Engineering Hydrology
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Lecture – 31
Summary of Module II

Hello all, welcome back. In the previous lecture we were discussing about evapotranspiration and also, we have solved one numerical example related to Penman's equation. So, there we have completed the module on atmospheric hydrology, atmospheric water, that is we have completed the second module.

Now let us have the summary of this second module, just will go through the things which we have covered in previous couple of lectures. Atmospheric water, you all know, it is the study of water which is present in the atmosphere.

In the atmosphere mainly, it is present in the form of vapor but water is present in liquid form and also in the form of just like ice crystals also it is present in atmosphere. But the major form is in the form of vapor. So, when we started with atmospheric water, we have started with the water vapor dynamics, for understanding that we have gone through some of the atmospheric parameters.

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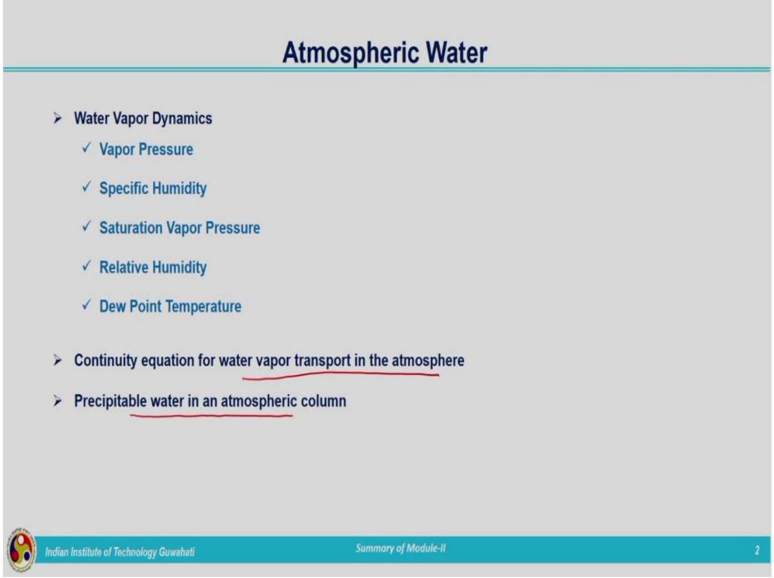

So, we have covered the details related to water vapor dynamics and understood the atmospheric parameters such as water vapor, specific humidity, saturation vapor pressure, relative humidity, dew point temperature and we have come up with the continuity equation which is representing the water vapor transport in the atmosphere and then we have moved to the precipitable water present in the atmospheric column.

So, different parameters related to atmospheric water we have studied, such as the vapor pressure, specific humidity, all those expressions we have seen and the interrelationship also we have found out and temperature pressure variation as we go up into the atmosphere, how it is varying? The pressure and temperature reduce as altitude increases and those things we have already seen in the beginning classes of atmospheric water.

After that, we have developed the equation related to it that is the continuity equation related to vapor transport. How the vapor transport is taking place in the atmosphere by making use of the Reynolds Transport theorem. Then we have moved on to the topic related to precipitable water which is present in the atmospheric column.

We have considered a cylindrical atmospheric column and how much is the quantity or mass of the water vapor which is present in that particular column which can be precipitable onto the earth. So, that expression also we have derived.

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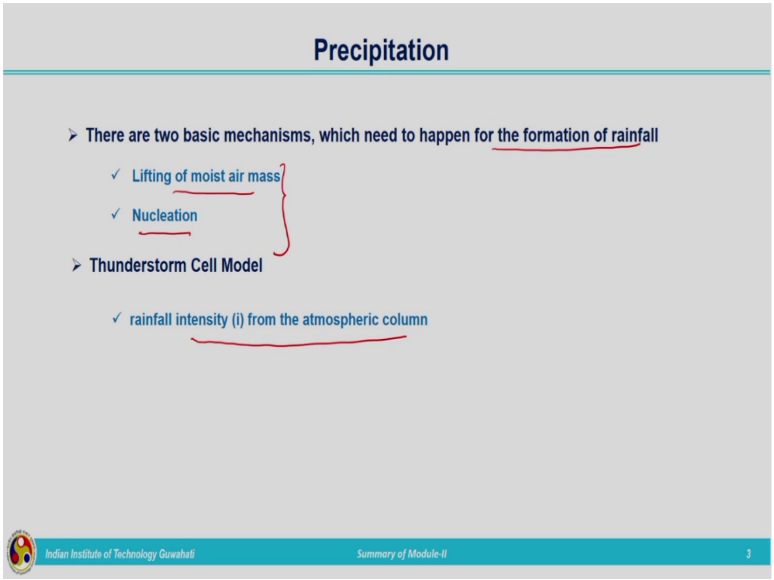

