical aspects of planning involves

Predicting changes in land use/covers and economic activities at watershed and river basin levels

Estimation of the costs and benefits of any measures being and to be taken to manage the basin‟s water resource including engineering structures, canals, diversion structures etc.

Identification and evaluation of alternative management strategies and also alternative time schedules for implementing those measures

Economic and Financial aspects

Water should be treated as an economic commodity to extract the maximum benefits as well as to generate funds to recover the costs of the investments and of the operation and maintenance of the system. Water had been treated for long as a free commodity. Revenues recovered are far below the capital cost incurred. Financial component of any planning process is needed to recover construction costs, maintenance, repair and operation costs. In management policies, financial viability is viewed as a constraint that must be satisfied; not as an objective whose maximization could result in a reduction in economic efficiency, equity or other non-monetary objectives.

Institutional aspects Successful project implementation needs an enabling environment. National, provincial and local policies, legislation and institutions are crucial for implementation of the decisions. The role of the government is crucial since water is (i) not a property right (ii) a resource that often requires large investment to develop and (iii) a medium that can impulse external effects. The main causes of failure of water resources development project are insufficient institutional setting and lack of a sound economic evaluation and implementation.

CONCEPTS FOR PLANNING WATER RESOURCE DEVELOPMENT

Utilisation of available water of a region for use of a community has perhaps been practiced from the dawn of civilization. In India, since civilization flourished early, evidences of water utilization has also been found from ancient times. For example at Dholavira in Gujarat water harvesting and drainage systems have come to light which might had been constructed somewhere between 300-1500 BC that is at the time of the Indus valley civilization. In fact, the Harappa and Mohenjodaro excavations have also shown scientific developments of water utilization and disposal systems. They even developed an efficient system of irrigation using several large canals. It has also been discovered that the Harappan civilization made good use of groundwater by digging a large number of wells. Of other places around the world, the earliest dams to retain water in large quantities were constructed in Jawa (Jordan) at about 3000 BC and in Wadi Garawi (Egypt) at about 2660 BC. The Roman engineers had built log water conveyance systems, many of which can still be seen today, Qanats or underground canals that tap an alluvial fan on mountain slopes and carry it over large distances, were one of the most ingenious of ancient hydro-technical inventions, which originated in Armenia around 1000BC and were found in India since 300 BC.

Although many such developments had taken place in the field of water resources in earlier days they were mostly for satisfying drinking water and irrigation requirements. Modern day projects require a scientific planning strategy due to:

1. Gradual decrease of per capita available water on this planet and especially in our country.
2. Water being used for many purposes and the demands vary in time and space.
3. Water availability in a region – like county or state or watershed is not equally distributed.
4. The supply of water may be from rain, surface water bodies and ground water.

This lesson discusses the options available for planning, development and management of water resources of a region systematically.

WATER RESOURCES PROJECT PLANNING

The goals of water resources project planning may be by the use of constructed facilities, or structural measures, or by management and legal techniques that do not require constructed facilities. The latter are called non-structural measures and may include rules to limit or control water and land use which complement or substitute for constructed facilities. A project may consist of one or more structural or non-structural resources. Water resources planning techniques are used to determine what measures should be employed to meet water needs and to take advantage of opportunities for water resources development, and also to preserve and enhance natural water resources and related land resources.

The scientific and technological development has been conspicuously evident during the twentieth century in major fields of engineering. But since water resources have been practiced for many centuries, the development in this field may not have been as spectacular as, say, for computer sciences. However, with the rapid development of substantial computational power resulting reduced computation cost, the planning strategies have seen new directions in the last century which utilises the best of the computer resources. Further, economic considerations used to be the guiding constraint for planning a water resources project. But during the last couple of decades of the twentieth century there has been a growing awareness for environmental sustainability. And now, environmental constrains find a significant place in the water resources project (or for that matter any developmental project) planning besides the usual economic and social constraints.

Priorities for water resources planning

Water resource projects are constructed to develop or manage the available water resources for different purposes. According to the National Water Policy (2002), the water allocation priorities for planning and operation of water resource systems should broadly be as follows

1. Domestic consumption This includes water requirements primarily for drinking, cooking, bathing, washing of clothes and utensils and flushing of toilets.
2. Irrigation

Water required for growing crops in a systematic and scientific manner in areas even with deficit rainfall.
3. Hydropower

This is the generation of electricity by harnessing the power of flowing water.

4. Ecology / environment restoration

Water required for maintaining the environmental health of a region.

5. Industries

The industries require water for various purposes and that by thermal power stations is quite high.
6. Navigation

Navigation possibility in rivers may be enhanced by increasing the flow, thereby increasing the depth of water required to allow larger vessels to pass.
7. Other uses

Like entertainment of scenic natural view.

This course on Water Resources Engineering broadly discusses the facilities to be constructed / augmented to meet the demand for the above uses. Many a times, one project may serve more than one purpose of the above mentioned uses.

Basin – wise water resource project development

The total land area that contributes water to a river is called a Watershed, also called differently as the Catchment, River basin, Drainage Basin, or simply a Basin.

A watershed may also be defined as a geographic area that drains to a common point, which makes it an attractive planning unit for technical efforts to conserve soil and maximize the utilization of surface and subsurface water for crop production. Thus, it is generally considered that water resources development and management schemes should be planned for a hydrological unit such as a Drainage Basin as a whole or for a Sub-Basin, multi-sectorially, taking into account surface and ground water for sustainable use incorporating quantity and quality aspects as well as environmental considerations.

Let us look into the concept of watershed or basin-wise project development in some detail. The objective is to meet the demands of water within the Basin with the available water therein, which could be surface water, in the form of rivers, lakes, etc. or as groundwater. The source for all these water bodies is the rain occurring over the Watershed or perhaps the snowmelt of the glacier within it, and that varies both temporally and spatially.

Further due to the land surface variations the rain falling over land surface tries to follow the steepest gradient as overland flow and meets the rivers or drains into lakes and ponds. The time for the overland flows to reach the rivers may be fast or slow depending on the obstructions and detentions it meet on the way. Part of the water from either overland flow or from the rivers and lakes penetrates into the ground and recharge the ground water. Ground water is thus available almost throughout the watershed, in the underground aquifers. The variation of the water table is also fairly even, with some rise during rainfall and a gradual fall at other times. The water in the rivers is mostly available during the rains. When the rain stops, part of the ground water comes out to recharge the rivers and that results in the dry season flows in rivers.

Note:

Temporal: That which varies with time

Spatial: That which varies with time

Tools for water resources planning and management

The policy makers responsible for making comprehensive decisions of water resources planning for particular units of land, preferably a basin, are faced with various parameters, some of which are discussed in the following sections.

The supply of water

This may be divided into three sources

- **Rain falling within the region**-This may be utilized directly before it reaches the ground, for example, the roof – top rain water harvesting schemes in water scarce areas.
- **Surface water bodies.** These static (lakes and ponds) and flowing (streams and rivers), water bodies may be utilized for satisfying the demand of the unit, for example by constructing dams across rivers.
- **Ground water reservoirs.** The water stored in soil and pores of fractured bed rock may be extracted to meet the demand, for example wells or tube – wells.

Water transferred in and out of the unit

If the planning is for a watershed or basin, then generally the water available within the basin is to be used unless there is inter basin water transfer. If however, the unit is a political entity, like a nation or a state, then definitely there shall be inflow or outflow of water especially that of flowing surface water. Riparian rights have to be honored and extraction of more water by the upland unit may result in severe tension.

Note: Riparian rights mean the right of the downstream beneficiaries of a river to the river water.

Regeneration of water within the unit

Brackish water may be converted with appropriate technology to supply sweet water for drinking and has been tried in many extreme water scarce areas. Waste water of households may be recycled, again with appropriate technology, to supply water

The demand of water

Domestic water requirement for urban population

This is usually done through an organized municipal water distribution network. This water is generally required for drinking, cooking, bathing and sanitary purposes etc, for the urban areas. According to National Water Policy (2002), domestic water supplies for urban areas under various conditions are given below. The units mentioned “lpcd” stands for Liters per Capita per Day”.

1. 40 lpcd where only spot sources are available

2. 70 lpcd where piped water supply is available but no sewerage system

3. 125 lpcd where piped water supply and sewerage system are both available. 150 lpcd may be allowed for metro cities.

Domestic and livestock water requirement for rural population

This may be done through individual effort of the users by tapping a local available source or through co-operative efforts, like Panchayats or Block Development Authorities. The accepted norms for rural water supply according to National Water Policy (2002) under various conditions are given below.

- 40 lpcd or one hand pump for 250 persons within a walking distance of 1.6 km or elevation difference of 100 m in hills.
- 30 lpcd additional for cattle in Desert Development Programme (DDP) areas.

Irrigation water requirement of cropped fields

Irrigation may be done through individual effort of the farmers or through group cooperation between farmers, like Farmers‟ Cooperatives. The demands have to be estimated based on the cropping pattern, which may vary over the land unit due to various factors like; farmer‟s choice, soil type, climate, etc. Actually, the term "Irrigation Water Demand" denotes the total quantity and the way in which a crop requires water, from the time it is sown to the time it is harvested.

Industrial water needs

This depends on the type of industry, its magnitude and the quantity of water required per unit of production.

Structural tools for water resource development

This section discusses the common structural options available to the Water Resources Engineer to development the water potential of the region to its best possible extent. Dams

These are detention structures for storing water of streams and rivers. The water stored in the reservoir created behind the dam may be used gradually, depending on demand. Barrages

These are diversion structures which help to divert a portion of the stream and river for meeting demands for irrigation or hydropower. They also help to increase the level of the water slightly which may be advantageous from the point of view of increasing navigability or to provide a pond from where water may be drawn to meet domestic or industrial water demand.

Canals/Tunnels

These are conveyance structures for transporting water over long distances for irrigation or hydropower.

These structural options are used to utilise surface water to its maximum possible extent. Other structures for utilising ground water include rainwater detentions tanks, wells and tube wells.

Another option that is important for any water resource project is **Watershed Management practices.** Through these measures, the water falling within the catchment area is not allowed to move quickly to drain into the rivers and streams. This helps the rain water to saturate the soil and increase the ground water reserve. Moreover, these measures reduce the amount of erosion taking place on the hill slopes and thus helps in increasing the effective lives of reservoirs which otherwise would have been silted up quickly due to the deposition of the eroded materials.

Management tools for water resource planning

The following management strategies are important for water resources planning:

- Water related allocation/re-allocation agreements between planning units sharing common water resource.
- Subsidies on water use
- Planning of releases from reservoirs over time
- Planning of withdrawal of ground water with time.
- Planning of cropping patterns of agricultural fields to optimize the water availability from rain and irrigation (using surface and/or ground water sources) as a function of time
- Creating public awareness to reduce wastage of water, especially filtered drinking water and to inculcate the habit of recycling waste water for purposes like gardening.

Research in water management: Well established technological inputs are in verge in water resources engineering which were mostly evolved over the last century. Since, then not much of innovations have been put forward. However, it is equally known that quite a few of these technologies run below optimum desired efficiency. Research in this field is essential for optimizing such structure to make most of water resource utilization.

An example for this is the seepage loss in canals and loss of water during application of water in irrigating the fields. As an indication, it may be pointed out that in India, of the water that is diverted through irrigation canals up to the crop growing fields, only about half is actually utilized for plant growth. This example is also glaring since agriculture sector takes most of the water for its assumption from the developed project on water resources.

A good thrust in research is needed to increase the water application efficiently which, in turn, will help optimizing the system.

Inter-basin water transfer

It is possible that the water availability in a basin (Watershed) is not sufficient to meet the maximum demands within the basin. This would require Inter-basin water transfer, which is described below:

The National water policy adopted by the Government of India emphasizes the need for inter-basin transfer of water in view of several water surplus and deficit areas within the country. As early as 1980, the Minister of Water Resources had prepared a National perspective plan for Water resources development. The National Perspective comprises two main components:

a) Himalayan Rivers Development, and

b) Peninsular Rivers Development Himalayan rivers development

Himalayan rivers development envisages construction of storage reservoirs on the principal tributaries of the Ganga and the Brahamaputra in India, Nepal and Bhutan, along with interlinking canal systems to transfer surplus flows of the eastern tributaries of the Ganga to the west, apart from linking of the main Brahmaputra and its tributaries with the Ganga and Ganga with Mahanadi.

Peninsular rivers development

This component is divided into four major parts:

1. Interlinking of Mahanadi-Godavari-Krishna-Cauvery rivers and building storages at potential sites in these basins.
2. Interlinking of west flowing rivers, north of Mumbai and south of Tapi.
3. Interlinking of Ken-Chambal rivers.
4. Diversion of other west flowing rivers.

The possible quantity of water that may be transferred by donor basin may be equal to the average water availability of basin minus maximum possible water requirement within basin (considering future scenarios).

Note: A Donor basin is the basin, which is supplying the water to the downstream basin. The minimum expected quantity of water for recipient basin may be equal to the minimum possible water requirement within basin (considering future scenarios) minus average water availability of basin.

Note: A Recipient basin is the basin, which is receiving the water from the Donor basin. National Water Development Agency (NWDA) of the Government of India has been entrusted with the task of formalizing the inter-linking proposal in India. So far, the agency has identified some thirty possible links within India for inter-basin transfer based on extensive study of water availability and demand data.

Possible components of an inter-basin transfer project include the following:

- Storage Dam in Donor basin to store flood runoff
- Conveyance structure, like canal, to transfer water from donor to recipient basin
- Possible pumping equipments to raise water across watershed-divide

Possible implications of inter-basin transfer: Since a large scale water transfer would be required, it is necessary to check whether there shall be any of the following:

- River bed level rise or fall due to possible silt deposition or removal.
- Ground water rise or fall due to possible excess or deficit water seepage.
- Ecological imbalance due to possible disturbance of flora and fauna habitat.

- Desertification due to prevention of natural flooding (i.e. by diversion of flood water)
- Transfer of dissolved salts, suspended sediments, nutrients, trace elements etc. from one basin to another.

Tasks for planning a water resources project

The important tasks for preparing a planning report of a water resources project would include the following:

- Analysis of basic data like maps, remote sensing images, geological data, hydrologic data, and requirement of water use data, etc.
- Selection of alternative sites based on economic aspects generally, but keeping in mind environmental degradation aspects.
- Studies for dam, reservoir, diversion structure, conveyance structure, etc.

- Selection of capacity.
- Selection of type of dam and spillway.
- Layout of structures.
- Analysis of foundation of structures.
- Development of construction plan.
- Cost estimates of structures, foundation strengthening measures, etc.

- Studies for local protective works – levees, riverbank revetment, etc.
- Formulation of optimal combination of structural and non-structural components (for projects with flood control component).
- Economic and financial analyses, taking into account environmental degradation, if any, as a cost.
- Environmental and sociological impact assessment.

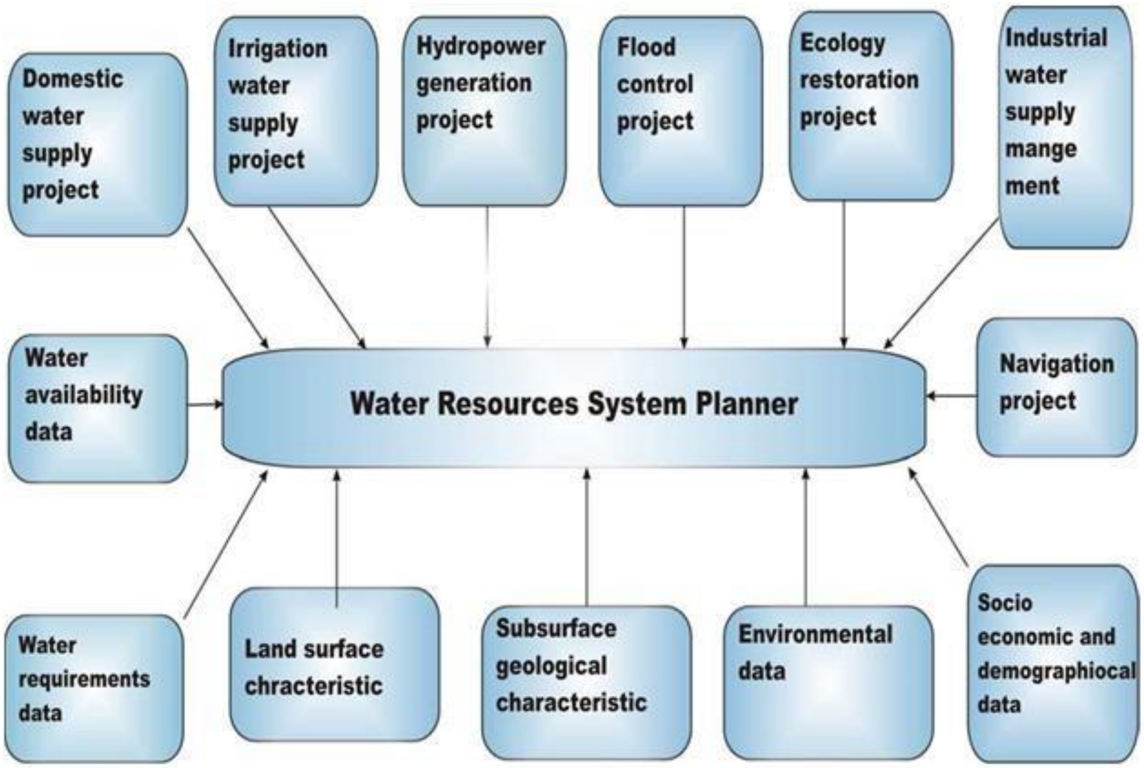
PLANNING AND ASSESSMENT DATA FOR PROJECT

A water resources systems planner is faced with the challenge of conceptualizing a project to meet the specific needs at a minimum cost. For a demand intensive project, the size of the project is limited by the availability of water. The planner then has to choose amongst the alternatives and determine the optimum scale of the project. If it is a multi-purpose project, an allocation of costs has to be made to those who benefit from the project. An important aspect of planning is that it has to prepare for a future date – its effects in terms of physical quantities and costs over a period of time spanning the useful life of project has to be evaluated. The return expected over the project period has to be calculated.

All this requires broader decisions, which affect the design details of the project. This chapter looks into the different aspects of preparing a project plan likely to face a water resources system planner, including the basic assessment of data that is primary to any project plan formulation.

Meeting the challenges

The major projects which water resources systems planner has to conceptualize are shown in Figure 1. Although the figure shows each project to be separate entity, quite a few real projects may actually serve more than one purpose. For example, the Hirakud or the Bhakra dams cater to flood control, irrigation and hydropower generation. On the other hand more than one project is necessary (and which actually forms a system of projects) to achieve a specific purpose.



Possible water resources projects requiring planning and necessary data requirement

For example, to control the floods in the Damodar River, which earlier used to havoc in the districts of Bardhaman, Hooghly and Howrah in West Bengal, a number of dams were constructed on the Damodar and its tributaries between 1950s and 1970. For irrigation projects, a dam may be constructed across a river to store water in the upstream reach and a barrage may be constructed in the downstream reach to divert and regulate the water through an off taking canal

Project planning for domestic water supply

The project for supplying drinking water to a township would usually consist of a network of pipelines to reach the demand area. The source of water could be underground or from a surface water body, usually a river. At times, it could be a judicious combination of the two. A water resources systems planner has to design the whole system from the source up to the distribution network. However, the scope of water resources engineering is generally be limited to the intake system design. The storage of water, its treatment and finally distribution to the consumers are looked after by the authorities of the township. Further details may be obtained in a course on Water and Waste Water Engineering.

Typical intake systems could possibly be one of the following, depending and the convenience of planning.

1. Construction of a water intake plant directly from the river

Example: Water intake system at Palta for Kolkata from river Hooghly.

2. Construction of a dam across a river and drawing water from the reservoir behind.

Example: Dam at Mawphlang on river Umiam for water supply to Shillong.

3. Construction of a barrage across a river and drawing water from the pool behind

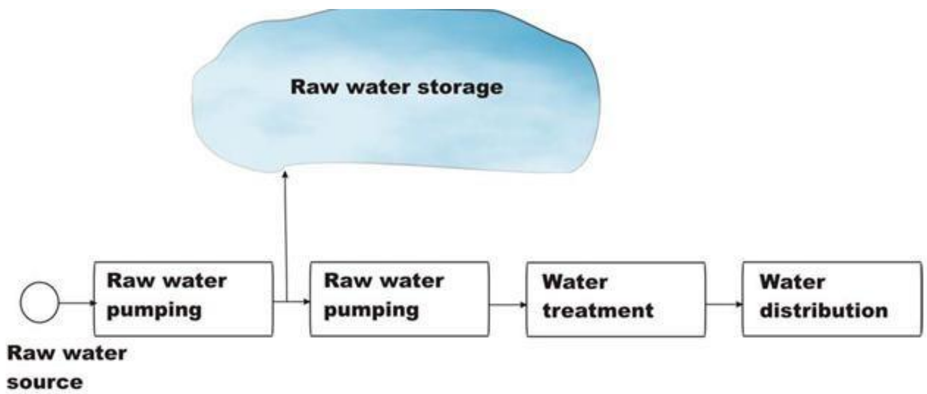
Example: Wazirabad barrage across river Yamuna for water supply to Delhi.

4. Construction of infiltration wells near a river to draw riverbed ground water

Example: For water supply to IIT Kharagpur campus from river Kangsabati.

5. Construction of deep wells to draw water from lower strata of ground water

Example: Water intake system for the city of Barddhaman.



A line diagram for intake, storage, treatment and distribution of a typical drinking water project

FIGURE NO. 6.

Data requirement for domestic water supply project

The following data is required for planning and designing a typical water supply system.

Demand of water

According to the norms laid out in the National Building Code, and revised under National Water policy (2002), the following demand of domestic water consumption may be adopted:
Rural water supply:

- 40 litres per capita per day or one hand pump 250 persons within walking distance of

1.6 km or elevation difference of 100m in hills

- 30 lpcd additional for cattle in desert development programmed areas

Urban water supply:

- 40 lpcd where only sources are available
- 70 lpcd where piped water supply is available but no sewerage system

- 125 lpcd where piped water supply and sewerage system are both available.
- 150 lpcd for main cities

- Additional water for other demands like commercial, institutional, firefighting, gardening, etc.

Since the water supply project would serve a future population, a realistic projection has to be made based on scientific projection methods like

- Arithmetic increase method.
- Geometric increase method.
- Incremental increase method.

Water supply projects, under normal circumstances, may be designed for a period of thirty years. This period may be modified in regard to certain components of the project, depending upon:

- The useful life of the component facility
- Ease in carrying out extensions, when required.
- Rate of interest.

Availability of water and other data

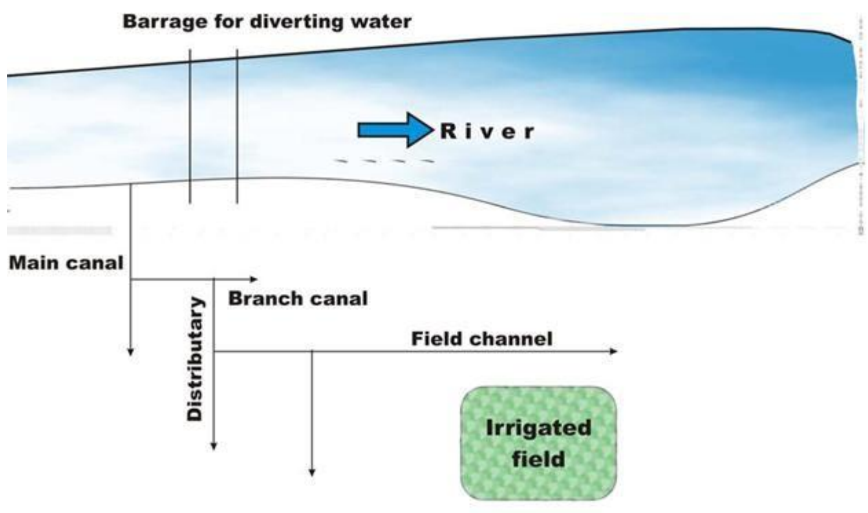
The availability of water has been discussed in a subsequent section of this lesson, which would be used to design the capacities of the intake by the water resources engineer, by comparing with the demand. The data for constructing the structures would usually be topography for locating the structure, geology for finding foundation characteristics and materials required for construction of the structure.

Project planning for irrigation water supply

The project may consist of supplying water to irrigate an area through a network of canals, by diverting some of the water from a river by constructing a barrage for water diversion and head regulator for water control. The water through canals mostly flows by gravity (except for pumped canal projects), the area under cultivation by the water of the canal is called the Command Area. This area is decided by the prevailing slope of the land. Although the main source of water for irrigating an area could be surface water, it could be supplemented with ground water. This combination of surface and ground water for irrigation is known as Conjunctive use.

The principal component of an irrigation scheme is a diversion structure – a weir or a barrage – though the latter is preferred in a modern irrigation project. Since the height of such a structure is rather small compared to that of a dam, the volume of water stored behind a barrage (the barrage pool) is small compared to that stored behind a dam (the dam reservoir). The elevated water surface of the barrage pool causes the water to be diverted into the canal, the entry of which is regulated through a canal head works. If the river is perennial, and the minimum flow of the river is sufficient to cater to the flow through the canal, this arrangement is perfectly fine to irrigate a command area using a barrage and an irrigation canal system. However, if the river is non-perennial, or the minimum flow of the river is less than the canal water demand, then a dam may be constructed at a suitable upstream location of the river. This would be useful in storing larger volumes, especially the flood water, of water which may be released gradually during the low-flow months of the river.

A conceptual scheme of a diversion scheme for irrigation is shown in Figure.



Diversion scheme for irrigation

FIGURE NO. 7

Data requirement for water supply to an irrigation project

The following data is required for planning and designing a typical irrigation system. Demand of water for irrigation water supply

The demand of water for an irrigation scheme is to be calculated from the cropping schedule that is proposed in the Command Area. Different crops have
different water requirements and their demand also varies with the growth of the plants. Further, Command Area may be able to cultivate more than one crop within since many of the crops have maturity duration of few months.

The field requirement decides the design discharge for the distributaries and so on up to the canal regulator. Of course, most canals are prone to losses with water seeping through the canal sides. Exceptions are the lined canals, though in this case, the loss of infiltrating water is very small. Thus the net demand at the head of the canal system, as a function of time, is calculated. Lessons of Module 3 deal in detail about the irrigation system demand of water.

Availability of water and other data

This has discussed in a subsequent section of this lesson. The data for demand and availability of water would be used to design the reservoir upstream of the dam for storage. This water, when released in a regulated way, would be diverted by a barrage and passed through a canal head regulator and water distribution network consisting of canals and other structures such as regulators and falls. The data requirements for construction of the structures are usually: Topography, geology or riverbed soil characteristics, and materials.

National water policy

- A Policy can be considered as a "Statement of Intent" or "Commitment".

Types of Policies

- Distributive policies
- Regulatory policies
- Constituent policies
- Miscellaneous policies

Water Policy- policy that encompasses all efforts to define the rules, intent, and instruments with which governments manage human uses of water, control water pollution, and meet environmental water needs. It considers not only the legal and regulatory framework, but also the planning around water resource allocation and the implementation practices by water managers and other stakeholders in support of this framework**.**

Need for a National Water Policy

1.1 Water is a prime natural resource, a basic human need and a precious national asset. Planning, development and management of water resources need to be governed by national perspectives.

1.2 As per the latest assessment (1993), out of the total precipitation, including snowfall, of around 4000 billion cubic metre in the country, the availability from surface water and replenishable ground water is put at 1869 billion cubic metre. Because of topographical and other constraints, about 60% of this i.e. 690billion cubic metre from surface water and 432 billion cubic metre from ground water, can be put to beneficial use. Availability of water is highly uneven in both space and time. Precipitation is confined to only about three or four months in a year and varies from 100 mm in the western parts of Rajasthan to over 10000 mm at Cherrapunji in Meghalaya. Rivers and under ground aquifers often cut across state boundaries. Water, as a resource is one and indivisible: rainfall, river waters, surface ponds and lakes and ground water are all part of one system.

1.3 Water is part of a larger ecological system. Realizing the importance and scarcity attached to the fresh water, it has to be treated as an essential environment for sustaining all life forms.

1.4 Water is a scarce and precious national resource to be planned, developed, conserved and managed as such, and on an integrated and environmentally sound basis, keeping in view the socio-economic aspect sand needs of the States. It is one of the most crucial elements in developmental planning. As the country has entered the 21st century, efforts to develop, conserve, utilize and perspective.

1.5 Floods and droughts affect vast areas of the country, transcending state boundaries. One-sixth area of the country is drought-prone. Out of 40 million hectare of the flood prone area in the country, on an average, floods affect an area of arour floods has to be co-ordinate and guided at the national level.

1.6 Planning and implementation of water resources projects involve a number of socio-economic aspects and issues such as environmental sustainability, appropriate resettlement and rehabilitation of project- affected people and livestock, public health concerns of water impoundment, dam safety etc.Common approaches and guidelines are necessary on these matters. Moreover, certain problems and
weaknesses have affected a large number of water resources projects all over the country. There
of agricultural land. Complex issues of equity and social justice in regard to
water distribution are required to be addressed. The development and overexploitation of groundwater resources in certain parts of the country have raised the concern and need for judicious and scientific
resource management and conservation. All these concerns need to be addressed on the l

1.7 Growth process and the expansion of economic activities inevitably lead to increasing demands for water for diverse purposes: domestic, industrial, agricultural, hydro-power, thermal-power, navigation, recreation, etc. So far, the
major consumptive use of water has been for irrigation. While the gross irrigation potential is estimated to have increased from 19.5 million hectare at the time of independence to about 95 million hectare by the end of the Year 1999-2000, further development of a substantial order is necessary if the food and fiber needs of our growing population are to be met with. The country‟s population which is over 1027 million (2001 AD) at present is expected to reach a level of around 1390million by 2025 AD. Ministry of Water Resources 2 April 1,2002

1.8 Production of food grains has increased from around 50 million tonnes in the fifties to about 208million tonnes in the Year 1999-2000. This will have to be raised to around 350 million tonnes by the year 2025 AD. The drinking water needs of people and livestock have also to be met. Domestic and industrial water needs have largely been concentrated in or near major cities. However, the demand in rural areas is expected to increase sharply as the development programmes improves economic conditions of the rural masses. Demand for water for hydro and thermal power generation and for other industrial uses is also increasing substantially. As a result, water, which is already a scarce resource, will become even scarcer in future. This underscores the need for the utmost efficiency in water utilization and a public awareness of the importance of its conservation

1.9 Another important aspect is water quality. Improvements in existing strategies, innovation of new techniques resting on a strong science and technology base are needed to eliminate the pollution of surface and ground water resources, to improve water quality. Science and technology and training have to play important roles in water resources development and management in general.

1.10 National Water Policy was adopted in September, 1987. Since then, a number of is (1987) has been reviewed and updated.

Issue	National Water Policy (1987)	National Water Policy (2002)	Draft policy (2012)
Allocation priority	1. Drinking water 2. Irrigation 3. Hydro-power 4. Navigation 5. Industrial and other uses"However these priorities might be modified if necessary in particular regions with reference to area specific considerations."	1. Drinking water 2. Irrigation 3. Hydro-power 4. Ecology 5. Agro-industries and non-agricultural industries 6. Navigation and other uses	Done away with explicit priorities."Water, over and above the pre-emptive need for safe drinking water and sanitation, should be treated as an economic good so as to promote its conservation and efficient use"."After meeting the minimum quantity of water required for survival of human beings and ecosystem, water must be used as an economic good with higher priority towards basic livelihood support to the poor and ensuring national food security".
Service provision	No mention.	Private sector participation should be encouraged in planning, development and management of	On the one hand the draft say that "Water needs to be managed as a community resource held, by the state, under public trust doctrine to achieve food security, livelihood, and equitable and sustainable

		water resource projects for diverse uses, wherever feasible.	development for all". On the other it mentions that: "The service provider role of the state has to be gradually shifted to

		Depending upon the specific situations, various combinations of private sector participation, in building, owning, operating, leasing and transferring of water resources facilities, may be considered.	that of a regulator of services and facilitator for strengthening the institutions responsible for planning, implementation and management of water resources. The water related services should be transferred to community and / or private sector with appropriate public private partnership model".

NATIONAL WATER POLICY (2012)

1. PREAMBLE

1.1 A scarce natural resource, water is fundamental to life, livelihood, food security and sustainable development. India has more than 18 % of the world"s population, but has only 4% of world"s renewable water resources and 2.4% of world"s land area. There are further limits on utilizable quantities of water owing to uneven distribution over time and space. In addition, there are challenges of frequent floodsand droughts in one or the other part of the country. With a population and rising needs of a fast developing nation as well as the given indications of the impact of climate change, availability of utilizable water will be under further strain in future

with the possibility of deepening water conflicts among different user groups. Low consciousness about the scarcity of water and its life sustaining and economic value results in its mismanagement, wastage, and inefficient use, as also pollution and reduction of flows below minimum ecological needs. In addition, there are inequities in distribution and lack of a unified perspective in planning, management and use of water resources. The objective of the National Water Policy is to take cognizance of the existing situation, to propose a framework for creation of a system of laws and institutions and for a plan of action with a unified national perspective.

1.2 The present scenario of water resources and their management in India has given rise to several concerns, important amongst them are;

(i) Large parts of India have already become water stressed. Rapid growth in demand for water due to population growth, urbanization and changing lifestyle pose serious challenges to water security.

(ii) Issues related to water governance have not been addressed adequately. Mismanagement of water resources has led to a critical situation in many parts of the country.

(iii) There is wide temporal and spatial variation in availability of water, which may increase substantially due to a combination of climate change, causing deepening of water crisis and incidences of water related disasters, i.e., floods, increased erosion and increased frequency of droughts, etc.

(iv) Climate change may also increase the sea levels. This may lead to salinity intrusion in ground water aquifers / surface waters and increased coastal inundation in coastal regions, adversely impacting habitations, agriculture and industry in such regions.

(v) Access to safe water for drinking and other domestic needs still continues to be a problem in many areas. Skewed availability of water between different regions and different people in the same region and also the intermittent and unreliable water supply system has the potential of causing social unrest.

(vi) Groundwater, though part of hydrological cycle and a community resource, is still perceived as an individual property and is exploited inequitably and without any consideration to its sustainability leading to its over-exploitation in several areas.

(vii) Water resources projects, though multi-disciplinary with multiple stakeholders, are being planned and implemented in a fragmented manner without giving due consideration to optimum utilization, environment sustainability and holistic benefit to the people.

(viii) Inter-regional, inter-State, intra-State, as also inter-sectoral disputes in sharing of water, strain relationships and hamper the optimal utilization of water through scientific planning on basin/sub-basin basis.

(ix) Grossly inadequate maintenance of existing irrigation infrastructure has resulted in wastage and under-utilization of available resources. There is a widening gap between irrigation potential created and utilized.

(x) Natural water bodies and drainage channels are being encroached upon, and diverted for other purposes. Groundwater recharge zones are often blocked.

(xi) Growing pollution of water sources, especially through industrial effluents, is affecting the availability of safe water besides causing environmental and health hazards. In many parts of the country, large stretches of rivers are both heavily polluted and devoid of flows to support aquatic ecology, cultural needs and aesthetics.

(xii) Access to water for sanitation and hygiene is an even more serious problem. Inadequate sanitation and lack of sewage treatment are polluting the water sources.

(xiii) Low consciousness about the overall scarcity and economic value of water results in its wastage and inefficient use.

(xiv) The lack of adequate trained personnel for scientific planning, utilizing modern techniques and analytical capabilities incorporating information technology constrains good water management.

(xv) A holistic and inter-disciplinary approach at water related problems is missing.

(xvi) The public agencies in charge of taking water related decisions tend to take these on their own without consultation with stakeholders, often resulting in poor and unreliable service characterized by inequities of various kinds.

(xvii) Characteristics of catchment areas of streams, rivers and recharge zones of aquifers are changing as a consequence of land use and land cover changes, affecting water resource availability and quality.

1.3 Public policies on water resources need to be governed by certain basic principles, so that there is some commonality in approaches in dealing with planning, development and management of water resources. These basic principles are:

(i) Planning, development and management of water resources need to be governed by common integrated perspective considering local, regional, State and national context, having an environmentally sound basis, keeping in view the human, social and economic needs.

(ii) Principle of equity and social justice must inform use and allocation of water.

(iii) Good governance through transparent informed decision making is crucial to the objectives of equity, social justice and sustainability. Meaningful intensive participation, transparency and accountability should guide decision making and regulation of water resources.

(iv) Water needs to be managed as a common pool community resource held, by the state, under public trust doctrine to achieve food security, support livelihood, and ensure equitable and sustainable development for all.

(v) Water is essential for sustenance of eco-system, and therefore, minimum ecological needs should be given due consideration.

(vi) Safe Water for drinking and sanitation should be considered as pre-emptive needs, followed by high priority allocation for other basic domestic needs (including needs of animals), achieving food security, supporting sustenance agriculture and minimum eco-system needs. Available water, after meeting the above needs, should be allocated in a manner to promote its conservation and efficient use.

(vii) All the elements of the water cycle, i.e., evapo-transpiration, precipitation, runoff, river, lakes, soil moisture, and ground water, sea, etc., are interdependent and the basic hydrological unit is the river basin, which should be considered as the basic hydrological unit for planning.

(viii) Given the limits on enhancing the availability of utilizable water resources and increased variability in supplies due to climate change, meeting the future needs will depend more on demand management, and hence, this needs to be given priority, especially through (a) evolving an agricultural system which economizes on water use and maximizes value from water, and (b) bringing in maximum efficiency in use of water and avoiding wastages.

(ix) Water quality and quantity are interlinked and need to be managed in an integrated manner, consistent with broader environmental management approaches inter-alia including the use of economic incentives and penalties to reduce pollution and wastage.

(x) The impact of climate change on water resources availability must be factored into water management related decisions. Water using activities need to be regulated keeping in mind the local geo climatic and hydrological situation.

2. WATER FRAMEWORK LAW

2.1 There is a need to evolve a National Framework Law as an umbrella statement of general principles governing the exercise of legislative and/or executive (or devolved) powers by the Centre, the States and the local governing bodies. This should lead the way for essential legislation on water governance in every State of the Union and devolution of necessary authority to the lower tiers of government to deal with the local water situation.

2.2 Such a framework law must recognize water not only as a scarce resource but also as a sustainer of life and ecology. Therefore, water, particularly, groundwater, needs to be managed as a community resource held, by the state, under public trust doctrine to achieve food security, livelihood, and equitable and sustainable development for all. Existing Acts may have to be modified accordingly.

2.3 There is a need for comprehensive legislation for optimum development of inter- State rivers and river valleys to facilitate inter-State coordination ensuring scientific planning of land and water resources taking basin/sub-basin as unit with unified perspectives of water in all its forms (including precipitation, soil moisture, ground and surface water) and ensuring holistic and balanced development of both the catchment and the command areas. Such legislation needs, inter alia, to deal with and enable establishment of basin authorities, comprising party States, with appropriate powers to plan, manage and regulate utilization of water resource in the
basins.

3. USES OF WATER

3.1 Water is required for domestic, agricultural, hydro-power, thermal power, navigation, recreation, etc. Utilisation in all these diverse uses of water should be optimized and an awareness of water as a scarce resource should be fostered.

3.2 The Centre, the States and the local bodies (governance institutions) must ensure access to a minimum quantity of potable water for essential health and hygiene to all its citizens, available within easy reach of the household.

3.3 Ecological needs of the river should be determined, through scientific study, recognizing that the natural river flows are characterized by low or no flows, small floods (freshets), large floods, etc., and should accommodate developmental needs. A portion of river flows should be kept aside to meet ecological needs ensuring that the low and high flow releases are proportional to the natural flow regime, including base flow contribution in the low flow season through regulated ground water use.

