Engineering Hydrology
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Lecture – 29
Evapotranspiration

Hello all, welcome back. In the couple of few lectures, we were discussing about the topic of evaporation. We have seen different methods of estimation of evaporation, experimental method, empirical methods and also analytical methods.

In today's lecture, we will move on to evapotranspiration. It is the combination of evaporation and transpiration. So, there will be similarities in the equations, which we will be using for the determination of evapotranspiration. Let us see first, what is meant by evapotranspiration after that we will move on to the methods of estimating evapotranspiration.

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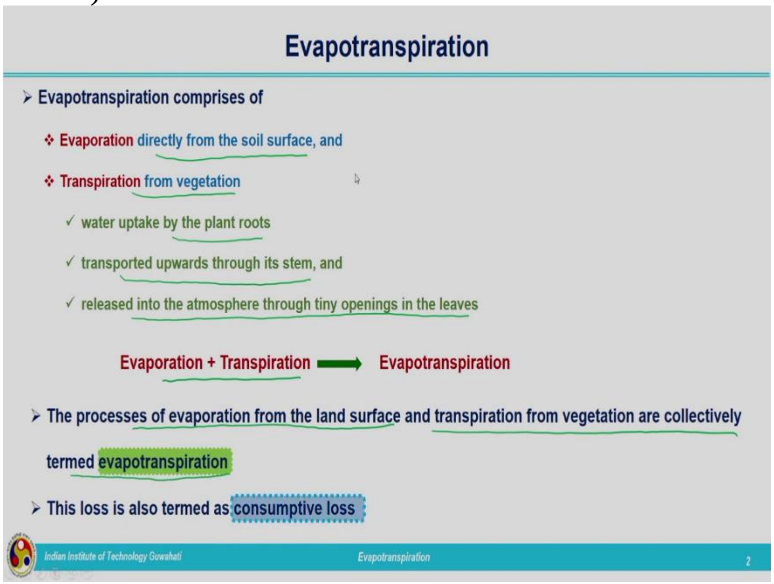

Evapotranspiration is the process by which water is lost to the atmosphere from the vegetated surface. So, it is the combination of evaporation directly from the soil surface and also transpiration from the vegetation. So, in detail we have already covered, what is meant by evaporation? What are the factors affecting evaporation? And the methods of estimation of evaporation?

Now coming to transpiration, what is meant by transpiration? Transpiration is the process by which the plants will be extracting water from the soil moisture, that is the water which is present beneath the ground surface. Some amount of water is present in the soils, that is what is termed as soil moisture.

So, roots of the plants will be extracting water from this soil moisture, the amount of water, which is extracted by the roots will be transported through the stem to the branches and from the branches to the leaves. And after that through the tiny pores, which are present in the leaves, some amount of water will be lost to the atmosphere. This loss of water from the tiny pores of leaves, which are present in the plants are termed as the process of transpiration.

So, once the roots extract water from the soil moisture, it will get transported upward through the stem. And after that it will be transported to the branches of the plants and towards the leaves. Then it is released to the atmosphere through the tiny openings in the leaves. This process is termed as transpiration.

So, evapotranspiration is the combination of evaporation and transpiration. Together we will be calling it as evapotranspiration. So, we can define it like this, the processes of evaporation from the land surface and transpiration from vegetation are collectively termed as evapotranspiration. So, two processes are coming into picture, one is the evaporation and also transpiration.

So, this is also termed as consumptive loss. Sometimes we will be calling evapotranspiration as the consumptive loss, that is the loss from the vegetative surface and also from the plants.

Now, coming to the factors affecting evapotranspiration. Since this is a process which is the combination of evaporation and transpiration, different factors which are influencing evaporation also will be influencing evapotranspiration. In addition to that whether there will be any other factor as far as evapotranspiration is concerned. Let us see that.

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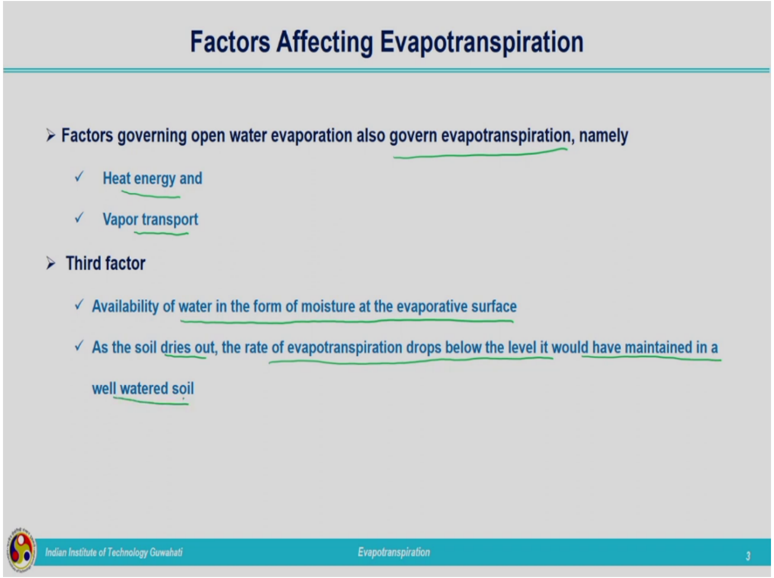

So, the factors governing open water evaporation also govern the evapotranspiration. That is, we have already seen heat energy is an important factor, then comes the vapor transport. These two we have considered along with the wind velocity while calculating the evaporation. Now, the third factor which needs to be incorporated in the case of evapotranspiration is the availability of water in the form of moisture at the evaporative surface. So, there should be some amount of moisture or water present in the evaporative surface, that is also responsible for the process termed as evapotranspiration.

So, as the soil dries out, the rate of evapotranspiration drops below the level, it would have been maintained in a well-watered surface. If the amount of moisture is very, very less or the soil is dry, then the rate of evapotranspiration taking place will be very, very less compared to a well-watered vegetated surface.

