Surface Water Hydrology
Professor Rajib Maity
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Lecture – 55
Basics of Hydrologic Design

This week we will be discussing that hydrologic design. And this one is divided into two parts; this week we will take up this hydrologic design I. In this very first lecture, we will discuss some of the basics of this hydrologic design.

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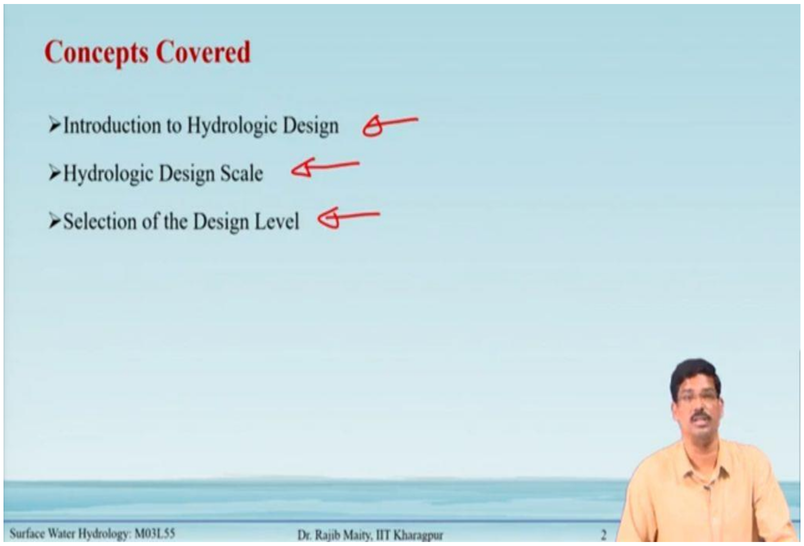

Concepts Covered

- Introduction to Hydrologic Design
- Hydrologic Design Scale
- Selection of the Design Level

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Under this concept, the introduction to hydrologic design, hydrologic design scale, and the selection of design level.

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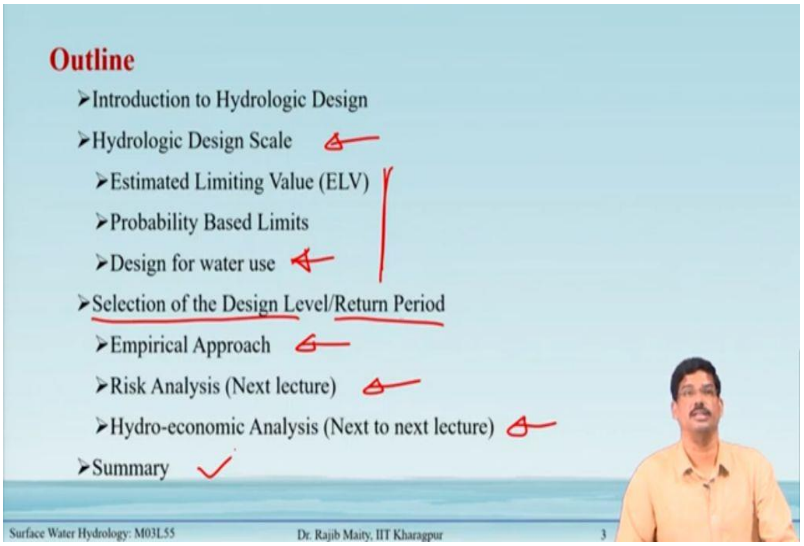

Outline

- Introduction to Hydrologic Design
- Hydrologic Design Scale
  - Estimated Limiting Value (ELV)
  - Probability Based Limits
  - Design for water use
- Selection of the Design Level/Return Period
  - Empirical Approach
  - Risk Analysis (Next lecture)
  - Hydro-economic Analysis (Next to next lecture)
- Summary

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The outline of our lecture goes like this, the introduction to hydrologic design, then the hydrologic design scale. Under this hydrologic design scale, we will be discussing different aspects. The first one, the most important one is the Estimated Limiting Value abbreviated as ELV. Then some probability-based limits on how to calculate those things. And what is the difference between when we talk about the higher side of the extreme and the lower side of the extreme, that comes in the case of the lower side of the extreme comes some aspect of the design up for water use?

Now, secondly that the selection of this design level or in terms of the return period, how it should, we should decide what should be the design level for a particular structure or a particular project. There are three approaches we will be discussing. In this approach after discussing the basic things, we will discuss this empirical approach. In the next lecture, we will discuss the risk analysis-based approach, and then, next lecture we will discuss the hydro-economic analysis, where the economic aspects are also considered and then we will summarize this particular lecture.

