Water Resources Engineering
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Lecture No. 21

We have looked at various abstractions from precipitation because as we have already said our interest is most of the times in the runoff which results from rainfall and for that to find out the runoff we should know how much is being abstracted from the precipitation. We have already discussed a few types of abstractions for example the initial abstraction which consists of the depression, storage interception and then we have some infiltration which goes underground. We have our evaporation and some transpiration. We would look at all these abstractions in terms of taking some examples and looking at the magnitude, rough estimate of how to estimate these quantities. We have looked at some of the equations and today we will look at some of the numerical examples to understand these equations better.

Let's start with the initial abstraction which is when the precipitation occurs there would be some small depressions on the storage. There would be some water on the tree leaves and then these may either evaporate directly from the surface or some of it will infiltrate. The initial abstraction is the one which occurs immediately after the rainfall and that means that without such …. this initial abstraction we will not have runoff. Initial abstraction is what initial amount is taken from the precipitation and after that the rest of it will go as runoff or part of it will infiltrate and evaporate. In the initial abstraction it would be including interception and depression storage. We have already discussed the mechanism of these and the estimation of these. The soil conservation service of the US SCS has proposed a technique because this is a very difficult to estimate quantity. Initial abstraction depends on a lot of factors which are changing from place to place and then again from a storm event to different storm event it may be different. A rough estimate of this can be made by this SCS method in which the initial abstraction is taken as 20% of S where S is a potential maximum retention.

Naturally if we have a surface which is paved then there would be very small retention on the surface. But if we have a land which is agricultural then there will be a lot of retention possible. Therefore S will depend on the land use and also what kind of soil it is. The SCS has related S with an empirical constant called curve number or CN and this CN is popularly known as the SCS curve number. The curve number depends on the type of soil and the land use of that area. It also depends on the existing moisture condition. If the soil is already moist then less infiltration will occur. If the soil is initially dry then more infiltration will occur. Initial abstraction will be high if the soil is dry initially. This relation between the curve number and the value of S which is the potential maximum retention is given by 25.4. This factor converts the inches because originally the formula was in inches. To convert this inch into millimeter we have this 25.4 factor then 1000 over CN minus 10.

As you can see from here CN can be a maximum of 100 because when CN is 100 then S will be zero. 100 means there is no storage; perfectly everything which falls down on the surface will go as runoff. There will be no infiltration, evaporation. The curve number can be as shown in this table for normal existing soil moisture conditions. If the soil is dry than the normal conditions or if it is better than the normal conditions then the curve number will change but for normal conditions depending on the land use and the type of the soil. We can find out the curve number from this table. A lot of other land use and soil combinations are not shown in this table. For example if you have paved area then naturally the soil type will not matter because the area is paved. So a curve number of 98 can be used for all types of soils. For industrial area which is not completely covered it may be 70% covered or 80% covered then the curve number will also depend on the type of soil. For sandy soil we have 81 curve number. For clay we have 93 curve number indicating that for the clay S will be small and the runoff will be larger; for sand S will be large and the runoff will be smaller.

Similarly if you have a cultivated area then the curve numbers are even smaller compared to the industrial area. Paved area will have very high curve number and high curve number, as you can see from this equation, will indicate low S and low S means low value of initial abstraction.