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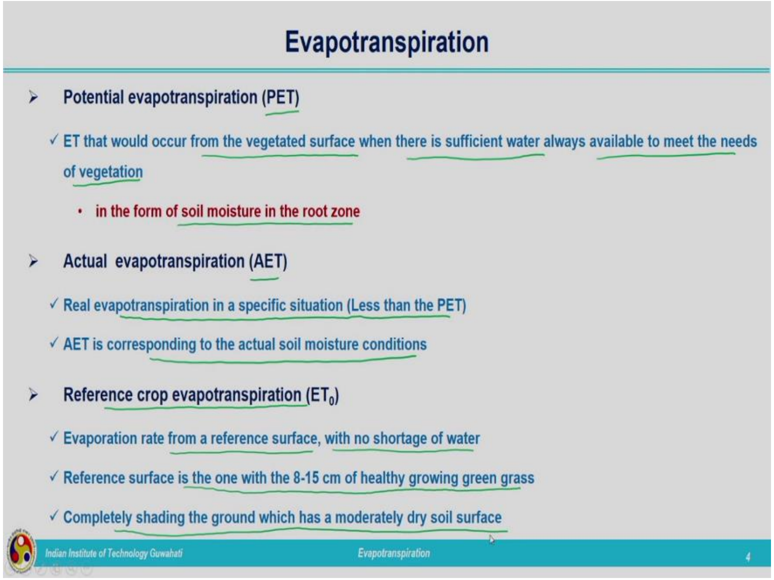

At this context, we need to have an understanding about two terms related to evapotranspiration depending on the availability of moisture in the root zone or in the soil. So, those two terms are potential evapotranspiration and actual evapotranspiration. So, two terms potential evapotranspiration and actual evapotranspiration, we will be representing it by PET and AET.

So, what is the difference between these two? Both are evapotranspiration only. Potential evapotranspiration is the evapotranspiration, that would occur from the vegetated surface when there is sufficient amount of water available to meet the needs of vegetation.

If we are providing sufficient amount of water or abundant quantity of water to the plants, the evapotranspiration which is taking place at that time in the presence of abundant quantity of water is termed as potential evapotranspiration. That is the maximum amount of evapotranspiration, which can be taken place from a vegetated surface.

So, the water which is provided to the vegetated surface will be in the form of soil moisture in the root zone. That is transpiration is mainly due to the water or the moisture absorbed by the roots from the soil moisture.

Now, coming to actual evapotranspiration, it is the real evapotranspiration in the particular vegetated surface, that will be less than potential evapotranspiration. Imagine a surface always there will not be abundant quantity of water. Sometimes depending on the seasons, the water availability in the form of soil moisture will be varying. So, always it will not be at a maximum level. So, depending on the actual prevailing soil moisture how much is the evapotranspiration taking place, that is termed as the actual evapotranspiration.

AET is corresponding to the actual soil moisture conditions and related to this another term also we should know, that is the reference crop evapotranspiration. Usually, we denote it by means of ET_0, reference crop evapotranspiration. What is it? It is the evaporation rate from a reference surface with no shortage of water. A surface is considered as the referenced surface, vegetated surface will be having grass planted over there, from that surface with the abundant quantity of water provided, what will be the evapotranspiration taking place, that is the reference crop evapotranspiration.

So, the reference surface is the one with 8 to 15 centimetres of healthy growing green grass. Green grass will be planted there, it will be around 8 to 15-centimetre height and it will be provided with sufficient amount of water. Then what will be the evapotranspiration taking place, that is considered as the reference evapotranspiration.

So, if we are having the value corresponding to reference evapotranspiration, that multiplied by a certain coefficient will be giving you the potential evapotranspiration at a particular location with a specific crop. That particular coefficient, which we are multiplying with the crop evapotranspiration is the crop coefficient. We will come to it. So, the importance of crop evapotranspiration is that, it is from a standard vegetative surface, which is having a vegetated growth, that is of 8 to 15 centimetres green grass planted on a surface with sufficient amount of water.

So, this grass is growing in such a way that it will be completely shading the ground, which has a moderately dry soil surface. There are certain norms for providing water to it, weekly we will be providing water based on that evapotranspiration will be calculated.

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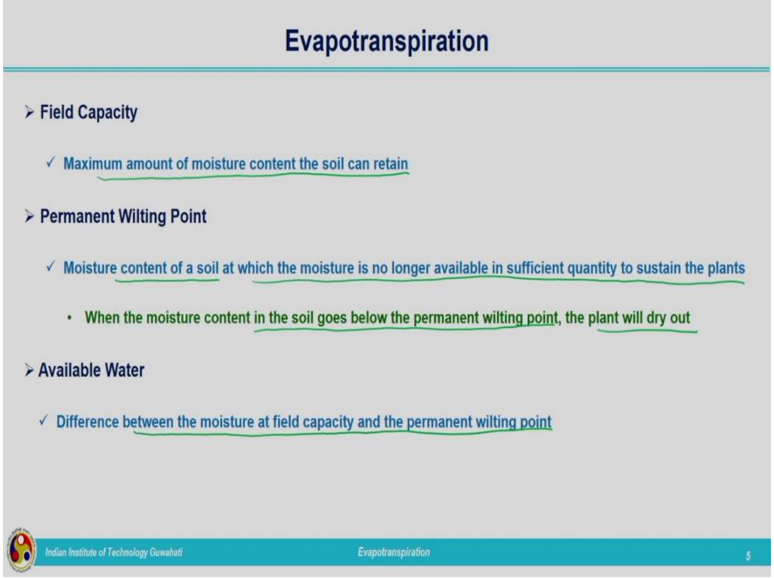

Related to this we need to have knowledge about two different terminologies, one is field capacity and the second one is permanent wilting point. Based on this field capacity and permanent wilting point, we can quantify how much is the available water. What is meant by field capacity? Field capacity is the maximum amount of moisture content the soil can retain. We will be watering the surface, vegetated surface will be watering frequently and based on that the water will be stored within the soil, which is termed as the soil moisture.

So, the maximum amount of soil moisture, which can be stored within the soil is termed as the field capacity. Beyond that if we are watering again and again, that water will not be stored within the soil, it will be drained out.

Second term is the permanent wilting point. It is the minimum amount of moisture that is the moisture content of a soil at which the moisture is no longer available in sufficient quantity to sustain the plants. Minimum amount of moisture content is there within the soil, that is these plants will not be able to extract water at that level of moisture content. That is termed as the permanent wilting point. At the moisture content corresponding to permanent wilting point and if the moisture content is reduced beyond that value, the plants will die out, because it will not be having capability to extract water from the soil.

Coming to available water, it is nothing but the difference between the moisture at the field capacity and the permanent wilting point. That is the difference between the maximum amount of moisture content and the minimum which can be retained within the soil. So, minimum it can go beyond then the plants will be drying out, maximum if we are watering again and again extra water will not be stored within the soil, it will be drained off. The difference between the field capacity and the permanent wilting point is termed as the available water to the plants.

