Course Name: Watershed Hydrology

Professor Name: Prof. Rajendra Singh

Department Name: Agricultural and Food Engineering

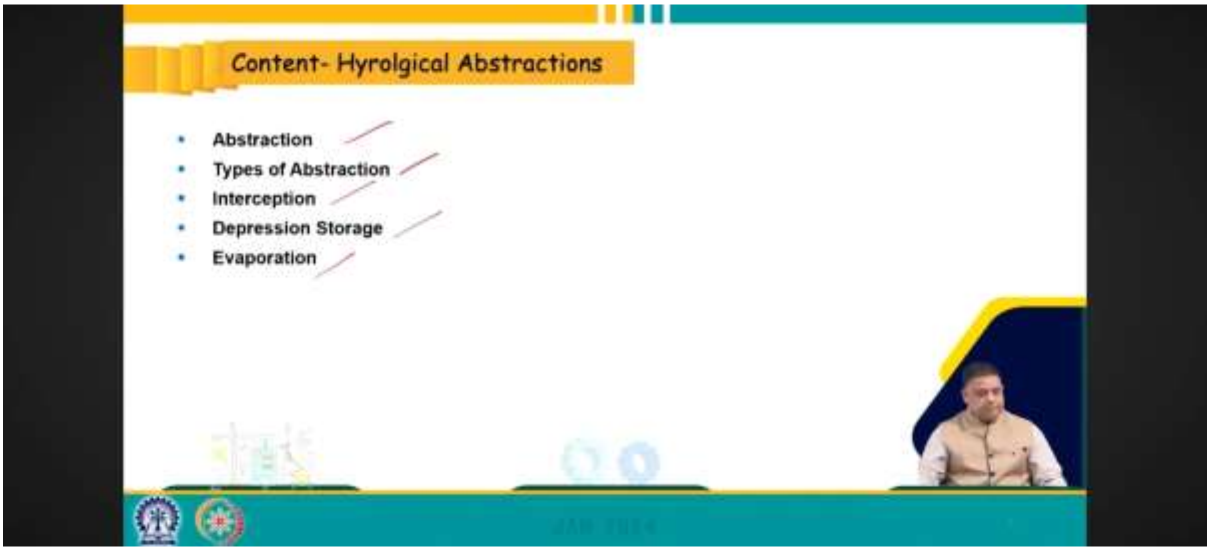
Institute Name: Indian Institute of Technology Kharagpur

Week: 02

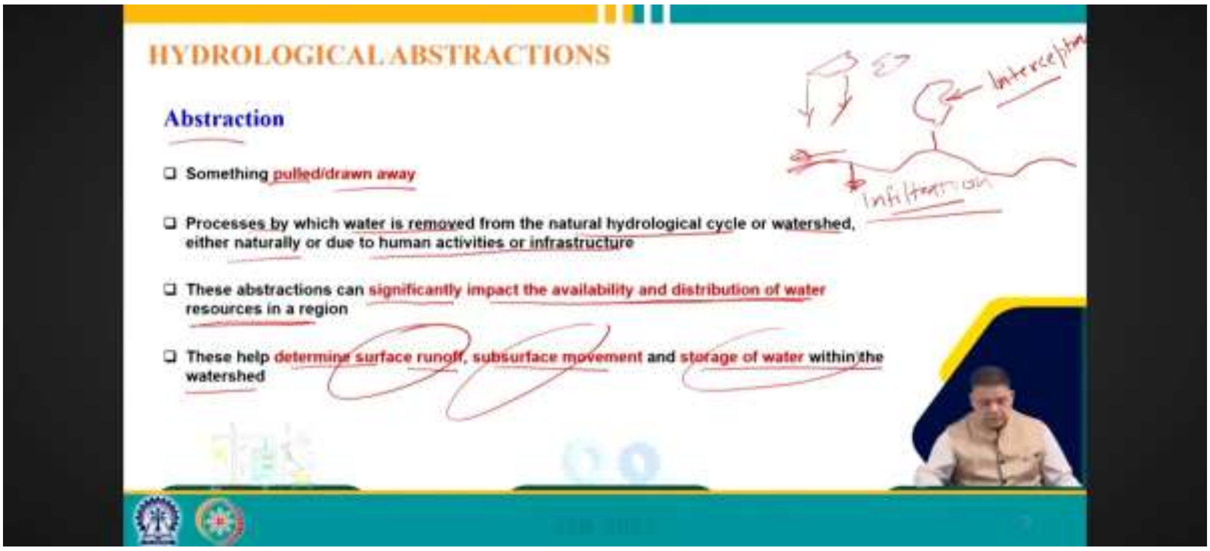
Lecture 06: Hydrological Abstractions

Hello friends, welcome back to this online certification course on Watershed Hydrology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are currently in Module 2, and this is Lecture 1 of Module 2, focusing on the topic of Hydrological Abstraction.

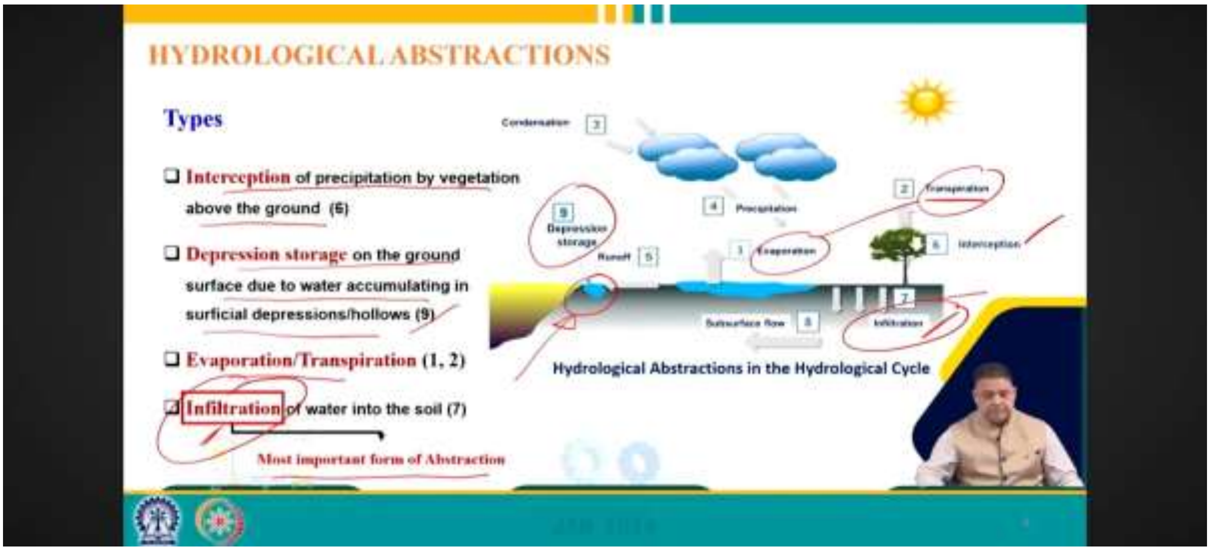
In this lecture, we will cover abstraction. We will begin by defining abstraction and discussing its various types. Subsequently, we will delve into interception, depression storage, and evaporation.



