Surface Water Hydrology
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Lecture – 26
Concept of Droughts and Environmental Flows

In this lecture number 25, we are discussing two important concepts; one is the concept of droughts and the environmental flow.

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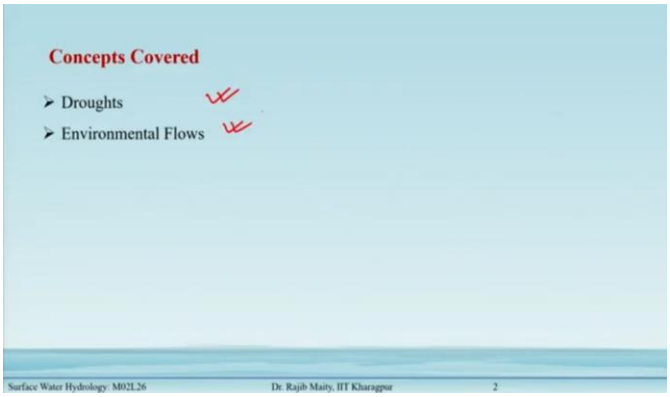

The two things covered under this concept; one is droughts and another one is environmental flow.

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The outline for this lecture goes like this; it is an introduction to hydrologic extremes. But, in this particular lecture whenever our main thing is discussing the runoff, we are discussing in that context, we are discussing the droughts.

So, in today's lecture on the droughts, we are going to give some basic introduction, then different types of droughts, then drought indices, drought management. And another very important concept is called the environmental flows, which is very much necessary. And finally, we will present some summary.

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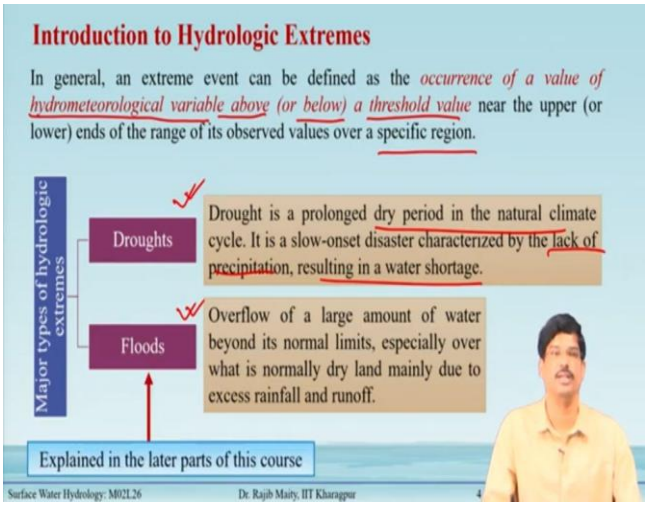

Introduction to Hydrologic Extremes

In general, an extreme event can be defined as the occurrence of a value of hydrometeorological variable above (or below) a threshold value near the upper (or lower) ends of the range of its observed values over a specific region.

- Major types of hydrologic extremes

Droughts: Drought is a prolonged dry period in the natural climate cycle. It is a slow-onset disaster characterized by the lack of precipitation, resulting in a water shortage.

Floods: Overflow of a large amount of water beyond its normal limits, especially over what is normally dry land mainly due to excess rainfall and runoff.

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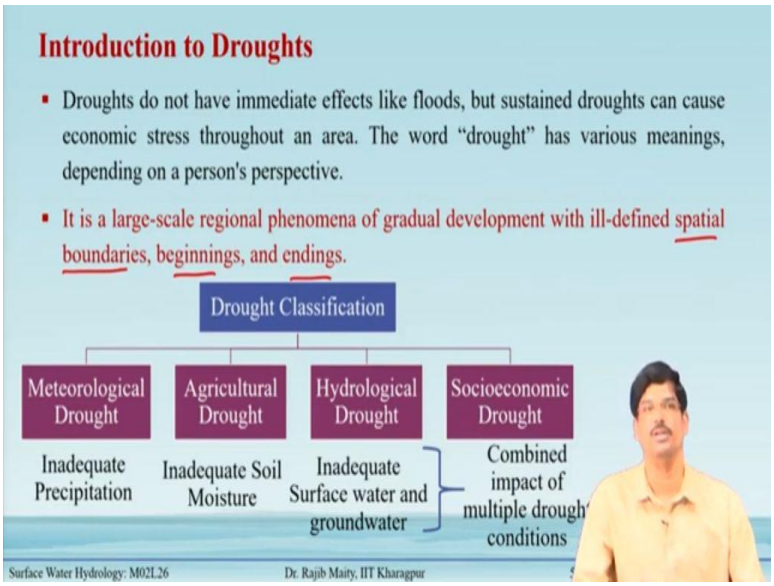

Introduction to Droughts

Droughts do not have immediate effects like floods, but sustained droughts can cause economic stress throughout an area. It is a large-scale regional phenomenon of gradual development with ill-defined spatial boundaries, beginnings, and endings.

Broadly, there are four classifications are there; the first one is meteorological drought, agricultural drought, hydrological drought, and socioeconomic drought.

So, far as the meteorological drought is concerned, it is inadequate precipitation, agricultural drought indicates inadequate soil moisture that impacts the crop yield. Hydrological drought is an inadequate surface water or groundwater storage that causes that hampers the day-to-day life through the water supply mechanism and all.

Finally, the socioeconomic drought is the combined effect of all these previous types of drought, where it can have some socioeconomic impacts also, adverse impact on the socio-economic development that is called the socioeconomic drought.

