Engineering Hydrology

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Lecture – 28

Evaporation – Empirical Method

Hello all, welcome back. In the couple of few lectures, we were discussing about methodologies related to estimation of evaporation. So, initially we have started with the experimental methods that is by means of evaporation pans, after that we have moved on to analytical techniques for estimation of evaporation.

So, under analytical techniques we have seen three different approaches, that is one is by energy balance method. In energy balance method, we have seen the predominant factor which is causing evaporation is the heat energy. So, the net radiation from the sun is causing evaporation, that assumption we have taken and proceeded with the derivation of the equation. And after that we have seen the aerodynamic method. In that we have considered other two factors such as the specific humidity and also wind velocity.

Then we found that all the three factors, such as the heat energy or the heat radiation, wind velocity and also the specific humidity gradient, all these three are very important as far as evaporation is concerned. So, we have seen the combined method for the estimation of evaporation. So, that particular expression has been modified by Prisley and Taylor by conducting so many experiments in different, different water bodies and a simplified expression has been given in the combined form. So, there we stopped in the previous lecture.

Today, let us move on to the third method, that is the empirical method. Different empirical methods are there for the estimation of evaporation. So, let us see some of these empirical methods, which are commonly used for the estimation of evaporation in today's lecture.

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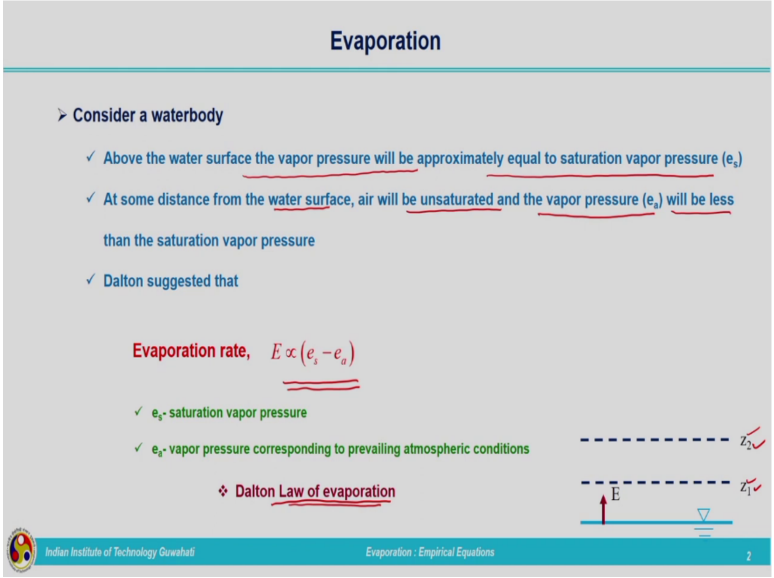

So, here also what we are going to do? We are going to consider a water body and this is the water surface and from this evaporation is taking place in the upward direction. So, above the water surface the vapor pressure is approximately equal to the saturation vapor pressure. That surface, that is just above the water surface, the vapor pressure will be almost entire air will be filled with moisture. That is why we will be assuming that just above the water surface, saturation vapor pressure will be prevailing. So, we are considering two depths z_1 and z_2, z_1 is very close to the water surface, there we are assuming, that the saturation vapor pressure is present.

Now, at some distance, that is at the layers z_2, at some distance from the water surface, air will be unsaturated and the vapor pressure corresponding to the particular temperature present at that time, which will be less than the saturation vapor pressure. So, that is denoted by e_a, e_a will be always less than e_s, which is the saturation vapor pressure. Here we can make use of the saturation vapor pressure curve, or by making use of the expression, we can calculate the saturation vapor pressure by making use of the known temperature.

Then Dalton's law everybody knows and according to Dalton, evaporation rate is proportional to the deficit in vapor pressure, that is at these two levels z_1 and z_2, we are having different vapor pressure, z_1 we are having a saturation vapor pressure and at z_2 air is in the unsaturated state and the vapor pressure is lesser than that of the saturation vapor pressure. So, there itself a deficit in vapor pressure is caused, that deficit is enabling us to make the vapor transport with the action of wind.

So, that deficit is the reason behind the evaporation. So, what Dalton has suggested that, evaporation rate is proportional to that deficit that is

$$E \propto (e_s - e_a)$$

So, this is known as the Dalton's law of evaporation. So, we have seen this type of expression, when we were talking about the aerodynamic equation, there also that constant, which we have named as the coefficient of vapor transport B multiplied by e_s minus e_a. So, there also similar form as such provided by Dalton, the same form has been derived by means of aerodynamic approach. So, according to Dalton evaporation rate is directly proportional to the vapor pressure deficit e_s minus e_a.