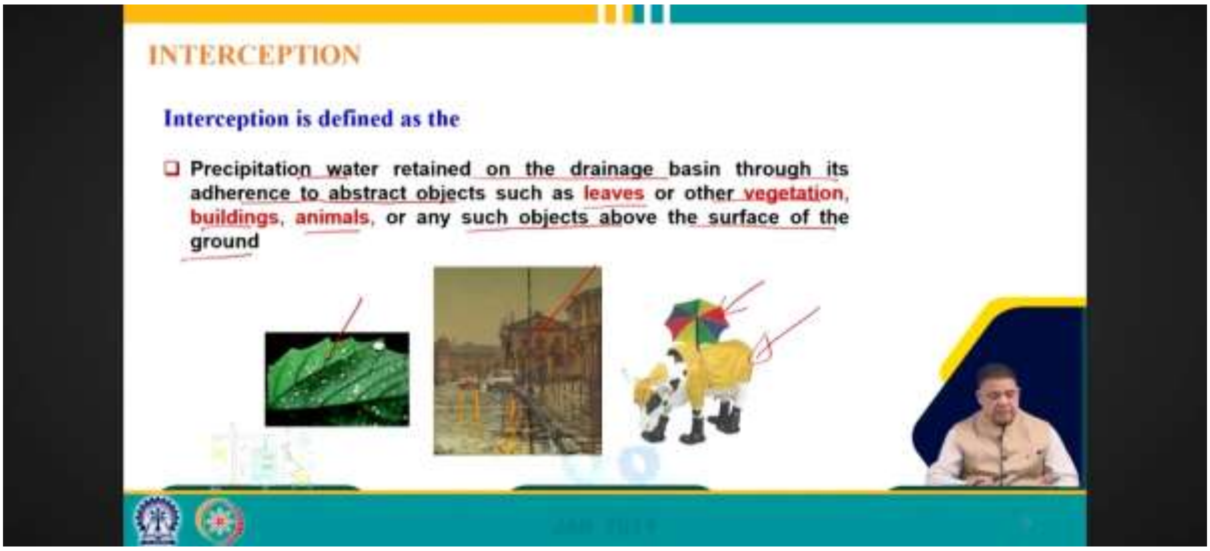
Let's commence with the definition of abstraction. Abstraction literally means something pulled or drawn away. This implies something taken away from a system, which essentially denotes a loss to the system. So, abstraction is the process or processes by which water is removed from the natural hydrological cycle or watershed, either naturally or due to human activity or infrastructure. Let's recall the hydrological cycle: when water reaches the atmosphere, cloud formation occurs, conditions form, precipitation happens, and once precipitation falls, before reaching the ground surface, it is intercepted by plants, buildings, or any abstract object. So, from the system's perspective, this represents a loss because water doesn't reach the surface where it can be utilized effectively. This is essentially what abstraction means, and it can significantly impact the availability and distribution of water resources in a region. Naturally, if abstraction increases, runoff decreases. Similarly, another form of abstraction occurs after water reaches the ground surface in the hydrological cycle infiltration occurs . From the perspective of runoff or surface runoff, this also represents a loss. So, that means, this is how abstractions can impact the availability and distribution of water resources in the region. And of course, once we understand abstractions, they help determine surface runoff, subsurface movement, and water storage within the watershed. So, if we consider the hydrological cycle, and specifically the role of plants, cloud formation leads to precipitation, which then reaches the surface. Once it reaches the surface, infiltration occurs, and plants intercept some of the water. While there are other factors involved, let's focus on these two for now. When interception occurs, the total rainfall reaching the ground surface decreases. Similarly, when infiltration occurs, the amount of water available for overland flow reduces. Therefore, understanding interception, infiltration, and other abstractions allows us to calculate how much water is available for surface runoff. If we know infiltration, then we know how much water is available for subsurface movement or for storage, both on and below the surface or within the soil. So, this highlights the importance of abstractions.



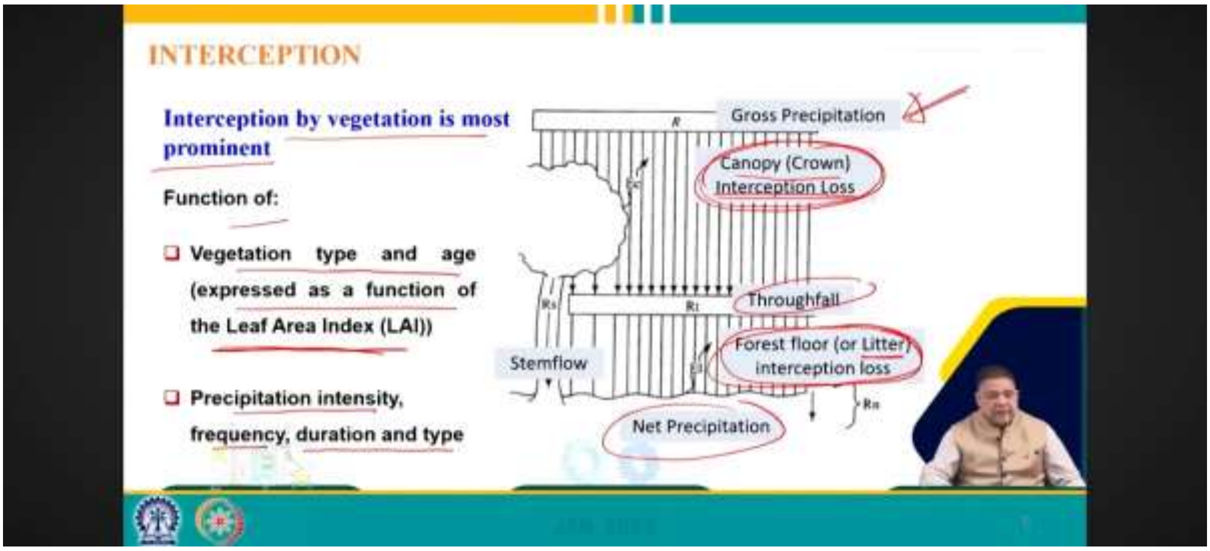
Abstraction can take various forms, as we discussed earlier. This presents another aspect of hydrological abstraction within the hydrological cycle. We just discussed interception and infiltration in terms of abstractions. Interception of precipitation by vegetation above the ground is an abstraction, and of course, water is transpired, representing a loss from the system perspective. Evaporation occurs from water bodies. When evaporation and transpiration combine, we get evapotranspiration, which is also an abstraction. Once runoff begins on the surface, water may accumulate in hollows or potholes, forming depression storage. This depression storage, caused by water collecting in surface depressions or hollows, is also an abstraction. And of course, we have already discussed the infiltration of water into the soil. So, here you can observe that this particular process was not included earlier in the hydrological cycle. However, at that time, I mentioned that there are many more processes. One such process could be depression storage, which is now added to the hydrological cycle diagram, representing an abstraction—depression storage. Among all these abstractions, infiltration is the most important one. It holds significant importance in the hydrological cycle.



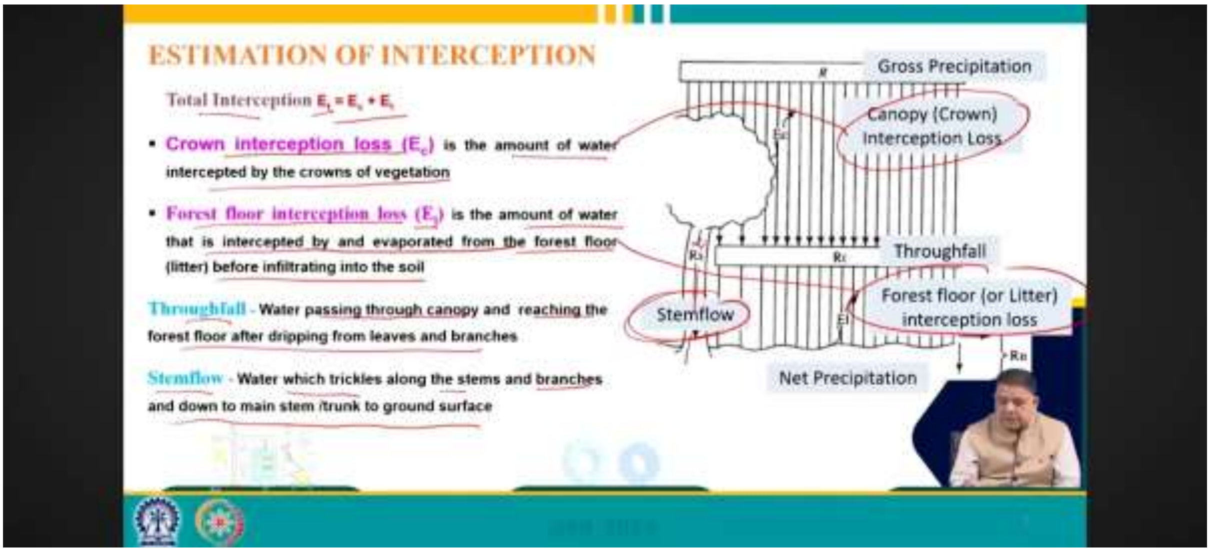
Now, let's define interception. Interception is described as precipitation water retained on the drainage basin through its adherence to abstract objects such as leaves, vegetation, buildings, animals, or any such object above the surface of the ground. So, when precipitation occurs before reaching the ground, if it is retained by any abstract object—such as plant leaves, buildings, animals, or even an umbrella—then essentially, that is interception. Interception refers to a portion of precipitation that does not reach the ground surface but adheres to abstract objects, whether leaves, vegetation, buildings, animals, or any such object. Out of all these abstract objects, interception by vegetation is the most prominent in the hydrological cycle .



