Watershed Management

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Module No. # 04

Lecture No. # 14

Hydrologic Processes

and welcome back to the video course on watershed management in module number 4, lecture number 14. Today, we will discuss hydrologic processes. So, various topics covered in today's lecture include hydrologic cycle, hydrologic processes, precipitation, interception, infiltration, evaporation, transpiration, evapotranspiration and runoff.

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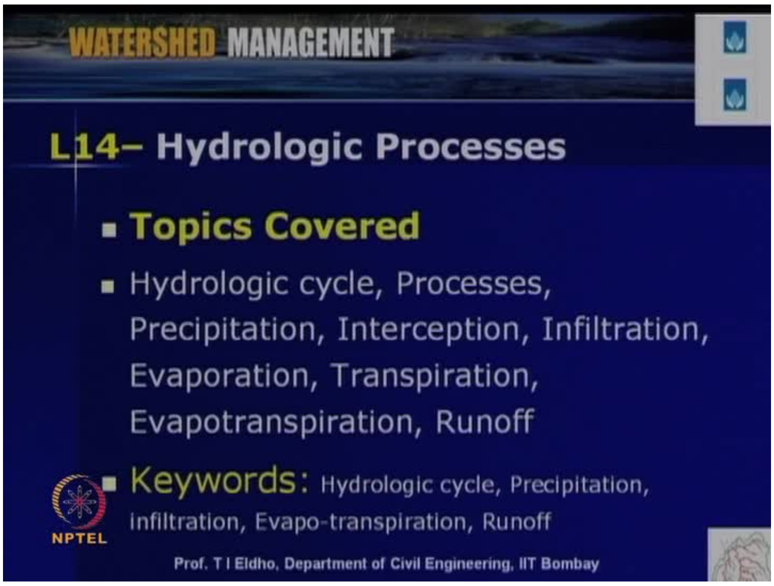

Some of the important keywords for today's lecture hydrologic cycle, precipitation, infiltration, evapotranspiration and runoff.

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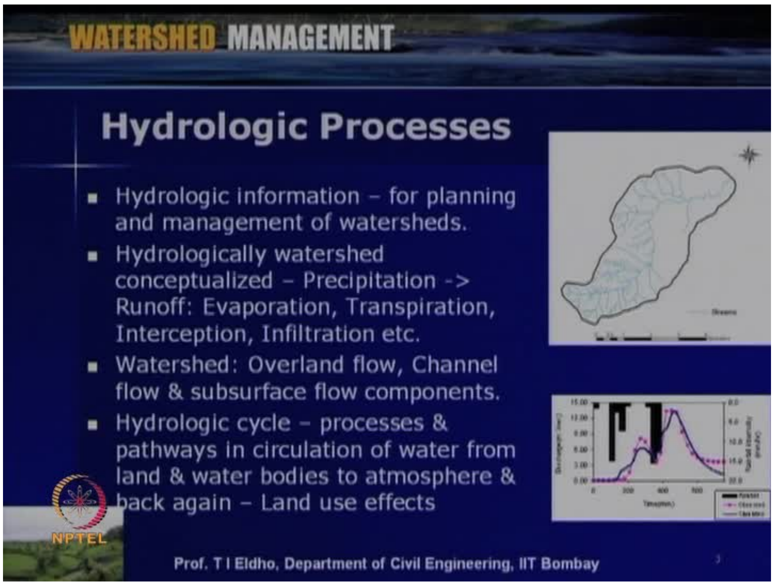

So, as we already discussed related to watershed management, water is one of the most important resource. As far as the watershed is concerned, so as far as a watershed or as far as any area is concerned, the main source of water precipitation over the rainfall. As we have discussed earlier, when the rainfall takes place, then various hydrologic process will be taking place. So and That rainfall to transform into runoff, number of processes will be there in between like interception, then evapotranspiration, then infiltration, percolation, like that so many processes are there.

So, these processes actually decide how much will be the runoff for the given rainfall condition. So, the hydrologic information whatever we are looking for is as far as the water as a resource is for the watershed planning and management. This hydrologically watershed - first we can conceptualize as we have discussed in the last lecture. So, once we have conceptualization as far as the watershed is concerned, like the boundary of the watershed, the drainage network, the areas of the watershed and various topographical and geographical conditions; then, when we consider the water as a resource; so we have to see the various hydrological aspects or hydrological processes taking place within the watershed. So, as far as the hydrology is concerned, once precipitation taking place; precipitation to runoff as I mentioned already, there are number of processes like evaporation, transpiration, interception, infiltration, etcetera.

So, now as far as watershed is concerned, when we deal with the water within the watershed, we have to mainly deal with the, how much will be the runoff, or how much is the overland flow, or how much is the channel flow and then, how much is the subsurface flow components, like related to infiltration and the groundwater flow components.

So, what these aspects we have to quantify when we go for hydrologic modeling as far as the watershed is concerned? As we discussed earlier, all these processes are one way or another way of the form of hydrologic cycle. So, hydrologic as we have discussed, in the processes and pathways, in circulation of water from land and water board is to atmosphere and back again. This is what is happening with in the various hydrological processes or hydrological cycle. So, start with the rainfall. Then, various other processes; so that there will be a circulation of the water within the earth and then the atmosphere and within the hydrosphere, which we consider. Of course, as far as the various processes are concerned, land use effects has a considerable effect as far as, the watershed is concerned. The various processes what you can take place within the watershed, depends upon the land use and then the topographical conditions.

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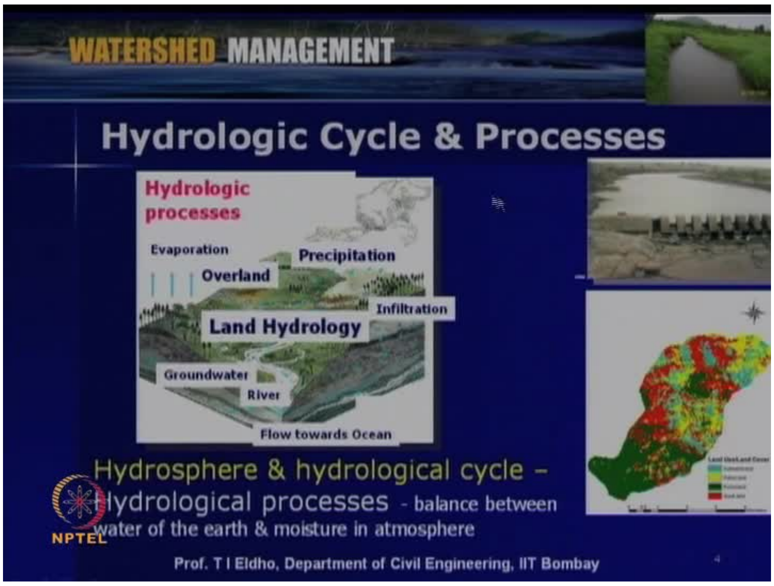

So within this context, say hydrological processes as I mentioned, now the rainfall is taking place than before the runoff is formed. Evaporation taking place, then interception, from the various vegetation and then the infiltration taking place and then finally, we can see that the runoff starts and that runoff is will be going to the drainage, network or the river and that river will be finally joining the sea or the ocean or flow towards the ocean. So, that is the way within the hydrologic cycle, the various hydrologic processes taking place. Everything is within the hydrosphere; so there is a balance between water of the earth and moisture in the atmosphere due to this hydrologic cycle.

So, that is what is happening; of course, as far as the precipitation is concerned, there is various with respect to the space and time but overall, there will be a balance between the water of the earth and the moisture in the atmosphere within the hydrologic cycle.

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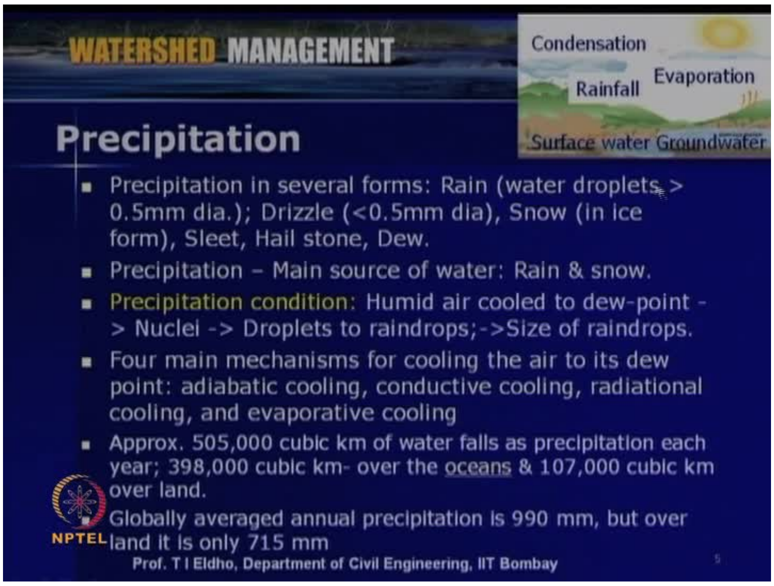

Now, as we have seen the most important aspect of the water as a resource. As far as a watershed is concerned, it is the precipitation. So, precipitation can be either in the form of rainfall or it can be in the form of snowfall. Precipitation we can see that, we call it as rainfall when the water droplets are having a diameter of more than point 5 mm and we call it has drizzle when it is less than point 5 mm and then, it can be either in the form of snow that means in ice form or sleet or hail stone or dew. So, various conditions can be there; so overall we called it. Everything, including a rainfall, snowfall, everything we together call it as a precipitation.

As I mentioned, precipitation is the main source of water as far as the watershed or the as the earth is concerned. That too, out of this, so many components or so many forms. Rain and snow are the most important form as far as the precipitation is concerned. When we considered a watershed or a the land, the precipitation is concerned as, a precipitation happens when a specific condition taking place within the atmosphere. so the What is happening is that the water evaporates on the surface of the earth or the surface of the ocean and then it goes to the atmosphere and then the condensation takes place.

So you can see that there is the precipitation happens only during some specific conditions like a humid air cooled to dew-point and formation of the nuclei and then their droplets are formed to raindrops and then finally, when the raindrops form to certain size then only the precipitation is happening. So, we can see that the operation is always taking place but we are not getting the rainfall all the time. That means the certain specific condition should takes place at specified locations or within the atmosphere so that we will be having the rainfall.

When the rainfall happens or precipitation as far as precipitation condition is concerned we can see that there are four main mechanisms for cooling the air to its dew-point. As I mentioned, the first is the formation of dew-point; that is the first step as far as the precipitation condition is concerned. So 4 mechanisms for the formation of dew-point is say like adiabatic cooling, conductive cooling, radiational cooling and evaporative cooling. Depending upon the condition how effectively or how much is happening all these 4 main mechanisms then the dew-point formation taking place and then finally droplets formation and raindrops formation happens.

