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Internal Assessment Test 2 – April. 2018

Sub:	Water Resource Engineering					Sub Code:	10CV846	Branch:	CIVIL
Date:	19/04/18	Duration:	90 min's	Max Marks:	50	Sem/Sec:	VIII	OBE	

Attempt any four questions from part A & any one question from part B.

		MARKS	CO	RBT
	PART-A			
1	What do you understand by **flood plain management**	[10]	CO1	L2
2	Write short note on (i) **Levees (ii) floodwalls**	[10]	CO1	L2
3	Briefly explain the **water** needs for **agriculture** and **irrigation.**	[10]	CO2	L2
4	Classify the various **irrigation system** practices.	[10]	CO2	L2
5	Briefly explain the differences between **furrow type irrigation** and **sprinkler type irrigation** practices in India.	[5+5]	CO2	L2
6	Explain the impact of **drought** on following sectors: agriculture and industrial economy.	[10]	CO3	L2
	PART-B			
7	Briefly explain the **structural** and **non structural flood control measures**	[10]	CO3	L2
8	Explain the flood **damage risk analysis** (Net benefit cost estimation) in details.	10]	CO3	L2

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CMR INSTITUTE OF TECHNOLOGY

Department of Civil Engineering

IAT-2 April, 2018 SUBJECT: WATER RESOURCE ENGINEERING (10CV846)

Q.1 Flood Plain Management?

Floods have altered the floodplain landscape. These areas are continuously shaped by the forces of water—either eroded or built up through deposit of sediment. More recently, the landscape has been altered by human development, affecting both the immediate floodplain and events downstream.

These areas had fertile soils, making them prime agricultural lands. This pattern of development continued as communities grew. In recent decades, development along waterways and shorelines has been spurred by the aesthetic and recreational value of these sites.

The purpose of this study is to familiarize you with how this problem can be curbed through proper management of how your floodplains are developed. Communities that guide development following the standards of the National Flood Insurance Program have seen the results – their new buildings and neighborhoods have had less damage and suffering from flooding.

To start, we need an orientation into the natural processes of flooding, such as watershed and coastal erosion that are used throughout the course

Floods are part of the Earth's natural hydrologic cycle.

The cycle circulates water throughout the environment . This process maintains an overall balance between water in the air, on the surface and in the ground.

Sometimes the hydrologic cycle gets outs of balance, sending more water to an area than it can normally handle.

The result is a flood.

A flood inundates a floodplain. There are different types of floodplains and they are based on they type of flooding that forms them.

Most floods fall into one of three major categories:

♦ Riverine flooding

♦ Coastal flooding

♦ Shallow flooding

RIVERINE FLOODING

A watershed is an area that drains into a lake, stream or other body of water. Other names for it are basin or catchment area.

Watersheds vary in size. Larger ones can be divided into sub-watersheds.

The boundary of a watershed is a ridge or divides. Water from rain and snowmelt are collected by the smaller channels (tributaries) which send the water to larger ones and eventually to the lowest body of water in the watershed (main channel).

Channels are defined features on the ground that carries water through and out of a watershed. They may be called rivers, creeks, streams or ditches. They can be wet all the time or dry most of the time.

When a channel receives too much water, the excess flows over its banks and into the adjacent floodplain. Flooding that occurs along a channel is called riverine flooding.

In hilly and mountainous areas, a flood may come scant minutes after a heavy rain. Such a flash flood gives short notice and moves so fast that it is particularly dangerous to people and property in its path.

Overbank flooding

The most common type of flooding in the United States is called overbank flooding.

Overbank flooding occurs when downstream channels receive more rain or snowmelt from their watershed than normal, or a channel is blocked by an ice jam or debris. For either reason, excess water overloads the channels and flows out onto the floodplain.

Overbank flooding varies with the watershed's size and terrain. One measure of a flood is the speed of its moving water, which is called velocity. Velocity is measured in feet per second.

Hilly and mountainous areas have faster moving water, so velocity can pose a serious hazard. In flat areas, the flood may move slowly, making its velocity less of a hazard.

Terrain may affect how much warning people have that a flood is building. Conditions on a river that drains a large watershed may warn of a pending flood hours or even days before actual flooding.

Flood depths vary, as do flood durations. Generally, the larger the river, the deeper the flood and the longer it will last. However, in hilly or mountainous areas with narrow valleys, flooding can be very deep in small watersheds.

Flash flooding A severe storm that drops much rainfall in a short time can generate a flash flood. All flash floods strike quickly and end swiftly.

While flash floods occur in all fifty states, areas with steep slopes and narrow stream valleys are particularly vulnerable, as are the banks of small tributary streams. In hilly areas, the high-velocity flows and short warning time make flash floods hazardous and very destructive.

In urban areas, flash flooding can occur where impervious surfaces, gutters and storm sewers speed runoff. Flash floods also can be caused by dam failure, the release of ice-jam flooding, or collapse of debris dams.

Erosion changes the shape of channels

COASTAL FLOODING

Development along the coasts of the oceans, the Gulf of Mexico, and large lakes can be exposed to two types of flood problems not found in riverine areas: coastal storms and coastal erosion. The Pacific and Caribbean coasts face a third hazard: tsunamis.

Coastal storms Hurricanes and severe storms cause most coastal flooding. These include “Nor’easters,” which are severe storms on the Atlantic coast with winds out of the northeast.

Persistent high wind and changes in air pressure push water toward the shore, causing a storm surge which can raise the level of a large body of water by several feet. Waves can be highly destructive as they move inland, battering structures in their path.

On open coasts, the magnitude of a flood varies with the tides. Because these landforms provide natural buffers from the effects of a storm, their preservation is important to the protection of inland development.

Coastal erosion Long-term coastal erosion is another natural process that shapes shorelines. It is a complex process that involves natural and human-induced factors. The natural factors include sand sources, sand size and density, changes in water level, and the effects of waves, currents, tides and wind.

SHALLOW FLOODING

Shallow flooding occurs in flat areas where a lack of channels means water cannot drain away easily. Shallow flood problems fall into three categories: sheet flow, ponding and urban drainage.

Sheet flow Where there are inadequate or no defined channels, floodwater spreads out over a large area at a somewhat uniform depth in what’s called sheet flow.