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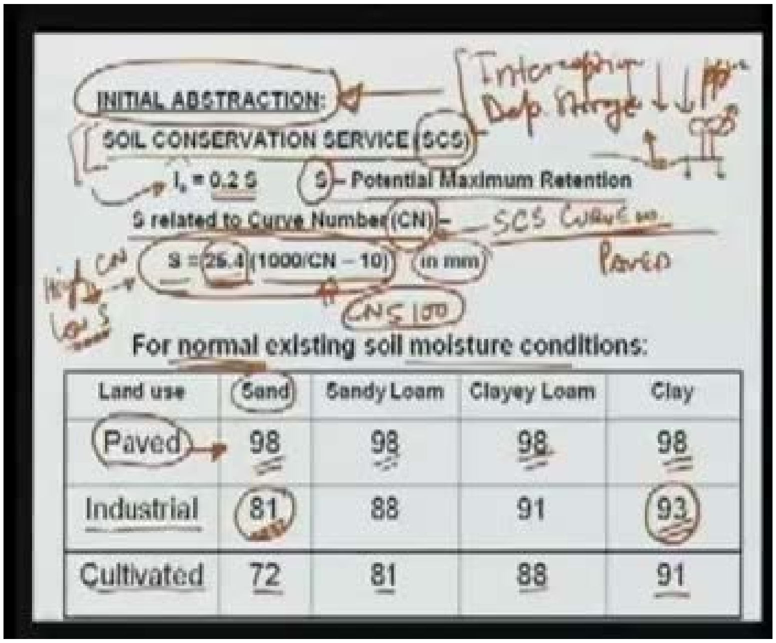

For paved area initial abstractions will be very small. For example paved area using a curve number of 98 we can S equal to 5.18 millimetre and initial abstraction of 1.04 millimetre. This indicates that if the rainfall is less than about 1 millimetre then we can expect that all of it will be absorbed by the catchment area and there will be no runoff. Once the rainfall exceeds 1 millimetre, only then the runoff will occur. Similarly if we have a cultivated sandy soil we can look at the curve number which is 72. Using that curve number of 72 we can get S equal to 3.89 millimetre and initial abstraction of 0.78 millimetre. Curve number can be as small as 25. For example if we have a forest area and soil is sandy and good cover; that means the foliage density is very high. The sandy soil will cause more infiltration. Curve number of 25 will give us initial abstraction which will be 20% of this; 6 millimetre which is quite high and that means that your initial rainfall of 6 millimetre would be completely absorbed by the catchment and there will be no runoff. For forest area with permeable soil, sandy soil with a very good cover the initial abstraction is quite high and it also depends on the climate. If we have a warmer climate we can reduce the curve number. For paved area we have already seen that the curve number is 98 for all types of soils. But if the climate is warmer then we would expect little more evaporation and we can reduce the curve number to 95.

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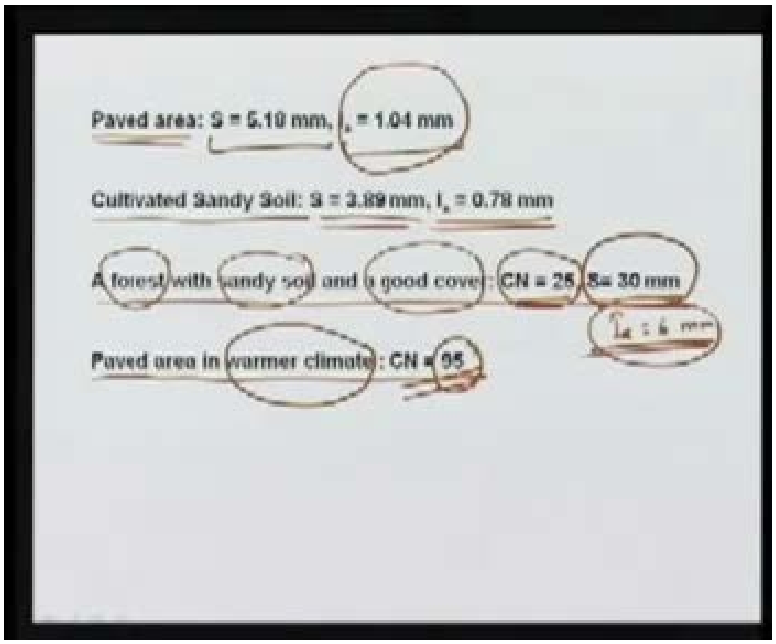

This method gives us an idea of how to find out initial abstraction from the precipitation. It's an empirical method. Tables of curve numbers are available for different types of land uses, different types of soils and different types of existing moisture conditions what is known as the antecedent moisture conditions and under normal conditions we have shown the table. This is under normal conditions. If dry or wet then there are other tables or other equations which relate the curve number with the land use and the type of soil but we will not go into details of that.