If we consider, as far as the earth as a whole then we can see that an approximation of say for example for 505000 cubic kilometer of waterfalls as precipitation each year and out of this ah three 398000 cubic kilometer happens over the oceans and then 107000 cubic kilometer happens over the land. So you can see that land component is concerned it is a very small, almost one-fifth of slightly more than one-fifth. So, that is what is the rainfall what is happening or the precipitation happening over the land surface. Globally, if you consider for example, average annual precipitation is concerned it is about 990 millimeter but as far as the land is concerned, it is only about 715 millimeter. So, that is the precipitation pattern as far as the total earth or the land is concerned as far as the precipitation.

Now, when we talk about the water resource quantification within a watershed, the most important aspect is precipitation. So, we have to quantify how much is the precipitation happening within a watershed and then how much of percentage of that precipitation is transforming to runoff; all this very important as far as the water resource assessments or quantification as far as a particular area of or a watershed is concerned.

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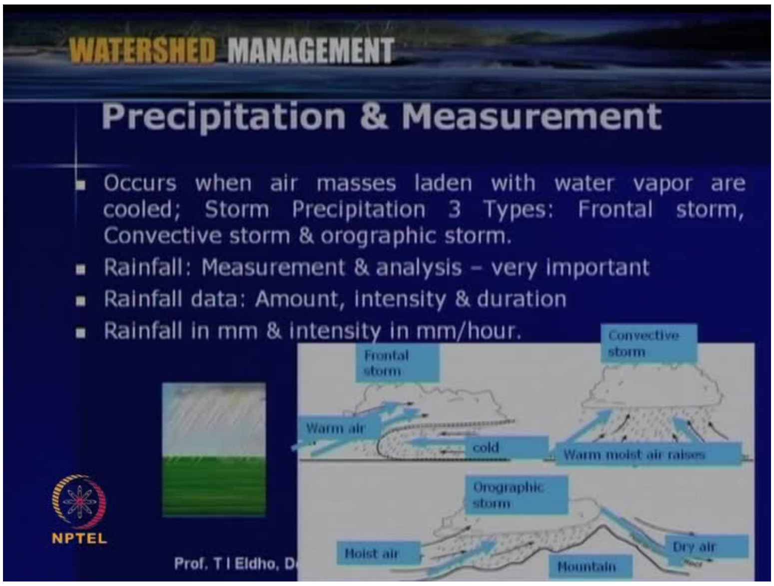

So, the precipitation as we discussed generally happens when air masses laden with water vapor are cooled. So, this precipitation we can classify into 3 types - so the storm precipitation into 3 types. First one is called a frontal storm. Frontal storm means for example, the cold air is coming in this direction and warm air is coming like this; so that there is the mixing is as in between the cold front and warm front and then the various condition takes place and then from that the frontal storm taking place. So, that is one type of storm precipitation. Second type is so-called convective storm. As far as convective storm is concerned, warm moist air raises with respect to both as shown in this figure and then convection taking place and then finally, when the appropriate situation or condition takes place convective storm happens. The last one is so-called orographic storm. In the case of orographic storms mainly, if there is a mountain or a hilly region on the land surface then moist air is coming from this side and dry air from this side and then the various circulation taking place and finally, when the precipitation condition occurs, we call that kind of storm as orographic storm. So, generally we can classify the storm precipitation into 3 types: frontal storm, convective storm and the orographic storm.

Now, as far as rainfall for the particular area is concerned we have to measure the rainfall and then we have to analyze, how is the pattern of the rainfall. These are very important as far as the water resource quantification for a watershed or a particular area is concerned. So, rainfall data we have to measure the rainfall and then we have to assess how much is the total amount of rainfall; then what is the intensity of rainfall and how much is the duration of the rainfall. These are all very important aspects as far as the water resource assessment for a particular watershed is concerned.

Generally, we can describe the rainfall in terms of depth of water; in terms of millimeter and then, as far as the intensity of rainfall generally, we describe in terms of millimeter per hour.

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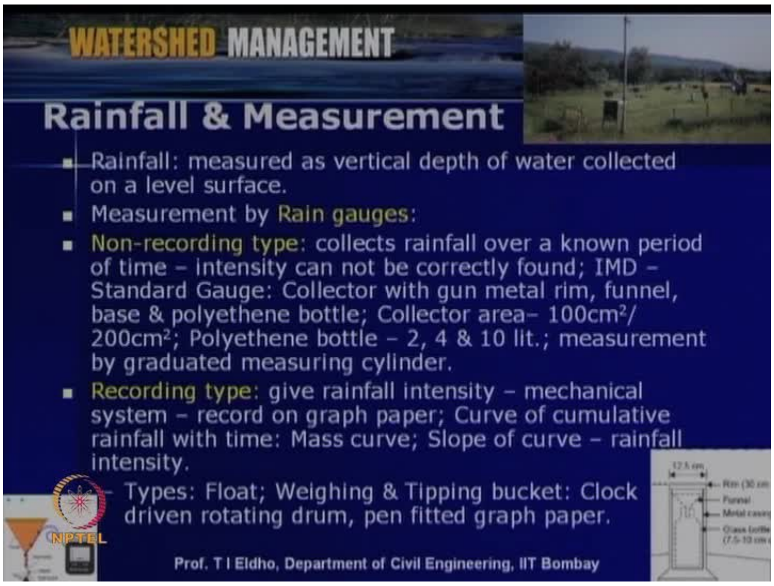

Now, with the, as I mentioned, rainfall is concerned, we have to measure the rainfall and then we have to quantify how much is the rainfall taking place at particular locations. So, rainfall we can measure as the vertical depth of water collected on a level surface.

Generally, we can measure the rainfall using say, equipment called rain gauges. So, generally if you go through the hydrological literature, we can see there are two types of rain gauges; first one is called non-recording type rain gauge. Here, in the non-recording type rain gauge, we collect the rainfall over a known period of time. So, here we cannot directly get the intensity from the,… since we are simply collecting the rainfall, for example, in the India Meteorological Department – IMD. The standard gauge is concerned, this is a standard gauge; there is a collector with a gun metal ring; so this is a collector and then there will be a funnel like this (Refer Slide Time: 13:45) and then there will be a polyethene bottle where we can transfer this end; find out how much is the rainfall. So, then collector area can vary from 100 square centimeter to 200 square centimeter and the polyethene bottle can be of the form of 2 liter, 4 liter and 10 liters and measurement by graduated measuring cylinder.

What we do? we wherever We install this rain gauge, particular location where there are the norm obstruction in an open area. We can install this rain gauge and then, once in a day, particular time we can measure how much is the rainfall took place and then that gives the total quantity of the rainfall.

Other type of rainfall rain gauge is called recording type rain gauge. Actually, this is slightly sophisticated rain gauge. This directly gives the rainfall intensity; there is a mechanical system within the rain gauge, so that records on the graph paper or directly on that tracquisition system. So, we can get the curve of cumulative rainfall with the time; we can plot the mass curve - time versus the rainfall intensity. So, the slope of the curve gives the rainfall intensity. There are different types of recording type rain gauges like, a floating type weighing bucket, then tipping bucket, then clock driven floating drum, pen fitted graph paper; so like that number of recording type rain gauges are used.

Now-a-days, we are early used non-recording type rain gauges most of the time. We will use the recording type rain gauge so that we get the total quantity of the rainfall as well as, the rainfall intensity directly; so that we can have better hydrological predictions as far as the various processes are concerned. This shows a particular type of like a weighing type the rain gauge.

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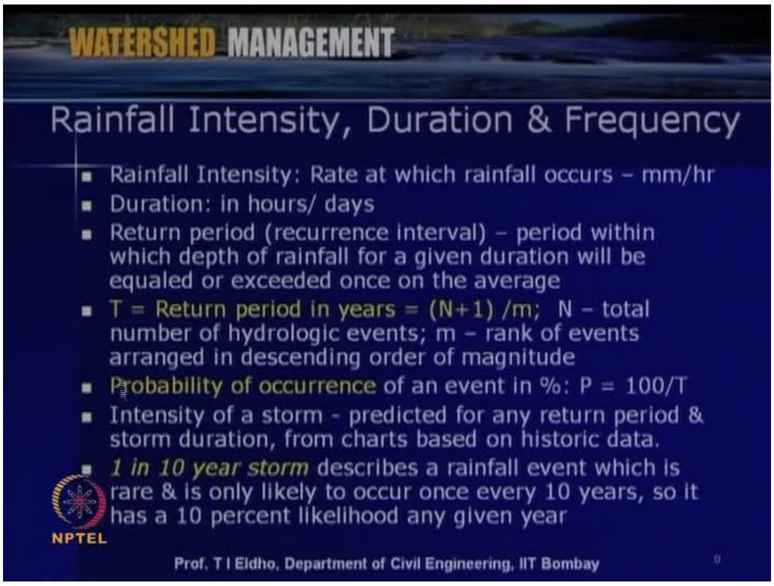

So then Some of the important terms as far as the rainfall or precipitation is concerned: first one is the rainfall intensity; second one is the duration and third one is the frequency.

Now, rainfall intensity as I mentioned that is, that gives the rate at which rainfall occurs; so it can be generally millimeter per hour and then duration is concerned. Generally, we prescribe in terms of in a number of hours or number of days like that. Then, another important term in hydrology is, so-called return period or recurrence interval. This shows the periods within which depth of rainfall for a given duration will be equal or exceeded once on the average. So, that is the definition of the return period or recurrence interval. So, if T is the return period in years, we can put in this form T is equal to N plus 1 m where N is the total number of hydrologic events, m is the rank of events arranged in descending order of magnitude.

So, from that we can find the frequency or the probability of occurrence of an event in percentage. We can put P is equal to 100 by T; so this is in percentage, that indicates the possibility of a return of a rainfall. So, then intensity of a storm that gives the return period and storm duration; we can have charts based upon the historic data. So, we can assess the historic data for example, for a 5 years, 10 year, or 50 years, or 100 years and then we can identify… particular location is concerned, particular area is concerned, how is the rainfall pattern and then how much is the maximum intensity, average intensity, minimum intensity. Then, we can find average annual rainfall; so like that, say once we get the measured data from a rain gauge station, we can get various details as far as the rainfall pattern for the considered watershed.

