Engineering Hydrology

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Module 3 - Lecture 42

Summary

Hello all, welcome back. So, in the previous lecture, we have completed all the topics related to subsurface water which I was planning to complete within this course on Engineering Hydrology.

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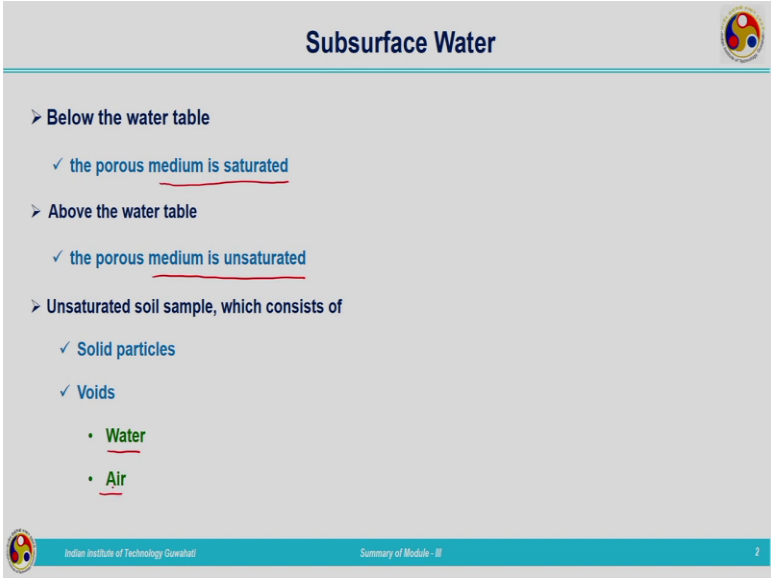

Now, let me summarize the third module, that is the subsurface water. In the beginning itself, I have explained that we are discussing about the water which is present beneath the ground surface. Beneath the ground surface itself, when we discuss we are having two different zones, one is unsaturated zone and the other one is the saturated zone. There is a clear boundary which is differentiating between the unsaturated zone and the saturated zone. That is the groundwater table.

Below the groundwater table, we are having the saturated zone and above that we are having the unsaturated zone. And in this course, we were discussing about the water present in the unsaturated zone, that is related to the process infiltration. So, below the water table, the porous medium (soil or rock strata through which flow is taking place) is saturated, that is all the pores are filled with water and then above the water table, the porous medium is unsaturated.

If you consider an unsaturated soil sample, within the soil sample, in addition to soil there are so many voids present. These voids can be filled up by water or by means of air. If the voids present in the soil is fully filled with water then we will be calling it as saturated soil and if it is partially filled with water that is some of the voids are filled with air then we will be calling it as unsaturated soil. Sometimes, all the pores will be filled with air only, there will not be water present, then we will be calling it as the soil is in the dry state.

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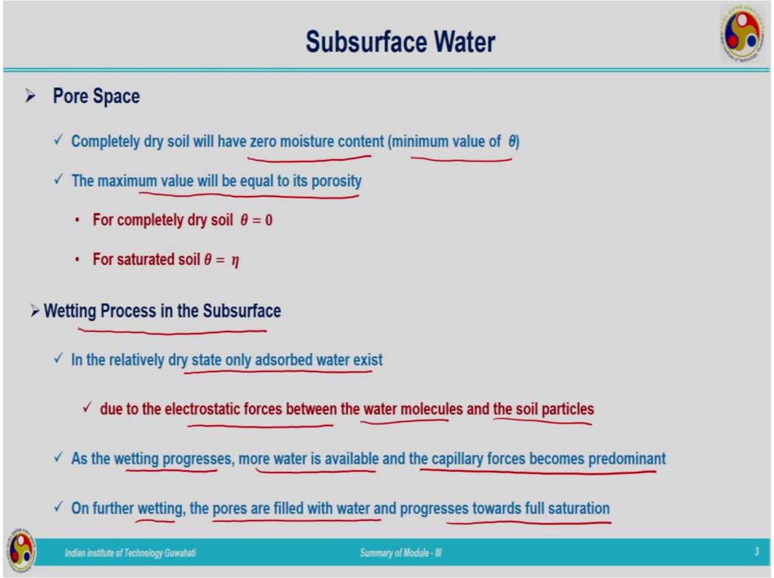

