UNIT 7 WATER

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7.1 INTRODUCTION

All human activities require fresh-water, which needs to be made available in adequate amounts at the right place and at the right time. This is why all early civilizations flourished along rivers. As far as agriculture is concerned, land and water are the two most vital natural resources. We have discussed some issues related to land and soil in Unit 6. In this unit, we take up the issue of water resources. Unfortunately, in arid and semi-arid regions, in densely populated countries and in most of the industrialized world, the competition for scarce water resource has already set in. Water resource is under tremendous stress today. It has been well said that the next world war might be fought for water. Signs of cold war on this resource both in India and abroad have already emerged. Since water resource is finite, per capita water resource is decreasing rapidly.

Water withdrawals are made both for consumptive uses such as irrigation or for non-consumptive uses such as hydropower, domestic and industrial purposes, navigation and tourism. Besides, some water needs to be drained to the sea for eco-system maintenance. On a global scale 70 % of the water withdrawal is for consumptive purposes. Although a part of the water is returned to the rivers/groundwater, most of the water for non-consumptive uses is returned back with degraded quality.

It is a paradox that in spite of impending water crisis, of which all of us are aware, water is used most luxuriously or wastefully. While water use efficiency in agriculture is less than 50 % in most irrigation commands (could be as low as 30 % in some cases), the wastage of water is equally discernible in the domestic and industrial sectors. Following a rainstorm, water is drained into rivers as if it would not be needed any more. Surprisingly, within few days cries of water scarcity are heard. With increasing groundwater development, a paradoxical situation is developing in many parts of the world. On the other hand, groundwater storage in many areas is increasing, raising the water table at an alarming rate. Besides the loss of water through capillary rise, it leads to soil salinization.

If water is managed inadequately, its quality can degrade, jeopardizing the future use of water. Moreover, its availability for specific use may reduce or it may not be available at all. Although we are becoming conscious of water quality, our contribution to these efforts has been minimal. Our rivers, which were revered in the past, become sewer drains during the non-monsoon months. Groundwater is being polluted indiscriminately by industries.

Fresh water is a finite resource having spatial and temporal variability. Besides the cost of controlling and developing the water resource, water is a sensitive subject. Any minor change in policy would result in gainers and losers. Therefore any change is likely to be welcomed and opposed depending upon the gains and losses. Since water sustains civilized human life, it has many facets all of which cannot be covered here. In this unit, we introduce you to the hydrological cycle. You will learn about the quantity and quality aspects of water. Since too much or too little water or both affect production and productivity, you would be familiarized with issues related to floods, water logging and drought. Finally we introduce the concept of Watershed Management. In the next unit we discuss the issues involved in conserving biodiversity.

Objectives

After studying this unit, you should be able to:

- discuss the relevance of water for increased production and productivity in agriculture;
- describe surface and ground water resources and their interdependence;
- analyse the extremes in the availability of water leading to floods and droughts;
- describe the adverse effects of water logging on soil health as well as the remedial measures required;
- comprehend the water quality concerns especially related to agriculture; and
- explain the concept of watershed management.

7.2 THE HYDROLOGICAL CYCLE

The total amount of water in the **hydrosphere** has been estimated at 1500 million km^3, which if spread over the entire surface of the earth, would rise to 3000 m above the surface. Only 5% of this water is fresh in nature, the remaining being saline. Of this only 20% is in the liquid form, the remaining being in frozen form. Thus, only 1% of the water in the hydrosphere is available for use. Around 99 % of this water is in the form of groundwater. These global average values may vary from one continent to another, from one region to another or from one country to another. But it is abundantly clear that water has multifarious uses in various sectors of economy, each competing with the other to get a lion's share of this scarce quantity. In such a situation, it is necessary that limited water resources are exploited and used in a judicious manner.

When we talk of water resources of the hydrosphere, our main interest is in the transfer of water from one form to another. Since the total amount of water in the hydrosphere is constant, it is clear that this transfer occurs in the form of a continuous cycle or a series of cycles. Moisture constantly circulates between land, ocean and the sky. The cycle has neither a beginning nor an end. This is known as the **hydrological cycle.** you have studied about it in the first course of this programme. We repeat it here briefly. The major elements of this cycle over a region are shown in Fig.7.1. (See Fig.7.2 for a pictorial version of hydrological cycle).

The term precipitation includes all forms of water that is received by earth from the atmosphere. It includes rainfall, snow, frost, drizzle and hail etc. On a global scale, some 110,000 km^3 of water is received. The vegetation intercepts a part of the precipitation while a part is retained as soil moisture. Most of it gets evaporated (70,000 km^3) and is known as **green water**. Of the green water, 18,000 km^3 is being exploited for agriculture while the remaining meets the water needs of all non-irrigated vegetation, including forest and woodlands, grassland and rain fed crops.

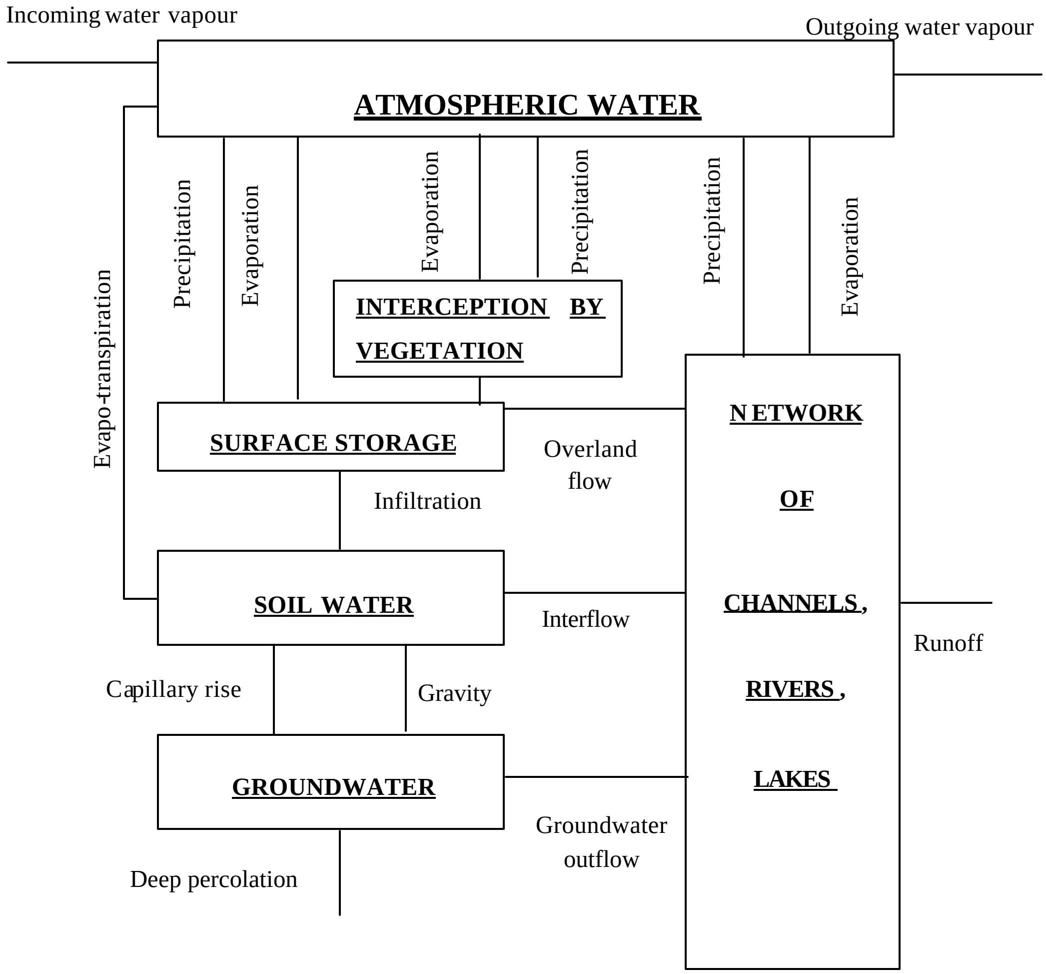

Fig.7.1: Flow diagram showing various components of the hydrological cycle

The remaining 40,000 km^3 remains on the earth as blue water or ground water and flows to the sea or lakes unless stored, transported and exploited to meet human needs. Only 12,500 km^3 of this water is accessible for human use as per the present technologies available.