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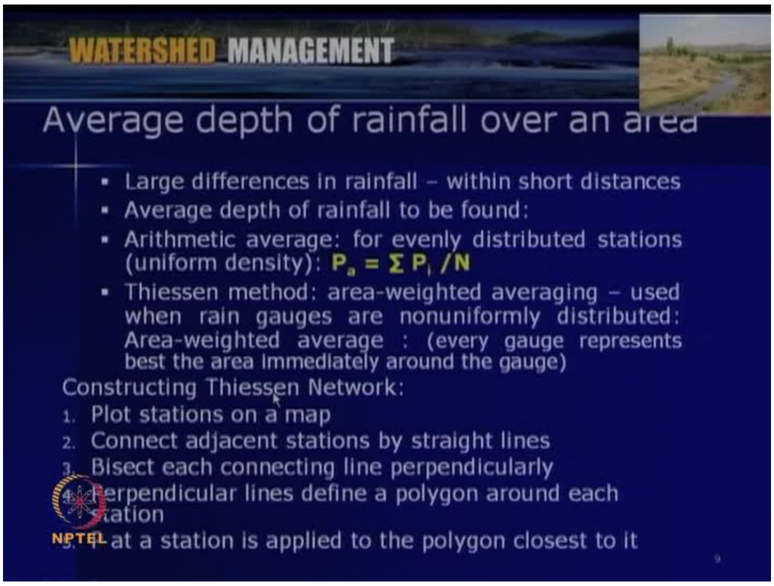

For example, now if the probability occurrence is 1 in 10 year storm means that describe a rainfall event which is a rare and is only likely to occur once every 10 years. So, it has a 10 percent of likelihood for any given year. So, like that once we get the rainfall data we can simulate it and then identify the rainfall intensity, average annual rainfall, then the rainfall duration, the rainfall frequency, etcetera. Then another important aspect is the average depth of rainfall over an area. So, when we go for hydrologic modeling we can see that for the particular location which we consider there may not be a rain gauge. In that case we may have to consider some averaging of the rainfall pattern for the given storm condition.

There will be the reason, is that large differences in rainfall within short distances; so whenever we are going from one location to location, there will be huge variation as far as the quantity of rainfall and rainfall intensity is concerned. That is why we may have to consider the average depth of rainfall say, as far as particular location is concerned.

Generally, 3 methods we use to get this average depth of rainfall. First one is called an arithmetic average; for example, a particular area is concerned, we can identify which are the nearby rain gauge stations and then for identifying for a particular given storm of rainfall.

We can identify what will be the rainfall in all those rain gauge stations nearby and then we can get the arithmetic average by just simply adding or the rainfall for the given storm condition and then we can divide by the number of stations. So, that is simple average so that is called a arithmetic average.

Then so Generally, this arithmetic average the accuracy will be very less in say, we are simply taking the sum the rainfall for given storm and then we simply divide by the number of stations; but, then there are more accurate methods like a Thiessen method and then Isohyetal method. In the Thiessen method what we do is, it actually gives the area weighted averaging. So, we use the rain gauge stations which are nearby. Actually, the rain gauge stations may be nonuniformly distributed at various locations; so that is why we are considering an area weighted average. Every gauge represents best, the area immediately around the gauge; so that is the basic principle of using this Thiessen method.

So, we can construct Thiessen polygon like this. Actually, there are step by step method. First, we can plot the stations on a map like these are the stations say 5 – a, b, c, d, e; then we can connect the adjacent stations by straight lines.

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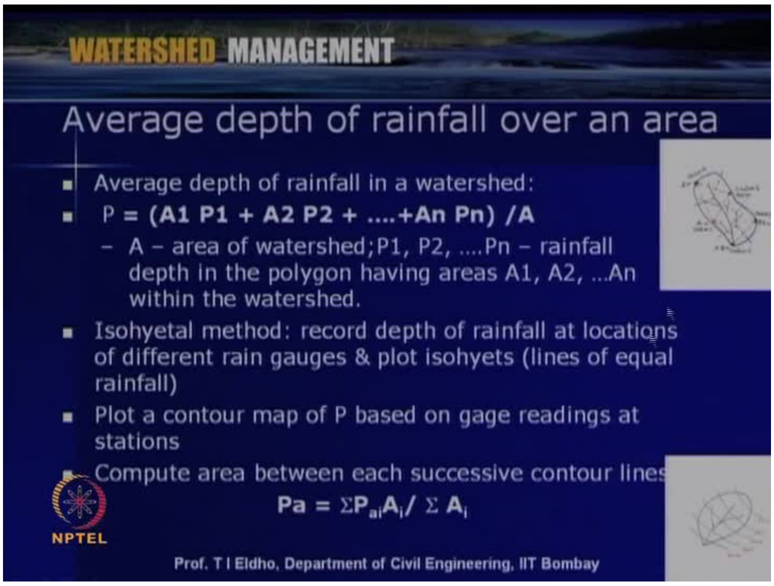

We first connect the adjacent lines; say between each station we connect each station by adjacent line, by straight lines; then bisect each connecting line perpendicularly. So, you can see that this blue line (Refer Slide Time: 22:02) indicates we bisect each connecting lines by perpendicular lines. Then perpendicular lines define a polygon around each station. So, you can see that here if this is the station A then, this is the area which we can say approximate as far as this station is concerned. Similarly, for this station, each station we can see here. Then the P at station, the rainfall at a station, is applied to the polygon closest to it. This figure shows how we do using the Thiessen method. So, the average depth of rainfall in a, in that particular area which we want to identify, will be P is equal to A1 P1 plus A2 P2 plus like that, plus An Pn divided by A; where A is the area of watershed. So, total area of the watershed P1, P2, to Pn are rainfall depths in the polygon having areas A1, A2, to An within the watershed. So, this is as if we do not have large number rain gauges for a given watershed. We can use the adjacent nearby rain gauge station and then identify how much is the rainfall for a given storm in the particular rain gauge stations and then we can use this method.

The third method is called Isohyetal method. Here, actually in various stations we get the rainfall for the given storms and then we record depth of rainfall at locations of different rain gauges and then plot a contour line called isohyets. So, actually these are the lines of equal rainfall; so that lines are called isohyets. This is say for example, 50 centimeter isohyets, then 45 centimeter isohyets, then 40 centimeter isohyets; so we can plot the isohyet as far as the that area which we consider.

Then, say, plot a contour map of P based on the gauge readings at stations. Now, say for example, this would be the 50 centimeter isohyets, this is 45 centimeter isohyets. We can identify how much is the area between this 50 to 45; so we can compute the area between each successive contour lines and then the average rainfall will be sigma P ai A i divided by sigma A i. Sigma A i is the total area as far as the watershed which we consider so we can identify with this. This will be somewhat more accurate method since we are getting these isohyets and from that what is coming is the area is we are considering. So, this formula gives the average rainfall as far as the, by using the Isohyetal method. That way, we can identify how much is the rainfall for the particular station or particular location or particular watershed which we consider using either arithmetic average or Thiessen polygon method or the Isohyetal method.

Once we get the rainfall condition for the particular watershed, now to identify how much will be the runoff, we can look into the various hydrologic processes which you will be taking place within the watershed.

So, as I mentioned earlier precipitation to runoff number of or the transformation of precipitation to runoff number of processes will be there. So, we will be considering the important processes as far as the particular watershed is concerned and then we can quantify how much will be the losses like interception losses, evaporation losses or the infiltration losses. So, then so based upon that we can identify how much is the runoff which we will be coming to the outlet of the watershed. From that we can assess how much is the water if we are going construct a say for example, a check dam and the outlet; so this much storage is possible with respect to the given rainfall condition.

Now, when we consider the various hydrologic processes then some of the important hydrologic processes, we will now discuss and we will try to say we will discuss the important equations as far as the quantification is concerned, or the methodology is concerned. Then, we will identify how we can go to the various processes and then finally, how much will be the runoff. So, the various processes as far as hydraulic processes are concerned, now we will discuss.

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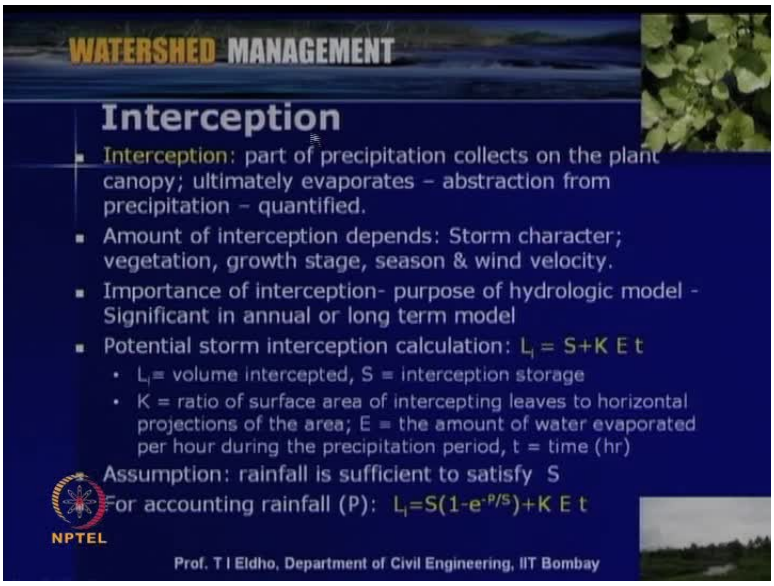

Now, the first one is when the rainfall takes place. So, first thing what can happen is that within the watershed, so vegetation will be there; say large or small or million type trees will be there. First what happens is that these the leaves and the trees themselves catch some of the rainfall. So, interception means the part of the precipitation collects over the plant canopy; that is so-called interception. Actually, this intercepted water ultimately evaporates and then so that goes to the atmosphere and some of those things. The intercepted water may be absorbed by the plant also but that will be very minor percentage. But, most of the water will be going back to the atmosphere as evaporation from the plants.

So, ultimately this intercepted water evaporates. But, of course, when we are looking for the, in the quantification, we have to see this abstraction from the precipitation and then we have to quantify. So, the amount of interception depends; the various factors are there. So, like a storm character, what is intensity of rainfall? How much is the duration? then vegetation? So, mainly how much is whether it is thickly forested or thin vegetations are like this or grass or what kind of canopy is there; so accordingly, the interception varies. Then what is the growth stage if you are considering the crops? What is the growth stage of the crops? Then season; what kind of season? Whether it is dry season or a wind season or and then of course, wind velocity

The importance of interception is depends upon whether we are going for very accurate hydrologic modeling. Then we have to consider this interception loss also. Actually, when we consider for a long duration like annual or a long term modeling is concerned, interception is important. There is a significant loss will be there in terms of, in case, interception.

Now, say one of the commonly used equation (Refer Slide Time: 29:04f) here I have shown the potential storm interception. We can calculate using this equation L i is equal to S plus K into E into t; so where L i is the volume of water intercepted, S is the interception storage, K is the ratio surface area of intercepting leaves to horizontal projections of the area, E is the amount of water evaporated per hour during the precipitation period and t is the time in hour.

So, the assumption here is the rainfall is sufficient to satisfy this S here and now, if you want to accounting the rainfall also, then this equation can be modified like L i is equal to S into 1 minus e to the power minus p by s plus K into E into t. So, this is one sample equation and number of other types of equations are available in literature to quantify the interception.