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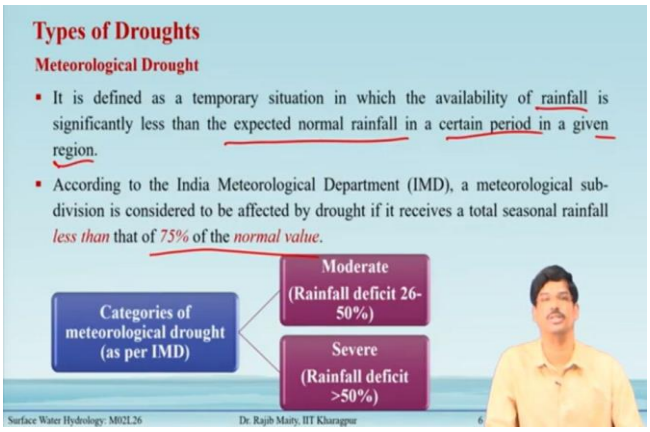

Meteorological Drought

It is defined as a temporary situation in which the availability of rainfall is significantly less than the expected normal rainfall in a certain period in a given region. According to the India Meteorological Department (IMD), a meteorological sub-division is considered to be affected by drought if it receives a total seasonal rainfall less than 75% of the normal value.

Now, categories for the meteorological droughts as well IMD, that it is moderate when the deficit is 26 to 50 percent; and it is severe when it is more than 50 percent of the deficit.

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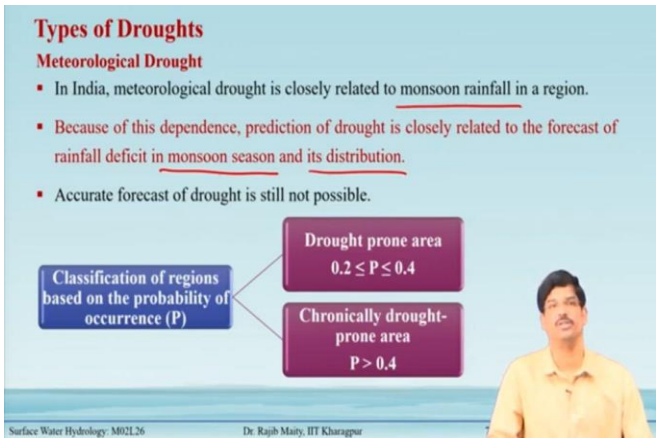

In India, the meteorological drought is closely related to monsoon rainfall. As you know that we receive more than 70 percent of the annual rainfall during this monsoon season only. So, during

the monsoon time if the rainfall is lower than normal, then it has a huge impact; and generally, it is related to the monsoon time, this is the reason.

Because of this dependence on the monsoon, the prediction of the drought is closely related to the forecast and the rainfall deficit in the monsoon time. So, that is why, so far as Indian hydroclimatology is concerned.

It is not only that total all India monsoon pattern, but it is also depending on its distribution; how it is distributed from north to south and east to west that is also a point of concern. So, an accurate forecast of the drought is still not possible; and there are different methods are being developed to capture, characterize and monitor the drought status.

The classification of the region is based on the probability of the occurrence; we call that it is a drought-prone area when this probability of occurrence of drought lies between 0.2 to 0.4. And other regions if the probability is greater than 0.4, we call it a chronically drought-prone area.

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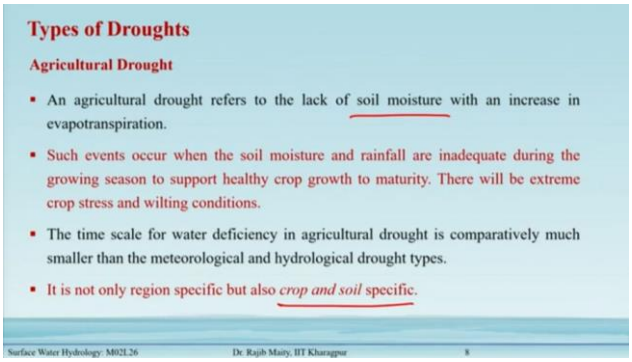

Agricultural Drought

This agricultural drought refers to the lack of soil moisture, with an increase in evapotranspiration. So, such events occur when soil moisture and rainfall are inadequate during the growing season to support the healthy crop; and that in turn affects the crop yield.

And due to the crop stress and wilting condition, the timescale of the water deficiency in the agricultural drought is comparatively much smaller than the meteorological drought and the hydrological drought. Because the growing season itself if there is a hamper; then it will impact the total yield of the crop. It is not only region-specific, but also it is the crop and the soil specific

event; because there are different types of crops. The requirement of the soil moisture is different; and of course, it depends on the soil characteristics.

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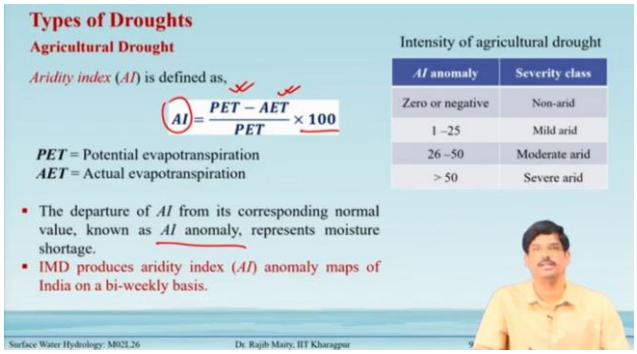

One popular index is known as the aridity index is defined as follows;

$$AI = \frac{PET - AET}{PET} \times 100$$

PET = Potential evapotranspiration

AET = Actual evapotranspiration

Intensity of agricultural drought

AI anomaly	Severity class
Zero or negative	Non-arid
1 –25	Mild arid
26 –50	Moderate arid
> 50	Severe arid

The departure of AI from its corresponding normal value, known as AI anomaly, represents moisture shortage. IMD produces aridity index (AI) anomaly maps of India on a bi-weekly basis.