And after understanding this, we need to have proper understanding related to pore space which is present in the soil. So, in the case of a completely dry soil we are having 0 moisture content or if you are talking about relatively dry soil, there will be some amount of moisture content present depending on the initial condition, so, there will be a minimum value of θ (θ is the representation used for representing the volumetric moisture content). And in the case of soil which is having maximum soil moisture content that is equivalent to the porosity of the soil (η). So, completely dry soil will be having $\theta = 0$ and saturated soil, $\theta = \eta$. So, this soil moisture content can vary between 0 to η.

After seeing the pore space, we have moved on to the wetting process. Relatively dry soil we have considered to see how the wetting takes place within the subsurface. So, in the case of relatively dry soil condition there will be only adsorbed water. The main reason behind this adsorbed water is the electrostatic force between the soil particles and the water molecules. Rainfall or infiltration or may be due to some agricultural activities taking place in the soil, the process of wetting will be progressing and more water is available, that time, the capillary forces become predominant.

So, when the relatively dry state is becoming wet, some water is getting infiltrated or some wetting process is taking place, the capillary forces will come into picture that is the suction forces. After that again and again continuous wetting is taking place, all the pores will be filled with water and it will be progressing towards saturation.

So, when all the pores are getting filled up, initially it was relatively dry then electrostatic forces were predominant, then some more water is added then capillary forces coming into action. After that the flow of water is continuing, wetting process is continuing, at that time we will be having saturation and gravity force will be predominant.

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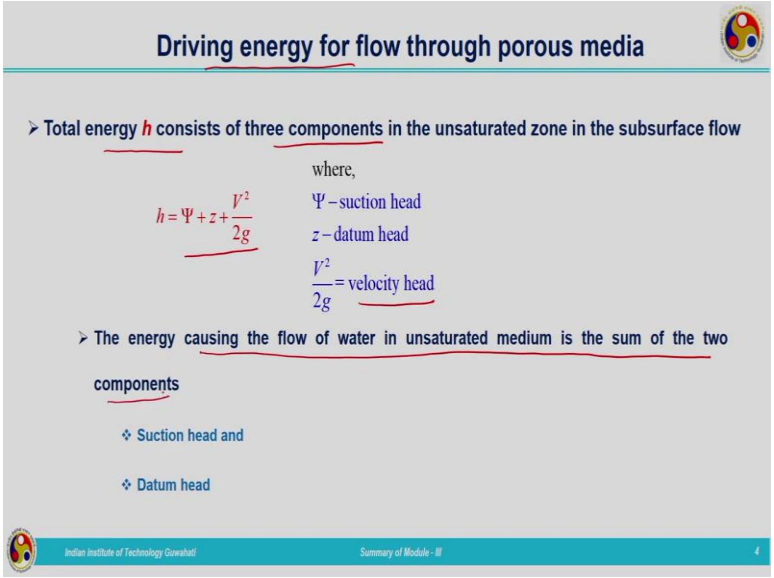

Now, after understanding the pores space and wetting process which is taking place within the subsurface, we have moved on to the driving energy for flow through porous media. So, the total energy was represented by h. It was consisting of three components in the unsaturated region given by

$$h = \Psi + z + \frac{V^2}{2g}$$

In this Ψ was representing the suction head, z datum head and $V^2/2g$, the corresponding velocity head.

So, we have found that compared to the value of Ψ and z, that is the datum head and the suction head, the velocity with which the flow is taking place through the soil is very very small. So, velocity head will be very small and that can be neglected. So, in total if we talk about the total head causing the flow within the unsaturated region, we can write the expression as sum of Ψ and z that is sum of suction head and the datum head. So, the energy causing the flow of water in unsaturated medium is the sum of two components, Ψ and z.