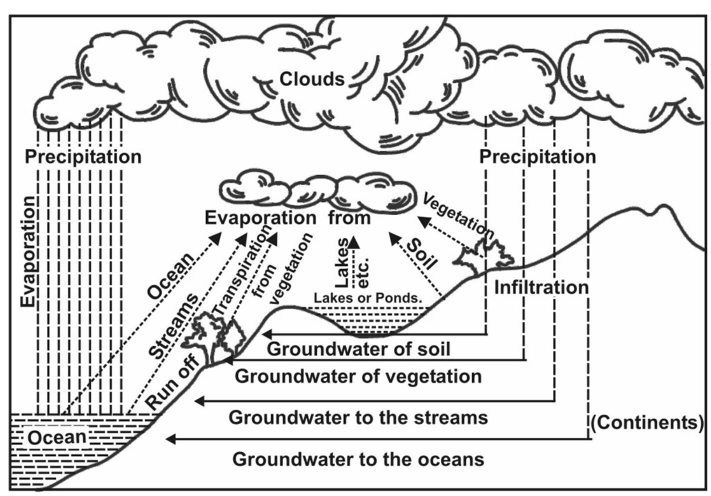

Fig.7.2: Hydrological Cycle

In the hydrological cycle, soil acts as a reservoir and water is always in transitory storage in soil. Considerable time may elapse before this stored water flows underground to stream or is returned to the atmosphere by evaporation. Eventually, however, all water temporarily stored in the soil must enter the transitory part of the hydrological cycle by percolating to underground streams or entering into atmosphere by evaporation. There are many opportunities to influence the hydrological cycle and affect water conservation in agriculture. We discuss this issue in the next section. But first you may like to concretize the understanding of hydrological cycle by attempting an exercise.

SAQ 1

a) What do you understand by the hydrological cycle?
b) Explain the role of soil in the hydrological cycle.

7.3 WATER RESOURCES AND AGRICULTURE

A greater part of human requirement, food, fibre and accessories for shelter are met from agriculture. Logically, a major part of human water use is in agriculture. On a global basis, 70% of the water withdrawals are claimed by agriculture. On regional basis, and particularly in arid regions, it might go as high as 90% of the total water withdrawals. Since rain fed agriculture cannot be expected to keep up with growing demand for food because of environmental constraints, within the agriculture sector, the largest share of water is claimed to roughly irrigate about 250 million ha of irrigated lands worldwide. The importance of this water allocation could be gauged from the fact that 40% of the total food and agricultural commodities are produced on these irrigated lands, which is only 17% of the total cultivated area. The remaining 60% is produced by 83% of the cultivated area. According to statistics from India and other parts of the globe, a 50 to 200% increase in agricultural production could be obtained upon introduction of irrigation. In today's perspective, irrigated agriculture seems to be the only weapon to fight with to produce additional food for the 800 million undernourished today and 2 billion more people expected to join us by 2025.

Accessible blue water needs to meet some of the essential requirements such as water for drinking by human and animals, for hygiene, sanitation, municipal use, for industrial establishment, aquatic life and environment. All these requirements would also have a quantum jump because of increasing population, increased standard of life and changing eating habits of the populace. Apparently agriculture has to compete with these sectors that have a higher potential and precedence. These sectors can pay more for water than agriculture. Thus increasingly, agriculture has to leave its share of fresh water to other sectors and rely upon water used once by these sectors.

Performance of agriculture under irrigation depends to a great extent on the timely and adequate supply of good quality water. Safe, reliable and adequate quantities of water are also needed for livestock and for processing operations. As such, a large infrastructure to supply water is needed to achieve these goals. Operation and maintenance cost of this infrastructure is also quite high. Pricing of water should be so fixed that at least it covers the cost of operation and maintenance.

It is assessed that to develop irrigation on one ha of land in India presently costs Rs. 100,000 or more.

While irrigated agriculture consumes the largest amount of water, it is known to be the most inefficient sector in the use of water. The **water use efficiency** in some cases being as low as 30%, a major fraction of the water is wasted and adds to the groundwater storage. Water use efficiency has many facets. **Resource saving**, **financial saving** and **environmental benefits** are all linked to the improved water use efficiency.

World Water Vision has projected that with increasing efficiency 40% more food products can be produced by 15-20% additional water. By improving the water use efficiency, financial savings would occur in operational cost of pumping, treatment of water and wastewater and additional income would be generated as a result of expanded area under irrigation. Environmental benefits would also emerge from reduced problems of water logging and soil salinization, increased discharge for in stream use, and reduced pollution of groundwater or surface water resources. Whatever agricultural advances are made, the fact remains that to grow more food we require more water whether the agriculture is rain fed or irrigated. It is estimated that by 2025, demand for water in agriculture sector would increase by 15-20%. Some of this water can come from rainwater harvesting in arid and semi-arid regions. Exploitation of shallow saline water aquifers and use of grey and black waters could be other sources that could increase water for use in agriculture.

Categories of Water and their Role in Agriculture

Available global or regional water for use in agriculture have been grouped in five categories besides a category based on implication of export-import of agricultural products.

Category of water	**Source**	**Potential for use in agriculture or remarks**
Blue water	Sea, lakes, rivers, canals, etc.	Extensively used for irrigation. Its availability is likely to decrease with increasing competition from other sectors.
Green water	Soil moisture and water in plants	Mostly used by plants and agricultural crops particularly forest, grass lands and rain fed agriculture.
Fossil water	Groundwater	Used for domestic and agricultural uses. Its availability to agriculture would decrease with time as a result of competitive demand from other sectors.
Grey water	Wastewater from bathroom, kitchen and washbasins.	Potential for use in crop production. Suitable for kitchen gardening and irrigating lawns.
Black water	Domestic sewage/Industrial waste	Potential for use in crop production. 21st century water resource for agriculture. Cleaner technologies required to avoid heavy metals/pathogens entering human chain.
Virtual water	Water used in producing grains/animal product	Export-import of food grains/animal product indirectly results in export-import of water. One kg of rice or wheat export means export of 2000 litres of water for rice and 800 litres of water for wheat. It is going to assume importance in export-import during the next few decades.

So far you have learnt how improving the efficient use of water can help one in better management of this resource. The question is how to do it? We look into the issues involved but first you may want to answer the following question.

SAQ 2

What are the major benefits of improving water use efficiency? Give examples of each.

Strategies for Increasing Productivity of Water in Agriculture

A five-pronged strategy is required to meet the increasing demand of water for meeting the food needs of the world.

- Improved agricultural technologies for increasing water productivity: more crop per drop;
- Harnessing new resources of water to augment existing water resources;
- Water conservation;
- Water reuse;
- Improving water institutions and stakeholders participation for improved water governance.

India is home to 18% of the world's human population, and 15% of the animal population, but owns only 3.7% of the world's water resources.

Let us see how these strategies can be used to manage water resources.

♦ **Development of Surface Water Resources**

Development of surface water resources like tanks, ponds, wells etc. has been a major thrust area in the past few decades and therefore, huge investments have been made in most countries. It has been estimated that due to extreme variability in precipitation, it may not be possible to store all the water that is available as runoff. this is because assured storage of all the water is not possible and limited storage space is available in hills and plains.

Although great strides have been made in developing the irrigation potential, some issues have cropped up, which require immediate attention.

- The cost of creation of irrigation potential is increasing exponentially.
- The gap between the potential created and potential utilized is huge in all developing countries. For example, it is provisionally assessed at 4.6 million ha in India which means at the present cost of potential creation, more than Rs. 460 billions has been locked.
- In spite of huge investments being pumped in creating irrigation potential, the production and productivity of irrigated lands is abysmally low. An average productivity of 2.5t ha^{-1} is considered low by any standards and it seems there are some inherent lacunae in our irrigation planning and providing necessary support and infrastructure.
- As per recent assessment, many million ha of agricultural lands have gone out of cultivation because of the spread of water logging and soil salinization. Apparently, besides loss in production at current prices, it has locked a huge investment (Rs.560 billion in India). It is believed that a large chunk of the area in commands might be experiencing these problems to varying degree, affecting production and productivity.

♦ **Groundwater Development**

Groundwater resource that can be replenished is mostly derived from precipitation. Of the total rainfall, about half percolates into the ground, out of which only one fourth joins the groundwater. A part of this water regenerates into streams but simultaneously, there is net addition of water through streams and irrigation.