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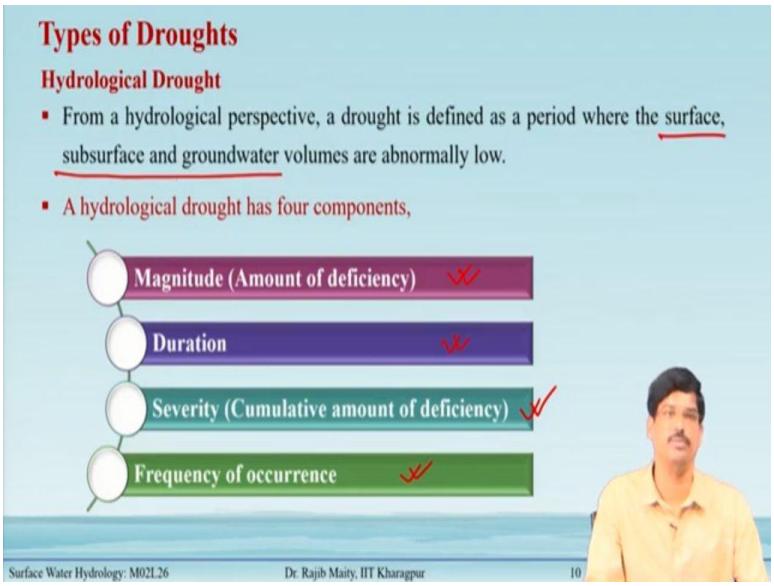

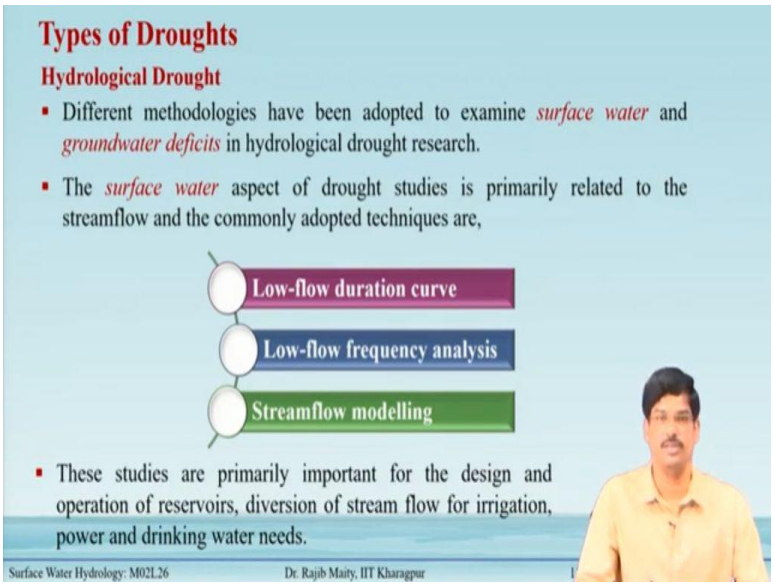

Hydrological Drought

From a hydrological perspective, drought is defined as the period where the surface, subsurface, and groundwater volumes are abnormally low. So, all three things that we are talking about, come from different sources. If those sources are suffering from water stress, then it reaches a condition that is called the hydrological drought.

So, a hydrological drought has four components, this magnitude; magnitude means how much is the amount of the deficiency; the duration, how long it occurs, the severity, the cumulative amount of the deficiency, and frequency of occurrences.

The different methodologies are there to examine the surface water and the groundwater deficit in the hydrological drought research. The surface water aspect of the drought studies is primarily related to the streamflow and commonly adopted techniques are the flow duration curve that we discussed in the previous lecture. Low flow frequency analysis and stream flow modeling.

So, these are the three things that are widely used to characterize the condition of hydrological droughts. And these studies are primarily important for the design and the operation of the reservoir diversion of the streamflow for irrigation, and the power and the drinking water needs.

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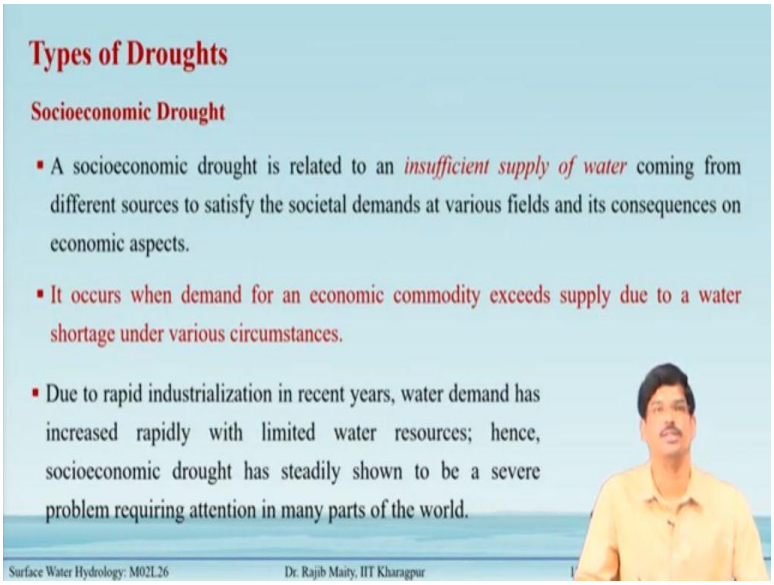

Socioeconomic Drought

Socioeconomic drought is related to an insufficient supply of water coming from different sources to satisfy the societal demand as to various fields, and its consequence on the economic aspects. So, if there are some types of droughts in any type like the meteorological, agricultural, hydrological. So, at some societal aspects, it can affect in such a way that its socioeconomic development may get hampered; then we call that it is a socioeconomic drought.

This type of drought occurs when the demand for an economic commodity exceeds the supply due to the water shortage under various circumstances can happen, including the change in the climatic condition, change in the water supply thing, the vagaries of the rainfall from one year to another year, all those things. Due to rapid industrialization in recent years, water demand has increased rapidly with limited water resources; hence, socioeconomic drought has steadily shown to be a severe problem requiring attention in many parts of the world.