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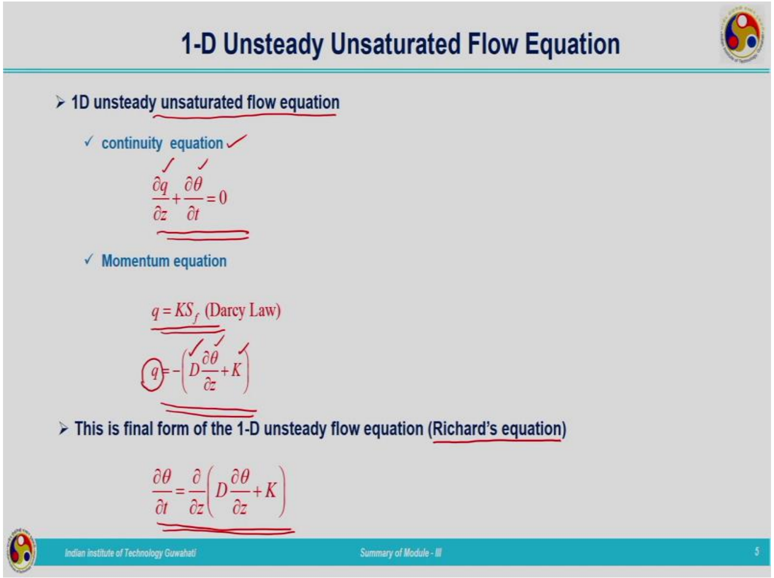

After understanding the driving energy which is taking place within the unsaturated zone, we have moved on to the derivation of the unsteady unsaturated flow equation. One dimensional unsteady unsaturated flow equation was derived. It was consisting of the fundamental equations related to continuity equation and the momentum equation. That is the mass and momentum conservation equations together were considered to develop the one-dimensional unsteady flow equation in the unsaturated zone.

So, continuity equation was given by this partial differential equation

$$\frac{\partial q}{\partial z} + \frac{\partial \theta}{\partial t} = 0$$

and momentum equation we have considered the Darcy's law and it was given by

$q = KS_f$ (Darcy Law)

$$q = -\left(D\frac{\partial \theta}{\partial z} + K\right)$$

In this case, continuity equation we were having the terms related to Darcy's flux and the soil moisture content. So, from this equation (momentum equation), q has been substituted in the continuity equation and then derived the final form of the 1-D unsteady flow equation. So, this unsteady flow equation is commonly known as the Richards equation and is given by

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial \theta}{\partial z} + K\right)$$

So, this is the equation representing the unsteady flow through unsaturated zone.

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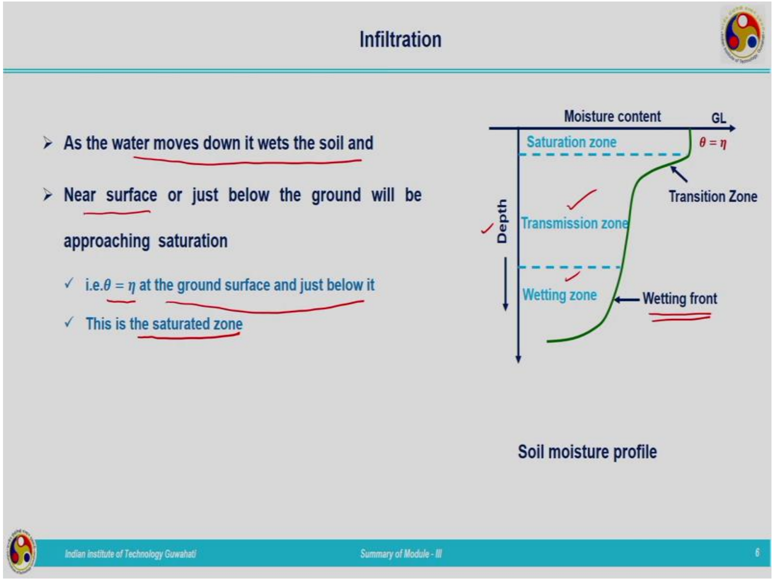

And after that we have moved to the hydrologic process which is known as infiltration which is the process in which the water is getting infiltrated into the ground from the ground surface. This process in detail we have understood and for understanding that we have studied the soil moisture profile. So, as the water moves down, it wets the soil. So, as time passes the near surface soil will become saturated or it may approach saturation. That is as the rainfall is continuously happening or we are watering the agricultural land, at that time the surface soil is becoming saturated and will be having $\theta = \eta$. And this is termed as the saturated zone.