And after completing that we have moved on to precipitation. So, when we talk about precipitation there are two mechanism which need to happen for the formation of rainfall those are lifting of moist air mass and second one is the important process termed as nucleation.

So, these two processes, mechanisms should take place then only we will be experiencing the precipitation. Whatever be the form of precipitation, for precipitation to take place we need to have the lifting of moist air mass from the water body, that is when the process of evaporation takes place, water from the water body will be converted to water vapor and this water vapor should be continuously lifted up, removed from that particular location. This is taking place due to wind action. Once it is lifted up, temperature will be reducing and after that the cloud formation will be taking place and nucleation of the clouds will be leading to the condensation and then we will be experiencing the precipitation. So, these two processes are very, very important as far as precipitation is concerned.

After understanding the mechanism behind the formation of precipitation that is this lifting up of air mass and the nucleation, we have moved on to thunderstorm cell model, convective cell. Thunderstorm cell model was a convective cell which we have considered and we have considered the steady state convective cell.

In that what we have studied? We could find out expression for rainfall intensity, the intensity of rainfall from an atmospheric column was obtained by making use of the principle of thunderstorm cell model. In this part we have assumed that the movement of air mass is taking place due to convective action or convection.

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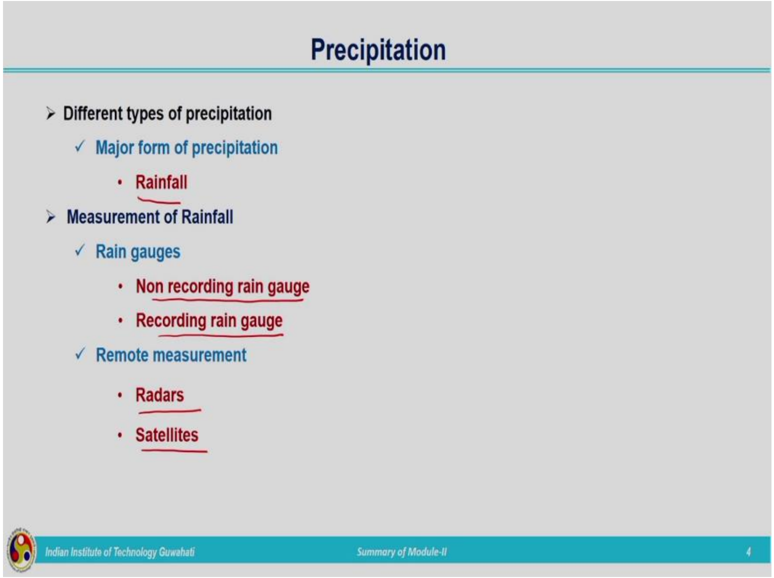

Then we have moved to different types of precipitation. Major form we found that it is rainfall and then we have moved on to the measurement of rainfall and rainfall also we have understood one particular terminology known as fall velocity. Fall velocity is the velocity with which the droplets are falling.

So, depending on the air velocity and the velocity with which it is falling, it may get taken up and also it can come down. So, it is very important to understand what is meant by fall velocity and an expression also we have found out for that. So, if the fall velocity is more to overcome the wind velocity so it will be falling down and we will be experiencing precipitation.

And after that we have moved on to different measurement methodologies. When we are talking about rainfall, mainly the terms which are coming into our mind is measurement of rainfall by means of rain gauges. Different types of rain gauges we have seen, non-recording rain gauges and also recording rain gauges.

Earlier days we were having non recording rain gauges and later now all the non-recording rain gauges have been replaced by the recording type of rain gauges. So, automatically the rainfall values will be recorded. These rain gauges will be giving you the rainfall which is occurring at a particular point so it is also referred as the point measurement of rainfall.