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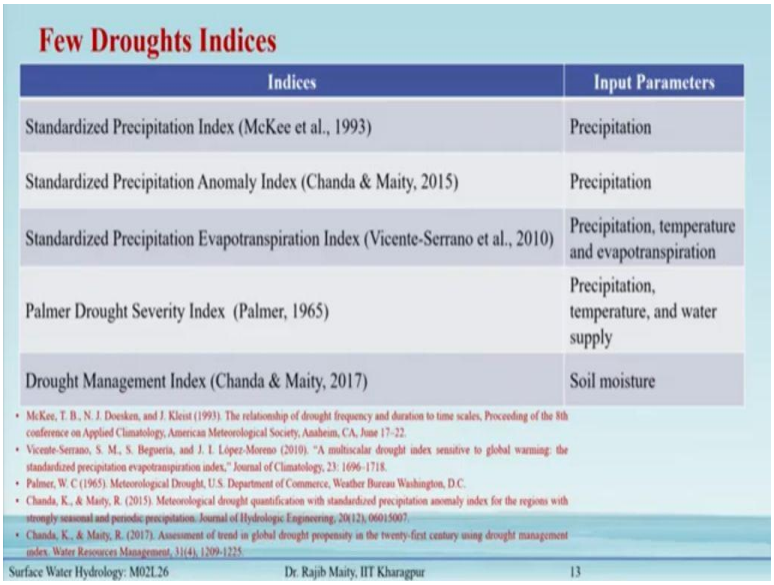

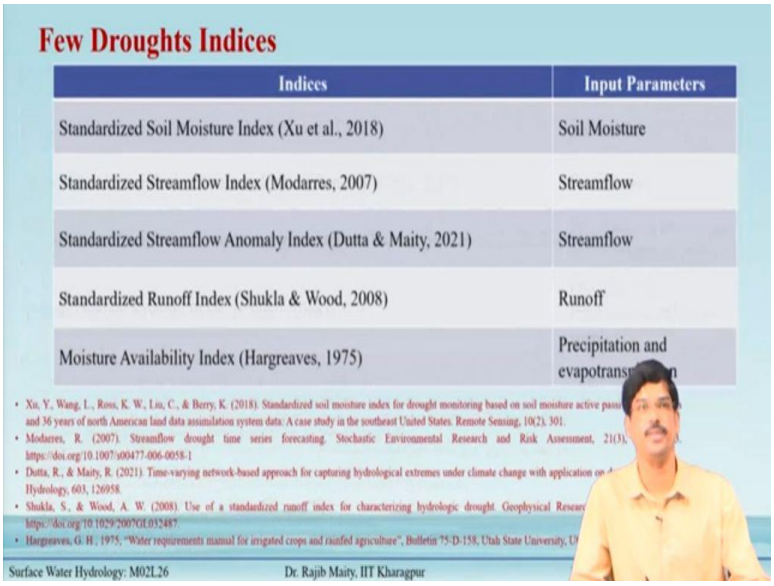

Few Droughts Indices

Indices	Input Parameters
Standardized Precipitation Index (McKee et al., 1993)	Precipitation
Standardized Precipitation Anomaly Index (Chanda & Maity, 2015)	Precipitation
Standardized Precipitation Evapotranspiration Index (Vicente-Serrano et al., 2010)	Precipitation, temperature and evapotranspiration
Palmer Drought Severity Index (Palmer, 1965)	Precipitation, temperature, and water supply
Drought Management Index (Chanda & Maity, 2017)	Soil moisture

Indices	Input Parameters
Standardized Soil Moisture Index (Xu et al., 2018)	Soil Moisture
Standardized Streamflow Index (Modarres, 2007)	Streamflow
Standardized Streamflow Anomaly Index (Dutta & Maity, 2021)	Streamflow
Standardized Runoff Index (Shukla & Wood, 2008)	Runoff
Moisture Availability Index (Hargreaves, 1975)	Precipitation and evapotranspiration

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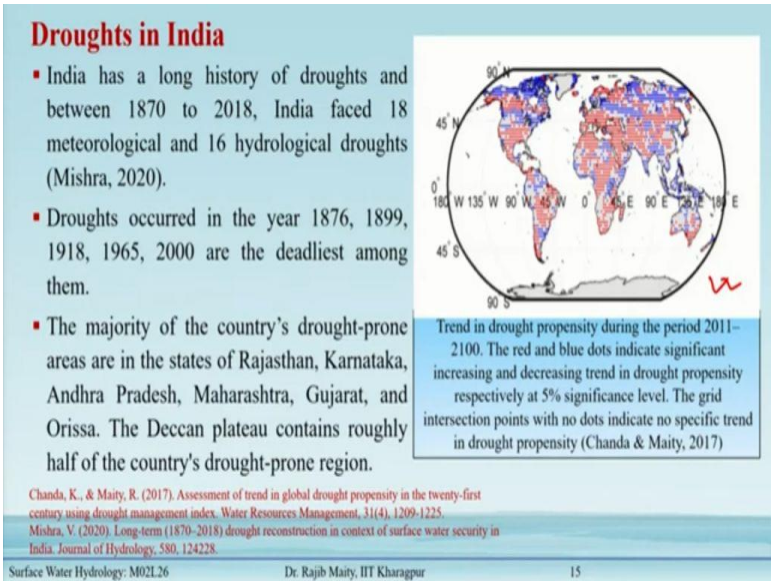

Droughts in India

India has a long history of drought in several places. For example, starting from our when the monitoring has started way back in 1870 to 2018, the very recent year India faced 18 meteorological, and 16 hydrological droughts. And the drought that occurred in the year 1876, 1899, 1918, 1965, 2000 is some of the examples of very severe drought.

The majority of the country's drought-prone areas are in the state of Rajasthan, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Orissa; and the Deccan Plateau contents roughly half of the country's drought-prone region. The trend in drought propensity during the period 2011–2100. The red and blue dots indicate a significant increasing and decreasing trend in drought propensity respectively at a 5% significance level. The grid intersection points with no dots indicate no specific trend in drought propensity (Chanda & Maity, 2017).