3.4 Rivers and other water bodies should be considered for development for navigation as far as possible and all multipurpose projects over water bodies should keep navigation in mind right from the planning stage.

3.5 In the water rich eastern and north eastern regions of India, the water use infrastructure is weak and needs to be strengthened in the interest of food security.

3.6 Community should be sensitized and encouraged to adapt first to utilization of water as per local availability of waters, before providing water through long distance transfer. Community based water management should be institutionalized and strengthened.

4. ADAPTATION TO CLIMATE CHANGE

4.1 Climate change is likely to increase the variability of water resources affecting human health and livelihoods. Therefore, special impetus should be given towards mitigation at micro level by enhancing the capabilities of community to adopt climate resilient technological options.

4.2 The anticipated increase in variability in availability of water because of climate change should be dealt with by increasing water storage in its various forms, namely, soil moisture, ponds, ground water, small and large reservoirs and their combination. States should be incentivized to increase water storage capacity, which inter-alia should include revival of traditional water harvesting structures and water bodies.

4.3 The adaptation strategies could also include better demand management, particularly, through adoption of compatible agricultural strategies and cropping patterns and improved water application methods, such as land leveling and/or drip / sprinkler irrigation as they enhance the water use efficiency, as also, the capability for dealing with increased variability because of climate change. Similarly, industrial processes should be made more water efficient.

4.4 Stakeholder participation in land-soil-water management with scientific inputs from local research and academic institutions for evolving different agricultural strategies, reducing soil erosion and improving soil fertility should be promoted. The specific problems of hilly areas like sudden run off, weak water holding capacity of soil, erosion and sediment transport and recharging of hill slope aquifers should be adequately addressed.

4.5 Planning and management of water resources structures, such as, dams, flood embankments, tidal embankments, etc., should incorporate coping strategies for possible climate changes. The acceptability criteria in regard to new water resources projects need to be re-worked in view of the likely climate changes.

5. ENHANCING WATER AVAILABLE FOR USE

5.1 The availability of water resources and its use by various sectors in various basin and States in the country need to be assessed scientifically and reviewed at periodic intervals, say, every five years. The trends in water availability due to various factors including climate change must be assessed and accounted for during water resources planning.

5.2 The availability of water is limited but the demand of water is increasing rapidly due to growing population, rapid urbanization, rapid industrialization and economic development. Therefore, availability of water for utilization needs to be augmented to meet increasing demands of water. Direct use of rainfall, desalination and avoidance of inadvertent evapo-transpiration are the new additional strategies for augmenting utilizable water resources.

5.3 There is a need to map the aquifers to know the quantum and quality of ground water resources (replenishable as well as non-replenishable) in the country. This process should be fully participatory involving local communities. This may be periodically updated.

5.4 Declining ground water levels in over-exploited areas need to be arrested by introducing improved technologies of water use, incentivizing efficient water use and encouraging community based management of aquifers. In addition, where necessary, artificial recharging projects should be undertaken so that extraction is less than the recharge. This would allow the aquifers to provide base flows to the surface system, and maintain ecology.

5.5 Inter-basin transfers are not merely for increasing production but also for meeting basic human need and achieving equity and social justice. Inter-basin transfers of water should be considered on the basis of merits of each case after evaluating the environmental, economic and social impacts of such transfers.

5.6 Integrated Watershed development activities with groundwater perspectives need to be taken in a comprehensive manner to increase soil moisture, reduce sediment yield and increase overall land and water productivity. To the extent possible, existing programs like MGNREGA may be used by farmers to harvest rain water using farm ponds and other soil and water conservation measures.

6. DEMAND MANAGEMENT AND WATER USE EFFICIENCY

6.1 A system to evolve benchmarks for water uses for different purposes, i.e., water footprints, and water auditing should be developed to promote and incentivize efficient use of water. The „project" and the „basin" water use efficiencies need to be improved through continuous water balance and water accounting studies. An institutional arrangement for promotion, regulation and evolving mechanisms for efficient use of water at basin/sub-basin level will be established for this purpose at the national level.

6.2 The project appraisal and environment impact assessment for water uses, particularly for industrial projects, should, inter-alia, include the analysis of the water footprints for the use.

6.3 Recycle and reuse of water, including return flows, should be the general norm.

6.4 Project financing should be structured to incentivize efficient & economic use of water and facilitate early completion of ongoing projects.

6.5 Water saving in irrigation use is of paramount importance. Methods like aligning cropping pattern with natural resource endowments, micro irrigation (drip, sprinkler, etc.), automated irrigation operation, evaporation-transpiration reduction, etc., should be encouraged and incentivized. Recycling of canal seepage water through conjunctive ground water use may also be considered.

6.6 Use of very small local level irrigation through small bunds, field ponds, agricultural and engineering methods and practices for watershed development, etc, need to be encouraged. However, their externalities, both positive and negative, like reduction of sediments and reduction of water availability, downstream, may be kept in view.

6.7 There should be concurrent mechanism involving users for monitoring if the water use pattern is causing problems like unacceptable depletion or building up of ground waters, salinity, alkalinity or similar quality problems, etc., with a view to planning appropriate interventions.

7. WATER PRICING

7.1 Pricing of water should ensure its efficient use and reward conservation. Equitable access to water for all and its fair pricing, for drinking and other uses such as sanitation, agricultural and industrial, should be arrived at through independent statutory Water Regulatory Authority, set up by each State, after wide ranging consultation with all stakeholders.

7.2 In order to meet equity, efficiency and economic principles, the water charges should preferably / as a rule be determined on volumetric basis. Such charges should be reviewed periodically.

7.3 Recycle and reuse of water, after treatment to specified standards, should also be incentivized through a properly planned tariff system.

7.4 The principle of differential pricing may be retained for the pre-emptive uses ofwater for drinking and sanitation; and high priority allocation for ensuring food security and supporting livelihood for the poor. Available water, after meeting the above needs, should increasingly be subjected to allocation and pricing on economic principles so that water is not wasted in unnecessary uses and could be utilized more gainfully.

7.5 Water Users Associations (WUAs) should be given statutory powers to collect and retain a portion of water charges, manage the volumetric quantum of water allotted to them and maintain the distribution system in their jurisdiction. WUAs should be given the freedom to fix rates subject to floor rates determined by WRAs.

7.6 The over-drawal of groundwater should be minimized by regulating the use of electricity for its extraction. Separate electric feeders for pumping ground water for agricultural use should be considered.

8. CONSERVATION OF RIVER CORRIDORS, WATER BODIES AND INFRASTRUCTURE

8.1 Conservation of rivers, river corridors, water bodies and infrastructure should be undertaken in a scientifically planned manner through community participation. The storage capacities of water bodies and water courses and/or associated wetlands, the flood plains, ecological buffer and areas required for specific aesthetic recreational and/or social needs may be managed to the extent possible in an integrated manner to balance the flooding, environment and social issues as per prevalent laws through planned development of urban areas, in particular.

8.2 Encroachments and diversion of water bodies (like rivers, lakes, tanks, ponds, etc.) and drainage channels (irrigated area as well as urban area drainage) must not be allowed, and wherever it has taken place, it should be restored to the extent feasible and maintained properly.

8.3 Urban settlements, encroachments and any developmental activities in the protected upstream areas of reservoirs/water bodies, key aquifer recharge areas that pose a potential threat of contamination, pollution, reduced recharge and those endanger wild and human life should be strictly regulated.

8.4 Environmental needs of Himalayan regions, aquatic eco-system, wet lands and embanked flood plains need to be recognized and taken into consideration while planning.

8.5 Sources of water and water bodies should not be allowed to get polluted. System of third party periodic inspection should be evolved and stringent punitive actions be taken against the persons responsible for pollution.

8.6 Quality conservation and improvements are even more important for ground waters, since cleaning up is very difficult. It needs to be ensured that industrial effluents, local cess pools, residues of fertilizers and chemicals, etc., do not reach the ground water.

8.7 The water resources infrastructure should be maintained properly to continue to get the intended benefits. A suitable percentage of the costs of infrastructure development may be set aside along with collected water charges, for repair and maintenance. Contract for construction of projects should have inbuilt provision for longer periods of proper maintenance and handing over back the infrastructure in good condition.

8.8 Legally empowered dam safety services need to be ensured in the States as well as at the Centre. Appropriate safety measures, including downstream flood management, for each dam should be undertaken on top priority.

9. PROJECT PLANNING AND IMPLEMENTATION

9.1 Considering the existing water stress conditions in India and the likelihood of further worsening situation due to climate change and other factors, water resources projects should be planned as per the efficiency benchmarks to be prescribed for various situations.

9.2 Being inter-disciplinary in nature, water resources projects should be planned considering social and environmental aspects also in addition to techno-economic considerations in consultation with project affected and beneficiary families. The integrated water resources management with emphasis on finding reasonable and generally acceptable solutions for most of the stakeholders should be followed for planning and management of water resources projects.

9.3 Considering the heavy economic loss due to delay in implementation of projects, all clearances, including environmental and investment clearances, be made time bound.

9.4 Concurrent monitoring at project, State and the Central level should be undertaken for timely interventions to avoid time and cost over-runs.

9.5 All components of water resources projects should be planned and executed in a pari-passu manner so that intended benefits start accruing immediately and there is no gap between potential created and potential utilized.

9.6 Local governing bodies like Panchayats, Municipalities, Corporations, etc., and Water Users Associations, wherever applicable, should be involved in planning of the projects. The unique needs and aspirations of the Scheduled caste and Scheduled Tribes, women and other weaker sections of the society should be given due consideration.

9.7 All water resources projects, including hydro power projects, should be planned to the extent feasible as multi-purpose projects with provision of storage to derive maximum benefit from available topology and water resources.

10. MANAGEMENT OF FLOOD & DROUGHT

10.1 While every effort should be made to avert water related disasters like floods and droughts, through structural and non-structural measures, emphasis should be on preparedness for flood / drought with coping mechanisms as an option. Greater emphasis should be placed on rehabilitation of natural drainage system.

10.2 Land, soil, energy and water management with scientific inputs from local, research and scientific institutions should be used to evolve different agricultural strategies and improve soil and water productivity to manage droughts. Integrated farming systems and non-agricultural developments may also be considered for livelihood support and poverty alleviation.

10.3 In order to prevent loss of land eroded by the river, which causes permanent loss, revetments, spurs, embankments, etc., should be planned, executed, monitored and maintained on the basis of morphological studies. This will become increasingly more important, since climate change is likely to increase the rainfall intensity, and hence, soil erosion.

10.4 Flood forecasting is very important for flood preparedness and should be expanded extensively across the country and modernized using real time data acquisition system and linked to forecasting models. Efforts should be towards developing physical models for various basin sections, which should be linked to each other and to medium range weather forecasts to enhance lead time.

10.5 Operating procedures for reservoirs should be evolved and implemented in such a manner to have flood cushion and to reduce trapping of sediment during flood season. These procedures should be based on sound decision support system.

10.6 Protecting all areas prone to floods and droughts may not be practicable; hence, methods for coping with floods and droughts have to be encouraged. Frequency based flood inundation maps should be prepared to evolve coping strategies, including preparedness to supply safe water during and immediately after flood events. Communities need to be involved in preparing an action plan for dealing with the flood/ drought situations.

10.7 To increase preparedness for sudden and unexpected flood related disasters, dam/embankment break studies, as also preparation and periodic updating of emergency action plans / disaster management plans should be evolved after involving affected communities. In hilly reaches, glacial lake outburst flood and landslide dam break floods studies with periodic monitoring along with instrumentation, etc., should be carried out.

11. WATER SUPPLY AND SANITATION

11.1 There is a need to remove the large disparity between stipulations for water supply in urban areas and in rural areas. Efforts should be made to provide improved water supply in rural areas with proper sewerage facilities. Least water intensive sanitation and sewerage systems with decentralized sewage treatment plants should be incentivized.

11.2 Urban and rural domestic water supply should preferably be from surface water in conjunction with groundwater and rainwater. Where alternate supplies are available, a source with better reliability and quality needs to be assigned to domestic water supply. Exchange of sources between uses, giving preference to domestic water supply should be possible. Also, reuse of urban water effluents from kitchens and bathrooms, after primary treatment, in flush toilets should be encouraged, ensuring no human contact.

11.3 Urban domestic water systems need to collect and publish water accounts and water audit reports indicating leakages and pilferages, which should be reduced taking into due consideration social issues.

11.4 In urban and industrial areas, rainwater harvesting and de-salinization, wherever techno-economically feasible, should be encouraged to increase availability of utilizable water. Implementation of rainwater harvesting should include scientific monitoring of parameters like hydrogeology, groundwater contamination, pollution and spring discharges.

11.5 Urban water supply and sewage treatment schemes should be integrated and executed simultaneously. Water supply bills should include sewerage charges.

11.6 Industries in water short regions may be allowed to either withdraw only the make up water or should have an obligation to return treated effluent to a specified standard back to the hydrologic system. Tendencies to unnecessarily use more water within the plant to avoid treatment or to pollute ground water need to be prevented.

11.7 Subsidies and incentives should be implemented to encourage recovery of industrial pollutants and recycling / reuse, which are otherwise capital intensive.

12. INSTITUTIONAL ARRANGEMENTS

12.1 There should be a forum at the national level to deliberate upon issues relating to water and evolve consensus, co-operation and reconciliation amongst party States. A similar mechanism should be established within each State to amicably resolve differences in competing demands for water amongst different users of water, as also between different parts of the State.

12.2 A permanent Water Disputes Tribunal at the Centre should be established to resolve the disputes expeditiously in an equitable manner. Apart from using the „good offices" of the Union or the State Governments, as the case may be, the paths of arbitration and mediation may also to be tried in dispute resolution.

12.3 Water resources projects and services should be managed with community participation. For improved service delivery on sustainable basis, the State Governments / urban local bodies may associate private sector in public private partnership mode with penalties for failure, under regulatory control on prices charged and service standards with full accountability to democratically elected local bodies.

12.4 Integrated Water Resources Management (IWRM) taking river basin / sub-basin as a unit should be the main principle for planning, development and management of water resources. The departments / organizations at Centre / State Governments levels should be restructured and made multi-disciplinary accordingly.

12.5 Appropriate institutional arrangements for each river basin should be developed to collect and collate all data on regular basis with regard to rainfall, river flows, area irrigated by crops and by source, utilizations for various uses by both surface and ground water and to publish water accounts on ten daily basis every year for each river basin with appropriate water budgets and water accounts based on the hydrologic balances. In addition, water budgeting and water accounting should be carried out for each aquifers.

12.6 Appropriate institutional arrangements for each river basin should also be developed for monitoring water quality in both surface and ground waters.

12.7 States should be encouraged and incentivized to undertake reforms and progressive measures for innovations, conservation and efficient utilization of water resources.

13. TRANS-BOUNDARY RIVERS

13.1 Even while accepting the principle of basin as a unit of development, on the basis of practicability and easy implementability, efforts should be made to enter into international agreements with neighbouring countries on bilateral basis for exchange of hydrological data of international rivers on near real time basis.

13.2 Negotiations about sharing and management of water of international rivers should be done on bilateral basis in consultative association with riparian States keeping paramount the national interest. Adequate institutional arrangements at the Center should be set up to implement international agreements.

14. DATABASE & INFORMATION SYSTEM

14.1 All hydrological data, other than those classified on national security consideration, should be in public domain. However, a periodic review for further declassification of data may be carried out. A National Water Informatics Center should be established to collect, collate and process hydrologic data regularly from all over the country, conduct the preliminary processing, and maintain in open and transparent manner on a GIS platform.

14.2 In view of the likely climate change, much more data about snow and glaciers, evaporation, tidal hydrology and hydraulics, river geometry changes, erosion, sedimentation, etc. needs to be collected. A programme of such data collection needs to be developed and implemented.

14.3 All water related data, like rainfall, snowfall, geo-morphological, climatic, geological, surface water, ground water, water quality, ecological, water extraction and use, irrigated area, glaciers, etc., should be integrated with well defined procedures and formats to ensure online updation and transfer of data to facilitate development of database for informed decision making in the management of water.

15. RESEARCH & TRAINING NEEDS

15.1 Continuing research and advancement in technology shall be promoted to address issues in the water sector in a scientific manner. Innovations in water resources sector should be encouraged, recognized and awarded.

15.2 It is necessary to give adequate grants to the States to update technology, design practices, planning and management practices, preparation of annual water balances and accounts for the site and basin, preparation of hydrologic balances for water systems, benchmarking and performance evaluation.

15.3 It needs to be recognized that the field practices in the water sector in advanced countries have been revolutionized by advances in information technology and analytical capabilities. A re-training and quality improvement programme for water planners and managers at all levels in India, both in private and public sectors, needs to be undertaken.

15.4 An autonomous center for research in water policy should also be established to evaluate impacts of policy decisions and to evolve policy directives for changing scenario of water resources.

15.5 To meet the need of the skilled manpower in the water sector, regular training and academic courses in water management should be promoted. These training and academic institutions should be regularly updated by developing infrastructure and promoting applied research, which would help to improve the current procedures of analysis and informed decision making in the line departments and by the community. A national campaign for water literacy needs to be started for capacity building of different stakeholders in the water sector.

16. IMPLEMENTATION OF NATIONAL WATER POLICY

16.1 National Water Board should prepare a plan of action based on the National Water Policy, as approved by the National Water Resources Council, and to regularly monitor its implementation.

16.2 The State Water Policies may need to be drafted/revised in accordance with this policy keeping in mind the basic concerns and principles as also a unified national perspective.

Climatological and Meteorological Data Required for Water Resources Management

Purpose	Features	Required Data
Hydrological characterisation	Catchment/Watershed planning General water balance	Precipitation Temperature Humidity Wind speed
Flood management and control	Structures (dams, river training)	Precipitation Temperature Humidity Wind speed and direction
	Flood forecasting and warning	Precipitation Temperature Evapotranspirtation Synoptic information Forecasts and alerts Medium- and long-term forecasts
	Flood plain zoning/Flood frequency estimation	Precipitation Evapotranspiration Temperature Synoptic information
	Coastal inundation	Wind speed Wind direction Synoptic information Forecasts and alerts

Irrigation and drainage	Supply Demand scheduling	Precipitation Temperature Humidity Wind speed Medium/long-range forecasts

Groundwater	Recharge Groundwater flooding	Precipitation Temperature Humidity Wind speed Medium/long-range forecasts
Navigation	Canal systems Dredging	Precipitation Temperature Medium/long-range forecasts
Power generation	Hydropower Cooling water	Precipitation Temperature Humidity Wind speed Medium/long-range forecasts
Water supply	Potable water Industrial processing	Precipitation Temperature Humidity Wind speed Medium/long-range forecasts
Water quality	Pollution control Dilution Salinity and sedimentation	Precipitation Temperature Humidity Wind speed Forecasts and alerts
Fisheries and conservation	Hydro-ecology Hydromorphology	Precipitation Temperature Humidity Wind speed Medium/long-range forecasts

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DEPARTMENT OF CIVIL ENGINEERING

UNIT – II - BASIC CONCEPTS OF HYDROLOGY – SCI1305

BASIC CONCEPTS OF HYDROLOGY

Hydrology is the science, which deals with the occurrence, distribution and disposal of water on the planet earth: it is the science which deals with the various phases of the hydrologic cycle. The importance of hydrology in the assessment, development, utilization and management of the water resources, of any region is being increasingly realized at all levels.

HYDROLOGIC CYCLE

Hydrologic cycle is the water transfer cycle, which occurs continuously in nature; the three important phases of the hydrologic cycle are:

(a) Evaporation and evapotranspiration

(b) Precipitation

(c) Runoff

The globe has one-third land and Two-thirds Ocean. Evaporation from the surfaces of ponds, lakes, reservoirs, ocean surfaces, etc. and transpiration from surface vegetation i.e., from plant leaves of cropped land and forests, etc.take place. These vapors rise to the sky and are condensed at high altitude by condensation nuclei and form clouds, resulting in droplets growth. The clouds melt and sometimes burst resulting in precipitation of different forms like rain, snow, hail, sleet, mist, dew and frost. A part of this precipitation flows over the land runoff part infiltrates into the soils which build up groundwater table.

The surface runoff joins the streams and the water is stored in the reservoir. A portion of runoff and the groundwater flows back to ocean. Again evaporation starts from the surfaces of lakes, reservoirs and ocean and the cycle repeats.

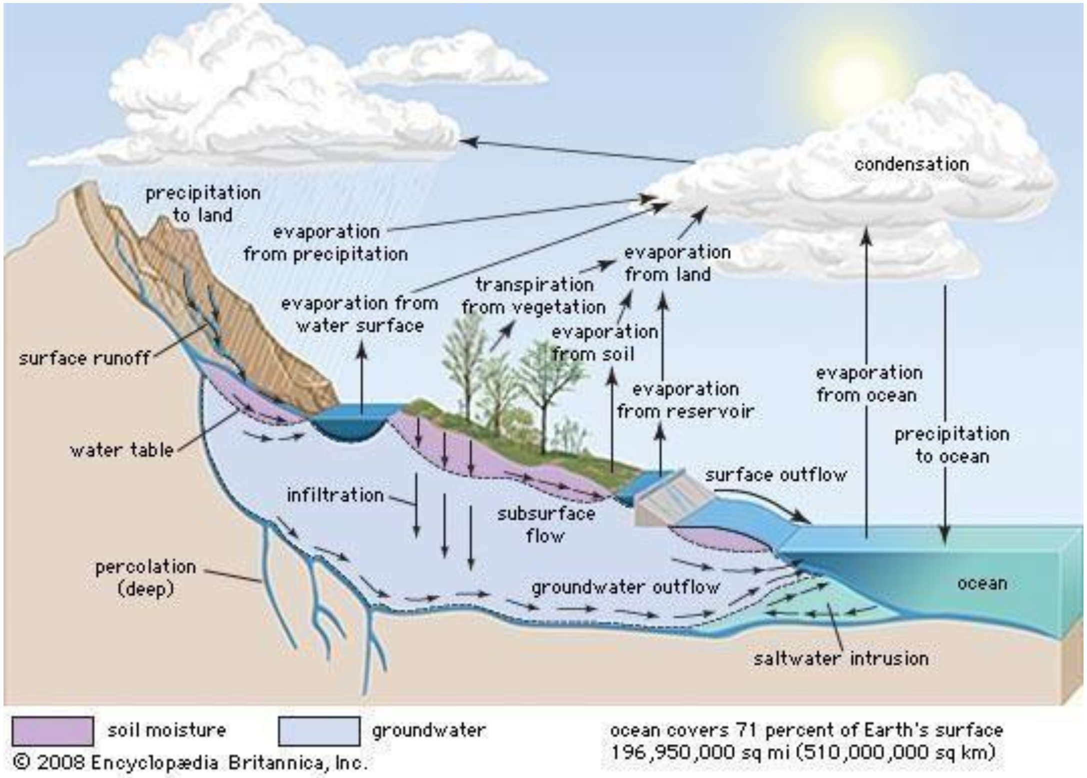


FIGURE NO. 2.1

Evaporation is the process by which water changes from a liquid to a gas or vapor. Evaporation is the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapor. Studies have shown that the oceans, seas, lakes, and rivers provide nearly 90 percent of the moisture in our atmosphere via evaporation, with the remaining 10 percent being contributed by plant transpiration.

Transpiration is the process by which moisture is carried through plants from roots to small pores on the underside of leaves, where it changes to vapor and is released to the atmosphere. Transpiration is essentially evaporation of water from plant leaves. It is estimated that about 10 percent of the moisture found in the atmosphere is released by plants through transpiration.

Condensation is the process in which water vapor in the air is changed into liquid water. Condensation is crucial to the water cycle because it is responsible for the formation of clouds. These clouds may produce precipitation, which is the primary route for water to return to the Earth's surface within the water cycle. Condensation is the opposite of evaporation.

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Most precipitation falls as rain.

Infiltration is the process by which precipitation or water soaks into subsurface soils and moves into rocks through cracks and pore spaces. As we mentioned before, the bulk of rainwater and melted snow end up infiltrated.

PRECIPITATION

Precipitation is any form of solid or liquid water that falls from the atmosphere to the earth‟s surface. Rain, drizzle, hail and snow are examples of precipitation. In India, rain is the most common form of precipitation. Evapotranspiration is the process which returns water to the atmosphere and thus completes the hydrologic cycle. Evapotranspiration consists of two parts, Evaporation and Transpiration. Evaporation is the loss of water molecules from soil masses and water bodies. Transpiration is the loss of water from plants in the form of vapour.

Forms of Precipitation

Precipitation occurs in many forms e.g. drizzle, rain, glaze, sleet, snow, hail, dew and frost, depending upon the causes and temperature at the time of formation. Dew is condensation on the ground of atmospheric vapor caused by radiational cooling of the lower layers of atmosphere, usually at night. Frost is dew formed under freezing conditions. Dew and frost are quantitatively unimportant and rarely measured.

1. Drizzle: Drop size < 0.5 mm in dia. and intensity is usually < 1 mm/hr and generally occurs in conjunction with warm frontal lifting.
2. Rain: Drop size is between 0.5 to 6 mm in dia. Drops bigger than 6 mm tend to break up as they fell. It is formed by condensation and coalescence of cloud droplets at temperatures above the freezing point.
3. Glaze: It is the ice coating formed when drizzle or rain freezes as it comes in contact with cold objects on the ground.

4. Sleet: It is frozen raindrops cooled to ice stage while falling through air at sub-freezing temperature.
5. Snow: It is a precipitation in the form of ice crystals resulting from sublimation, i.e., directly from water vapor to ice.
6. Snow Flake: It is made of a number of ice crystals fused to gather.
7. Hail: It is precipitation in the form of balls or lumps of ice over 5 mm diameter formed by alternate freezing and melting as they are carried up and down in highly turbulent air currents.

Mechanisms for Production of Rainfall

The following four conditions are necessary for the production of rainfall.

Mechanism to produce cooling of the air – The pressure reduction due to ascending air from surface to upper levels in the atmosphere is the only known mechanism capable of producing large drops in the temperature.

Mechanism to produce condensation – Condensation in the atmosphere takes place on "hygroscopic nuclei" small particles of substances that have an affinity for water.

Mechanism for droplet growth – A tendency for the droplets to remain small and therefore to resist falling is called "colloidal stability". The most effective processes for droplet enlargement are,

1. The difference in speeds between large and small droplets, and
2. The co-existence of ice crystals and water droplets.

to produce accumulation of moisture of sufficient intensity to account for the observed rates of rainfall – Regardless of whether or not the other conditions for precipitation are fulfilled, continuity considerations demand that there must be a good amount of moisture present in the atmosphere so that evaporation losses between ground and cloud be compensated, if there is to be appreciable rain.

Rain

Technically, rain isn"t just any liquid that falls out of the sky. Rain is defined as being water droplets of 0.5mm or greater. Droplets smaller than half a millimeter is classified as drizzle. Raindrops often form when small cloud particles collide and stick together, forming bigger drops. Once the drops get large enough, they are too small for rising air to support; gravity draws them down to the ground. In air below 0 °F, raindrops may start as snow or ice crystals but melt when they fall into warmer air. Another reason rain may not reach the ground is updrafts. If the wind is blowing upward faster than the rain is falling, the rain cannot reach the ground.

Clouds

Clouds, visible aggregates of minute droplets of water or tiny crystals of ice, are one form of condensation. Clouds are classified on the basis of two criteria: form and height. The three basic cloud forms are: cirrus (high, white, and thin), cumulus (globular, individual cloud masses), and stratus (sheets or layers).

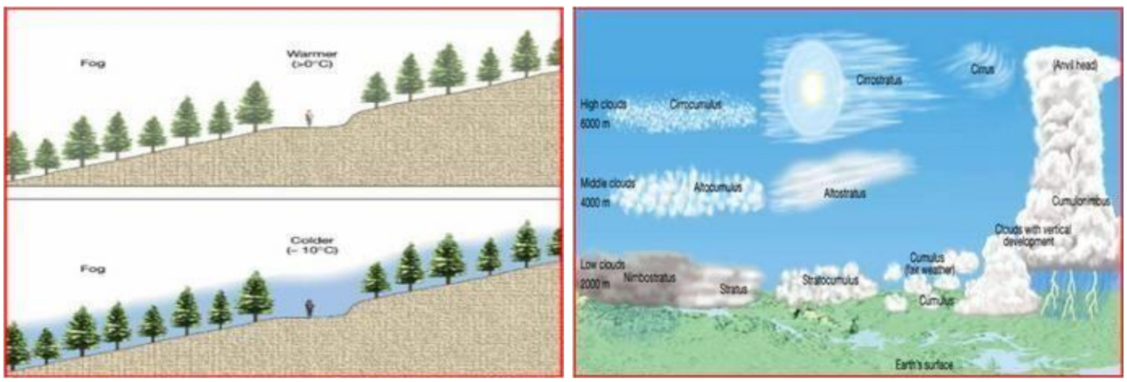


FIGURE NO. 2.2

Fog -Fog, generally considered an atmospheric hazard, is a cloud with its base at or very near the ground. Fogs formed by cooling include: radiation fog (from radiation cooling of the ground and adjacent air), advection fog (when warm and moist air is blown over a cold surface), and up-slope fog (created when relatively humid air moves up a slope and cools adiabatically).

Dew and White Frost -Dew is the condensation of water vapor on objects that have radiated sufficient heat to lower their temperature below the dew point of the surrounding air. White frost forms when the dew point of the air is below freezing.

Types of Precipitation

There are three major types of precipitation: cyclonic, convective, and orographic. Each type represents a different method of lifting an air mass, resulting in cooling and condensation of atmospheric water vapor.

Cyclonic Precipitation: It is caused by lifting associated with the horizontal convergence of inflowing atmosphere into an area of low pressure. There are two kinds of cyclonic precipitation. Non-frontal precipitation involves only this convergence and lifting. Frontal precipitation results when one air mass is lifted over another. A front is defined as the boundary between two air masses of different temperatures and densities. The types of fronts and their commonly associated precipitation are described below.

A warm front is the result of a warm air mass overriding a cold air mass, causing extensive areas of cloudiness and precipitation. As the warm front approaches a given area, the precipitation becomes more continuous and intense. Warm fronts move at a speed of 15-50 km/h (10-30 mph).

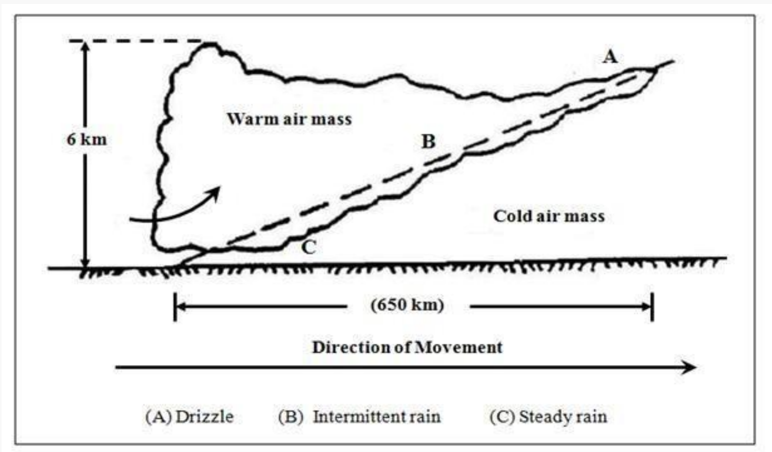


FIGURE NO. 2.3

Warm Front.(Source:Singh, 1994)

A cold front results from a strong push of a cold air mass against and beneath a warm air mass. At the front towering clouds develop together with intense short duration precipitation. Cold fronts move at a speed of 30-80 km/h (20-50 mph).

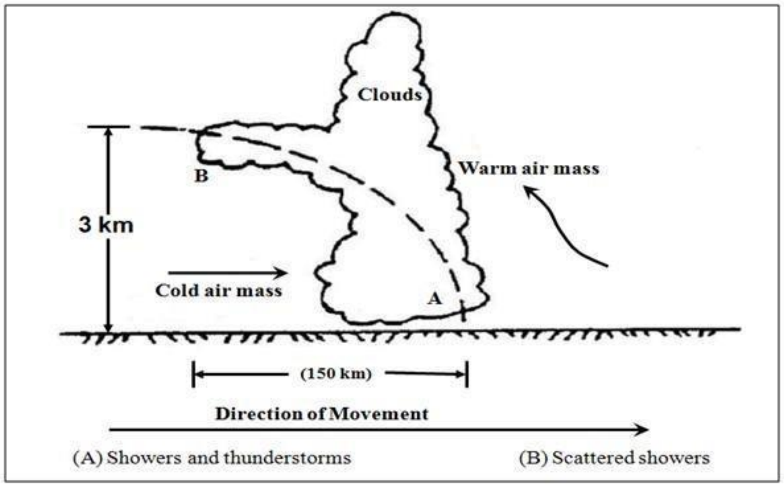


FIGURE NO. 2.4

Fig. Cold Front.(Source:Singh, 1994)

An occluded front occurs when a cold front overtakes a warm front. The precipitation pattern is a combination of both warm and cold frontal distribution. Occluded fronts move at a speed of from 8-50 km/h (5-30 mph).

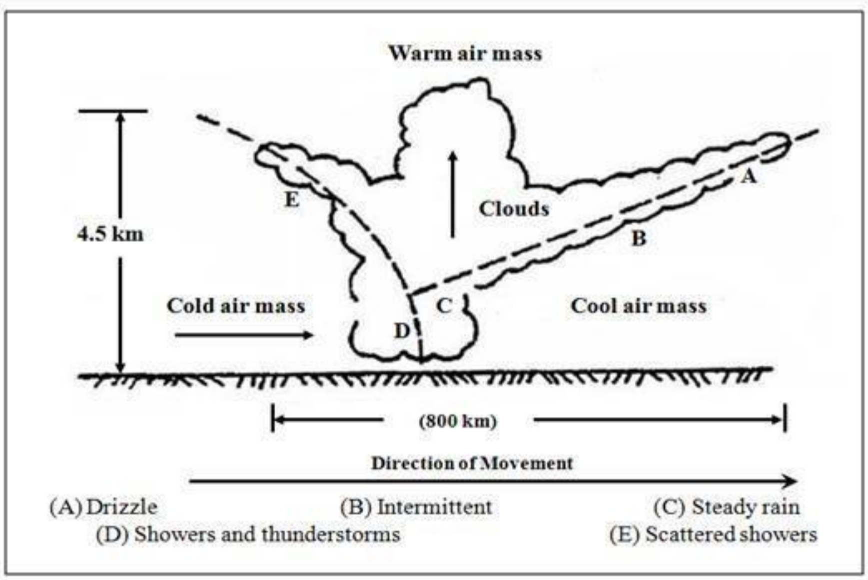


FIGURE NO. 2.5

Fig. Occluded Front.(Source: Singh, 1994)

Convective Precipitation:

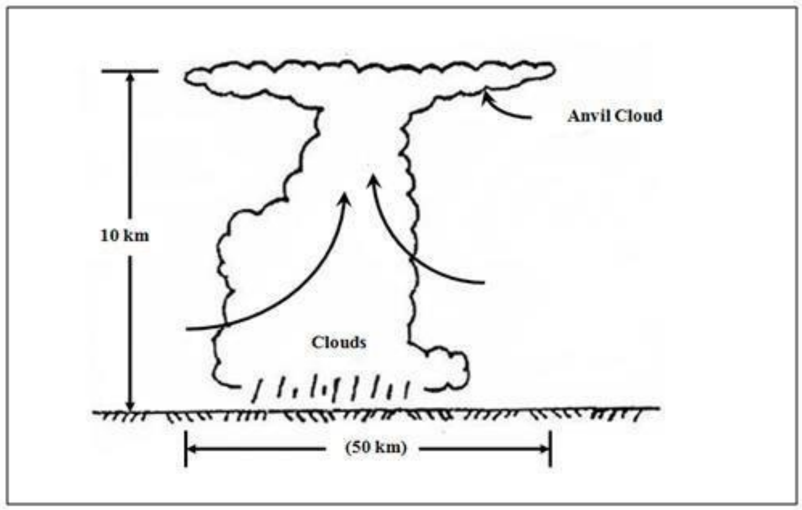


FIGURE NO. 2.6

Fig. Thunderstorm.(Source:Singh, 1994)

It results when air that is warmer than its surrounding rises and cools. The precipitation is of a shower type, varying from light showers to cloudbursts. The typical thunderstorms resulting from heating of the atmosphere in the afternoon hours is the best example of convective rainfall. Thunderstorms occur throughout the world, especially in the summer. They are the characteristic form of rain in the tropics, wherever cyclonic circulation does not operate. A cross section through a typical thunderstorm is shown in the Fig 4.4

Orographic Precipitation: It is caused when air masses are lifted as they move over mountain barriers. Such orographic barriers tend to increase both cyclonic and orographic precipitation due to the increased lifting involved. Precipitation is generally heavier on the windward slope than on the leeward slope.

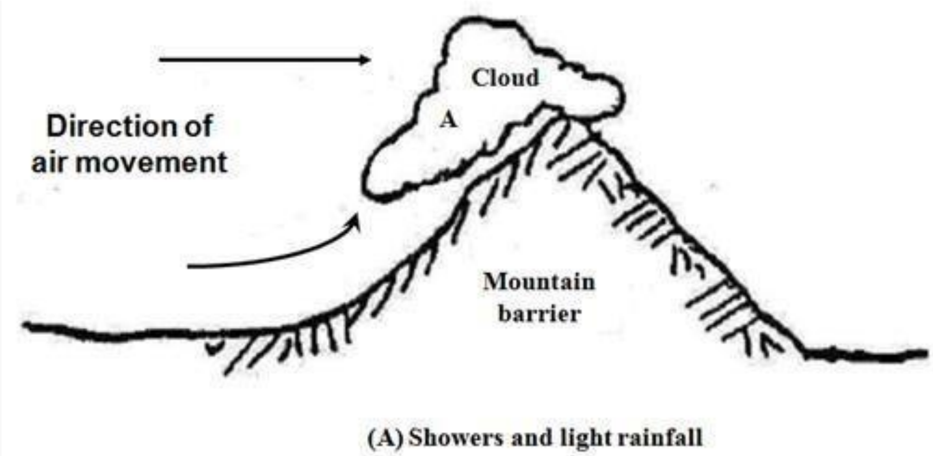


FIGURE NO. 2.7

Fig. Orographic Precipitation.(Source:Singh, 1994)

Measurement of rainfall

One can measure the rain falling at a place by placing a measuring cylinder graduated in a length scale, commonly in mm. In this way, we are not measuring the volume of water that is stored in the cylinder, but the „depth' of rainfall. The cylinder can be of any diameter, and we would expect the same „depth' even for large diameter cylinders provided the rain that is falling is uniformly distributed in space.

Now think of a cylinder with a diameter as large as a town, or a district or a catchment of a river. Naturally, the rain falling on the entire area at any time would not be the same and what one would get would be an „average depth". Hence, to record the spatial variation of rain falling over an area, it is better to record the rain at a point using a standard sized measuring cylinder.

In practice, rain is mostly measured with the ***standard non-recording rain gauge*** the details of which are given in Bureau of Indian Standards code IS 4989: 2002. The rainfall variation at a point with time is measured with a ***recording rain-gauge***, the details of which may be found in IS 8389: 2003. Modern technology has helped to develop Radars, which measures rainfall over an entire region. However, this method is rather costly compared to the conventional recording and non-recording rain gauges which can be monitored easily with cheap labour.

Rain gauge: The purpose of the rain gauge is to measure the depth and intensity of rain falling on a flat surface without considering infiltration, runoff or evaporation. The problems of measurements include effects of topography, nearby vegetation and the design of gage itself.