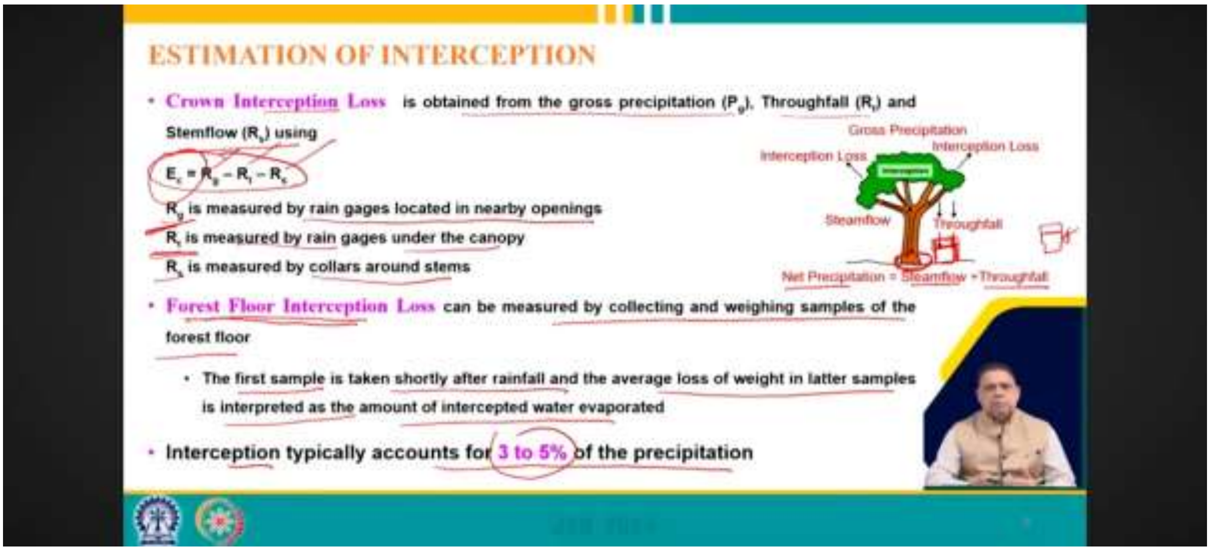
Interception by vegetation is most prominent in hydrological cycle and that is our main focus when discussing interception. Interception by vegetation is influenced by vegetation type and age, expressed as a function of leaf area index. Leaf area index represents the amount of leaf surface area per unit ground area. Vegetation type and age are considered in terms of leaf area index; for a particular vegetation type, the age is quantified using leaf area index. Additionally, interception by vegetation is also influenced by precipitation intensity, frequency, duration, and type. So, of course, it depends on precipitation and, in this case, the abstract object which is vegetation. Now, if we examine this scenario, what occurs is that we have gross precipitation occurring, and once precipitation happens, a portion of it is intercepted by the canopy of the plantation, referred to as canopy or crown interception loss. So, the first aspect we encounter is canopy or crown interception loss. Then, of course, water reaches the ground surface, and once the water is intercepted, a portion of it also falls in the form of throughfall, reaching the surface. However, in densely vegetated areas such as forests, one can expect that there will be a lot of litter—tree leaves, branches, or portions of roots—scattered on the forest floor. And so, the precipitation, before reaching the ground or soil, will again be intercepted by this litter or forest floor. This is referred to as forest floor interception loss. And of course, some of the water will drip down through the stems and reach the surface. This constitutes net precipitation. Thus, from ground precipitation, there will be canopy interception loss and forest floor interception loss.



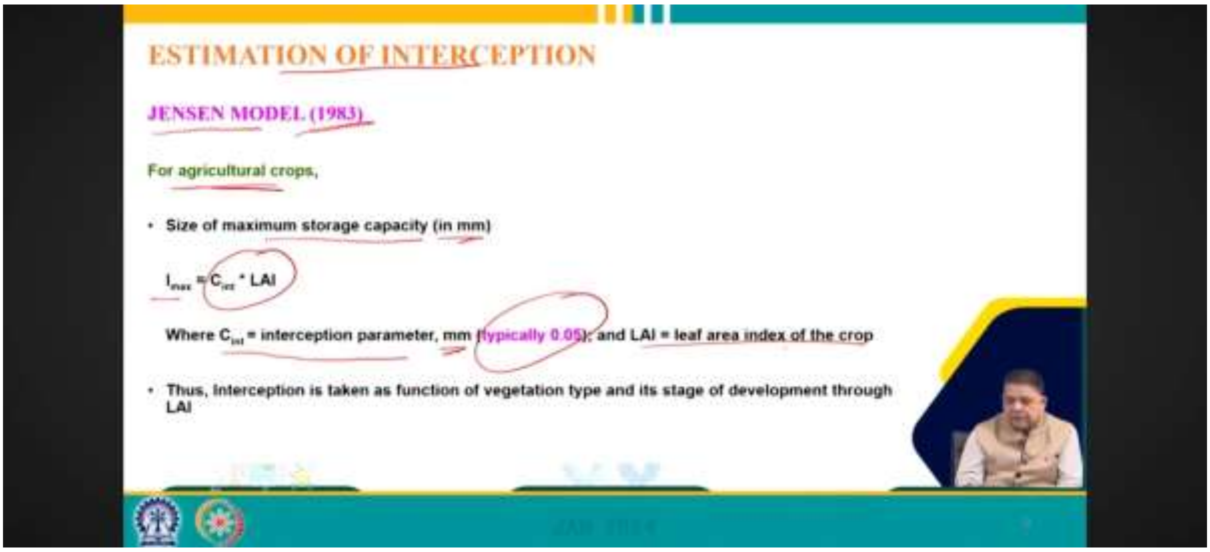
In this way, we can say that interception, in terms of estimation, has two components : Et = Ec + El. Ec represents crown interception loss, which is the amount of water intercepted by the crowns of the vegetation. The second component, El, represents forest floor interception loss, which is the amount of water intercepted by and evaporated from the forest floor before infiltrating into the soil. So, whatever is intercepted and evaporated before infiltrating into the soil constitutes forest floor interception loss. Additionally, there are two more terms which we will discuss further. So, this canopy interception loss is represented by Ec, and here we are defining forest floor interception loss. There are two other terms: throughfall and stem flow. Throughfall refers to the water passing through the canopy and reaching the forest floor after dripping from leaves and branches. Typically, if you stand below a tree after rainfall, you will see a lot of water dripping through, and that is throughfall. Additionally, there is stem flow, where water trickles along the stems and branches, eventually reaching the main stem or trunk and then the ground surface. So, from different parts, water will reach the main trunk and then trickle down to the ground surface, referred to as stem flow. These are the various components typically encountered in a vegetated area or soil.