So, what we are assuming is that, the near surface soil will be in the saturated condition at the time of infiltration, not at the beginning after some time. So, for understanding the infiltration process we have gone through the soil moisture profile. Soil moisture profile was having the schematic representation as shown in the figure.

So, soil moisture we have put on the x-axis and soil depth on the y-axis and we have found that it can be divided into four different zones. At the top we are having the saturation zone, just beneath that we are having a transition zone which is separating the saturated zone and the unsaturated zone. And within the unsaturated zone itself, three ways it has been divided that is the transition zone, transmission zone, and wetting zone. Transition zone is the one which represents the change from saturated to unsaturated state and below the transition zone we were having transmission zone and wetting zone. And we have seen an important terminology known as wetting front, that is the clear boundary which is separating the two regions; before wetting and after wetting. So, within the wetting front we have found a sharp boundary which is having a soil moisture variation, too much of variation.

After that we have seen how the infiltration can be represented. We were representing infiltration by means of two terminologies infiltration rate and cumulative infiltration. As we were discussing about the rainfall, infiltration also one in terms of cumulative depth and the other in terms of depth divided by time.

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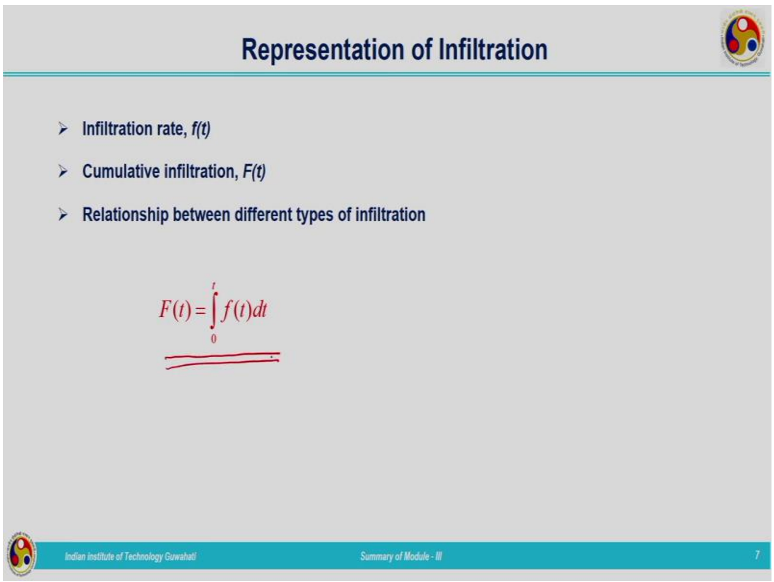

So, infiltration rate is representing the rate with which the water is getting infiltrated and cumulative infiltration is the water accumulated over time (that is how much is the infiltration taking place within a particular interval of time). We are not considering the interval, only total time and total water which is getting infiltrated, we are considering in the case of cumulative infiltration.

After that we have seen the relationship between infiltration rate and cumulative infiltration. Relationship is given by

$$F(t) = \int_0^t f(t)dt$$

So, how much is the time elapsed between the beginning to end, within that limits if we integrate the infiltration rate curve then we will get the cumulative infiltration. Or if we are having the cumulative infiltration with us, we can differentiate that to get the infiltration rate.