Ponding In some flat areas, runoff collects in depressions and cannot drain out, creating a ponding effect. Ponding floodwaters do not move or flow away. Floodwaters will remain in the temporary ponds until they infiltrate into the soil, evaporate or are pumped out.

Urban drainage An urban drainage system comprises the ditches, storm sewers, retention ponds and other facilities constructed to store runoff or carry it to a receiving stream, lake or the ocean. Other man-made features in such a system include yards and swales that collect runoff and direct it to the sewers and ditches.

SPECIAL FLOOD HAZARDS

The flooding types described so far are the more common types found in the United States. There are many special local situations in which flooding or floodrelated problems do not fit the national norm.

This section discusses five of those special flood hazards:

♦ Closed basin lakes ♦ Uncertain flow paths. ♦ Dam breaks. ♦ Ice jams. ♦ Mudflows.

NATURAL AND BENEFICIAL FLOODPLAIN FUNCTIONS

Floodplain lands and adjacent waters combine to form a complex, dynamic physical and biological system found nowhere else. When portions of floodplains are preserved in their natural state, or restored to it, they provide many benefits to both human and natural systems

Natural flood and erosion control Over the years, floodplains develop their own ways to handle flooding and erosion with natural features that provide floodwater storage and conveyance, reduce flood velocities and flood peaks, and curb sedimentation.

Natural controls on flooding and erosion help to maintain water quality by filtering nutrients and impurities from runoff, processing organic wastes and moderating temperature fluctuations.

Biologic resources and functions- Floodplains enhance biological productivity by supporting a high rate of plant growth. This helps to maintain biodiversity and the integrity of ecosystems

Societal resources and functions People benefit from floodplains through the food they provide, the recreational opportunities they afford and the scientific knowledge gained in studying them.

Wild and cultivated products are harvested in floodplains, which are enhanced agricultural land made rich by sediment deposits. They provide open space, which may be used to restore and enhance forest lands, or for recreational opportunities or simple enjoyment of their aesthetic beauty.

FLOODPLAIN MANAGEMENT STRATEGIES

Strategy 1: Modify human susceptibility to flood damage Reduce disruption by avoiding hazardous, uneconomic or unwise use of floodplains.

Strategy 2: Modify the impact of flooding Assist individuals and communities to prepare for, respond to and recover from a flood.

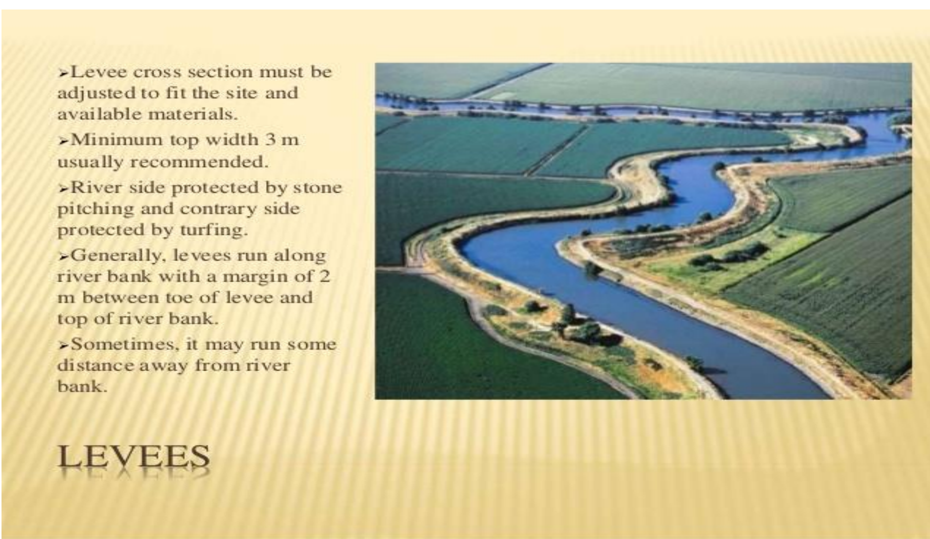
Strategy 3: Modify flooding itself Develop projects that control floodwater

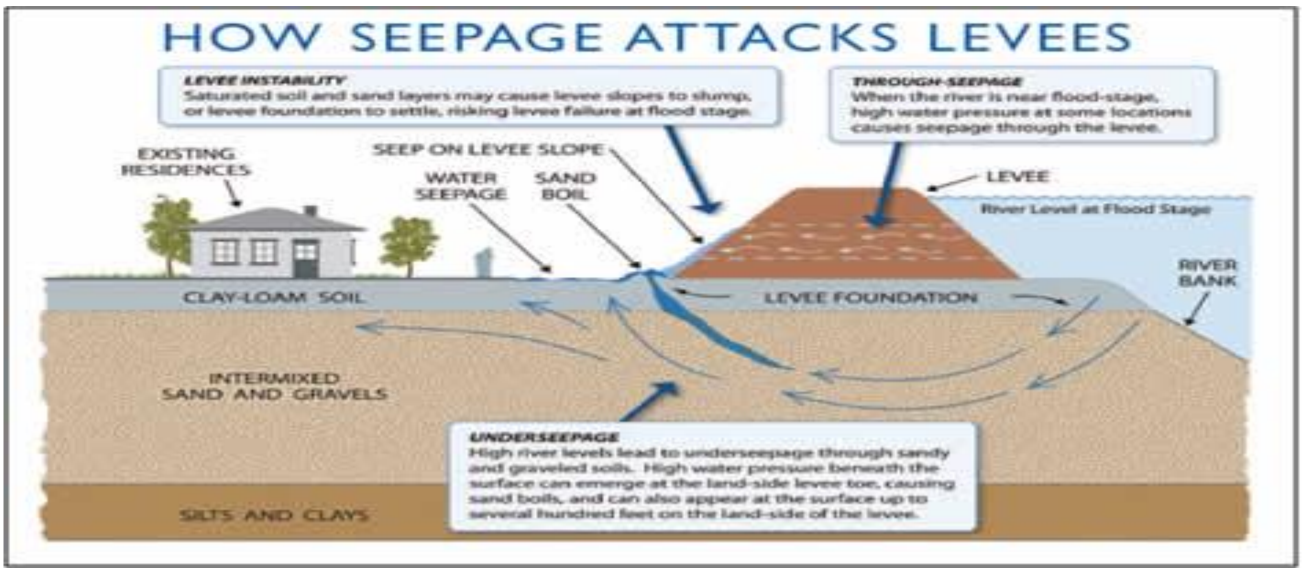
Strategy 4: Preserve and restore natural resources Renew the vitality and purpose of floodplains by reestablishing and maintaining floodplain environments in their natural state.