Non-recording Gauge

The standard raingage, known as Symon‟s gage is recommended and installed by the Indian Meteorological Department. This is a vertical, cylindrical container with top opening 127 cm in diameter. A funnel shaped hood is inserted to minimize evaporation losses. The water is funneled into an inner cylinder.

Considerations for Installation

1. The site should be an open place,
2. The distance between the raingauge and the nearest object should be at least twice the height of the object,
3. As for as possible it should be a level ground,
4. In the hills, the site should be so chosen where it is best shielded from high winds and wind does not cause eddies, and
5. If a fence is erected, it should be at least at a distance of twice the height.

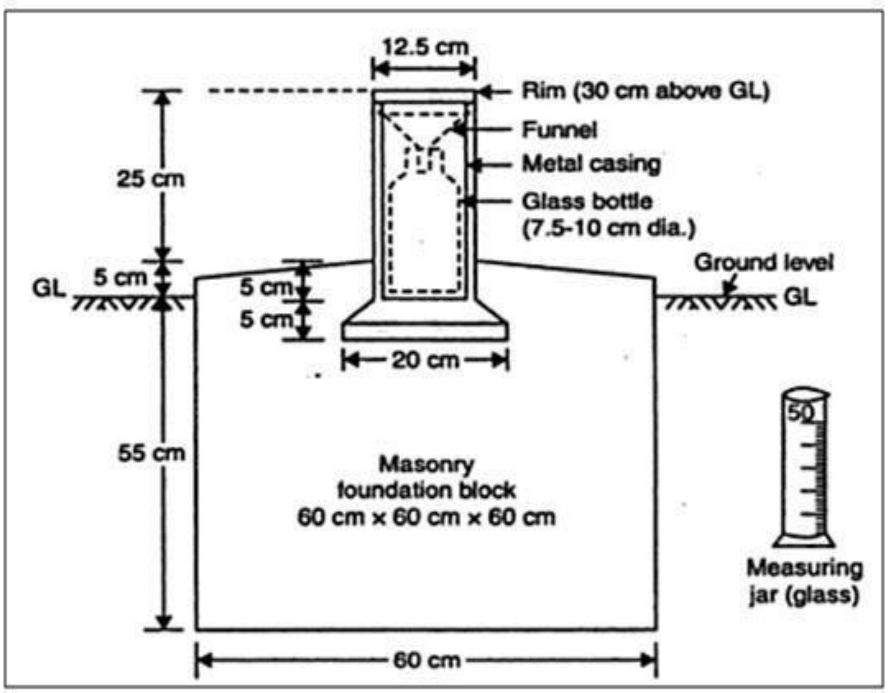


FIGURE NO. 2.8

Symon's Rain gauge. (Source: Raghunath, 2006)

Recording or Automatic Rain gauge

Weighting Bucket Type Rain gauge - This gauge weighs the rain, which falls into a bucket set on a platform of a spring or level balance. The increasing weight of bucket and its counts are recorded on the chart held by a clock driven drum. The record shows the accumulation of precipitation with time in the shape of a mass curve of precipitation. The gage must be serviced about once a week when the clock is re-wound and the chart is replaced. For high rainfall, the recording mechanism reverses the direction of record immediately on reaching the upper edge of the recording chart.

Tipping Bucket Type Raingage - The tipping bucket raingage consists of a 30 cm diameter sharp edge receiver. At the end of the receiver a funnel is provided. A pair of buckets are pivoted under the funnel in such a way that when one bucket receives 0.25 mm of rainfall it tips, discharging its contents in to a tank bringing the other bucket under the funnel. Tipping of the bucket completes an electric circuit causing the movement of a pen to mark on a clock driven revolving drum which carries a record sheet.

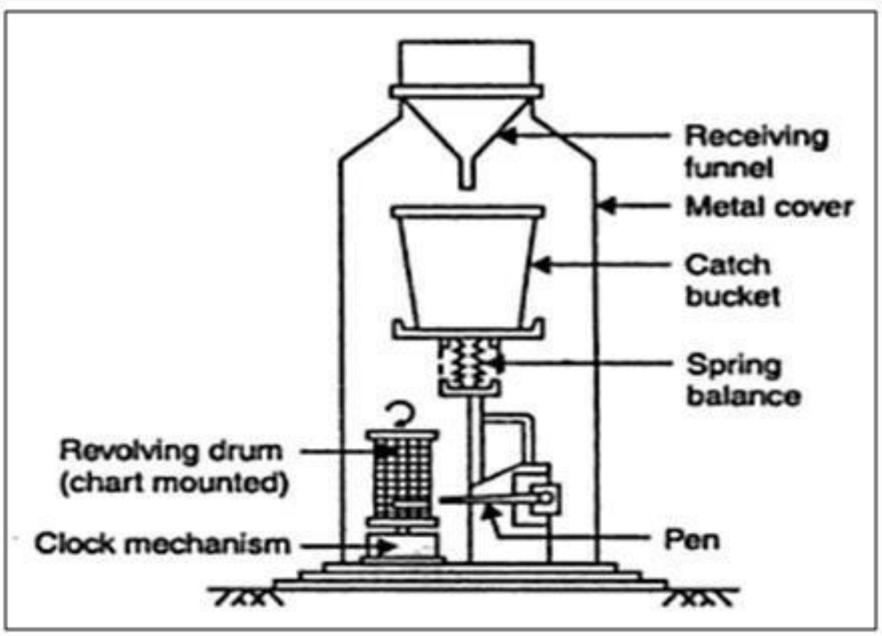


FIGURE NO. 2.9

Weighing bucket type rain gauge.(Source: Raghunath,2006)

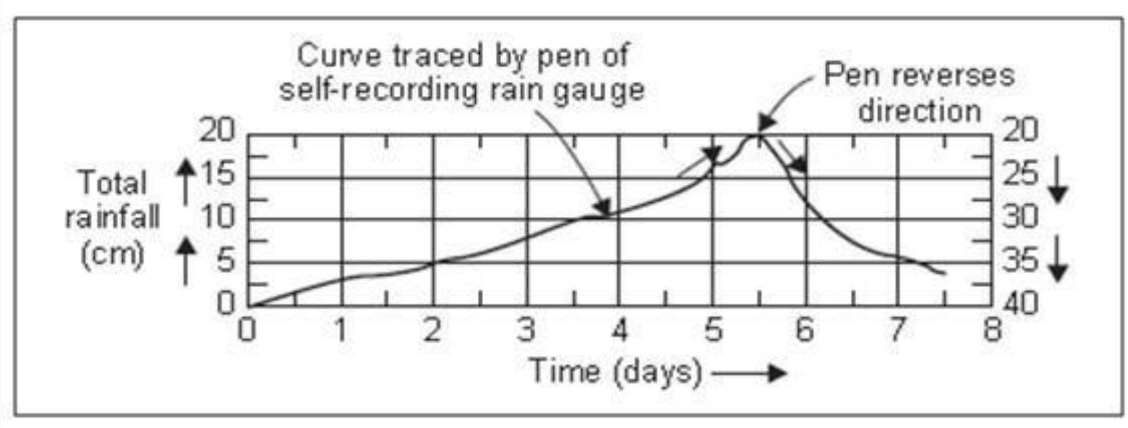


FIGURE NO. 2.10

Recorded mass curve of precipitation in weighing bucket type rain gauge.(Source: Raghunath, 2006)

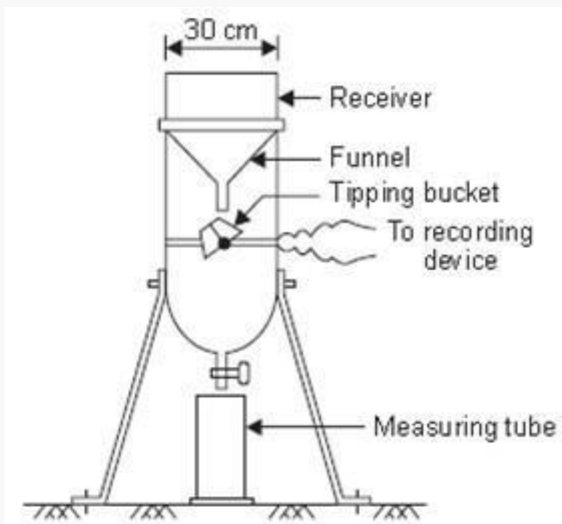


FIGURE NO. 2.11

Tipping bucket type rain gauge.(Source: Raghunath, 2006)

Siphon Type Automatic Rainfall Recorder - In the siphon gage, also known as the float type of recording raingage, the rain is fed into a float chamber containing a light, hallow float. The vertical movement of the float, as the level of water rises, is transmitted by a suitable mechanism in to the movement of the pen on a revolving chart. By suitably adjusting the dimensions of the receiving funnel, float and float chamber, any desired scale value on the chart can be obtained. Siphoning arrangement is provided for emptying the float chamber quickly whenever it becomes full, the pen returns to the bottom of the chart.

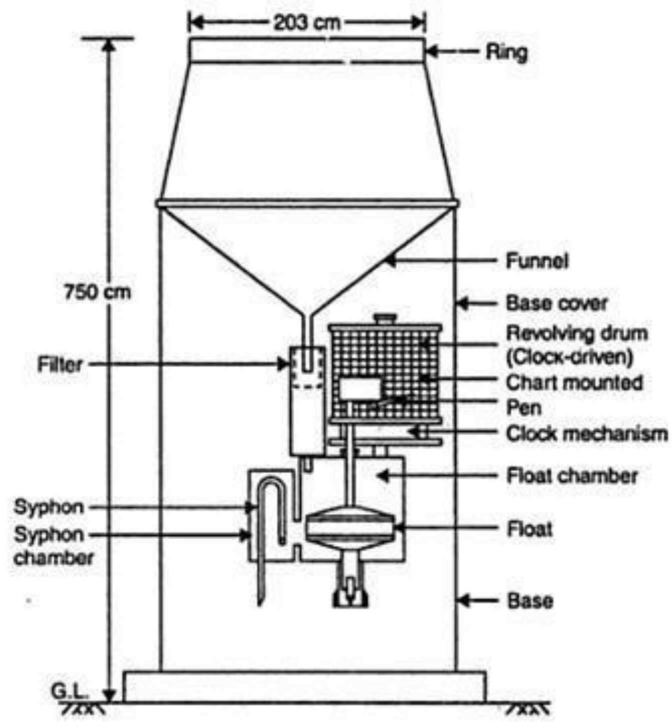


FIGURE NO. 2.12

Siphon type automatic rainfall recorder.

Errors in Rainfall Measurements

There are three main sources of errors in rainfall measurements –

a) Instrumental defects,

b) Improper sitting (location) of the gage, and

c) Human errors

Each recording type gage has inherent errors caused by mechanical parts of the instrument. In addition to mechanical errors, some precipitation is also lost in wetting the collecting funnel and measuring cylinder surface if the gage is dry before it begins to collect measurable amount of water (approximately 25 mm per year). Similarly, evaporation from a non-recording gage could cause a small loss of measurable water over the year.

The improper location of the raingage can tend to either over- or under-catch rainfall. The largest errors in all gages are the effect of wind on the entrance of rain or snow into the instrument. Errors due to wind are greater for light rain than for heavy rains.

In order to avoid erroneous conclusions it is important to give the proper interpretation to precipitation data, which often cannot be accepted at face value. For example, a mean annual precipitation value for a station may have little significance if the gage site has been changed significantly during the period for which average is computed. Also, there are several ways of computing average precipitation over an area; each may give a different answer.

Raingage Network

There is no single answer to determining the mean areal rainfall because it is affected by so many factors. However, the denser the gage network, the more accurate is the representation. Gauges are not evenly spaced, high variability areas have more gages and relatively uniform rainfall areas have fewer gauges. In addition, costs of installation, maintenance of the network, as well as its accessibility to the observer, are also important consideration.

In general, the sampling errors of rainfall tends to increase with increasing mean areal rainfall, and decrease with increasing network density, duration of rainfall, and areal extend. Accordingly, larger average errors are produced by a particular network for storm rainfall than for monthly, seasonal or annual rainfall.

Indian Standard Recommendation

- One station per 520 km^2 –in plains.
- One station per 260-390 km^2– in regions of average elevation of 1000 m.
- One station per 130 km^2 – in predominantly hilly areas with heavy rainfall.

Estimation of Mean Areal Rainfall

A single point precipitation measurement is quite often not representative of the volume of precipitation falling over a given catchment area. The representative precipitation over a defined area is required in many engineering applications, whereas the gauged observation pertains to the point precipitation. A dense network of point measurements and/or radar estimates can provide a better representation of the true volume over a given area. A network of precipitation measurement points can be converted to areal estimates using any of the following techniques:

1. Arithmetic or Station Average Method
2. Thiessen Polygon Method
3. Isohyetal Method.

Arithmetic Mean Method

This method consists of computing the arithmetic average of the values of the precipitation for all stations within the area. Since this method assigns equal weight to all stations irrespective of their relative location and other factors, it should be adopted in area where rainfall is uniformly distributed.

$$\overline{P} = \frac{1}{n}\sum_{i=1}^{n} P_i$$

Where average precipitation is over an area, P is the precipitations at individual station i, and n is the number of stations. The simplest of all is the Arithmetic Mean Method, which taken an average of all the rainfall depths as shown in Figure 2.

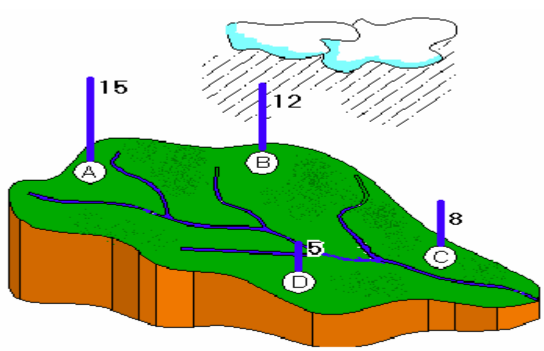


FIGURE 2. Representation of the rainfall recorded in the four rain gauges (values in mm)

FIGURE NO. 2.13

Average rainfall as the arithmetic mean of all the records of the four rain gauges, as shown below:

[(15+12+8+5)/4]=10.0mm

Theissen polygon method

This is a graphical technique which calculates station weights based on the relative areas of each measurement station in the Thiessen polygon network. Rainfall varies in intensity and duration from one place to other; hence rainfall recorded by each station should be weighed according to the area (polygons) it is assumed to influence. The individual weights are multiplied by the station observation and the values are summed to obtain the areal average precipitation. This method is useful for areas, which are more or less plain and are of intermediate size (500 to 5000 km^2). This method is also used when there are a few raingage stations compared to size. The polygons are formed as follows:

1. The stations are plotted on a map of the area drawn to a scale.
2. The adjoining stations are connected by the dashed lines.
3. Perpendicular bisectors are constructed on each of these dashed lines.
4. These bisectors form polygons around each station (effective area for the station within the polygon). For stations close to the boundary, the boundary lines form the closing limit of the polygons.

Area of each polygon (A_i) is determined and the average precipitation is calculated using the following equation

$$\overline{P} = \frac{\sum_{i=1}^{n} P_i A_i}{A}$$

This method, first proposed by Thiessen in 1911, considers the representative area for each rain gauge. These could also be thought of as the areas of influence of each rain gauge, as shown in Figure 3

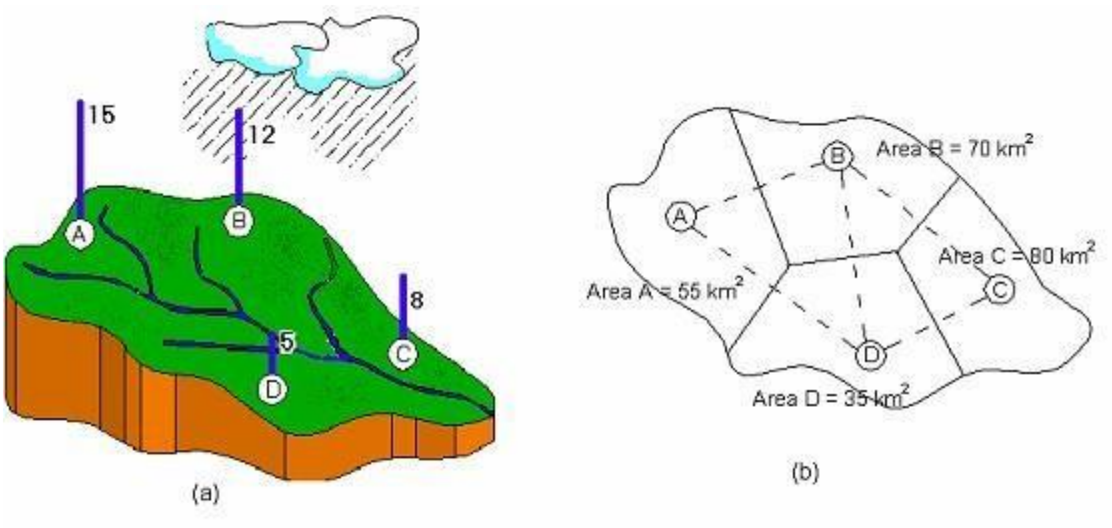


FIGURE NO. 2.14

For the given example, the "weighted" average rainfall over the catchment is determined as,

{[(55x15)+(70x12)+(35x8)+(80x5)] / [(55+70+35+80)] } =10.5mm.

Isohyetal Method

This is a graphical technique which involves drawing estimated lines of equal rainfall over an area based on point measurements. Then multiply the area between each contour by the average precipitation in the area to get the rainfall volume in the area. Sum these volumes to get the total rainfall volume, and then divide the total rainfall volume by the area of the watershed to get the average areal precipitation in the watershed.

Let"s take it step by step:

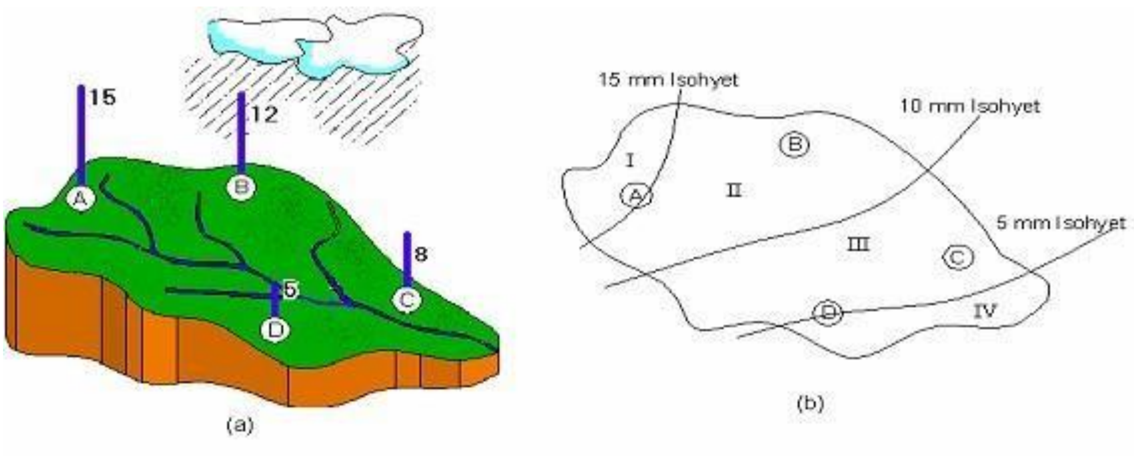
Step1: Determine what contours of equal precipitation (called isohyets) you will use. This varies from situation to situation, but you want to have as many contours as necessary to get an accurate model, but not so many that your construction becomes cluttered.

Step2: Draw a line between gauges that will be separated by isohyets.

Step3: Plot points on those lines that correspond to the isohyets determined in Step 2. Step4: Now sketch the isohyets.

Step5: Redraw the construction onto graph paper with the isohyetal lines. Then count the boxes between each of the isohyetal lines.
Step6: Find the actual watershed area between each isohyet. These areas will be lettered starting with A at the top and moving alphabetically toward the bottom of the construction.
Step7: Multiply the areas found in Step 6 by the average precipitation in the area. Step8: Divide the sum of the values found in Step 7 by the total area of the watershed to get the average rainfall in the area.

This is considered as one of the most accurate methods, but it is dependent on the skill and experience of the analyst. The method requires the plotting of ***isohyets*** as shown in the figure and calculating the areas enclosed either between the isohyets or between an isohyet and the catchment boundary. The areas may be measured with a ***planimeter*** if the catchment map is drawn to a scale.



Rainfall measurement by the Isohyetal method. (a) Recorded rainfall; (b) Isohyets and the areas enclosed bewteen two consecutive isohyets.

FIGURE NO. 2.15

For the problem shown in Figure 4, the following may be assumed to be the areas enclosed between two consecutive isohyets and are calculated as under:

Area I = 40 km^2

Area II = 80 km^2

Area III = 70 km^2

Area IV = 50 km^2

Total catchment area = 240 km^2

The areas II and III fall between two isohyets each. Hence, these areas may be thought of as corresponding to the following rainfall depths:

Area II : Corresponds to (10 + 15)/2 = 12.5 mm rainfall depth

Area III : Corresponds to (5 + 10)/2 = 7.5 mm rainfall depth

For Area I, we would expect rainfall to be more than 15mm but since there is no record, a rainfall depth of 15mm is accepted. Similarly, for Area IV, a rainfall depth of 5mm has to be taken. Hence, the average precipitation by the isohyetal method is calculated to be

{[(40x15)+ (80x12.5)+(70x7.5)+(50x5)]/ 240} = 9.9mm

Isohyets: Lines drawn on a map passing through places having equal amount of rainfall recorded during the same period at these places (these lines are drawn after giving consideration to the topography of the region). ***Planimeter***: This is a drafting instrument used to measure the area of a graphically represented planar region.

Estimation of Missing Rainfall Data

Estimating Missing Data

The point observation from a precipitation gage may have a short break in the record because of instrument failure or absence of the observer. Thus, it is often necessary to estimate the missing record using data from the neighboring station. The following methods are most commonly used for estimating the missing records.

1. Simple Arithmetic Method
2. Normal Ratio Method
3. Modified normal ratio method
4. Inverse distance method
5. Linear programming method

For m stations, 1, 2, 3, …,m, the annual precipitation values are P1, P2, P3, …, Pm, respectively. At station x (not included in the above m stations), the missing annual precipitation (Px) should be found out. The normal annual precipitation N1, N2, N3, …,Ni at each of the above (m+1) stations including the station x is known.

1. Normal Precipitation - It is the average value of precipitation at a particular date, month or year over a specified 30 year period. Thus, the term normal annual precipitation at station A means the average annual precipitation at A based on a specified 30 year of record.

2. Simple Arithmetic Average - The missing precipitation Px can be determined using simple arithmetic average, if the normal annual precipitation at various stations are within 10% of the normal precipitation at station, x, as follows:

$$Px = \frac{1}{m}[P1 + P2 + \cdots + Pm]$$

3. Normal Ratio Method - If the normal precipitations vary considerably then Px is estimated by weighting the precipitation at various stations by the ratios of normal annual precipitation. The normal ration method gives Px as:

$$Px = \frac{Nx}{m}\left[\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pm}{Nm}\right]$$

This method is based selecting m (m is usually 3) stations that are near and approximately evenly spaced around the station with the missing record.

4.Modified Normal Ratio Method

Normal ratio method is modified to incorporate the effect of distance in the estimation of missing rainfall.

$$r_x = \frac{\sum_{i=1}^{n} {D_i}^{1/b} \left(\frac{\overline{r_x}}{\overline{r_i}}\right) r_i}{\sum_{i=1}^{n} {D_i}^{1/b}}$$

Where is normal rainfall, is the distance between the index station i and the gauge station with missing data or un gauged station, n is the number of index stations and b is the constant by which the distance is weighted (normally 1.5-2.0) commonly used $D^{0.5}$

5. Inverse Distance Method

The inverse distance method has been advocated to be the most accurate method as compare to other two methods discussed above.

Amount of rainfall to be estimated at a location is a function of;

1. rainfall measured at the surrounding index stations
2. distance to each index station from the un gauged location

Rainfall r_x at station x is given by;

$$r_x = \frac{\sum_{i=1}^{n}\left(\frac{r_i}{D_i{}^b}\right)}{\sum_{i=1}^{n}\left(\frac{1}{D_i{}^b}\right)}$$

b = 2 is commonly used.

As in inverse distance method the weighting is strictly based on distance, hence this method is not satisfactory for hilly regions.

Rainfall intensity This is the amount of rainfall for a given rainfall event recorded at a station divided by the time of record, counted from the beginning of the event.

Effective rainfall

A part of the rainfall reaching the earth‟s surface infiltrates into the ground and finally joins the ground water reservoirs or moves laterally as interflow. Of the interflow, only the quick response or prompt interflow contributes to the immediate rise of the stream flow hydrograph. Hence, the rainfall component causing perceptible change in the stream flow is only a portion of the total rainfall recorded over the catchment. This rainfall is called the effective rainfall.

The infiltration capacity varies from soil to soil and is also different for the same soil in its moist and dry states. If a soil is initially dry, the infiltration rate (or the infiltration capacity of the soil) is high. If the precipitation is lower than the infiltration capacity of the soil, there will be no overland flow, though interflow may still occur. As the rainfall persists, the soil become moist and infiltration rate decreases, causing the balance precipitation to produce surface runoff.

INFILTRATION

Water is constantly evaporated from the earth, and is precipitated back on the earth, mainly in the form of rainfall. One part of this rainfall sinks into the ground, forming groundwater reservoir; second major part flows as runoff in the form of rivers; and the rest is lost in evaporation and transpiration. The part of the rainfall which sinks into the ground is discussed in this chapter.

Infiltration Process

It is well-known that when water is applied to the surface of a soil, a part of it seeps into the soil. This movement of water through the soil surface is known as infiltration and plays a very significant role in the runoff process by affecting the timing, distribution and magnitude of the surface runoff. Further, infiltration is the primary step in the natural groundwater recharge.

Infiltration is the flow of water into the ground through the soil surface and the process can be easily understood through a simple analogy. Consider a small container covered with wire gauze, if water is poured over the gauze, a part of it will go to container and a part overflows. Further, the container can hold only a fixed quantity and when it is full no more flow into the container can take place. This analogy, though a highly simplified one, underscores two important aspects, viz., the maximum rate at which the ground can absorb water, the infiltration capacity and the volume of water that it can hold, the field capacity.

Factors Affecting Infiltration Rate

The major factors affecting the infiltration of water into the soil are,

1. Initial moisture content
2. Condition of the soil surface
3. Hydraulic conductivity of the soil profile
4. Texture
5. Porosity
6. Degree of swelling of soil colloids
7. Organic matter
8. Vegetative cover
9. Duration of irrigation or rainfall
10. Viscosity of water

The antecedent soil moisture content has considerable influence on the initial rate and total amount of infiltration, but decreasing as the soil moisture content rises. The infiltration rate of any soil is limited by any restraint to the flow of water into and through the soil profile. The soil layer with the lowest permeability, either at the surface or below it, usually determines the infiltration rate. Infiltration rates are also affected by the porosity of the soil which is changed by cultivation or compaction. Cultivation influences the infiltration rate by increasing the porosity of the surface soil and breaking up the surface seals. The effect of tillage on infiltration usually lasts only until the soil settles back to its former condition of bulk density because of subsequent irrigations. Infiltration rates are generally lower in soils of heavy texture than in soil of light texture. It has been established that in surface irrigation, increased depth increases initial infiltration slightly but the depth of application has negligible effect after prolonged irrigation. Infiltration rates are also influenced by the vegetal cover. Infiltration rates on grassland are subsequently higher than bare uncultivated land. Addition of organic matter increases infiltration rate substantially. The hydraulic conductivity of soil profile often change during infiltration, not only because of increasing moisture content, but also because of the puddling of the surface caused by reorientation of surface particles and washing of finer materials into the soil. Viscosity of water influences infiltration. The high rates of infiltration in the tropics under otherwise comparable soil conditions are due to the low viscosity of warm water.

Measurement of Infiltration

Information about the infiltration characteristics of the soil at a given location can be obtained by conducting controlled experiments on small areas. The experimental set-up is called an infiltrometer. There are two kinds of infiltrometers:

1. Flooding-type infiltrometer
2. Rainfall simulator

1 Flooding-Type lnfiltrometer

This is a simple instrument consisting essentially of a metal cylinder, 30 cm diameter and 60 cm long, open at both ends. This cylinder is driven into the ground to a depth of 50 cm (Fig.14.1). Water is poured into the top part to a depth of 5 cm and a pointer is set to mark the water level. As infiltration proceeds, the volume is made up by adding water from a burette to keep the water level at the tip of the pointer. Knowing the volume of water added at different time intervals, the plot of the infiltration capacity vs lime is obtained. The experiments are continued till a uniform rate of infiltration is obtained and this may take 2-3 h. The surface of the soil is usually protected by a perforated disk to prevent formation capacity vs time is obtained. The experiments are continued till a uniform rate of infiltration is obtained and this may take 2-3 h.

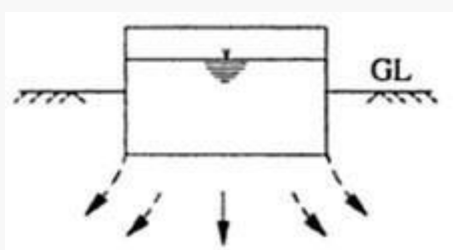


FIGURE NO. 2.16

Simple Infiltrometer.(Source:Subramanya, 2006)

The surface of the soil is usually protected by a perforated disk to preventformation of turbidity and it‟s settling on the soil surface.A major objection to the simple infiltrometer

as above is that the infiltered waterspreads at the outlet from the tube (as shown by dotted lines in Fig. 14.1) and assuch the tube area is not representative of the area in which infiltration takesplace.

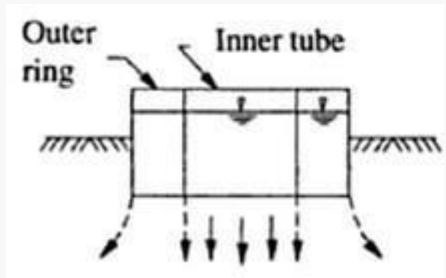


FIGURE NO. 2.17

Ring Infiltrometer.(Source:Subramanya, 2006)

To overcome this ring infiltrometer consisting of a set of two concentric rings (Fig. 14.2) is used. In this two rings are inserted into the ground and water is maintained on the soil surface, in both the rings, to a common fixed level. The outer ring provides a water jacket to the infiltering water of the inner ring and hence prevents the spreading out of the infiltering water of the inner tube. The measurement of water volume is done on the inner ring only.

The main disadvantages of flooding-type infiltrometer are:

(1) The raindrop-impact effect is not simulated;

(2) The driving of the tube or rings disturbs the soil structure;

(3) The results of the infiltrometer depend to some extent on their size with thelarger meters giving fewer rates than the smaller ones; this is due to the border effect.

Rainfall Simulator

In this a small plot of land, of about 2 m X 4 m size, is provided with a size of nozzles on the longer side with arrangements to collect and measure the surface runoff rate. The specially designed nozzles produce raindrops falling from a height of 2 m and are capable of producing various intensities of rainfall. Experiments are conducted under controlled conditions with various combinations of intensities and durations and the surface runoff is measured in each case. Using the water-budget equation involving the volume of rainfall, infiltration and runoff, the infiltration rate and its variation with time is calculated. If the rainfall intensity is higher than the infiltration rate, infiltration-capacity values are obtained.

Rainfall simulator type infiltrometers give lower values than flooding type infiltrometers. This is due to the effect of the rainfall impact and turbidity of the surface water present in the former.

Infiltration indices

Hydrological calculations involving floods it is found convenient to use a constant value of infiltration rate for the duration of the storm. The average infiltration rate is called infiltration index and two types of indices are in common use.

1 Φ-index

The Φ index is the average rainfall above which the rainfall volume is equal to the runoff volume. The Φ index is derived from the rainfall hyetograph with the knowledge of the resulting runoff volume. The initial loss is also considered as infiltration. The Φ value is found by treating it as a constant infiltration capacity. If the rainfall intensity is less than 0, then the infiltration rate is equal to the rainfall intensity; however, if the rainfall infiltration. TheΦ value is found by treating it intensity is larger than Φ the difference between rainfall and infiltration in an interval of time represents the runoff volume (Fig. 3).

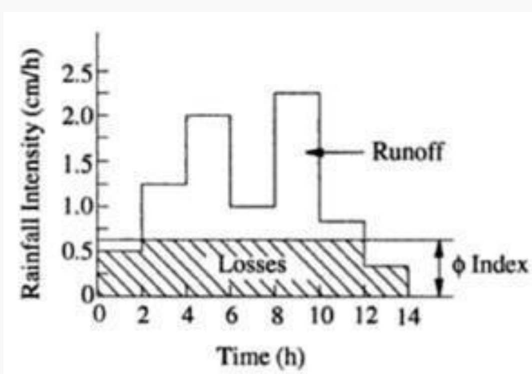


FIGURE NO. 2.18

Φ-index.(Source:Subramanya, 2006)

The amount of rainfall in excess of the Φ index is called rainfall excess. The Φ -index thus accounts for the total abstraction and enables runoff magnitudes to be estimated for a given rainfall hyetograph.

2 W- Index

In an attempt to refine the Φ-index the initial losses are separated from the total abstraction and an average value of infiltration rate called the W index is defined as

$$W = \frac{P - R - I_a}{t_e}$$

Where, P is total precipitation (cm), R is total storm runoff (cm), I_a is initial losses (cm), t_e is the duration of the rainfall excess, i.e. the total time in which the rainfall intensity is greater than W (in hours) and W is the average rate of infiltration (cm/h).

Since I_a values are difficult to obtain, the accurate estimation of the W index is ratger difficult. The minimum value of the W index obtained under very wet soil conditions, representing the constant minimum rate of infiltration of the catchment, is known as $W_{min.}$ Both theW-index and Φ index vary from storm tostorm.

Ponding Time

A crucial time for determining runoff is the time to ponding. The ponding time tp is the elapsed time between the time rainfall begins and the time water begins to pond on the soil surface (after which rainfall intensity exceeded the potential infiltration rate). Prior to the ponding time (t < tp), the rainfall intensity is less than the potential infiltration rate and the soil surface is unsaturated. Ponding begins when the rainfall intensity exceeds the potential infiltration rate. At this time (t = tp), the soil surface is saturated. As rainfall continues (t > tp), the saturated zone extends deeper into the soil and overland flow occurs from the ponded water.

The **infiltration rate** is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface, will take one hour to infiltrate.

In dry soil, water infiltrates rapidly. This is called the **initial infiltration** rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic **infiltration rate.** The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles)

Double ring infiltrometer (Parr and Bertrand, 1960): The double ring infiltrometer is a widely used method of infiltration test used in many applications; i.e. design of land drainage pipes, design of sports surfaces, golf courses, isolation layers of the communal waste, etc. The infiltrometer consists of two concentric metal rings (see Fig 1), which are driven into the soil, and of a perforated metal plate.

Equipment

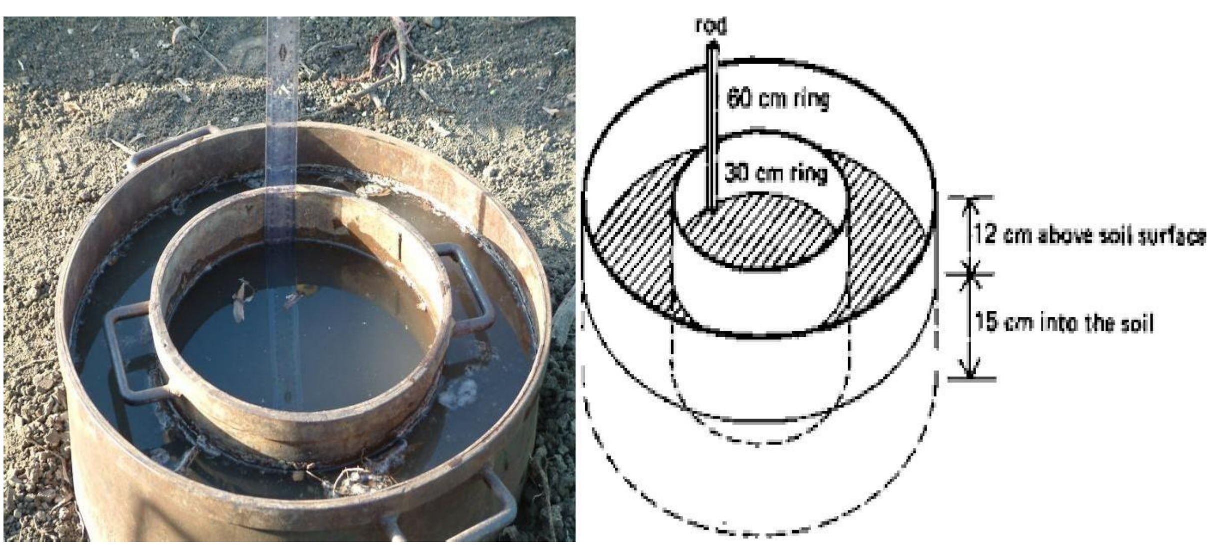


FIGURE NO. 2.19

Numerical problems

1. **A 12-hour storm rainfall with the following depths in cm occurred over a basin: 2.0, 2.5, 7.6, 3.8, 10.6, 5.0, 7.0, 10.0, 6.4, 3.8, 1.4 and 1.4. The surface runoff resulting from the above storm is equivalent to 25.5 cm of depth over the basin. Determine the average infiltration index (Φ-index) for the basin.**

   Solution:

   Φ-index = (rainfall-Runoff) / duration

   Total rainfall in 12 hours (p) = 61.5 cm

   Total runoff in 12 hours (R) = 25.5 cm

   Total infiltration in 12 hours = 61.5-25.5= 36 cm

   Average infiltration = 3.0 cm/hr

2. **The rainfall intensities for the successive1-hour period for 8-hrs storm is given as20,24,30,15,35,20,10,12 mm/hr ,if the total runoff is 80mm,determine the value of Φ-index.**

   Solution:

   Total rainfall = 20+24+30+15+35+20+10+12 =166mm Total runoff = 80mm

   Infiltration losses = Rainfall-Runoff = 166-80 =86mm Φ-index= (86/8) = 10.75 mm/hr = 1.075 cm/hr

3. **In a catchment area of 5km^2, the intensity of rainfall per hour for a 5hr duration storm are 10, 15, 20,22,5 mm. The volume of direct runoff is measured as 0.5cumec-day. Determine the Φ-index. For the catchment.**

   Solution:

   Total rainfall =72mm

   Average rate of rainfall (intensity of rainfall) = (72/5) = 14.4mm/hr.

   Total volume of rainfall over the catchment = (72 x 5x10^6)/ 1000

   = 360000m^3

   Total volume of runoff over the catchment = 0.5x 60 x60 x24

   =43200m^3

   Infiltration losses = Rainfall-Runoff =360000 -43200

   =316800m^3

   Depth of water over Catchment = (316800/ 5x10^6)

   =0.0633 m

=63mm

Φ-index=63/5

=12.6mm/hr

RUNOFF

Runoff is one of the important hydrological processes, which influence the various soil and water conservation and development programs in a watershed. Several attempts have been made in the past to estimate rainfall-runoff volume using mathematical models. Runoff is the drainage of precipitation from catchments, which flows out through its natural drainage system. After the occurrence of infiltration and other losses from the precipitation, the excess rainfall flows out through the small natural channels on the land surface to the main drainage channel. Most environmental process show complicated interrelations, both time and space, leading to numerical models with a complex mathematical structure. Also environmental models require huge amount of data often coming from many sources like remote sensing. Knowledge of runoff that depends upon many factors like precipitation, recharge of the basin, type of soil etc. is one such important parameter.