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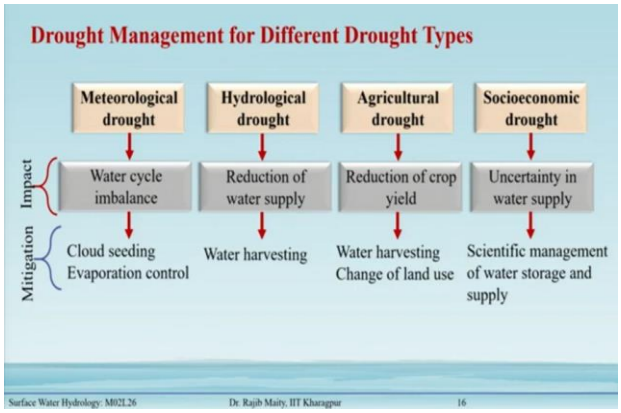

Drought Management for Different Drought Types

Drought management for the different types of droughts requires a different analysis. For example, the meteorological drought and the water cycle imbalance are there; and some sort of cloud seeding and Evaporation control; are some of the mitigation steps that can be considered. Under the category of hydrological drought reduction of the water supply, there we can adopt water harvesting.

Agricultural drought with the reduction of the crop yield, that is the impact; and we can use the water harvesting change in the land use. Socioeconomic drought, there is uncertainty in the water

supply. So, scientific management of the water and the storage and supply that can be utilized, so far as the mitigation of the socio-economic droughts are concerned.

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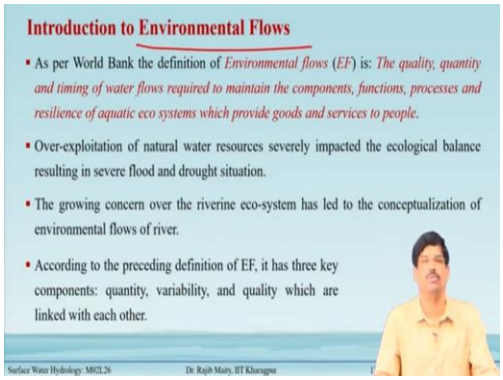

Introduction to Environmental Flows

As per World Bank, the definition of Environmental flows (EF) is The quality, quantity, and timing of water flow required to maintain the components, functions, processes, and resilience of aquatic ecosystems which provide goods and services to people.

Over-exploitation of natural water resources severely impacted the ecological balance resulting in severe floods and drought situations. The growing concern over the riverine ecosystem has led to the conceptualization of the environmental flows of the river. According to the preceding definition of EF, it has three key components: quantity, variability, and quality which are linked with each other.

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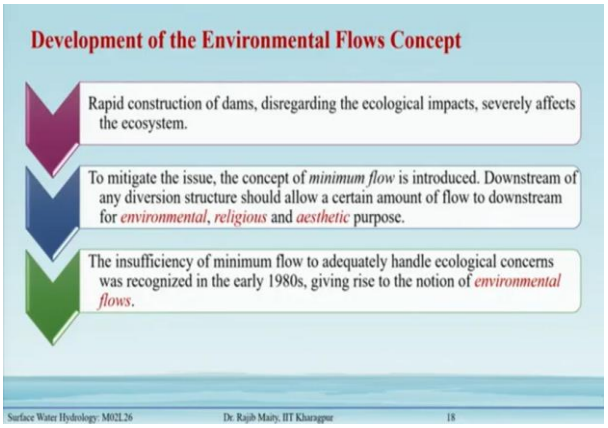

Development of the Environmental Flows Concept

The rapid construction of the dams; this regarding the ecological impacts in on particularly on the downstream as well as in the upstream also for some part. It severely affects the ecosystem.

To mitigate this issue, the concept of the minimum flow is introduced, so that the downstream of any diversion structure should allow a certain amount of flow to the downstream of the environmental, religious, and aesthetic purpose.

The insufficiency of the minimum flow to adequately handle the ecological concern was recognized in the early 1980s and gave rise to the notion of environmental flows.

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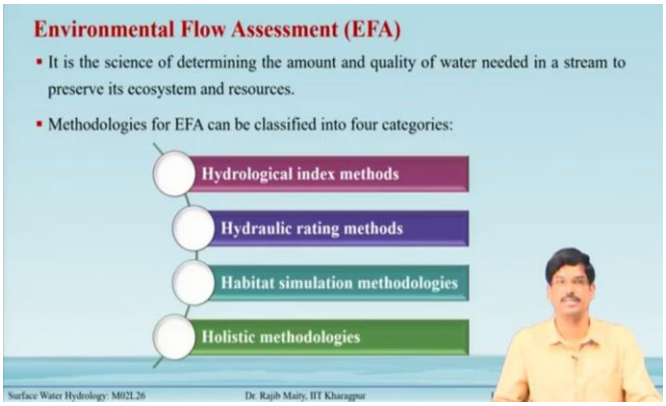

Environmental Flow Assessment (EFA)

It is the science of determining the amount and quality of water needed in a stream to preserve its ecosystem and resources.

Methodologies for EFA can be classified into four categories:

I. Hydrological index methods

II. Hydraulic rating methods

III. Habitat simulation methodologies

IV. Holistic methodologies

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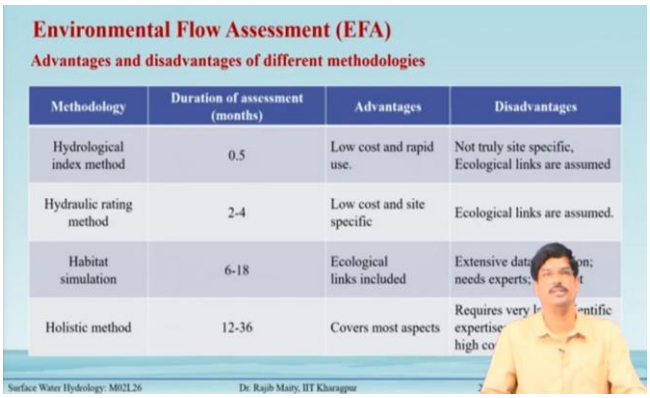

Advantages and disadvantages of different methodologies

Methodology	Duration of assessment (months)	Advantages	Disadvantages
Hydrological index method	0.5	Low cost and rapid use.	Not truly site specific, Ecological links are assumed
Hydraulic rating method	2-4	Low cost and site specific	Ecological links are assumed.
Habitat simulation	6-18	Ecological links included	Extensive data collection; needs experts; high cost
Holistic method	12-36	Covers most aspects	Requires very large scientific expertise; very high cost.