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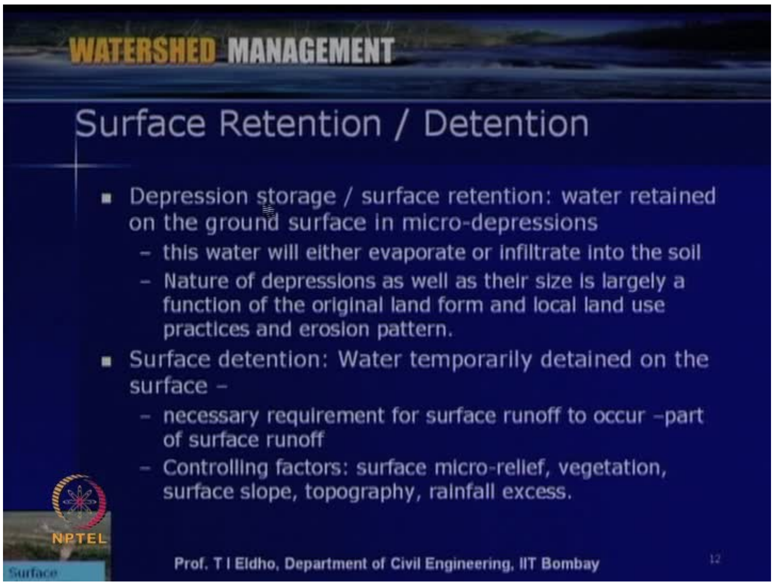

So, interception is a major loss or major, it is significant when we consider long term hydrologic modeling; at least, when we talk in terms of annual losses. Interception we have to consider; then another important one is the intercepted and then the rainfall is continuing. Then, other type of losses can be either surface retention or detention. So, we can see that as far as the surface is concerned, the land surface is concerned, number of small small depressions will be there and then all these depressions has to be filled by the water before the runoff can start.

So, depression storage also, this is the surface retention; that is, water retained on the ground surface in micro depression. There can be small small depressions over them - micro depressions. So, this water will either evaporate or infiltrate into the soil.

These small small holdings here, you can see that either it can evaporate or it can infiltrate down to the soil. Then the nature of depression as well as their size is largely a function of the original land form and local land use practices and the erosion pattern. So, that is as far as the erosion pattern also concerned; that is very important.

Now, surface detention is the water detained or water temporarily detained on the surface. This is one of the necessary requirements for surface runoff to occur. So, this is actually somewhat when we are considering hydrologic modeling; it can be part of surface runoff itself. Some of the controlling factors are surface micro relief vegetation, surface slope topography and rainfall excess.

So, depending upon whether we are going for very accurate way of hydraulic modeling we can consider the surface retention or detention. Actually, it is a very complex; very complicated to identifying how much will be the retention or detention. So, in general may be a small percentage of the rainfall can be considered as surface retention or a detention. Then the next very important hydrologic process is so-called infiltration so actually that is one of the most important hydrologic process which will decide how much will be the,… from when the precipitation to runoff; how much will be the water loss. Actually, it is not a loss; it is going to the earth or through a soil to the occupy system.

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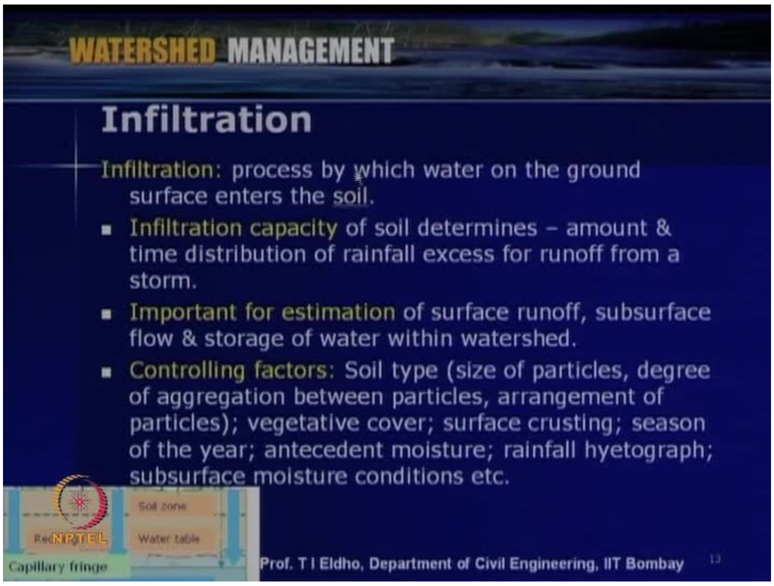

So, this infiltration now we will discuss in detail. Infiltration is the process by which water on the ground surface enters the soil; so infiltration capacity of soil determines like amount and time of distribution of rainfall excess for runoff from a given storm

So you can see that now rainfall taking place and then what is happening here the rainfall taking place. This is the soil condition; now through the soil pores the water will be infiltrating down to the soil. So, this is unsaturated layer and then it is slowly goes to the capillary fringe and finally, to the ground water. So, this is very important; infiltration is concerned very important for estimation of surface runoff and also subsurface flow and storage of water within a watershed. How much is subsurface storage is all decided by the infiltration.

Some of the important controlling factors as far as the infiltration is concerned, like soil type, like size of particles, then degree of aggregation between the particles, arrangement of particles; then what kind of soil it is; clay soil, sand is soil then a vegetative cover so whether it is a the vegetation cover is sand now the grass or a what kind of vegetation cover is there; either, a forested or non-forested, then surface crusting then season of the year; then some of the other controlling factors like antecedent moisture; what is a moisture holding of the soil, then rainfall hyetograph, what is the excess rainfall

This rainfall is, whether if it is continuously taking place then the infiltration will keep on reducing then, subsurface moisture conditions etcetera. There are so many controlling factors. Actually, this infiltration process is very difficult to quantify since the soil nature is very complex and then it is not so easy to identify. But, anyway number of methodologies has been developed by various researchers and the last few decades and so, using either one of this methodology suitable to particular area we can identify how much is the infiltration losses.

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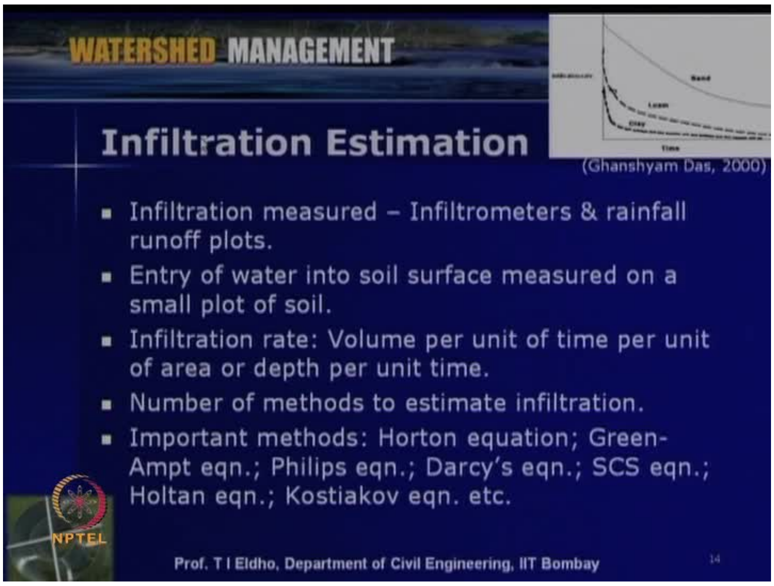

Next one is the infiltration estimation: infiltration measured, we can measure for the given location; we can use infiltrometer. So, this is so-called double ring infiltrometer. We can do experiment for the particular location and then identify how much is the infiltration rate. And, then rainfall runoff plots, particular plot is concerned, we can say small small plot we can consider and then, so if you identify how much is the evaporation losses then how much is the runoff from that, we can identify how much is the infiltration taking place. Then entry of water into soil surface: measure on a small plot of soil and then that gives the infiltration rate. So, infiltration rate generally we put as volume per unit of time per unit of area or depth per unit time. This shows, taking from Ghanshyam Das, with respect to time infiltration rate is given here. So, it can be say like a mm per hour; so it depends upon the soil like a sand-then-loam-then-clay; so it is drastically varying.

As I mentioned, number of methods are available to estimate the infiltration. Some of the important methods includes Horton equation Green Ampt equation Philips equation Darcy's equation; soil conservation service care number equation; Holtan equation Kostiakov equation; like that. So, number of equations is available in literature to identify the infiltration estimation.

Depending upon the data availability for the particular location, depending upon the accuracy which we are looking for and then data availability, we can choose particular infiltration estimation method and then we can calculate the infiltration.

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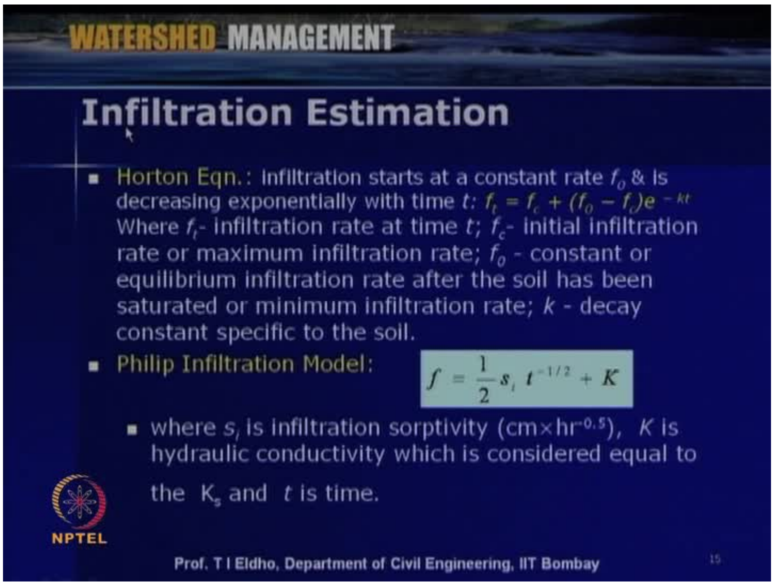

Here, we will discuss 2-3 important methods. Say, one of the commonly used methods is called a Horton equation. So, here the assumption is that infiltration starts at a constant rate f 0 and is decreasing as exponentially with time t. So, the equation is, f t is equal to f c plus f 0 minus f c into e to the power minus kt, where f t is the infiltration rate at time t. f c is the initial infiltration rate or maximum infiltration rate, f 0 is the constant or equilibrium infiltration rate after the soil has been saturated or a minimum infiltration rate.

Then k is so-called decay constant specific to the particular soil. So, this equation we can utilize Horton equation. Then another commonly used equation so-called Philip infiltration model; so the equation is say f is equal to half s i into t to the power minus half plus K, where s i is the infiltration sorptivity, K is hydraulic conductivity which is considered equal to saturate hydraulic conductivity K s and t is the time.