Components of Runoff

Runoff means the draining or flowing off of precipitation from a catchment area through a surface channel enters into a stream channel. It represents the output from catchment in a given unit of time. Fig. 1 shows components of runoff.

Consider a catchment area receiving precipitation. For a given precipitation, when the evapotranspiration, initial loss, infiltration and detention storage requirements are satisfied, the excess precipitation moves over the land surfaces to reach smaller channels. This portion of runoff is called overland flow and involves building up of storage over the surface and draining off the same. Flows from several small channels join bigger channels and flows from these in turn combine to form a larger stream, and so on, till the flow reaches the catchment outlet. The flow in this mode, where it travels all the time over the surface as overland flow and through the channels as open- channel flow and reaches the catchment outlet is called surface runoff.

A part of the precipitation that infilters moves laterally through upper crusts of the soil and returns to the surface at some locations away from the point of entry into the soil. This component of runoff is known variously as interflow, through flow, storm seepage, subsurface flow or quick return flow.

Depending upon the time delay between the infiltration and the outflow, the interflow is sometimes classified into prompt interflow, i.e. the interflow with the least time lag and delayed interflow.

Another route for the infiltered water is to undergo deep percolation and reach the groundwater storage. The time lag, i.e. the difference in time between the entry into the soil and outflows from it is very large, being of the order of months and years. This part of runoff is called groundwater runoff or groundwater flow.

Based on the time delay between the precipitation and the runoff, the runoff is classified into two categories; as (a) Direct runoff (b) Base flow.

a) Direct runoff

It is the part of runoff which enters the stream immediately after the rainfall. It includes surface runoff, prompt interflow and rainfall on the surface of the stream. In the case of snow-melt, the resulting flow entering the stream is also a direct runoff. Direct storm runoff and storm runoff are also used to designate direct runoff.

b) Base flow

The delayed flow that reaches a stream essentially as groundwater flow is called base flow.

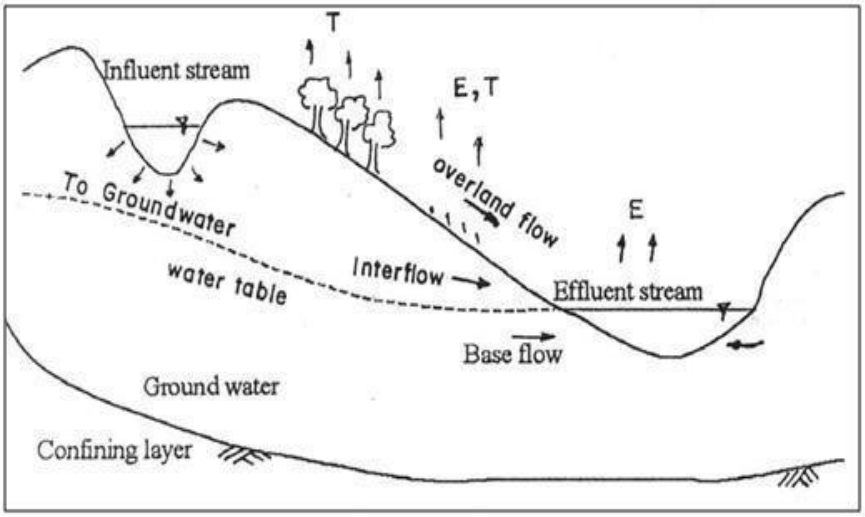


FIGURE NO. 2.20
Components of runoff.(Source: Subramanya, 2008)

Physical characteristics affecting runoff:

- Land use
- Vegetation
- Soil type
- Drainage area
- Basin shape
- Elevation
- Topography, especially the slope of the land
- Drainage network patterns
- Ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or delay runoff from continuing downstream

Factors Affecting Runoff

The main factors affecting the runoff from a catchment area are:

a) Precipitation characteristics

b) Shape and size of catchment

c) Topography

d) Geologic characteristics

e) Meteorological characteristics

f) Storage characteristics of a catchment

1. Precipitation Characteristics

Precipitation is the most important factor, which affects runoff. The important characteristics of precipitation are duration, intensity and areal distribution.

Duration Total runoff depends on the duration of rainstorm. For a given rainfall intensity and other conditions, a longer duration rainfall event will result in more runoff.

Intensity Rainfall intensity influences both rate and volume of runoff. The runoff volume and also runoff rate will be greater for an intense rainfall event than for less intense event.

Areal Distribution It also influences both the rate and volume of runoff. Generally, the maximum rate and volume of runoff occurs when the entire watershed contributes.

2. Shapes and Size of Catchment

The runoff from a catchment depends upon the size, shape and location of the catchment. The following are the general observations:

a) More intense rainfall events are generally distributed over a relatively smaller area, i.e., larger the area lower will be the intensity of rainfall.

b) The peak normally decreases as the area of the basin increase. (peak flow per unit area)

c) Larger basins give a more constant minimum flow than the smaller ones. (effect of local rains and greater capacity of the ground-water reservoir)

d) Fan shaped catchments give greater runoff because tributaries are nearly of same size and hence time of concentration of runoff is nearly same. On the contrary, discharges over fern leaf arrangement of tributaries are distributed over long period because of the different lengths of tributaries.

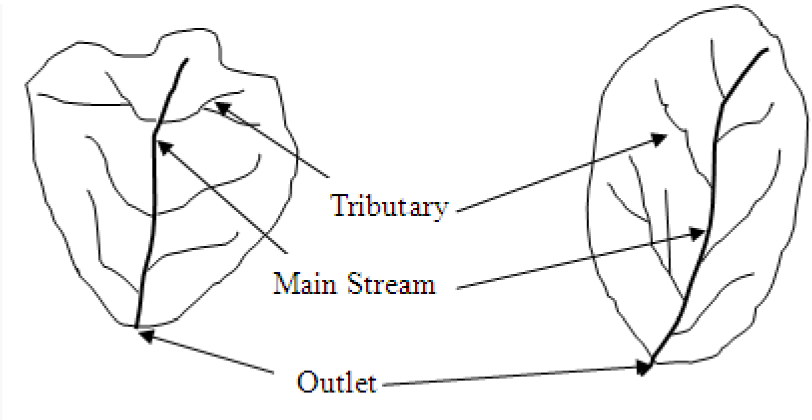


FIGURE NO. 2.21

Fan shaped catchment. Fig.b.Leaf shaped catchment.(Source: Subramanya, 2008)

3. Topography

The runoff depends upon surface condition, slope and land features. Runoff will be more from a smooth surface than from rugged surface. Also, if the surface slope is steep, water will flow quickly and adsorption and evaporation losses will be less, resulting in greater runoff. On the other hand if the catchment is mountainous, the rainfall intensity will be high and hence runoff will be more.

4. Geologic Characteristics

Geologic characteristics include surface and sub-surface soil type, rocks and their permeability. Geologic characteristics influence infiltration and percolation rates. The runoff will be more for low infiltration capacity soil (clay) than for high infiltration capacity soil (sand).

5. Meteorological Characteristics

Temperature, wind speed, and humidity are the major meteorological factors, which affect runoff. Temperature, wind speed and humidity affect evaporation and transpiration rates, thus soil moisture regime and infiltration rate, and finally runoff volume.

Meteorological factors affecting runoff:

- Type of precipitation (rain, snow, sleet, etc.)
- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over the drainage basin
- Direction of storm movement
- Precipitation that occurred earlier and resulting soil moisture
- Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season

6. Storage Characteristics of a Catchment

Presence of artificial storage such as dams, weirs etc. and natural storage such as lakes and ponds etc. tend to reduce the peak flow. These structures also give rise to greater evaporation.

Definition of Hydrograph

The hydrograph which results due to an isolated storm is typically singlepeaked skew distribution of discharge and is known variously as storm hydrograph, flood hydrograph or simply hydrograph.

The hydrograph is the response of a given catchment to a rainfall input. It consists of flow in all the three phases of runoff, viz. surface runoff, interflow and base flow and embodies in itself the integrated effects of a wide variety of catchment and rainfall parameters having complex interactions.

Elements of Hydrograph

Hydrograph has three characteristic regions: (i) the rising limb AB, joining point A, the starting point of the rising curve and point B, the point of inflection, (ii) the crest segment BC between the two points of inflection with a peak P in between, (iii) the falling limb or depletion curve CD **starting from the second point of inflection C.**

Rising Limb

The rising limb of a hydrograph, also known as concentration curve represents the increase in discharge due to the gradual building up of storage in channel and over the catchment surface. The initial losses and high infiltration losses during the early period of a storm cause the discharge to rise rather slowly in the initial periods. The basin and storm characteristics control the shape of the rising limb of a hydrograph.

Crest Segment

The crest segment is one of the most important parts of hydrograph as it contains the peak flow. The peak now occurs when the runoff from various parts of the catchment simultaneously contribute amounts to achieve the maximum amount of flow at the basin outlet. Generally for large catchments, the peak flow occurs after the cessation of rainfall, the time interval from the centre of mass of rainfall to the peak being essentially controlled by basin and storm characteristics. Multiple-peaked complex hydrographs in a basin can occur when two or more storms occur in succession. Estimation of the peak flow and its occurrence, being important in flood-flow studies are dealt with in detail elsewhere in this book.

Recession Limb

The recession limb, which extends from the point of inflection at the end of the crest segment (point C)to the commencement of the natural groundwater flow (point D.) represents the withdrawal of water from the storage built up in the basin during the earlier phase of the hydrograph. The starting point of the recession limb, i.e. the point of inflection represents the condition of maximum storage. Since the depletion of storage takes place after the cessation of rainfall, the shape of this part of the hydrograph is independent of storm characteristics and depends entirely on the basin characteristics.

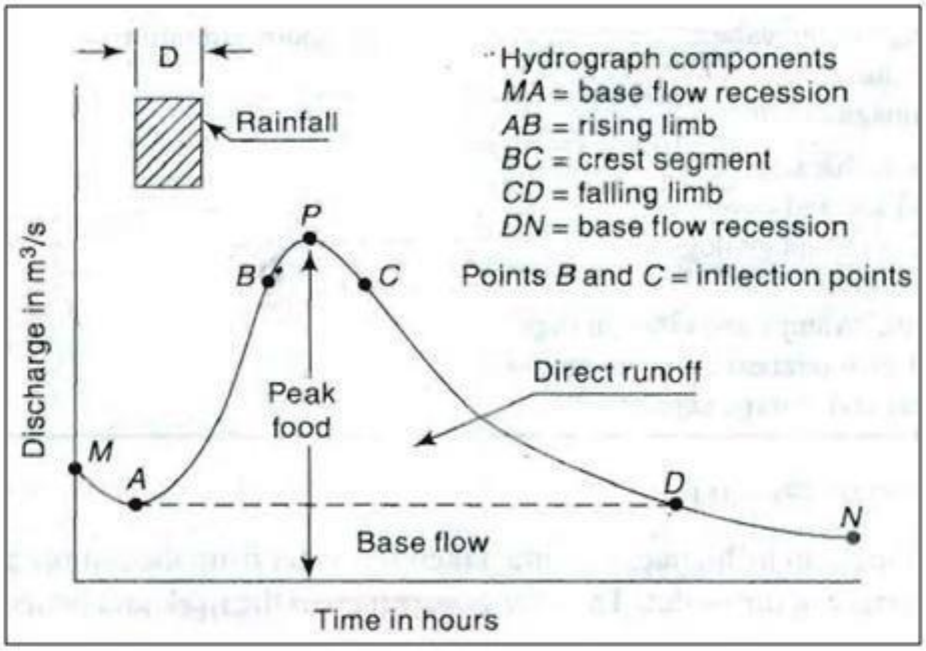


FIGURE NO. 2.22

Elements of a hydrograph. (Source: Subramanya, 2008)

Stream flow Recession

The storage of water in the basin exists as (i) surface storage, which includes both surface detention and channel storage, (ii) interflow storage, and (iii) groundwater storage, i.e. base-flow storage.

Lag Time (T_L)

It is the difference in time between the center of mass of net rainfall and center of mass runoff.

Time to Peak (T_P)

It is the time difference between the beginnings of direct runoff (point B) to peak.

Rainfall Duration (T_r)

It is the effective rainfall duration, which causes direct runoff. Curve between point M and A represents recession from previous storm.

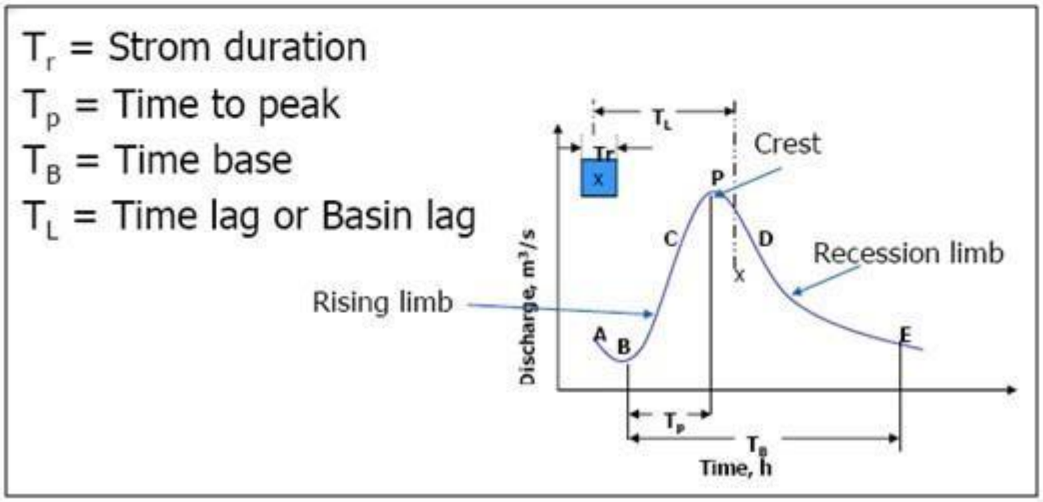


FIGURE NO. 2.23

Hydrograph time characteristics. (Source:Subramanya, 2008)

Definition of Unit Hydrograph

This method was first suggested by Sherman in 1932

A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth (1 cm) of rainfall excess occurring uniformly over the basin and at a uniform rate for a specified duration (D hours).

The definition of a unit hydrograph implies the following:

- The unit hydrograph represents the lumped response or the catchment to a limit rainfall excess of D-h duration to produce a direct-runoff hydrograph. It relates only the direct runoff to the rainfall excess. Hence the volume of water contained in the unit hydrograph must be equal to the rainfall excess. As 1 cm depth of rainfall excess is considered the area of the unit hydrograph is equal to a volume given by 1cm over the catchment.
- The rainfall is considered to have an average intensity of excess rainfall (ER) of 1/D cm/h for the duration D-h of the storm.
- The distribution of the storm is considered to be uniform all over the catchment.

Uses of Unit Hydrograph

1. Development of flood hydrograph for extreme rainfall magnitudes for use in the design of hydraulic structures.
2. Extension of flood-flow records based on rainfall records.
3. Development of flood forecasting and warning systems based on rainfall.

Factors Affecting Hydrograph

Physiographic factors	Climatic factors
1. Basin characteristics (a) Shape (b) Size (c) Slope (d) Nature of the valley (e) Elevation (f) Drainage density 2. Infiltration characteristics (a) Land use and cover (b) Soil type and geological conditions (c) Lakes, swamps and other storage 3. Channel characteristics: cross-section, roughness and storage capacity	1. Storm characteristics: precipitation, intensity, duration, magnitude and movement of storm 2. Initial loss 3. Evapotranspiration

Types of Watersheds

Definition of Drainage Basin

It is defined as, "any portion of the earth's surface within a physical boundary defined by topographic slopes that divert all runoff to the same drainage outlet."

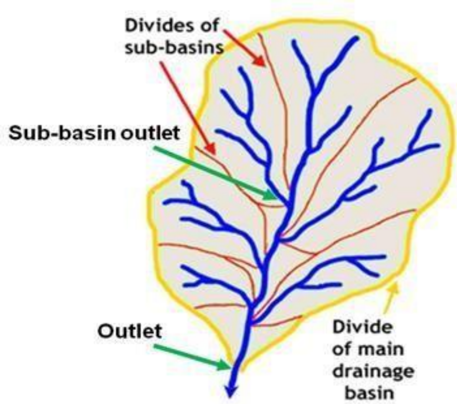


FIGURE NO. 2.24

Drainage basin with its sub-basins.

By definition, any point on the main drainage system can be selected as the basin outlet. Thus, a basin is defined with respect to the outlet.

The physical boundary of the drainage basin is called the drainage divide. The watershed area includes all the points that lie above the elevation of the outlet and within the drainage divide that separates adjacent watersheds.

Other terms synonymous with drainage basin are watershed, catchment, basin, river basin, runoff area, and stream basin. Watershed, catchment and basin are most commonly used terms by hydrologists.

Watersheds can be classified based on size, mean slope, length, land use, etc. Two hydrologically meaningful criteria are size and land use.

Classification of Watersheds by Size

Three types of watershed are distinguished according to size:

1. Small size: < 250 km^2
2. Medium size: between 250 km^2- 2500 km^2
3. Large: >250 km^2

This classification is vague, but the implication is in terms of spatial heterogeneity and dampening (averaging) of hydrological processes.

Runoff generation on these watersheds can be considered in two phases: i) land phase and ii) channel phase. Each phase has its own storage characteristics.

Large Watersheds

1) They have well-developed channel networks and channel phase, and, thus, channel storage is dominant.

2) They are less sensitive to high-intensity rainfalls of short duration.

Small Watersheds

1) They have dominant land phase and overland flow, have relatively less conspicuous channel phase.

2) They are highly sensitive to high-intensity, short-duration rainfalls.

Two watersheds of the same size may behave very differently if they do not have similar land and channel phases.

Small watersheds are usually least heterogeneous and large watersheds are most heterogeneous. In other words, spatial variability of watershed characteristics increases with size.

As the watershed size increases, storage increases and averaging of hydrologic processes increases as a result. The effect of averaging is to linearise the watershed behavior.

Classification of Watersheds by Land Use

Land use defines exploitation of watershed. Accordingly, watersheds can be classified as agricultural, urban, mountainous, forest, desert, coastal or marsh, or mixed - a combination of two or more of the previous classifications. These watersheds behave hydrologically so differently that different branches of hydrology have arisen:-

1) Urban watersheds: urban hydrology
2) Agricultural watersheds: agricultural hydrology
3) Forest watersheds: forest hydrology
4) Mountainous watersheds: mountain hydrology
5) Desert watersheds: desert hydrology
6) Coastal watersheds: coastal hydrology
7) Wetland/marsh watersheds: wetland hydrology

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DEPARTMENT OF CIVIL ENGINEERING

UNIT – III – GROUNDWATER HYDROLOGY– SCI1305

Groundwater is the water that occurs in a saturated zone of variable thickness and depth below the earth's surface. It is therefore the water beneath the earth's surface from which wells, springs, and groundwater run-off are supplied. Groundwater hydrology may be defined as the science of the occurrence, distribution and movement of water below the surface of the earth. Groundwater referred to without further specification is commonly understood to mean water occupying all the voids within a geological stratum. The main source of groundwater is precipitation. A portion of rain falling on the earth's surface infiltrates into ground travels down and, when checked by impervious layer to travel further down, forms ground water. The ground water reservoir consists of water held in voids within a geologic stratum.

Groundwater may flow into streams, rivers, marshes, lakes and oceans, or it may discharge in the form of springs and flowing wells. Groundwater flows through permeable material, which contains interconnected cracks or spaces that are both numerous enough and large enough to allow water to move freely. In some permeable materials groundwater may travel several meters in a day, in other places, it moves only a few centimeters in a very slowly through relatively impermeable materials such as clay and shale. Thus, the residence time of the groundwater i.e, the length of time water spends in the groundwater portion of the hydrologic cycle, varies enormously.

Groundwater is distinctive from surface water in the following respects: (a) Groundwater exists in voids in the subsurface and its movement is very slow. (b) Pore geometry, soil or rock fracture, surface tension, and flow resistance fundamentally affect groundwater movement, both in saturated and unsaturated conditions. (c) Topographic and geologic structures strictly govern groundwater flows. (d) Soil, stratum, rock mineral and geothermal conditions exert a great influence on the chemical properties of groundwater. Natural topographic and geologic systems control the occurrence of groundwater. Thus groundwater has various types in flow systems based on the topographic and geologic conditions. The water content in the geologic formations varies with depth below ground surface.currence of groundwater

The geologic zones important to groundwater must be identified as well as their structure in terms of water holding and water yielding capabilities. Groundwater occurs in many types of geologic formations known as aquifers.

Aquifer (Groundwater reservoir/water bearing formation)

Formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. Unconsolidated sands and gravels are a typical example. Aquifers are in general areal extensive and may be overlain or underlain by a confining bed which may be defined as relatively impermeable material.

There are various types of confining beds

Aquiclude – A saturated but relatively impermeable material that does not yield appreciable quantity of water to wells. Eg- Clay.

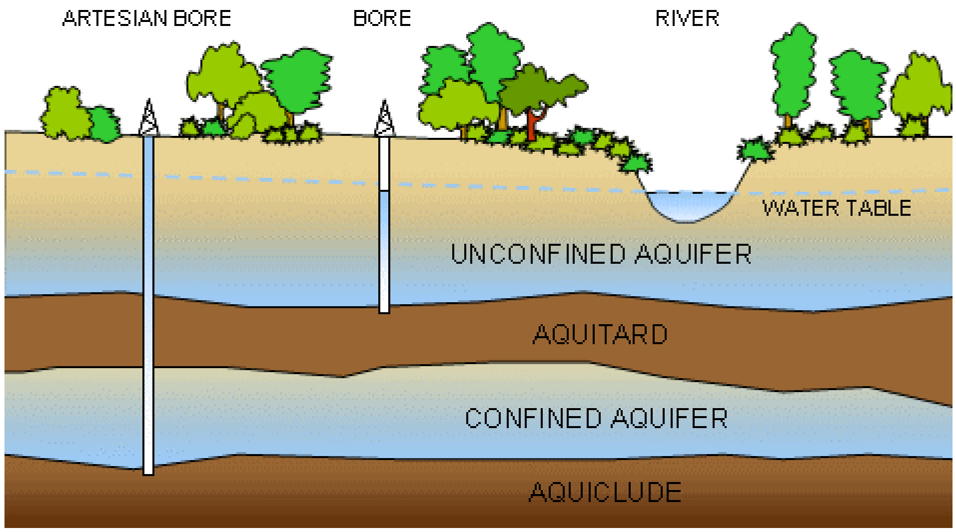


Fig 3.1 Different types of water bearing stratum

Aquifuge- A relatively impermeable formations neither containing nor transmitting water. Eg- Solid granite

Aquitard- A saturated but poorly permeable stratum that impeds groundwater movement, less yield but it can transmit appreciable amount of water. Eg- Sandy clay

Vertical movement of groundwater

Water, below the surface, at a pressure greater than atmospheric pressure, which thus flows freely into a hole through interconnected void spaces ,is groundwater. .The following Figure illustrates the various zones of water found beneath the surface. Water beneath the surface can essentially be divided into three zones:1) the soil water zone, or vadose zone, 2) an intermediate zone, or capillary fringe and 3) the ground water, or saturated zone. The top two zones, the vadose zone and capillary fringe, can be grouped into the zone of aeration, where during the year air occupies the pore spaces between earth materials.

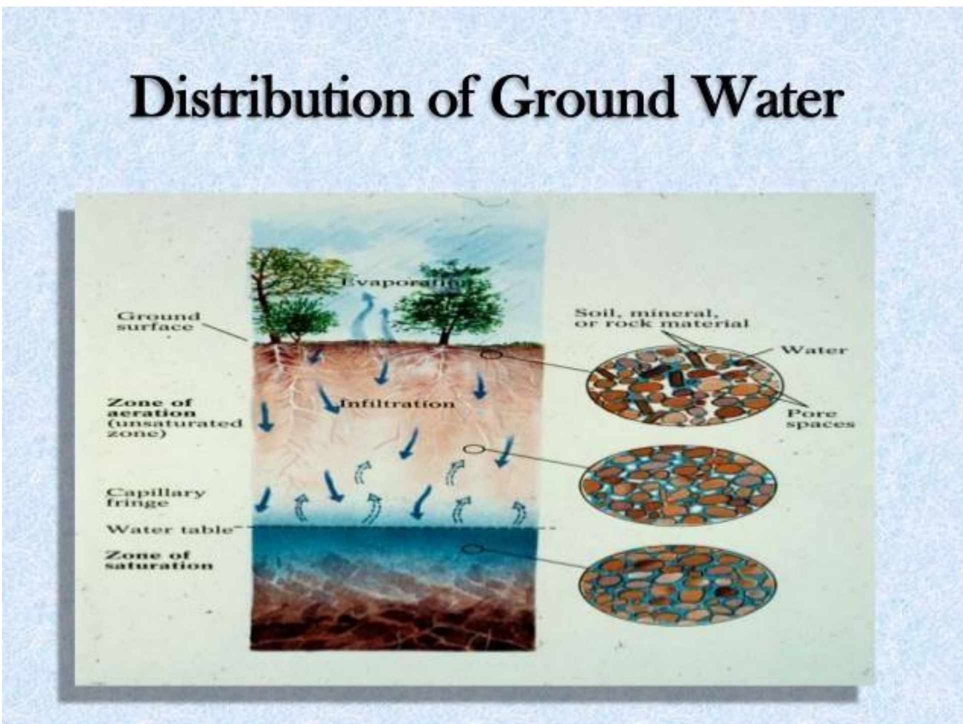


Fig 3.2 Distribution of groundwater

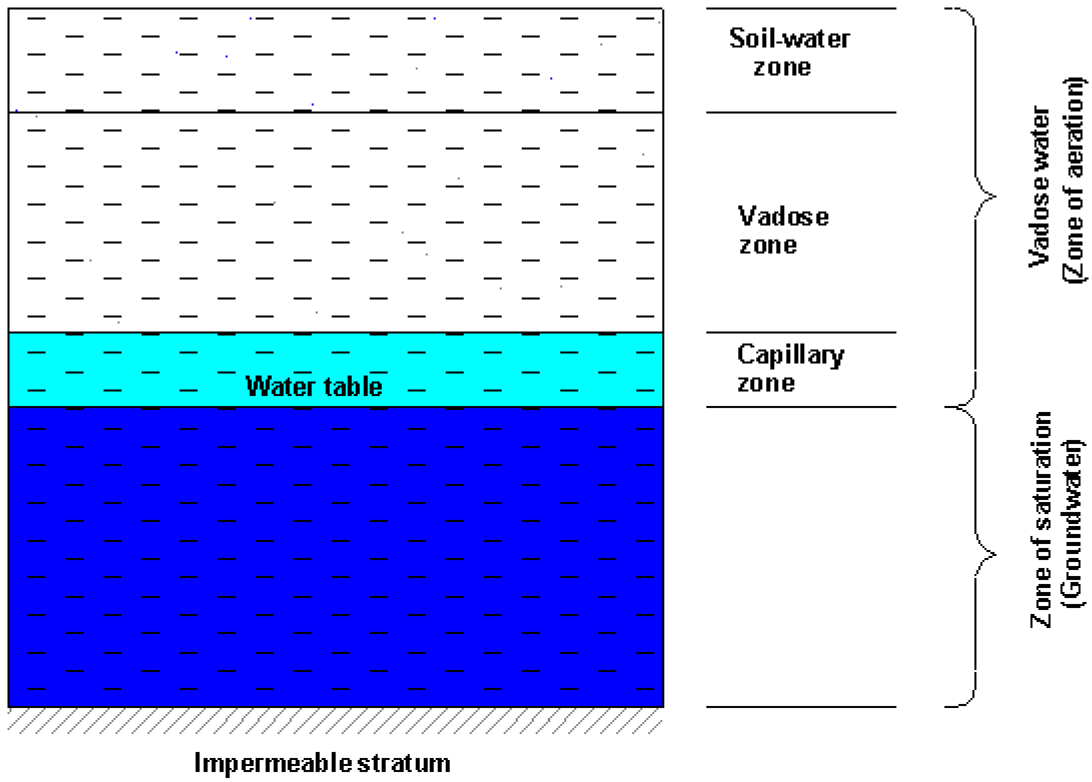


Fig 3.3

Sometimes, especially during times of high rainfall, those pore spaces are filled with water. Aeration from the zone of saturation. The elevation of the water table is determined to be where the pore water pressure, Pw, is equal to atmospheric pressure, Pa. The height of the water table will fluctuate with precipitation, increasing in elevation during wet periods and decreasing during dry. In general, the water table has an undulating surface which generally follows the surface topography, but with smaller relief.

The zone of aeration is the region between the earth's surface and the water table. The main components of this region are the soil and rocks. Their pores are at times partly filled with water and air, and aeration occurs when the air and water mix or come into close contact. pose

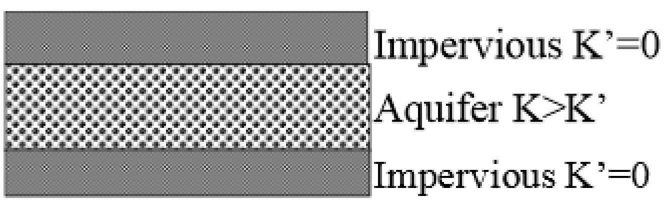
The zone of saturation is the ground immediately below the water table. The pores and fractures in soil and rocks are saturated with water.

1. AQUIFER CLASSIFICATION

Aquifers may be classed as confined, unconfined or leaky which can be taken as a combination of the unconfined and confined.

A confined aquifer is confined above and below by an impervious (may contain water but can't transmit it)layer under pressure greater than the atmospheric. Therefore, in a well penetrating such an aquifer, the water level rises above the bottom of the top confining bed. The water in a confined aquifer is called confined or artesian water. Artesian water flows freely without pumping and the well producing such water is called an artesian or a free flowing well.

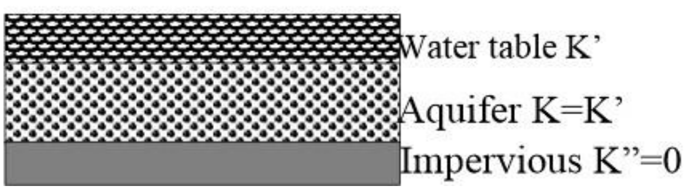
Confined Aquifer (Pressure or piezometric aquifers)



Unconfined Aquifer (Phreatic, Water table)

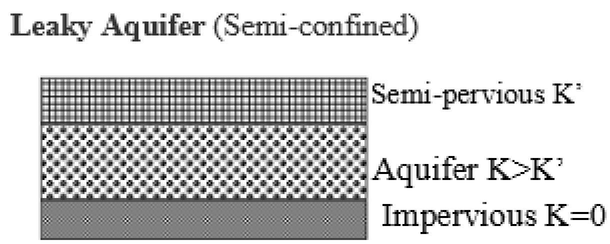
The water level in well taping an unconfined aquifer and the water table in the aquifer are the same. Therefore, contour maps and profiles of the water table can be prepared from the elevations of water in wells that tap the aquifer to determine the quantities of water available, their distribution and movement.

Unconfined Aquifer (Phreatic, Water table)
An unconfined aquifer is one in which a water table (phreatic surface) serves as its upper boundary. A phreatic aquifer is directly recharged from the ground surface above it.



A leaky aquifer

It is an underlain or overlain by semi-pervious strata. Pumping from a well in a leaky aquifer removes water in two ways: by horizontal flow within the aquifer and by vertical leakage or seepage through the semi-confining layer into the aquifer. Aquifers that are completely confined or unconfined occur less frequently than leaky aquifers.



Perched Aquifers

Perched aquifers, are special kinds of phreatic aquifers occurring whenever an impervious (or semi –pervious) layer of limited extent is located between the water table of a phreatic aquifer and the ground surface, thereby making a ground water body, separated from the main groundwater body to be formed. Sometimes, these aquifers exist only during a relatively short part of each year as they drain to the underlying phreatic aquifer. Therefore wells taping such aquifers yield only temporary or small quantities of water.

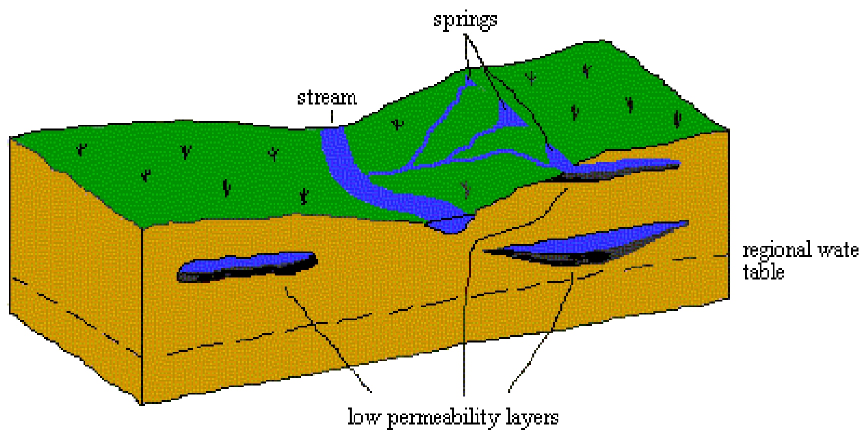


Fig 3.4

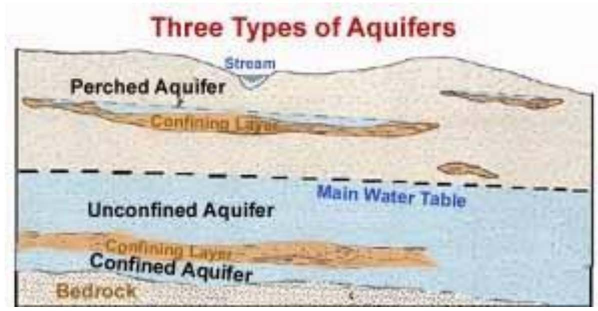


Fig 3.5 Types of Aquifer

2. Recharge and Discharge

Groundwater recharge represents the portion of rainfall which reaches an aquifer. Groundwater therefore owes its existence directly or indirectly to precipitation. Artificial recharge occurs from excess irrigation seepage from canals and water purposely applied to augment groundwater supplies. Seawater can enter underground along the coasts where the hydraulic gradients slope in an inland direction. The most direct way of quantifying recharge is by examination of borehole hydrograph. This method requires that the specific yield of the aquifer is known. Another approach is to use meteorological data inputs to a recharge simulation model. Natural recharge includes stream bed percolation, deep percolation of rainfall, leakage from ponds, lakes and reservoirs.

Discharge of groundwater occurs when water emerges from underground. Most natural discharge occurs as flows into the surface water bodies e.g. streams, lakes and oceans. Discharge to the ground surface appears as springs. Groundwater discharge also occurs by evaporation from within the soil and by transpiration from vegetation that has access to the water table. However, pumpage from wells constitutes the major artificial discharge of groundwater.

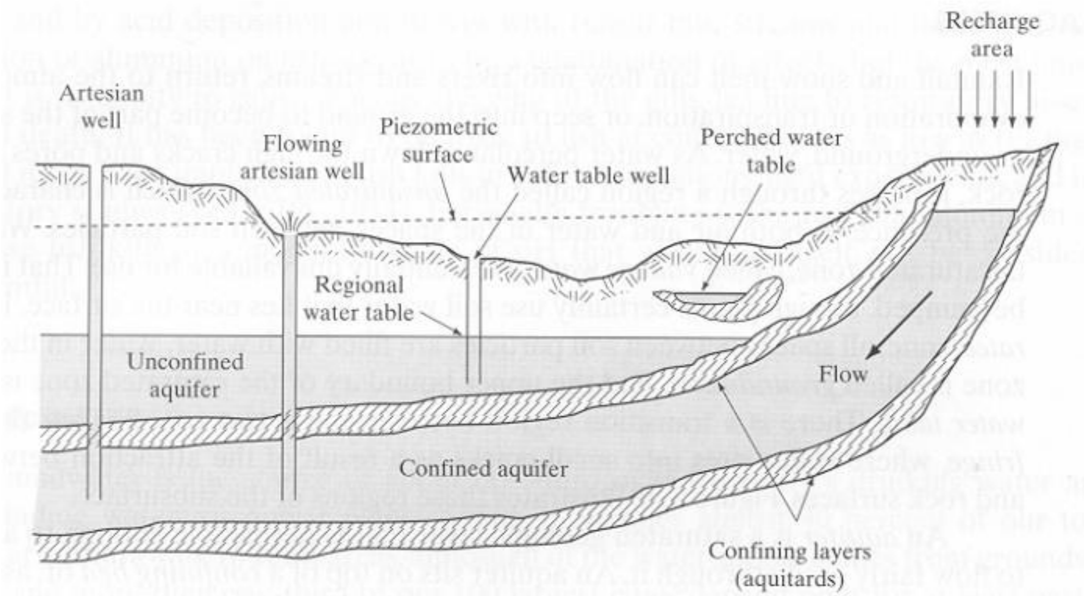


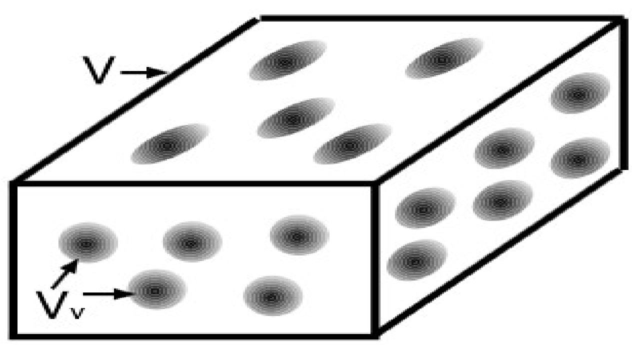
Fig 3.6 Types of aquifer

3. Hydrogeological parameters Porosity

Ground water and soil moisture occur in the cracks, voids, and pore spaces of the Otherwise solid earth materials. Porosity, is the percentage of the total volume that is void of material,

$$n = 100 \times \frac{V_v}{V},$$

where V_v is the volume of void space, and V the total volume. We can write V_v as $V_v = V - V_s$, where the subscript s refers to the volume of the solid phase, $V_s = m_d/\rho_s$, the dry weight divided by the density of the soil/rock.



The term effective porosity refers to the amount of interconnected pore space available for fluid flow and is also expressed as the ratio of the interstices to total volume. Shape, size, packing and degree of cementation affect porosity. Uniformly graded sand has a higher porosity than a less uniform, fine and coarse mixture, because in the latter the fines occupy the voids in the coarse material. In square packing for example, the porosity is as high as 48% while in rhombic packing, it is as low as 26%. Angularity tends to increase porosity while cementation decreases porosity.

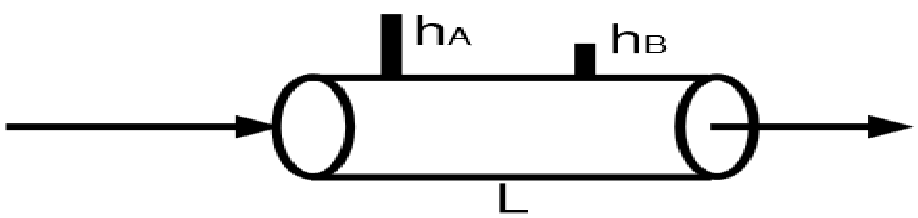
4. Conductivity and permeability

Some rocks are porous, but the voids are not, or poorly, interconnected. These rockscannot convey water from one void to another. Permeability is the property of an aquifer to transmit water through its pores. The horizontal permeability and vertical permeability may differ.