A paradoxical situation is developing due to the uneven distribution of groundwater structures. While in many blocks water table is declining, in other areas the water table is rising. Since the rising water table is clearly correlated with saline/sodic groundwater areas, water logging and soil salinization are also developing in these areas. Thus, efforts to tap and use poor quality groundwater for agriculture need to be upgraded.

SAQ 3

Outline the major issues involved in the development of surface and ground water resources.

7.4 WATER STRESS CONDITIONS

Weather plays a positive role in the production of crops. But at times, it also plays havoc and destroys the crops and vegetation. Floods in South Asian regions, which usually follow excessive rains cause misery to human and animal population, affect infrastructure and adversely affect crop production and productivity.

7.4.1 Floods

Floods usually occur whenever the intensity of rainfall exceeds the rate of disposal of runoff in the catchments. They also occur when the river in the downstream cannot accommodate the large volumes of inflow and spills over from the riverbanks or breaches inundating the low-lying areas along the course of stream flow. Flood damage due to overflow is more common along banks of major rivers. Construction of dams provides some respite from floods. Flash floods due to cyclonic storms in coastal districts of these countries are quite common. Flood events coupled with high wind velocity cause enormous losses.

Agricultural Production and Floods

Floods have both positive and negative effects on agriculture. One of the positive effects is that silt carried by floods gets deposited on agricultural fields. This silt could raise the fertility of agricultural land enhancing future production. On the contrary, partial to complete damage of production could be anticipated during the flood event depending upon the severity of the floods, duration of flood, type of crops grown and the growth stage of the crop at which flood event has occurred. For example, cereal crops and sugarcane crop can tolerate flood events better than pulse crops. Similarly, damage would be more, if flood events occur at germination / seedling stage or reproductive stage than at other stages. Silt deposited on the plant leaves can significantly lower the photosynthetic activity in the plants resulting in lower productivity. Besides in some cases, silt from already eroded lands is brought and it might lower the productivity upon deposition rather than raising it.

Since floods cause severe damage to agricultural crops and human habitations, it is best to devise measures for flood control. We should all know certain basic principles underlying these measures.

Principles of Flood Control

Several preventive and curative measures have been adopted to minimize flood damage. In any strategy, one or more of the following basic principles are involved.

- Treatment and management of watershed to reduce runoff. Most soil conservation measures help in flow regulation or reduced runoff.

- The retention of part or whole of the runoff. Construction of multi-purpose reservoirs and detention basins fall in this category.

- The diversion of a part or whole of the runoff. Flood ways or river diversion schemes are a part of this strategy.
- The confinement of floods to a certain part of the flood plain. Levelling, bank stabilization, strengthening embankments, construction of embankments around densely populated or highly industrialized urban areas utilize this principle.

SAQ 4

a) How do floods affect agricultural production?
b) Explain the basic principles of flood control.

7.4.2 Water Logging

Water logged soils occur in almost all climatic zones particularly in monsoon climatic regions. Due to simplicity, the definition proposed by Clayton has been adopted in many countries, which **defines a land as water logged if the water table is within ± 150 cm of the ground surface**. Apparently it accounts for both the surface and subsurface water logging. Thus, the word water logging is used to designate stress due to water stagnation or the shallow water table since similar conditions could occur as a result of any of the two causative factors. However, to designate the problem of water stagnation on the land surface, besides water logging, surface stagnation and flooding have also been used synonymously. Occurrence of deep submergence depths caused by floods are generally excluded from water logging since the causative factors as well as the solutions to such a problem could be different.

Surface Stagnation

Areas in humid and sub-humid regions, particularly heavy textured soils, are prone to surface stagnation during monsoon season. Besides the degree and duration of water stagnation is increasing even in semi-arid areas due to inadequate provision of drainage in developmental activities, poor maintenance and upkeep of drainage systems, encroachment of wetlands and rising water table in irrigation commands. The problem may or may not be accompanied by shallow water table. Surface drainage alone can help to reclaim these lands.

High Water Table

Problem of rising water table is usually experienced in irrigated lands when surface irrigation is introduced without providing for adequate drainage. In such a situation rise in water table is an inevitable consequence. For example, recent experiences in India reveal that in the Indira Gandhi *Nahar Pariyojana*, the water table has risen at the rate of 1m per annum (Fig.7.3).

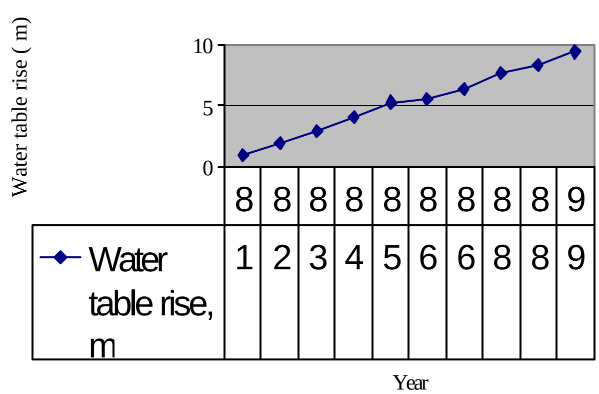

Fig.7.3: Rise of water table in GNP

As a result, water logging and soil salinity appeared much earlier than anticipated. The problem is generally associated with the problem of surface drainage although shallow water table is more critical to crop damage. As such, investments need to be made both on surface and subsurface drainage. Field investigation would only reveal the most optimal solution to the problem. You may wonder what is involved in such investig ations. Let us find out.

Field measurement/laboratory investigations need to be undertaken to ascertain the kind and degree of the problems.

- Standing water or wet spots in parts of the field where crop stand is poor.
- Open wells, gravel pits and deep channels are observed, which show the depth to groundwater. If soil horizons are reached which are wet and contain black or red mottles, one can assume that soils are poorly drained at this level.
- Salts present in the form of a white crust on the soil surface also reveal the problem of water logging. Since the problem of water logging could occur even in the absence of such a crust, its absence does not mean that there is no problem of water logging.
- A general yellowing of the crop can be noticed in areas affected by water logging, soil sodicity and soil salinity.
- Vegetative cover is a good index to depth to water table in many areas. Trees such as willows, cottonwood and poplar often thrive in high water table areas. Reed grass and sedges are also common.
- Absence of surface drains or their condition (full of vegetation or plugged up) could also indicate the problem of water logging/ drainage.

Field Measurements to Assess the Problem

Under field situation, water logging is measured/assessed through physical measurement of the depth to water table using open wells, tube wells or observation wells. Depth to water table in the range of 0-1.5 m would usually indicate the problem of water logging although it would depend upon the soil and crop characteristics. A relatively shallow water table may not be a problem in a coarse textured soil but even a relatively deeper water table could cause problem in a fine textured soil.

Under field situation, Oxygen Diffusion Rate (ODR) is a good measure of the oxygen deficiency. ODR is measured with an oxygen diffusion rate meter. The oxidation-reduction potential (redox potential, RP) of the soil is also used as an indicator of the problem of water logging. In practice the RP of the soil is measured with an oxygen meter using an Ag-AgCl reference electrode.

Water Logging and Crop Yield

Principally, water logging inhibits aeration, resulting in excess of CO_2 and decline in O_2 concentration in the root zone. Besides, water logging adversely affects mineral nutrition, causes imbalance in uptake of plant nutrients and aids in several chemical and biological reactions leading to production of toxic ions in the root zone. As a result of one or a combination of these factors, crop yield is adversely affected. The yield is also affected because of inhibited leaching and secondary soil salinization due to shallow water table. Cropping intensity is much less in water logged saline lands compared to non-affected areas. The choice of crops is also limited.

Water logging often leads to delay in sowing of crops because it is difficult to till the land when wet. If heavy machinery is used on wet lands it would adversely affect its physical properties. Since, each crop has some optimum date of sowing, any delay in sowing would lower the productivity.

Besides what has been stated above, the excess water and the resulting continuously wet root zone can lead to some serious and fatal diseases of the root and stem (Poysa et al. 1987).

Water Logging/ Soil Salinity and Socio-economic Implications

Not only the farming community but also the non-farming communities feel its adverse impact in one-way or the other. In fact, as a result of the twin problems, the whole region is caught in an economic quagmire (Table 7.1).