Rain gauges are installed at a particular location, we will be collecting the data from there and that is a representative value corresponding to that particular location. But what we do, we will assume that surrounding to that particular rain gauge the same rainfall is experienced. There are certain ways to measure remotely also, certain locations are there where we cannot install rain gauges such as mountainous region, oceans, areas where the water bodies are present. So, those places we will not be able to install rain gauges and at remotest places we will not be able to install rain gauges. In such cases, we can make use of remote measurement of rainfall data. How we have we can do this remote measurement, that we have seen through the case with the radars and satellite. Satellites and radars are giving us the spatial distribution of rainfall even if the location is not reachable it does not matter, we can make use of this remote measurement technologies for making use of the rainfall data. But the rainfall which is obtained from these remote measurements such as radars and satellites need to be corrected for so many errors, so many bias correction techniques have to be applied before utilizing it for a certain study related to hydrologic analysis. So, majority cases for accurate analysis we will be depending on the rain gauge data.

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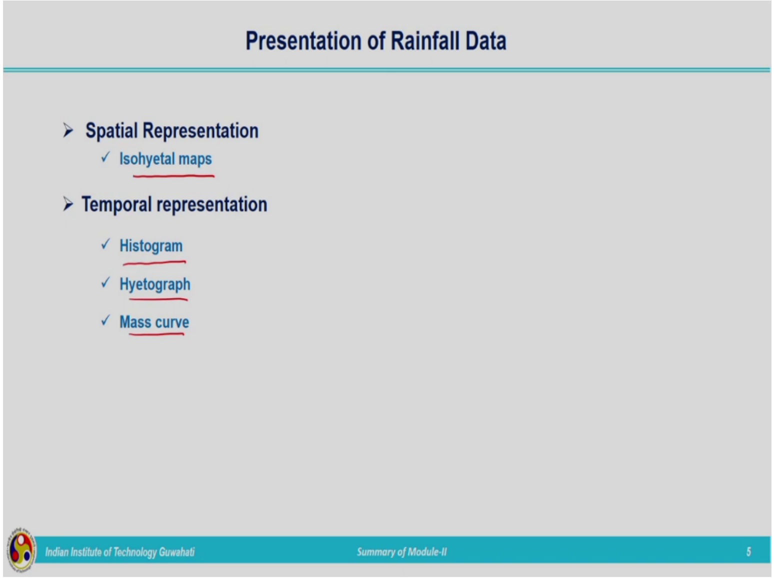

Then we have moved on to the representation or presentation of rainfall. So, rainfall representations in terms of spatially and also temporally we have seen. In the case of spatial representation, we were making use of Isohyetal maps. Isohyets are the line representing rainfall having equal depth.

Then coming to temporal representation, we have seen three representations, histogram, hyetograph and mass curve. In the case of histogram, rainfall depth versus time was marked in terms of bar chart. So, this will be giving us idea about at a particular time how much was the rainfall depth. And then we have seen hyetograph, hyetograph was giving us the details related to rainfall intensity versus time. How much is the intensity of rainfall which has occurred at a particular time. So, details related to rainfall depth and rainfall intensity can be obtained from histogram and hyetograph. Then the third one which we have seen was mass curve. Mass curve is the representation of rainfall with respect to time only. But in the case of mass curve, we were plotting the cumulative rainfall depth. Cumulative rainfall depth that is from the beginning to end, the rainfall is added up. Cumulative value is plotted with respect to time. So, that way we will get the total amount of rainfall at the end of the time period or in between the time period. How much rainfall we have experienced up to that particular time can be obtained from the mass curve and we have found that mass curve is always an increasing curve because it is representing the cumulative rainfall depth and if there is no rainfall it can move as a straight line only, parallel to x-axis. It cannot come down and then again rainfall is experienced then it will be again an increasing curve. So, these ways that is

Isohyetal and other three methods histogram, hyetograph and mass curve, these were utilized for the presentation of rainfall either spatially or temporarily.