Co efficient of permeability K is also known as hydraulic conductivity and has the dimensions as those of the velocity of flow. It depends on the fluid property as well as the property of the aquifer soil sample. In the mid-1800s, Henry Darcy, a French engineer, made the first systematic study of the movement of water through a porous medium. Darcy's law is illustrated in the following Figure, and states that the rate of flow per unit area of an aquifer is proportional to the gradient of potential flow in the

$$q = \frac{Q}{A} = -K\frac{dh}{dl},$$

where q [L T^{-1}] is specific discharge (sometimes called Darcian velocity), A [L^2] is cross-sectional area, Q [L^3 T^{-1}] is discharge, dh/dl is the hydraulic gradient, and K *hydraulic conductivity* [L T^{-1}].



A horizontal pipe filled with sand to demonstrate Darcy's experiment. Water is applied under pressure at point A and discharges at point B.

direction of flow.

Fig 3.7

Groundwater movement is governed by established hydraulic properties such as porosity, permeability, hydraulic conductivity etc. The ability of an aquifer to receive, store or transmit water or contaminants on the rock properties within the aquifer.

Hydraulic conductivity (unit length per unit time):

The coefficient that describes the ability of a geologic medium to ". . . transmit in unit time a unit volume of ground water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through unit length of flow." Hydraulic conductivity can be calculated by dividing the transmissivity by the aquifer thickness (Lohman, 1979).

Hydraulic Conductivity (K)

K is the specific discharge (v) per unit hydraulic gradient (dh/dl) at a specified temperature and expresses the ease with which fluid is transported through a porous matrix.

$K = v/(dh/dl)$ where $v=Q/A$

It is therefore a coefficient which depends on both matrix and fluid properties. The relevant fluid properties are density ρ and viscosity μ (or in the combined form of kinematic viscosity ν). The relevant solid matrix properties are mainly grain- (or pore-) size distribution, shape of grains, arrangement of pores and porosity.

$K = k\rho g/ \mu = kg/ \nu$

where k (dimensions of L^2) – called the permeability, or intrinsic permeability, of the porous matrix – depends solely on properties of the soil matrix. Field measurements of hydraulic conductivity are usually made by carrying out pumping test on wells while laboratory measurements are done using parameters.

Transmissivity (square unit length per unit time): "The rate at which water of the prevailing kinematic viscosity is transmitted [horizontally] through a unit width of the aquifer under a unit hydraulic gradient."

Transmissivity (T) T=Kb where K is the hydraulic conductivity and b, the thickness of the aquifer. T defines the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Specific yield (unitless): "The ratio of (1) the volume of water which after being saturated, it [rock or soil] will yield by gravity to (2) its [rock or soil] own volume." Specific yield is virtually the same as the storativity for unconfined aquifers.it also known as drainable porosity.

$S_y = V_{wd}/V_t$

S_y - Specific yield

V_{wd}-Volume of water drained

V_t– total rock or material volume

Specific Yield is the volume of water, expressed as a percentage of the total volume of the saturated aquifer that can be drained by gravity. The volume retained (by molecular and surface tension forces) against the force of gravity, expressed as a percentage of the total volume of the saturated aquifer, is called the specific retention.

Porosity = Specific yield + Specific retention.

Specific yield can be determined in the laboratory by simple saturation and drainage, while in the field by pumping a known volume of water out and determining the volume of sediments drained by observing the depth of the water lowered.

Specific yield = (Volume of water pumped out /Volume of sediments drained) x 100

Storage Coefficient or Storativity (unitless): "The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It defines the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface. It is a dimensionless quantity involving a volume of water per volume of aquifer.

Specific retention

The ratio of the volume of the water the rock or sediment will retain against the pull of gravity to the total volume of the rock or sediment.

Unconfined aquifer- 0.02 to 0.3
Confined aquifer – 0.00005 to 0.005

Static water level: is the level of water in the well when no water is being taken out.

Dynamic Water level: is the level when water is being drawn from the well. The cone of depression occurs during pumping when water flows from all directions toward the pump.

Numerical problems

1. **In a phreatic aquifer extending over 1 km^2 the watervtable was initially at 25m below ground level. Sometime after irrigation with a depth of 20cm of water, the water table rose to a depth of 24m bgl. Later 3x10^5 m^3 of water**

was pumped out and the water table dropped to 26.2 m bgl. Determine i) specific yield of the aquifer ii) deficit in soil moisture (below field capacity) before irrigation.

Solution

Volume of water pumped out = Area of aquifer x drop in g.w.t x specific yield

$3x10^5$ = 10^6x2.2x Sy

Sy = **0.136 or 13.6%**

Volume of irrigation water recharging the aquifer = Area of aquifer xrise in g.w.t x Sy Considering an area of $1m^2$ of aquifer

1xy = 1x1x0.136

Recharge volume in terms of depth (y) = 0.136 m or 136 mm

Soil moisture deficit before irrigation = 200-136 = **64mm**

2. **In an area of 100 ha, the water table dropped by 4.5m. if the porosity is 30% and the specific retension is 10% determine i) the specific yield of the aquifre ii) change in groundwater storage.**

Solution

Porosity=

Sy+ Sr

30%=

Sy+ 10%

Sy= 20% or b0.2

Change in groundwater storage = area of aquifer x drop in gwtx Sy

= 100x4.5x0.2

= 90 ha-m or 90x10^4 m^3

5. STEADY STATE FLOW IN TO A WELL

When a well is pumped, water flows into the well from the surrounding aquifer because of difference in hydraulic heads at the well and in the aquifer caused by pumping. Before pumping, water level in the well stands at a height theoretically equal to the static water pressure in the saturated layer around the well. This water level is known as ‘static water level’ or ‘pre-pumping water level’ (Fig. 10.1). When pumping starts, water is removed from the aquifer surrounding the well and the water level in the well ‘piezometric level’ in case of confined aquifers (Fig. 10.1a) and ‘water table’ in case of unconfined aquifers (Fig. 10.1b)] starts lowering. The water level in the well at any instant during pumping is known as ‘pumping water level’.

Steady flow occurs when the water level has ceased to decline as a result of equilibrium between the discharge of the pumped well and the recharge of the aquifer buy outside source. The Dupuit (1863) equation, later modified by Theim, 1906 can be used for analysing steady flow to wells.

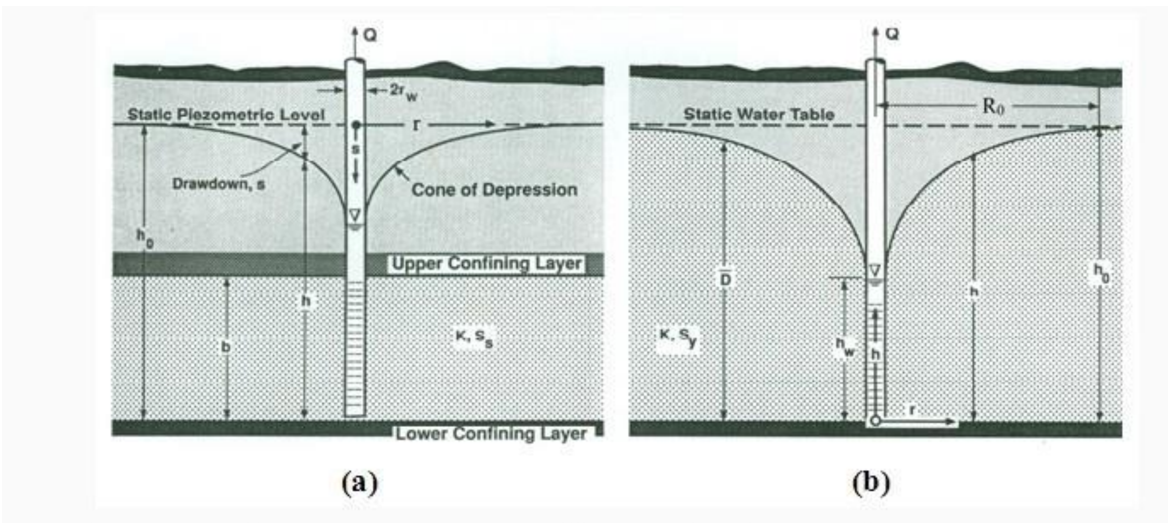


Fig 3.8 Drawdown pattern in: (a) Confined aquifer; (b) Unconfined aquifer. (Source: Roscoe Moss Company, 1990)

The difference between the static water level and the pumping water level at any instant is called ‘drawdown’, which is a function of pumping rate, pumping duration and distance from the pumping well. Drawdown is always maximum at the pumping well and it decreases with an increase in the distance from pumping well (Fig. 10.1). The rate of pumping from an aquifer significantly affects the hydraulic gradient in the aquifer. The faster the well is pumped, the steeper the hydraulic gradient will be in the vicinity of the well.

A drawdown curve at a given time shows the variation of drawdown with distance from the pumping well. In three dimensions, the drawdown curve takes the shape of an inverted cone centered on the pumping well, which is known as cone of depression. The outer limit of the cone of depression defines the area of influence of the well. The boundary of the area of influence is called circle of influence and the radius of the circle of influence is called radius of influence. Thus, the radius of influence (R_0) is the distance from a pumping well to the edge of the cone of depression (Fig. 10.1) where drawdown is zero.

As more and more groundwater is pumped through the well, the more water comes from aquifer storage. As a result, the radius of influence increases until when the rate of pumping (discharge) becomes equal to the rate of flow into the well from the area around the well. At this instant of time, a steady flow condition exists in the aquifer and the cone of depression gets stabilized (i.e., it does not change with pumping time). This equilibrium condition changes when the pumping rate is increased or decreased. Note that under steady-state conditions, the entire pumped water is assumed to be coming from external sources beyond the radius of influence. In contrast, under unsteady-state (transient-flow) conditions, either entire pumped water is assumed to be coming from the aquifer storage within the radius of influence or the pumped water is assumed to be coming partly from the aquifer storage within the radius of influence and partly from external sources beyond the radius of influence depending on field conditions.

Confined Aquifers

The following Figure shows a pumping well fully penetrating a confined aquifer and is subjected to pumping. Groundwater level under equilibrium conditions is also depicted. Under equilibrium (steady-state) conditions, the rate of pumping (Q) is equal to the rate that the aquifer transmits water to the well. This problem was first solved by G. Thiem in 1906, which is presented below.

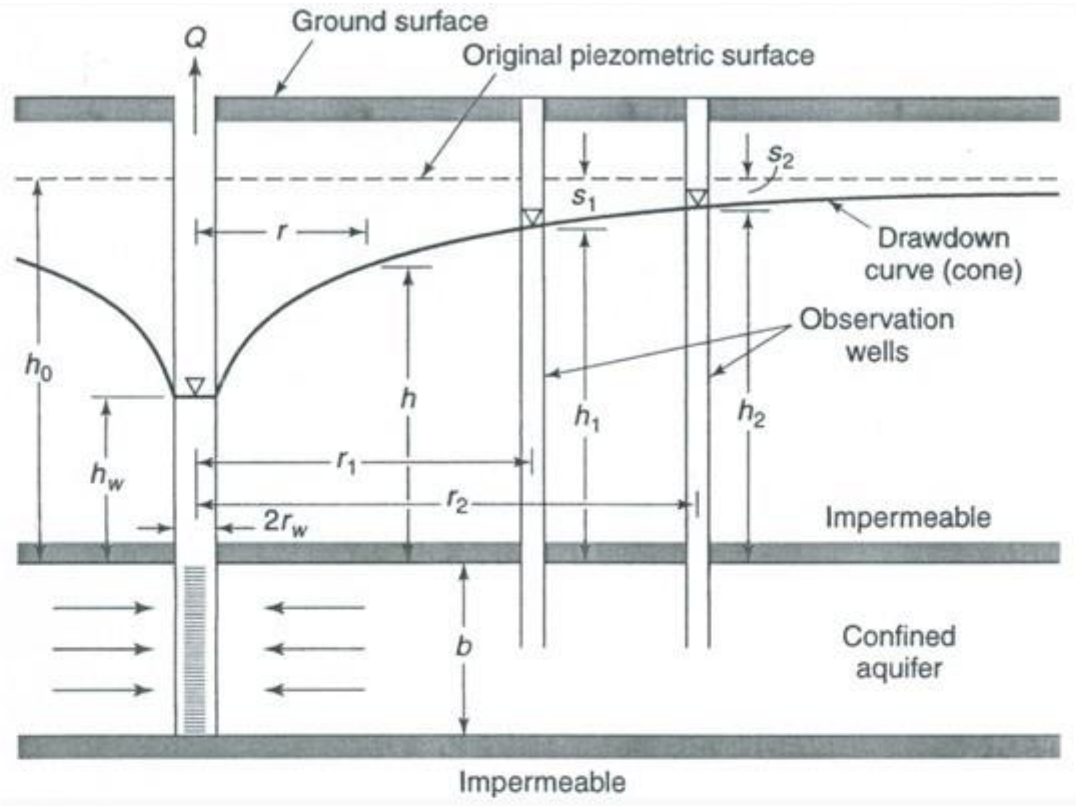


Fig 3.9 Steady flow to a pumping well in a confined aquifer. (Source: Todd, 1980)

The yield from the well is Q = KiA (Darcy's law)

From the Darcy's law, the flow of water through a circular section of the aquifer towards the pumping well is given as:

$$Q = (2\pi rb) \times K \times \frac{dh}{dr}$$

Where, Q = constant rate of pumping from the well, r = radial distance from the circular section to the pumping well, b = thickness of the confined aquifer, K = hydraulic conductivity of the confined aquifer, and dh/dr = hydraulic gradient.

Since transmissivity (T) is the product of aquifer thickness (b) and hydraulic

$$Q = 2\pi r T \times \left(\frac{dh}{dr}\right)$$

conductivity (K), the above Eqn. can be expressed as:

$$dh = \frac{Q}{2\pi T} \times \frac{dr}{r}$$

Let's consider that two observation wells are installed in the aquifer at distances r_1 and r_2 from the pumping well, respectively with hydraulic heads h_1 and h_2.

Rearranging and integrating with appropriate boundary conditions

$$\int_{h_1}^{h_2} dh = \frac{Q}{2\pi \mathrm{T}} \int_{r_1}^{r_2} \frac{dr}{r}$$

$$\Rightarrow \quad h_2 - h_1 = \frac{Q}{2\pi T} \times \ln\left(\frac{r_2}{r_1}\right)$$

$$\therefore \quad Q = 2\pi T \times \frac{h_2 - h_1}{\ln\left(\frac{r_2}{r_1}\right)}$$

In practice, instead of the hydraulic head (h), drawdown (s) is measured, and hence after expressing h_1 and h_2 as draw downs, Eqn. can be written as:

$$Q = 2\pi T \times \frac{(s_1 - s_2)}{\ln\left(\frac{r_2}{r_1}\right)}$$

Where, s_1 and s_2 are steady draw downs in the two observation wells located respectively at r_1 and r_2 distances from the pumping well.

Furthermore, if we consider that the first observation well is located at a distance r_w (radius of the pumping well) where hydraulic head is h_w and instead of the second observation well at r_2, we consider that $r_2 = R_0$ (radius of influence) where drawdown (s_2) is zero and hence hydraulic head is h_0 (static or pre-pumping groundwater level), the Thiem equation can be expressed as follows:

$$Q = 2\pi T \times \frac{h_0 - h_w}{\ln\left(\frac{R_0}{r_w}\right)}$$

$$Q = 2\pi T \times \frac{s_w}{\ln\left(\frac{R_0}{r_w}\right)}$$

The above is referred to as the equilibrium or Theim's equation. r_1, r_2 are respective distances of piezometers (observation wells) to the pumped well h_2, h_1 are their respective water levels. The Theim's equation enables the K or T of an aquifer to be determined from a pumped well being monitored from at least two observation wells at different distances from the pumped well.

If the drawdown in the observation wells are s_1 and s_2, then $h_2-h_1 = s_1-s_2$. The assumptions in **Theim's equation** are:

1. The aquifer is confined.
2. The aquifer has an infinite areal extent.
3. The aquifer is homogeneous, isotropic and of uniform thickness over the area influenced by the test.
4. Prior to pumping, the piezometric surface is horizontal over the area that will be influenced by the test.
5. The aquifer is pumped at a constant discharge rate.
6. The well penetrates the entire saturated thickness of the aquifer.
7. The flow to the well is at steady state.

Unconfined Aquifers

The analysis of flow in unconfined aquifers is more complicated than that in confined aquifers. Thiem also derived an equation for steady radial flow in unconfined aquifers which is discussed in this section. Besides the basic assumptions and the assumptions of radial symmetry and steady-state condition mentioned above, the following additional assumptions are made in this case:

(1) The aquifer is unconfined and underlain by a horizontal confining layer.

(2) The well is pumped at a constant rate.

(3) The Dupuit-Forchheimer assumptions are valid.

Using the Darcy's law, the radial flow in the unconfined aquifer (Fig. 10.3) can be described as:

Q = KiA (**Darcy's law**)

Where, Q = Constant rate of pumping, r = radial distance from the circular section to the pumping well, h = saturated thickness of the unconfined aquifer, K = hydraulic conductivity of the unconfined aquifer, and dh/dr = hydraulic gradient.

$$Q = (2\pi r h) \times K \times \frac{dh}{dr}$$

$$h dh = \frac{Q}{2\pi K} \times \frac{dr}{r}$$

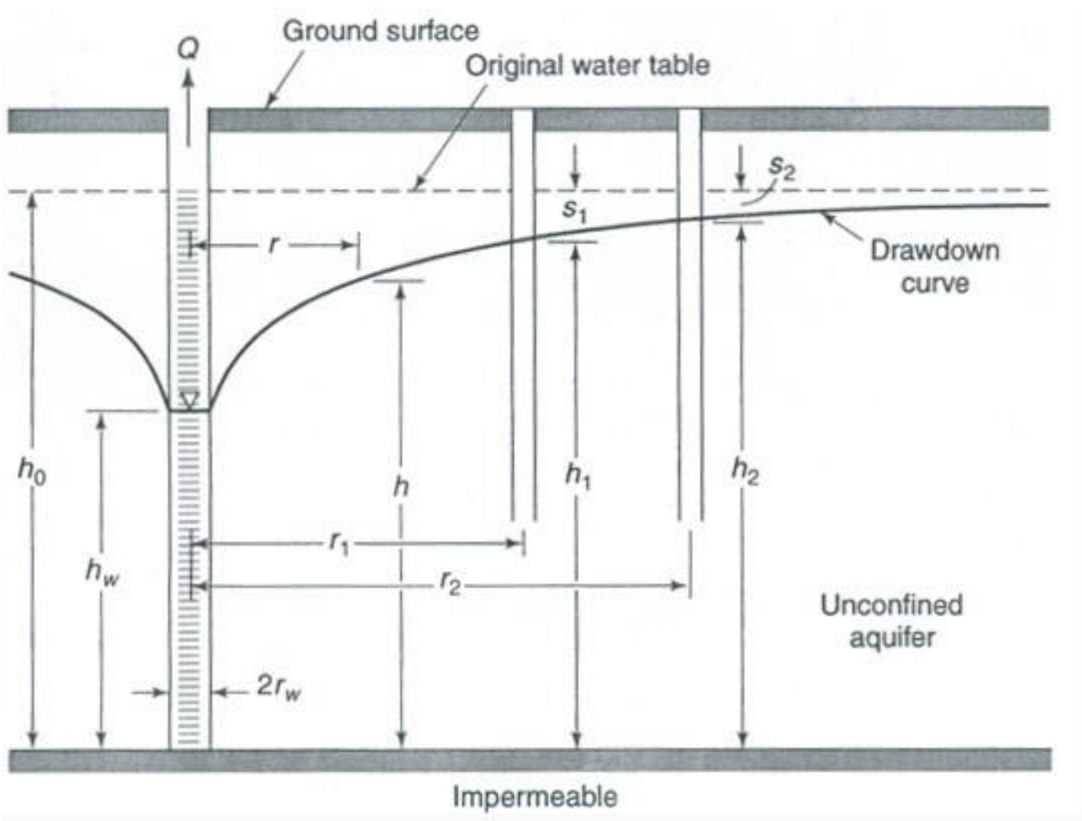


Fig 3.8 Unconfined Aquifer

Steady flow to a pumping well in an unconfined aquifer (Source: Todd, 1980)

Let's consider that two observation wells are located in the unconfined aquifer at distances r_1 and r_2, with hydraulic heads h_1 and h_2, respectively (Fig. 10.3). Now, Eqn. (10.10) can be integrated with these boundary conditions as:

$$Q = K.I.A.$$

$$Q = K \cdot \frac{dh}{dr} \cdot 2\pi r h$$

where K = Coefficient of permeability

$$\frac{dr}{r} = \frac{2\pi K}{Q} \cdot h \cdot dh.$$

Integrating between the limits r_w and R, we get

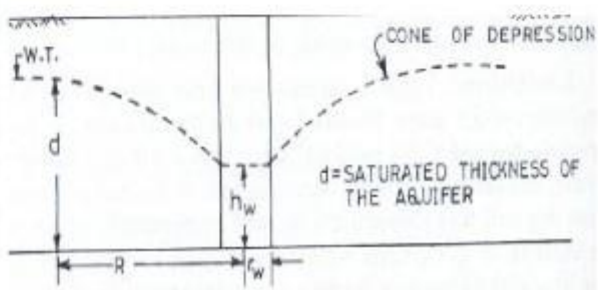
$$\int_{r_w}^{R} \frac{dr}{r} = \frac{2\pi K}{Q} \int_{h_w}^{d} h.dh$$

$$\left| \log_e r \right|_{r_w}^{R} = \frac{2\pi K}{Q} \left| \frac{h^2}{2} \right|_{h_w}^{d}$$

$$\log_e \frac{R}{r_w} = \frac{\pi K}{Q} \cdot [d^2 - h_w^2]$$

$$2.3 \log_{10} \frac{R}{r_w} = \frac{\pi K}{Q} [d^2 - h_w^2]$$

$$Q = \frac{\pi K (d^2 - h_w^2)}{2.3 \log_{10} \frac{R}{r_w}}$$



Where the drawdown is appreciable, the heads h1 and h2 can be replaced by (h0 - s1) and (h0-s2) respectively.h0 is the original water table. In unconfined aquifers, the Dupuit-Theim also assume that the slope of the phreatic surface is very small, therefore flow is considered to be purely horizontal and also uniformly distributed with depth.

Dupuit's equilibrium formula-Unconfined aquifer

Confined aquifer

$$Q = KIA$$

or $$Q = K \cdot \frac{dh}{dr} 2\pi \cdot rH$$

or $$\frac{dr}{r} = \frac{2\pi KH}{Q} \cdot dh$$

Integrating between r_w and R, we get

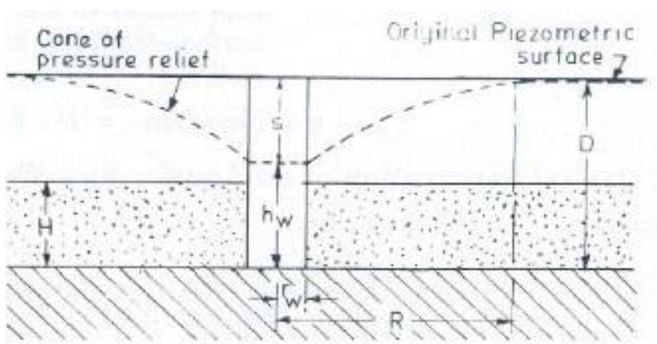
$$\int_{r_w}^{R} \frac{dr}{r} = \frac{2\pi K}{Q} \cdot H \int_{h_w}^{D} dh$$

or $$\left| \log_e r \right|_{r=r_w}^{r=R} = \frac{2\pi K}{Q} \cdot H \left| h \right|_{h=h_w}^{h=D}$$

or $$2.3 \log_{10} \frac{R}{r_w} = \frac{2\pi KH}{Q} [(D - h_w)]$$

$$K = \frac{2.3\, Q \log_{10} \frac{R}{r_w}}{2\pi . H. \, (D - h_w)}$$

$$\boxed{Q = \frac{2\pi KH\,(D - h_w)}{2.3 \log_{10} \frac{R}{r_w}}}$$



Numerical Problems

1. **A 30cm well fully penetrates a confined aquifer 30 m deep.After a long period of pumping at a rate of 1,200 lpm,the drawdowns in the wells at 20 and 45 m from the pumping well are found to be 2.2 and 1.8 m respectively. Determine the transmissibility of the aquifer.what is the drawdown in the pumped well?**

Solution

$$Q = 2\pi T \times \frac{(s_1 - s_2)}{\ln\left(\frac{r_2}{r_1}\right)}$$

Q= 1.2 m^3/min; s_1=2.2m; s_2= 1.8m; r_1= 20m; r_2=
45m 1.2= 2x3.14xTx(2.2-
1.8)/[2.303$\log_{10}$(45/20)]

$T = 559 m^{2/} day$

2. **A 30 cm well penetrates 50 m below the static water table. After a long period of pumping at a rate of 1800 lpm, the drawdown in the wells at 15**

   and 45 m from the pumped well were 1.7 and 0.8 m, respectively. Determine the transmissibility of the aquifer. what is the drawdown in the pumped well?

Solution

$$Q = \pi K \times \frac{h_2^2 - h_1^2}{\ln\left(\frac{r_2}{r_1}\right)}$$

S_1= 1.7m;H1=48.3m; s_2= 0.8m; h_2= 49.2m; r_1= 15m; r_2=45m;Q=1.8 m^3/min or Q=1.8x60x24 m^3/day; H=50m

By applying the above eqn **K= 10.07 m/day**; T= KxH T= 10.07x 50=**503m^2/day**

Drawdown in the pumped well

To find out the drawdown in the pumped well, the eqn can be rewritten as

Q= 3.14xKx $(h_2^2 - h_w^2)/\ln(r_2/r_w)$ (applying the eqn between well 2 and pumping well)

Find h_w

$h_w = 44.19$m

To find out drawdown in the pumped well
(s_w) $s_w = (h_2 – h_w) + s_2 =$ **5.81m**

5. WELL DESIGN

Wells may be dug, bored, driven, jetted or drilled. The drilled types are commonly referred to as boreholes. A well design involves selection of dimensions (depth/length, diameter) and type of the well (mode of construction), casing, screens (material) and of completion methods. The choice of water well and method of design depends upon topography, availability of space, hydrogeology, depth of groundwater table, rainfall, climate, quantity of water required and available funds.

Diameter

- ✓ significantly affects cost
- ✓ large enough to accommodate the proposed pump
- ✓ Well yield is not proportional to well diameter as can be seen from Theim's equation.

Depth

- o usually to the bottom of the aquifer
- o Because 'hard rock is intersected is not necessarily any reason to stop, as water fissures can be encountered after hard rock.
- o Poor quality aquifers encountered can be sealed to prevent contamination of good quality water.

- ✓ 70 – 80% of aquifer thickness is screened
- ✓ slot size is taken as 40 – 70% of the size of aquifer material 15
- ✓ material selected depends on quality of groundwater, strength requirement.

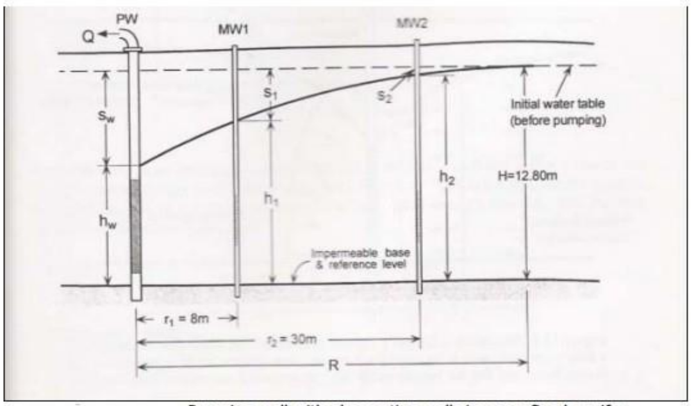
The screen material should be resistant to incrustation and corrosion and should have strength to withstand the column load and collapse pressure. Principal indicators of corrosive groundwater are low pH, presence of dissolved oxygen, $CO_2 > 50$ ppm, $Cl > 500$ ppm. Principal indicators of incrusting groundwater are total hardness > 330 ppm, iron content > 2 ppm, pH > 8. Mineral and slime deposits can be removed by chlorine and acid.

6. Measurement of yield Pumping test

Pumping Test is the examination of aquifer response, under controlled conditions, to the abstraction of water. Pumping test can be well test (determine well yield and well efficiency), aquifer test(determine aquifer parameters and examine water chemistry). Hydrogeologists try to determine the most reliable values for the hydraulic characteristics of the geological formations.

The objectives of the pumping test are:

1. Determine well yield,
2. Determine well efficiency,
3. Determine aquifer parameters
4. Examine water chemistry



Pumping well with observation wells in unconfined aquifer

Fig. 3.10

Fig. 3.11

Fig 3.12

Pumping test in the

3.13

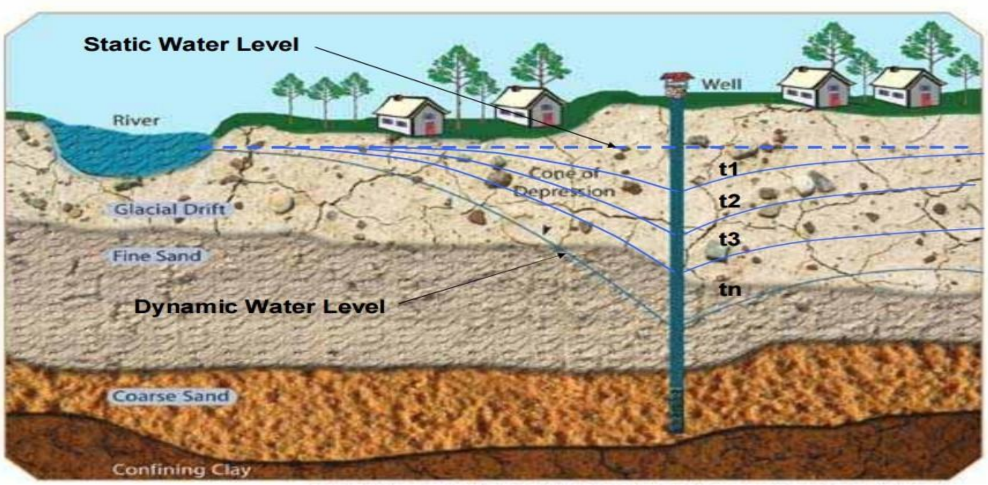


Fig 3.14

General notes about pumping test:

1. Pump testing is major investigative tool-but expensive.
2. Proper planning, observations, interpretation essential!
3. It is cheaper (much) if existing wells can be used.
4. Pump testing also carried out in newly constructed wells, as a well test.

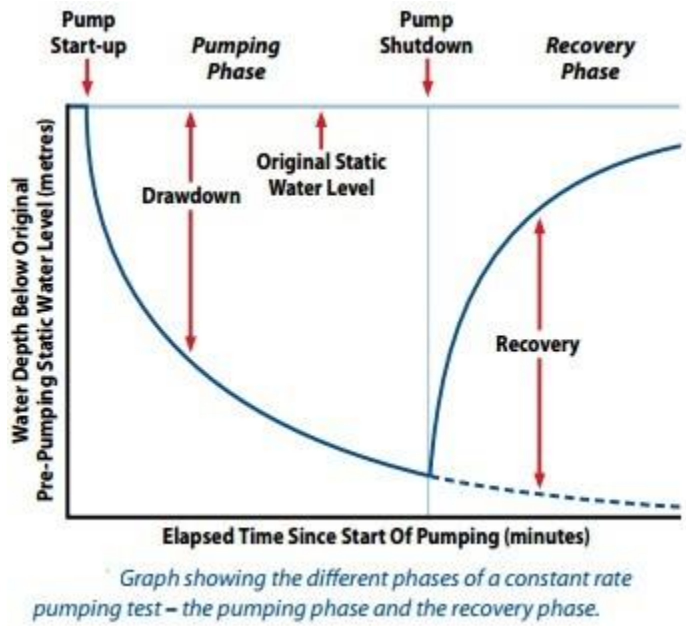


Fig. 3.15

The principle of a pumping test involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response to that stress by monitoring drawdown as a function of time.

V =

$(\pi D^2/4)$x d Rate of seepage in to the well = (Qt –

V)/t

V = Volume of water stored in the

well D= Diameter of the well

d= Depth of water

column Q= Pumping
rate

Pumping tests are carried out to determine:

1. How much groundwater can be extracted from a well based on long-term yield, and well efficiency?
2. The hydraulic properties of an aquifer or aquifers.
3. Spatial effects of pumping on the aquifer.
4. Determine the suitable depth of pump.
5. Information on water quality and its variability with time.

The methods of measurement are:

1 Water level

Dippers

Water Level Records Data Loggers

2. Discharge

Orifice

Plate

“V”

Notch

Weir

Flow

Meter

Tank

Orifice Bucket

Measuring pumping rate by flow meter

Fig 3.16

Measuring water level by M-scope

Fig 3.17

Recuperation test

Though constant level of pumping gives an accurate value of safe yield of an open well, it is sometimes very difficult to regulate the pump in such a way that constant level is maintained in the well. In such circumstance, a recuperation test can be performed to assess the aquifer parameters. In the recuperation test, water level is depressed to any level below the normal level h_1 and the pumping is stopped. The time taken (t) for the water to recuperate to the normal level h_2 is noted.

C= (2.303/t)log

$_{10}(h_1/h_2)$ Q= CAH

C = Specific yield of the well per unit cross sectional area per unit depression head

h_1 = water level after pumping stopped

h_2 = water level after time t

A= Cross sectional area of the

well H= Safe working

depression head Q= Pumping

rate

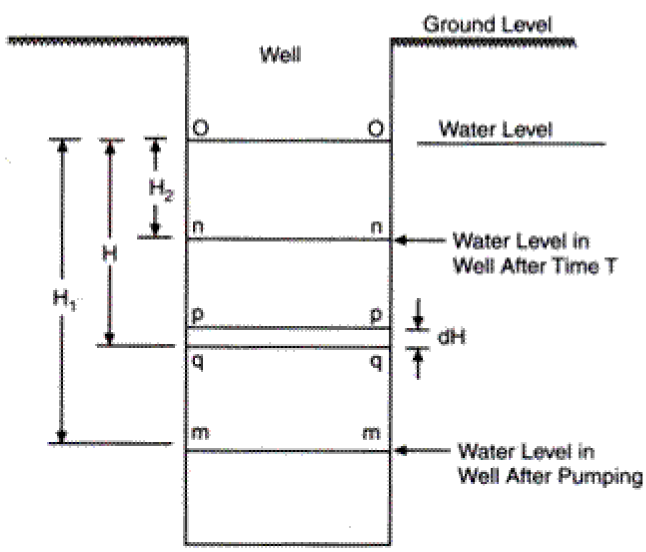


Fig. 3.18

O – O represents normal or original water level in the well.

m — m represents the water level in the well after pumping.

n – n represents the water level in the well at time T after stoppage of pumping.

q – q represents the water level in the well at any time t after stoppage of pumping.

p – p represents the water level in well at time t + dt after stoppage of pumping.

7. Tube wells and open wells

Borewells and Tubewells are very very similar.

There are three basic difference between borewell and tube well :

- ✓ Casing: In case of bore well the casing is of PVC; in case of tube well casing is of Galvanized Iron.
- ✓ Bore well is usually used where there is a non collapsiblehardrock; tubewell is used where there is a collapsible soft rock or alluvial soil.
- ✓ Though tubewells and borewells both go deep; usually the tubewell casing goes far deeper; whereas borewell casing does not go completely into the bore hole and goes only until hardrock.

A bore well is drilled with casing pipe put only up to the soil-rock boundary and this is done normally for shallow depths in hard rock or in crystalline rock. But in a tube well, the casing pipes are put up to the bottom of the bore wells, with perforation in the pipes in some level. Normally the Tube wells are drilled in sand and gravel where the availability of water is much below the ground level.

8. Groundwater Pollution

GROUNDWATER POLLUTION May be defined as the artificially induced degradation of natural groundwater quality. Most pollution stems from disposal of wastes on or into the ground and the pollutants may be of organic (e.g. chlorinated phenoxy acid herbicides), inorganic (e.g. nitrate), biological (e.g. coliform bacteria), physical (colour) and radiological (e.g. barium) types.]

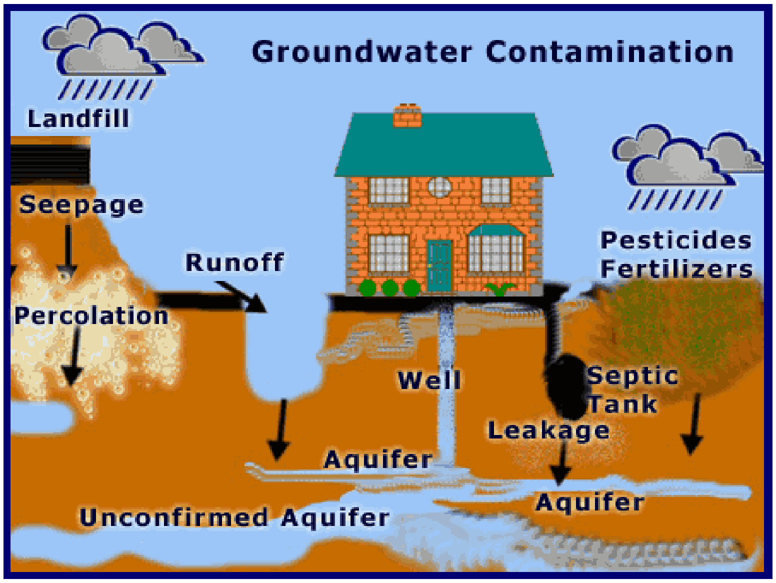


Fig 3.19

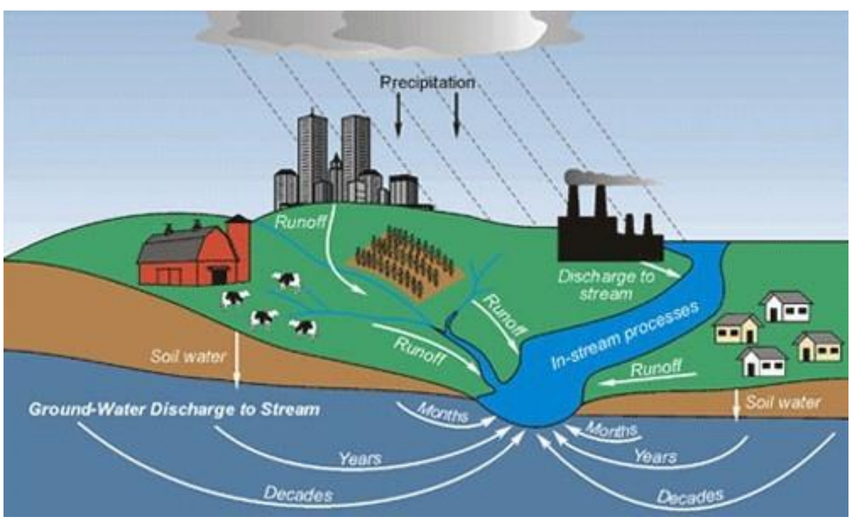


Fig 3.20

Groundwater- Pollution from farms, cities and suburbs can seep into underground aquifers, contaminating groundwater

Fig 3.21

Methods of disposal of wastes include discharge in to the sea and streams, placement in percolation ponds, on the ground surface, (spreading or irrigation), in landfills, into disposal wells and into injection wells. Waste can be defined to be all undesirable or superfluous by-products, emissions, residues or remainders of any process or activity, whether gaseous, liquid or solid, or a combination of these. For practical reasons, material is taken to become waste when it is committed to storage (to last three months or longer) or leaves the site or enters the environment.