After initial abstraction then we have other abstractions like evaporation, infiltration and transpiration. The evaporation from a water surface can be described as changing with time of the year. In summer months we would expect a very high evaporation. For winter it would be lower. A typical variation of evaporation can be seen in this figure in which January has very small evaporation, December has small evaporation but as we can see here May, June and July may have high evaporation as high as may be up to about 170 millimetres. This is a monthly evaporation. Evaporation for the whole month may be about 175, 170. This is for a typical station. Sometimes evaporation may be as high as 200 or even higher than that. In most of the dry areas in India it would be higher than 200; 220 millimetres per month.

The question is how to find out this evaporation which varies over a wide range? If you look at this value it is close to about 40, 50 and if you look at this value it is close to 170, 175.

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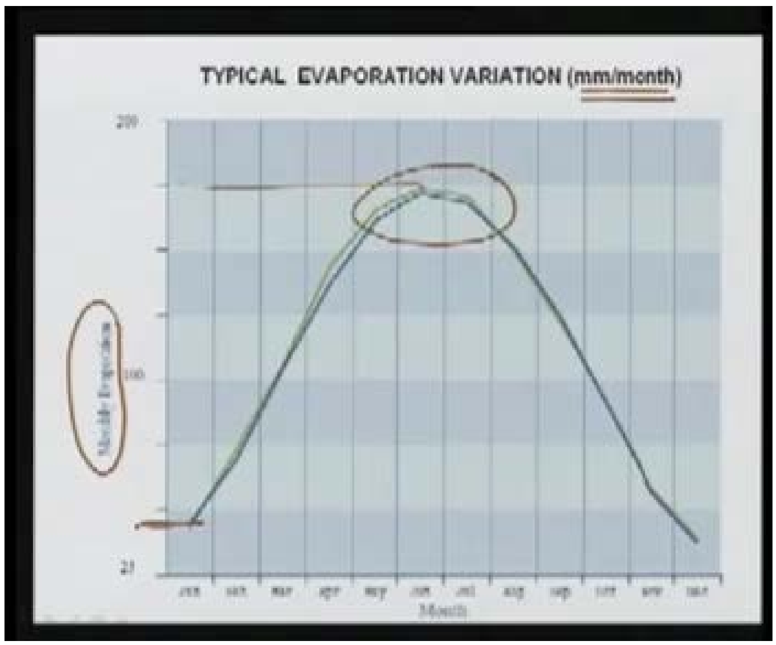

Evaporation will vary a lot from month to month and for a typical month or for a typical year if you want to find out evaporation then there are empirical equations which are given. We have already seen that we can measure the evaporation by using evaporation pan and then using a pan coefficient. That measurement can be done but there are some empirical equations which can be used if data is not available from evaporation pans. Some of the empirical equations we have seen for evaporation. We have the Meyer's equation and the Rohwer's equation.

Rohwer's equation and Meyer's equation both are based on the fact that the evaporation will be directly proportional to the vapour pressure deficit. So e_w here as we have seen is the saturation vapour pressure and e_a is the actual vapour pressure. e_w-e_a denotes the deficit from the saturation value to the actual value and this will govern the amount of evaporation from a water surface. We have also seen that not only the deficit but also the wind velocity will affect the evaporation because the wind velocity ‘u’ will affect how fast the saturated air from here is removed from over the surface and then another air packet which once becomes saturated is moved away. Then a dryer air will come and then evaporation can continue. Larger wind speed will mean larger rate of evaporation.

Most of the equations have one factor which depends on the saturation deficit and another factor which depends on the wind velocity.

In the Rohwer's we have an additional factor which accounts for atmospheric pressure also at that location. We would need to know e_w, the saturation vapour pressure.