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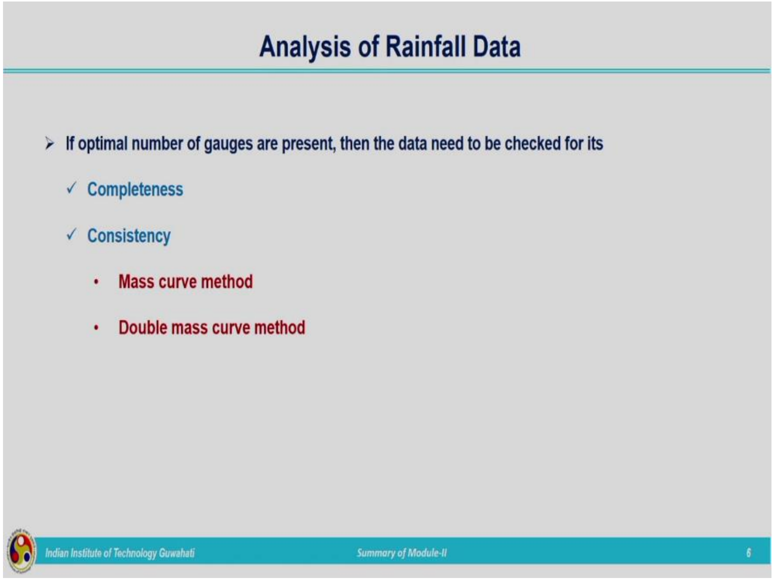

After that we have moved to analysis of rainfall data. So, I have told you, rain gauges will be giving you point rainfall measurement, point data and for getting the spatial representation of rainfall data, we need to have network of rain gauges. So, in a particular catchment itself we will be having certain number of rain gauges present. So, then optimum number of rain gauges required within a catchment we have seen by making use of certain statistical principles. So, that way we can find out whether the number of rain gauges present in the catchment is sufficient, if it is not sufficient we can provide extra number which are required.

So, if sufficient number of rain gauges are there and after that we are getting rainfall data from all these rain gauges. Then before using it for analysis, we need to do certain checks with the data. So, these checks are related to completeness of the data and consistency of the data. Completeness of the data means whether the rainfall data which we have collected from the rain gauges or which we have collected from the corresponding authorities which are dealing with the rain gauge data. In India we will be making use of the data from Indian Meteorological Department. So, whether the data is complete or not we will be checking the completeness of the data series. If there are certain missing data there are different methods, we have found how to fill up the gap or how to find out the missing data and regarding consistency whether the data series which we have collected for hydrologic analysis is consistent or not, so that consistency check is done by means of mass curve method and double mass curve method.

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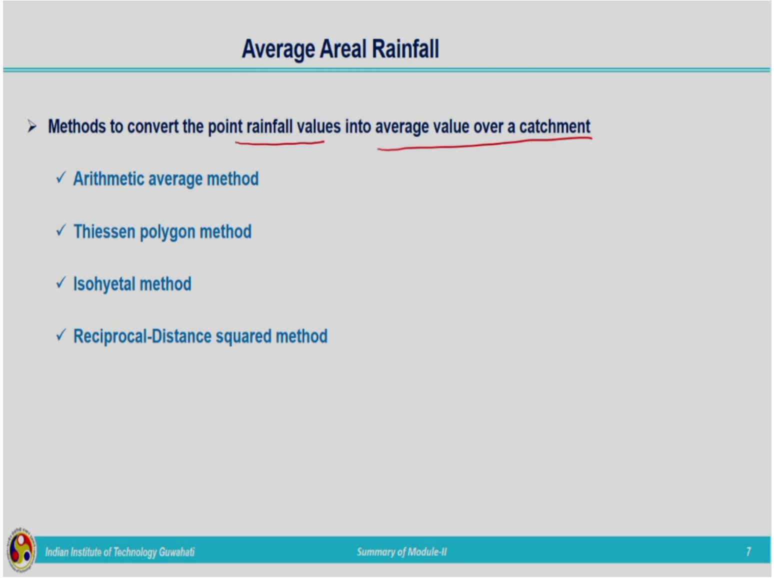

Then we have moved on to average aerial rainfall. We have made use of different approaches, one is Arithmetic average method, Thiessen polygon method, Isohyetal method and Reciprocal-distance squared method. So, these are the four different methods which we have used when we are having the spatial distribution of rain gauges or the point rainfall data are converted into average value over a catchment by means of these techniques.