The principal sources of pollution include Municipal – sewer leakages, liquid and solid wastes Industrial – Mining activities, tank and pipeline leakage, oil field brines, liquid wastes Agriculture – Irrigation return flows, fertilizers, pesticides, animal wastes Miscellaneous – saline water intrusion, septic tank and cesspools, roadway deicing, interchange through wells. The sources can be point (singular location), line (with a liner alignment) or diffuse (occupying extensive areas) sources.

The aims of groundwater pollution investigation are varied, but may include

- Determination of the extent of pollution by quantifying the amount of pollutants
- Determination of the sources of possible pollutants to the groundwater regime
- Quantification of the contribution from different sources
- The study of the migration rate of the pollutants through the aquifers
- Model the local and regional movement of pollutants through the aquifer and predict future water qualities

- Suggestion of management strategies whereby the influence of disposal can be minimized. Remedial measures which can be used to prevent or reduce aquifer contamination include

- Surface water control o increases runoff, reduces infiltration
- Groundwater control o seals off lateral flow in shallow aquifers
- Plume management o lower water table below contaminant o scavenger wells to extract leachate o injection to create hydraulic barrier
- Excavation o physical removal of contaminant to safe site. The choice of which remedial measure is most appropriate or cost effective depends on : extent of contamination
- Type of contaminant – is the contaminant "toxic or hazardous" material or a convectional pollutant.
- Whether the material is organic or inorganic
- How tightly bound the contaminant is to the soil.
- Hydrological setting The generator of hazardous waste should be liable for damage

resulting from the disposal of hazardous waste.

9. Rainwater Harvesting

Water has been harvested in India since antiquity, with our ancestors perfecting the art of water management. To address the challenges of water security in the new millenium, a mixture of traditional wisdom and new techniques must be employed. Various methods of rainwater harvesting are described in this section.

1. Surface runoff harvesting

In urban area rainwater flows away as surface runoff. This runoff could be caught and used for recharging aquifers by adopting appropriate methods.

2. Roof Top rainwater harvesting

It is a system of catching rainwater where it falls. In rooftop harvesting, the roof becomes the catchments, and the rainwater is collected from the roof of the house/building. It can either be stored in a tank or diverted to artificial recharge system. This method is less expensive and very effective and if implemented properly helps in augmenting the ground water level of the area.

2.1 Components of the roof top rainwater harvesting

The illustrative design of the basic components of roof top rainwater harvesting system is given in the typical schematic diagram shown in Fig.

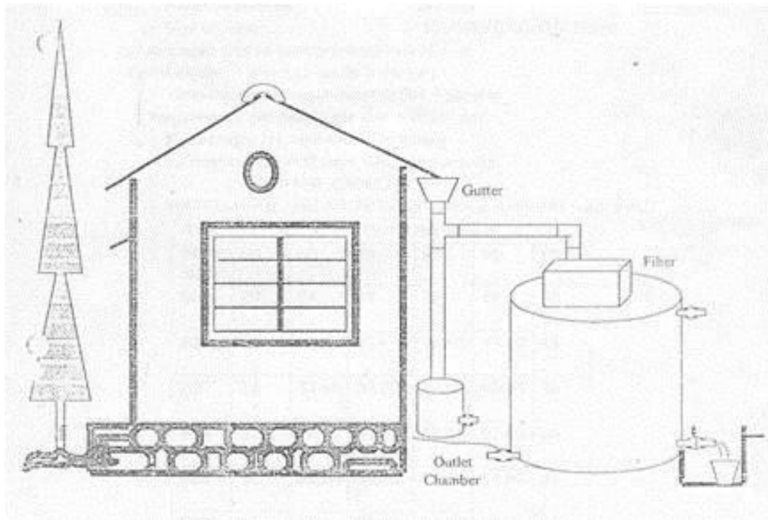


Fig 3.22

Components of Rainwater harvesting

The system mainly constitutes of following sub components:

i)Catchments ii) Transportation iii) First flush iv) Filter

Catchments

The surface that receives rainfall directly is the catchment of rainwater harvesting system. It may be terrace, courtyard, or paved or unpaved open ground. The terrace may be flat RCC/stone roof or sloping roof. Therefore the catchment is the area, which actually contributes rainwater to the harvesting system.

Transportation

Rainwater from rooftop should be carried through down take water pipes or drains to storage/harvesting system. Water pipes should be UV resistant (ISI HDPE/PVC pipes) of required capacity. Water from sloping roofs could be caught through gutters and down take pipe. At terraces, mouth of the each drain should have wire mesh to restrict floating material.

First Flush

First flush is a device used to flush off the water received in first shower. The first shower of rains needs to be flushed-off to avoid contaminating storable/rechargeable water by the probable contaminants of the atmosphere and the catchment roof. It will also help in cleaning of silt and other material deposited on roof during dry seasons Provisions of first rain separator should be made at outlet of each drainpipe.

Filter

There is always some skepticism regarding Roof Top Rainwater Harvesting since doubts are raised that rainwater may contaminate groundwater. There is remote possibility of this fear coming true if proper filter mechanism is not adopted. Secondly all care must be taken to see that underground sewer drains are not punctured and no leakage is taking place in close vicinity. Filters are used fro treatment of water to effectively remove turbidity, colour and microorganisms. After first flushing of rainfall, water should pass through filters. A gravel, sand and 'netlon' mesh filter is designed and placed on top of the storage tank. This filter is very important in keeping the rainwater in the storage tank clean. It removes silt, dust, leaves and other organic matter from entering the storage tank. The filter media should be cleaned daily after every rainfall event. Clogged filters prevent rainwater from easily entering the storage tank and the filter may overflow. The sand or gravel media should be taken out and washed before it is replaced in the filter.

A typical photograph of filter is shown in the following Fig.

Fig 3.23

Photograph of typical filter

There are different types of filters in practice, but basic function is to purify water. Different types of filters are described in this section.

a) Sand Gravel Filter

These are commonly used filters, constructed by brick masonry and filleted by pebbles, gravel, and sand as shown in the figure. Each layer should be separated by wire mesh. A typical figure of Sand Gravel Filter is shown in Fig.

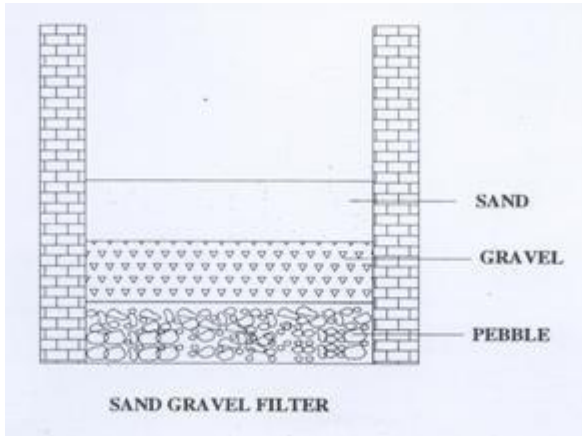


Fig. 3.24 Sand Gravel Filter

Charcoal Filter

Charcoal filter can be made in-situ or in a drum. Pebbles, gravel, sand and charcoal as shown in the figure should fill the drum or chamber. Each layer should be separated by wire mesh. Thin layer of charcoal is used to absorb odor if any. A schematic diagram of Charcoal filter is indicated in Fig .

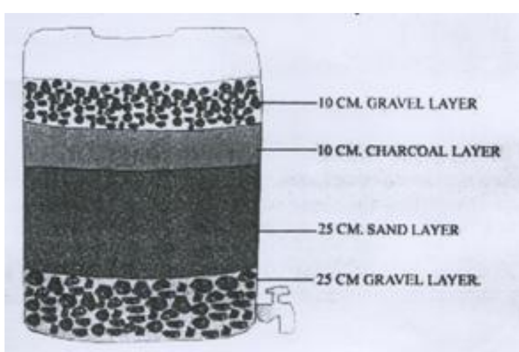


Fig 3.25 Charcoal Filter

PVC –Pipe filter

This filter can be made by PVC pipe of 1 to 1.20 m length; Diameter of pipe depends on the area of roof. Six inches dia. pipe is enough for a 1500 Sq. Ft. roof and 8 inches dia. pipe should be used for roofs more then 1500 Sq. Ft. Pipe is divided into three compartments by wire mesh. Each component should be filled with gravel and sand alternatively as shown in the figure. A layer of charcoal could also be inserted between two layers. Both ends of filter should have reduce of required size to connect inlet and outlet. This filter could be placed horizontally or vertically in the system. A schematic pipe filter is shown in Fig .

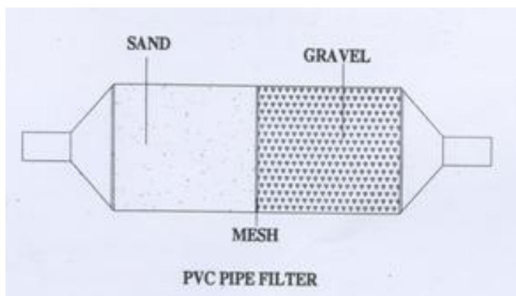


Fig 3.26 PVC-Pipe filter

Sponge Filter

It is a simple filter made from PVC drum having a layer of sponge in the middle of drum. It is the easiest and cheapest form filter, suitable for residential units. A typical figure of sponge filter is shown in Fig .

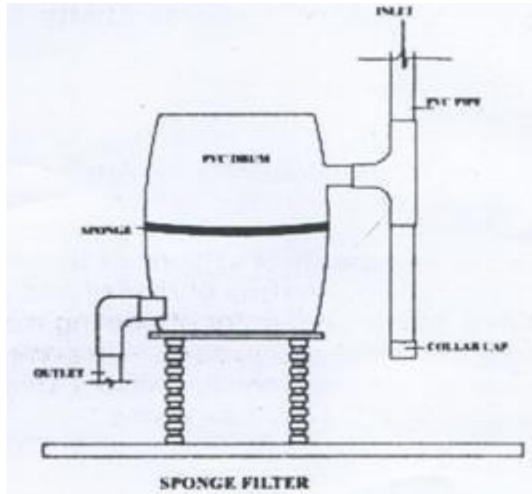


Fig 3.27 Sponge Filter

2.2 ***Methods of roof top rainwater harvesting***

Various methods of using roof top rainwater harvesting are illustrated in this section.

a) Storage of Direct Use

In this method rain water collected from the roof of the building is diverted to a storage tank. The storage tank has to be designed according to the water requirements, rainfall and catchment availability. Each drainpipe should have mesh filter at mouth and first flush device followed by filtration system before connecting to the storage tank. It is advisable that each tank should have excess water over flow system.

Excess water could be diverted to recharge system. Water from storage tank can be used for secondary purposes such as washing and gardening etc. This is the most cost effective way of rainwater harvesting. The main advantage of collecting and using the rainwater during rainy season is not only to save water from conventional sources, but also to save energy incurred on transportation and distribution of water at the doorstep. This also conserves groundwater, if it is being extracted to meet the demand when rains are on.

b) Recharging ground water aquifers

Ground water aquifers can be recharged by various kinds of structures to ensure percolation of rainwater in the ground instead of draining away from the surface. Commonly used recharging methods are:-

a) Recharging of bore wells

b) Recharging of dug wells.

c) Recharge pits

d) Recharge Trenches

e) Soak ways or Recharge Shafts

f) Percolation Tanks

c) Recharging of bore wells

Rainwater collected from rooftop of the building is diverted through drainpipes to settlement or filtration tank. After settlement filtered water is diverted to bore wells to recharge deep aquifers. Abandoned bore wells can also be used for recharge.

Optimum capacity of settlement tank/filtration tank can be designed on the basis of area of catchement, intensity of rainfall and recharge rate. While recharging, entry of floating matter and silt should be restricted because it may clog the recharge structure. First one or two shower should be flushed out through rain separator to avoid contamination. A schematic diagram of filtration tank recharging to bore well is indicated in Fig .

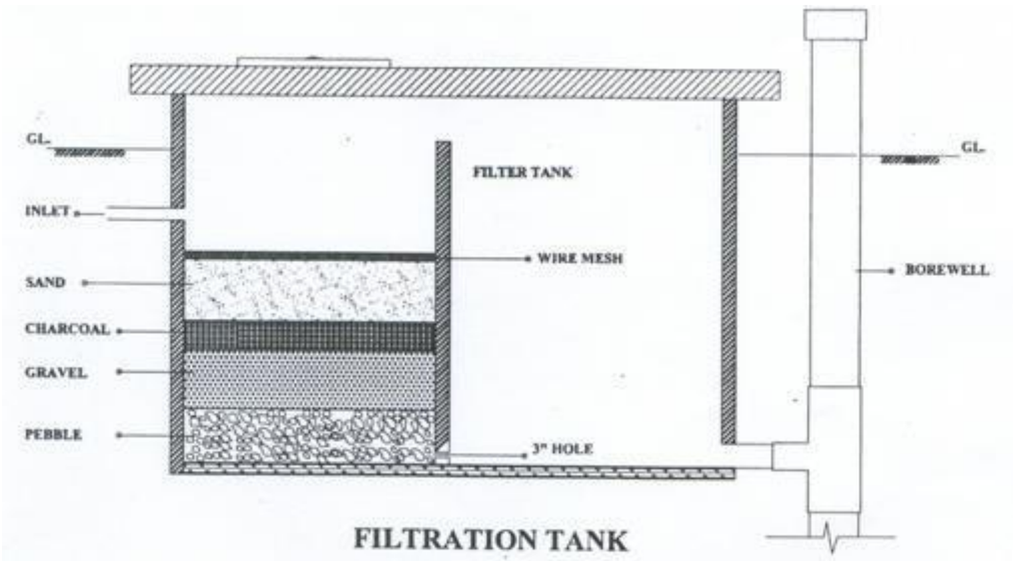


Fig :3.28 Filtration tank recharging to bore well

d)Recharge pits

Recharge pits are small pits of any shape rectangular, square or circular, contracted with brick or stone masonry wall with weep hole at regular intervals. Top of pit can be covered with perforated covers. Bottom of pit should be filled with filter media.

The capacity of the pit can be designed on the basis of catchment area, rainfall intensity and recharge rate of soil. Usually the dimensions of the pit may be of 1 to 2 m width and 2 to 3 m deep depending on the depth of pervious strata. These pits are suitable for recharging of shallow aquifers, and small houses. A schematic diagram of recharge pit is shown in Fig .

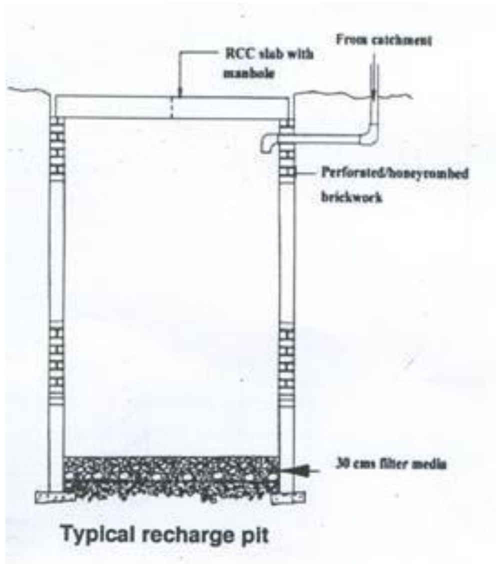


Fig 3.29 Recharge pit

e) Soak way or Recharge shafts

Soak away or recharge shafts are provided where upper layer of soil is alluvial or less pervious. These are bored hole of 30 cm dia. up to 10 to 15 m deep, depending on depth of pervious layer. Bore should be lined with slotted/perforated PVC/MS pipe to prevent collapse of the vertical sides. At the top of soak away required size sump is constructed to retain runoff before the filters through soak away. Sump should be filled with filter media. A schematic diagram of recharge shaft is shown in Fig .

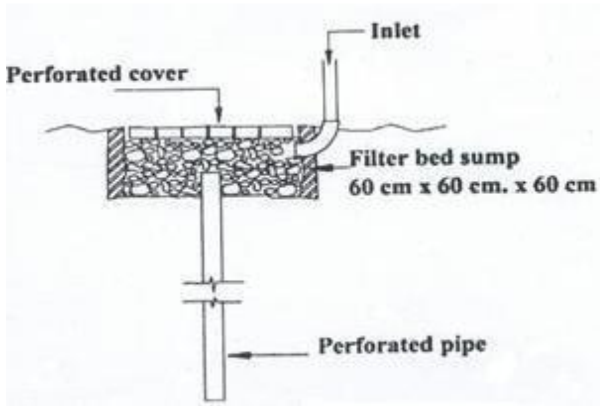


Fig 3.30: Schematic Diagram of Recharge shaft

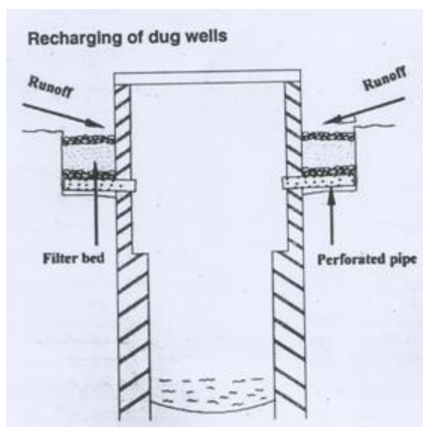


Fig 3.31 Schematic diagram of recharging to dug well

Recharging of dug wells

Dug well can be used as recharge structure. Rainwater from the rooftop is diverted to dug wells after passing it through filtration bed. Cleaning and desalting of dug well should be done regularly to enhance the recharge rate. The filtration method suggested for bore well recharging could be used. A schematic diagram of recharging into dug well is indicated in Fig 11shown below.

f) Recharge trenches

Recharge trench in provided where upper impervious layer of soil is shallow. It is a trench excavated on the ground and refilled with porous media like pebbles, boulder or brickbats. it is usually made for harvesting the surface runoff. Bore wells can also be provided inside the trench as recharge shafts to enhance percolation. The length of the trench is decided as per the amount of runoff expected. This method is suitable for small houses, playgrounds, parks and roadside drains. The recharge trench can be of size 0.50 to 1.0 m wide and 1.0 to 1.5 m deep. A schematic diagram of recharging to trenches is shown in Fig below .

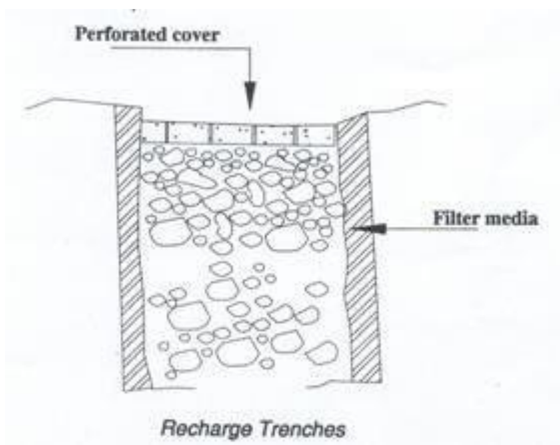


Fig 3.32 Recharging to trenches

g) Percolation tank

Percolation tanks are artificially created surface water bodies, submerging a land area with adequate permeability to facilitate sufficient percolation to recharge the ground water. These can be built in big campuses where land is available and topography is suitable. Surface run-off and roof top water can be diverted to this tank. Water accumulating in the tank percolates in the solid to augment the ground water. The stored water can be used directly for gardening and raw use. Percolation tanks should be built in gardens, open spaces and roadside green belts of urban area.

EVALUATIONOFAQUIFER PROPERTIES

Darcy’s Experiment

In the year 1856, Henry Darcy, a French hydraulic engineer investigated the flow of water through a vertical homogeneous sand filter. Based on his experiments, he concluded that the rate flow through the porous media is proportional to the head loss and is inversely proportional to the length of the flow path. Figure 3.1 shows the setup of Darcy's experiment. As shown in the figure, the length of the vertical sand filter is L, the cross sectional area of the filter is A, the piezometric heads at top and bottom of the filter are h_1 and h_2. Thus the head loss is (h_1 - h_2). The piezometric heads are measured with respect to an arbitrary datum. As per the conclusions made by Darcy, the flow rate Q is

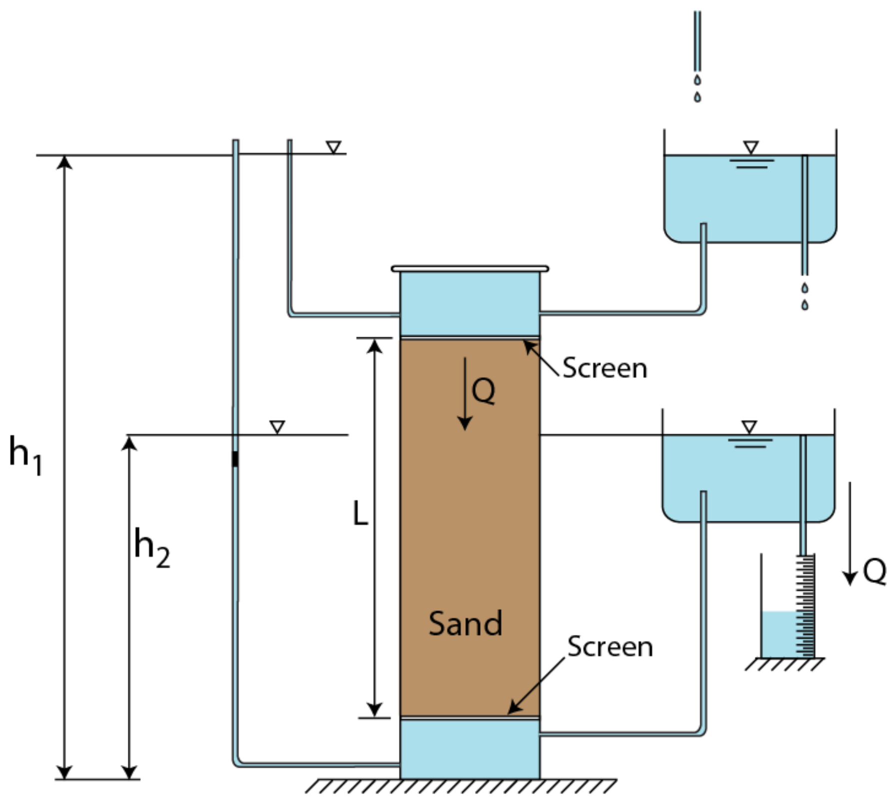


Fig. 3.33 Darcy’s Experiment in vertical sand filter

- proportional to the cross sectional area *(A)* of the filter
- proportional to the difference in piezometric heads

- inversely proportional to the length *(L)* of the filter

After combining these conclusions, we have

$$Q = KA\left(\frac{h_1 - h_2}{L}\right) \qquad (3.1)$$

Where,
Q is the flow rate, *i.e.* the volume of water flows through the sand filter per unit time.
K is the coefficient of proportionality and is termed as hydraulic conductivity of the medium. It is a measure of the permeability of the porous medium. It is also known as coefficient of permeability.
h_1 and h_2 are the piezometric heads.
Now, defining $J = \frac{h_1 - h_2}{L}$ and $q = \frac{Q}{A}$
Where J is the hydraulic gradient and q is the specific discharge, *i.e.* the discharge per unit area.

The equation 3.1 can also be written as,

$$q = KJ \qquad (3.2)$$

Now consider an inclined homogeneous sand filter as shown in Fig. 3.2 In this case, the Darcy's formula can be written as,

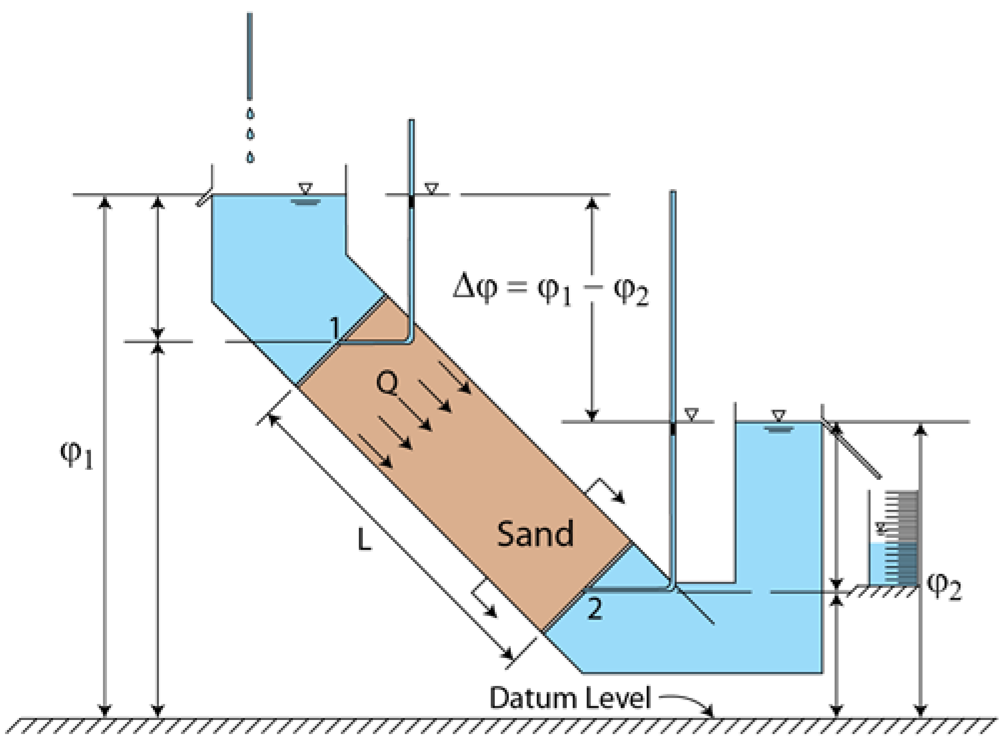


Fig. 3.34 Darcy's Experiments in inclined sand filter

$$Q = KA(\frac{\varphi_1 - \varphi_2}{L}) \quad (3.3)$$

or,

$$q = K(\frac{\varphi_1 - \varphi_2}{L}) \quad (3.4)$$

or,

$$q = KJ \quad (3.5)$$

Where, $J = \frac{\varphi_1 - \varphi_2}{L}$ and $\varphi_1 = z_1 + \frac{p_1}{\gamma}$ and $\varphi_2 = z_2 + \frac{p_2}{\gamma}$

z_1 and z_2 are the datum head or elevation head

p_1/γ and p_2/γ are the pressure head

It should be noted here that q and K have the same dimension with the velocity. The value of q will be equal to K for unit hydraulic gradient. As such for the case of isotropic medium, the hydraulic conductivity (*K*) may be defined as the specific discharge (*q*) occurs under unit hydraulic gradient (*J*= 1).The hydraulic conductivity is dependent on both porous matrix properties and fluid properties and can be expressed as

$$K = \frac{k\rho g}{\mu} = \frac{kg}{\upsilon} \quad (3.6)$$

Where, ρ is the density of the fluid, μ is the viscosity of the fluid, v is the kinematic viscosity, k is the intrinsic permeability of the soil which depends on the properties of the porous matrix.

Considering (3.6), the Darcy's Law can be written as

$$q = \left(\frac{k\rho g}{\mu}\right).J \quad (3.7)$$

It may be noted that in Darcy's law, we have neglected the kinetic energy of water. The velocity of water in case of porous medium is very low and along the flow path, the change in piezometric head is much smaller than the change in kinetic energy. Hence, kinetic energy can be neglected.

Further, it may be noted that the flow takes place from higher piezometric head to lower piezometric head and not from higher pressure to lower pressure. Only in case of horizontal flow ($z_1 = z_2$), the flow takes place from higher pressure to lower pressure. Thus incase of horizontal flow, the Darcy's formula can be written as,

$$q = K\left(\frac{P_1 - P_2}{\gamma L}\right) \qquad (3.8)$$

Moreover, In case of flow through porous medium, the flow takes place only through the pores of the medium. Therefore, the cross sectional area through which the flow actually takes place is ηA. Where η is the porosity of the porous medium. As such, the average velocity of the flow can be expressed as

$$V = \frac{Q}{\eta A} = \frac{q}{\eta} = \frac{KJ}{\eta}$$

Cone of Depression

- Before pumping, the water level in the well stands up to the same elevation as the water table or piezometric surface depending on the type of aquifer.
- When pumping starts, the water is removed from the aquifer surrounding the well, and in and around; the well the water table or piezometric surface is lowered and assumes the shape of an inverted cone which is known as cone of depression.
- The area of the base of this cone is known as the area of influence, because it is this area which gets affected by the pumping of the well.
- The boundary of the area of influence is known as the circle of influence. The radius of the circle of influence is known as the radius of influence.

- Further at any point the difference in elevation of the water table or piezometric surface before and after pumping is known as drawdown.
- The maximum drawdown occurs at the well and it decreases with increase in the distance from the well. The variation in drawdown with distance from the well is shown by a drawdown curve.
- The analysis of radial flow of ground water towards a well was first proposed by Dupuit (1863) and later modified by
- **The Dupuit-Theim theory is based on the following assumptions:**
- (i) The aquifer is homogeneous, isotropic, of uniform thickness and of infinite areal extent.
- (ii) The well penetrates and receives water from the entire thickness of the aquifer.
- (iii)The pumping has been continued for a sufficiently long time at a uniform rate so that an equilibrium stage or a steady flow condition has been reached.
- The coefficient of transmissibility is constant at all places and at all times.
- (v) The flow lines are radial and the flow of groundwater is horizontal.
- (vi) Flow is laminar and Darcy's law is applicable. However, the hydraulic gradient may be represented by tan 0 instead of sin 0 where 0 is the angle between the hydraulic grade line and the horizontal.
- (vi) The well is infinitely small with negligible storage and all the pumped water comes from the aquifer.
- On the basis of these assumptions the radial flow equations which relate the well discharge to drawdown for steady flow condition have been derived for wells completely penetrating a confined aquifer and an unconfined aquifer as indicated below.

Steady State Flow to Wells in Confined Aquifer (i.e., Artesian Wells or Pressure Wells):

- Figure shows a well of radius r fully penetrating a confined aquifer. Let b be the thickness of the aquifer measured between the top and bottom impervious strata, and H be the height of the initial piezometric surface measured above the impermeable strata at the bottom.

- When the well is pumped at a constant rate Q for a long time so that the water level in the well has been stabilized then the drawdown curve as shown in Fig. is developed. At this stage let h be the depth of water in the well measured above the impermeable strata at the bottom. Further let R be the radius of influence.

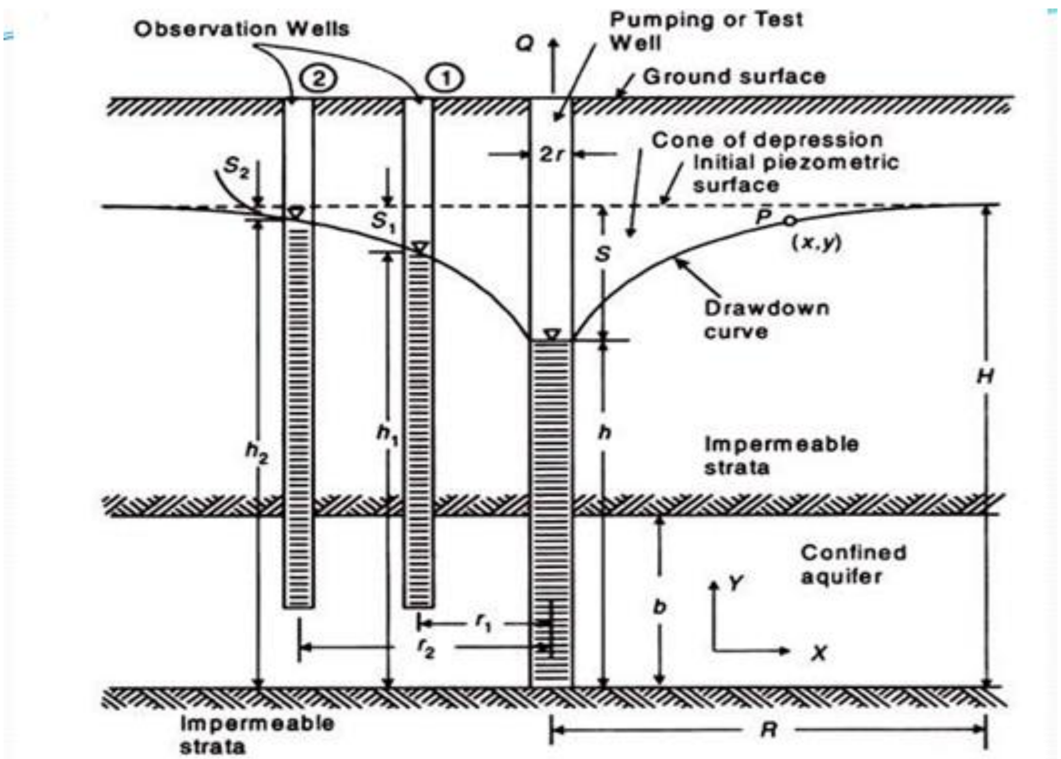


Fig 3.35 Well penetrating confined aquifer

- Let (x, y) be the coordinates of any point P on the drawdown curve with respect to origin O at the centre of the well at its bottom, if a vertical cylindrical surface passing through point P and surrounding the well located at its centre is considered then the area of the portion of the cylindrical surface which is lying within the aquifer is equal to ($2\pi xb$).

- Further if (dy/dx) is the hydraulic gradient at P, then from Darcy's law the rate of flow of water through this portion of the cylindrical surface is equal to [k(dy/dx)2πxb] which by continuity is also equal to the well discharge

$$Q = k\frac{dy}{dx}(2\pi xb)$$

or

$$Q\frac{dx}{x} = 2\pi kb\,dy \quad \text{...(i)}$$

Integrating both sides of Eq. (i) between the limits, at $x = r, y = h$ at the well and at $x = R, y = H$ at the extremity of the area of influence, we get

$$Q\int_r^R \frac{dx}{x} = 2\pi kb \int_h^H dy$$

or

$$Q = \frac{2\pi kb(H-h)}{\log_e(R/r)} \quad \text{...(4.11)}$$

or

$$Q = \frac{2\pi kb(H-h)}{2.303\log_{10}(R/r)} \quad \text{...(4.11 a)}$$

or

$$Q = \frac{2.73kb(H-h)}{\log_{10}(R/r)} \quad \text{...(4.11 b)}$$

Equation 4.11 is known as equilibrium equation or Thiem equation.

If s is the drawdown at the well then since $s = (H - h)$, Eq. 4.11 may be expressed as

$$Q = \frac{2\pi kbs}{\log_e(R/r)} \quad \text{...(4.12)}$$

or

$$Q = \frac{2.73kbs}{\log_{10}(R/r)} \quad \text{...(4.12 a)}$$

Further for a confined aquifer since the coefficient of transmissibility T = kb, Eqs. 4.11 and 4.12 become-

$$Q = \frac{2\pi T(H-h)}{\log_e(R/r)} \quad ...(4.13)$$

$$Q = \frac{2.73T(H-h)}{\log_{10}(R/r)} \quad ...(4.13\text{ a})$$

$$Q = \frac{2\pi Ts}{\log_e(R/r)} \quad ...(4.14)$$

or

$$Q = \frac{2.73Ts}{\log_{10}(R/r)} \quad ...(4.14\text{ a})$$

Again as indicated below the use of R can be avoided if the observation wells are available.

- As shown in Figure let there be two observation wells at radial distances r_1 and r_2 and the depth of water in them be h_1 and h_2 respectively.
- Integrating Eq. (i) between the limits, at $x = r_1$, $y = h_1$ at the observation well No. 1 and at $x = r_2$, $y = h_2$ at the observation well No. 2, the following equation may be obtained which does not involve R.

$$Q = \frac{2\pi kb(h_2 - h_1)}{\log_e(r_2/r_1)} \quad ...(4.15)$$

or

$$Q = \frac{2.73kb(h_2 - h_1)}{\log_{10}(r_2/r_1)} \quad ...(4.15\text{ a})$$

Further if s_1, and s_2 are the respective drawdowns at the two observation wells, then

$$h_2 = H - s_2$$

and

$$h_1 = H - s_1$$

Introducing these expressions in Eq. 4.15, we get

$$Q = \frac{2\pi kb(s_1 - s_2)}{\log_e(r_2/r_1)} \quad ...(4.16)$$

or

$$Q = \frac{2.73kb(s_1 - s_2)}{\log_{10}(r_2/r_1)} \quad ...(4.16\text{ a})$$

Further since $T = kb$ Eq. 4.16 may be expressed as

$$Q = \frac{2\pi T(s_1 - s_2)}{\log_e(r_2/r_1)} \quad ...(4.17)$$

or

$$Q = \frac{2.73T(s_1 - s_2)}{\log_{10}(r_2/r_1)} \quad ...(4.17\text{ a})$$

Steady State Flow to Wells in Unconfined Aquifer (i.e., Gravity Wells or Water Table Wells):

- Figure 4.29 shows a well of radius r completely penetrating an unconfined aquifer. Let H be the thickness of the aquifer measured from the impermeable strata to the initial level of the water table.

- When the well is pumped at a constant rate Q for a long time so that the water level in the well has been stabilised, i.e., an equilibrium stage or a steady flow condition has been reached, then the drawdown curve as shown in Fig. 4.29 is developed. At this stage let h be the depth of water in the well measured above the impermeable strata. Further let R be the radius of influence (or the radius of inappreciable or zero drawdown) measured from the centre of the well to a point where the drawdown is inappreciable.

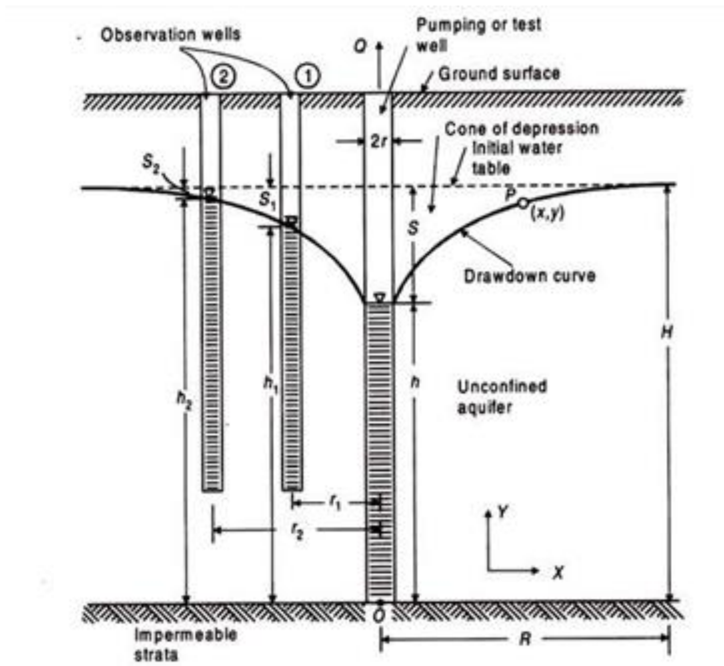


Fig 3.36 Well penetrating an unconfined aquifer

- Considering the origin at a point O at the centre of the well at its bottom, let the coordinates of any point P on the drawdown curve be (x, y).
- If a vertical cylindrical surface passing through point P and surrounding the well located at its center is considered then the area of the portion of cylindrical surface which is lying within the aquifer below point P is equal to ($2\pi xy$). Further if (dy/dx) is the hydraulic

gradient at P then from Darcy's law the rate of flow of water (or discharge) through the cylindrical surface is equal to $\left[k\left(\frac{dy}{dx}\right)2\pi xy\right]$. By continuity this rate of flow of water is equal to the well discharge, and hence

$$Q = k\frac{dy}{dx}(2\pi xy)$$

or

$$Q\frac{dx}{x} = 2\pi ky\,dy \quad \text{...(ii)}$$

Integrating both sides of Eq. (ii) between the limits, at $x = r$, $y = h$ at the well and at $x = R$, $y = H$ at the extremity of the area of influence, we get

$$Q\int_r^R \frac{dx}{x} = 2\pi k \int_h^H y\,dy$$

or

$$Q = \frac{\pi k\left(H^2 - h^2\right)}{\log_e (R/r)} \quad \text{...(4.18)}$$

or

$$Q = \frac{\pi k\left(H^2 - h^2\right)}{2.303 \log_{10} (R/r)} \quad \text{...(4.18 a)}$$

or

$$Q = \frac{1.36k\left(H^2 - h^2\right)}{\log_{10} (R/r)} \quad \text{...(4.18 b)}$$

Equation 4.18 may also be expressed in a different form as indicated below.