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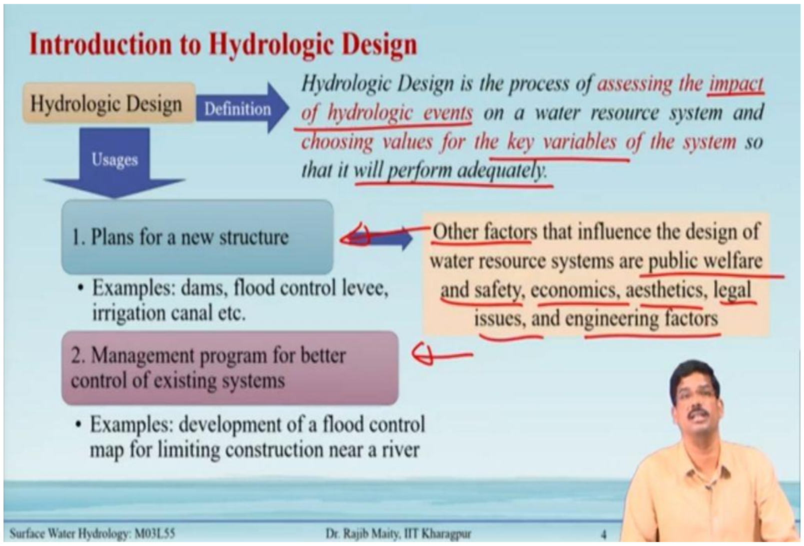

Introduction to Hydrologic Design

Hydrologic Design is the process of assessing the impact of hydrologic events on a water resource system and choosing values for the key variables of the system so that it will perform adequately.

1. Plans for a new structure
   - Examples: dams, flood control levee, irrigation canal etc.

Other factors that influence the design of water resource systems are public welfare and safety, economics, aesthetics, legal issues, and engineering factors

2. Management program for better control of existing systems
   - Examples: development of a flood control map for limiting construction near a river

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Introduction to Hydrologic Design

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Usages of Hydrologic Design

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Other factors that influence the design of water resource systems are public welfare and safety, economics, aesthetics, legal issues, and engineering factors.

Examples: dams, flood control levees, irrigation canals, etc.

2. Management program for better control of existing systems

Examples: development of a flood control map for limiting construction near a river

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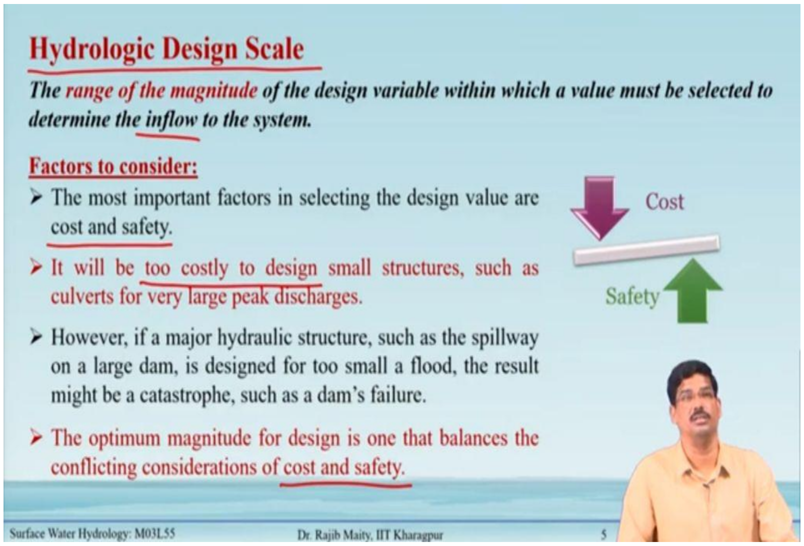

Hydrologic Design Scale

The range of the magnitude of the design variable within which a value must be selected to determine the inflow to the system.

Factors to consider:

- The most important factors in selecting the design value are cost and safety.
- It will be too costly to design small structures, such as culverts for very large peak discharges.
- However, if a major hydraulic structure, such as the spillway on a large dam, is designed for too small a flood, the result might be a catastrophe, such as a dam's failure.
- The optimum magnitude for design is one that balances the conflicting considerations of cost and safety.

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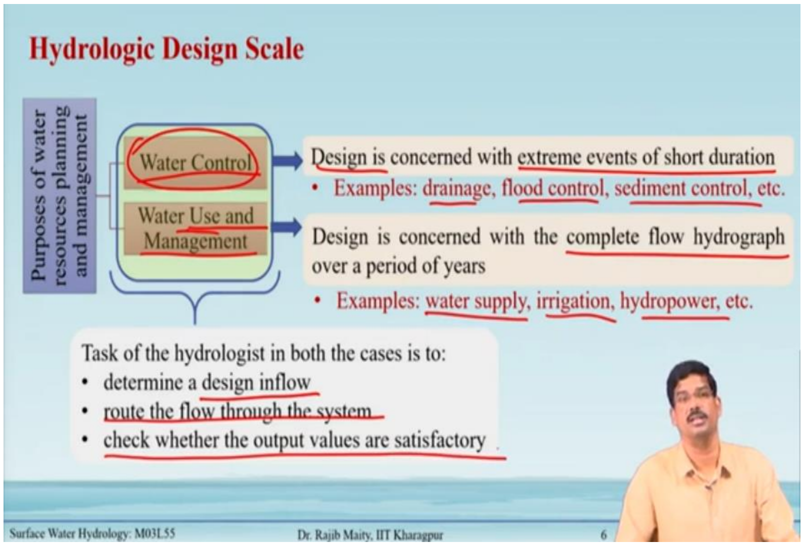

Hydrologic Design Scale

Purposes of water resources planning and management

Water Control

Water Use and Management

Design is concerned with extreme events of short duration

- Examples: drainage, flood control, sediment control, etc.

Design is concerned with the complete flow hydrograph over a period of years

- Examples: water supply, irrigation, hydropower, etc.