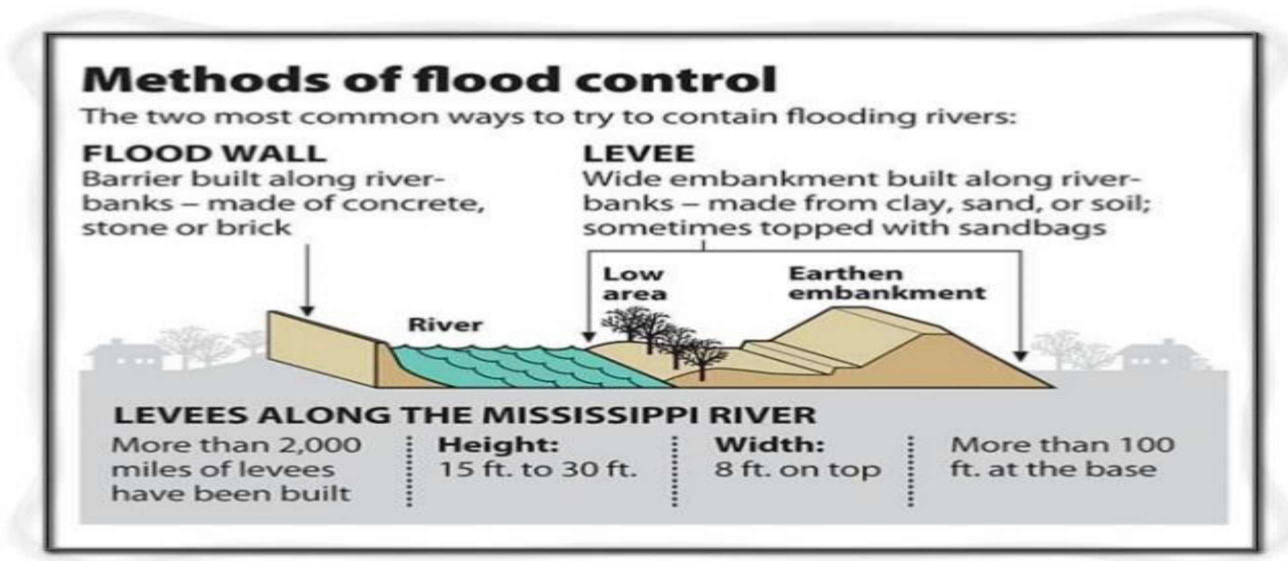
Q.2 NOTES ON:

A. LEVEES B. FLOOD WALLS

LEVEES: It is easier to increase your **flood protection** level with a **levee** than with other permanent systems. When built with a broad, well-compacted base, **levees** can be topped with sandbags or water-inflated dams. **Levees are good at protecting bits of land and communities where we've deemed it unacceptable that they be exposed to repeated floods.**