If s is the drawdown measured at the well then

$$s = H - h$$

$$H = s + h$$

and

$$H + h = s + 2h$$

$$\therefore \quad H^2 - h^2 = (H - h)(H + h) = s(s + 2h)$$

Introducing this expression in Eq. 4.18, we get

$$Q = \frac{\pi k s(s + 2h)}{\log_e (R/r)} \quad ...(4.19)$$

or

$$Q = \frac{1.36 k s(s + 2h)}{\log_{10} (R/r)} \quad ...(4.19\text{ a})$$

If the drawdown s is small then $(H + h) \approx 2H$ and hence

$$H^2 - h^2 = (H + h)(H - h) = 2H(H - h) = 2Hs$$

Thus from Eq. 4.18, we get

$$Q = \frac{2\pi k H s}{\log_e (R/r)} \quad ...(4.20)$$

or

$$Q = \frac{2.73 k H s}{\log_{10} (R/r)} \quad ...(4.20\text{ a})$$

Since for an unconfined aquifer the coefficient of transmissibility $T = kH$, Eq. 4.20 becomes

$$Q = \frac{2\pi T s}{\log_e (R/r)} \quad ...(4.21)$$

or

$$Q = \frac{2.73\, T s}{\log_{10} (R/r)} \quad ...(4.21\text{ a})$$

Equation 4.21 is similar to the one derived for a confined aquifer.

These equations can however be used only if the radius of influence R is known. In practice, the selection of the radius of influence R is approximate and arbitrary, but the variation in Q is small for a wide range of R. The values of R in general fall in the range of 150 to 300 metres.

As shown in Fig. 4.29 let there be two observation wells at radial distances r_1 and r_2 and the depths of water in them be h_1 and h_2 respectively. Integrating both sides of Eq. (ii) between the limits at $x = r_1$ $y = h_1$ at the observation well No. 1 and at $x = r_2$, $y = h_2$ at the observation well No. 2, the following equation may be obtained which does not involve R.

$$Q = \frac{\pi k\left(h_2^2 - h_1^2\right)}{\log_e\left(r_2/r_1\right)} \quad \text{...(4.23)}$$

or

$$Q = \frac{1.36k\left(h_2^2 - h_1^2\right)}{\log_{10}\left(r_2/r_1\right)} \quad \text{...(4.23 a)}$$

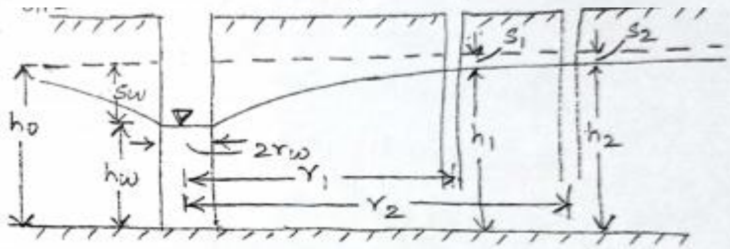
② A 30cm well penetrates 50m below the static water table. After a long period of pumping at a rate of 1800 lpm, the drawdowns in the wells at 15 and 45m from the pumped well are 1.7m and 0.8m, respectively. Determine the transmissibility of the aquifer. What is the drawdown in the pumped well.

$h_0 = 50m$, $r_w = 0.15m$

$Q = 1.8\ m^3/min.$

$r_1 = 15m$, $r_2 = 45m$

$s_1 = 1.7m$, $s_2 = 0.8m$



$\therefore h_1 = 48.3m$, $h_2 = 49.2m.$

$$Q = \frac{\pi k (h_2^2 - h_1^2)}{2.303 \log_{10}(r_2/r_1)} \Rightarrow 1.8 = \frac{\pi \times k \times (49.2^2 - 48.3^2)}{2.303 \log_{10}\left(\frac{45}{15}\right)}$$

$$k = 7.195 \times 10^{-3}\ m/min = 7.195 \times 60 \times 24$$

$$k = 10.36\ m/day, \quad T = Kh_0 = 10.36 \times 50 = 518\ m^2/day$$

Assuming $r_0 = 300m$, $$Q = \frac{\pi k (h_0^2 - h_w^2)}{2.303 \log_{10}\left(\frac{r_0}{r_w}\right)}.$$

$$1.8 = \frac{\pi \times 7.195 \times 10^{-3} \times (h_0^2 - h_w^2)}{2.303 \times \log_{10}\left(\frac{300}{0.15}\right)} \Rightarrow h_0^2 - h_w^2 = 605m$$

$$h_w^2 = h_0^2 - 605 = 1894$$

$$h_w = 43.5m$$

$$S_w = h_0 - h_w = 6.47m$$

(5). In an artesian aquifer of 8m thick, a 10cm diameter well is pumped at a constant rate of 150 lpm. The steady state drawdown observed in two wells located at 15m and 40m distance from the centre of the well are found to be 2m and 0.05m respectively. Compute T & K of the aquifer.

$Q = 150\ lpm\ (or)\ 0.0025\ m^3/sec.$, $b = 8m$

$r_1 = 15m$, $r_2 = 40m$, $S_1 - S_2 = 2 - 0.05$

$S_1 - S_2 = 1.95m.$

$$Q = \frac{2\pi k b (S_1 - S_2)}{2.303 \log_{10} \frac{r_2}{r_1}} \quad (or) \quad \frac{2.72\,T\,(S_1 - S_2)}{\log_{10}(r_2/r_1)}$$

$$0.0025 = \frac{2.72 \times T \times 1.95}{\log_{10}(40/15)}$$

$$T = 2.007 \times 10^{-4}\ m^2/sec \quad (or) \quad 17.34\ m^2/day.$$

$(2.007 \times 60 \times 60 \times 24)$

$$T = k \times b \Rightarrow 17.34 = k \times 8$$

$$k = 2.16\ m/day$$

Partially penetrating well

- Partial penetration, especially for confined aquifers, may significantly affect the associated well(s) hydraulics due to the incidence of vertical flow in the vicinity of the well.
- This induces additional head losses, affects the potential pumping rate, and the related peizometeric head distribution around the well.

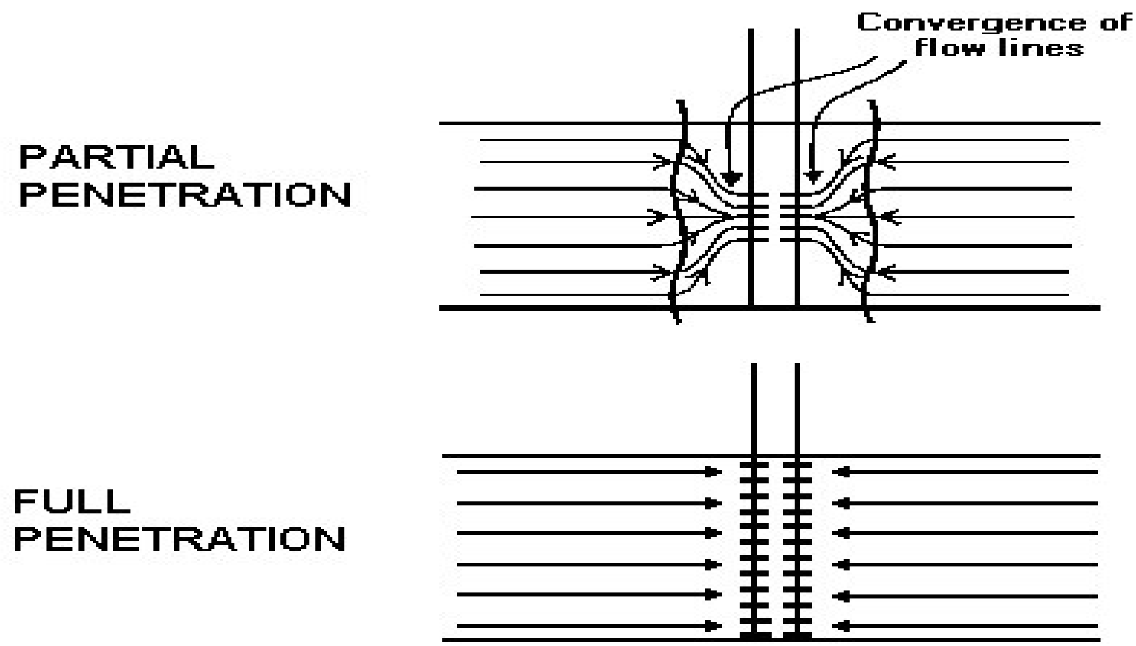


Fig 3.37 Partial and Full Penetration

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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF CIVIL ENGINEERING

UNIT – IV - RESERVOIR PLANNING – SCI1305

RESERVOIR PLANNING

Definition:

When a barrier is constructed across some river in the form of dam, water gets stored on the upstream side of a barrier, forming a pool of water, generally called a dam reservoir an impounding reservoir or a river reservoir.

Storage reservoir serve the following purpose:

- Irrigation
- Water supply
- Hydroelectric power generation
- Flood control
- Navigation
- Recreation
- Development of fish & wild life
- Soil conservation

Investigations for reservoir planning

A proper investigation has to be done for reservoir planning. The steps to be followed are

1. Engineering Surveys
2. Geological Investigation
3. Hydrological investigation

Engineering Surveys

In this survey, area of the site (dam site, reservoir and associated works) aresurveyed and contour map of the entire area is prepared. From contour map, storage capacity and water spread area of reservoir at various elevations can be determined

- Water spread area at any elevation determined by measuring the area enclosed by the contour corresponding to that elevation with a planimeter
- Storage capacity of reservoir determined by taking contour areas at equal interval and summing up by trapezoidal formula, cone formula or prismoidal formula.

Geological Investigation

Geological investigations are required to determine the suitability of foundation for dam, water tightness of the reservoir basin and the location of quarry sites for obtaining suitable construction materials.

Hydrological Investigation

This is done to estimate the quantity of water likely o be available in river

- Study of runoff pattern of river at the proposed dam site to determine the storage capacity of reservoir
- Determination of hydrograph of the worst flood to determine the spillway capacity and design.

Zones of Storage in a reservoir

The storage capacity in the reservoir is divided into three or four parts.

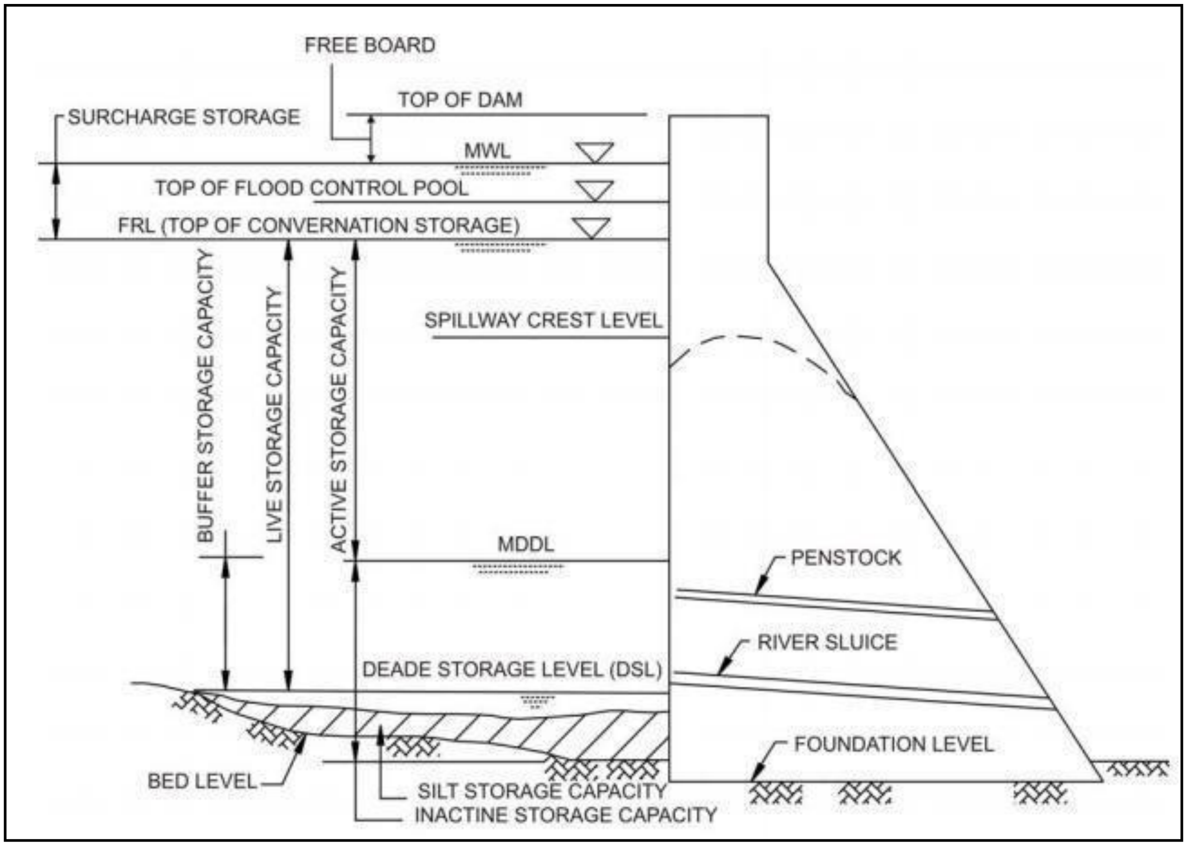


FIGURE 4.1

- **Full reservoir level (FRL):**The full reservoir level (FRL) is the highest water level to which the water surface will rise during normal operating conditions.

- **Maximum water level (MWL):**The maximum water level is the maximum level to which the water surface will rise when the design flood passes over the spillway.

- **Minimum drawdown level (MDDL):** It is the level below which the reservoir will not be able to drawdown so as to maintain a minimum head required in power projects.

- **Minimum pool level:**The minimum pool level is the lowest level up to which the water is withdrawn from the reservoir under ordinary conditions.

- **Dead storage:**The volume of water held below the minimum pool level is called the dead storage. It is provided to cater for the sediment deposition by the impounding sediment laid in water. Normally it is equivalent to volume of sediment expected to be deposited in the reservoir during the design life reservoir.

- **Live/useful storage:** The volume of water stored between the full reservoir level (FRL) and the minimum pool level is called the useful storage. It assures the supply of water for specific period to meet the demand.

- **Bank storage:** is developed in the voids of soil cover in the reservoir area and becomes available as seepage of water when water levels drops down. It increases the reservoir capacity over and above that given by elevation storage curves.

- **Valley storage:**The volume of water held by the natural river channel in its valley up to the top of its banks before the construction of a reservoir is called the valley storage. The valley storage depends upon the cross section of the river.

The reservoir may be a **single purpose conservation reservoir** or a **single purpose flood control reservoir** or a **Multipurpose reservoir** serving all purpose in a balanced way.

Yield is the volume of water which can be withdrawn from a reservoir in a specified period of time.

Safe yield is the maximum quantity of water which can be supplied from a reservoir in a specified period of time during a critical dry year.

Secondaryyield is the quantity of water which is available during the period of high flow in the rivers when the yield is more than the safe yield.

Averageyield is the arithmetic average of the firm yield and the secondary yield over a long period of time.

Designyield is the yield adopted in the design of a reservoir. The design yield is usually fixed after considering the urgency of the water needs and the amount of risk involved.

Reservoir Capacity depends upon the inflow available and demand.

- If the inflow in the river is always greater than the demand, there is no storage required
- If the inflow in the river is small but the demand is high, a large reservoir capacity is required

The required capacity for a reservoir can be determined by the following methods:

1. Graphical method, using mass curves.
2. Analytical method

Determination of reservoir capacity for a specified yield or demand using mass curve

1. Prepare a mass inflow curve from the flow hydrograph of the site for a number of consecutive years including the most critical years (or the driest years) when the discharge is low.

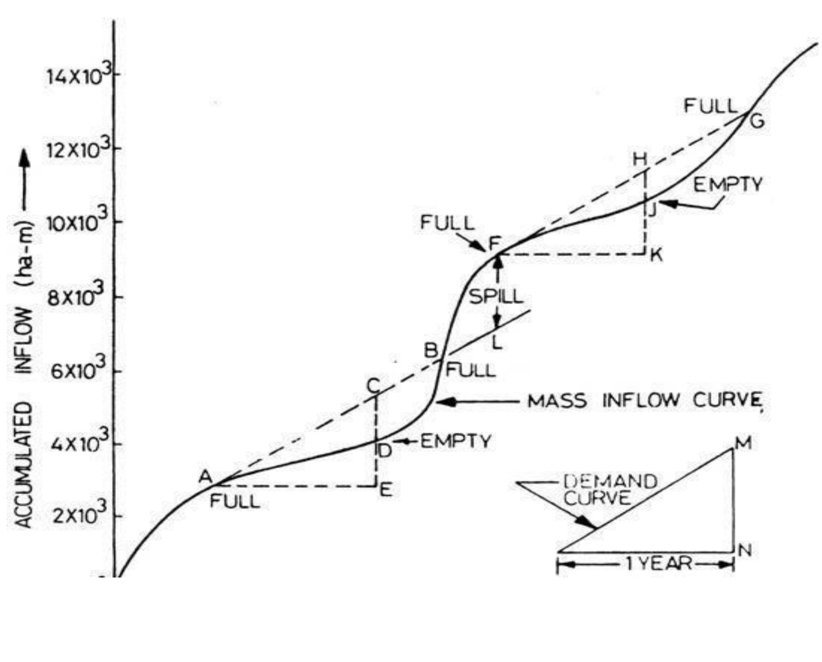
2. Prepare the mass demand curve corresponding to the given rate of demand. If the rate of demand is constant, the mass demand curve is a straight line. The scale of the mass demand curve should be the same as that of the mass inflow curve.

3. Draw the lines *AB, FG, etc. such that*

(i) They are parallel to the mass demand curve, and

(ii) They are tangential to the crests A, F, etc. of the mass curve.

4. Determine the vertical intercepts CD. HJ, etc. between the tangential lines and the mass inflow curve. These intercepts indicate the volumes by which the inflow volumes fall short of demand.



Assuming that the reservoir is full at point A, the inflow volume during the period AE is equal to ordinate DE and the demand is equal to ordinate CE. Thus the storage required is equal to the volume indicated by the intercept CD.

5. Determine the largest of the vertical intercepts found in Step (4). The largest vertical intercept represents the storage capacity required.

The following points should be noted.

(i) The capacity obtained in the net storage capacity which must be available to meet the demand. The gross capacity of the reservoir will be more than the net storage capacity. It is obtained by adding the evaporation and seepage losses to the net storage capacity.

(ii) The tangential lines AB, FG; etc. when extended forward must intersect the curve. This is necessary for the reservoir to become full again, If these lines do not intersect the mass curve, the reservoir will not be filled again. However, very large reservoirs sometimes do not get refilled every year. In that case, they may become full after 2-3 years.

(iii) The vertical distance such as FL between the successive tangents represents the volume of water spilled over the spillway of the dam.

Analytical Method

In the analytical method, capacity of the reservoir is determined from the net inflow and demand.Storage is required when the demand exceeds the net inflow. The total storage required is equal to the sum of the storage required during the various periods.

1. Collect the stream flow data at the reservoir site during the critical dry period. Generally, the monthly inflow rates are required. However, for very large reservoirs, the annual inflow rates may be used.

2. Ascertain the discharge to be released downstream to satisfy water rights or to honour the agreement between the states or the cities.

3. Determine the direct precipitation volume falling on the reservoir during the month.

4. Estimate the evaporation losses which would occur from the reservoir. The panevaporation data are normally used for the estimation of evaporation losses during the month.

5. Ascertain the demand during various months.
6. Determine the adjusted inflow during different months as follows: Adjusted

inflow = Stream inflow + Precipitation - Evaporation

– Downstream Discharge

7. Compute the storage capacity for each months. Storage

required = Adjusted inflow – Demand

8. Determine the total storage capacity of the reservoir by adding the storages required found in Step 7.

Determination of Yield from a Reservoir

The yield from a reservoir of a given capacity can be determined by the use of the mass inflow curve

1. Prepare the mass inflow curve from the flow hydrograph of the river.

2. Draw tangents AB, FG, etc. at the crests A, F, etc. of the mass inflow curve in such a way that the maximum departure (intercept) of these tangents from the mass inflow curve is equal to the given reservoir capacity.

3. Measure the slopes of all the tangents drawn in Step 2.

4. Determine the slope of the flattest tangent.

5. Draw the mass demand curve from the slope of the flattest tangent (see insect). The yield is equal to the slope of this line.

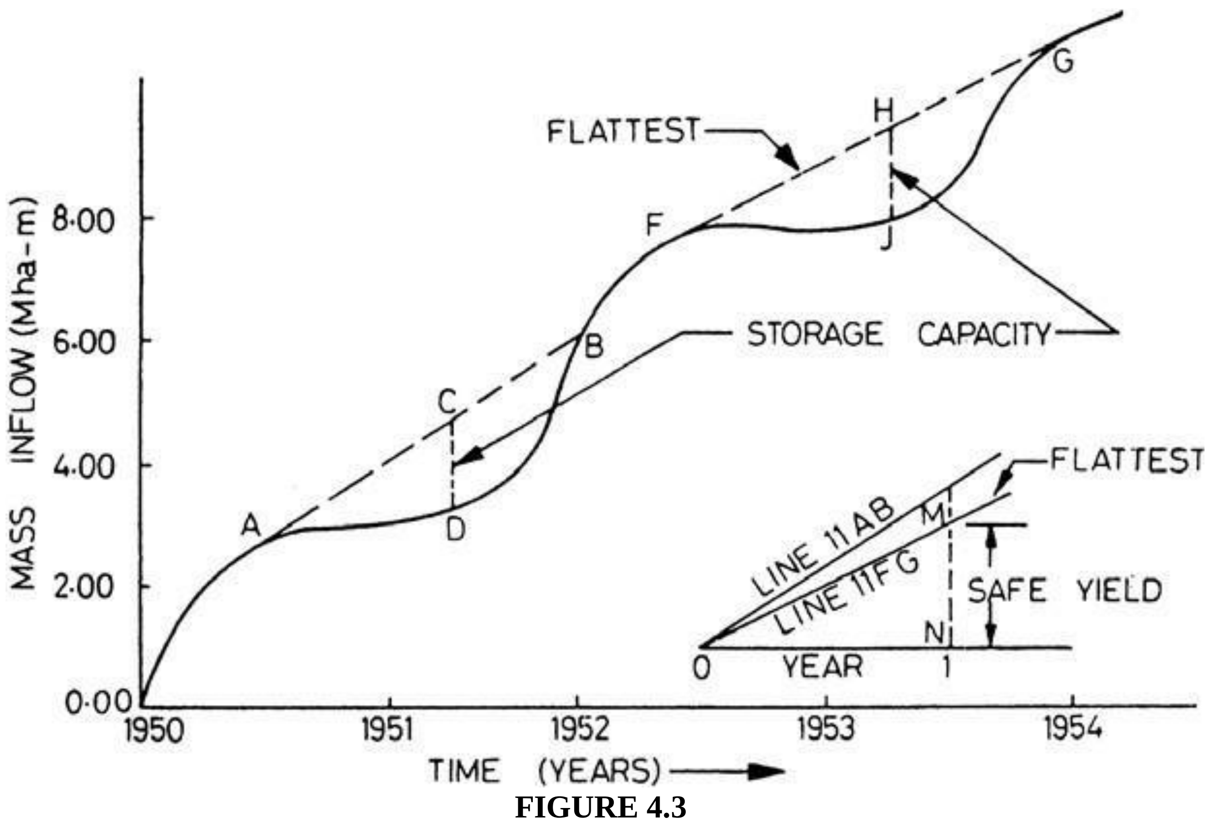


FIGURE 4.3

Reservoir Sedimentation:

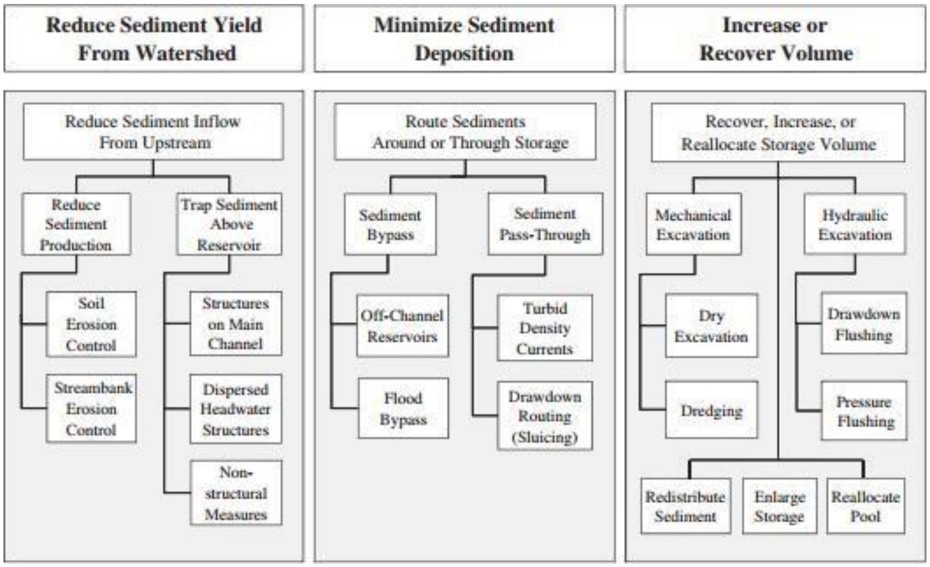
It is a difficult problem for which an economical solution has not yet been discovered, except by providing a "dead storage" to accommodate the deposits during the life of the dam. Disintegration, erosion, transportation and sedimentation are the different stages leading to silting of reservoir.

The different causes of sedimentation in catchment area are nature of soil in catchment area, topography of the catchment area, cultivation in catchment area, vegetation cover in catchment area and intensity of rainfall in catchment area.

Maximum efforts should be taken to manage sedimentation. Water should be released so that less sediments should retain in reservoir. Following options are:

- Catchment Vegetation
- Construction of coffer dams/low height barriers
- Flushing and desilting of sediments
- Low level outlets / sediment sluicing
- **Excavation** A method to remove soil-storing area in reservoir by heavy
- **Dredging** A method to remove sediments settled under water by dredger
- **Check dam (+excavation work)** Construction of check dam on the river and to remove sediments stored at the check dam by heavy machine
- **Flushing Sediments** flushing by temporarily lowering water level of reservoir
- **Construction of bypass tunnel** Sediments are diverted directly downriver through the bypass tunnel
- **Dry excavation** to create a greater depth of water Periodical reservoir emptying to excavate and remove sediments under water

– Reduced Sediment Loads Downstream of Dams



SINGLE PURPOSE RESERVOIRS

The common principles of single purpose reservoir operation are given below:

a) Flood control- Operation of flood control reservoirs is primarily governed by the available flood storage capacity of damage centers to be protected, flood characteristics, ability and accuracy of flood/ storm forecast and size of the uncontrolled drainage area. A regulation plan to cover all the complicated situations may be difficult to evolve, but generally it should be possible according to one of the following principles:

1) Effective use of available flood control storage: Operation under this principle aims at reducing flood damages of the locations to be protected to the maximum extent possible, by effective use of flood event. Since the release under this plan would obviously be lower than those required for controlling the reservoir design flood, there is distinct possibility of having a portion of the flood control space occupied during the occurrence of a subsequent heavy flood. In order to reduce this element of risk, maintenance of an adequate network of flood forecasting stations both in the upstream and down stream areas would be absolutely necessary.

2) Control of reservoir design flood: According to this principle, releases from flood control reservoirs operated on this concept are made on the same hypothesis as adopted for controlling the reservoir design flood, that is the full storage capacity would be utilized only when the flood develops into the reservoir design flood. However, as the design flood is usually an extreme event, regulation of minor and major floods, which occur more often, is less satisfactory when this method is applied.

3) Combination of principle (1) and (2): In this method, a combination of the principles (1) and

(2) is followed. The principle (1) is followed for the lower portion of the flood reserve to achieve the maximum benefits by controlling the earlier part of the flood. Thereafter releases are made as scheduled for the reservoir design flood as in principle (2). In most cases this plan will result in the best overall regulation, as it combines the good points of both the methods.

4) Flood control in emergencies: It is advisable to prepare an emergency release schedule that uses information on reservoir data immediately available to the operator. Such schedule should be available with the operator to enable him to comply with necessary precautions under extreme flood conditions.

b) Conservation: Reservoirs meant for augmentation of supplies during lean period should usually be operated to fill as early as possible during filling period, while meeting the requirements. All water in excess of the requirements of the filling period shall be impounded. No spilling of water over the spillway will normally be permitted until the FRL is reached. Should any flood occur when the reservoir is at or near the FRL, release of flood waters should be affected, so as not to exceed the discharge that would have occurred had there been no reservoir. In case the year happens to be dry, the draft for filling period should be curtailed by applying suitable factors. The depletion period should begin thereafter. However, in case the reservoir is planned with carry-over capacity, it is necessary to ensure that the regulation will provide the required carry-over capacity at the end of the depletion period.

Operation of multi purpose reservoirs: The general principles of operation of reservoirs with these multiple storage spaces are described below:

1. Separate allocation of capacities- When separate allocations of capacity have been made for each of the conservational uses, in addition to that required for flood control, operation for each of the function shall follow the principles of respective functions. The storage available for flood control could, however be utilized for generation of secondary power to the extent possible. Allocation of specific storage space to several purposes with the conservation zone may some times be impossible or very costly to provide water for the various purposes in the quantities needed and at the time they are needed.

2. Joint use of storage space- In multi-purpose reservoir where joint use of some of the storage space or storage water has been envisaged, operation becomes complicated due to competing and conflicting demands. While flood control requires low reservoir level, conservation interests require as high a level as is attainable. Thus, the objectives of these functions are not compatible and a compromise will have to be effected in flood control operations by sacrificing the requirements of these functions. In some cases parts of the conservational storage space is utilized for flood moderation, during the earlier stages of the monsoon. This space has to be filled up for conservation purpose towards the end of monsoon progressively, as it might not be possible to fill up this space during the post-monsoon periods, when the flows are insufficient even to meet the current requirements. This will naturally involve some sacrifice of the flood control interests towards the end of the monsoon

MULTIPURPOSE DAMS

Multipurpose dams combine two or more functions of traditional single-purpose dams into one hydro infrastructure project. A multipurpose dam may combine storing and supplying water for irrigation, industry and human consumption with other uses such as flood control, power generation, navigation, run-off storage and water discharge regulation.
The construction of multipurpose dams is based on the same principles used for single purpose dams (barriers across a body of water), but additional features may be included to accommodate their different purposes, such as irrigation channels or power generation facilities. Multipurpose dams are particularly appropriate in developing countries, as the multi-functionality of the

operations can help meet a number of development goals simultaneously, such as those related to energy, water and food security, and economic development.

Implementation

Local community needs should always be considered when establishing the multipurpose dam's benefits, in addition to how the benefits should be prioritized amongst the various users. Further steps include dam site identification and an environmental impact assessment as appropriate. Calculations on water retention capacity, flow rates and minimum water requirements for various uses should be conducted for planning purposes. Socio-economic and environmental evaluations should be conducted at the selected sites, and criteria should be established to monitor potential community and environmental changes after construction. Dam designs vary, and the chosen design is agreed upon between planners and construction engineers. Operational management includes flushing out sediments and monitoring selected environmental and socioeconomic variables, amongst other activities.

Environmental Benefits

- Mitigates climate change through production of renewable energy.
- Provides climate change adaptation through reducing seasonal water stress and improving access to water during droughts.

Socioeconomic Benefits

- Provides flood regulation and protection.
- Increases water and food security.
- Makes inland navigation possible on large dams, improving trade and development. Inland navigation is a relatively cost-effective and a less-polluting form of transport.
- Provides recreational benefits for local communities.

Opportunities and Barriers

Opportunities:

- Climate change mitigation and adaptation benefits and contribution to a number of cross sectorial development objectives (e.g. energy production and agricultural development)

- Provides multiple benefits from a single investment
- Often an attractive investment for government and donors due to contribution to a multitude of development objectives
- Navigation development

Barriers:

- Higher planning and operating complexity than single purpose dams (need to negotiate competing uses)
- Changed natural river flows can negatively impact aquatic ecosystems. Impacts may include blocking migratory routes for fish and altering the chemical composition and temperature of water. Care must be taken to minimize these risks
- Still water in dams is a potential habitat for organisms such as mosquitos, which could increase the rates of vector borne diseases
- The separate functions of multipurpose dams often mean that no single function can operate at a maximum capacity level, unlike single-purpose dams

Implementation considerations*

Technological maturity: 2-3

Initial investment: 4-5

Operational costs: 3-4

Implementation timeframe: 2-3

* This adaptation technology brief includes a general assessment of four dimensions relating to implementation of the technology. It represents an indicative assessment scale of 1-5 as follows:
Technological maturity: 1 - in early stages of research and development, to 5 – fully mature and widely used
Initial investment: 1 – very low cost, to 5 – very high cost investment needed to implement technology
Operational costs: 1 – very low/no cost, to 5 – very high costs of operation and maintenance
Implementation timeframe: 1 – very quick to implement and reach desired capacity, to 5 – significant time investments needed to establish and/or reach full capacity

This assessment is to be used as an indication only and is to be seen as relative to the other technologies included in this guide. More specific costs and timelines are to be identified as relevant for the specific technology and geography.

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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF CIVIL ENGINEERING

UNIT – V – WATERSHED MANAGEMENT – SCI1305

FLOOD

A "flood" may be defined as a great flow of water, but usually a flood is consider to be an unusually high stage of a river at which a stream channel becomes filled and above which it overflows its banks and floods near by land. Thus whenever an overflows through the banks it is said to be flooded

The maximum flood that any structure can safely pass is called the "Design Flood" and is selected after consideration of economic and hydrologic factors.

A flood is an unusual high stage of a river overflowing its banks and inundation the marginal lands. This is due to severe storm of unusual meteorological combination, sometimes combined with melting of accumulated snow on the catchment .This may also be due to shifting of the course of the river, earthquake causing bank erosion, or blocking of river, or beaching of the river flood banks. Floods have swept vast regions in India, particularly in the basins of rivers Kosi, Brahmaputra, Godavari, Narmada and tapti.Floods cause much loss of life and property,disruption of communication, damage to crops, famine, epidemic diseases and other indirect losses.

Various methods adopted for flood control can be classified into 3 categories:

- ❑ Method adopted to modify the flood
- ❑ Method adopted to modify the susceptibility of flood
- ❑ Method adopted to reduce the losses

1) Method adopted to modify the flood

✓ Control measures for channel phase

- Construction of Reservoirs
    - Improvement of river channels
- Construction of levees and flood walls
- Diversion of flood water to flood ways
    - Use of natural detention basin
- Construction of emergency flood ways
    - Adoption of inter basin transfer

- Bank stabilization
  - Construction of ring bunds, and
- Development of underground storage.

✓ Flood control measures for land phase

- Watershed management,
- Engineering measures for flood abutment,
- Agronomic measures for flood abutment, and
- Afforestation.

✓ Atmospheric phase - Weather modification

2) Methods adopted to modify susceptibility of flood damage

- Flood plain management
- Adoption of suitable development policies
- Effective structural changes
- Flood proofing areas
- Disaster preparedness and response for plan
- Flood forecasting and flood warning
- Susceptibility of flood damage

3) Methods to reduce the losses

- Emergency evacuation
- Flood fighting
- Adopting suitable public health measures

- Providing disaster relief
  - Tax remission

The objective of the flood control is to reduce or to alleviate the negative consequences of flooding .Alternative measures that modify the flood runoff are usually referred to as flood control facilities and consist of engineering structures or modifications .Construction of flood control facilities referred to as structural measures are usually designed to consider the flood characteristics including reservoirs, diversions, levees or dikes, and channel modifications. Flood control measures that modify the damage susceptibility of floodplains are usually referred to as nonstructural measures and may require minor engineering works. Nonstructural measures are designed to modify the damage potential for permanent facilities and provide for reducing potential damage during a flood event. Nonstructural measures include flood proofing, flood warning, and land- use controls.

Flood control by Reservoirs:

- The purpose of flood control reservoir is to temporarily store the portion of flood so that the flood peaks are flattened out.
- The “reservoir Location” may be ideally suited immediately upstream side of the area to be protected and the water discharged into the channel downstream at its safe capacity.
- All the inflow into the reservoir in excess of the safe channel capacity is stored until the inflow drops below the channel capacity and the stored water is released to recover the storage capacity for the next flood
- If there is some distance between the reservoir and the protected area but no local inflow between these points, the reservoir operation is similar to the above but the peak will further be reduced due to storage in the reach down stream from the reservoir .

Types of flood control Reservoirs

- Detention Reservoirs
- Retarding Reservoirs

A Detention Reservoir is provided with sluice gate and sluice ways which can be operated by manual. The Detention Reservoir is similar to an ordinary conservation reservoir except that the former has a comparatively larger sluice way capacity.It permits rapid drawdown in advance of flood and just after it.

Retention Reservoir is provided with ungated spill way which automatically regulate the flood flow from the dam depending upon the water level in the reservoir.The arrangement usually consist of a large ungated spill way or one or more ungated sluice ways.This type of sluice selected for a particular reservoir depends upon the storage characteristics and nature of the flood problems.

DROUGHT:

Drought is a normal, recurrent feature of climate, although it is erroneously considered as a rare and random event. It differs from aridity, which is restricted to low rainfall regions and is a permanent feature of climate. Drought should be considered relative to some long-term average conditions of the balance between precipitation and evapotranspiration (i.e., evaporation + transpiration) in a particular area. It is also related to the timing (principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains.

An operational definition of drought helps people to identify the beginning, end, and degree of severity of a drought. This definition is usually made by comparing the current situation to the historical average, often based on a 30-year period of record (according to World Meteorological Organization recommendations). The following categories of drought are usually considered:

- **Meteorological**Meteorological drought is usually defined on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as specific to a region since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

- **Agricultural**Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth.

• **Hydrological**Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale.

• **Hydrological with respect of the land use** Although climate is a primary contributor to hydrological drought, other factors such as changes in land use (e.g., deforestation), land degradation, and the construction of dams all affect the hydrological characteristics of the basin.

Drought is a natural hazard, it has a slow onset, and it evolves over months or even years. It may affect a large region and causes little structural damage. The impacts of drought can be reduced through preparedness and mitigation.

The components of a drought preparedness and mitigation plan are the following:

- Prediction
- Monitoring
- Impact assessment
- Response.

Prediction can benefit from climate studies which use coupled ocean/atmosphere models, survey of snow packs, anomalous circulation patterns in the ocean and atmosphere, soil moisture, assimilation of remotely sensed data into numerical prediction models, and knowledge of stored water available for domestic, stock, and irrigation uses.

Monitoring exists in countries which use ground-based information such as rainfall, weather, crop conditions and water availability. Satellite observations complement data collected by ground systems. Satellites are necessary for the provision of synoptic, wide-area coverage.