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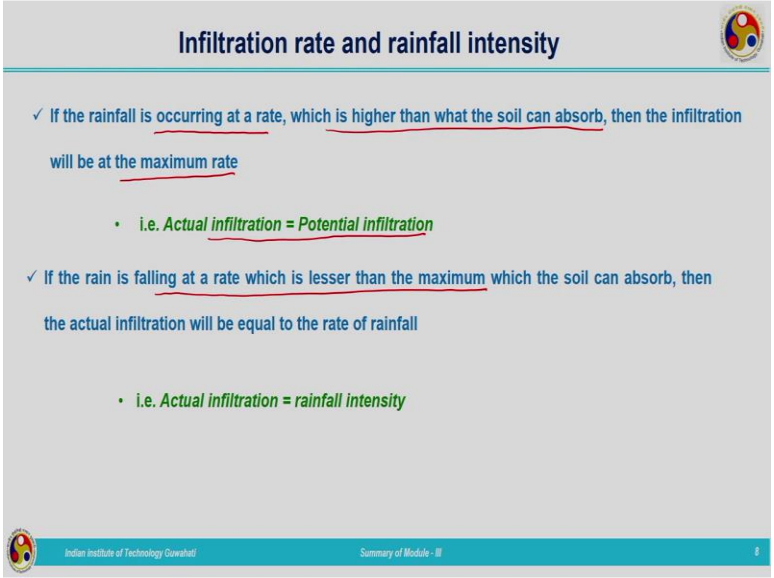

Then how this infiltration is taking place? Either we are watering or by means of rainfall. So, we can find out certain relationship between infiltration rate and rainfall intensity. As in the case of evapotranspiration, here also we have seen different terminologies, actual infiltration and also potential infiltration. Potential infiltration is the infiltration which is taking place when sufficient amount of water is there to infiltrate and actual infiltration is the one which is taking place actually in the field. So, while comparing infiltration rate and rainfall intensity, if the rainfall is occurring at a rate which is higher than what the soil can absorb, then the infiltration will be at maximum rate, that is the actual infiltration will be equal to the potential infiltration. The rainfall is having higher value than that of the infiltration rate. So, we are having sufficient amount of water available. So, if sufficient amount of water is present, the infiltration taking place will be the potential infiltration.

And, in some cases, if the rainfall is falling at a rate which is lesser than the maximum, that is the maximum moisture soil can absorb or the maximum infiltration that can take place at that particular location is more compared to the rainfall intensity, then what will happen? Whatever rainfall is falling, completely it will be infiltrated into the ground. So, in this case the actual infiltration will be less than that of the potential infiltration but actual infiltration can be equated to intensity of rainfall.

So, there are two cases, one is rainfall intensity is more than that of the infiltration capacity. Another is, *i* is less than that of the infiltration capacity. So, if *i* is less than that of the infiltration capacity, entire rainfall will be infiltrated into the ground. So, at that time *f* can be equated to intensity of rainfall that is the actual infiltration, it is less than potential infiltration. On the other hand, if the rainfall intensity is more than that of the maximum capacity, maximum infiltration rate then we will be having potential infiltration taking place. Actual infiltration can be equated to potential infiltration.

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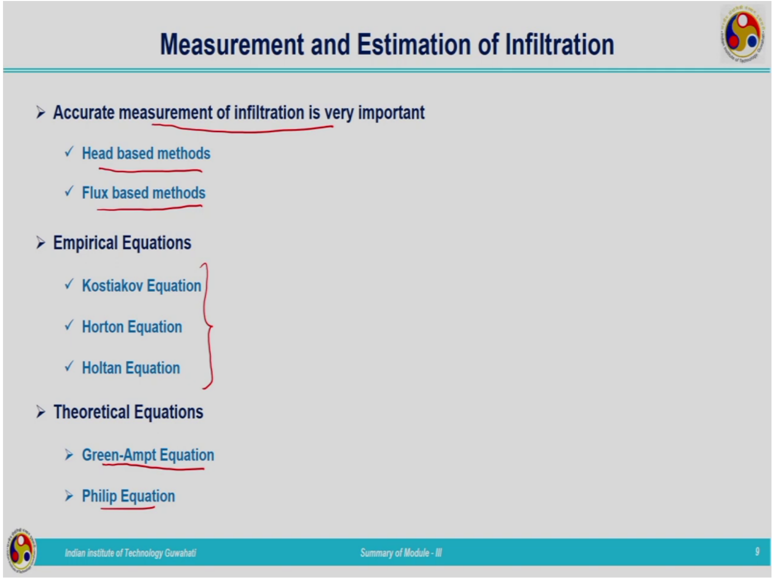