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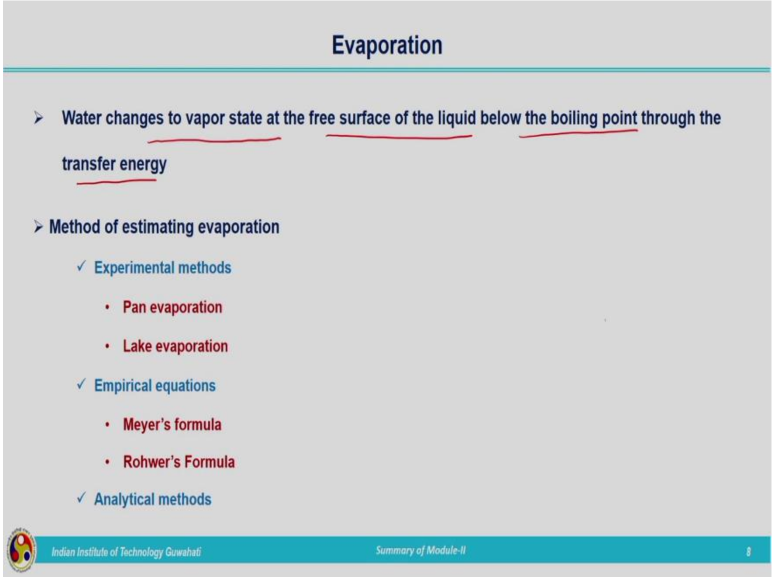

Then we have moved on to the topic evaporation. Different processes related to atmospheric water we were discussing, out of that initially we have started with the precipitation. Precipitation mainly we were focusing on rainfall. So, rainfall mechanism, formation of rainfall, then measurement of rainfall, analysis of rainfall, presentation and average representation of rainfall, after that we have moved on to the second process related to atmospheric water that is evaporation.

So, evaporation is the process by which water changes to its vapor state at the free surface of the liquid below the boiling point through the transfer of energy. So, at the time of evaporation, the temperature will not be at boiling point. It will be below the boiling point and we have understood the term latent heat of vaporization in that context and different ways of estimating evaporation we have seen. Experimental methods, empirical methods and also analytical methods. Experimental methods incorporated, pan evaporation and lake evaporation. Experimental methods when we were doing, we were making use of standard pans, different pans with standard dimensions are available and by making use of that we have found out the quantity of water getting evaporated from the pan.

So, that measurements, how much we will be filling the water up to certain level and the lowering of the level will be measured, that is representing the evaporation of water which is taking place at that particular location and once the pan evaporation is calculated for finding out the lake evaporation, we have multiplied that particular value by means of a pan coefficient. Each and every evaporation pan will be provided with standard pan coefficient values. So, corresponding values will be taken and that will be multiplied with the evaporation value which is measured at the field by means of evaporation pans. Why we are multiplying this evaporation depth which is measured by using the pan coefficient because we cannot expect the same value of evaporation which is measured here in the case of pans to happen in the case of lakes or the water bodies.

Different factors we have seen while explaining evaporation which are affecting the process called evaporation. So, depth of the water body, area of the water body and quality of water, so all these factors are influencing. So, we cannot expect the same evaporation to take place from the water body as we have measured in the case of evaporation pans. That is why we are multiplying with a pan coefficient. It varies between 0.7 to 0.9, 0.95 that way depending on the different pans the values will be different.

After the explanation of experimental methods, we have moved on to empirical methods. Empirical methods which we have covered are Meyer’s formula and Rohwer’s formula. These Meyer’s formula and Rohwer’s formula we have learned after seeing the analytical methods because under the topic of analytical method, we have seen the important factors. We have prioritized which are the important factors influencing evaporation and based on those factors the analytical methods have been derived. So, when we were looking into the empirical formula, we were in a position to compare with the analytical methods because empirical formula or empirical equations are derived based on the experimental results obtained after conducting the pan evaporation experiments. So, this thing correlated with the analytical equations we can find out that empirical equations also make use of different factors which are influencing evaporation.