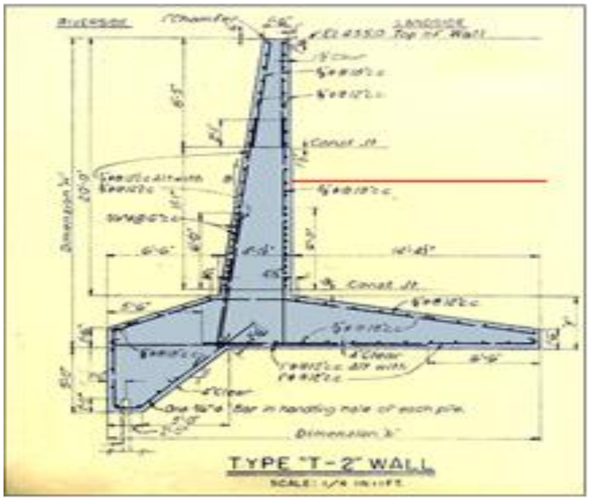


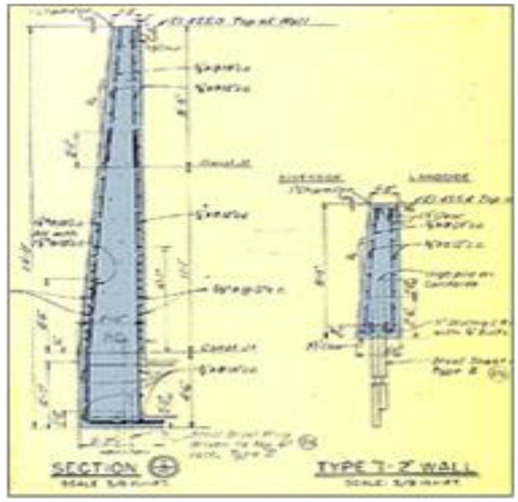


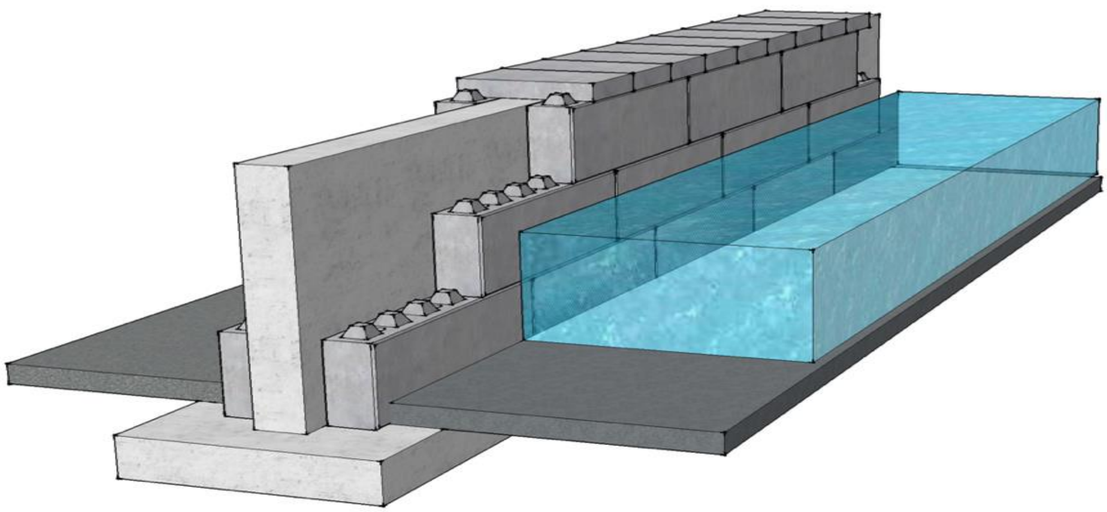


A flood wall (or flood barrier) is a primarily vertical artificial barrier designed to temporarily contain the waters of a river or other waterway which may rise to unusual levels during seasonal or extreme weather events. Flood walls are mainly used on locations where space is scarce, such as cities or where building levees or dikes (dykes) would interfere with other interests, such as existing buildings, historical architecture or commercial use of embankments.

FLOODWALLS







Flood walls are nowadays mainly constructed from pre-fabricated concrete elements. Flood walls often have floodgates which are large openings to provide passage except during periods of flooding, when they are closed. As a flood wall mostly consist of relatively short elements compared to dikes, the connections between the elements are critical to prevent the failure of the flood wall.

Q.3 WATER NEEDS FOR AGRICULTURE AND IRRIGATION:

Water use in agriculture is at the core of any discussion of water and food security. Agriculture accounts for, on average, 70 percent of all water withdrawals globally, and an even higher share of "consumptive water use" due to the evapotranspiration requirements of crops. Worldwide, over 330 million hectares are equipped for irrigation. Irrigated agriculture represents 20 percent of the total cultivated land, but contributes 40 percent of the total food produced worldwide.

Competition for water resources is expected to increase in the future, with particular pressure on agriculture. Significant shifts of inter-sectoral water allocations will be required to support continued economic growth.

Due to population growth, urbanization, industrialization, and climate change, improved water use efficiency will need to be matched by reallocation of as much as 25 to 40% of water in water stressed regions, from lower to higher productivity and employment activities. In most cases, this reallocation is expected to come from agriculture, due to its high share of water use. The movement of water will need to be both physical and virtual. Physical movement of water can occur through changes in initial allocations of surface and groundwater resources as well as conveyance of water 'sales', mainly from agricultural to urban, environmental, and industrial users. Water can also move virtually as the production of water intensive food, goods, and services is concentrated in water abundant localities and is traded to water scarce localities.

At the same time, water in agriculture will continue to play a critical role in global food security. Population is expected to increase to over 10 billion by 2050, and whether urban or rural, this population will need food and fiber for its basic needs. Combined with the increased consumption of calories and more complex foods, which accompanies income growth in much of the developing world, it is estimated that agricultural production will need to expand 70% by 2050. If this expansion is not to come at the expense of massive land conversions and the consequent impact on carbon emissions, agriculture will have to intensify. Given that irrigated agriculture is, on average, at least twice as productive per unit of land, provides an important buffer against increasing climate variability, and allows for more secure crop diversification, it is certain that irrigation will continue to play a key role in ensuring global food and nutrition security.

The above projections for both water and food security appear, at first look, to be contradictory, On one hand, there is a need to use less water in agriculture, but on the other hand, more intensive use of water in agriculture is a key element of sustainable intensification of food production. Resolving this apparent quandary requires a thorough reconsideration of how water is managed in the agricultural sector, and how it can be repositioned in the broader context of overall water resources management and water security.

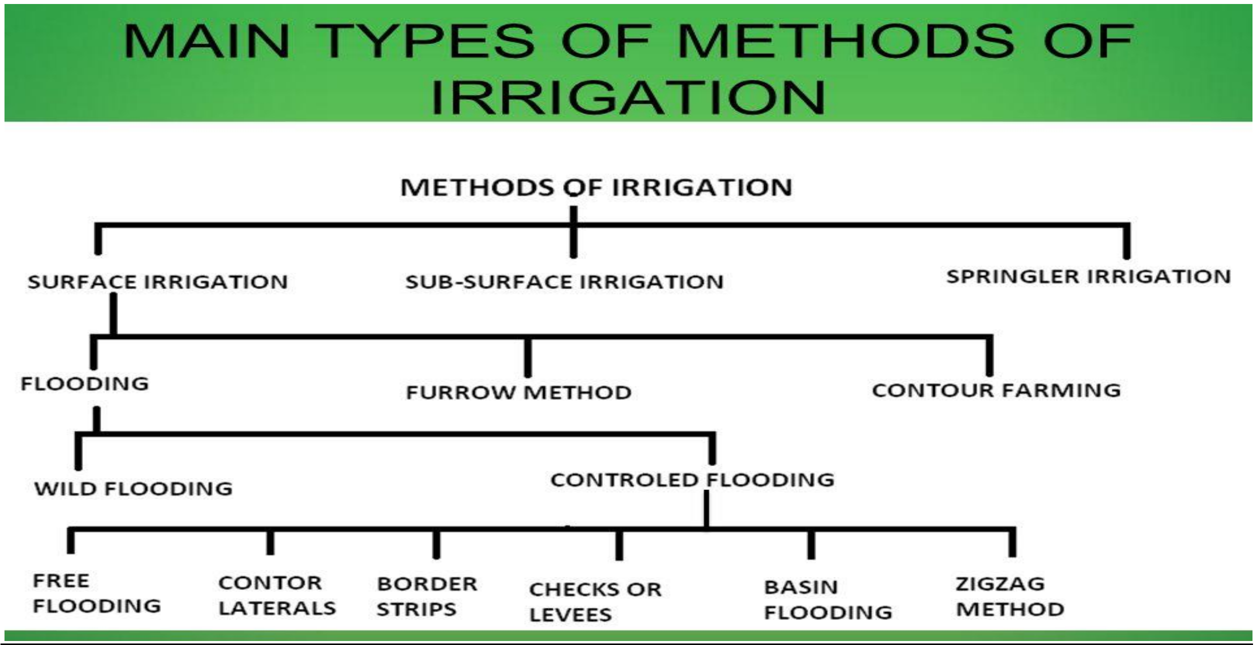
Practical Challenges for Water in Agriculture