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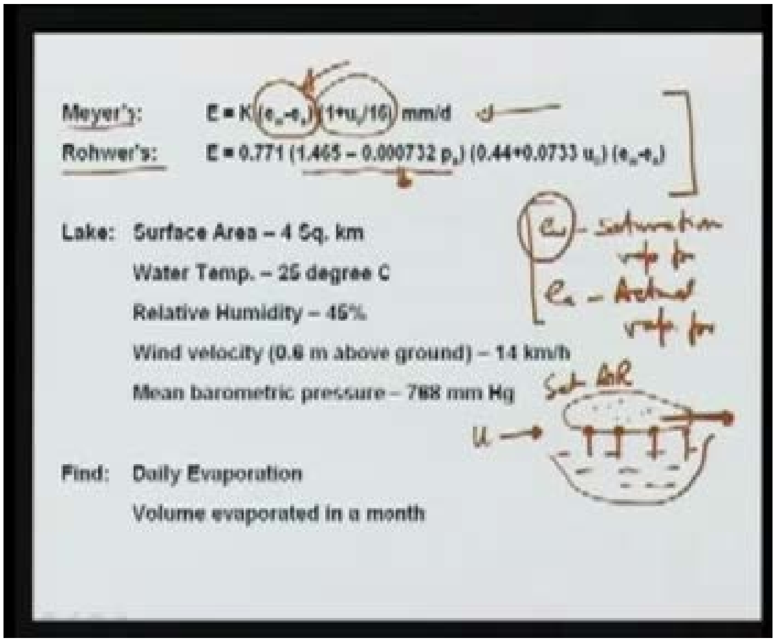

Saturation vapour pressure is generally a function of temperature and if we know the temperature we can find out the value of the e_w. Some of the tables are easily available in literature. One of the tables is shown here in which with temperature there is variation of vapour pressure and there is slope of vapour pressure curve. This we will need in some other equations later on but for now this is what is important; how the saturation vapour pressure e_w changes with temperature.

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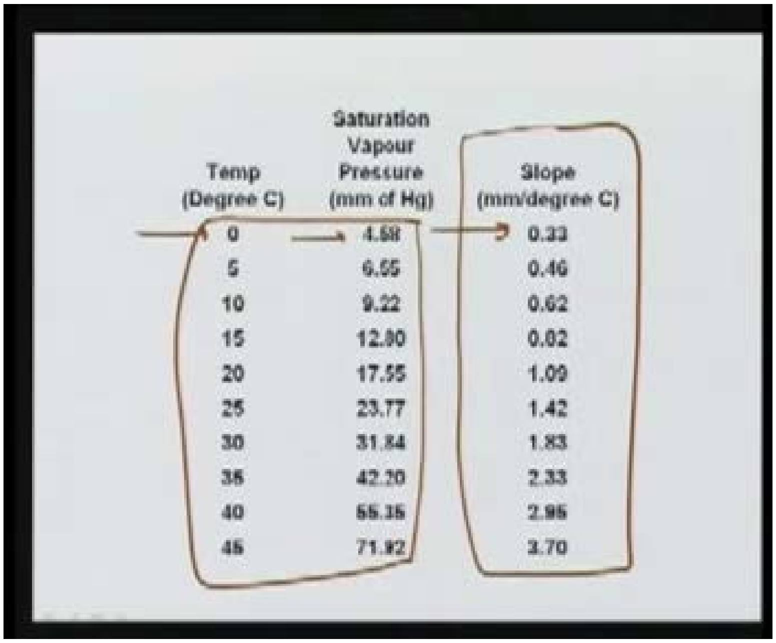

Temp (Degree C)	Saturation Vapour Pressure (mm of Hg)	Slope (mm/degree C)
0	4.58	0.33
5	6.55	0.46
10	9.22	0.62
15	12.80	0.82
20	17.55	1.09
25	23.77	1.42
30	31.84	1.83
35	42.20	2.33
40	55.35	2.95
45	71.92	3.70

There are equations also given for this and there are figures available like this which show for any temperature what is the saturation vapour pressure in terms of millimetre of mercury. If we take the example of a lake we want to find out the evaporation from the lake given some data. For example surface area of the lake is given as 4 square kilometres; water temperature is 25 degree Celsius. This water temperature means that we have to find out e_w at 25 degrees. 1514