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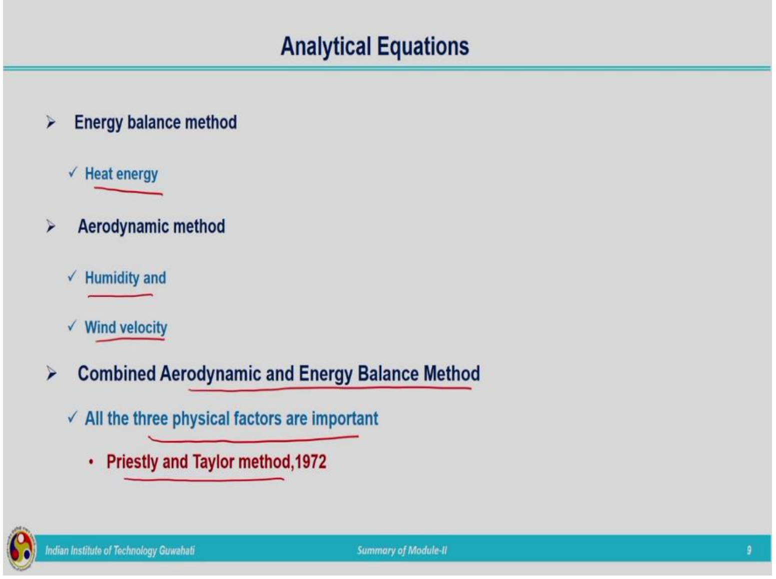

Let us see what are the different analytical methods derived. One is based on energy balance method, second one was aerodynamic method and third one combined aerodynamic and energy balance method. We have not separately derived the combined method, we have made use of the energy balance method and the aerodynamic method.

So, in the energy balance method, the important factor which was influencing evaporation was considered as heat energy. We know the water is getting evaporated into the atmosphere by absorbing the heat energy from sun. So, the main predominant factor which is influencing evaporation is considered as the heat energy in the case of energy balanced method. And we have made use of Reynold's Transport Theorem and by making use of that we have derived the continuity and momentum equation and combined together to get the final form of energy balance equation. And after that we have moved to the second method that is the aerodynamic method. In the aerodynamic method we have considered the wind velocity and also humidity. It is pointed out that, humidity is also an important factor. Humidity which is present in the atmosphere. It is a main factor which determines how much quantity of water vapor can be added to the atmosphere again. So, we cannot ignore that and the other factor is that how the vapor transport is taking place by means of wind velocity. If the water vapor which is produced is just stagnant above the water body more and more evaporation is not possible because more and more water vapor to be accommodated in the air means the initially evaporated vapor should get transported. So, for that the effect of wind velocity also needs to be incorporated.

So, in the case of aerodynamic method, two factors incorporated were humidity and wind velocity. And from studies it is found that, all these factors that is all these three factors: heat energy, humidity, wind velocity all these are very important. So, we cannot ignore one, we cannot tell that one is above the other.

So, that is why a combination method is also developed. So, combined aerodynamic and energy balance method which will be giving you accurate value of the evaporation, that is it is incorporating all the major factors which are influencing evaporation that is heat energy, wind velocity and specific humidity. And one common method which we have found is Priestly and Taylor method. In Priestly and Taylor method, these researchers have conducted so many experiments and found that they have calculated the evaporation based on the energy balance method and aerodynamic method and found that the evaporation taking place due to aerodynamic method is almost 30 percentage of the evaporation which is taking place due to energy balance method. So, they have proposed a new equation by incorporating a 0.3 factor for the evaporation component coming from the aerodynamic method. So, that way they have given us a compact simple expression for finding out the evaporation. So, that much about the measurement of evaporation.