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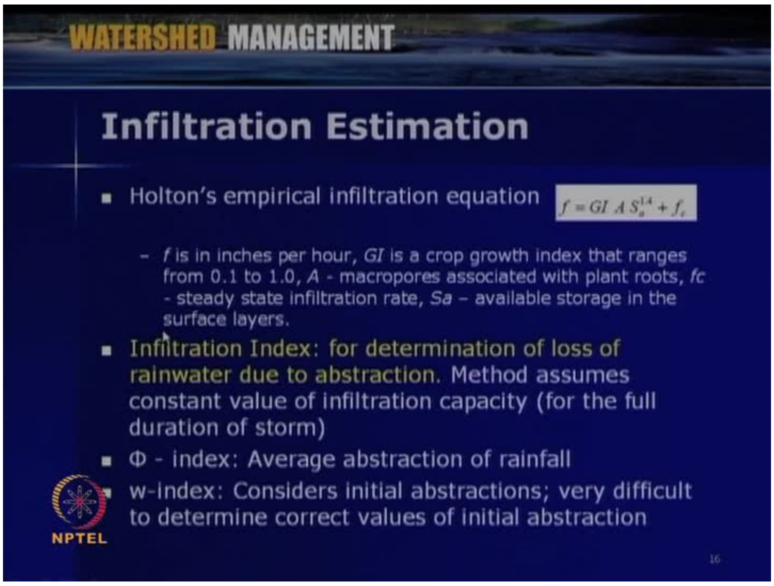

Philip infiltration model is also another commonly used infiltration model and then another infiltration equation is so-called a Holton equation. So, here the equation is f is equal to GI A into S a to the power 1.4 plus f c where the f is in inches per hour; GI is a crop growth index that ranges from 0.1 to 1.0; A is the macropores associated with the plant roots; f c is a steady state infiltration rate and Sa is the available storage in the surface layers.

So, like this various equations are available; depending upon the data availability and depending upon the soil nature and other conditions, we can choose a particular equation to estimate the infiltration. So, if we are not going for a very complex equation like Horton or any of this equation, we can consider certain percentage of the rainfall is going as infiltration. So, we can describe in terms of infiltration index for determination of loss of rain water due to abstraction. This method assumes constant values of infiltration capacity for the full duration of storm like phi index.

We can consider average abstraction of rainfall like a 10 percent, 20 percent or 30 percent like that. So, phi index and another index called the w-index, this considers initial abstraction and then very difficult to determine the correct values of initial abstraction. Commonly, this phi index we can simply say that this much percentage of the precipitation is going as phi index.

So, but if sufficient data is available and if you are looking for accurate measurement of the infiltration then, we have to use various models like Philips model or Horton equation or Horton's empirical infiltration equation like that. So, this is about the estimation of the infiltration. As I mentioned, infiltration is one of the most important hydrologic processes which we have to consider and it's precipitation to runoff depends upon how much is the percent of the infiltration taking place at the considered location.

Now, we will discuss some of the other important hydrologic processes. Next one is the evaporation. As I mentioned, there is always say, when the rainfall is taking place continuously, the evaporation may loss may be less but otherwise, evaporation is taking place, from all the surface water board or from the soil or as transpiration and evaporation from the plants. So, all this is taking place; so, evaporation is another important hydrologic process which we have to consider.

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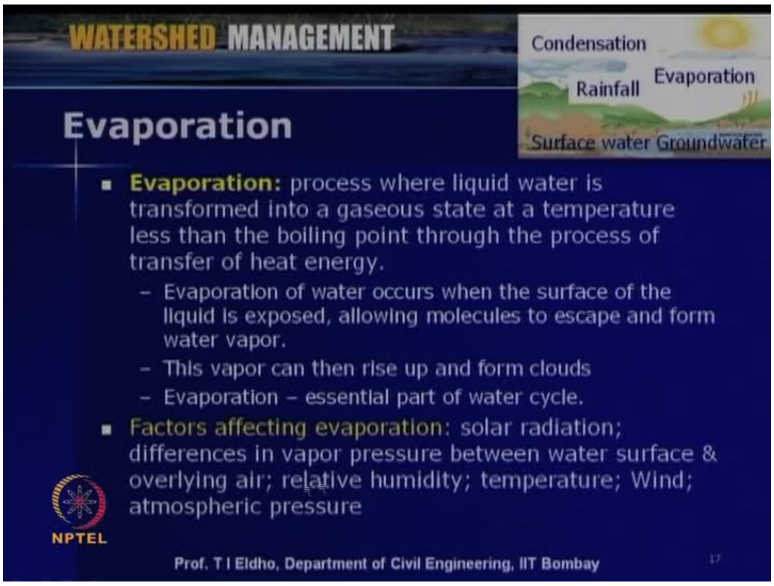

Evaporation is the process where liquid water is transformed into a gaseous state at a temperature less than the boiling point through the process of transfer of heat energy. So, evaporation of water occurs when the surface of the liquid is exposed, then allowing molecules to escape and form the water vapor. This vapor, can then rise up and form the clouds. So, you can see that evaporation from the water surface taking place and then cloud formation taking place and then that is a part of the hydrologic cycle. Then the factors - important factors affecting evaporation: here I have listed like a solar radiation differences in vapor pressure between water surface and overlying air; then relative humidity, temperature,, wind atmospheric pressure, etcetera.

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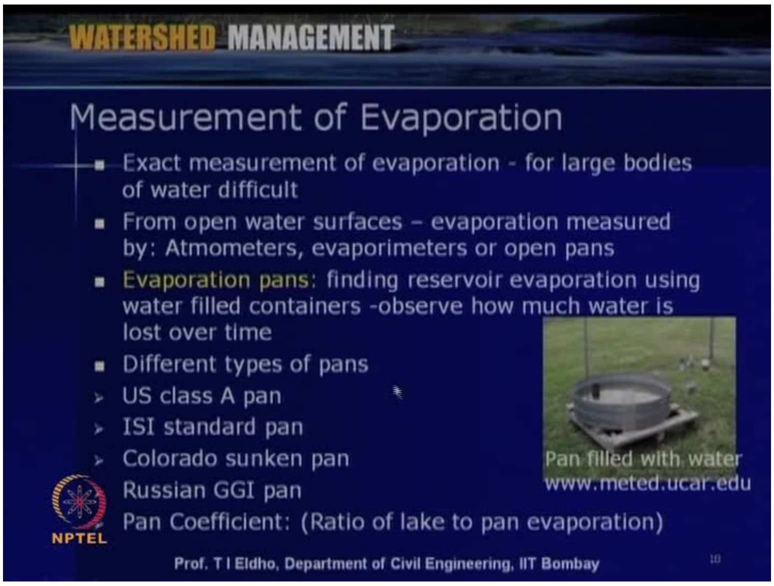

So, there are number of factors affecting the evaporation; some of the important factors I have listed. Now, when we are looking for water resources assessment, as far as a watershed is concerned say, we have to identify how much is evaporation process. For example, from the lakes, from the reservoirs or from the river or called any other water body and then of course the various other losses from the soil etcetera.

Now, the exact measurement of the evaporation is very very difficult. Generally, for large water bodies we can consider some experiments or we can use some equations which are already developed. So, from open water surfaces we can measure the evaporation using various equipments like atmometers, then evaporimeters or open pans. So, this shows a typical plan; this photo is taken from this website (Refer Slide Time: 41:53). So, from this we can fill this pan and then according to the various with respect to time how the variation in depth taking place. Accordingly, we can identify how much is the evaporation loss; so evaporation pans are concerned, that gives the evaporation using the water filled in containers like this. So, we can observe how much of water is lost over time.

Different types of pans are available like US class A pan,, ISI standard pan Colorado sunken pan, Russian GGI pan, so like that. We can identify a coefficient called pan coefficient which is the ratio for example - lake to pan evaporation.

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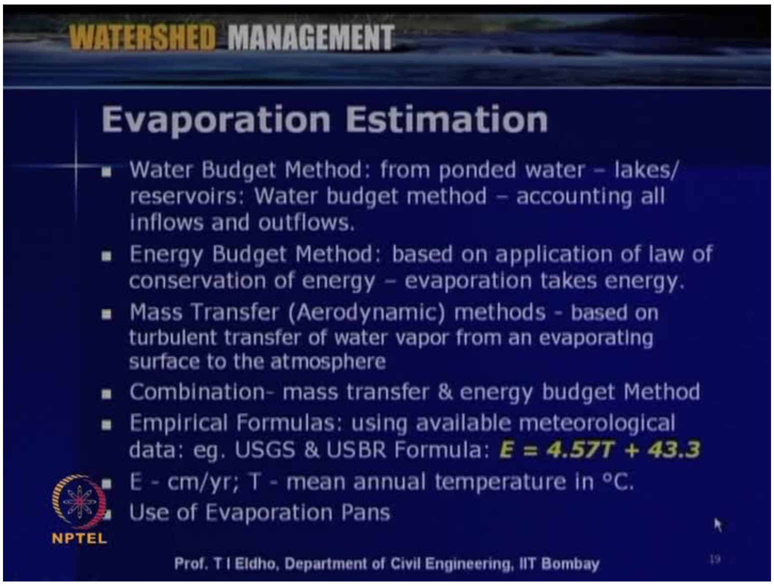

We can identify the coefficient and then multiply to identify how much is the evaporation taking place for the given water body or given reservoir or the lake which we consider. So, other than these experimental measurements we can also estimate using various equations or various methodologies listed here, like a water budget method. so this From ponded water or lakes, reservoirs, we can identify, we can account all the inflows and outflows and then we can identify how much is the evaporation.

Then, energy budget method: based on application of law of conservation of energy, we can identify how much energy is taken for evaporation and from that we can calculate the evaporation. Then mass transfer: so-called aerodynamic methods. This is based on turbulent transfer of water vapor from an evaporating surface to the atmosphere. So, number of mass transfer models, are available in literature.

Then a combination of these like, mass transfer and energy budget methods; then also, number of empirical formulas are used for evaporation estimation like a USGS and USBR formula where evaporation is equal to 4.57T plus 43.3, where E is the evaporation in centimeter per year, T is the mean annual temperature in degree centigrade; like that we can identify. So, as I mentioned, evaporation pans also we can utilize.