Table 7.1: Anticipated losses due to water logging

Agriculture	Landscape and infrastructure	Socio-economic
Decline in agricultural production	Damage to infrastructure	Increased socio-economic disparity
Restriction on crops	Landscape degradation	Increased expenditure on health related services
Decline in product quality	Decline in eco-system health Damage to soil health	Migration from rural to urban areas Increased gender disparity

The obvious question that may have come to your mind is: How do we take care of this problem?

Management and Reclamation of Water Logged Lands

Since water logging is a widespread problem under different agro-climatic conditions, several options have been field tested to minimize its adverse effects. Some of the management options are: land forming (bed plantation, raised and sunken beds), crop selection in favour of tolerant crops (Table 7.2), skipping or delaying irrigation so that crops can draw a part of their water requirement from the shallow water table, applying less water per irrigation, cultural practices such as hoeing and weeding including chemical control of weeds, application of additional doses of nutrients through soil or foliar application and mulching to minimize secondary salinization.

Table 7.2: Tolerance levels of crops to high groundwater table (Groundwater at 50 cm)

Tolerance level	Crops
High tolerance	Sugarcane, potatoes, rice, willow, plum, broad beans strawberries, some grasses
Medium tolerance	Sugar beet, wheat, oats, citrus, bananas, apple, barley, peas, cotton pears, blackberries, onion
Sensitive	Maize, tobacco, peaches, cherries, olives, peas, beans, date palm

Improved Drainage: The Only Way to Ameliorate Water Logging

Inadequate drainage is the principle cause of the water logging and therefore, solution of the problem is also through improved drainage. Productivity of agricultural lands can only be sustained if drainage improvements are undertaken on cropland currently affected by submergence or high water tables. Farmers who have heavy textured soils, soils with plow layer, which commonly develops in lowland rice-wheat system, alkali lands with poor water absorption characteristics or those who rely mainly on surface irrigation should have adequate surface drainage facilities to remove excess water If the recharge to the groundwater is more than the discharge and natural drainage is unable to take care of this recharge, such a situation calls for providing subsurface drainage. Subsurface drainage may be accomplished either through the construction of open trenches or through buried clay or concrete tiles or perforated pipe. It must, however, be realized that most crops have an optimum depth to water table to get optimum crops.

In the monsoon climatic conditions an integrated drainage system consisting of appropriate capacity surface drains aided by appropriately spaced subsurface drainage or vertical drainage could reclaim the affected lands in the shortest possible time. Such a set-up would allow cultivation of lands in the first year itself while the full potential of yields could be realized in 2-3 years.

Surface Drainage

It is defined as the process of removal of water from the land surface by means of surface flow. The amount of water to be removed is expressed in units of mm day^{-1}. The system that is designed to improve surface drainage of an area is known as surface drainage system.

In order to provide relief against recurring floods and to save the crops from damage, surface drains have been implemented at regional scale in many regions. But because of the underlying principle that collectors and main drains are provided by the state while field drains are to be constructed by the farmers, drainage systems have worked well only as flood control measure. The crops continue to suffer adversely because of lack of field drains, which are rarely constructed by the farmers. Improved surface drainage alone could help to increase the yield by 10-25% or even more in some cases.

Subsurface Drainage

Surface drainage can only remove surface stagnation of water; as such it would prevent/delay the rise in the water table. To control the water table in areas where water table is already in the root zone, some kind of subsurface drainage is very essential. Removal of excess groundwater to control the groundwater table is known as subsurface drainage. A system that is designed to control the water table is known as subsurface drainage system. Subsurface drainage can be accomplished through several ways. Most promising are:

Horizontal subsurface drainage or pipe drainage: Drainage is accomplished by laying pipes with holes, which collect and convey the excess water to collector and main drains. Some of the standard layouts to construct effective drainage system are shown in Fig. 7.4. Horizontal pipe drainage is an effective intervention to control water table, improve aeration and help to leach down the excessive salts from the root zone.

Vertical Drainage: Tube well or wells act as drainage structure in this kind of drainage system. Encouraging farming community to install tube wells for irrigation, which also act as vertical drainage systems, seems to have worked well under the Indian conditions.

Bio-drainage: Plants like Eucalyptus that consume water luxuriously are grown to lower the water table. This system of drainage can be successfully adopted in preventing the rise in water table.

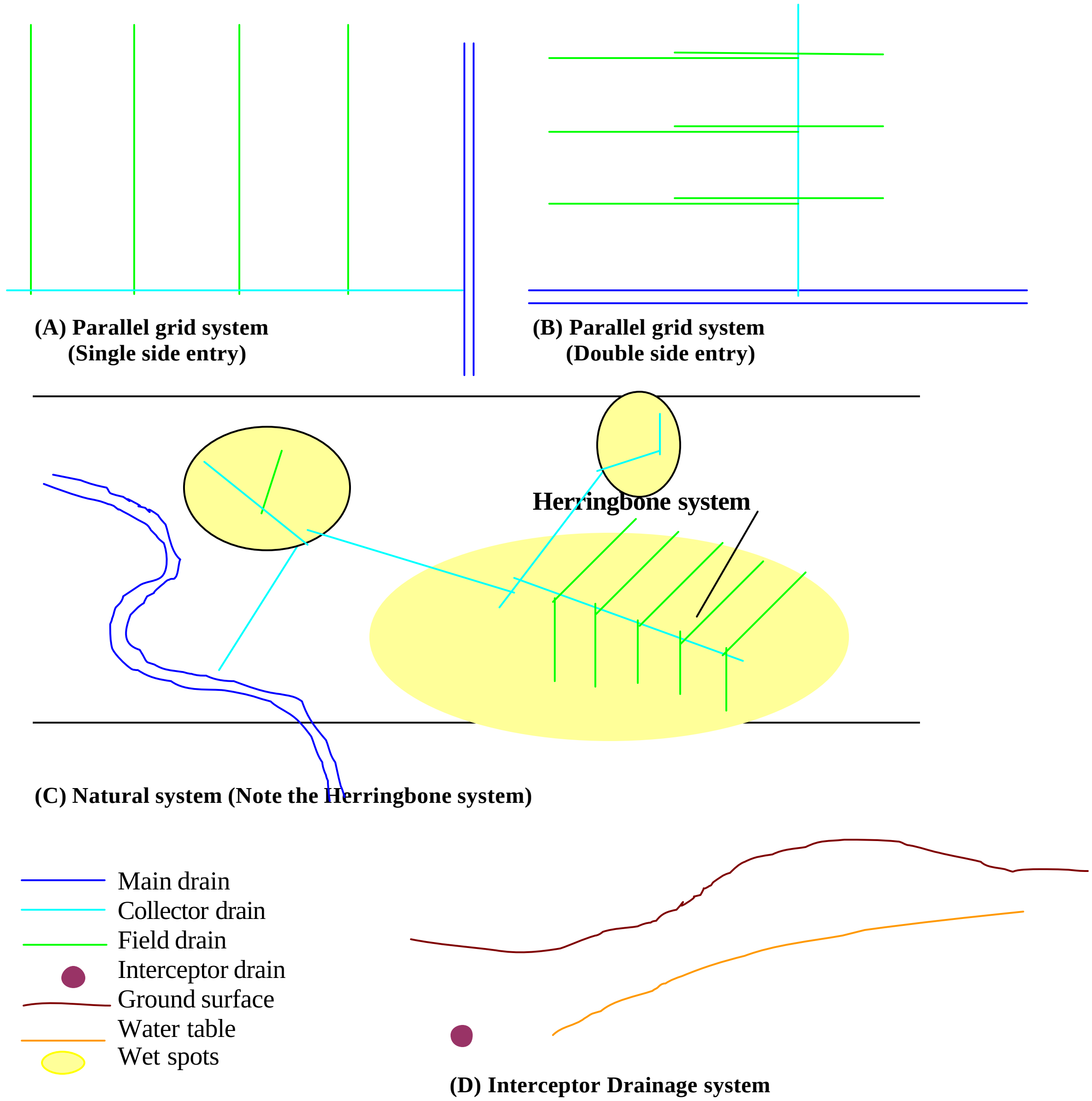

Fig.7.4: Standard layouts for drainage systems

SAQ 5

a) How has water logging been defined? Why is Clayton definition commonly adopted to classify water logged lands?

b) List the causes of yield decline in water logged lands.

Along with floods, droughts occur frequently in some parts of South Asian Countries. Therefore, we now discuss its implications for agriculture.