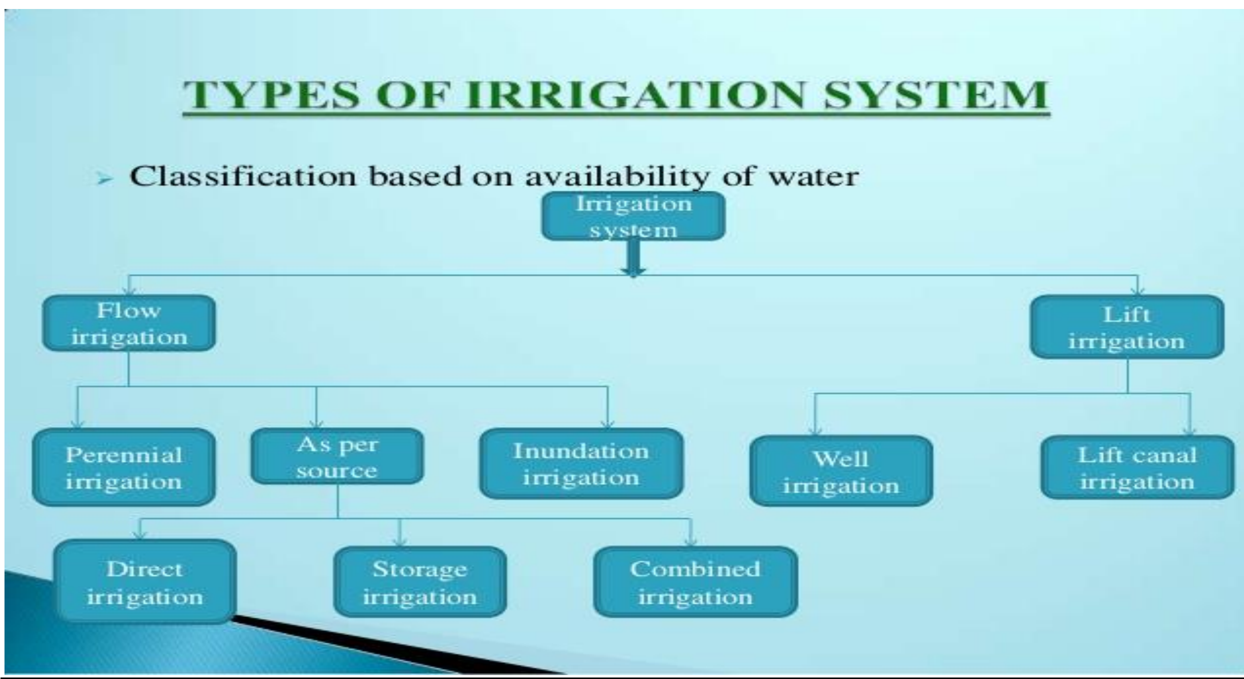
The ability to improve water management in agriculture is constrained by perverse policies, major institutional performance, and financing limitations. The critical public and private institutions – including agricultural and water ministries, basin authorities, irrigation managers, water user and farmer organizations – generally lack the authorizing environment and capacities to carry out their functions effectively. For example, basin authorities often have limited ability to enforce allocations, and hence, to convene stakeholders. The institutions charged with developing irrigation often limit themselves to capital intensive, larger scale schemes, and tend to rely on public sector approaches rather than develop opportunities for private financing and management. Farmers and their organizations are often responding to highly distorted incentive frameworks in terms of water pricing and agricultural support policies.

Most governments and water users fail to invest adequately in the maintenance of irrigation and drainage (I&D) systems. While inadequate management and operation may play a part in the poor performance of I&D systems, it is especially the failure to adequately maintain systems that results in their declining performance and the subsequent need for rehabilitation. This failure to provide adequate funds for maintenance of the I&D system has resulted in the all too familiar "build-neglect-rehabilitate-neglect" cycle.

Improving the efficiency of water use in agriculture will also depend on matching off-farm improvements with incentives and technology transfer for on-farm investments in improved soil and water management and improved seeds. Options such as enhanced seeds, low-till, alternate wetting and drying, sustainable rice intensification, and others exist, but require matching improvements in water delivery systems to provide on-demand service, with the use of information technology like soil moisture sensors and satellite evapotranspiration measurement to improve efficiency and productivity of water in agriculture.

Q.4 IRRIGATION METHODS:





- **Surface irrigation**
- **Uncontrolled flooding**
- **Border strip method**
- **Check method**
- **Basin method**
- **Furrow method**

- **<u>Subsurface irrigation</u>**
- **<u>Sprinkler irrigation</u>**
- **<u>Trickle irrigation</u>**

<u>SPRINKLER TYPE IRRIGATION</u>

<u>FURROW TYPE: IRRIGATION</u>

Q.5 DIFFERENCE BETWEEN FURROW TYPE AND SPRINKLER TYPE IRRGATION

1) Furrow Irrigation Method:

Furrow irrigation method is resorted to where crops are one grown in rows. Along the side of rows of crops, ‘Dol’is formed, and in between two such ‘Dols’, a furrow is formed in which water flows for irrigation. The quantity of flow of water depends on demand of water by plants and the rate of infiltration.

They are mainly of five types:

1. Slopy Furrow

2. Leveled Furrow

3. Contour Furrow

4. Serial Furrow

5. Corrugated Furrow

Sprinkler Irrigation Method:

In present times, when water crisis is developing very fast everywhere, we should adopt improved techniques of irrigation to encourage suitable water management. Sprinkler irrigation method is an easy and simple method of irrigation in present times.

The whole land becomes available for cultivation of crops, whereas in traditional irrigation methods, 15 to 20 per cent land remains vacant in depressions and boundaries. Modern equipment’s can also be used in it due to absence of depressions and boundaries. Rate of infiltration is higher in sandy soils where frequency of watering is more. Hence, sprinkler irrigation method is more suited to sandy soils.

In sprinkler irrigation method, water is taken from source to the fields through pipes, whereas in surface irrigation methods only 30-45 per cent water reaches the crops. Such loss of water is avoided in sprinkler irrigation method. The problem of water logging or ‘kallar’ may be caused in case of excess water from surface irrigation, whereas no such problem is caused in sprinkler irrigation method. The balance of groundwater is also maintained

Q. **6 IMPACT OF DRAUGHT ON AGRICULTURE AND INDUSTRIAL ECONOMY**

Drought affects all parts of our environment and our communities. The many different drought impacts are often grouped as "economic," "environmental," and "social" impacts. All of these impacts must be considered in planning for and responding to drought conditions.