After that we have moved on to the measurement of infiltration. Measurement of infiltration is also very important because it is an important factor when we talk about losses, losses from rainfall. We have seen two different approaches for measurement of infiltration. One was head-based approach and second one was flux based approach. So, in the head-based approach we were providing certain head of water and based on that the measurements have been carried out.

In the flux-based approach, we have provided certain intensity or flux for infiltration to take place. But we have not gone deep into flux-based approach, we were giving importance to commonly used head-based approaches based on the infiltrometers. And the double ring infiltrometer in detail we have seen. We have started with single ring infiltrometer and then we have moved on to double ring infiltrometer. After understanding the disadvantages of single ring infiltrometer, we have gone to double ring infiltrometer and we have seen how infiltration can be represented in curves by means of infiltration rate and cumulative infiltration depth. Cumulative infiltration depth curve was an increasing curve as in the case of mass curve and infiltration rate curve was a decreasing curve.

Empirical equation and then we have seen the theoretical equation. So, empirical equation, three different equations which we have seen are Kostiakov Equation, Horton's Equation and Holtan Equation. When you go through different journal papers, you can see different methods. So, many methods are available but important methods which are explained in the textbooks, we have covered over here.

After that we have moved to theoretical equation, theoretical equations which are derived based on the fundamental laws, that is the mass conservation and momentum conservation principles. Those two equations which we have seen were Green Ampt Equation and Phillips Equation. So, in detail all these we have seen. After that we have solved some of the numerical examples.

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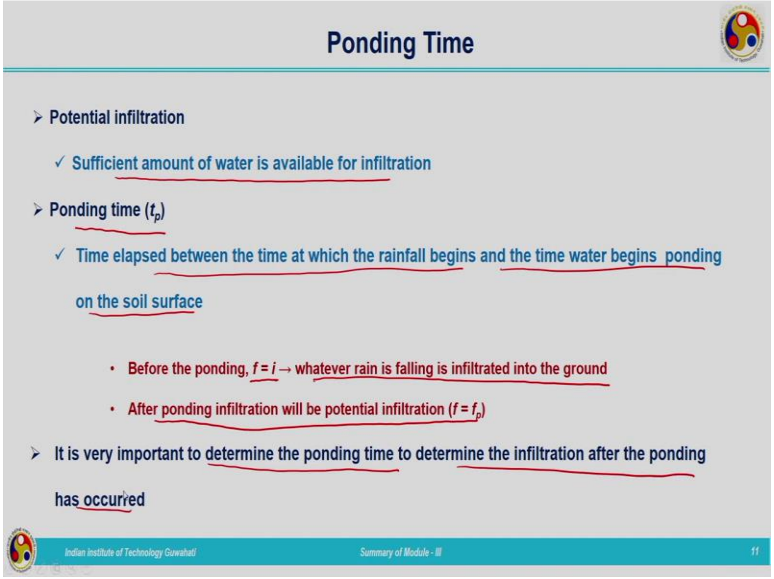

And once completing Green Ampt Equation, we have understood a concept termed as ponding time. By making use of the Green Ampt Equation, we have found out an expression for ponding time. So, potential infiltration is the one, in which sufficient amount of water was available for infiltration. Whenever we are having any rainfall, initially there will not be any ponding taking place. That is initially whatever rainfall is occurring that will be infiltrating into the ground. At that time, it is not the potential infiltration. When sufficient quantity of water is not available, the actual infiltration will be less than that of the potential infiltration.