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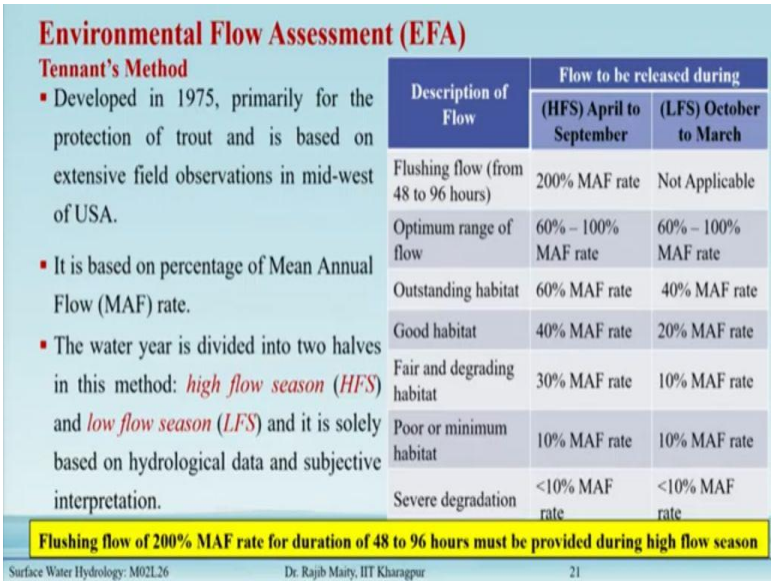

Tennant's Method

One of the environmental flow assessment methods is known as the Tennant method. It was developed in 1975, primarily for the protection of some aquatic life; and it is based on extensive field observation in the mid-west of the USA. It is based on the percentage of mean annual flow MAF which is the concept of the rate MAF rate. The water year is divided into two halves in this method: high flow season (HFS) and low flow season (LFS) and it is solely based on hydrological data and subjective interpretation.

Description of Flow	Flow to be released during	
	(HFS) April to September	(LFS) October to March
Flushing flow (from 48 to 96 hours)	200% MAF rate	Not Applicable
Optimum range of flow	60% – 100% MAF rate	60% – 100% MAF rate
Outstanding habitat	60% MAF rate	40% MAF rate
Good habitat	40% MAF rate	20% MAF rate
Fair and degrading habitat	30% MAF rate	10% MAF rate
Poor or minimum habitat	10% MAF rate	10% MAF rate
Severe degradation	<10% MAF rate	<10% MAF rate

And for so far as the flushing flow is concerned that 200 MAF rate for the duration of 48 to 96 hours, must be provided during the high flow season only; and it is specifically applicable for the Indian condition also. As we know that August and September or July-August is the peak monsoon time, where the flow is in its maximum phase.

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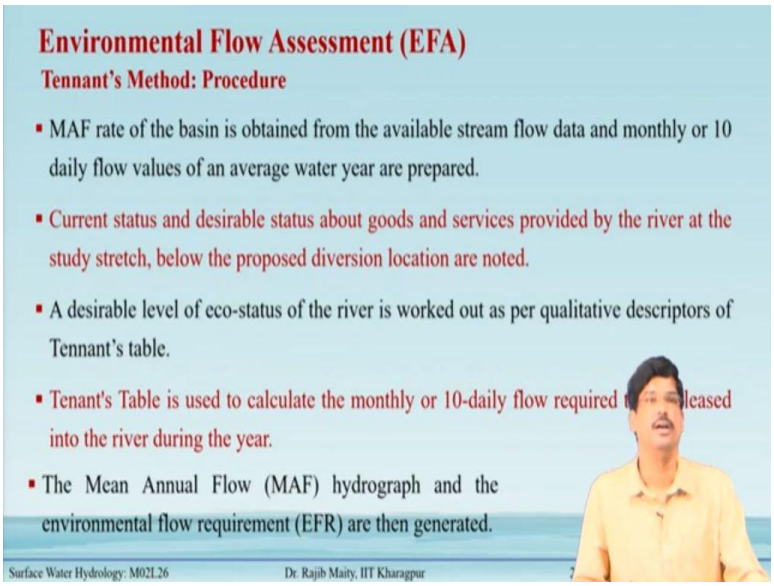

Tennant's Method: Procedure

- MAF rate of the basin is obtained from the available streamflow data and monthly or 10 daily flow values of an average water year are prepared.
- Current status and desirable status about goods and services provided by the river at the study stretch, below the proposed diversion location are noted.
- A desirable level of eco-status of the river is worked out as per qualitative descriptors of Tennant's table.
- The tenant's Table is used to calculate the monthly or 10-daily flow required to be released into the river during the year.
- The Mean Annual Flow (MAF) hydrograph and the environmental flow requirement (EFR) are then generated.