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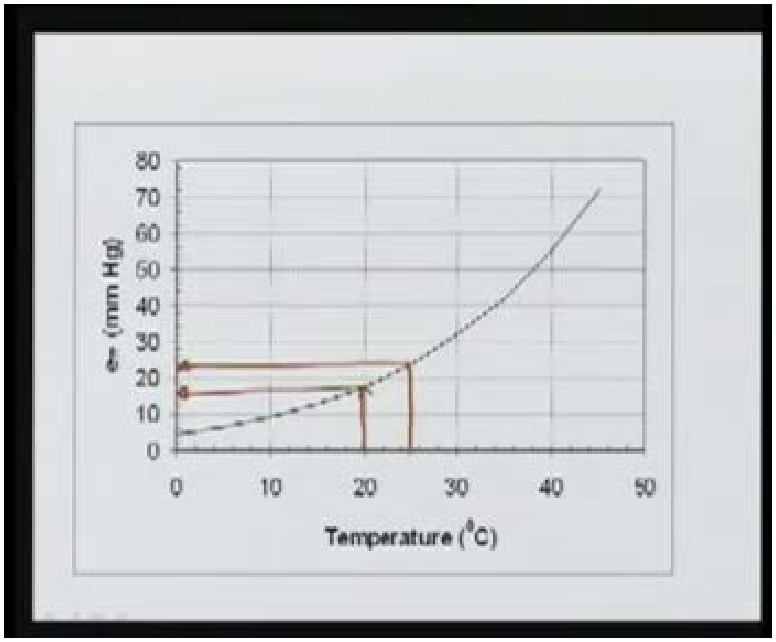

We can use the graph or some equations to find out the e_w corresponding to this temperature and as you can see from here it is obtained as 23.77 millimetre of mercury which we can get from the figure or the table also. For a temperature of 25 degree Celsius vapour pressure of 23.77 is obtained. The actual vapour pressure will be obtained by multiplying this saturation vapour pressure with the relative humidity and the data which is given for this problem is a relative humidity of 45%. This will indicate that the actual vapour pressure would be 45% of the saturation vapour pressure which is obtained as 10.70 millimetre of mercury.

In the Meyer's equation there is an empirical constant K here which depends on the kind of water body which we are dealing with. If we have a large and deep body then K is taken as 0.36. Since this is large body 4 kilometre square area we can take K as 0.36. Knowing K, e_w and e_a we are now left with obtaining the value of u_9 which is the velocity at 9 meters above the ground level. The data which is given is for wind velocity at 0.6 meter above ground. Wind velocity will be given based on where is this velocity measuring point and in this case we have data which is available at 0.6 meter above ground and the wind velocity is 14 kilometres per hour at 0.6 meter. What we need in the Meyer's equation is u at 9 meters.

We need to use some correlation. We can use the one seventh power law which tells that the velocity varies as one seventh power of the distance from the surface. Using that relationship we can estimate the velocity at 9 meters. The wind velocity profile would be like this. At 0.6 meter the velocity is given as 14 and our interest is in finding out at 9 meters what this velocity is. If you assume one seventh power law then the velocity at 9 meters can be obtained as 14 into 9 divided by 0.6 which is the depth ratio to the power 1 by 7 and it turns out to be 20.6 kilometres per hour. Looking back at the Meyer's equation, now we know everything. We have K, we have the e_w and e_a; we have u_9 and we can obtain the evaporation rate in terms of millimetres per day. 0.36 is the value of K, saturation deficit, 20.6 is the velocity at 9 metres. In this equation 1 plus u_9 by 16 we have 20.6 by 16. This turns out to be 10.77 millimetres per day.