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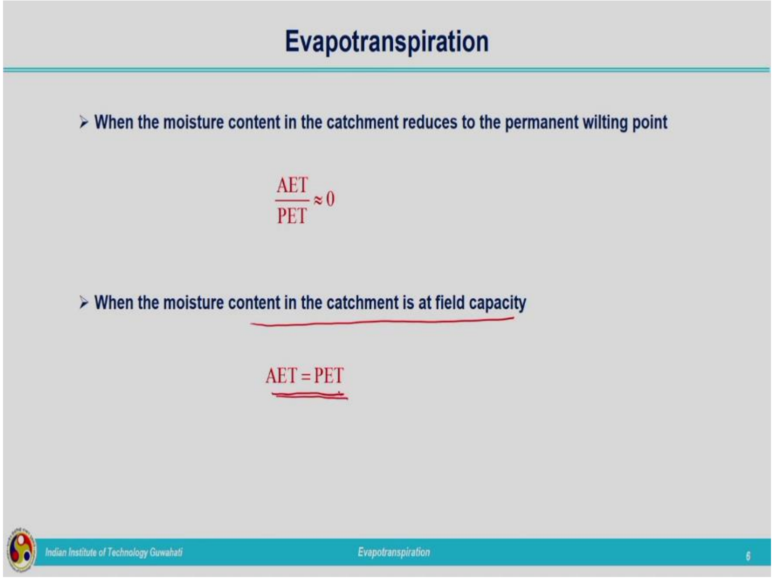

When the moisture content in the catchment reduces to permanent wilting point, if you are relating the potentially evapotranspiration and the actual evapotranspiration, we can tell that

$$\frac{AET}{PET} \approx 0$$

that is the actual evapotranspiration divided by potential evapotranspiration will be, approximately equal to zero. Because at the moment of permanent wilting point, there will not be any evapotranspiration taking place. That will be approximately equal to zero. Actual evapotranspiration reduces to zero and the potential evapotranspiration is related to field capacity. So, that ratio will be approximately equal to zero.

Now, take the condition in which we are having sufficient amount of water present in the soil. When the moisture content in the catchment is at field capacity, then AET divided by PET, when we compare the actual evapotranspiration and potential evapotranspiration both will be same, i.e.,

$$AET = PET$$

Because it is having sufficient amount of moisture present in the soil. So, the actual evapotranspiration will be equal to the potential evapotranspiration at the field capacity.

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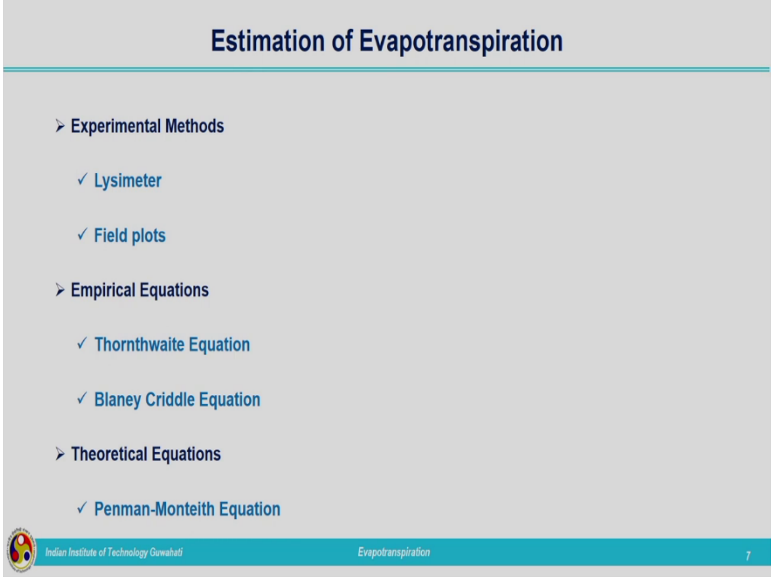

Now, let us move on to the estimation of evapotranspiration. Estimation of evapotranspiration, evapotranspiration is the combination of evaporation and transpiration. So, we know the factors which are influencing evaporation also will be influencing the evapotranspiration. So, different methods are there experimental, empirical and theoretical equations.

As we have discussed in the case of evaporation, in the case of evapotranspiration also we can have three different ways of estimating evapotranspiration. Commonly used experimental method is by using Lysimeter and also field plots. Empirical equations are Thornthwaite equation and Blaney Criddle equation and theoretical equations include Penman-Monteith equation. So, different equations you can see in literature related to estimation of evapotranspiration, very common methods only will be discussed here in this lecture.

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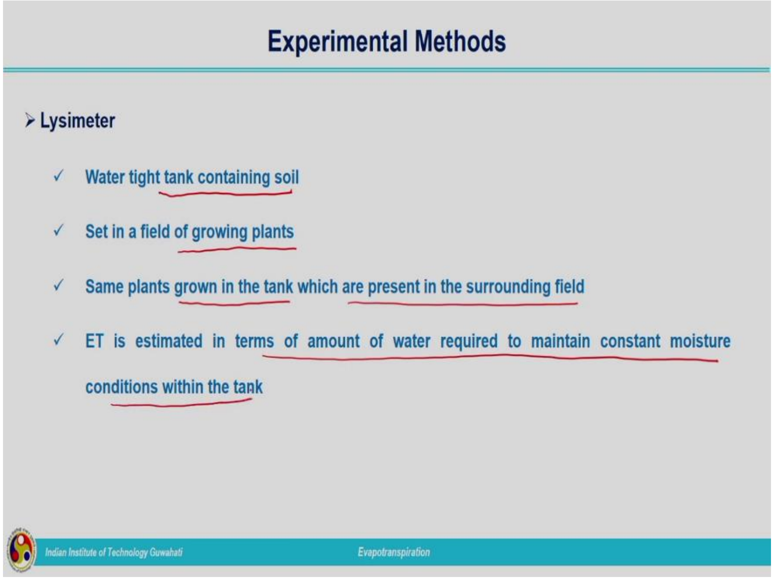

So, let us start with the experimental method that is Lysimeter. Lysimeter is a water tight tank containing soil. When we were talking about estimation of evaporation, experimentally how did we determine that? That is by using evaporation pans. Standard pans were available those pans can be utilized for calculating the evaporation. And here in this case, we will be using Lysimeter, the tank which is used for computing or estimating evapotranspiration is known as Lysimeter. It is a water tight tank containing soil and it is set in a field which is having growing plants. Same plants will be grown in the tank which are present in the surrounding field. We are keeping the Lysimeter in the field where we need to determine the evapotranspiration. So, in order to maintain the similar condition as that of the field condition we will be growing the same kind of plant in the Lysimeter also. And evapotranspiration is estimated in terms of amount of water required to maintain constant moisture conditions within the tank.