Impact assessment is carried out on the basis of land-use type, persistence of stressed conditions, demographics and existing infrastructure, intensity and areal extent, and its effect on agricultural yield, public health, water quantity and quality, and building subsidence.

Response includes improved drought monitoring, better water and crop management, augmentation of water supplies with groundwater, increased public awareness and education, intensified watershed and local planning, reduction in water demand, and water conservation.

Drought preparedness and mitigation can be accomplished with the following practices: (1) soil and water conservation, and (2) herd management.

1. Soil and Water Conservation

Conservation practices minimize the disruption of the soil's structure, composition and natural biodiversity, thereby reducing erosion and soil degradation, surface runoff, and water pollution.

The following are established practices of soil and water conservation:

- Crop rotation
- Contoured rowcrops
- Terracing
- Tillage practices
- Erosion-control structures
- Water retention and detention structures
- Windbreaks and shelterbelts
- Litter management
- Reclamation of salt-affected soil.

Soil and water conservation can be approached through agronomic and engineering measures. Agronomic measures include contour farming, off-season tillage, deep tillage, mulching and providing vegetative barriers on the contour. These measures prevent soil erosion and increase soil moisture.

Engineering measures differ with location, slope of the land, soil type, and amount and intensity of rainfall. Measures commonly used are the following:

Contour bunds, trenches and stone walls

These features prevent soil erosion and obstruct the flow of runoff. The retained water increases soil moisture and recharges the groundwater.

Check dams and other gully-plugging structures

Check dams are temporary structures constructed with locally available materials. Types of check dams are the brush-wood dam, the loose-rock dam and the woven-wire dam.

Percolation ponds

These features store water for livestock and recharge the groundwater. They are constructed by excavating a depression to form a small reservoir, or by constructing an embankment in a natural ravine or gully to form an impoundment.

Water-supply projects can also be implemented for drought mitigation, with a view to strengthen drought preparedness. Activities such as water-use planning, rain-water harvesting, runoff collection using surface and underground structures, improved management of channels and wells, exploration of additional water resources through drilling and dam construction, are implemented as a part of a drought-mitigation plan.

To increase moisture availability, the following in-situ moisture-conservation practices can be adopted:

- For agricultural crops, measures include ridges and furrows, basins, and water spreading.
- For tree crops, measures include saucer basins (Fig. 3), semi-circular bunds, crescent-shaped bunds, catch pits and deep pitting.
- Rainwater harvesting collects rainfall or moisture for immediate or eventual use in irrigation or domestic supplies. Part of the rainwater collected from roofs can be stored in a cistern or tank for later use.
- Landscape contouring is used to direct runoff into areas planted with trees, shrubs, and

turf.

2. Herd management

Herd management is an important strategy for drought mitigation. Factors to be considered include the expected drought duration, the current water and feed supplies, the composition and body condition of the herd, and the financial resources available.

Herd management practices include the following:

Reduction in herd numbers

When feed resources are getting short, one solution is to critically evaluate the members of the herd and eliminate those that are less useful. Sale or agistment (relocating herd to non-affected pastures) are the two options available to reduce stock numbers.

Strategic weaning of calves

During a drought, the production of milk rapidly depletes a cow's body reserves, while the calf derives little benefit. Weaning the calf gives the cow a better chance of survival. However, the decision to wean must be made in relation to the time of year and age of the calf. In normal years, the nutritive value of pasture falls towards the end of autumn, at which time, beef cows may be producing as little as 1 liter of milk per day. If the calf is 5 to 6 months of age, weaning by the end of autumn will maintain or improve the cow's condition.

In drought years, early weaning is recommended. However, calves should not be weaned before 3 months of age unless absolutely necessary. Young calves need to be fed some true protein meal or preferably milk powder. Most calves over three months of age will survive on grain and Lucerne hay or molasses and protein meal diets.

Herd segregation

Segregating animals into classes gives the herd a better chance of getting needed feed supplies. Segregation makes possible the preferential treatment of vulnerable classes. The older dry cows can be moved to the poorer forage fields. Pregnancy testing is a useful tool to identify heavily pregnant cows for special feeding, especially young cows that are pregnant for a second time.

Parasite control

Cattle under nutritional and other stresses are less resistant to parasites than in normal conditions. Worms can be a serious problem with young cattle. During drought conditions, all cattle under 18 months of age should be treated for worms.

Optimizing use of drought-affected paddock

Cattle do not graze well areas located far away from watering points. Use of a drought-affected paddock can be encouraged by providing local water facilities, with supplementary hand feeding as an attractant.

Attention to contaminated water supplies

Polluted surface waters represent a death trap for drought-weakened cattle.
Fencing may be necessary to separate cattle from undesirable water holes.

Salinity may increase with the depletion of the water table, with the water becoming too salty for the herd. The upper limit of total soluble salts should not exceed 8500 ppm. In addition, the sum of chlorides and sulphates of calcium and magnesium should not exceed 1400 ppm.

Potential problems arising from drought conditions are:

- Use of salt to limit feed intake may increase water intake 50 to 75%, or approximately 50 gallons of additional water for each pound of salt. Water must not be limited in any way or salt toxicity may result.
- Over consumption of urea-containing supplements by cattle grazing on forage-scarce ranges can result in urea toxicity. Generally, performance of cattle on urea-type supplements is poor wherever forage is in short supply.
- Hay cut under moisture-stress conditions, especially sorghum-type hays, may contain

high levels of nitrate. Tests for nitrate should be performed before feeding these hays, especially before feeding large amounts. Farmers who cut drought corn or sorghum for hay should check nitrate levels before feeding.

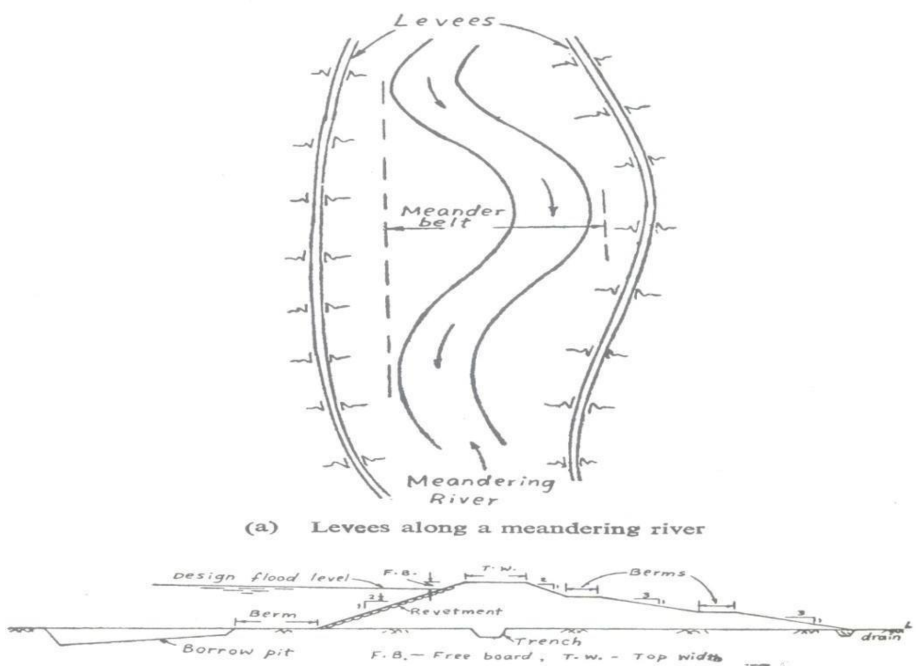
- Prussic acid or cyanide poisoning can be a problem in grazing drought- stunted plants such as Johnson grass, sorghum, sorghum hybrids, and sudan grass. Prussic acid is generally not a problem when forage for hay is allowed to sun cure for 3 to 5 days, in order to bleach out any bright green color.
- Cattle that graze short or drought-stunted pasture are more likely to consume toxic plants.

LEVEES:

It is one of the oldest and most widely used methods of protecting land from flood water is to erect a barrier preventing overflow.Levees are most frequently used for flood mitigation because they can be built at relatively low cost of materials available at the site.Levees are usually built of materials excavated from borrow pits paralleling the levee line. The material should be placed in layers and compacted with the least pervious materials along the river side of the levee.

The effects of levees on flood flow are

1. increase in the rate of flood flow
2. increase in the flood water elevation
3. increase in the carrying capacity of the channel
4. increase in the scouting action
5. decrease of surface slope of stream above the leveed section



(a) Levees along a meandering river

(b) Typical levee cross section

Fig. 8.8 Flood Control by Levees

FLOOD WALLS:

Due to flat side slope of levees, a levee of any considerable height requires a very large base width so that the land for earth dykes are not possible. In this case concrete flood walls are preferable. Flood walls are designed to withstand the hydrostatic pressure exerted by the water when at the design flood level. If the wall is backed by an earth fill, it must also serve as a retaining wall against the earth pressure when stages are low.

CHANNEL IMPROVEMENT:

The reduction in stage at a specific point on a stream can often be achieved by merely improving the hydraulic capacity of the channel.

Removal of brush and snags, dredging of bars, straightening of bends and other devices can be effective, though care should not be taken to make the channel susceptible to bank erosion. The channels may be completely lined and straightened.

Channel improvement. At the diversion structure, a headwork regulates the flow into a canal. This canal, which takes its supplies directly from the river, is called the main canal and usually direct irrigation from the waters of this canal is not carried out. This acts as a feeder channel to the branch canals, or branches. Branch canals generally carry a discharge higher than 5 m3/s and acts as feeder channel for major distributaries which, in turn carry 0.25 to 5 m3/s of discharge. The major distributaries either feed the water courses or the minor distributaries, which generally carry discharge less than 0.25 m3/s. Though irrigation canals may be constructed in natural or compacted earth, these suffer from certain disadvantages, like the following

• Maximum velocity limited to prevent erosion • Seepage of water into the ground • Possibility of vegetation growth in banks, leading to increased friction • Possibility of bank failure, either due to erosion or activities of burrowing animals.

All these reasons lead to adoption of lining of canals, though the cost may be prohibitive.

Hence, before suggesting a possible lining for a canal, it is necessary to evaluate the cost vis-à-vis the savings due to reduction in water loss through seepage.

Apart from avoiding all the disadvantages of an unlined canal, a lined canal also has the advantage of giving low resistance and thus reducing the frictional loss and maintaining the energy and water surface slopes for the canal as less as possible. This is advantageous as it means that the canal slope may also be smaller, to maintain the same discharge than for a canal with higher friction loss. A smaller canal slope means a larger command area.

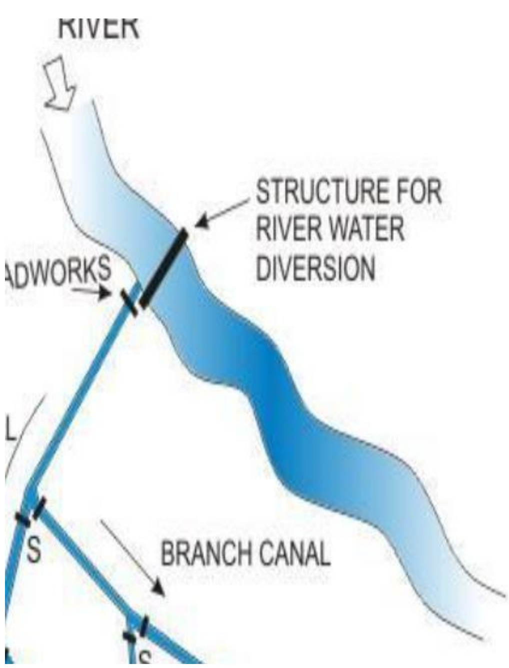


FIGURE NO 5.1

This may be achieved by,

- Decreasing the Manning's n for the reach
- Increasing the hydraulic radius by increasing the depth
- Increasing the channel slope by shortening the channel length.

Imagine a watershed as an enormous bowl. As water falls onto the bowl's rim, it either flows down the inside of the bowl or down the outside of the bowl. The rim of the bowl or the watershed boundary is sometimes referred to as the ridgeline or watershed divide. This ridge line separates one watershed from another.

Topographic maps created by the United States Geological Survey (USGS 7.5 minute series) can help you to determine a watershed's boundaries. Topographic maps have a scale of 1:24,000 (which means that one inch measured on the map represents 24,000 inches [2000'] 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.

We describe basic topographic map concepts and symbols below, but more information can be found at the U. S. Geological Survey's website on Topographic Map Symbols:

Here's how you can delineate a watershed:

STEP 1:

Use a topographic map(s) to locate the river, lake, stream, wetland, or other waterbodies of interest. *(See the example, West Branch of Big River, in **Figure D-1.**)*

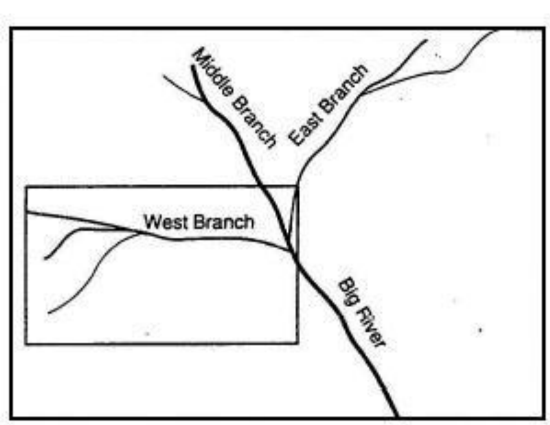


FIGURE NO 5.2

West Branch of Big River

STEP 2:
Trace the watercourse from its source to its mouth, including the tributaries ***(Figure D-2).*** This step determines the general beginning and ending boundaries.

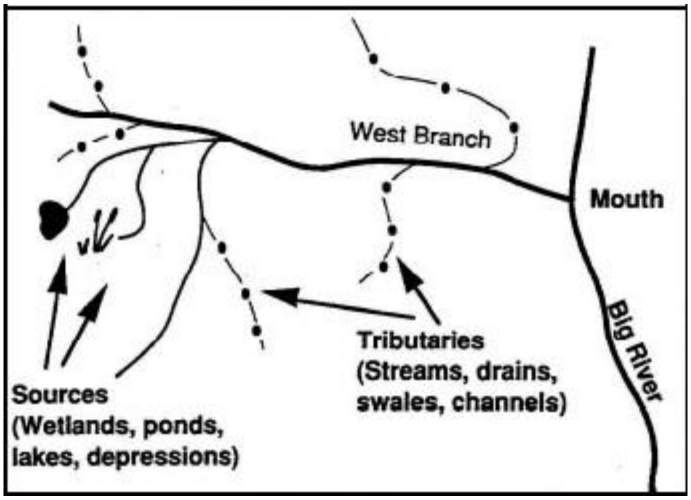


Figure 5.3: West Branch subwatershed

Step 3

Examine the **brown lines** on the topographic map that are near the watercourse. These are referred to as contour lines.

Contour lines connect all points of equal elevation above or below a known reference elevation.

- The dark brown contour lines (thick lines) will have a number associated with them, indicating the elevation.

- The light brown contour lines (thin lines) are usually mapped at 10 (or 20) foot intervals, and the dark brown (thick) lines are usually mapped at 50 (or 100) foot intervals.

Be sure to check the map's legend for information on these intervals.

- To determine the final elevation of your location, simply add or subtract the appropriate contour interval for every light brown (thin) line, or the appropriate interval for every dark brown (thick) line. ***Figure D-3*** shows a point (X) at an elevation of 70 feet above mean sea level.

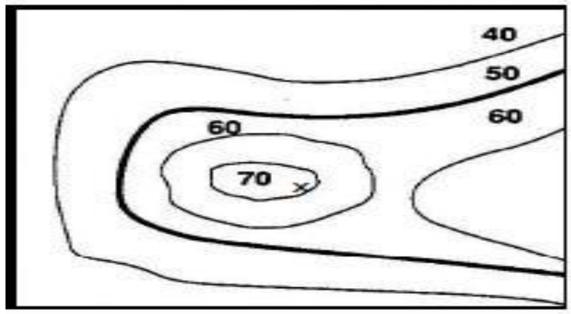


Figure 5.4: Contour lines and an example point (X) at an elevation of 70 feet above sea level.

STEP 4:

• Contour lines spaced far apart indicate that the landscape is more level and gently sloping (i.e., they are flat areas). Contour lines spaced very close together indicate dramatic changes (rise or fall) in elevation over a short distance (i.e., they are steep areas) ***(Figure D-4)***.

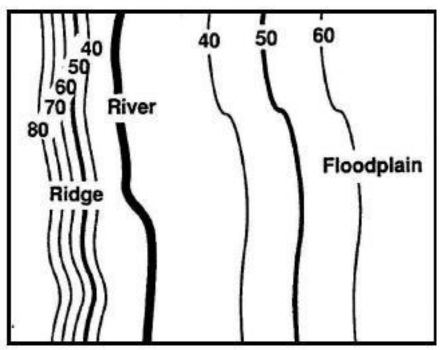


Figure 5.5: Floodplains and ridges

STEP 5:

Check the slope of the landscape by locating two adjacent contour lines and determine their respective elevations. The slope is calculated as the change in elevation, along a straight line, divided by the distance between the endpoints of that line.

• A depressed area (valley, ravine, swale) is represented by a series of contour lines "pointing" towards the highest elevation ***(Figure D-5).***

• A higher area (ridge, hill) is represented by a series of contour lines "pointing" towards the lowest elevation ***(Figure D-6)***.

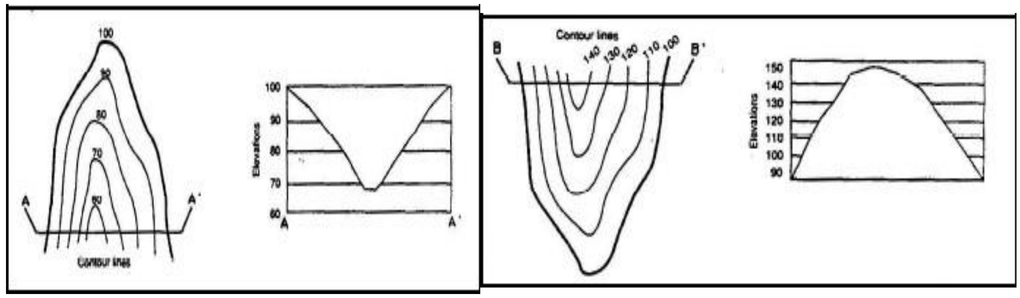


FIGURE NO 5.6

STEP 6:

Determine the direction of drainage in the area of the waterbody by drawing arrows perpendicular to a series of contour lines that decrease in elevation.

Stormwater runoff seeks the path of least resistance as it travels downslope. The “path” is the shortest distance between contours, hence a perpendicular route ***(Figure D-7)***.

Mark the break points surrounding the waterbody. The “break points” are the highest elevations where half of the runoff would drain towards one body of water, and the other half would drain towards another body of water **(Figure D-8)**.

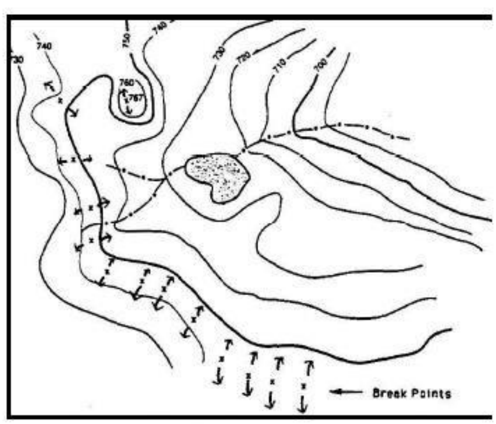


Figure D-7: Direction of drainage

FIGURE NO 5.7

STEP 8: IDENTIFY BREAK POINTS

Connect the break points with a line following the highest elevations in the area. The completed line represents the boundary of the watershed ***(Figures D-8 and D-9)***.'

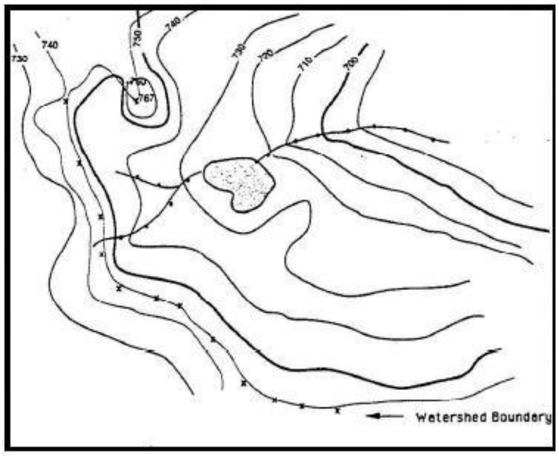


Figure 5.8: Watershed Boundary

STEP 9:

Once you've outlined the watershed boundaries on your map, imagine a drop of rain falling on the surface of the map. Imagine the water flowing down the slopes as it crosses contour lines at right angles.

Follow its path to the nearest stream that flows to the water body you are studying. Imagine this water drop starting at different points on the watershed boundaries to verify that the boundaries are correct.

STEP 10:

Distribute copies of your watershed map to your group.

STEP 11:

Watersheds sometimes have what are termed subwatersheds within them. Rivers, large streams, lake, and wetland watershed often have more than one subwatershed (usually smaller tributary watersheds) within them.

Generally, the larger the waterbody you are examining, the more subwatersheds you will find. Your watershed map can be further divided into smaller sections or subwatersheds if it helps organize your study better.

STEP 12:

Once the watershed and subwatershed (optional) boundaries have been delineated on the map, your team can verify them in the field, if necessary.

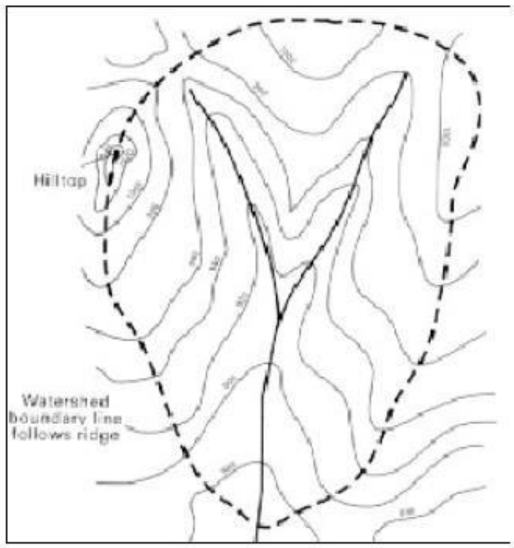


Figure NO 5.9: Idealized Watershed Boundary

Applications of Remote Sensing in Water Resources

Estimation of the hydro-meteorological state variables and delineation of the surface water bodies by using the remote sensing techniques find application in the areas of rainfall-runoff

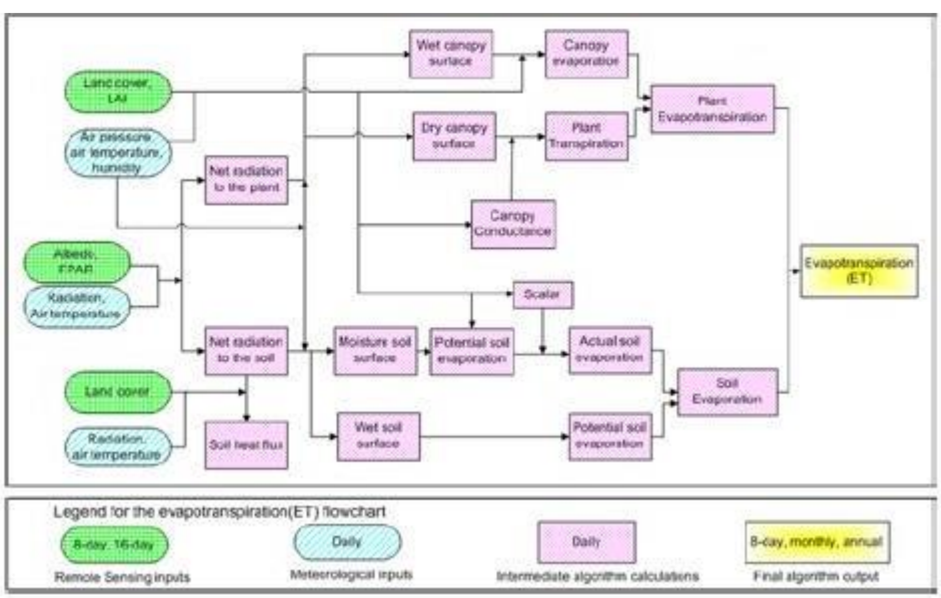


FIGURE NO 5.10

modeling, irrigation management, flood forecasting, drought monitoring, water harvesting and watershed planning and management. Some of these applications are briefly mentioned in the following subsections.

Rainfall-runoff studies

The most common application of the remote sensing techniques in the rainfall-runoff studies is the estimation of the spatially distributed hydrometeorological state variables that are required for the modeling, e.g., rainfall, temperature, ET, soil moisture, surface characteristics and land use land cover classes. Remote sensing methods used for the estimation of these parameters are described in the previous sections. Advantage of the remote sensing techniques over the conventional methods is the high spatial resolution and areal coverage that can be achieved relatively easily.96

While selecting the hydrological model for integration with the remote sensing data, spatial resolution of the hydrological model structure and the input data must be comparable. Papadakis et al.97 carried out a detailed sensitivity analysis in the river basins in West Africa to find the spatial,temporal and spectral resolution required for the hydrologic modeling. Fine resolution data was found to be relevant only if the hydrologic modeling uses spatially distributed information of the all the relevant input parameters sufficient enough to capture the spatial heterogeneity, and when the highly dynamic processes were monitored.

Hydrologic models that incorporate the remote sensing information include regression models, conceptual model, and distributed model. One of the widely used conceptual model is the SCS-CN model,98 which compute the surface runoff using the parameter Curve Number (CN). The CN is related to the soil and land use characteristics. Application

of the remote sensing data allowed a better representation of the land use, and thus a more reliable estimation of the relevant CN.99 Use of remote sensing data also helps in updating the land use changes in the hydrologic models, particularly in the areas where the land use pattern is highly dynamic, causing significant variation in the hydrologic processes.

Another commonly used model is the Variable Infiltration Capacity (VIC) model.100 VIC model requires information about the atmospheric forcing, surface meteorology and surface characteristics, which can be derived from the remote sensing data.100 Remote sensing application also helps to improve the hydrologic modeling by providing vital

information about the soil moisture content101,102 and ET rates.103,104 Use of radar images for estimating the Saturation Potential Index (SPI), an index used to represent the saturation potential of an area, is another application of the remote sensing in runoff modeling. Gineste et al.105 used the SPI derived from remote sensing, together with the topographic index in the TOPMODEL to improve the runoff simulation. With the advancement of technology, today it is possible to estimate the stream discharge by measuring the channel cross section and slopes from remote sensing platforms. Durand et al.106 used radar images from the Surface Water and Ocean Topography (SWOT) mission to extract the water surface elevation, which was further used in a depth and discharge estimation algorithm to calculate the channel flow depth and the discharge in the Ohio River. The error in the instantaneous discharge measurement was found to be less than 25% in 86% of the observations. In another study by Bjerklie et al.,107 surface velocity and width information obtained using the C-band radar image from the Jet Propulsion Laboratory's (JPL's) AirSAR was used to estimate the discharge in the Missouri River with 72% accuracy.

Drought monitoring

Monitoring of drought events and quantification of impact of the drought are important to place appropriate mitigation strategies. The advantage of remote sensing application in drought monitoring is the large spatial and temporal frequency of the observation, which leads to a better understanding of the spatial extent of drought, and its duration. Satellite remote sensing techniques can thus help to detect the onset of drought, its duration and magnitude.

Remote sensing methods are now being widely used for large scale drought monitoring studies, particularly for monitoring agricultural drought.

Agricultural drought monitoring from the remote sensing platform is generally based on the measurement of the vegetation condition (e.g. NDVI) and/or the soil moisture condition,14 using which various drought monitoring indices are derived, at a spatial resolution of the imagery. A map of the drought monitoring index can be used to understand the spatial variation in the drought intensity. Figure 9 shows a sample weekly Palmer Drought Index map, derived using the satellite remote sensing data, for the United States published by NOAA.

Remote sensing methods of drought monitoring can also be used to predict the crop yield inadvance.108 A concise review of the remote sensing applications in drought monitoring has been provided by McVicar and Jupp.14 Remote sensing data from the satellites/sensors viz., AVHRR,109,110 Landsat TM and ETM□,111,112 IRS LISS-1 and LISS-2,113,114 SPOT115 and MODIS116,117 have been widely used in drought monitoring. Some of the operational drought monitoring and early warning systems using remote sensing application are the following: Drought

Monitor of USA using NOAA-AVHRR data, Global Information and arly Warning System (GIEWS) and Advanced Real Time Environmental Monitoring Informatio System (ARTEMIS) of FAO using Meteosat
and SPOT—VGT data, and Drought assessmentin South west Asia using MODIS data by the International Water Management Institute.

The National Agricultural Drought Assessment and Monitoring System (NADAMS) project of India is another very good example of effective drought monitoring and early warning system using satellite remote sensing. The NADAMS
project uses moderate resolution data from Advanced Wide Field Sensor (AWiFS) of Resourcesat 1 (IRS P6), and WiFS of IRS 1C and 1D for detailed assessment of agricultural drought at district and sub-district level in Andhra Pradesh, Karnataka, Haryana and Maharashtra.

Flood forecasting

The poor weather condition generally associated with the floods, and the poor accessibility due to the flooded water makes the ground and aerial assessment of the flood inundated areas a difficult task. Application of satellite remote sensing helpsto overcome these limitations. Through the selection of appropriate sensors and platforms, remote sensing can provide accurate and timely estimation of the flood inundation, flood damage and

flood-prone areas. It provides a list of satellites commonly used for flood monitoring and their characteristics. Satellite remote sensing uses both IR and microwave bands for delineating the flooded areas. The algorithms used for delineating the flooded areas are based on the absorption of the IR bands by water, giving darker tones for the flooded areas in the resulted imagery.130 Images from Landsat TM and ETM, SPOT and IRS LISS-3 and LISS-4 are largely used in the flood analysis. Satellite images acquired in different spectral bands during, before and after a flood event can provide valuable information about the
extent of area inundated during the progress or recession of the flood.131 For example, Figure (from Bhatt et al.)132 shows the IRS P6 LISS-3 and LISS-4 images of the Bihar floods which occurred in August 2008 due to the breeching of the Kosi River embankment. The images taken shortly after the flood (Fig. 10a) shows the extent of inundated
areas, compared to the image taken 8 months after the flood (Fig. 10c).Sensors operational in the optical region of
the EMR spectrum generally provides very fine spatial resolution. Nevertheless, major limitations of the optical remote sensing (e.g., Landsat and IRS satellites) in flood monitoring are the poor

penetration capacity through cloud cover and poor temporal coverage. Revisit periods of these satellites typically varies from 14 to 18 days. Even though the AVHRR sensors onboard NOAA satellites provide daily images, spatial resolution of the images is very coarse. In addition, operational difficulty in the poor weather condition is also a major limitation. Microwave, particularly radar remote sensing, is advantageous over the optical remote sensing as the radar signals can penetrate through the cloud

cover and can extract the ground information even in bad weather conditions. Taking the benefits of radar imaging and optical remote sensing, in many studies, a combination of both has been used for flood monitoring.13,128,133,134 Digital Elevation Model (DEM) derived using the remote sensing methods (e.g. SRTM and ASTER GDEM) also finds application in flood warning. When a hydrologic model is used to predict the flood volume, elevation information

can be obtained from the DEM, using which the areas likely to be inundated by the projected flood volume can be identified.135 With finer and more accurate vertical accuracy of the DEM, better analyses can be undertaken using it. With the technological development, it is feasible to generate very fine resolution DEM using the Light Detection and Ranging (LiDAR) data, and this can significantly improve the flood warning services.

Table 5.1

Table 4: Some of the important satellites and sensors used for flood monitoring.

Sensor	Satellite	Characteristics	References
Landsat TM	Landsat 4–5	30 m spatial resolution, Temporal coverage: once in 16 days, Poor cloud penetration	118, 119
IRS LISS-3	IRS 1C/1D	23 m spatial resolution, Temporal coverage: once in 24 days, Poor cloud penetration	120, 121
SPOT	SPOT	8–20 m spatial resolution, Temporal coverage: once in 5 days, Poor cloud penetration	122
AVHRR	NOAA	~1.1 km spatial resolution, Temporal coverage: Daily coverage, Poor cloud penetration	123, 124
MODIS	Terra	250 m spatial resolution, Temporal coverage: Daily coverage, Poor cloud penetration	125, 126
SAR	Envisat, ERS 1, 2, Radarsat	20–30 m spatial resolution, Temporal coverage: 1–3 days, Good cloud penetration	127–129

In India, disaster management using satellite remote sensing has been operational for more than two decades136 by the National Remote Sensing Agency (NRSA), and the Indian Space Research Organization (ISRO). In case of a flood event, maps showing the flood affected areas and the flood damage statistics are released near real-time.

The system uses the near real-time meteorological data from KALPANA-1 satellite and the rainfall data from the TRMM to generate the flood warning. Also, satellite imageries (from IRS satellites) are collected at different intervals to detect the changes in the inundated areas. This information is integrated with the other data like land cover maps, basin utility maps, administrative boundaries etc., to analyze the flood damage.

Irrigation management

Remote sensing application in irrigation management includes crop classification, irrigated area mapping, performance evaluation of the irrigation systems, and irrigation advisory services. Crop classification using the satellite remote sensing images is one of the most common applications of remote sensing in agriculture and irrigation management. Multiple images corresponding to various cropping periods are generally used for this purpose. The spectral reflectance

values observed in various bands of the images are related to specific crops with the help of ground truth data.137,138 Identification of the irrigated area from the satellite images is based on the assessment of the crop health and the soil moisture condition.139–141 For example, Biggs et al.142 used data from the MODIS sensor to map the irrigated areas in the Krishna basin in India. Time series of the NDVI were generated from the MODIS images and used to assess the crop health, and to group the crops into various random classes. Ground truth and the statistical information were then used to identify the irrigated and non-irrigated areas from these random classes. In irrigation management studies satellite

remote sensing data are used to capture the spatial and temporal variations in the crop ET and soil moisture. This information is clubbed with various models to simulate the crop production and to estimate the irrigation efficiency. Performance of the irrigation system is generally evaluated using indices such as relative water supply and relative irrigation supply.143 Bastiaanssen144 has listed a set of irrigation performance indices derived with the help of the remote sensing data. Soil-Adjusted Vegetation Index (SAVI), NDVI, Transformed Vegetation

Index (TVI), Normalized Difference Wetness Index (NDWI), Green Vegetation Index (GVI) are a few of them. Several studies conducted in the past show the potential of the remote sensing data from Landsat TM, MODIS, IRS-LISS and WiFS sensors in the evaluation of the irrigation system performance.143,145–147

Irrigation Advisory Services (IAS) are the services used to help the farmers to improve the irrigation efficiency and to optimize the agricultural production from the use of irrigation water.16 Irrigation scheduling information based on the crop type, agro-meteorology and the soil moisture availability, is an example.90 The conventional methods of IAS using *in-situ* measurement from the field were less capable of providing the information

at a spatial and temporal resolution toadequately represent the dynamics of the problem. The use of remote sensing to capture the dynamic crop characteristics has drastically improved the capability of the IAS systems.

Remote sensing

application in IAS system includes the extraction of the spatial variation in the crop characteristics such as cropping pattern, estimation of the crop ET and crop indices such as NDVI, and the regular update of the information to capture the temporal variation.16 With the help of remote sensing data, the spatio-temporal variation in the irrigation water demand is better captured, resulting in a more efficient irrigation scheduling. DEMETER (DEMonstration of Earth observation Technologies in Routine irrigation advisory services) is a very good example of the use of satellite remote

sensing in IAS. DEMETER has a few pilot scale implementations in Spain, Italy and Portugal.16,148

Rain water harvesting

The techniques of rainwater harvesting are highly location specific149 and need extensive field analysis. Identification of the rainwater harvesting potential of the area, and suitable locations for the water harvesting structures are the essential prerequisites for the successful implementation of any rainwater harvesting projects. Remote sensing techniques, due to their wide range of capabilities for identifying the geomorphologic and surface characteristics, is advantageous in analyzing the water harvesting potentials and to identify the suitable sites for the water harvesting structures.149–152

In a study by Jasrotia et al.,149 satellite images from IRS 1D LISS-3 were used to extract the land use land cover map. This information was integrated with the other data like soil, slope, and drainage maps to identify the suitability of various water harvesting sites in Devak-Rui watershed in Jammu District, in India. In another study, Kumar et al.150 used images from IRS LISS-2 sensors to prepare thematic layers of land use/land cover, geomorphology, and lineaments. These

layers, along with the geology and drainage information were used to identify the potential sites for rainwater harvesting in the Bakhar watershed in Uttar Pradesh, India. Results of these studies show the advantages of the remote sensing data in estimating the runoff harvesting potential and in identifying
suitable locations for the water harvesting structures.

Watershed planning and management

Remote sensing through air-borne and spaceborne sensors, can be effectively used for watershed characterization and watershed priorityassessment. Application of remote sensing has multiple dimensions in the watershed management like water resource mapping, land cover classification, estimation of water yield,soil erosion, land prioritization and water harvesting, as mentioned in the previous sections. Mapping of saline and water logged areas is another application of the remote sensing data in watershed management. Remote sensing data have been clubbed with the hydrological models to simulate the impacts of human interventions (e.g. agricultural practices, reservoirs, water harvesting) and external influences (e.g. climate change) on the water balance. Rainfall and hydro-meteorological variables, watershed topography, watershed area, size and boundary, surface characteristics, drainage
pattern, land use/land cover, soil moisture condition,
ET, water quality parameters etc. are a few of the essential information that remote sensing can supply for the hydrologic monitoring of the watershed. Data products from the Landsat MSS, ETM□, IRS LISS-3, IKONOS, AMSR- E, MODIS, and AVHRR sensors have been widely applied in watershed management studies at various levels as mentioned in the previous sections. In addition, active microwave remote sensing using SAR are also largely used in watershed studies (e.g., SRTM DEM, radar for rainfall estimation, ASCAT soil moisture data). With the technological advancement, currently hyper-spectral sensors are also used to achieve high resolution crop classification and water quality estimation in watershed management studies. Use of IRS LISS-2 and LISS-3 images for watershed characterization and to study the suitability of soil conservation measures in different terrain and land use conditions,153 use of Landsat TM images in a watershed prioritization study to identify the potential for soil and water conservation,154 prioritization of sub-watersheds based on the satellite remote sensing (IRS LISS-3) derived river morphometric parameters,155 are some good case studies of the remote sensing application in watershed management.

Groundwater studies

Another important application of remote sensingis in groundwater assessment and management. Comprehensive reviews of the remote sensing application in the groundwater studies have been provided by Meijerink156 and Brunner et al.157 Remote sensing application in the groundwater studies are generally classified into three broad reas: estimation of the geomorphologic parameters essential for the groundwater modeling, estimation of the groundwater storage, and estimation of the groundwater potential Extraction of geological and surface information such as presence of faults, dykes and lineaments, changes in the lithology, terrain characteristics, using different types of sensors (e.g., Landsat TM, IRS LISS) have been some of the common applications of remote sensing in groundwater studies. Remote sensing techniques can also be used to extract the water levels in the lakes and rivers, which is an essential input for the

groundwater modeling. Terrain height, another important parameter, particularly in the case of phreatic aquifer, can also be derived from the remote sensing techniques. With the use of modern techniques like radar interferometry and Lidar altimetry, fine resolution DEM is now available, which can significantly improve the groundwater simulations. Remote sensing data, when combined with the ground–based observations and numerical modeling have been found to have many applications in the groundwater studies.158