7.4.3 Drought and Agriculture

Many attempts have been made to define drought in terms of precipitation or in terms of deficiency of water to crops. Depending upon the time of occurrence of drought, drought has been categorized into three categories as follows:

- Early-season drought resulting from delayed start of the rainy season or prolonged dry spell after early or normal start;

- Mid-season drought; and
- Terminal drought due to early cessation of the rainy season.

From a purely agricultural point of view, climate alone cannot define drought since soil properties and crop/ soil management practices also influence plant survival. From this point of view, a drought is defined as a period in which lack of water reduces growth and final yield of crops in a region. Crops have the capacity to use soil water initially stored in the root zone. The soil water in the matric potential range of –0.3 bar to –15.0 bar (–30 kPa to –1500 kPa) is available to the plants. This range is between the field capacity and the permanent wilting point. If this water is enough to meet the water requirement of the plant for the drought period, crops can survive the drought. Drought tolerant plants however can use soil water below –15.0 bar. Since the matric potential at this limit decreases rapidly in most soils, it is expected that very little water would be available for agricultural crops beyond permanent wilting point. In that case plants lose vigour, get wilted and meet a premature death.

A plant's ability to survive dry conditions depends, besides the severity of drought, on the plant's characteristics. On the basis of these characteristics plants have been divided into three groups namely:

Drought escapers : These are plants with a short growing period. These plants escape drought by germinating, growing and producing in a very brief life span. These plants can mature if there is enough moisture to germinate the seed. Most desert ephemerals are included in this category.

Drought evaders: These plants have intensive deep root system as well as systems to restrict water loss by reducing evapo-transpiration. They also adjust to drought conditions by reducing leaf area or closing leaf stomata.

Drought endurers: These plants endure the drought by means of storing water in some organs (cacti) or by shedding leaves and becoming dormant such as mesquite.

From the agricultural point of view, most crops must come from drought evading group. Since drought is not a regular phenomenon, farmers usually opt for high yielding crops and varieties rather than going for drought resistance characteristics, which might yield less.

SAQ 6

List the three categories of drought. Categorize the kind of plants based on their characteristics to tolerate drought.

Having developed a scientific understanding of drought, you may like to learn about the strategies to tackle drought.

Strategies to Mitigate Drought Conditions

A three-pronged strategy could be adopted to mitigate the adverse effects of drought on plants.

- ❖ Efficient conservation of rainwater through comprehensive land management techniques such as by adopting mechanical and vegetative structures, tillage practices and creation of water resources through rainwater harvesting and storage. Inter-plot water harvesting, construction of dead furrows, sowing across the slope and ridging, contour farming, graded border strips and raised bed and sunken systems are some of the successful strategies adopted for rain water conservation under various rainfall patterns and soil types. For rainwater harvesting, check dams and farm ponds could be constructed to meet the crop requirement at the most critical periods.

- Adoption of improved crop management technologies could be useful depending upon site specific situations. These include off-season tillage, timely planting of crops, use of improved crop varieties, intercropping, double cropping, weed control to minimize competition for water and nutrients, contingent crop planning with varieties suitable for late sowing, mulching, timely and adequate nutrient application, deep seeding and spray of urea.

- The third strategy is to develop alternate land use system for maximizing productivity of food, fibre, fodder and fuel. The planning should be based on land capability classes. Some of the promising land uses are: Agri-silviculture for soils in land capability class IV with annual rainfall up to 750 mm, silvipasture involving a tree component with perennial grass or legume species for land capability class V and higher, agri-horticulture in land capability class II to IV receiving average annual rainfall more than 750 mm.

We now discuss the issue of water quality that is equally important in the management of water resources.

7.5 WATER QUALITY

Pure water rarely occurs in nature. By the time a raindrop reaches the surface of earth, different kinds of gases and suspended materials of the atmosphere mix with it. Water being a universal solvent, many kinds of salts gets dissolved in it as it moves over the land surface or gets percolated into the ground. The kind of salts present in the water to a great extent would depend upon the parent materials of the soil encountered throughout its course. Chemical and biological pollution through point and non-point sources also determines the quality of water.

Quality of water has different meaning for different people. The quality standard for drinking purposes would be entirely different than quality standards for other domestic uses. Industrial quality standard for different kinds of industry would vary. Within agricultural sector, the water quality standard for aquaculture would be different than for crop production or for animal husbandry. Apparently, the quality of water must be evaluated on the basis of its suitability for the intended use.

Water Quality Evaluation for Agriculture

Physical, chemical and biological measurements provide valuable tools to assess water quality problems. From the agricultural point of view, a series of **water quality parameters are important** to evaluate water quality. These include silt content, turbidity, dissolved oxygen, total dissolved solids, pH, faecal coliform, faecal enterococci, toxics, micro-invertebrates and biochemical oxygen demand.

7.5.1 Water Quality for Crop Production

To classify water with respect to their suitability for irrigation, four parameters are in vogue.

- Total salt concentration given by its Electrical Conductivity (EC);
- Relative proportion of sodium to other cations given by Sodium Adsorption Ratio (SAR) of the water;
- Residual Sodium Carbonate (RSC); and
- Toxicity.

Electrical conductivity refers to the reciprocal of the electrical resistivity. Resistance of a metallic or electrolytic conductor, which has a cross-sectional area of 1 cm^2, is expressed in Ohms. Electrical conductivity being reciprocal of resistance is expressed in mhos per centimetre. For convenience, small units such as millimhos cm^{-1} or micromhos cm^{-1} are used to designate EC of water. Currently EC is expressed in dSm^{-1}, which is equivalent to 1 millimho cm^{-1}.

The **pH** of water is a measure of the degree of its acidity or alkalinity. Waters having pH less than 7 are acidic while with pH above 7.0 are alkali in nature. However, such waters may not be confused with alkali waters having RSC > 2.5. As such pH has a limited role in determining the water quality. A pH range of 6.5-8.4 is considered good for growing most crops.

Sodium Adsorption Ratio is the relative concentration of mono-valent cation sodium over the divalent cations calcium and magnesium. It is given by the relation:

$$SAR = \frac{Na^{+}}{[(Ca^{++} + Mg^{++})/2]^{1/2}}$$

Here concentration of cations is expressed in meq L^{-1}.

Residual sodium carbonate is defined as the excess of carbonates and bicarbonates over calcium and magnesium as per the following relations:

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}), \text{ expressed in meq } L^{-1}.$$

Since high RSC of water is a cause of the build-up of alkalinity in the soil, these waters are designated as alkali waters. These have RSC > 2.5 and may or may not have high SAR.

On the basis of these 3 parameters, the quality of water has been grouped into 3 main classes: **good**, **saline** and **sodic**. Saline and sodic classes have further been categorized into 3 groups each (Table 7.4) with increasing problems in their use for crop production.

Table 7.4: Grouping of poor quality water

Water quality	EC_{iw} (dS m^{-1})	SAR_{iw} (mmol $l^{-1})^{1/2}$	RSC (meq l^{-1})
A. Good	< 2	< 10	< 2.5
B. Saline			
i. Marginally saline	2-4	< 10	< 2.5
ii. Saline	> 4	< 10	< 2.5
iii. High-SAR saline	> 4	> 10	< 2.5
C. Alkali waters			
i. Marginally alkali	< 4	< 10	2.5 – 4.0
ii. Alkali	< 4	< 10	> 4.0
iii. High-SAR alkali	variable	> 10	> 4.0

SAQ 7

Explain the terms Electrical Conductivity (EC), Sodium Adsorption Ration (SAR), and Residual Sodium Carbonate (RSC).

Harmful Effects of Saline Water

Saline water per se is not harmful to the plants. The harmful effects of saline water irrigation are mainly associated with accumulation of salts in the soil profile and are manifested through non-availability of water to plants due to increased osmotic potential, poor and delayed germination and slow growth rate. Excessive salts in root zone can induce early wilting and the effects are almost similar to those of drought. Some of the visual symptoms are that the plants look stunted; leaves are smaller but thicker and often have dark green colour as compared to plants growing in a salt free soil irrigated with good quality water.

Harmful Effects of Sodic Water

Sodic water, on the other hand, adversely affects soil physical properties. The increased exchangeable sodium percentages (ESP) resulting from their long-term use leads to breakdown of soil structure due to swelling and dispersion of clay particles. Fine textured soils remain dispersed and puddled when wet and hard when dry. These soils do not easily attain proper soil moisture conditions for cultivation. A thin crust is often formed at the soil surface, which acts as a barrier to water penetration and seedling emergence. Increase in soil pH reduces the availability of a number of plant nutrients like nitrogen, zinc, iron, etc. It also results in decreased availability of calcium and magnesium and toxicity of sodium. In most cases, the yield of crops is adversely affected by a combination of these factors.