Majority of the equations are giving the potential infiltration values that is sufficient amount of water is available for infiltration to take place. So, there we have explained the concept of ponding time, time elapsed between the time at which rainfall begins and the time water begins to ponding on the soil surface. That in between time is considered as the ponding time. So, when we are talking about potential infiltration, we are considering already ponding has taken place or sufficient amount of water is there to infiltrate. So, if we want to calculate the infiltration which has taken place after ponding has occurred, we need to have some understanding of ponding time.

So, before ponding,

$f = i$ (intensity of rainfall), whatever rain is falling, is infiltrated into the ground.

After ponding,

$f = f_p$ (infiltration will be potential infiltration).

After ponding has occurred means there is sufficient amount of water available and then the infiltration process is continuing. Before ponding means, rainfall is occurring or watering is taking place, entire water is getting infiltrated into the ground. So, based on the ponding time, we can find out how much is the infiltration taken place after ponding has occurred. So, it is very important to determine the ponding time to determine the infiltration after ponding has occurred.

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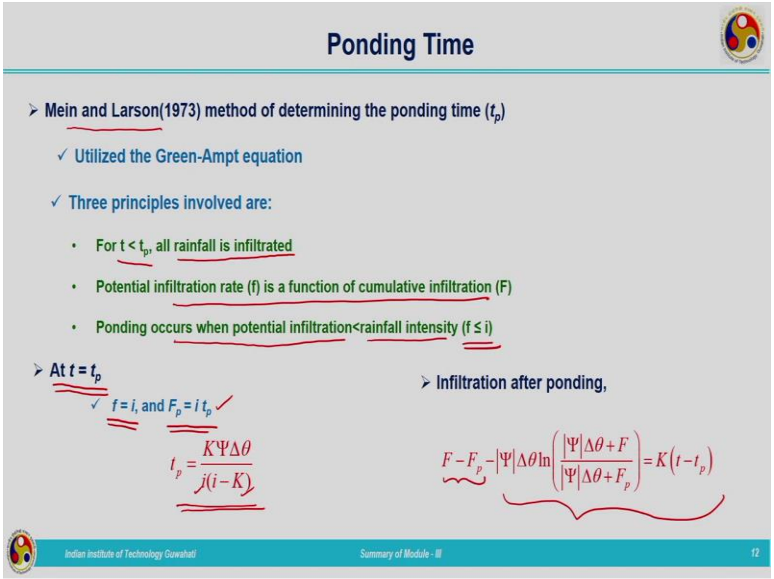

So, for that Mein and Larson have derived an expression by using the Green Ampt Equation (which is derived as a combination of continuity and momentum equation). That particular equation is used and three principles were considered.

- When $t < t_p$, entire water is infiltrated
- Potential infiltration rate (f) is a function of cumulative infiltration (F),
- Ponding occurs when potential infiltration is < rainfall intensity, ($f \leq i$)

So, at time $t = t_p$,

$f = i$, and $F_p = it_p$

So, with that conditions, we have derived the expression for ponding time. After that we have made use of the expression from Green Ampt Equation and found out the expression for ponding time, it is given by this simple equation.

$$t_p = \frac{K\Psi\Delta\theta}{i(i-K)}$$

So, infiltration after ponding was calculated by finding out the difference between F - F_p.

$$F - F_p - |\Psi|\Delta\theta \ln\left(\frac{|\Psi|\Delta\theta + F}{|\Psi|\Delta\theta + F_p}\right) = K\left(t - t_p\right)$$

So, this equation has to be solved by iterative methods because it is an implicit equation in infiltration on both the sides. So, some trial and error techniques need to be utilized for solving this equation.

And after that we have solved some of the numerical examples for finding out the solution of these things. So, all the technical details about this hydrologic process named infiltration, we have covered under the topic of subsurface water. Again, I am repeating that we have not looked into groundwater hydrology. Groundwater hydrology is beyond the scope of this course. So, we have considered the water which is present in the unsaturated zone or the vadose zone. That much we have covered under the topic of subsurface water. Here I am winding up the module 3 on subsurface water. Thank you very much.