So, we will be maintaining a particular soil moisture condition within the soil, that used to be measured by using soil moisture sensors. So, for that we will be continuously watering at regular intervals in order to maintain the soil moisture to be at a constant level. So, based on the water which is added to the Lysimeter, we can calculate how much water is lost to the atmosphere due to evapotranspiration.

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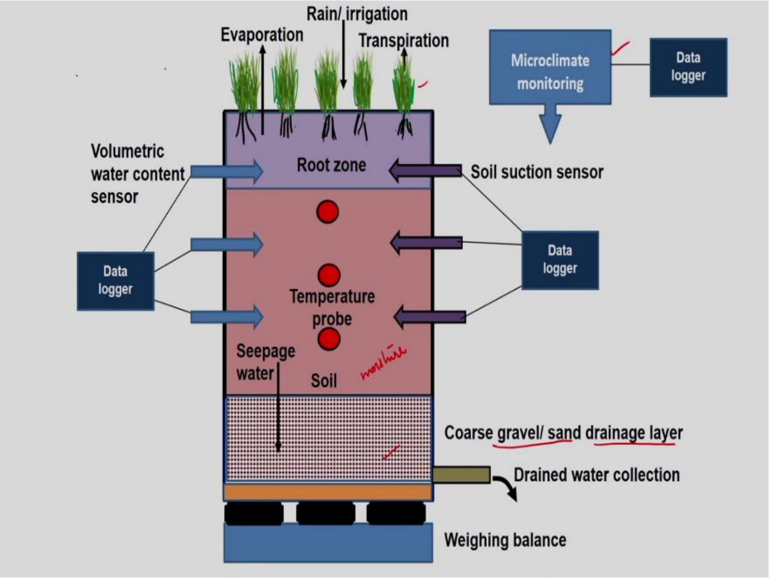

Let us see an engineered Lysimeter, this is a tank which can be used as a Lysimeter. So, bottom layer we are having the coarse gravel or sand drainage layer. So, we are not completely filling the tank with soil, it will be having different layers, bottom layer is fixed for draining of the water. So, in this region we will be filling the coarse gravel or sand. Above that, we will be filling the soil and upper part is the root zone and will be growing different plants.

These plants are chosen in such a way that we will be considering the similar kind of plants which are grown in the field where we need to determine the evapotranspiration. This is mainly used in the agricultural fields and we will be watering the plants at regular intervals, irrigated water or sometimes due to rainfall the plants will be getting water. And from the vegetative surface evaporation will be taking place and from the plant leaves transpiration will be taking place. And regarding the atmospheric parameters, micro climate monitoring will be carried out. If you are doing the monitoring of the atmospheric parameter, temperature, rainfall, vapor pressure, wind velocity, all these things can be obtained from the micro climate monitoring system and that will be connected to the data logger and that will be transferring the data to the computer.

And now regarding the soil pressure, that measurement will be done by means of sensors at different levels these sensors will be installed. So, these will be soil suction sensors, that also will be connected to the data logger. Finally, data will be available to us within our computer. Then we will be having the temperature probes within the soil in order to understand the prevailing temperature within the soil. And also soil moisture sensors, volumetric water content sensors will be present and that also connected to data logger and finally the data will be transferred to the computer.

And the water which is due to rain water or irrigated water, soil moisture which is present in the soil, soil moisture will be increasing. Excess moisture will be collected at the bottom as seepage water and that will be collected through this drainage pipe, which is provided at the bottom. This drained water can be measured by means of a weighing balance.

So, this is the principle of a Lysimeter, we are having a water tight tank within that bottom layer is a drainage layer above that will be filling soil and at the top layer we will be planting the plants which are similar to that of the one which are growing in the field where we need to determine evapotranspiration. The watering of the plants will be done at regular intervals and soil moisture, temperature and pressure required for the movement of water within the soil all these things will be measured by means of sensors and will be getting all these data within our computer by means of data loggers. And regarding the atmospheric parameters such as wind velocity, humidity, temperature, rainfall, all these things can be monitored by means of microclimate model.

So, by getting all these values making use of these values we can calculate evapotranspiration. And also, what will be the soil moisture variation, with respect to time how much variation is taking place. So, by using the water balance equation, we can calculate the evapotranspiration taking place. So, this is the basic methodology behind the working of a Lysimeter. Always all these sensors may not be available, in that case the quantity of water which is added to maintain constant soil moisture will be measured. So, for that we will be having the volumetric moisture content measuring sensors installed within the Lysimeter.

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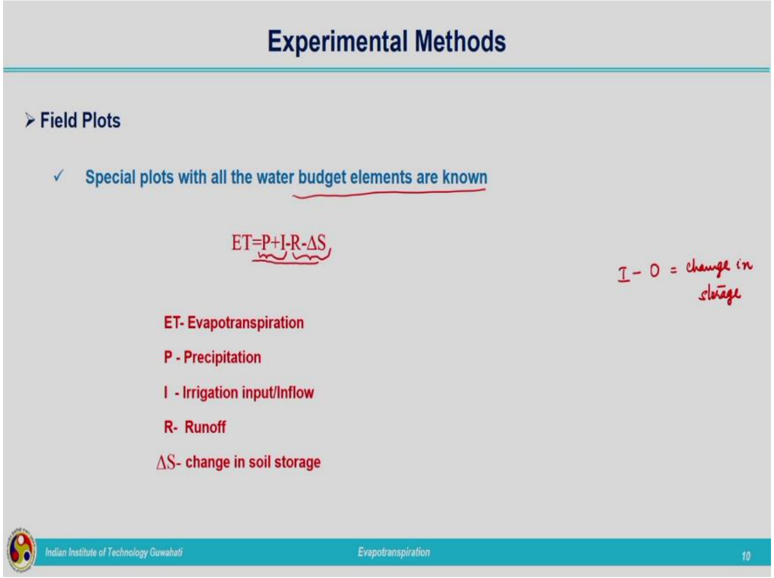

Now, second way of conducting experiments is by means of field plots. In this we are not taking separately a tank or pan nothing like that, a separate field is considered, special plots with all water budget elements are known. In that case, we need to know all the parameters which are required for the water balance equation. And then we will be making use of the water balance equation evapotranspiration is given by

$$ET = P + I - R - \Delta S$$

So, this is nothing but our water balance equation, mass balance equation inflow minus outflow is equal to change in storage. This equation we have already seen, so the same equation will be utilizing here also. Inflow minus outflow is change in storage, here P and I both are contributing as inflow and R is the outflow and S is the storage.