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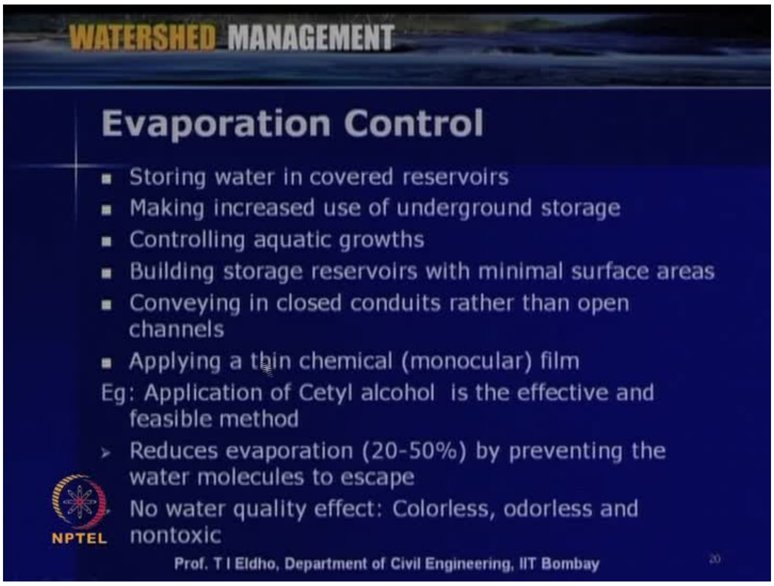

Evaporation is a major loss as far as the surface water reservoirs are concerned. So, it is always depending upon the area like (( )) areas; it can go to 30 percent, 40 percent or even up to 50 percent of evaporation losses from the reservoirs or the lakes. So, if we can control the evaporation by using various measures so that we can reduce the evaporation and then we can know how better use of the available water.

So, here I have listed various evaporation control measures like storing water in covered reservoirs; then making increased use of underground storage; then controlling aquatic growths and then building storage reservoirs with minimal surface areas; then conveying in closed conduits rather than open channels; then applying a thin chemical or monocular film like by using Cetyl alcohol and then, that reduces evaporation say about 20 to 50 percent by preventing the water molecules to escape from the water surface. So, actually this we can, only thing is that, it is slightly expensive but, no water quality effect like it is colorless, odorless and nontoxic. So, even we can use this chemical film also to control the evaporation.

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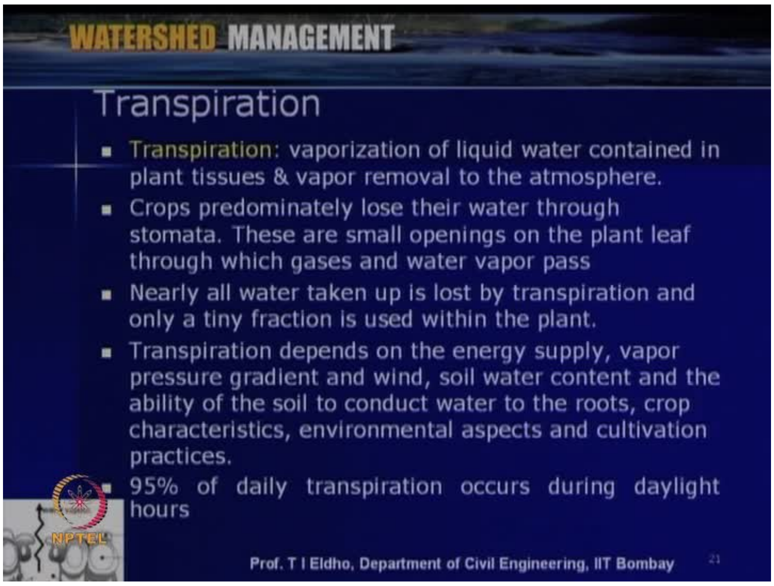

So, if you can reduce the evaporation then, the water stored in lakes or reservoirs we can use for dry periods. Then, another important hydrologic process is the transpiration. The transpiration is the vaporization of the liquid water contained in the plant tissues and the vapor removal to the atmosphere.

Since most of the land surface is covered by the vegetation then, accordingly the transpiration varies. So, crops predominately lose their water through stomata; you can see that this is a typical - the cell structure within the leaf. This so-called stomata then, these are small openings as you can see here small openings on the plant leaf through which gases and water vapor pass (Refer Slide Time: 46:33). So, nearly all water taken up is lost by transpiration and only tiny fraction is used within the plant. So, plants also take lot of water through its roots and then the photosynthesis taking place and then, so much of water vapor will be lost as transpiration through the stomata.

So, transpiration depends on the energy supply vapor pressure gradient and wind soil water content and the ability of the soil to conduct water to the roots; crop characteristics, environmental aspects and cultivation practices. Actually, most of the say transpiration would be taking place during the day time; so 95 percent of daily transpiration occurs during the daylight hours.

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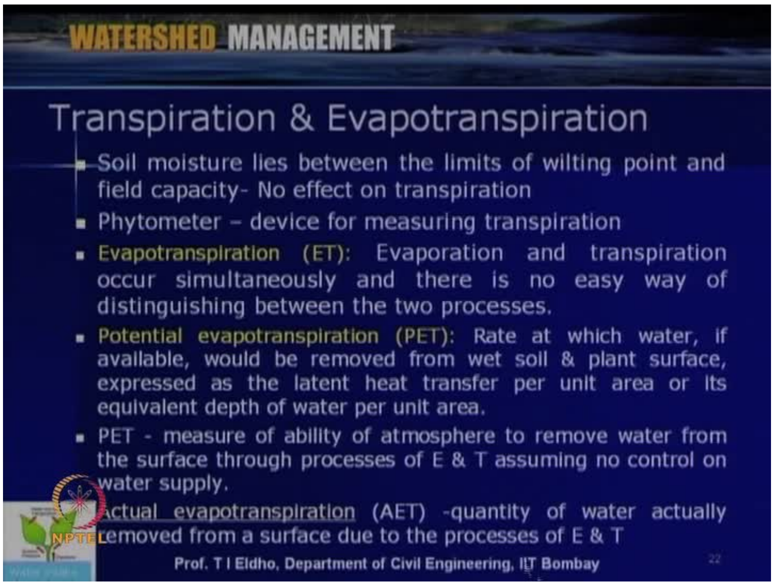

Now, most of the time it is very difficult to separate this transpiration and evaporation; so that is why we will be using a term called evapotranspiration. Soil moisture lies between the limits of wilting point and field capacity, so that there is no effect on transpiration. Now, say transpiration is concerned, there are certain equipment called phytometer which we can use to measure the transpiration. For the given plant is concerned, as I mentioned it is very difficult to separate evaporation of transpiration; so we use the term called evapotranspiration. So, evaporation, transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

So, say as far as the plant water is taken through the root and then say some water taking going as evaporation also and then transpiration also. Some of the important definitions as far as evapotraspiration is concerned: first one is potential evapotranspiration – PET. This is the rate at which water if available, would be removed from the wet soil and plant surface and expressed as the latent heat transfer per unit area or its equivalent depth of water per unit area and then this PET is the measure of ability of atmosphere to remove water from these surface through process of evaporation and transpiration, assuming no control on the water supply.

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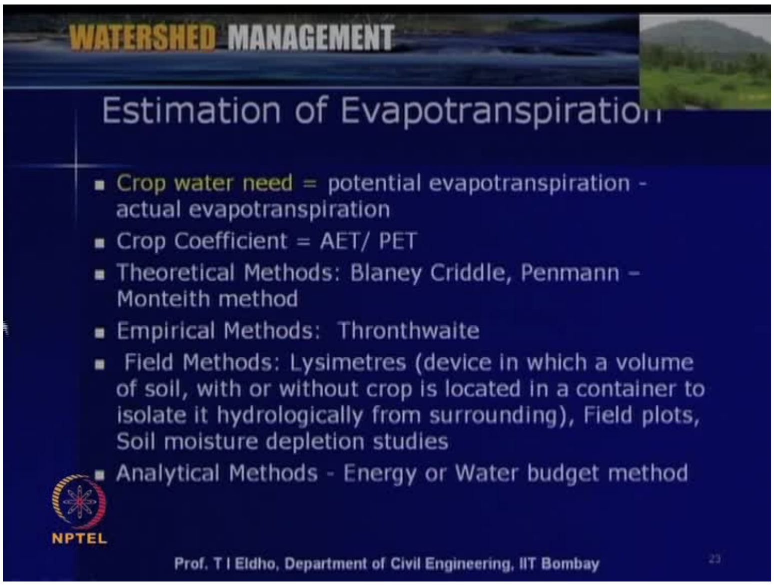

Then another important definition is so-called actual evaporation; then this is a quantity of water actually removed from a surface due to the process of evaporation and transpiration. Now, we can also estimate evapotranspiration using various equations so like the crop water need is actually potential evapotranspiration minus actual evapotranspiration and we can put a coefficient called crop coefficient which is the ratio of actual evapotranspiration to potential evapotranspiration.

So, there are various theoretical methods like a Blaney -Criddle, Penmann-Monteith method then empirical methods like a Thronthwaite method; then field methods like Lysimetres and then field plots, soil moisture depletion studies, etcetera. Also, we can use analytical methods like energy or water budget methods like evaporation. So, here also we can use the analytical method as far as the estimation of evapotranspiration is concerned.

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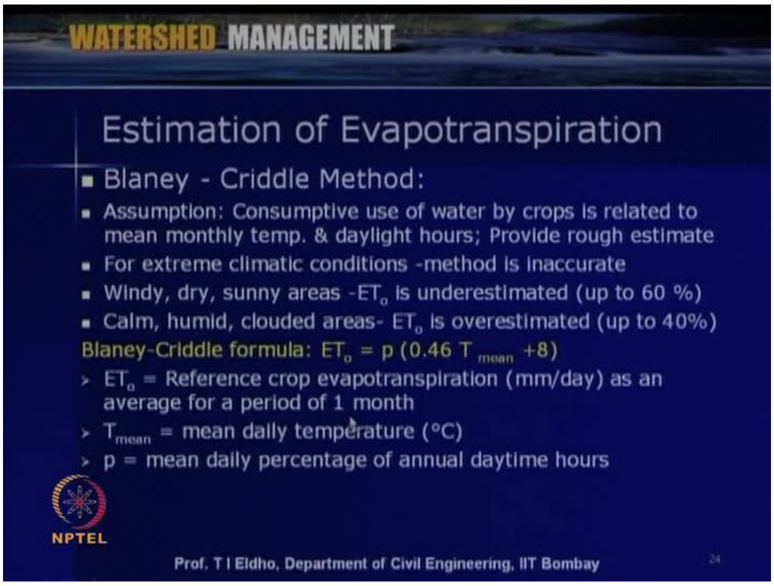

So, for example, one of the commonly used method is so-called a Blaney--Criddle method. Here, the assumption is consumptive use of water by crops is related to mean monthly temperature and day light hours. So, this provides a rough estimate; so for extreme climatic conditions - method is inaccurate; this depends upon whether the windy, dry or sunny areas. So, here the reference crop evapotranspiration is obtained by p into 0.46 t mean plus 8 where p is the mean daily percentage of hours annual daytime as far as the particular location is concerned and T mean is the mean daily temperature. Which equation we can utilize depends upon the area; this p can be identified and once the temperature is known, we can identify how much is the evapotranspiration for the given location.