We have evaporation from the lake surface equal to almost 1 centimetre in a day and we can also find out in a month how much volume of water will evaporate from that lake. The surface area is 4 square kilometres. We convert into metre square. This is millimetre per day converted into metres and 30 days assuming in a month we have 1.29 million metre cube of water evaporated from the lake in a month. We can also use the Rohwer's equation and see how much estimate of the evaporation we get. Since all these are empirical equations they would naturally give different values because they are based on different data. Rohwer's equation has this additional parameter Pa and we have this given information mean barometric pressure is let's say 768 millimetres of mercury. This is in millimetres of mercury.

The wind velocity which is used in Rohwer's equation is U_0 which is at the surface. But since the velocity at the surface is very difficult to measure, ideally would be zero if we say no slip condition. U_0 is taken as $U_{0.6}$ and that is what we have measured here U at 0.6 above ground as 14 kilometre per hour. Using the Rohwer's equation we have this constant 0.771 barometric pressure term, wind velocity term and saturation deficit term and this U_0 we will be using as $U_{0.6}$. Using this data we get a value of 13.33 millimetres per day. You can see that here we have 10.77 millimetres per day. Here we have obtained a value of just 13.33 millimetre per day. They are a little different and not exactly the same thing.

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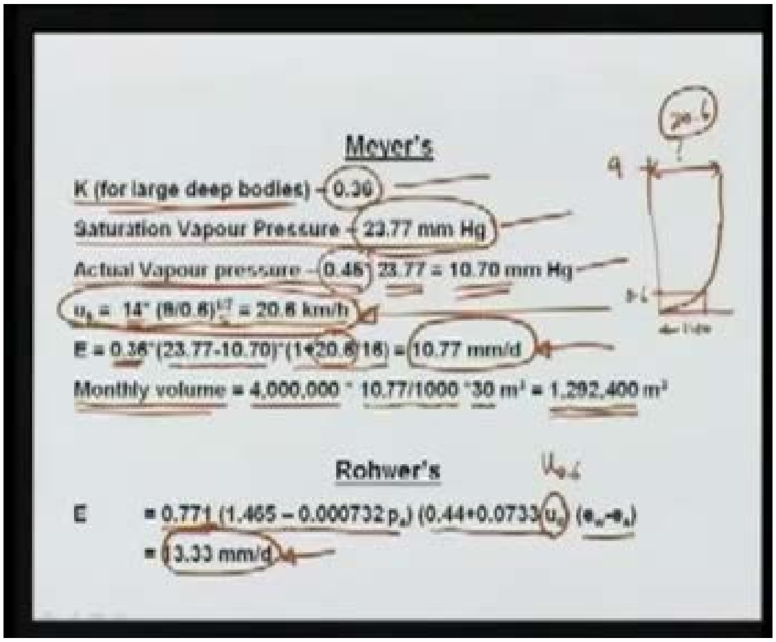

This is only evaporation; most of the times we would be interested in combining evaporation and transpiration. We need to know what is the evaporation from a water body as well as water transpiration from plants or vegetation in that area and as we have already discussed we combine these two and called that evapotranspiration. Evapotranspiration will depend on a lot of factors. For example the solar radiation available at that point and the number of day light hours because if we have cloud cover then naturally evapotranspiration will be smaller. We need a lot of information. There are again empirical methods which use some equations and there are some theoretical methods which are a little more based on theory rather than only empirical coefficients. We would look at some of these techniques and see how to compute evapotranspiration based on some of the empirical and theoretical approaches.

We have seen the Blaney Criddle equation which says that the evapotranspiration is equal to 25.4; again this 25.4 comes because we convert inches into millimetre and there is some factor K here which will be function of the crop type. This will affect the transpiration, the crop type. Therefore this factor K will come and F is a consumptive use factor, monthly consumptive use factor, which we will see later on how to compute and another method which is commonly used is the Thornthwaite equation which again tells that ET is equal to 16 La is a factor which depends on the latitude and the month, T average is the average temperature and using these two equations we can find out the evapotranspiration at a particular latitude for a given month where average temperature will be known. Let's take this data. We have a location where the latitude is 30 degrees north, crop is given as wheat and for wheat we know that the value of K in the Blaney Criddle equation is taken as 0.65; for rice it is 1.1. Let's look at 2 months, months of November and December for which the mean monthly temperature are 15 for November and 12 for December and what we need to find out is evapotranspiration for this period of 2 months November and December.