Task of the hydrologist in both the cases is to:

- determine a design inflow
- route the flow through the system
- check whether the output values are satisfactory

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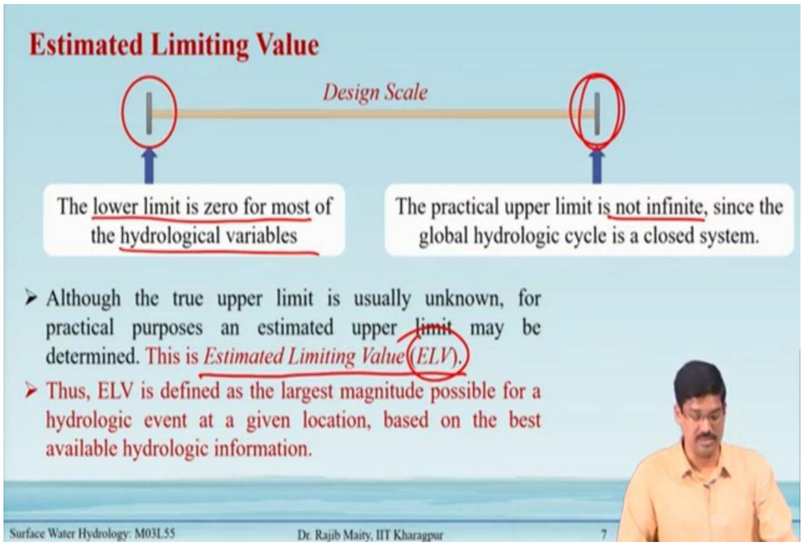

Estimated Limiting Value

Design Scale

The lower limit is zero for most of the hydrological variables

The practical upper limit is not infinite, since the global hydrologic cycle is a closed system.

- Although the true upper limit is usually unknown, for practical purposes an estimated upper limit may be determined. This is *Estimated Limiting Value* (*ELV*).
- Thus, ELV is defined as the largest magnitude possible for a hydrologic event at a given location, based on the best available hydrologic information.

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Estimated Limiting Value

In a design scale, if the lower limit is zero for most of the hydrological variables such as stream flow, the lower limit is zero then the upper limit we cannot say that it is infinite, it is not infinite, because as we know that the global hydrologic system is a close one. So, the true upper limit is generally unknown for practical purposes and the estimated upper limit may be determined this estimated upper limit is what we call the Estimated Limiting Value abbreviated as ELV.

So, definition wise ELV is defined as the largest magnitude possible for a hydrologic event at a given location, based on the best available hydrologic information.

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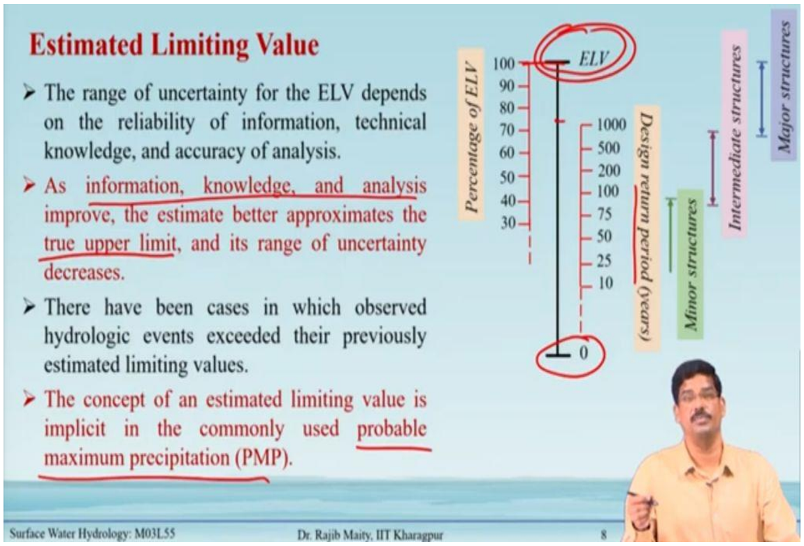

Estimated Limiting Value

- The range of uncertainty for the ELV depends on the reliability of information, technical knowledge, and accuracy of analysis.
- As information, knowledge, and analysis improve, the estimate better approximates the true upper limit, and its range of uncertainty decreases.
- There have been cases in which observed hydrologic events exceeded their previously estimated limiting values.
- The concept of an estimated limiting value is implicit in the commonly used probable maximum precipitation (PMP).

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Design scale range from 0 to this upper limit ELV, then percentage-wise can show that this level is 100 percent of this ELV. And this gradually goes down as it goes down to the 0. Another way of describing this one is that design return period values also.

So, a particular percentage for a particular case may correspond to some of the return periods. these are some of the links from the ELV and this design return period and depending on that there are different structures are there. For example, the major structures maybe a return period of more than 500 years or so, intermediate structures have some range of these either percentage of the ELV, or through this design return period. And the minor structures may also correspond to each other.

Now, the range of the uncertainty for the ELV depends on the reliability of the information, technical knowledge, and accuracy of the analysis. As the information knowledge and analysis improve, the estimate better approximates the upper true upper limit. It is very difficult to ascertain and its range of uncertainty may decrease if this information's are very much reliable to us. There have been cases in which observed hydrologic events exceed their previously estimated limiting values.