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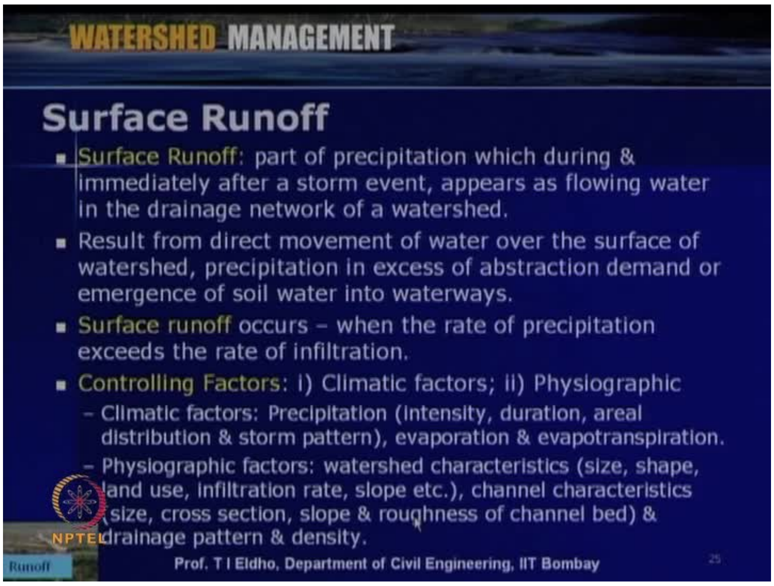

Now, after all these losses then, next step is the surface runoff taking place. So, surface runoff actually is the part of precipitation which occur during and immediately after a storm event; appears as flowing water in the drainage network on a of a watershed. This results from the direct movement of water over the surface of watershed, precipitation excess of abstraction demand or emergence of soil water into waterways.

The surface runoff generally occurs when the rate of precipitation exceeds the rate of infiltration; so that is one of the essential conditions. There are number of controlling factors which decides the surface runoff like climatic factors, like precipitation intensity, duration, aerial distribution and storm pattern; then, evaporation and evapotranspiration. Then, some of the physiographic factors like watershed characteristics, size, shape, land use infiltration rates slope etcetera then channel characteristics like a size cross sections slope, roughness of channel bed and then the drainage pattern and density of the drainage of the area which we consider.

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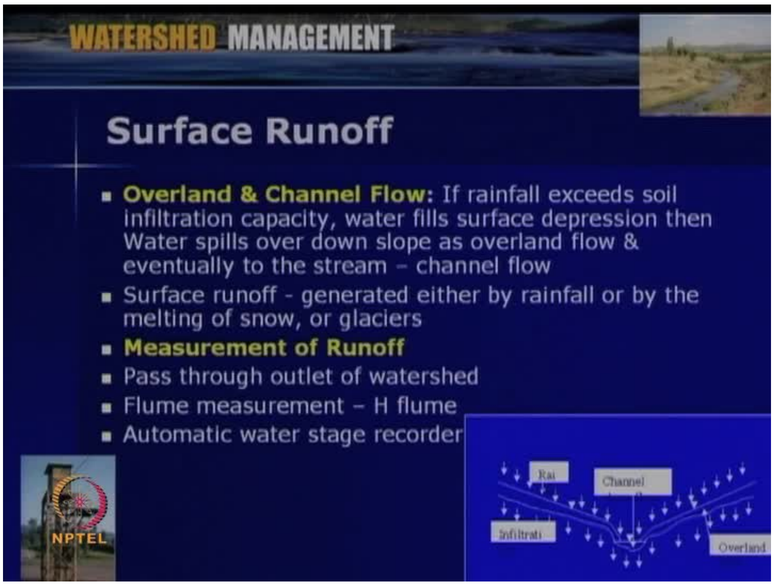

Then as far as the surface runoff is concerned, we can classify into overland runoff and then channel flow. Overland flow and channel flow: you can see that what is happening within the watershed. So, if rainfall exceeds the soil infiltration capacity, water fills surface depression then water spills over down slope as overland flow and eventually to the stream or the channel that is so-called a channel flow. So, surface runoff is generated either by rainfall or by the melting of snow or glaciers.

We can measure like, as far as the rain the runoff is concerned, in a channel we can measure using like a H flume or various automatic water stage recorder. We can use to measure the runoff what is happening within the outlet of a watershed or particular location of the stream or the river is concerned.

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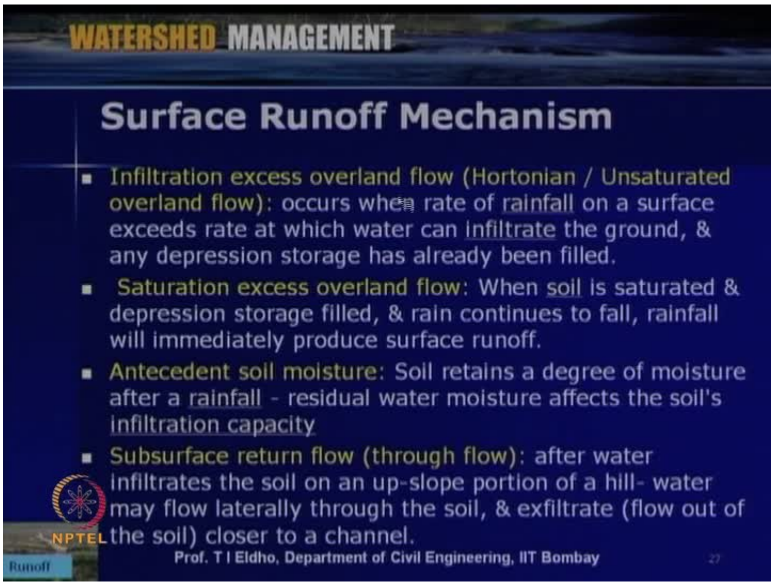

Then if we consider the various runoff mechanism then the precipitation runoff takes place when a infiltration excess or so-called excess overland flow. So, this is so-called a Hortonian or unsaturated overland flow. This occurs when rate of rainfall on a surface exceeds rate at which water can infiltrate the ground and any depression storage has already been filled; that is so-called Hortonian or unsaturated overland flow.

Then second mechanism is saturation excess overland flow. When soil is saturated and depression storage filled and rain continues to fall, rainfall will immediately produce some surface runoff. So, that is so-called a saturation excess overland flow. Then this depends, the runoff depends upon the antecedent soil moisture condition. So, soil retains a degree of moisture after rainfall. The residual water moisture affects the soil infiltration capacity. So, depending upon the antecedent soil moisture then when the next rainfall takes place, whether the fast runoff or slow runoff taking place; then finally, the subsurface retain flow, that is so-called a through flow. So, after water infiltrates the soil on up-slope, a portion of hill - water may flow laterally through the soil; so-called exfiltration flow out of the soil; so this is closer to a channel.

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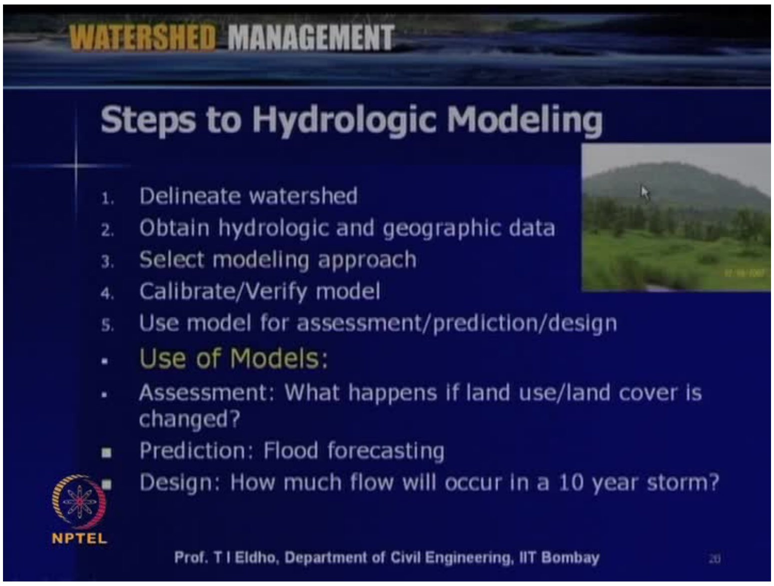

Finally, this will be also the part of runoff. Various surface runoff mechanisms are there as far as the precipitation to runoff is concerned; finally, the steps to hydrologic modeling. What we can do? We can delineate the watershed then we can identify the various hydrologic processes.

We can obtain the hydrologic and a geographic data then, select various modeling approaches as far as various hydrologic processes are concerned and then, we can estimate the various quantities then, we may go for calibration/verification and then we can use the particular models for the assessment or prediction as far as precipitation to runoff is concerned.

We can use models; we will be discussing about these various models in the next lecture. So, the model is concerned, we have to assess what happens if land use and land cover is changed so that, we have to assess. Then we can go for a prediction mode say, for the given rainfall condition of the flooding can take place. Then, we can go for design also how much flow will in 10 years storm or 5 years storm, can take place?

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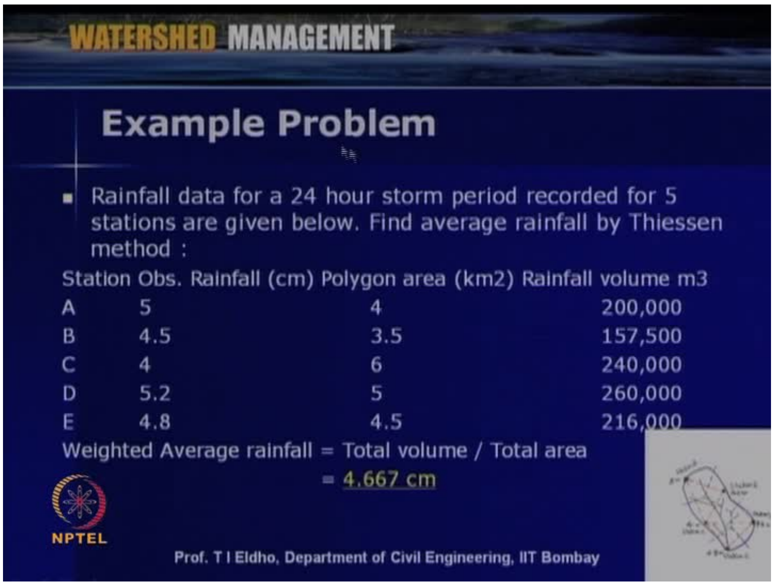

So, before closing this lecture here 2 example problems. First one is use of Thiessen method to identify the average rainfall. So, here this figure you can see that 5 rain gauge stations, the obsolete rainfalls are given here; then the polygon area we can identify as we have discussed. Then we can identify the rainfall volume; so, we can calculate the average rainfall by considering the total volume and then we can, so, total volumes obtained for station A. The rainfall multiplied by the polygon area so that will give the volume. Then we can sum it up and then we can divide by area that gives the weighted average annual rainfall; not average for the storm concerned; weighted average rainfall from that particular storm which we consider. So, that is the way - use of Thiessen polygon method.