Use of Saline/Sodic Water for Crop Production

For effective and productive use of saline/sodic waters, we need to know about the quality of water, suitable crops, mineral composition of soil, soil texture, climatic conditions and the management options that can be easily adopted. Selection of a salt tolerant crop is paramount to the use of saline/ sodic waters (see Unit 6). Some feasible strategies for its use for crop production are:

- Direct application;
- Conjunctive use.

In conjunctive use, any of the following two strategies can be used:

– Blending of saline/alkali waters with canal water
– Cyclic or rotational use of saline/fresh waters

Direct Application

Crop tolerance to salinity varies a great deal amongst the crop plants and to a lesser extent amongst their genotypes. These inter and intra-genic variations in salt tolerance of plants can be exploited to select crops/cultivars that produce satisfactorily under a given root zone salinity. In general, the oilseed crops requiring less water can tolerate waters of relatively higher salinity, whereas most of the pulses are sensitive. Vegetable crops are the most sensitive. Tolerance limits also vary with soil type. Comparatively speaking, high salinity waters can be used in coarser soils than heavy texture soils. Thus, depending upon the soil type a crop can be selected that can withstand the salinity of water.

Since improved irrigation practices can help to use relatively high salinity water than can be applied with surface irrigation techniques, sometime a switchover from surface irrigation to sprinkler or drip irrigation can help in directly using saline water to produce many crops of interest.

Conjunctive Use of Fresh and Saline/Sodic Waters

Highly saline/sodic waters cannot be used for crop production directly; such waters can be used in conjunction with fresh canal water. The successful strategies for the use of poor quality saline/sodic waters are through mixing or blending and cyclic use.

Saline waters of high salinity cannot be used directly for crop production since salinity build-up in the root zone would be quite fast and detrimental to crops. These waters can be used in conjunctive mode. Blending involves mixing two waters of different qualities to obtain water that is suitable for crop production. The salinity/sodicity of the water after mixing should be within the permissible limit, based on soil type, crop to be grown and climate of the area.

The cyclic use, also known as sequential application or rotational mode, facilitates effective conjunctive use of fresh and saline/sodic waters. In this strategy, canal water is replaced with saline/sodic water in a pre-decided sequence/cycle. A major advantage of the cyclic strategy is that steady state salinity conditions in the soil profile are never reached. It is due to the fact that the quality of irrigation water changes over time.

Sequential application: In this technique, canal and saline/sodic waters are applied in a pre-decided sequence. For example, alternate irrigation with canal and saline/sodic water could be one sequence.

7.5.2 Management Practices

Several cultural practices and management options can help to improve the crop productivity when saline/sodic waters are used for crop production. Apparently, these management practices aim at preventing the build-up of soil salinity/ sodicity and toxic ions in the root zone. These practices also control the salt balance in soil-water system as well as minimize the damaging effects of salinity on crop growth.

Pre-sowing Irrigation: From the point of view of salt tolerance, in most crops, the period of germination and seedling emergence is the most critical stage. Failure of the crop at this stage scales up to poor crop stand. As a result, one ends up with considerable decrease in yield.

Seed Rate: To ensure adequate plant population to compensate for mortality or poor tillering, seed rate, which is around 25% more than the seed rate recommended for cultivation of crops with normal waters, is recommended.

Nutrient Management: When saline/sodic waters are used for irrigation, balanced use of essential nutrients is very important to achieve optimum productivity. While it would be appropriate to apply nutrients as per regional recommendations for normal soils/waters or on soil test basis some additional points should be considered.

- Application of 25 per cent extra nitrogen is needed as compared to the normal conditions.
- Soils irrigated with chloride rich waters (saline) respond to higher dose of phosphorus, because chloride ions depress the availability of soil phosphorus to plants. The phosphorus requirement of crops is, therefore, enhanced to nearly 50 per cent more phosphorus than the recommended dose under normal conditions.
- In the case of saline water, the recommended doses of potassium and zinc based on soil tests values should be applied. However, for sodic waters Zinc sulphate @ 25 kg ha^{-1} should be added to supply additional zinc, particularly to the *rabi* crop.
- For high yields, organic materials such as green manures/ FYM should be used. They do not only supply nutrients to the plants, but also play an important role in

improving soil physical properties. As such, their application enhances leaching of salts accumulated in the root zone.

Irrigation Practices: Low depth high frequency irrigations are the preferred mode of irrigation with saline water. Since improved irrigation techniques allow easy application of water in this manner, switch over from surface to sprinkler or drip irrigation is recommended.

Application of Gypsum

The sodicity hazard of the sodic irrigation waters on the soil can be mitigated by neutralization of the RSC of irrigation water with gypsum. If the RSC of the irrigation water is 2.5 or less, the water is considered to be of good quality and in that case it is not necessary to add gypsum or any other amendment. However, for every additional 1 meq L^{-1} RSC to be neutralized, agriculture grade gypsum (70% purity) @ 90 kg ha^{-1} should be added for each irrigation of 7.5 cm depth. The quantity of gypsum to be added is, thus determined by the RSC of irrigation water and quantity of water required for irrigation during the growing season or on yearly basis.

Toxic Water

In addition to total electrolyte content, plant responses are also governed by the concentrations of different ions in soil solution. The toxic accumulation of sodium in plants due to use of high SAR water is reported. Chloride ions are more toxic than sulphate ions. Increased mg/cal ratio affects the uptake and transport of calcium due to antagonistic effects.

Trace elements or heavy metals cause growth reductions due to toxicities. Since very few experimental evidences have been generated to provide any firm guidelines, the suggested maximum concentrations of trace elements in water as reported by National Academy of Science (1972) are still used (Table 7.5).

Table 7.5: Recommended maximum concentrations of trace element in irrigation water

Element	Symbol	For water used continuously on all soils (mg L^{-1})	For use up to 20 years on fine textured soils of pH 6.0-8.5 (mg L^{-1})
Aluminium	Al	5.0	20.0
Arsenic	As	01	2.0
Beryllium	Be	0.1	0.5
Boron	B	-	2.0
Cadmium	Cd	0.01	0.02
Chromium	Cr	0.1	1.0
Cobalt	Co	0.05	5.0
Copper	Cu	0.20	5.0
Fluoride	F	1.0	15.0
Iron	Fe	5.0	20.0
Lead	Pb	5.0	10.0
Lithium [1]	Li	2.5	2.5
Manganese	Mn	0.2	10.0
Molybdenum	Mo	0.01	0.05[2]
Nickel	Ni	0.2	2.0
Selenium	Se	0.02	0.02
Vanadium	V	0.1	1.0
Zinc	Zn	2.0	10.0

[1] Recommended maximum concentration for citrus in 0.075 mgL^{-1}.
[2] For only acid fine textured soils or acid soils with relatively high iron oxide contents.

7.6 WATERSHED MANAGEMENT

A watershed is a topographically delineated natural unit of area that is drained by the common stream. A small watershed could be of few hectares that drain into a small stream (Tideman, 1996). This small watershed forms a part of a larger watershed which in turn could form a part of still larger watershed, until the watershed becomes a major river basin draining millions of square kilometres of land. A schematic view of a sub-watershed and a small watershed is shown in Fig. 7.5. The elevated line that forms a division between two areas drained by separate streams is marked with two sided arrows.