When there are some external factors like climate change impact comes on this water resource and hydrological sciences, then this the practical upper limit that we see whatever the way we calculated previously, that may have changed over the time. The concept of an estimated limiting value is sometimes implicit in many commonly used things. For example, the Probable Maximum Precipitation (PMP).

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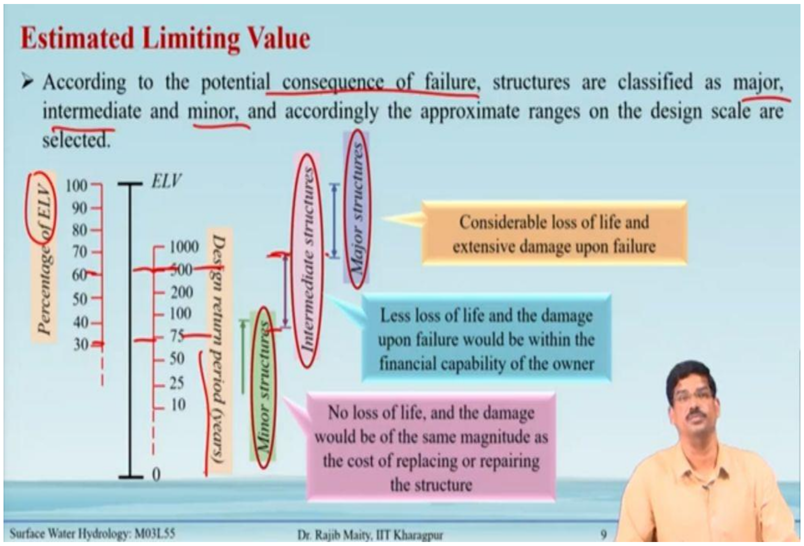

Estimated Limiting Value

- According to the potential consequence of failure, structures are classified as major, intermediate and minor, and accordingly the approximate ranges on the design scale are selected.

Considerable loss of life and extensive damage upon failure

Less loss of life and the damage upon failure would be within the financial capability of the owner

No loss of life, and the damage would be of the same magnitude as the cost of replacing or repairing the structure

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According to the potential consequence of the failure for different structures, the structures can be classified as the major intermediate, or minor, accordingly, the approximate range of the design scale can be selected. For example, here when we talk about the major structures, it may correspond to the range of say 500 years of the return period or 60 percent of the ELV like that.

When we call that a major structure, there is a considerable loss of life and extensive damage if those structures fail. On the other hand, in the intermediate structures when we say the range we can see from this one maybe 500 to the 100 or 75 years return period or 30 percent of the ELV. In these cases, the less loss of life and the damage upon failure would be within the financial capacity of the owner.

And similarly, for the minor structure, there is generally no loss of life, damage would be of the same magnitude at the cost of replacing or repairing the structure.

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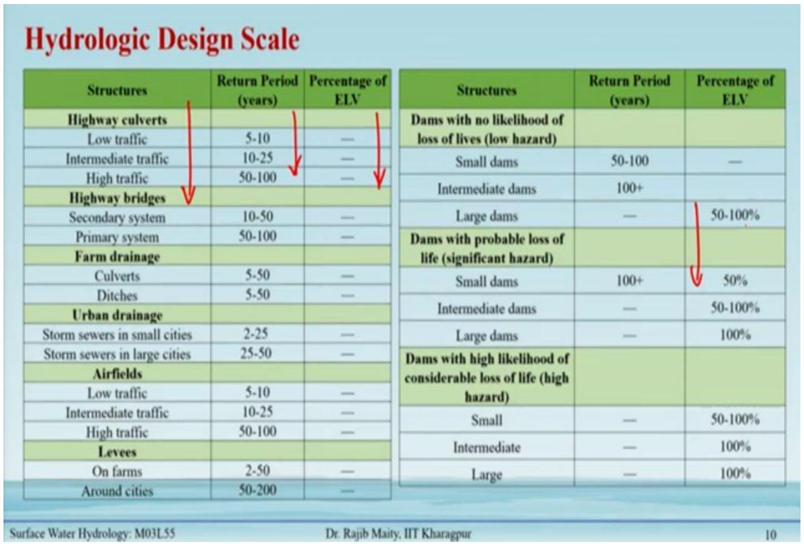

Hydrologic Design Scale

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Structures	Return Period (years)	Percentage of ELV
Highway culverts		
Low traffic	5-10	—
Intermediate traffic	10-25	—
High traffic	50-100	—
Highway bridges		
Secondary system	10-50	—
Primary system	50-100	—
Farm drainage		
Culverts	5-50	—
Ditches	5-50	—
Urban drainage		
Storm sewers in small cities	2-25	—
Storm sewers in large cities	25-50	—
Airfields		
Low traffic	5-10	—
Intermediate traffic	10-25	—
High traffic	50-100	—
Levees		
On farms	2-50	—
Around cities	50-200	—

Structures	Return Period (years)	Percentage of ELV
Dams with no likelihood of loss of lives (low hazard)		
Small dams	50-100	—
Intermediate dams	100+	
Large dams	—	50-100%
Dams with probable loss of life (significant hazard)		
Small dams	100+	50%
Intermediate dams	—	50-100%
Large dams	—	100%
Dams with high likelihood of considerable loss of life (high hazard)		
Small	—	50-100%
Intermediate	—	100%
Large	—	100%