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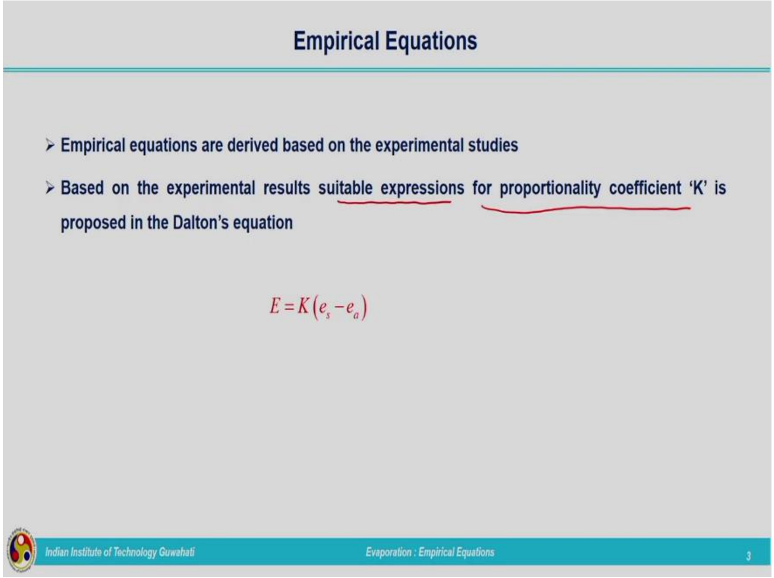

Now, based on these they different empirical equations have been derived by conducting so many experiments at different, different water bodies. So, empirical equations derived based on experimental studies, how they have derived the equation? So, they have found out suitable expressions for the proportionality coefficient K, that is evaporation rate according to Dalton is E is equal to K multiplied by e_s minus e_a. So, based on the experimental studies suitable coefficients have been proposed by different researchers. Thus, forming the empirical equations. So, this is about Dalton's law of evaporation,

$$E = K(e_s - e_a)$$

Factor K is derived or expression for K is developed based on the experimental results.

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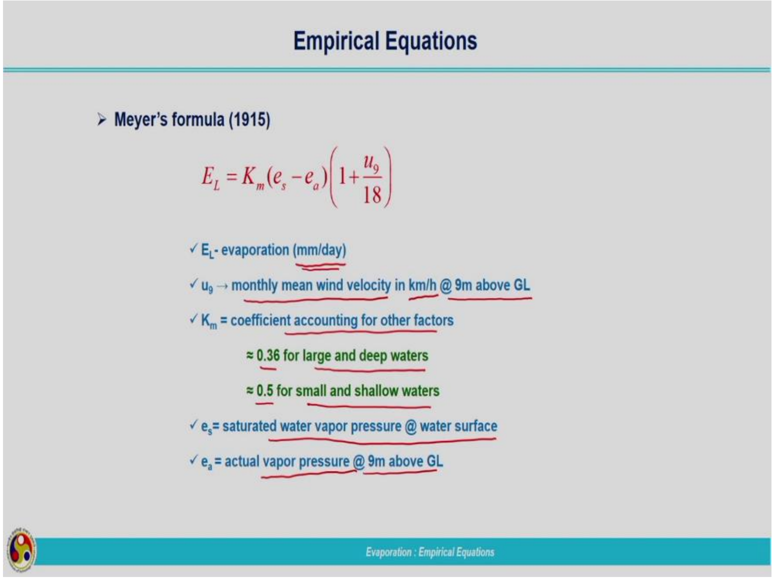

First formula that is the important empirical formula, which we commonly use is Meyer's equation. Meyer's equation is given by evaporation loss from the lake is given by

$$E_L = K_m(e_s - e_a)\left(1+\frac{u_9}{18}\right)$$

Let us see the terms one by one, E_L is the evaporation, you please be careful about the unit, that is millimetres per day. Since this is empirical equations you need to be careful about the units. E_L is the evaporation in millimetres per day, u_9 is the monthly mean wind velocity in kilometres per hour at an elevation of 9 meter above the ground level.

Wind velocity we are taking is at an elevation of 9 meters above the water surface, or the ground level. In some of the textbooks, you can see u_8, that means it is taken wind velocity is considered at a distance above the ground level or the water surface around 8 meters. So, K_m is the coefficient accounting for other factors. The value of K_m can be taken to be 0.36 for large and deep-water bodies.