Economic Impacts

Economic impacts are those impacts of drought that cost people (or businesses) money. Here are just a few different examples of economic impacts:

- Farmers may lose money if a drought destroys their crops.
- If a farmer's water supply is too low, the farmer may have to spend more money on irrigation or to drill new wells.
- Ranchers may have to spend more money on feed and water for their animals.
- Businesses that depend on farming, like companies that make tractors and food, may lose business when drought damages crops or livestock.
- People who work in the timber industry may be affected when wildfires destroy stands of timber.
- Businesses that sell boats and fishing equipment may not be able to sell some of their goods because drought has dried up lakes and other water sources.
- Power companies that normally rely on hydroelectric power (electricity that's created from the energy of running water) may have to spend more money on other fuel sources if drought dries up too much of the water supply. The power companies' customers would also have to pay more.
- Water companies may have to spend money on new or additional water supplies.
- Barges and ships may have difficulty navigating streams, rivers, and canals because of low water levels, which would also affect businesses that depend on water transportation for receiving or sending goods and materials.
- People might have to pay more for food.

Environmental Impacts

Drought also affects the environment in many different ways. Plants and animals depend on water, just like people. When a drought occurs, their food supply can shrink and their habitat can be damaged. Sometimes the damage is only temporary and their habitat and food supply return to normal when the drought is over. But sometimes drought's impact on the environment can last a long time, maybe forever. Examples of environmental impacts include:

- Losses or destruction of fish and wildlife habitat
- Lack of food and drinking water for wild animals
- Increase in disease in wild animals, because of reduced food and water supplies
- Migration of wildlife
- Increased stress on endangered species or even extinction
- Lower water levels in reservoirs, lakes, and ponds
- Loss of wetlands

- More wildfires
- Wind and water erosion of soils
- Poor soil quality

Social Impacts

Social impacts of drought are ways that drought affects people's health and safety. Social impacts include public safety, health, conflicts between people when there isn't enough water to go around, and changes in lifestyle. Examples of social impacts include:

- Anxiety or depression about economic losses caused by drought
- Health problems related to low water flows and poor water quality
- Health problems related to dust
- Loss of human life
- Threat to public safety from an increased number of forest and range fires
- Reduced incomes
- People may have to move from farms into cities, or from one city to another
- Fewer recreational activities

Impact of Droughts in India: Physical; Agriculture and Economic Impact!

Droughts have a wide range of effects on the masses in a developing country like India. The impact of droughts is specifically conspicuous in view of the tropical monsoon character of the country. Rainfall by the south-west monsoon is notorious for its vagaries.

i) Physical Impact:

Meteorological drought adversely affects the recharge of soil moisture, surface runoff and ground water table. Soils dry up, surface runoff is reduced and ground water level is lowered. Rivers, lakes, ponds and reservoirs tend to dry up wells and tube-wells are rendered unserviceable due to lowering of the ground water table.

(ii) Impact on Agriculture:

Indian agriculture still largely depends upon monsoon rainfall where about two-thirds of the arable land lack irrigation facilities and is termed as rainfed. The effect is manifested in the shortfalls of agricultural production in drought years. History is replete with examples of serious shortfall in cultivated areas and drop in agricultural productivity.

Severe shortage of food-grains had been felt and the country had to resort to import of food-grains to save the poor people from hunger and starvation. However, India has been able to build a buffer stock of food–grains and threat from droughts is not as serious as it used to be before the Green Revolution.

It is worth mentioning here that the shortfall in agricultural production may be the direct impact of meteorological droughts but the succeeding hydrological and agricultural droughts have a long range and far reaching impact on agriculture. This impact may be in the form of changes in the cropping patterns and impoverishment in cattle.

(iii) Social and Economic Impact:

Social and economic impact of a drought is more severe than the physical and agricultural impacts. A drought is almost invariably associated with famine which has its own social and economic consequences.

The impact of drought manifests itself in the following sequence:

1. Decline in cultivated area and fall in agricultural production (including crops and milk).

2. Fall in employment in agricultural sector.

3. Fall in purchasing power.

4. Scarcity of drinking water, food-grains and fodder.

5. Rise in inflation rate.

6. Distress sale of cattle and loss of cattle life.

7. Low intake of food and widespread malnutrition.

8. Ill health and spread of diseases like diarrhoea, dysentery, cholera and opthalmia caused by malnutrition, hunger and starvation.

9. Distress sale and mortgage of land, jewellery and personal property.

10. Migration of people from drought hit areas to other areas in search of livelihood and food.

11. Death due to malnutrition/starvation/diseases

12. Slowing down of secondary and tertiary activities due to fall in agricultural production and decline in purchasing power.

13. Low morale of the people.

14. Social stress and tension, disruption of social institutions and increase in social crime.

15. Growth of fatalism and belief in supernatural powers and superstitions.

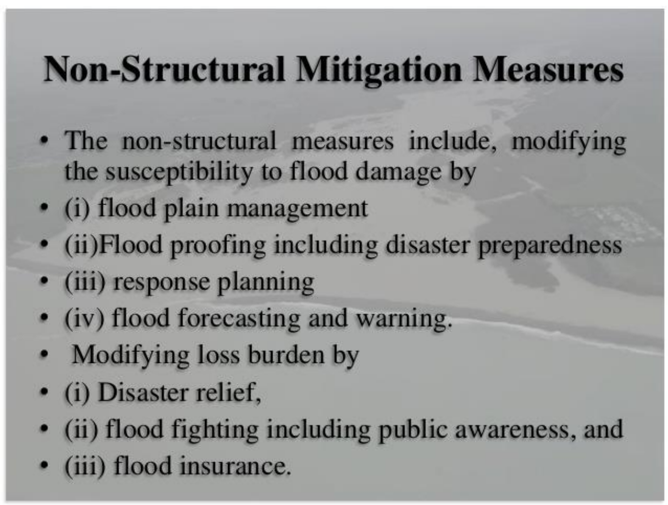
The greatest impact of a drought is seen on the weaker sections of society. These include landless labourers, small marginal farmers and artisans like weavers. Such people live in hand to mouth economy and do not have enough stock to sustain in the event of a drought.