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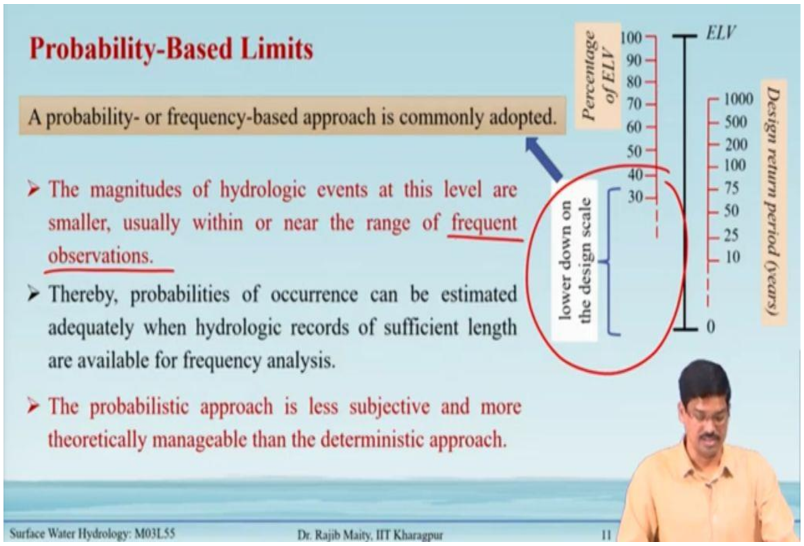
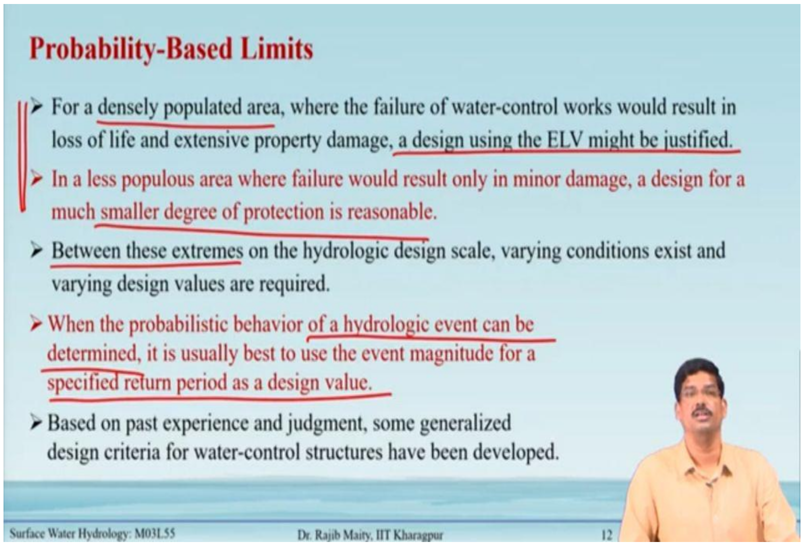


Probability-Based Limits

A probability- or frequency-based approach is commonly adopted.

- The magnitudes of hydrologic events at this level are smaller, usually within or near the range of frequent observations.
- Thereby, probabilities of occurrence can be estimated adequately when hydrologic records of sufficient length are available for frequency analysis.
- The probabilistic approach is less subjective and more theoretically manageable than the deterministic approach.



Probability-Based Limits

- For a densely populated area, where the failure of water-control works would result in loss of life and extensive property damage, a design using the ELV might be justified.
- In a less populous area where failure would result only in minor damage, a design for a much smaller degree of protection is reasonable.
- Between these extremes on the hydrologic design scale, varying conditions exist and varying design values are required.
- When the probabilistic behavior of a hydrologic event can be determined, it is usually best to use the event magnitude for a specified return period as a design value.
- Based on past experience and judgment, some generalized design criteria for water-control structures have been developed.

Probability-Based Limits

A probability- or frequency-based approach is commonly adopted because the magnitude of this hydrologic event at this level is smaller, and usually within or near the range of the frequent observations. So, in the observational record, these things can be recorded.

Thereby, the probabilities of the occurrence can be estimated adequately when hydrologic records of sufficient length are available for frequency analysis. The probabilistic approach is less subjective and more theoretically manageable than the deterministic approach. Now, this probability-based limit is two extremes. First of all, if the area is very highly densely populated, where the failure of the water-control works would result in the loss of life, extensive property, damage a design using the ELV might be justified. In a less populous area where the failure would result only in minor damage, a design for a much smaller degree of protection is reasonable.

Now, the first two are talking about them when it is a smaller degree of protection is reasonable. And whereas in the very highly populated one, a design that may be using the ELV might be justified, so these two are the two extremes. But, between these two extremes, the hydrologic design scale varying condition exists and varying design values are required.

Now, when the probabilistic behavior of a hydrologic event can be determined, this is one of the very important things. If those variables can capture their probabilistic behavior, it is usually best practice to use the event magnitude for a specific return period as a design value.