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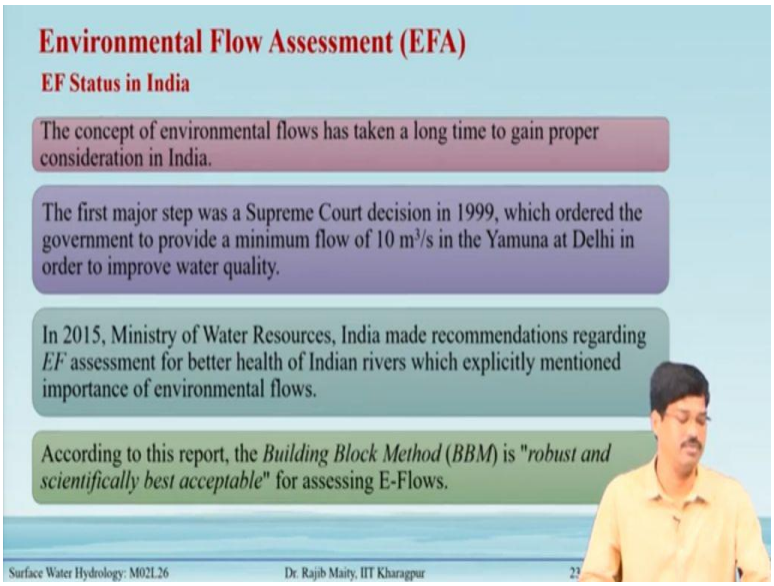

EF Status in India

- The concept of environmental flows has taken a long time to gain proper consideration in India.
- The first major step was a Supreme Court decision in 1999, which ordered the government to provide a minimum flow of 10 m^3/s in the Yamuna at Delhi to improve water quality.
- In 2015, the Ministry of Water Resources, India made recommendations regarding EF assessment for better health of Indian rivers which explicitly mentioned the importance of environmental flows.
- According to this report, the Building Block Method (BBM) is "robust and scientifically best acceptable" for assessing E-Flows.

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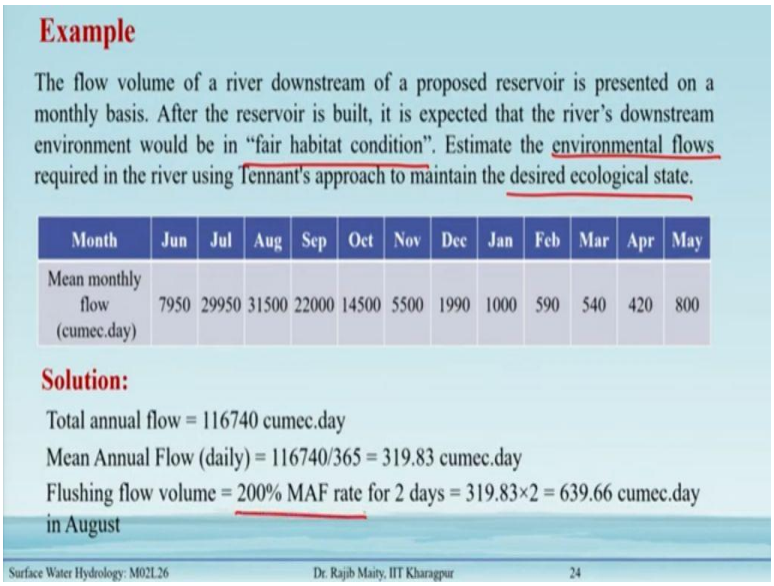

Example

The flow volume of a river downstream of a proposed reservoir is presented on a monthly basis. After the reservoir is built, it is expected that the river's downstream environment would be in "fair habitat condition". Estimate the environmental flows required in the river using Tennant's approach to maintain the desired ecological state.

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Mean monthly flow (cumec.day)	7950	29950	31500	22000	14500	5500	1990	1000	590	540	420	800

Solution:

Total annual flow = 116740 cumec.day

Mean Annual Flow (daily) = 116740/365 = 319.83 cumec.day

Flushing flow volume = 200% MAF rate for 2 days = 319.83×2 = 639.66 cumec.day in August

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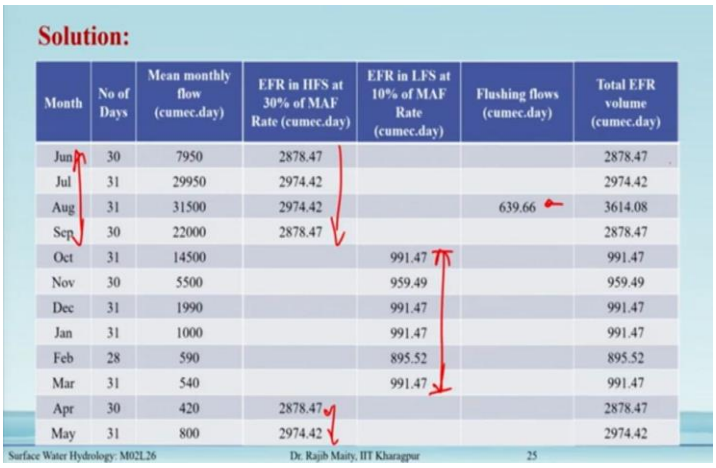

Solution:

Month	No of Days	Mean monthly flow (cumec.day)	EFR in HFS at 30% of MAF Rate (cumec.day)	EFR in LFS at 10% of MAF Rate (cumec.day)	Flushing flows (cumec.day)	Total EFR volume (cumec.day)
Jun	30	7950	2878.47			2878.47
Jul	31	29950	2974.42			2974.42
Aug	31	31500	2974.42		639.66	3614.08
Sep	30	22000	2878.47			2878.47
Oct	31	14500		991.47		991.47
Nov	30	5500		959.49		959.49
Dec	31	1990		991.47		991.47
Jan	31	1000		991.47		991.47
Feb	28	590		895.52		895.52
Mar	31	540		991.47		991.47
Apr	30	420	2878.47			2878.47
May	31	800	2974.42			2974.42