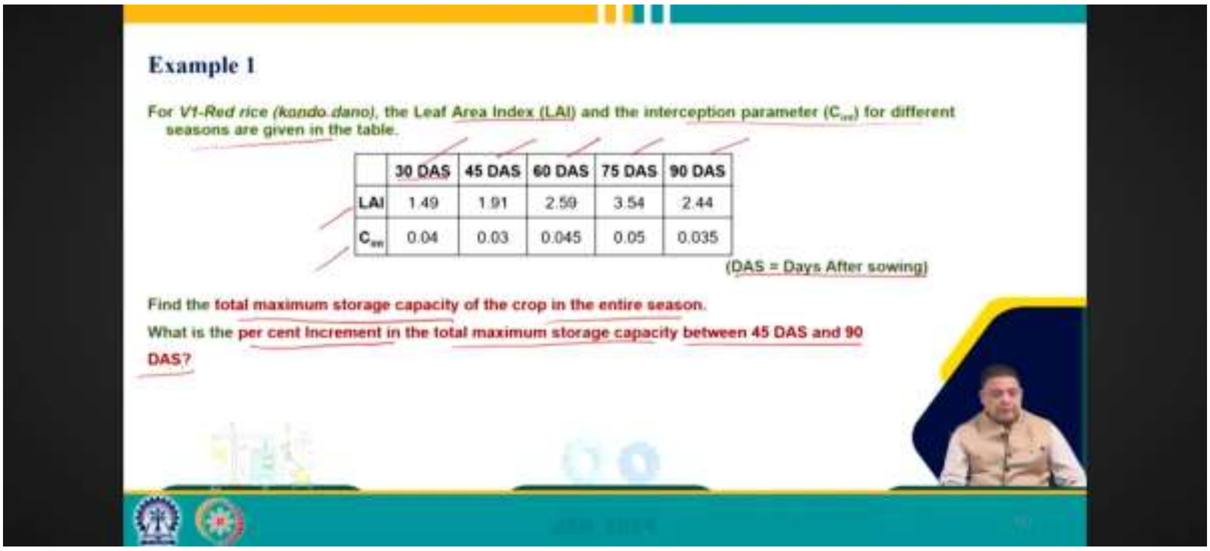
Now, we can discuss how to estimate interception, where crown interception loss is obtained from gross interception throughfall and stem flow. We can use the relationship Ec = Rg - Rt - Rs, where Rg is rainfall measured by rain gauges located in nearby openings, Rt is rainfall measured by rain gauges under the canopy, and Rs is stem flow measured by collectors around the stem. In a forested or plantation area, if you place certain rain gauges just below the trees, and others in open spaces, you can gather data for estimation. These rain gauges typically have cylindrical shapes. So, obviously, those which are placed in open spaces will not be impacted by intercepts. So, that is Rg. Rainfall will also be collected by the rain gauges located below the plantation or canopy, indicating that rainfall reaches the rain gauges after being intercepted by the canopy. This is why it is referred to as Rt, under the canopy. To determine stem flow, which is essentially the water trickling through the stem and reaching the ground surface, we place some kind of colour around the stem and collect it for a significant portion of time. Through this, we can calculate the net precipitation, which is stem flow plus throughfall, adding to the ground surface. By knowing Rg, Rt, and Rs, we can calculate the crown interception loss. So, it's very easy to obtain after experimentation. The next loss is forest floor interception loss, which can be measured by collecting and weighing samples of the forest floor. What is done is, as we discussed, there will be litter on the ground trapping and intercepting the rainfall. Therefore, if you collect a sample shortly after rainfall, when it is soaked with water, and then measure the average loss of weight in subsequent samples, it can be interpreted as the amount of intercepted water evaporated. So, if you take a sample immediately after rainfall where a lot of water or intercepted water is present, and then let this sample dry to measure the weight. So, the difference in weight will be solely due to the water that has evaporated or was intercepted by the forest floor. This is referred to as forest floor interception loss. Typically, interception accounts for 3 to 5 percent of the total precipitation, even under normal circumstances. Because it only accounts for 3 to 5 percent, many times in hydrological modeling, this portion may be neglected due to its small magnitude. However, there are many other models that take this interception loss into account while modeling or calculating the entire water balance equation.



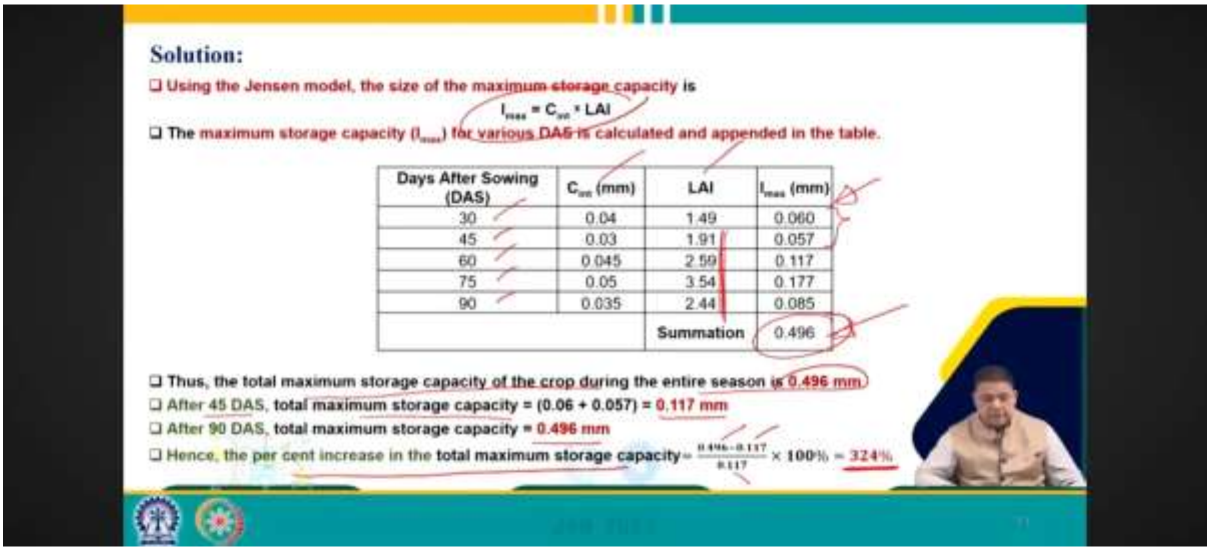
Now, let's discuss the estimation of interception. Besides experimentation, there are certain mathematical models available for estimating interception. One such model was proposed by Jensen in 1983. So, the Jensen model of 1983 can be used, which was primarily developed for agricultural crops. According to this model, the size of the maximum storage capacity, which is essentially the maximum interception (Imax), is calculated as Cint multiplied by LAI. Here, Cint represents the interception parameter in millimetres, and LAI is the leaf area index of the crop or vegetation. Although we are defining it in terms of agricultural crops, it can also be applied to plants. Typically, the value of Cint, the interception parameter, is taken as 0.05 for agricultural crops. Therefore, interception is considered a function of vegetation type and stage of development through the leaf area index, as we mentioned earlier.



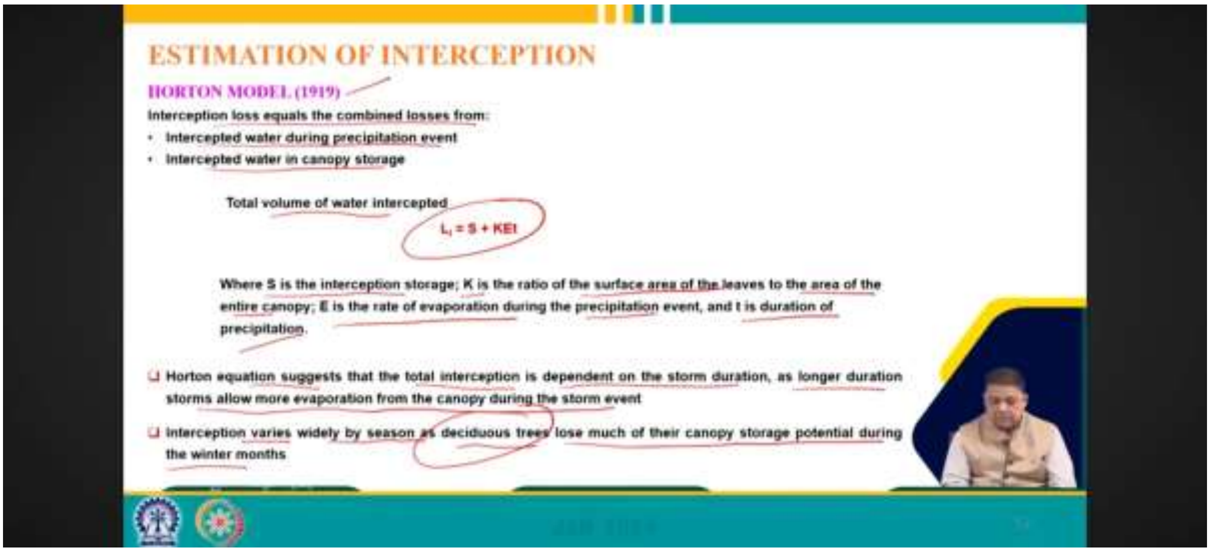
So, let's take an example. For V1 red rice, the vertical name (kondo dano) the leaf area index and the interception parameter for different seasons are given in the table. This table provides the LAI and Cint values for 30 days, 45 days, 60 days, 75 days, and 90 days after sowing (DAS). We need to find the total maximum storage capacity of the crop for the entire season and determine the percentage increment in the total maximum storage capacity between 45 DAS and 90 DAS.