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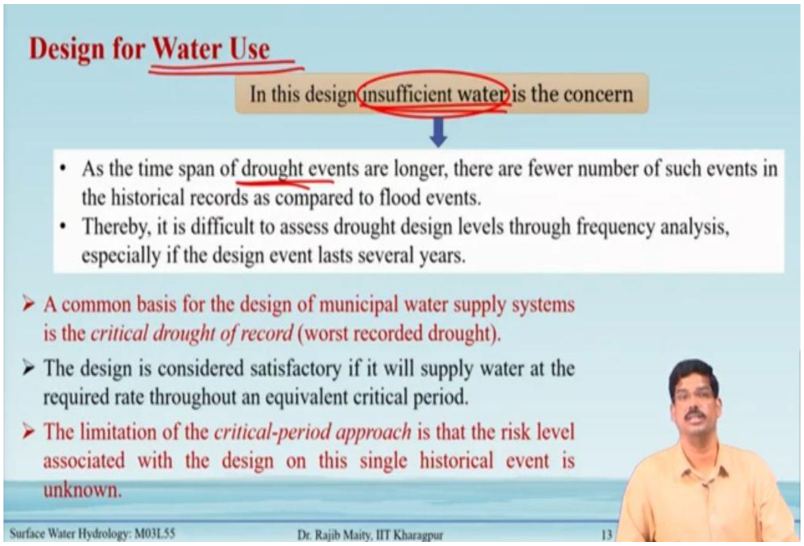


Design for Water Use

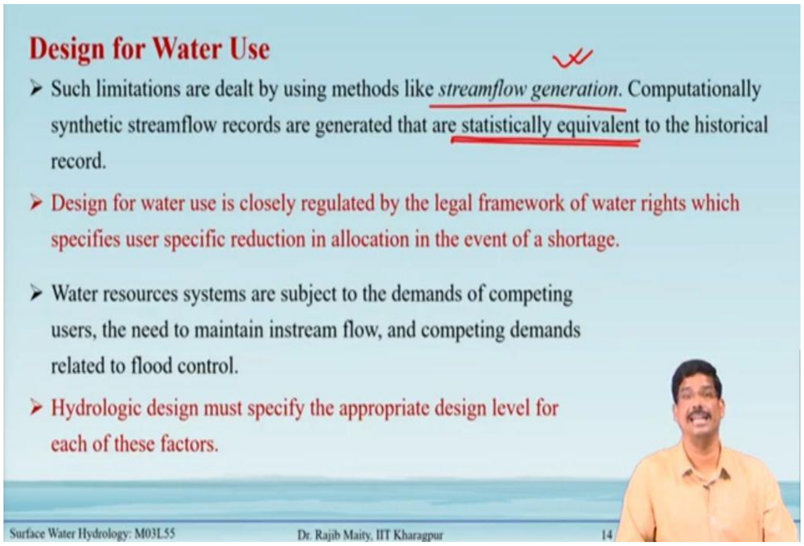
In this design insufficient water is the concern

- As the time span of drought events are longer, there are fewer number of such events in the historical records as compared to flood events.
- Thereby, it is difficult to assess drought design levels through frequency analysis, especially if the design event lasts several years.

➢ A common basis for the design of municipal water supply systems is the *critical drought of record* (worst recorded drought).

➢ The design is considered satisfactory if it will supply water at the required rate throughout an equivalent critical period.

➢ The limitation of the *critical-period approach* is that the risk level associated with the design on this single historical event is unknown.



Design for Water Use

- Such limitations are dealt by using methods like *streamflow generation*. Computationally synthetic streamflow records are generated that are statistically equivalent to the historical record.
- Design for water use is closely regulated by the legal framework of water rights which specifies user specific reduction in allocation in the event of a shortage.
- Water resources systems are subject to the demands of competing users, the need to maintain instream flow, and competing demands related to flood control.
- Hydrologic design must specify the appropriate design level for each of these factors.

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Design for Water Use

In this design, insufficient water is the concern, whether it will meet the requirement or not. So, far as the insufficient water is concerned the time span of the, for example, the drought is one of the things. The drought events are longer, there is a fewer number of such events in the historical records as compared to the flood events. So, thereby it is difficult sometimes to assess the drought design levels through the frequency analysis, especially if the design events last several years or so.

A common basis for the design of the municipal water supply, for example, is a critical drought of the record, the worst recorded drought in that particular area. The design is considered satisfactory if it will supply the water at the same required rate throughout an equivalent critical period. The limitation of the critical period approach is the risk level associated with the design of this single historical event is unknown.

Now, such limitations can be dealt with by the user and the method like the streamflow generation. So, in this streamflow generation, again the computationally synthetic streamflow records are generated that are statistically equivalent. These are all the key terms to maintain and the use of these probability statistics methods is required in this case.

So, the statistical properties should be preserved when going for this different streamflow generation to have larger synthetic data, based on the of course based on them, or that honoring the statistical property is in the historical record. The design of the water use is closely regulated by the legal framework of water rights, which specifies user-specific reduction in the allocation in the event of this shortage.

So, if there are multiple users are there, those things are decided on which ones should be given the more priority. Water resources systems are subject to the demand of competing interests and the need to maintain the in-stream flow, and competing demands related to flood control. Hydrologic design must specify the appropriate design level for each of this is factors.