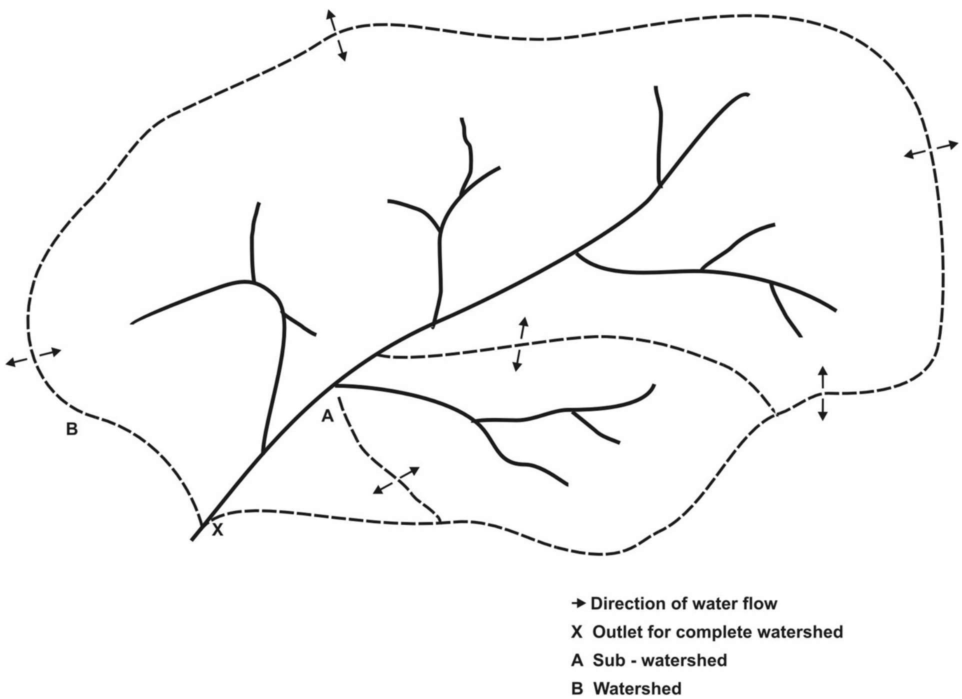

Fig.7.5: A view of sub-watershed within a watershed

In the watershed approach, development is not confined to agricultural lands alone, but covers the area, starting from the highest point of the area to the outlet of the *nalah* or the natural stream. Similarly, in terms of resource development, it starts from the most important one, that is water and extends to soil, vegetation, fuel, livestock and all associated components. In the watershed, different measures are adopted and executed in each of the topo-sequences according to the land capability. Now, a watershed is not only made up of its physical and natural resources but also includes human resources. Therefore, its management entails rational utilization of land and water resources for optimum production with minimum hazard to natural and human resource.

Watershed management has been defined as an integration of technologies within the natural boundaries of a drainage area for optimum development of land, water and plant resources to meet the basic minimum needs of the people in a sustainable manner. The watershed management approach clearly realizes the linkages between uplands and the down stream areas, i.e., actions of upstream users affect those living downstream.

Some general technical objectives of a watershed management programme could be as follows:

- To rehabilitate the watershed through sustainable land use, to carry out conservation practices to minimize erosion, increase the productivity of the land and water.
- To develop water resources for domestic and irrigation purposes, etc.
- To manage the watershed to minimize/mitigate natural disasters like floods or drought.
- To develop the watershed for economic uplift of the region.
- A combination of one or more of these general objectives.

Principal factors Influencing Watershed Operations

Physiography: Size, land slope and drainage pattern of the watershed influence runoff volume and its rate. Besides, slope of the land has major implications for land use. The drainage pattern of an area refers to the design of the stream courses and their tributaries. The slope of the land, lithology and structure influences it.

Soils and Geology: It determines the amount of water that would percolate (also determine the run off) and the need for treatments to improve percolation. It would also determine the anticipated silt load from the watershed area.

Land Use: It affects the rate of run off and soil infiltration rate.

Vegetative Cover: The change in the type and quality of vegetative cover is an important non-engineering intervention as these together influence runoff, infiltration rate, erosion and sediment production.

Climate: Precipitation is the most important factor as it determines the design peak runoff rates for various structures, runoff rate and volumes and the erosion hazard. Evapo-transpiration is another important factor that determines the crop water requirement.

Socio-economic Factors: Demographic and sociological features, land tenure system, farm structure, attitude and behaviour of farmers, all influence the success of a watershed management programme. While preparing a watershed management plan, socio-economic baseline survey is an essential pre-requisite.

SAQ 8

a) Define watershed. Explain the term with a free hand sketch.
b) Define the term watershed management.

7.6.1 Watershed Management Plan

A watershed management programme is essentially a rural development programme. A multi-disciplinary approach in planning is essential to derive optimum benefits out of such a programme.

Basic Information

To start a watershed management programme in a systematic manner, basic information on all the following components is necessary:

- Location,
- Size and shape,
- Climate, physiography, runoff and soil erosion problems,

- Population and livestock,
- Water resources and their utilization potential,
- Land utilization, cropping systems, yield, land capability,
- Socio-economic utility and land ownership,
- Market facilities,
- Health related facilities and other institutions.

A basic resource inventory before the intervention through watershed management should also be prepared to help in monitoring and evaluation of the programme.

Development Components

On the basis of the information generated, it would be prudent to identify the priority problems and clearly spell out the kinds of intervention and development activities that should be initiated. All these efforts could be made through discussions with the stakeholders. Some of the important activities are: soil conservation measures, water harvesting, groundwater recharge, changes in land use if necessary, water management including drainage, improvement in fuel-fodder production system including horticulture.

Some of the situations, problems and solutions have been listed in Table 7.7. However, there are no hard and fast ground rules and solutions since for the same situation and problem, the solution might vary from one location to another.

Building a Suitable Organization

A dynamic and vibrant organization that is multi-disciplinary and flexible in nature should be initially constituted. While specialist divisions could handle the execution of plans, the command and authority must come from a single authority. The constitution of the organization must provide for enlisting the co-operation of local people.

The ideal solution could be a watershed development agency at the unit level or a watershed authority with well-identified line departments to undertake the project under the overall supervision of the watershed authority. In the latter approach, watershed development agencies should be created as the programme proceeds to make it sustainable. To upgrade the skills of the people in the organization, regular training programmes should be a part and parcel of the organizational rules and regulations.

Costing and Finance

Since the economic level of the stakeholders is usually low, institutional financing, subsidies and outright grants are essential to make a watershed programme successful. Moreover, many activities are carried out on community lands or for community purpose.

Follow up, Maintenance and Monitoring and Evaluation

After the plan is implemented, an improved production plan is superimposed to get maximum benefits. Farmers are educated to maintain the structures. In order to assess the impact, regular monitoring and evaluation is essential. It would only determine the replication potential of the interventions and/or determine the shortcomings/gaps in implementation.

Table 7.7: Some common situations, problems encountered in watershed management and their possible solutions

Situation	Problem	Solution
1. Hill slopes (bare denuded, soil thin, texture-light)	Soil erosion, moisture conservation, retention of runoff and disposal. Establishing vegetation.	Contour trenching, bunding, terracing-afforestation, silvipasture, and agro-forestry.
2. Steep land slopes (denuded, eroded thin vegetation)	Runoff control, retention and disposal, stabilization and densification of vegetation.	Control and graded bunding, grassy waterways, water harvesting, contour cultivation, horticulture, agro forestry, pasture, strip cropping.
3. Medium to low slope agricultural lands	Soil and water management, water retention, runoff, control and reuse	Contour cultivation, strip cropping, buffer strip and boarder strips
4. Moderate to low slope and plain irrigated lands	Water management	Land levelling, design and layout of irrigation system, irrigation depth and interval control. Disposal of drainage water
5. Plain agricultural lands and lowlands	Drainage disposal and reutilization	Surface and subsurface drainage, recycling
6. Sand dunes on sea shores	Wind erosion stabilization of sand dunes, prevention of formation of sand dunes	Wind break, shelter belt establishment of vegetation, dune stabilization
7. Stream bank and gullied lands	Soil erosion, storage and disposal of excess water	Stream bank protection, gully control, protection of farm ponds, vegetation
8. Denuded and degraded forests	Soil and water conservation, afforestation	Prevention and control of felling forest trees, controlled grazing, stopping shifting cultivation, afforestation, silvipasture, agroforestry

7.6.2 Challenges and Opportunities in Watershed Management

The potential of watershed management in meeting the basic needs and in poverty alleviation has been proved beyond doubt, yet the success stories are very limited. In order to overcome the shortcomings, the following issues must be addressed in the future.

People's Participation

Small farms, which are a characteristic of rural India, forbid any attempt by individual farmers to improve their land to have a visible impact on land and water management. In most instances, participation of the community is indispensable. A top-down approach has failed globally and that is why a bottom-up approach in which stakeholders are involved from the planning stage itself has become quite common for the success and sustainability of a programme.