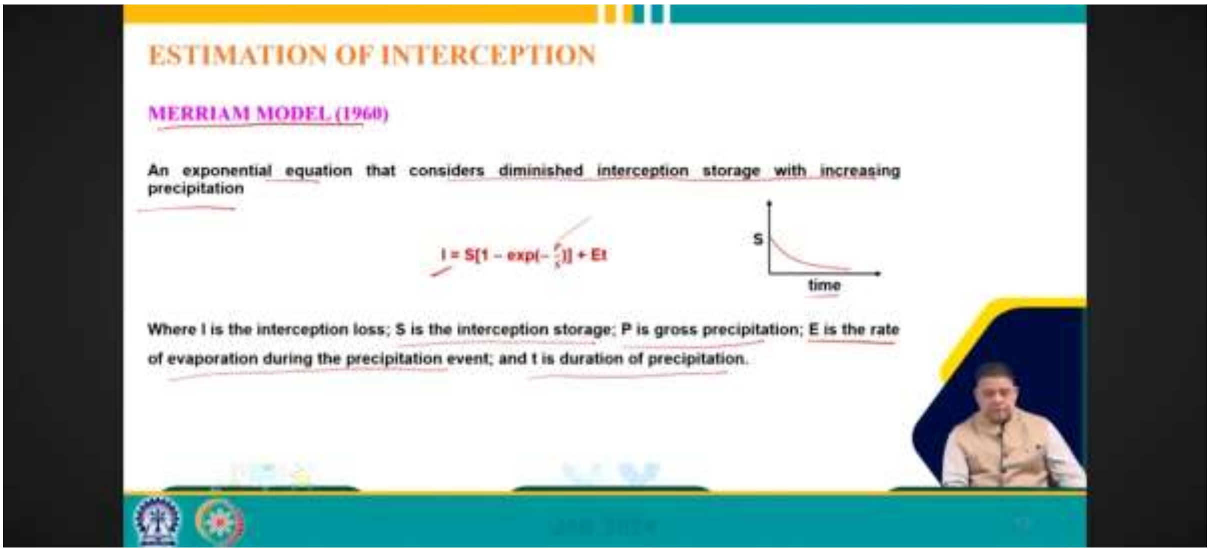
Obviously, according to the Jensen model, Imax is calculated as Cint multiplied by LAI. Because we have the Cint values and LAI varies, we can calculate the Imax or the maximum interception after 30, 45, 60, 75, and 90 days. After performing the calculations, the total maximum storage capacity comes out to be 0.496 millimetre. This indicates that the total maximum interception capacity of the crop during the entire season is 0.496 millimetre. So, the total maximum storage capacity is 0.496 millimetre. Regarding the second aspect, let's calculate the percent change between 45 DAS and 90 DAS. After 45 DAS, the total maximum storage capacity will be the sum of these two, which is 1.117 millimetre. By the end of the season at 90 days, as we already know, the total is 4.496 millimetre. So, the percent change in the total maximum storage capacity between 45 and 90 days is calculated as (0.496 - 0.117) / 0.117, resulting in 324 percent. This means that between 45 days and 90 days, the maximum storage capacity increases by 324% . This change is primarily due to the fluctuation in the leaf area index, which varies significantly over time.



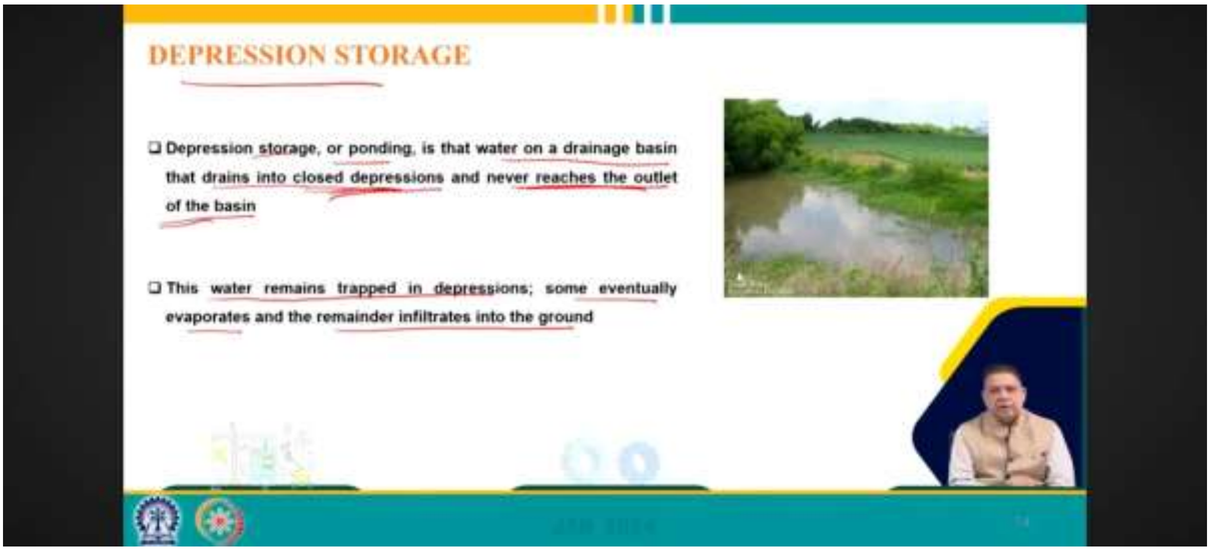
Then we also have the Horton model. The Horton model came into existence in 1919, and according to the Horton model, interception loss equals the combined losses from intercepted water during precipitation events and intercepted water in canopy storage. These are the two different components here. The total volume of water intercepted can be calculated using this formula or model: Li = S + KEt, where S represents the interception storage, K is the ratio of the leaf's surface area to the area of the entire canopy (similar to LAI but defined differently), E is the rate of evaporation during the precipitation event, and t is the duration of the precipitation. The Horton equation suggests that the total interception is dependent on the storm duration, as longer duration storms allow more evaporation from the canopy during the storm events. Therefore, if the value of t is high, then, naturally, because t here represents the duration of precipitation, the LAI will be high as well. Interception varies widely by seasons due to simple reasons. For example, deciduous trees lose much of their canopy storage potential during the winter months. So, in the winter months, if we have a plantation of deciduous trees, then the interception loss will be much lower because the value of K will be very low in that case.



Then we have another model given by Marion, called the Marion model from 1960, which is an exponential equation that considers diminished interception storage with increasing precipitation. So, the form of the equation is as follows: It states that the interception decreases exponentially, where S represents the interception storage, P is the gross precipitation, E is the rate of evaporation during the precipitation event, and t is the duration of pressure. This model is essentially a modification of the Horton model, presented in exponential form rather than linear terms.

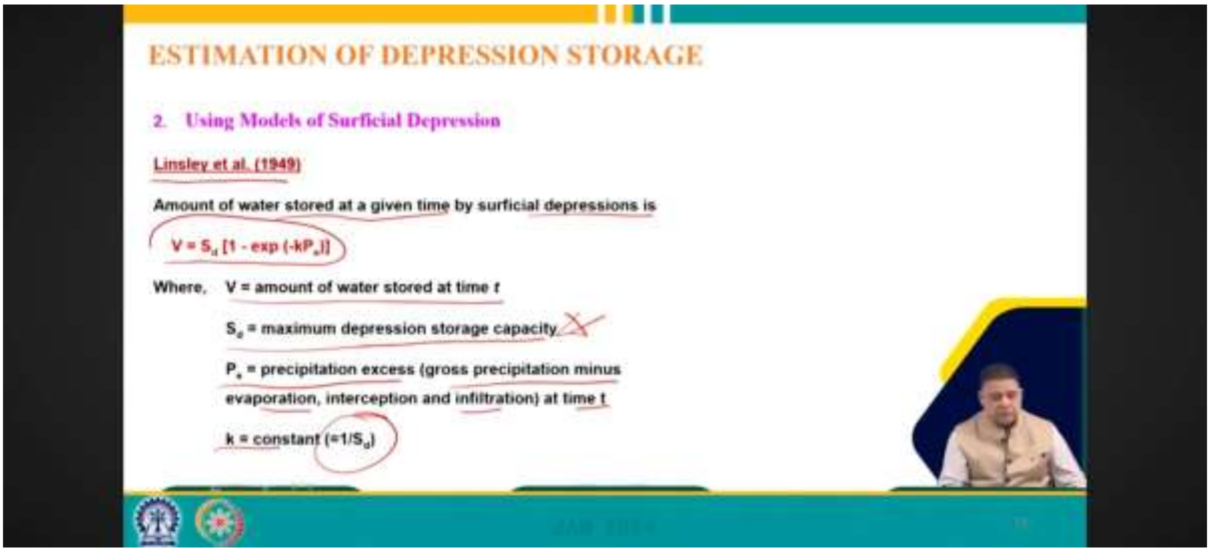


Now, moving on to the next part, which is depression storage. We have already defined depression storage or ponding as the water on the drainage basin that drains into closed depressions and never reaches the outlet of the basin. If you recall the hydrological cycle equation or picture we just saw, when rainfall occurs, interception happens in the form of infiltration, and then surface runoff or overland flow begins. Once the flow is on the surface, if it encounters a depression, hollow, or pothole, the water will be trapped there, and runoff will continue after filling the depression. The water retained in the depression will not reach the outlet; it will remain trapped in closed depressions. Some of this water eventually evaporates, while the remainder infiltrates into the ground. So, it does not become a part of the surface runoff, but instead, it infiltrates; thus, a portion of it is lost. Part of it infiltrates, while another part evaporates.