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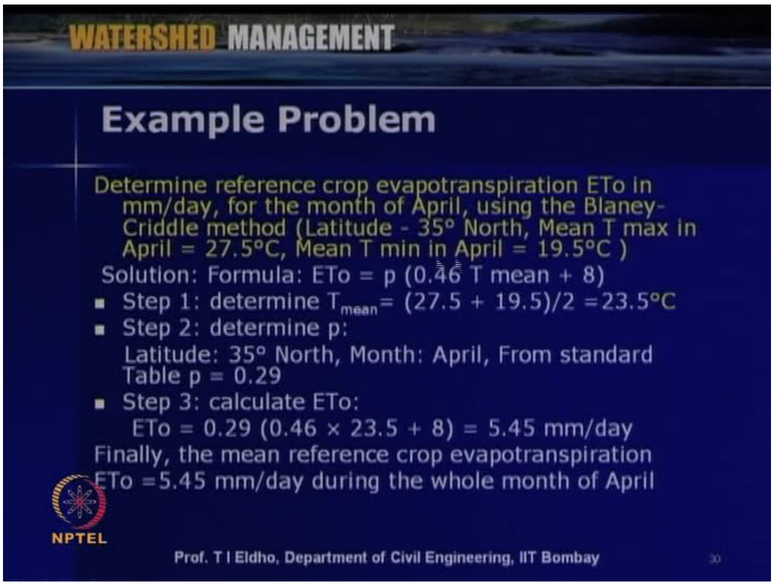

Then to calculate the evapotranspiration say, if you want to use Blaney-Criddle method, for example, temperature is given as 27.5 and 19.5 the maximum mean for April. Then we can use this Blaney -Criddle equation. Then from the given latitude, we can identify the p value as 0.29 and then we calculate the evapotranspiration. So, reference crop evapotranspiration by using this equation; so this shows how we can use the Blaney -Criddle method.

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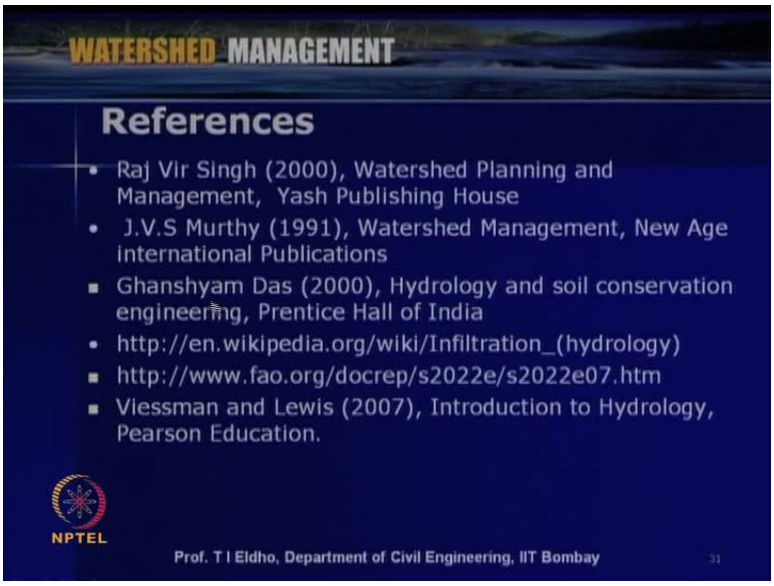

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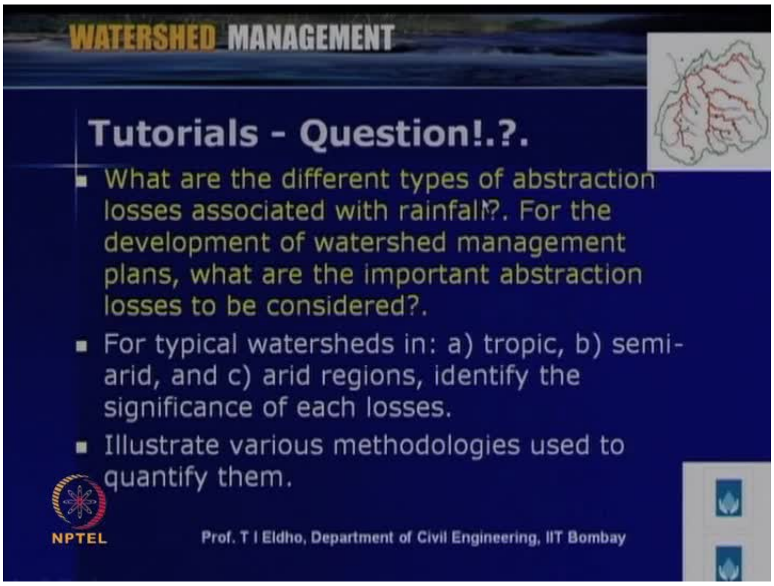

So, these are some of the important references used for today's lecture. Based upon this, books and websites, then before closing the lecture, one tutorial question: what are the different types of abstraction losses associated with the rainfall for the development of watershed management plans? What are the important abstraction losses to be considered?

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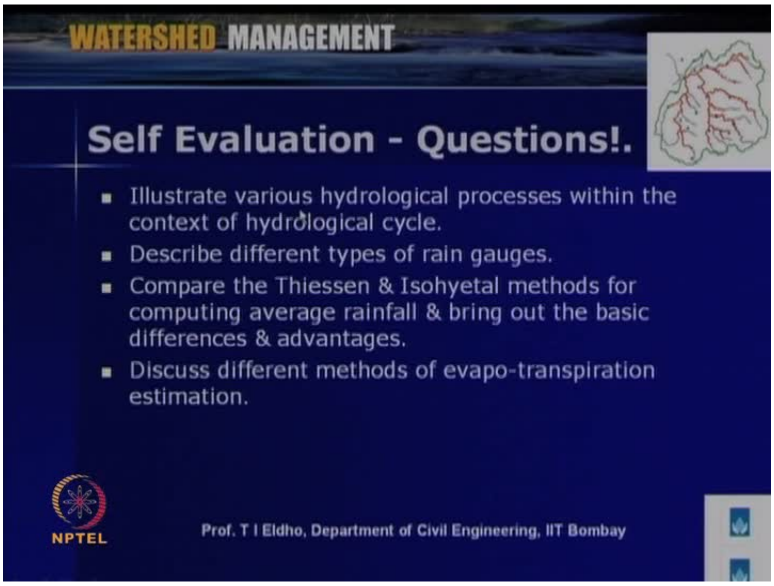

So, before the type typical watershed we can, tropic, semiarid or arid regions; identify the significance of each losses then, illustrate various methodologies used to quantify them, then few self evaluation questions like illustrate various hydrological processes within the contest of hydrological cycle. Then, describe different types of rain gauges, compare the Thiessen Isohyetal method for computing average rainfall and bring out the basic differences and advantages.

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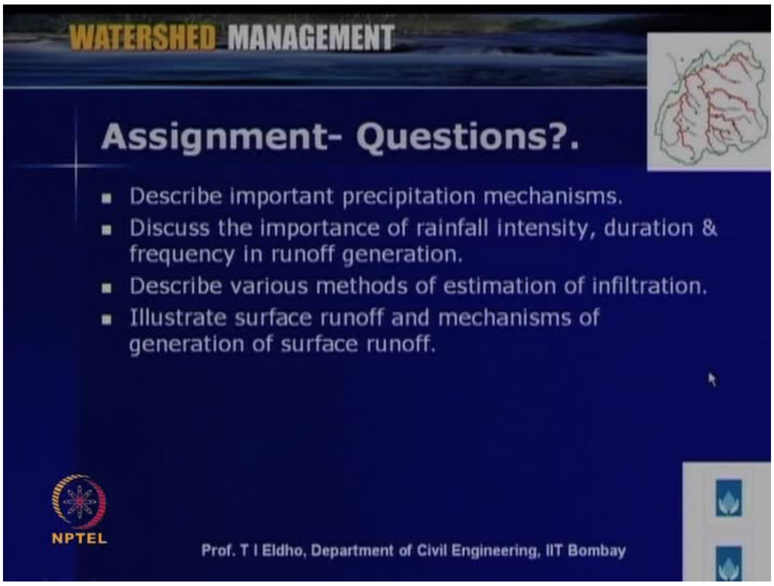

Then discuss different methods of evapotranspiration estimation and few assignment questions like, describe important precipitation mechanisms, discuss the importance of rainfall intensity, duration and frequency in runoff generation. Then, describe various methods of estimation of infiltration; then illustrate surface runoff and mechanisms of generation of surface runoff. So, all these related questions today's lecture we have discussed the details. Once you go through the lecture, we can answer all these questions.

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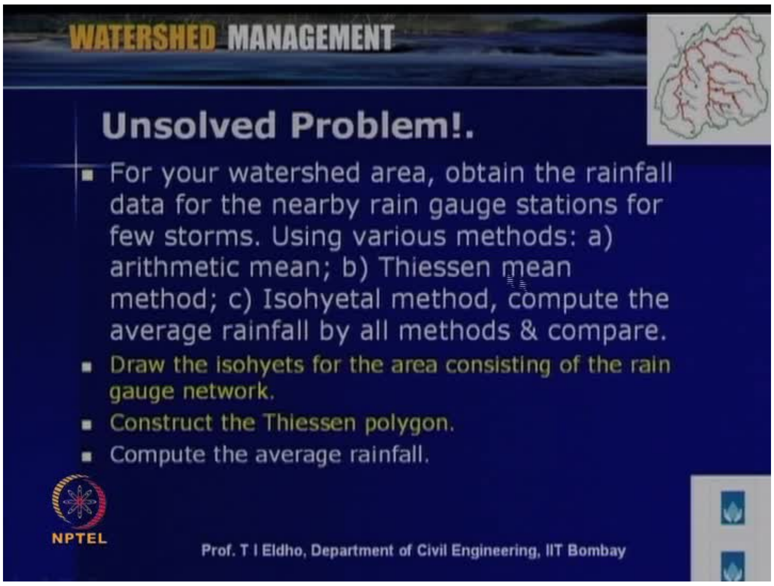

So, now one unsolved problem for your watershed area: obtain the rainfall data for the nearby rain gauge stations for few storms and using various methods like arithmetic mean, Thiessen mean method, Isohyetal method, you can compute the average rainfall by all methods and compare. We can identify say each the advantages and limitations of each method. Once you get the rainfall, that you can draw isohyets for the given area and construct the Thiessen polygon as we discussed earlier; then we can compute the average rainfall from the given storm conditions.

Now, based on today what we have discussed, is the various hydrologic processes. Now, we have seen various equations for various… how to estimate the various processes now based upon this? now, in the next lecture we will discuss the hydrologic modeling as far as the precipitation to runoff. So, we will discuss in detail the various models and then how we can go for watershed modeling based upon these models.

Thank you very much