So, evapotranspiration ET can be obtained by making use of the inflows, precipitation, and I is the irrigation input or inflow and R is the runoff and ΔS is the change in soil storage. How much change taking place in the soil moisture, that is the change in storage. So, by making use of this we can calculate the evapotranspiration by conducting experiments, either by using Lysimeter or by using the field plots.

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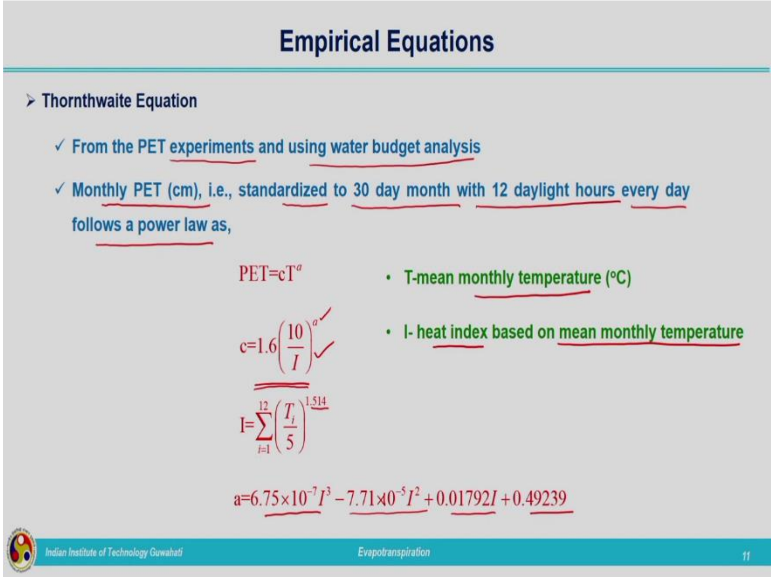

Now next is the empirical equations. First let us see the Thornthwaite equation. From the potential evapotranspiration experiments, we can compute the evapotranspiration by making use of the water budget analysis. In this case also we are making use of the water budget analysis. So, what we are calculating? We are calculating the monthly potential evapotranspiration. This is an empirical equation, so you need to be very much careful about the units. This equation is giving you the evapotranspiration in centimetres. So, monthly potential evapotranspiration, that is the standardized one to 30-day month with 12 daylight hours, every day is assumed to follow a power law.

So, monthly potentially evapotranspiration is calculated. So, we know it depends on the sunlight and in the case of evaporation whatever factors influencing, that is also influencing the evapotranspiration. In addition to that, regarding the water loss through the leaves that will be purely depending on the sunlight hours. So, sunlight hours and also depends on the type of plant.

So, here we are calculating the monthly potential evapotranspiration, conditions are there, it is standardized to 30-day month, a month is considered with 30 days and 12 hours of sunlight, daylight hours are considered. So, that is slightly at a higher range. Certain seasons we will not be getting 12 hours of sunlight.

So, PET potential evapotranspiration is calculated by the power law, which is given by

$$PET = cT^a$$

What are these terms? T is the mean monthly temperature in degree Celsius. So, that itself will be varying, when we are considering day to day, if we are checking the temperature there will be slight changes in the value, so here we are calculating the mean monthly temperature for calculating the potential evapotranspiration.

Then what is c? c is the coefficient and a is exponent, c can be calculated by using this formula,

$$c = 1.6\left(\frac{10}{I}\right)^a$$

Again, the exponent a has come into picture. What is I? I is the heat index based on mean monthly temperature. So, there is a term called heat indexes developed, that depends on the monthly temperature. Based on the temperature, heat index will be calculated, that heat index value is used for calculating the coefficient or the constant value c. How can we get this heat index? I is given by

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.514}$$

Here 1 to 12 represents the different months January to December. T_i is nothing but the monthly mean temperature in every month varying from 1st month to the 12th month. So, I can be calculated by using this formula

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)^{1.514}$$

So, once I is obtained we can calculate c, if a is already known.

So, how can we get the value corresponding to a? a can be obtained by using this cubical equation

$$a = 6.75\times10^{-7} I^3 - 7.71\times10^{-5} I^2 + 0.01792 I + 0.49239$$

These are the four terms present in the term a. So, by making use of this cubical equation, we can calculate the value of a, a is a function of heat index. Heat index I. How can we calculate I? We know by making use of the monthly mean temperature. So, first I will be calculated from the available value corresponding to the monthly mean temperature. Once I is obtained we can calculate the value of a and c can be calculated. Based on this power law that is

$$PET = cT^a$$

We can calculate the potential evapotranspiration. That is the monthly potential evapotranspiration in centimetres. But here you should understand, we have considered 30-day month and also the temperature we are having the sunlight hours considered as 12 hours. So, there is a need of correction factor for getting the actual value of potential evapotranspiration.

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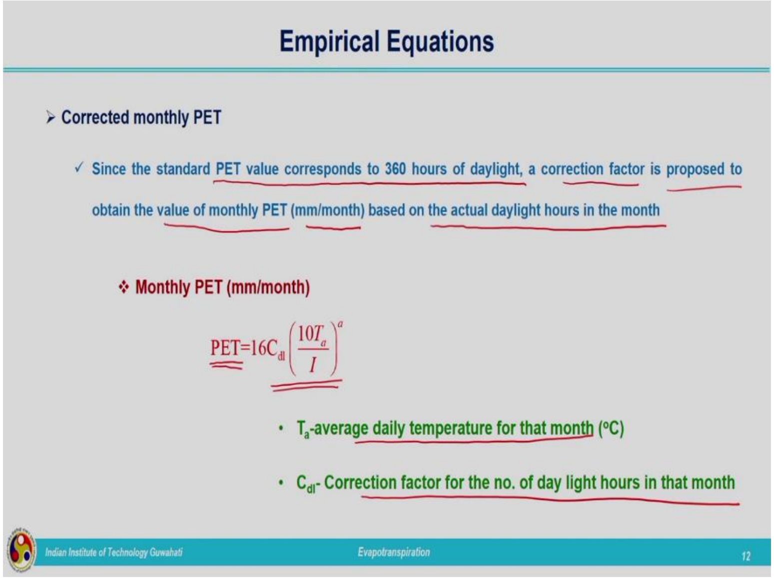

So, let us see what can be done for that? Corrected monthly potential evapotranspiration is required, that is since the standard potential evapotranspiration value is corresponding to 360 hours of daylight. 360 hours, how it is coming? 12 hours of sunlight is present for 30 days. So, that will be coming out to be 360 hours of sunlight. So, we know 12 hours of sunlight in a particular day, every day we cannot expect that. So, there is a need of a correction factor, that need to be proposed to obtain the actual value of monthly potential evapotranspiration.