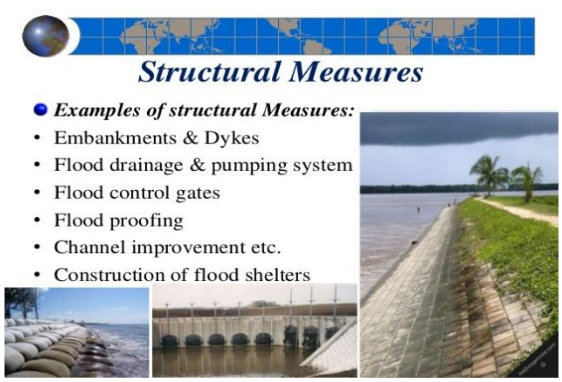
Whatever little stock they have, it is quickly exhausted and they are compelled to go in for distress sale or mortgage their belongings to rich landlords. Thus whereas a drought situation brings miseries and sufferings for the poor people, the rich people take undue advantage of the situation and exploit the poor people.

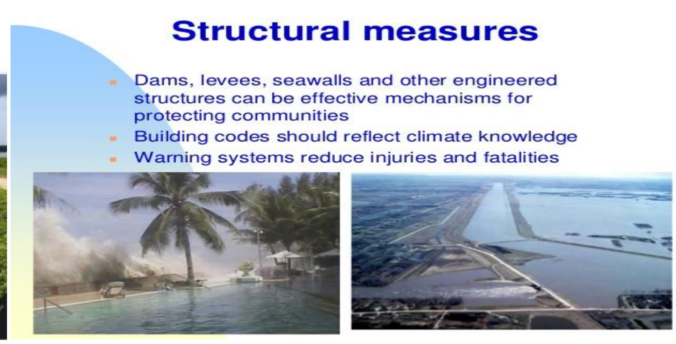
Often the poor becomes poorer and the rich becomes richer in a drought situation. A series of bad harvest plunges the small and marginal farmers in a vicious circle of poverty making them landless and penniless.

The money-lender charges high rate of interest and the inability of the farmer to repay the loan compels them to forfeit their mortgaged property. In extreme cases, the farmers tend to commit suicide. Cases of suicide by farmers in Andhra Pradesh, Karnataka, Orissa, Maharashtra and even in agriculturally rich states of Punjab and Haryana have been reported from time to time.

Q 7.Flood control measures:







<u>Benefit-Cost Analysis</u> BC analysis is commonly applied to determine the adequacy of a project to meet its goals. This type of analysis helps define the best composition of a project, identify whether a project is worth the investment, and compare and choose among competing alternatives.

In the case of flood protection, BC analysis is intended to provide a measure of how a project will provide National Economic Development (NED) benefits, which are defined as "increases in the economic value of the goods and services that result directly from a project."1 If the NED benefits of implementing a project are greater than the implementation costs (NED costs), then the BC ratio (NED benefits divided by NED costs) will be greater than one and the project will make a positive impact on the economy.

If there are several competing projects all of them with a BC ratio greater than one, the project with the highest NED net benefits (NED benefits minus NED costs) is the one that should be implemented; however, that project may not be the one with the greatest BC ratio.

Flood protection projects provide benefits throughout a defined useful life that depends on the type of project. A levee may have a useful life of 50 years, whereas relocation of a house outside the floodplain is a permanent solution. Every year that the project performs its functions provides benefits and, in principle, requires some expenditure, although most of the cost is incurred during construction. Therefore, the concept of present value (PV) is applied to compare these two series of unevenly distributed benefits and costs.

PV is a basic concept of engineering economics that accounts for the time value of money. To calculate the PV, the series of benefits accrued and the series of costs incurred every year are discounted using compound interest procedures. The discount rate used is typically set by the federal government and recently has varied between roughly 3 and 7 percent.

Standard economic engineering textbooks provide formulas to convert a uniform series of "payments" to their present value. All these formulas are based on the fact that PV for an amount P accrued in year t is

$$PV= P/(i+1)^t$$

Where i is the discount rate.

Conversely, the PV can be transformed into a series of equal amounts A over a given number of years n using the formula

$$A=PV\ i(1+i)^n/(1+i)^n-1$$

BC Ratio Computation Once the PVs of benefits and costs have been estimated, the BC ratio of the project can be computed using the formula

$$BC= \quad PV_{B/}PV_C$$

Where PVB is the present value of the benefits and PVC is the present value of the costs

$$NB=PV_B-PV_C$$

If the net benefits are positive, then the project is cost-effective and the BC ratio is greater than one. When several alternative project formulations are being considered, the project with the greatest net benefits (not the greatest BC ratio) is the optimal choice

Estimation of Flood Damages

Physical Damages As stated earlier, physical damages include structural damage to buildings (residential, commercial, industrial, public), loss of contents in those buildings (equipment, furnishings, raw materials, inventory), damages to infrastructure (roads, railways, sewers, power lines and other utilities), and damages to special facilities (power plants, hospitals, wastewater treatment plants). Physical damages may correspond to property damage, erosion damage, or transportation damage, although the majority of physical damages due to flooding are generally property damages. For all three damage categories, a floodplain inventory is necessary to understand what assets are at risk.

Physical damages depend on the severity of the flooding event. For riverine flooding, the severity is dictated mostly by the flooding levels but also by high flow velocities and duration of flooding. For coastal flooding, the inundation damage may be worsened by wave action. The severity of flooding is typically estimated using hydrologic and hydraulic.

Hydrologic and Hydraulic Modeling.

Hydrologic models are used to estimate the peak flows that are caused by a range of rainfall events. These models simulate physical watershed processes to convert rainfall into runoff.

Floodplain Inventory. The damages caused by a flood reaching a given elevation are a function of the flooding depth inside buildings that causes damages. Therefore, the zero-damage elevation, typically the elevation of the lowest occupied floor in each building, is necessary to determine the depth of the flood waters inside.

A floodplain inventory is needed to determine these zero-damage elevations as well as the types of buildings and other assets at risk.

Damage Curves.