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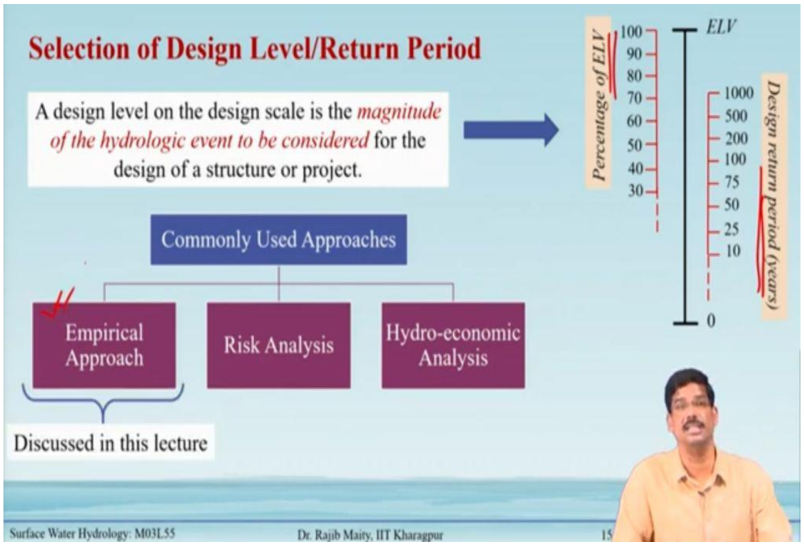

Selection of Design Level/Return Period

A design level on the design scale is the *magnitude of the hydrologic event to be considered* for the design of a structure or project.

Commonly Used Approaches

- Empirical Approach
- Risk Analysis
- Hydro-economic Analysis

Discussed in this lecture

Selection of Design Level/Return Period

The selection of the design level or the return period becomes very important. So, a design level on the design scale is a magnitude that we discussed a few slides back, you can just see that it can be either in the percentage of the ELV or in terms of the return period.

The magnitude of the hydrologic event to be considered for the design of a structure or the project, so that is, so these methods are there are can be grouped into three main methods. The first one is this empirical approach. And the other two are the risk analysis and hydro-economic analysis.

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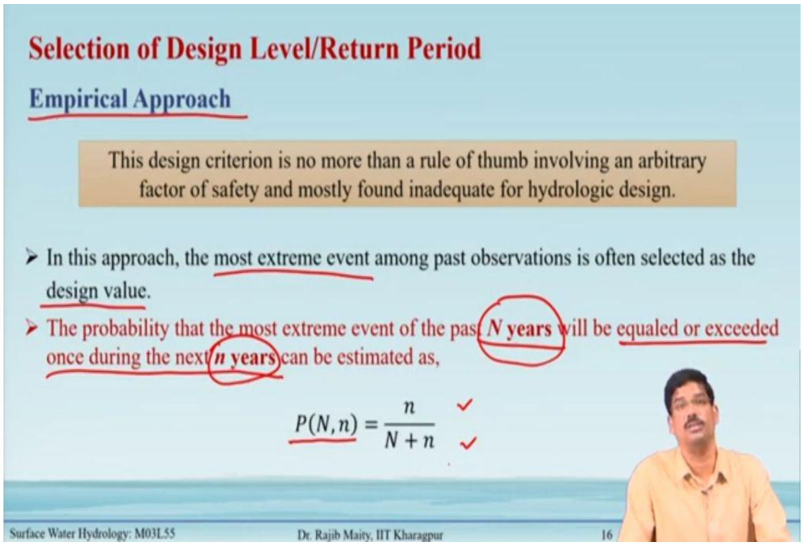

Selection of Design Level/Return Period

Empirical Approach

This design criterion is no more than a rule of thumb involving an arbitrary factor of safety and mostly found inadequate for hydrologic design.

- In this approach, the most extreme event among past observations is often selected as the design value.
- The probability that the most extreme event of the past N years will be equaled or exceeded once during the next n years can be estimated as,

$$P(N,n) = \frac{n}{N+n}$$

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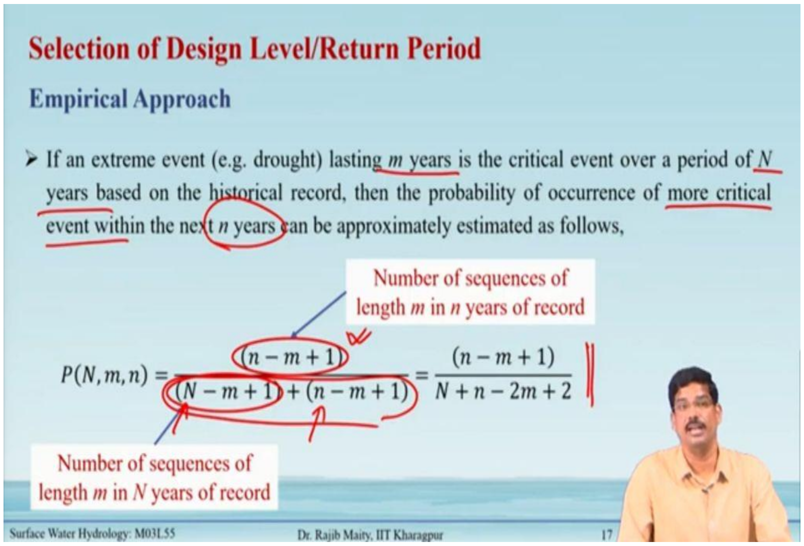

Selection of Design Level/Return Period

Empirical Approach

- If an extreme event (e.g. drought) lasting *m* years is the critical event over a period of *N* years based on the historical record, then the probability of occurrence of more critical event within the next *n* years can be approximately estimated as follows,

Number of sequences of length *m* in *n* years of record

$$P(N,m,n) = \frac{(n-m+1)}{(N-m+1)+(n-m+1)} = \frac{(n-m+1)}{N+n-2m+2}$$

Number of sequences of length *m* in *N* years of record

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Where $(n-m+1)$ is the number of sequences of length m in n years of record.