Capacity Building

Most organizations operating in watershed management programmes lack the confidence. This is because most of the field-level staff engaged by them cannot comprehend the magnitude of the task. They also do not have the technical and organizational skill to satisfy people when questioned on the issues relevant to the project. Training, a priority area, does not receive the kind of attention it should in preparing the staff to meet the stakeholders with confidence.

Monitoring of Impact

A major concern of many projects has been the lack of adequate monitoring of the progress and impact of the programme. Either the programme lacks facilities, or it defies the capacity of the project staff. Moreover, the monitoring of socio-economic impact lacks proper indices. Appropriate feedback is not available that would help to rectify the programme.

Flexibility and Coordination

The standardized, target-oriented blue print approach has been the hallmark of most programmes as these are run solely by the government organizations. Watershed management programmes call for flexibility and innovations and local non-governmental agencies/organizations need to be involved. Duplication of efforts due to lack of coordination is another grey area in watershed management programmes.

Sustainability and Replicability

Some tangible improvements have been reported in the existing conditions following interventions. Since such efforts lacked integrated, comprehensive and multi-faceted approach, anticipated success could not be achieved. Since long-term sustainability of the programme is not kept in view during planning, reversion to original conditions has been reported from many programmes following project withdrawals. As stated earlier, a rigid blue-print approach cannot be adopted. Replicability of programmes in regionally homogeneous areas, say, at the micro-watershed level, must be attempted, if watershed management programmes are to make a real head way in the country.

In this unit you have studied water, a natural resource that together with soil studied in the previous unit, determines the food and nutritional security of the nation. You have been introduced to hydrological cycle, and role of water in agriculture, floods and drought, water logging, water quality parameters, water quality for agriculture and watershed management. We now summarize the contents of this unit.

7.7 SUMMARY

- Water is a finite resource, which can, however, be replenished.
- The South Asian countries are fortunate to have ample resources of water, yet its spatial and temporal variability calls for its management through storage and distribution.
- Burgeoning population, increased living standard and environmental considerations have put tremendous stress on this resource.

- Increasing sectoral competition would snatch a part of the allocation of fresh water to agricultural sector. Since the demand in agriculture would increase, agricultural sector has to look for alternate resources of water as well as go in for 'more crop per drop'.
- There is a mismatch between the potential created and potential utilized. This means that the investments made on creation of the potential are not utilized and the investment is blocked.
- Introduction of irrigation has been a mixed blessing; while crop yields have improved by 50% to 200%, the mismanagement of water has resulted in the problem of water logging and creation of wet deserts.
- Flooding is an extreme event in which the adage "Water-water everywhere but not a drop to drink" applies well. Nearly 40 million ha area is prone to floods while annually on an average 7.5 million ha area is affected to various degrees of flooding.
- Flood control measures are based on the four principles of runoff reduction, retention, diversion and confinement.
- Water logging could occur either due to surface stagnation of water or due to rise in the water table. Both adversely affect aeration resulting in depletion of O_2 and increase in CO_2 in the root zone.
- Some toxic ions may be produced in the root zone as a result of water logging or it might affect the absorption of certain plant nutrients compared to others causing nutrient imbalance in the plants. In most cases, adverse effects are due to combination of these factors although reduced aeration dominates in many cases.
- Crops differ in their tolerance to water logging. Selection of crops, which can tolerate water logging, is one of the ways to manage waterlogged lands. Besides land management, high seed rate, application of higher doses of plant nutrients, raised and sunken bed system to grow crops could help to avoid the adverse effects.
- While management could help in the short-term, long-term solution of the problem is improved drainage. Surface drainage is an essential pre-requisite to avoid surface stagnation and reduce the rate of rise in the water table. Lands with shallow water table also require some kind of subsurface drainage to control water table.
- Horizontal pipe drainage, vertical drainage or bio-drainage and their combinations can be used to lower the water table.
- Soil salinity and water logging are twins. When both the problems have invaded the area, horizontal pipe drainage could be a quick and cost-effective technology to reclaim the lands.
- Drought is another extreme, which affects large areas in the region. Moisture stress due to drought could wipe out crops from fields and even affect the productivity of irrigated lands since only limited water is available in irrigation commands.
- Depending upon the mechanism of tolerance to drought, crops have been categorized as drought escapers, drought evaders and drought endurers. Drought resistant crops yield less.
- With increasing pollution of water resources, water quality degradation has assumed a serious dimension. Degradation in water quality indirectly affects the quantity, as the degraded water cannot be used for specific purposes depending upon the kind and extent of degradation.

- Silt, turbidity, dissolved oxygen, total dissolved solids, pH, faecal coliform, faecal enterococci, toxic elements, macro invertebrates and bio-chemical oxygen demand are some of the parameters that determine the physical, chemical and microbiological properties of water.

- Water quality for agriculture is determined through Electrical Conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and toxic elements. Based on their effect on soils and crops waters have been grouped as fresh, saline, alkali (sodic) and toxic waters.

  – Saline water per se is not harmful to plants. It is the accumulation of salts in the root-zone that leads to build-up of osmotic potential that makes water unavailable to plants. Poor and delayed germination and slow growth occur due to salinity build-up.

  – Alkali or sodic water on the other hand influences the physico-chemical properties of the soil and has adverse effect on crop growth. Breakdown of soil structure, formation of a thin crust at the soil surface, difficulty in attaining proper soil moisture condition and build-up of soil sodicity/pH are some of the adverse effects of continuous application of sodic waters.

  – Saline/sodic waters can be used for crop production through proper selection of crops and through application of appropriate management options. Use of sprinkler and drip irrigation can help to use relatively high salinity water to the same crop compared to surface irrigation. Low depth high frequency irrigations are helpful in managing salts.

  – Highly saline waters can be used through conjunctive mode with fresh water. For this purpose blending (mixing saline and fresh waters) and cyclic use strategies are commonly employed.

  – Besides the conjunctive use, several cultural practices can be employed to obtain optimum yield. Pre-sowing irrigation with fresh water, application of 25% more nitrogen than recommended for normal lands and waters, use of farm yard manure and green manures, high seed rate are some such practices.

  – In the case of alkali water, application of gypsum or any other calcium containing amendment could be employed to neutralize the residual sodium carbonate.

  – Since water, soil and vegetation can be effectively managed with watershed as a unit, watershed management concept has come to stay for planning and managing the natural resource.

  – A watershed management programme is undertaken to rehabilitate the watershed, to minimize soil erosion, to develop, conserve and efficiently utilise the water resource, to minimize natural disasters in the watershed or a combination of these objectiv e. However, the ultimate aim is to develop the watershed for economic upliftment of its inhabitants.

  – A well-conceived watershed management plan should be prepared before implementation of any programme. It must consist of collection of basic information and socio-economic resource inventory, identification of suitable development components in line with the objectives of the programme, identification and building a dynamic and vibrant organization, cost evaluation and maintenance.

  – Since, there are only a few success stories of watershed management programmes in India, people's participation, capacity building, monitoring, flexibility and co-ordination and sustainability and replicability have been discussed to understand the challenges that are ahead in making watershed management programme a people's movement.

7.8 TERMINAL QUESTIONS

1. What do you understand by the statement "Water is a scarce natural resource"?
2. Development of surface water resources has been a mixed blessing. Briefly explain the statement.
3. List at least four management options to manage water logged lands.
4. What do you understand by the term drought? Briefly describe the three strategies to mitigate drought conditions.
5. List the various objectives that could be an integral part of a watershed management programme. List important information that needs to be collected before initiating a watershed management programme.
6. What are the major features of a suitable organization for implementing watershed management programmes?

REFERENCES

1. Mooley, D.A. (1995) Rainfall analysis for India. In: Agricultural Droughts: Data Base Management, Lecture Notes of SERC School in Agrometeorology. IMD and IITM, Pune. 257-276.
2. National Academy of Sciences (1972) Water Quality Criteria. Environmental Studies Board, National Academy of Sciences/Engineering.
3. Poysa, V.W., Tan, C.S. and Stone, J.A. (1987) Flooding stress and the root Development of several tomato genotypes," Hort. Science, 22: 24-26.
4. Sharma, B.R. and Paul, D.K. (1998) Water resources of India. In 50 years of Natural Resource Management Research (Singh, G.B. and Sharma, B.R. Eds.). Indian Council of Agricultural Research, New Delhi. 31-48.
5. Tideman, E.M. (1996) Watershed Management; Guidelines for Indian Conditions, Omega Scientific Publishers, New Delhi. 372 pp.