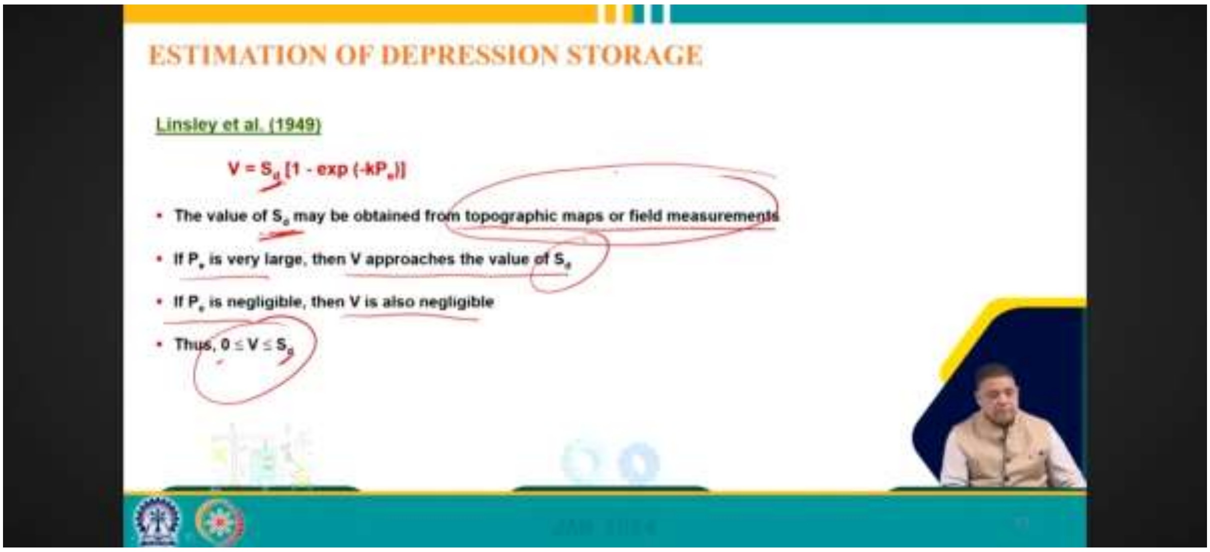


Now, let's discuss the estimation of depression storage. There are two different approaches to this. The first method involves using a hydrological budget. If you formulate a water balance equation in terms of depression storage, it comes out to be rainfall minus runoff minus infiltration minus evaporation minus interception. Throughout our discussion, the water balance equation will be examined in various contexts. Here, we are considering it in terms of depression storage. These are the various variables involved in the hydrological cycle. If we have the values of rainfall, runoff, infiltration, evaporation, and interception, we can estimate depression storage. Among these variables, rainfall, evaporation, and runoff can be directly measured, while infiltration and interception can be estimated. Thus, we can determine the depression storage. This is one method of estimating depression storage, using the hydrological budget equation.

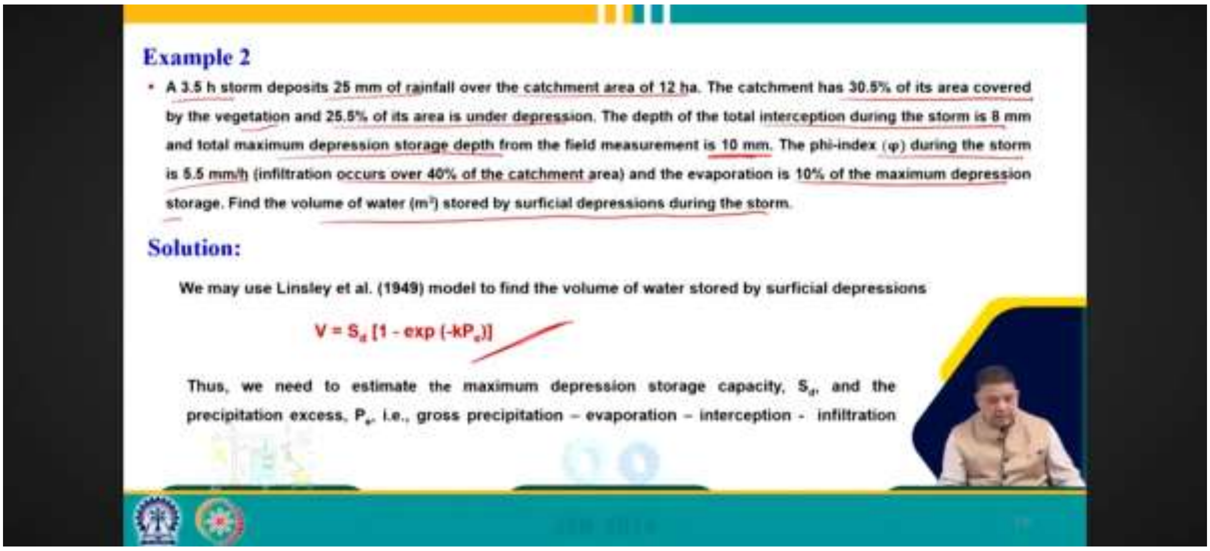
The other approach involves using models of surficial depression. One such model was proposed by Linsley in 1949. According to this model, the amount of water stored in a given time by a superficial depression is given by the equation V = Sd * (1 - exp(-k * Pe)), where V represents the amount of water stored at time t, Sd is the maximum depression storage capacity, Pe is the precipitation excess (gross precipitation minus evaporation minus interception minus infiltration) at any time t , and k is a constant expressed in terms of Sd, the maximum depression storage capacity. Therefore, if we know the variables, we can calculate the amount of water stored in that temporal depression, or we can estimate the depression storage.



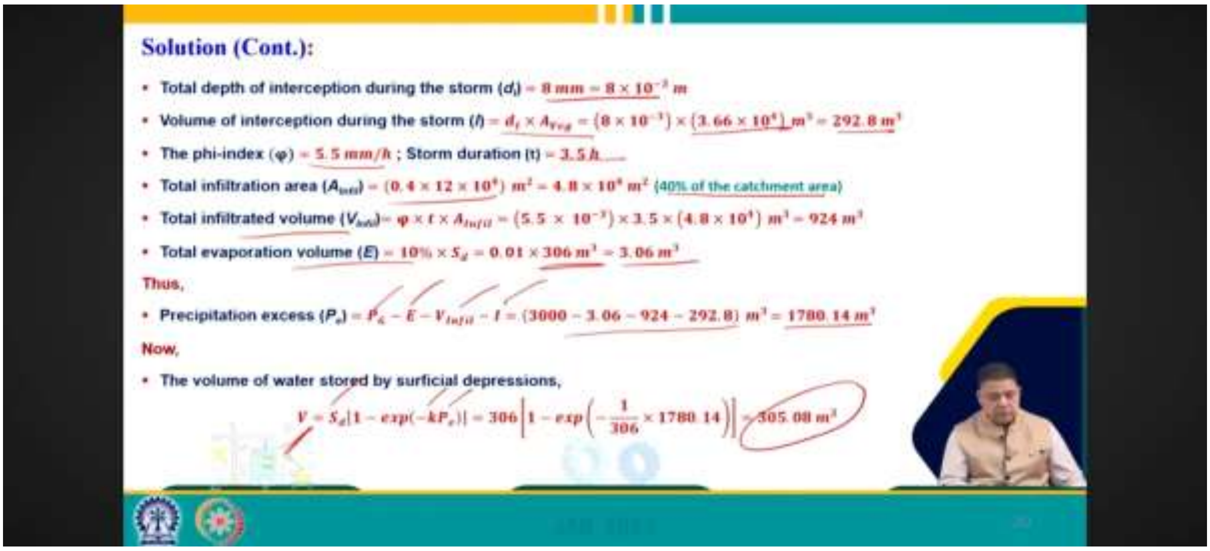
Now, the most important variable from the surface point of view is Sd, which represents the maximum depression storage capacity. This capacity is defined as the maximum amount of storage that the depression can hold. Therefore, we need to determine the size and shape of the depression, which can be obtained from topographic maps or field measurements. By examining contour maps or conducting field surveys to identify major potholes, we can ascertain the maximum storage capacity of these depressions. If Pe, the effective rainfall, is very large, then V approaches the value of Sd. This indicates that the depression storage will fully utilize the available capacity. Conversely, if Pe (precipitation) is negligible, then V (depression storage) will also be negligible. In other words, depression storage can range between 0 and Sd, where Sd represents the maximum depression storage capacity, which can be determined from topographic maps or field measurements.