So, this monthly potential evapotranspiration unit is in millimetres per month. Previous equation when we were talking about it was giving in centimetres, here it is in millimetres per month based on the actual daylight hours in the month. So, monthly potential evapotranspiration is given by

$$PET = 16C_{dl}\left(\frac{10T_a}{I}\right)^a$$

Here again different terms are T_a is the average daily temperature for that month. Instead of monthly mean temperature, here we are considering the average daily temperature for that month and C_{dl} is the correction factor for the number of daylight hours in that month. Depending on the season, summer, monsoon, winter that way, we cannot expect the same number of daylight hours. So, there is a correction factor required, that is represented by C_{dl} and once C_{dl} and T_a is available to us, we can calculate the potential evapotranspiration, that is the monthly potentially evapotranspiration millimetres per month.

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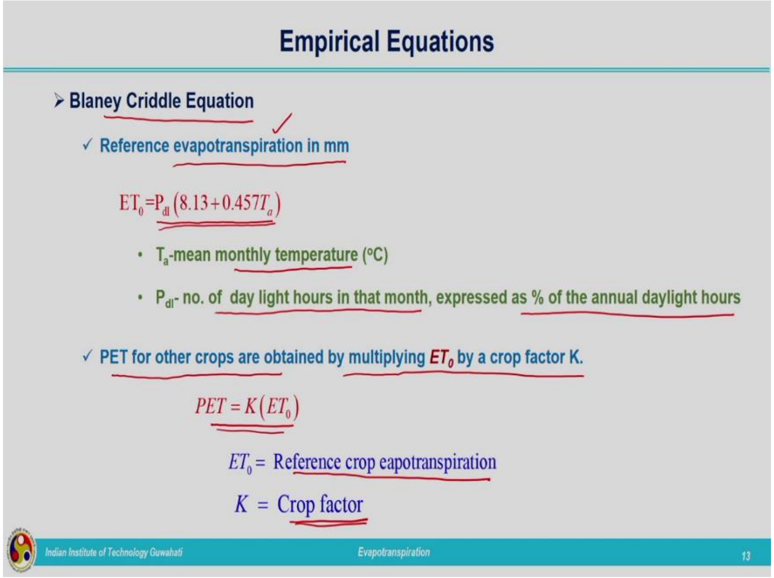

Now, second empirical equation which we are discussing is the Blaney Criddle equation. Blaney Criddle equation is giving us the reference evapotranspiration in millimetres. What is reference evapotranspiration? It is the reference crop evapotranspiration. We have seen a standardized vegetative surface from that how much is the evapotranspiration coming, that is the reference evapotranspiration.

So, that is given by

$$ET_0 = P_{dl}\left(8.13+0.457T_a\right)$$

Here again T_a is the mean monthly temperature in degree Celsius and P_{dl} is the number of daylight hours in that month. It is expressed as a percentage of the annual daylight hours. So, so many assumptions are there, so it may not be giving you the exact value, approximate value we can get based on these empirical equations.

So, once ET_0 is available to us, potential evapotranspiration for other crops can be obtained by multiplying ET_0 by a crop factor K. So, depending on the growth of different crops at different, different growth levels, this K value will be available to us and PET can be calculated, that is potential evapotranspiration corresponding to that particular crop can be calculated by using this formula,

$$PET = K(\mathrm{ET}_0)$$

ET_0 is the reference crop evapotranspiration, that is the reference evapotranspiration we have explained by using Blaney Criddle equation and K is the crop factor. So, once it is available to us, we can calculate potentially evapotranspiration corresponding to different types of crops. So, that much about the empirical equations.

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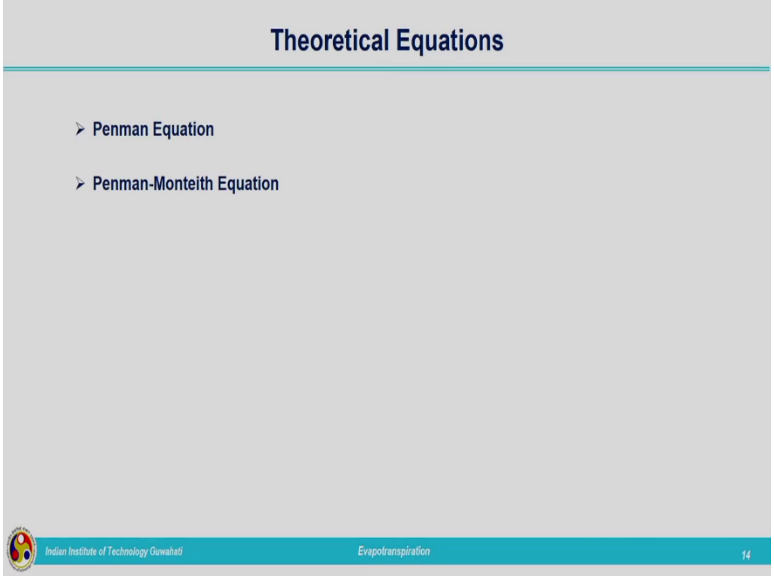

Now, let us move on to theoretical equation or the analytical equations. So, different equations which we are going to see are the Penman's equation and also Penman-Monteith equation. We are not going to see the detailed derivation of these equations because that much time we would not be having to cover the entire syllabus. So, let us see the equations first, these are similar to that of the analytical equations which we have derived in the case of evaporation.