So, we have seen when we were prioritizing the factors, which are responsible for evaporation, we have seen different factors, wind velocity, net radiation, vapor pressures, specific humidity and in that it was mentioned about the area of the water body and the depth of the water body. So, this K_m is the coefficient, which is accounting for this that is for large and deep waters we can consider K_m as 0.36 and for small and shallow waters, it can be considered as 0.5. That we have seen in the case of deep-water bodies, evaporation will be less compared to the shallow water bodies. So, that is why the coefficient is lesser for large and deep waters compared to small and shallow waters.

Then we already know, what are e_s and e_a and e_s is the saturation vapor pressure at water surface. We have considered two layers, first layer is just above the water surface or you can consider it as the water surface itself, there we have considering a vapor pressure of saturation vapor pressure. And e_a is the actual vapor pressure at 9 meters above the ground level. We are talking about the wind velocity at 9 meters above the ground level or the water surface. So, at the same height we will be considering the vapor pressure corresponding to that particular temperature.

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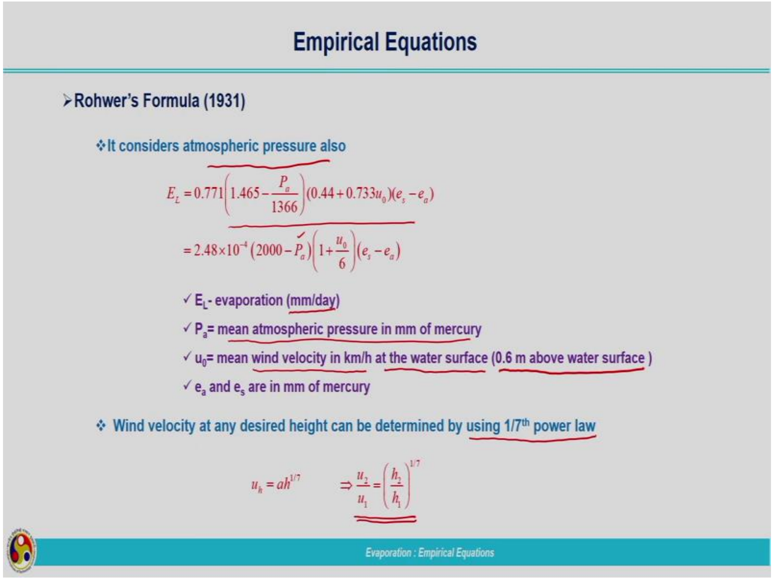

Second empirical formula which we are discussing is Rohwer's formula. This is also similar to the previous equation. It considers atmospheric pressure also. In the previous expression, we have not considered atmospheric pressure P, so in this that also will be incorporated. So, the expression is slightly lengthy, it is given by

$$E_L = 0.771\left(1.465 - \frac{P_a}{1366}\right)(0.44 + 0.733u_0)(e_s - e_a)$$

Expression when you look at, it is a slightly lengthy expression. So, this has been modified again and taken this form.

$$E_L = 2.48\times10^{-4}\left(2000 - P_a\right)\left(1+\frac{u_0}{6}\right)\left(e_s - e_a\right)$$

So, here we can see the atmospheric pressure is considered into account. So, E_L is the evaporation again in millimetres per day, P_a is the mean atmospheric pressure in millimetres of mercury. It is not in pascals, it is put in millimetres of mercury. So, you have to be careful about the unit here in this particular equation and u_0 is the mean wind velocity in kilometres per hour at the water surface. So, at the water surface measuring wind velocity will be slightly difficult, so we can consider around 0.6 meters above the water surface.

So, this is the particular equation, in that P_a is the atmospheric pressure and u_0 is the mean wind velocity in kilometres per hour. So, some units are in millimetres, some are in kilometres and in the case of pressure it is in millimetres of mercury and e_a and e_s are vapor pressure corresponding to the prevailing temperature and e_s is the saturation vapor pressure, that is also expressed in terms of millimetres of mercury.

Now, coming to wind velocity, wind velocity at different different heights we can calculate by making use of the boundary layer principle. So, we are having the equation corresponding to that which can be determined by using 1/7th power law. So, that is given by u_h, that is wind velocity at a height *h*, *h* is the height from the ground surface or the water surface.

So,

$$u_h = ah^{\frac{1}{7}}$$

So, if we are having 2 elevation, we can write

$$\frac{u_2}{u_1} = \left(\frac{h_2}{u_1}\right)^{\frac{1}{7}}$$

From this we can get the wind velocity at a different elevation u_2. So, this is the particular formula used under Rohwer's method.