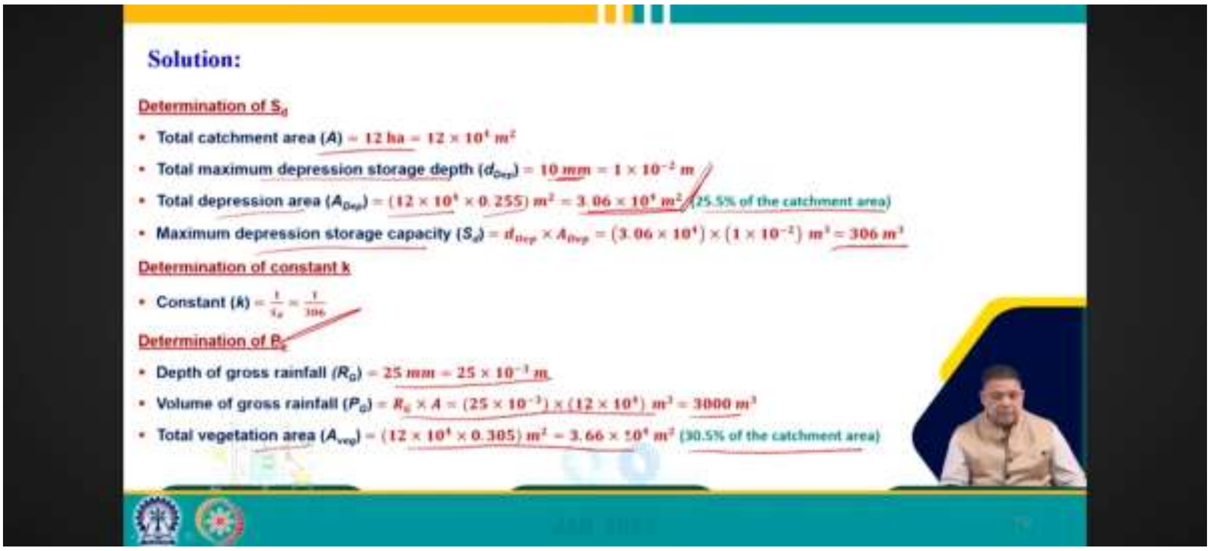
Now, let's consider an example: A 3.5-hour storm deposits 25 mm of rainfall over a catchment area of 12 hectares. The catchment has 30.5% of its area covered by vegetation, and 25.5 % of the area is under depression. The depth of total interception during the storm is 8 mm, and the total maximum depression storage depth from field measurements is 10 mm. The phi-index (ϕ) during the storm is 5.5 mm/h , (infiltration occurs over 40 percent of the catchment area) and the evaporation is 10 % of the maximum depression storage. To find the volume of water (m^3) stored by the surficial depression during the storm. We can utilize the formula we discussed earlier, such as the Linsley equation.



To determine Sd, we are provided with the total catchment area and the maximum storage depth, which is 10 mm. The total depression area is defined as 25 percent of the catchment area, which is 25.5 percent of the 12 hectares. This results in a total depression area of 3.06 * 10^4 m^2 . The maximum depression storage capacity can be calculated by multiplying these two numbers, resulting in 306 cubic meters. Thus, the constant K of the Linsley equation, which is 1/Sd, is 1/306. The gross precipitation, or effective rainfall, is given as 25 mm . The volume of gross rainfall can be obtained by multiplying it with the area of the catchment. The total

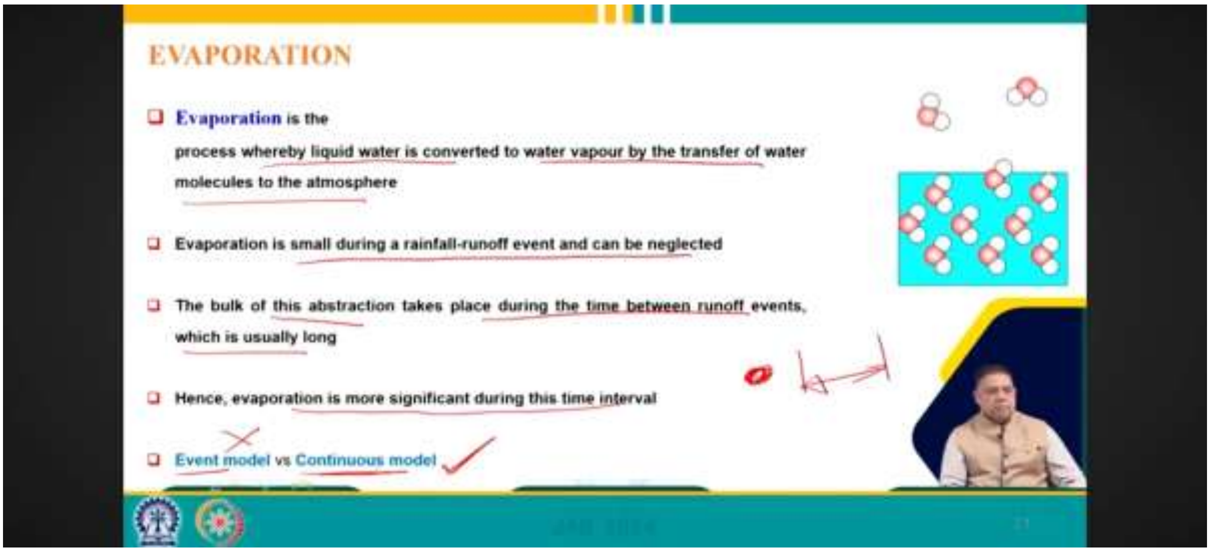


vegetation area is stated as 30.5 percent of the catchment area, allowing us to calculate the total vegetation area.