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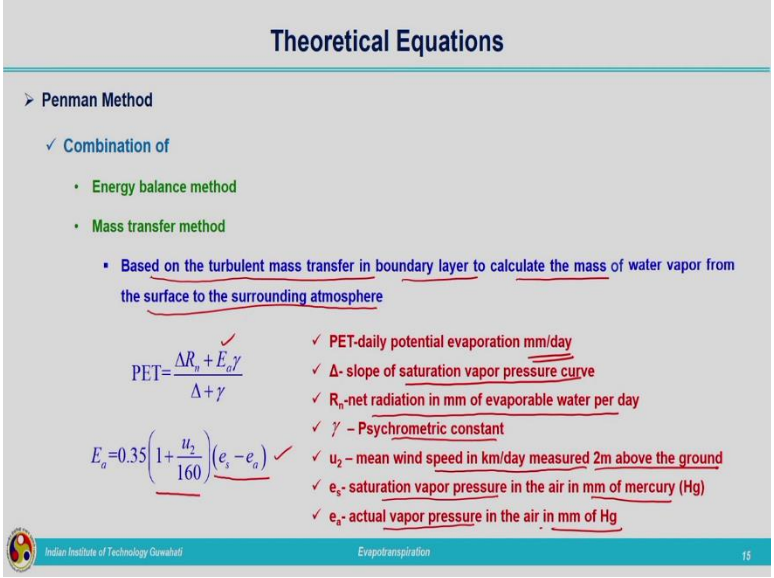

So, first let us see with the Penman method, it is a combination of energy balance method and the mass transfer method. Energy balance method we have seen already, which make use of the heat energy or the net radiation.

So, here the combination of the energy balance and the mass transfer method is utilized. So, what is mass transfer method? Mass transfer method is based on the turbulent mass transfer in boundary layer for the calculation of mass of water vapor from the surface to the surrounding atmosphere, vapor transport is taking place. So, how much is the vapor transport? Mass of the vapor transported from the surface to the atmosphere that will be calculated based on the mass transfer method.

So, Penman method is the combination of two approaches, energy balance method and the mass transfer approach. Let us see the expression corresponding to this equation, that is PET, potential evapotranspiration based on Penman equation is given by

$$PET = \frac{\Delta R_n + E_a \gamma}{\Delta + \gamma}$$

Different terms present in this particular equation is very much familiar to us, the same terms which are seen in the case of evaporation is also used here in the case of evapotranspiration. So, let us see one by one. *PET* is nothing but our daily potential evaporation in millimetres per day and Δ is the slope of saturation vapor pressure curve, that we have seen, we are having an empirical relationship related to saturation vapor pressure and temperature and a curve is also known to us. So, the slope of that particular curve is representing the value corresponding to delta.

Now, next is R_n, R_n is nothing but the net radiation in millimetres of evaporable water per day. So, usually we were using in terms of watt per meter square and that in terms of evaporable water per day in millimetre will be utilized here in this particular equation.

Next γ is the psychrometric constant and E_a is given by

$$E_a = 0.35\left(1+\frac{u_2}{160}\right)\left(e_s - e_a\right)$$

$e_s - e_a$ is coming that is similar to that of Dalton's law of vaporization, multiplied by using the certain factors, wind velocity is also coming into picture. So, this is representing the actual evaporation taking place, that is based on the aerodynamic method we have seen, how the equation is, this is similar to that of aerodynamic approach analytical equation used for estimation of evaporation. So, evaporation value is calculated by using this equation and that is used here in the calculation of potential evapotranspiration.

So, u_2 is the mean wind speed in kilometres per day measured at 2 meters above the ground surface, e_s and e_a we already know, that is the saturation vapor pressure and also the actual vapor pressure. You need to be careful it is in the unit of millimetres of mercury. It is not in pascal, it is in the unit millimetres of mercury, once it is available in pascal we can convert it into millimetres of mercury, that is not a difficult task. So, by using this particular equation we can calculate the potential evapotranspiration by using Penman's method.

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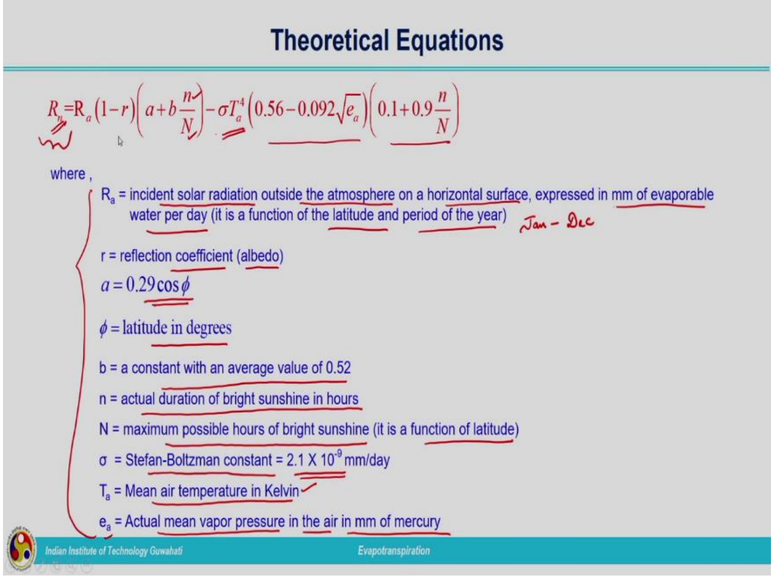

So, in the Penman equation, we were having a term corresponding to net radiation, R_n. How can we estimate the net radiation? For that, Penman has given a formula, it is slightly lengthy. So, it is given by

$$R_n = R_a(1-r)\left(a+b\frac{n}{N}\right)-\sigma T_a^4\left(0.56-0.092\sqrt{e_a}\right)\left(0.1+0.9\frac{n}{N}\right)$$

So, this lengthy expression is representing our net radiation.

Let us see different terms contained within the equation, R_a is the incident solar radiation, R_n we are talking about the net radiation and R_a is the incident solar radiation outside the atmosphere on a horizontal plane. It is also expressed in millimetres of evaporable water per day and this particular value, this incident solar radiation outside the atmosphere. It is a function of latitude and period of the year. Period of the year is nothing but our different months Jan to December.

Now, small r is representing the reflection coefficient, that is albedo. Albedo is the measure representing the reflection taking place from a particular surface. So, r is a particular term representing the reflection coefficient. a is incorporating the latitude of the area, that is depending on the latitude the sun rays which are reaching will be different.

So, a is given by the function

$$a = 0.29\cos\phi$$

ϕ is the latitude in degrees. So, for a particular location where you want to calculate the evapotranspiration, the latitude of that particular location will be considered. Then b is a constant with an average value of 0.52 it is a constant value which is considered in the Penman's equation.