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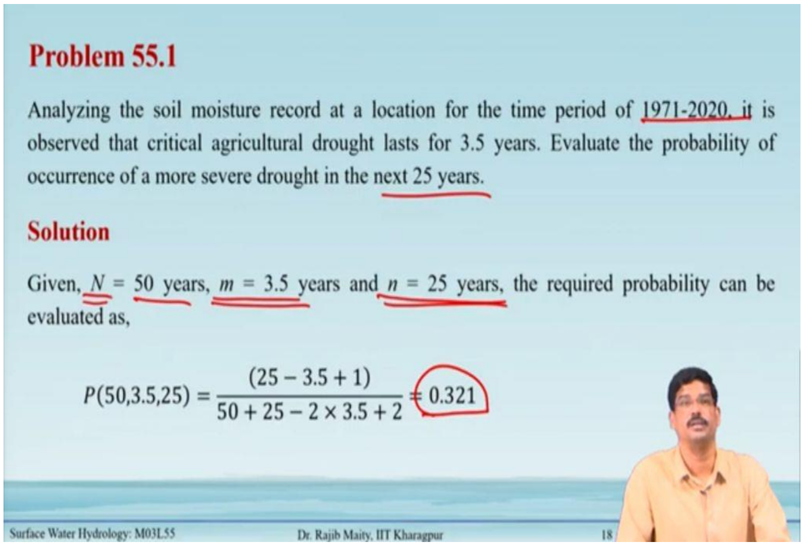

Problem 55.1

Analyzing the soil moisture record at a location for the time period of 1971-2020, it is observed that critical agricultural drought lasts for 3.5 years. Evaluate the probability of occurrence of a more severe drought in the next 25 years.

Solution

Given, N = 50 years, m = 3.5 years and n = 25 years, the required probability can be evaluated as,

$$P(50,3.5,25) = \frac{(25-3.5+1)}{50+25-2\times 3.5+2} = \boxed{0.321}$$

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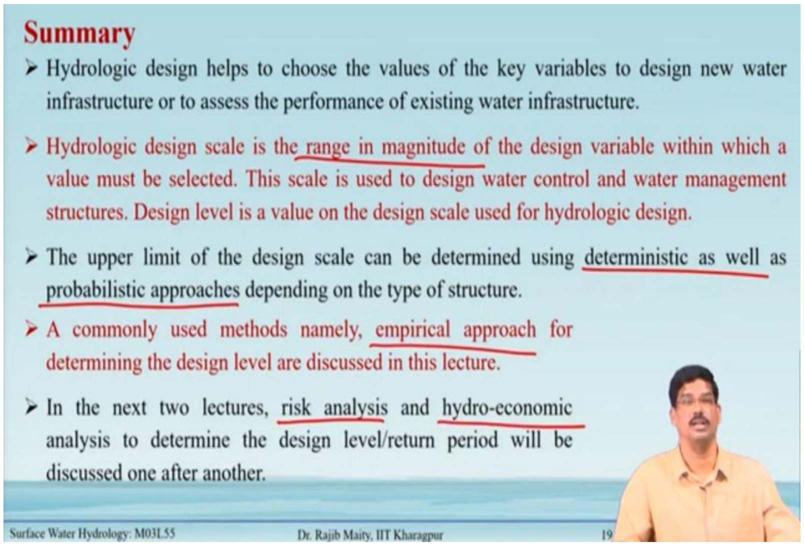

Summary

- Hydrologic design helps to choose the values of the key variables to design new water infrastructure or to assess the performance of existing water infrastructure.
- Hydrologic design scale is the range in magnitude of the design variable within which a value must be selected. This scale is used to design water control and water management structures. Design level is a value on the design scale used for hydrologic design.
- The upper limit of the design scale can be determined using deterministic as well as probabilistic approaches depending on the type of structure.
- A commonly used methods namely, empirical approach for determining the design level are discussed in this lecture.
- In the next two lectures, risk analysis and hydro-economic analysis to determine the design level/return period will be discussed one after another.

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Summary

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

- Hydrologic design helps to choose the values of the key variables to design new water infrastructure or to assess the performance of existing water infrastructure.
- The hydrologic design scale is the range in magnitude of the design variable within which a value must be selected. This scale is used to design water control and water management structures. The design level is a value on the design scale used for hydrologic design.
- The upper limit of the design scale can be determined using deterministic as well as probabilistic approaches depending on the type of structure.
- A commonly used method namely, the empirical approach for determining the design level is discussed in this lecture.
- In the next two lectures, risk analysis and hydro-economic analysis to determine the design level/return period will be discussed one after another.