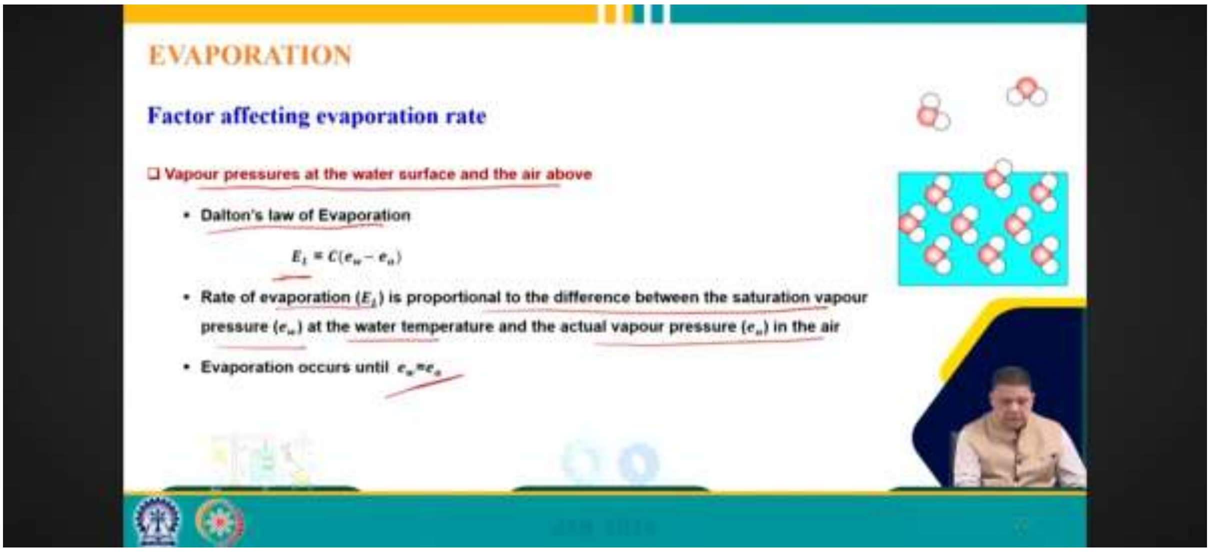


The depth of interception during the storm is 8 mm, so we can calculate the volume of interception during the storm by considering the total basin. Similarly, the phi index and duration are provided, enabling us to calculate the total infiltration volume as 40 percent of the catchment. Furthermore, the total evaporation volume is given as 10 percent of Sd, which we have already calculated to be 3.06 m^3. Now, precipitation excess (Pe) is PG – E – Vinfil – I. So, by plugging in these values, we obtain 1780.14 m^3. Now that we know Pe, K, and Sd, we can input them into the equation to calculate V, the volume of water stored by the superficial depression, which amounts to 305.08 cubic meters for the given data. This involves utilizing the Linsley equation and the total water balance to determine the precipitation excess.

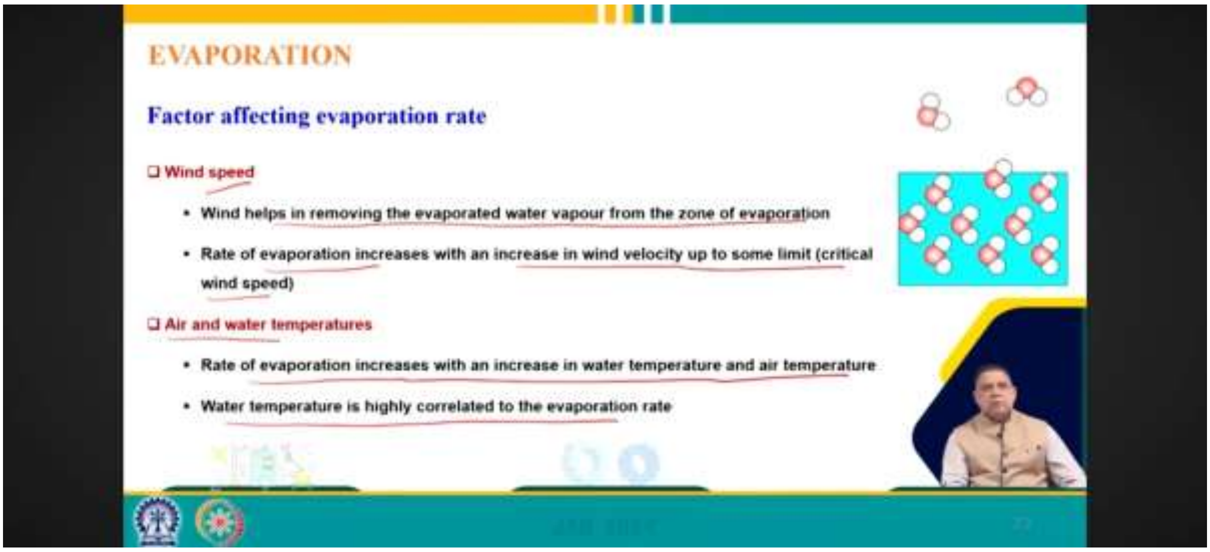
Moving on to evaporation, it's the process wherein liquid water transforms into water vapor through the transfer of water molecules to the atmosphere. This occurs due to heat and changes in vapor pressure. Evaporation is minimal during rainfall events and can be disregarded. The majority of this process occurs between runoff events, which typically span a longer duration. Consequently, evaporation becomes more significant during these intervals. While rainfall is ongoing, the air tends to be saturated, resulting in minimal evaporation. However, between two rainfall events, evaporation losses are substantially higher and become noteworthy. Hence, we may choose either an event model or a continuous model to account for these variations. In an event model, we might overlook evaporation, but for a continuous hydrological model, evaporation is crucial.



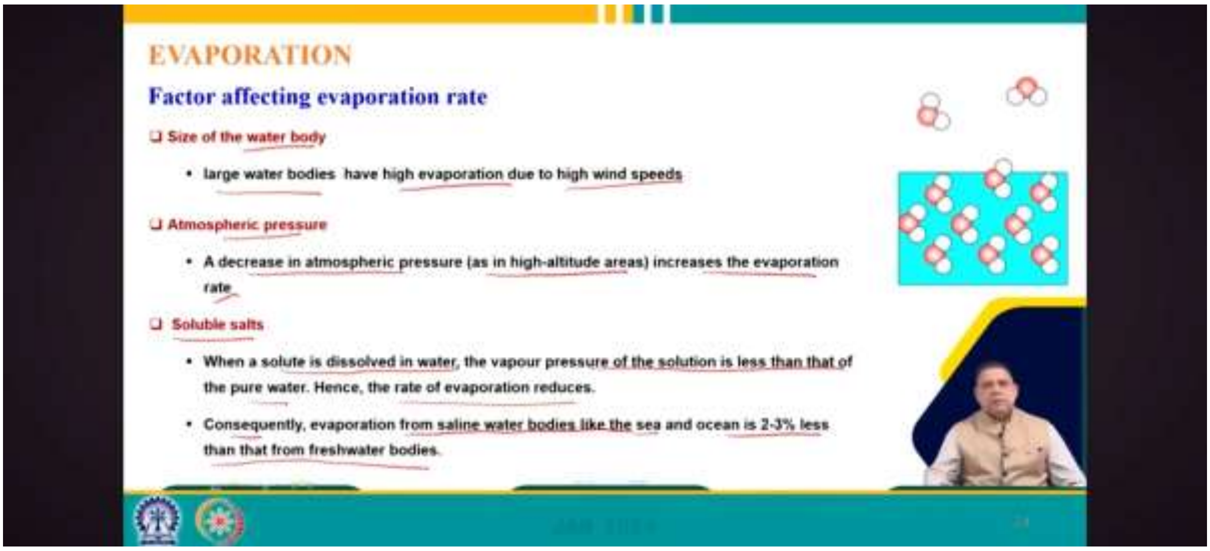
Now, let's delve into the factors influencing evaporation rate. Primarily, the vapor pressure at the water surface and the air above it are pivotal. This is governed by Dalton's law of evaporation, where EL represents C*(ew – ea) , indicating that the rate of evaporation is directly proportional to the disparity between the saturation vapor pressure (ew) at the water's temperature and the actual vapor pressure in the air (ea). Naturally, if this difference is substantial, evaporation will be more pronounced, occurring as long as ew exceeds ea . Once ew equals ea, evaporation ceases.



Wind speed plays a significant role in whisking away evaporated water vapor from the evaporation zone. Consequently, the rate of evaporation escalates with increasing wind velocity, up to a certain threshold known as the critical wind speed. Beyond this point, further increases in wind speed do not notably augment evaporation. Considering air and water temperature, it's reasonable to anticipate that the rate of evaporation intensifies with higher temperatures in both the air and the water. Moreover, water temperature is closely linked to the evaporation rate.



The size of the water body matters; larger bodies tend to have higher evaporation rates due to increased wind speeds, which are influenced by their size. Moreover, atmospheric pressure affects evaporation rates; areas at higher altitudes, where atmospheric pressure is lower, experience higher rates of evaporation. Additionally, the presence of soluble salts impacts evaporation. When a soluble solute is dissolved in water, the vapor pressure of the solution becomes lower than that of pure water, resulting in a reduced rate of evaporation. Consequently, evaporation from saline water bodies, such as seas and oceans, can be 2 to 3 percent lower than that from fresh water bodies. This concludes our discussion on evaporation and its influencing factors. In our next lecture, we will delve deeper into this topic.



Today, we covered abstraction in the form of interception and depression storage, and initiated our discussion on evaporation. Please feel free to provide feedback and raise any doubts or questions you may have, which can be addressed in our upcoming sessions. Thank you for your attention.


THANK YOU