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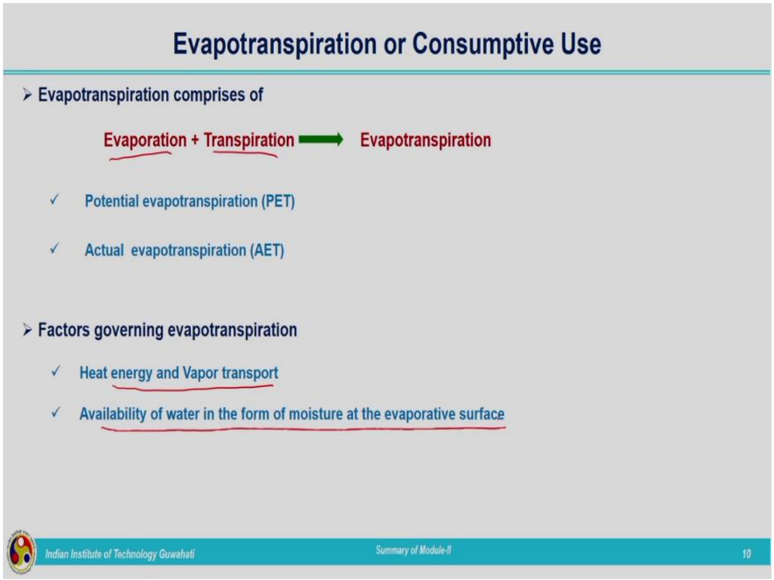

Then we have moved on to evapotranspiration or consumptive use. So, it is the combination of the evaporation and transpiration that is considered as evapotranspiration and when we were discussing about evapotranspiration we have seen two terms are utilized, one is the potential evapotranspiration and second one is the actual evapotranspiration. Because sufficient amount of water is available for the plants or soil moisture is available in the soil for the plants to extract. So, that time what is the evapotranspiration taking place that is what is termed as the potential evapotranspiration. But in actual conditions, always there may not be maximum amount of water available in the root zone. So, actually what is the evapotranspiration taking place that is termed as actual evapotranspiration. Actual evapotranspiration will be less than that of potential evapotranspiration. Potential evapotranspiration is the maximum that can take place because maximum amount of soil moisture will be available in the root zone.

So, these two we have seen and then we have gone to understand the factors governing evapotranspiration. Which are the factors influencing evaporation, those common factors are influencing evapotranspiration also, that is heat energy and the vapor transport. And one more factor which need to be taken into account is the availability of water in the form of moisture at the evaporative surface.

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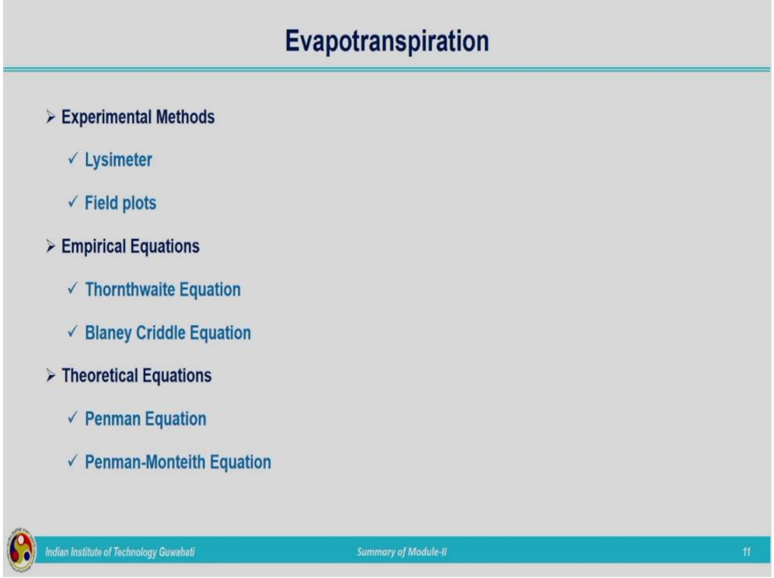

After that we have seen different methods of estimating evapotranspiration. First one is experimental, second, we have seen empirical and then theoretical equation. Theoretical or analytical equations. Experimental methods we have seen Lysimeter and Field plots. And coming to empirical equations, different empirical equations we have seen: Thornthwaite equation and Blaney Criddle equation.

And then we have moved on to theoretical equations, we have seen Penman Equation and Penman-Monteith equation and after that one numerical example we have solved by making use of Penman equation for the determination of evapotranspiration. There we stopped this module on atmospheric water. So, whatever processes related to atmospheric water that is precipitation, evaporation and evapotranspiration, these are the major hydrological processes related to atmospheric water taking place in the atmosphere.

So, in detail we have seen all these processes, mechanism, measurement, everything we have seen and now we are having the idea about different hydrologic processes related to atmospheric water. So, there ends this chapter or the module on atmospheric water. So, now I think it is time for me to wind up this module. Thank you very much.