Now, small n we are having two n terms, small n and capital N, small n is representing the actual duration of bright sunshine hours, that is certain days will be having different sunshine hours, some days will be cloudy, some days will be too sunny. So, the actual duration of a sunshine hours in a particular day is represented by small n and capital N is the maximum possible hours of bright sunshine. It is also a function of latitude, because definitely how the sun rays are falling it depends upon the angle with which it is lying, so that latitude plays an important role in the calculation of evapotranspiration.

Now, coming to σ, here we are having a term sigma σT_a^4. σ is nothing but our Stefan Boltzman constant, that is taken as $2.1\times10^{-9} mm/day$ and T_a is the mean air temperature in Kelvin. You need to be careful about the unit it is in Kelvin. Then one more term is present, that is e_a which is familiar to you, that is the actual mean vapor pressure in the air in millimetres of mercury.

So, here in the evapotranspiration equations we are making use of mean pressure or saturation vapor pressure everything in millimetres of mercury. So, if we know all these values or if we calculate all these values we can calculate the value corresponding to net radiation. Standard tables are given in textbooks corresponding to these values or else we can calculate based on the data given in a particular example.

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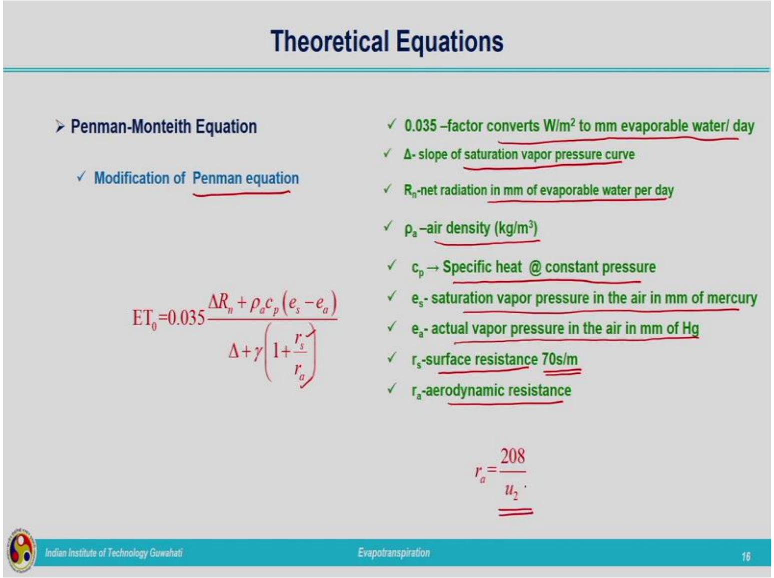

Penman- Monteith equation, is the modification of Penman equation and the expression is given by this equation

$$ET_0 = 0.035 \frac{\Delta R_n + \rho_a c_p (e_s - e_a)}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)}$$

Previous equation is slightly modified, you can see the form of the equation is same, but different combinations of terms have been included incorporated in this. And let us see one by one. What does it represent, that is what is meant by this 0.035? 0.035 is nothing but the factor which converts watt per meter square to millimetres of evaporable water per day, because we are not substituting in terms of watt per meter square, in the previous equation we told it should be in millimetres of evaporable water per day.

So, in this particular equation we are multiplying with 0.035 that takes into account the unit conversion. And Δ delta is the slope of the saturation vapor pressure curve. R_n is the net radiation in millimetres of evaporable water per day.

Then comes ρ_a we know it is air density in kilogram per meter cube approximately 1.2 kilogram per meter cube we will be using and c_p is the specific heat at constant pressure, then e_s and e_a, e_s is the saturation vapor pressure in air in millimetres of mercury and e_a is the actual vapor pressure in the air in millimetres of mercury.

Then two other terms are the r_s and r_a, what does it represent? r_s is the surface resistant, that is the value is 70 seconds per meter and r_a is the aerodynamic resistance, that can be calculated by using this formula

$$r_a = \frac{208}{u_2}$$

So, in the denominator the wind velocity is coming that is why the resistance unit is in seconds per meter, r_s is the surface resistance and also r_a is the aerodynamic resistance. So, remembering these equations are slightly difficult. So, whenever required you can refer to these equations and find out the value corresponding to evapotranspiration.

So, all the terms when you look into you are very much familiar to it because we have seen majority of the terms in the case of evaporation also. So, these are the two theoretical equations, which are related to calculation of evapotranspiration. So, other empirical equations we have seen, in that case you need to be very much careful about the units and then we have seen the experimental method of estimation of evapotranspiration by means of Lysimeter and also by means of field plots.

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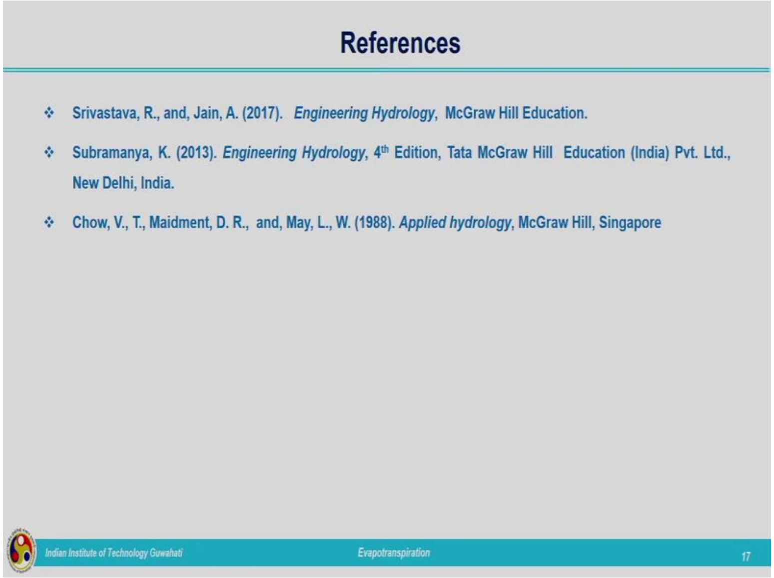

So, here I am winding up the discussion related to evapotranspiration. We need to see some of the numerical examples for understanding the equations in a better way, that we will see in the next lecture. For having more knowledge, please have a reading through these textbooks related to evapotranspiration. So, here I am winding up this lecture. Thank you.