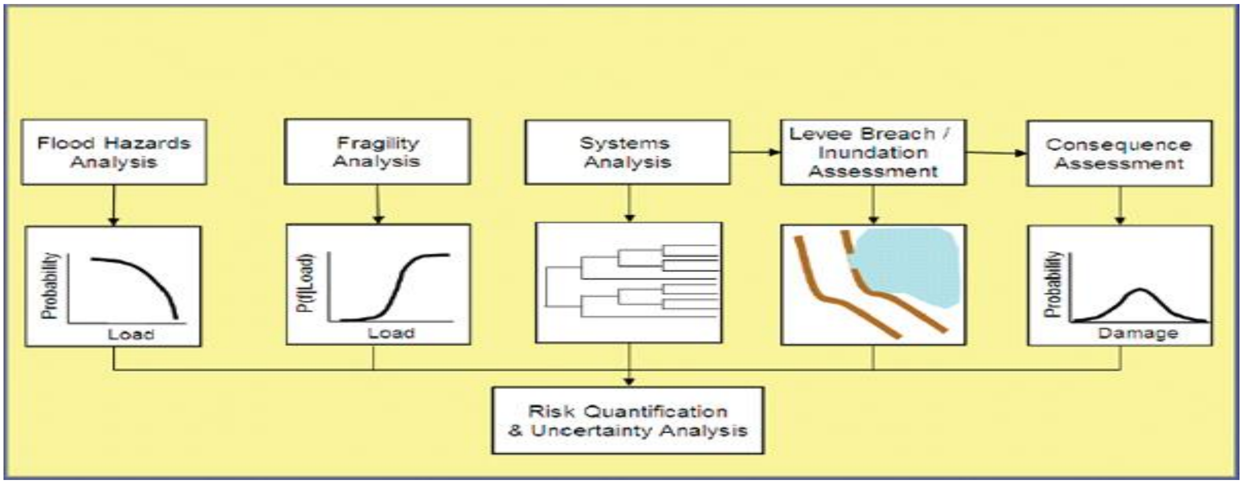
The discussion above indicates that physical damages depend on the depth and possibly the velocity of water and the duration of flooding affecting the buildings in the floodplain. These damages are typically estimated using depth-damage curves that relate the depth of water above the lowest occupied floor with the percent damage to a structure and its contents. For example, Figure 4 shows damage curves for structure and contents of a one-story single-family detached home. These curves are statistical averages from FEMA flood insurance actuarial data.

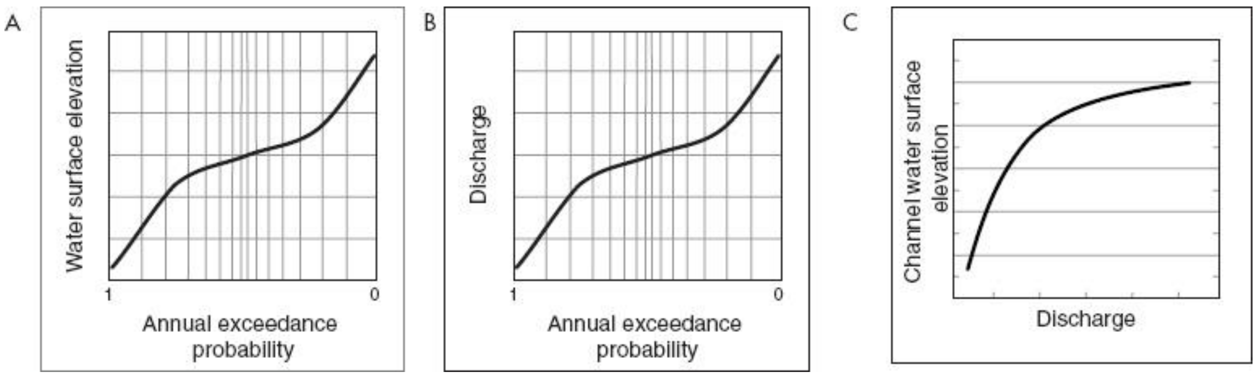
Elevation-Damage Relationships

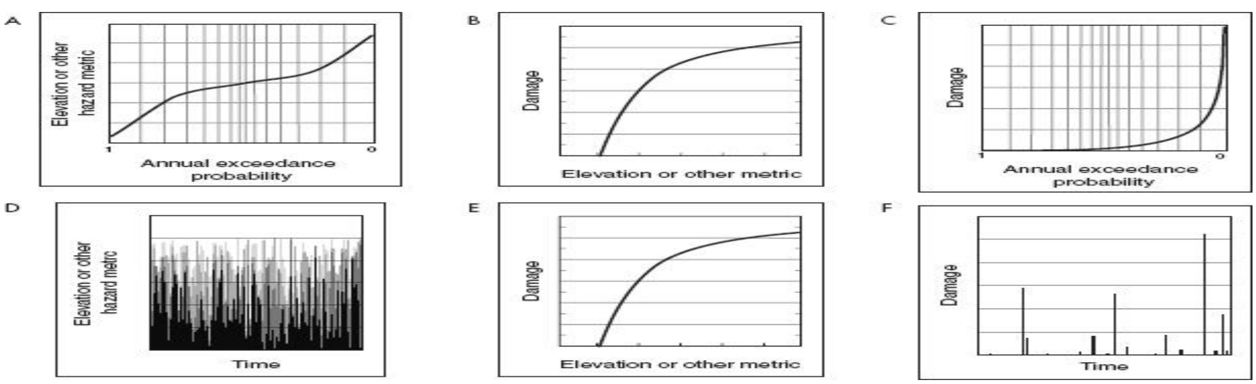
Damage-Frequency Relationships

Nonphysical Damages:

Damage Reduction by Flood Protection Measures


Flood Hazards Analysis
Fragility Analysis
Systems Analysis
Levee Breach / Inundation Assessment
Consequence Assessment
Probability
Load
P(f|Load)
Load
Probability
Damage
Risk Quantification & Uncertainty Analysis


A
Water surface elevation
1
0
Annual exceedance probability
B
Discharge
1
0
Annual exceedance probability
C
Channel water surface elevation
Discharge


A
Elevation or other hazard metric
1
0
Annual exceedance probability
B
Damage
Elevation or other metric
C
Damage
1
0
Annual exceedance probability
D
Elevation or other hazard metric
Time
E
Damage
Elevation or other metric
F
Damage
Time