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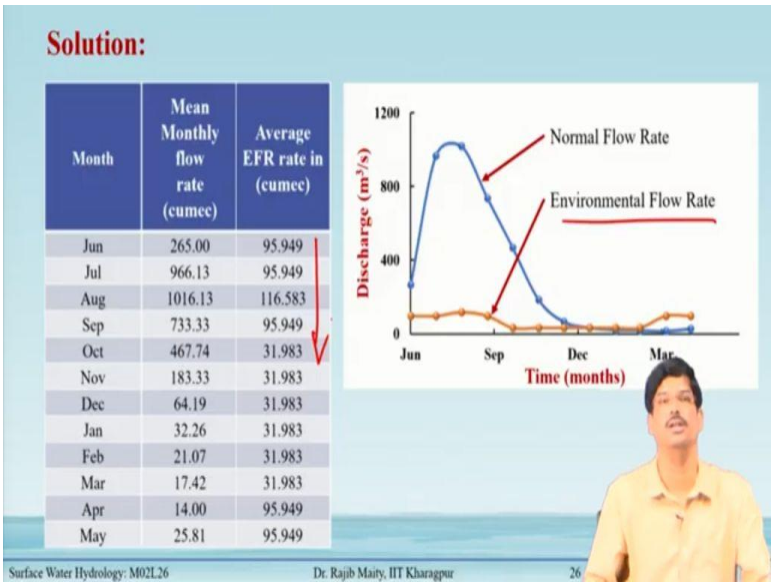

Month	Mean Monthly flow rate (cumec)	Average EFR rate in (cumec)
Jun	265.00	95.949
Jul	966.13	95.949
Aug	1016.13	116.583
Sep	733.33	95.949
Oct	467.74	31.983
Nov	183.33	31.983
Dec	64.19	31.983
Jan	32.26	31.983
Feb	21.07	31.983
Mar	17.42	31.983
Apr	14.00	95.949
May	25.81	95.949

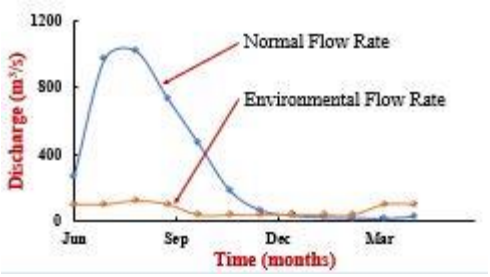

Fig.1 shows the hydrographs of normal streamflow and EFR

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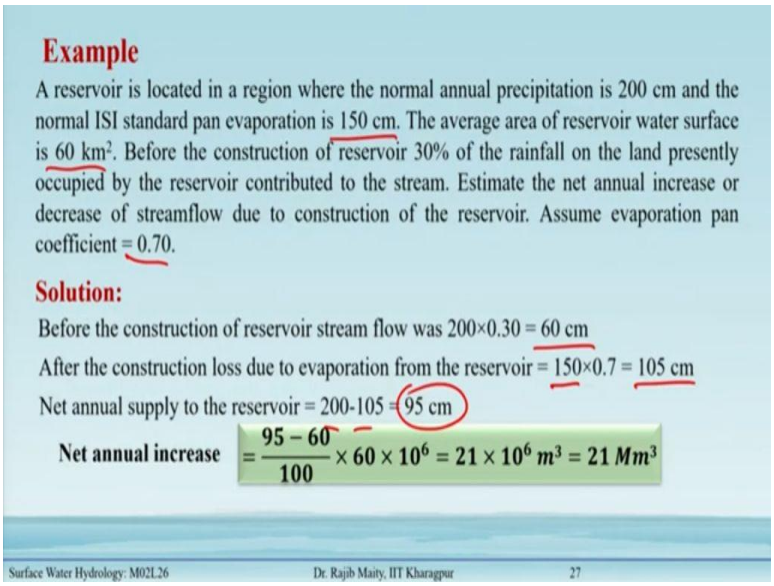

Example

A reservoir is located in a region where the normal annual precipitation is 200 cm and the normal ISI standard pan evaporation is 150 cm. The average area of the reservoir water surface is 60 km^2. Before the construction of the reservoir 30% of the rainfall on the land presently occupied by the reservoir contributed to the stream. Estimate the net annual increase or decrease of streamflow due to the construction of the reservoir. Assume evaporation pan coefficient = 0.70.

Solution:

Before the construction of the reservoir, streamflow was 200×0.30 = 60 cm

After the construction loss due to evaporation from the reservoir = 150×0.7 = 105 cm

Net annual supply to the reservoir = 200-105 = 95 cm

Net annual increase = $\frac{95-60}{100} \times 60 \times 10^6 = 21 \times 10^6\ m^3 = 21\ Mm^3$

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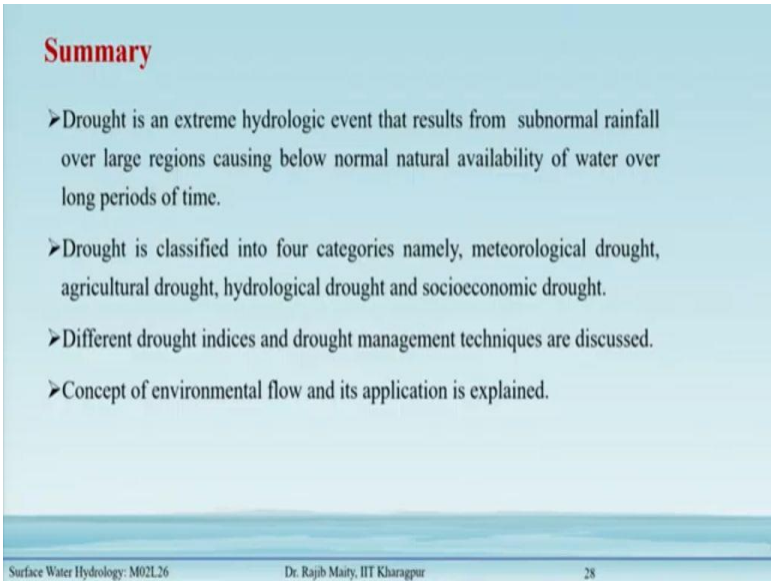

Summary

In summary, we learned the following points from this lecture:

- Drought is an extreme hydrologic event that results from subnormal rainfall over large regions causing below normal natural availability of water over long periods.
- Drought is classified into four categories namely, meteorological drought, agricultural drought, hydrological drought, and agricultural drought.
- Different drought indices and drought management techniques are discussed.

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