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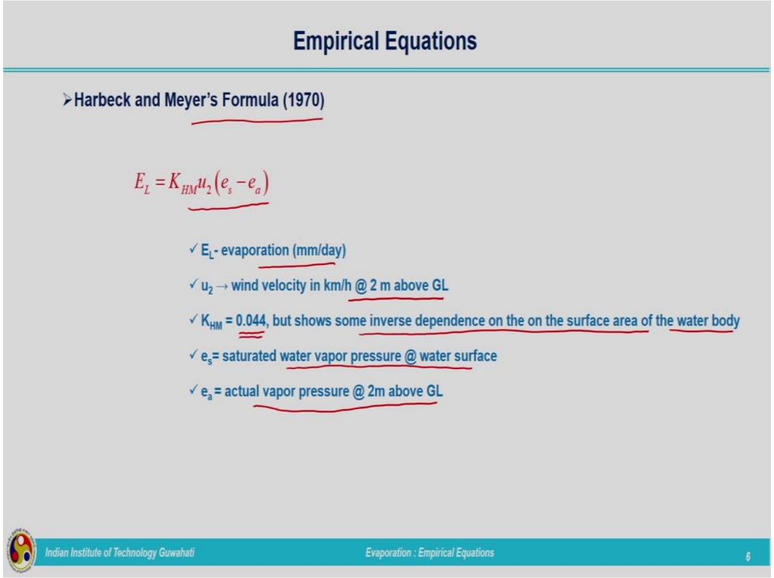

Then comes the Harbeck and Meyer's formula. Here the Meyer's formula is modified. So, it is given by

$$E = K_{HM} u_2 \left(e_s - e_a\right)$$

E_L is the evaporation in millimetres per day and u_2 is the wind velocity at 2 meters above the ground level, the unit is in kilometres per hour. Then, K_{HM} is considered as 0.044 but shows some inverse dependence on the surface area of the water body.

So, we have seen in Meyer's formula what are the values corresponding to different types of water bodies. Here in this Harbeck and Meyer's formula, there is a slight modification in that particular value, that is considered as 0.044 and e_s is the saturation vapor pressure at the water surface, that we know already at the water surface, the air will be fully saturated and corresponding to that we can consider saturated vapor pressure. And e_a is the actual vapor pressure at a distance of 2 meters above the ground level or the water surface.

So, here in this particular formula that is Harbeck and Meyer's formula, we are considering the wind velocity at 2 meters above the water surface. So, at the corresponding location, that is at 2 meters above the water surface, we will be considering the vapor pressure also.

So, these are the three equation empirical equations, which are commonly used for calculating the evaporation and so many other equations are also derived by making use of certain atmospheric parameters and some modifications to the existing equations. So, here I am not listing all the equations. So, with these three equations, I am winding up the empirical equations related to estimation of evaporation.

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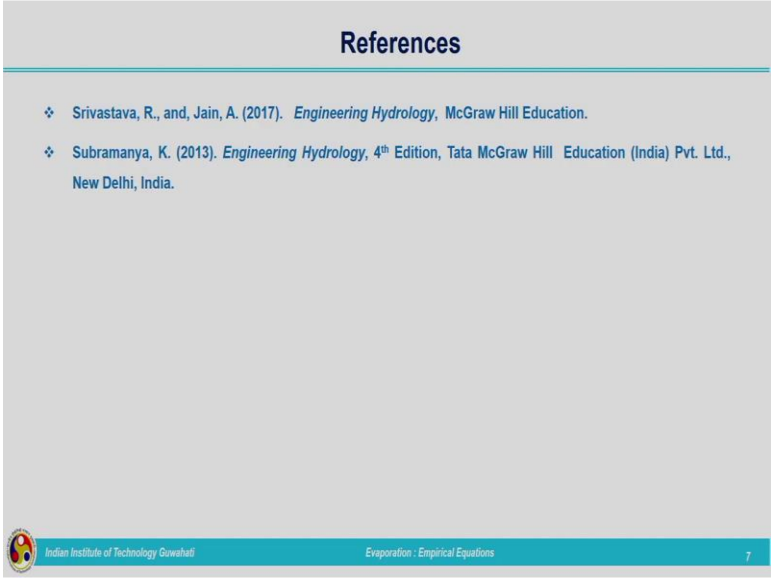

So, you can go through these textbooks for getting more details about the different empirical equations. So, that much about the estimation or the determination of evaporation by using empirical equations. Thank you.