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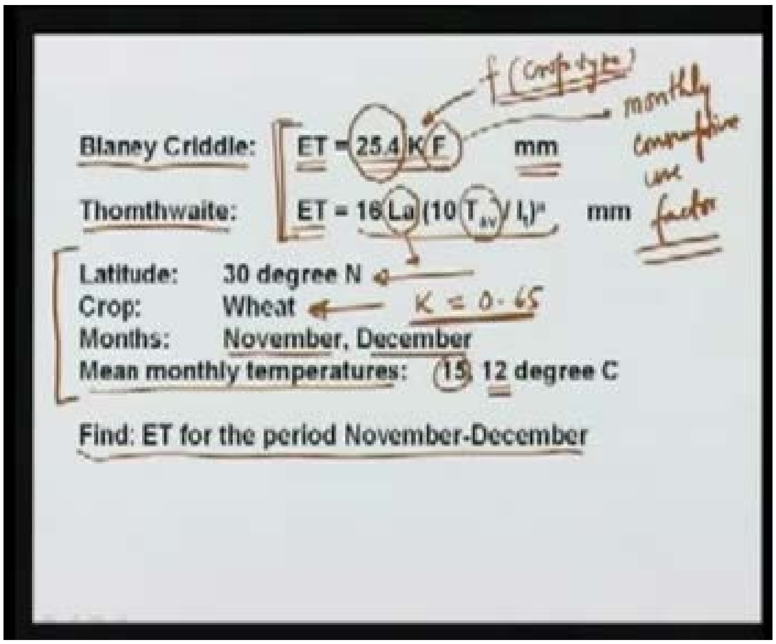

In the Blaney Criddle equation in which is written as evapotranspiration is 25.4 KF we have already discussed that for wheat K is given as 0.65. There is a table of values of K for different types of crops. Some of the values are rice 1.1, maize 0.65, sugarcane 0.9, natural vegetation if it is dense then the value can be taken as 1.2 to 1.3 and if it is light 0.8 to 1. Here since wheat is given we will take K equal to 0.65. The factor F is the summation of P_h. P_h is the monthly percent of annual daylight hours and this will depend on latitude and the time of year which we say as month. T average is given for November and December as 15 and 12 degree in the Blaney Criddle equation which was based on FBA system of units. The temperature was in degree Fahrenheit. We can convert this 15 and 12 degrees Celsius to 59 and 53.6 degrees Fahrenheit. 2623

The Ph value is obtained from a table of values which relate the monthly sunshine hour percent with the latitude and the time of the year and if we look at this table this gives us the daytime hour percentage for each month, for different latitude and different months we are given these percentages. For example if we are talking about equator zero degrees north in January there would be 8.5% percent daylight hours compared to the number of daylight hours for the whole year. 8.5% of the year daylight hours will occur in January. Similarly if we look at February the number of daylight hours in this case we would see it as smallest at 7.66. If the number of daylight hours is same in every month then the percentage would be 100 by 12 or 8.33%. But since February is a smaller month also and colder also the percentage of daylight hours is 7.66. As we move to the north you can see that in January the percentage is decreasing while in May it is increasing. This depends on the latitude as well as the season and therefore from this table we can find out the percentage which is required in the Blaney Criddle equation.

If we look at the data given for 30 degree north latitude and the month as November and December we can look at the percentage values; 7.19% for November and 7.15% for December. Using these two values of percentage and using the mean temperature we can estimate the value of F which is summation of P_h monthly percent. We have already seen this as 7.19 and 7.15%. T average is 59 for November, 53.6 for December. The summation of these two sigma P_h T average for these two months comes out to be 8.07. Knowing F and K we can find out the evapotranspiration; 25.4 is conversion from inch to millimetre, K for weight and F for November and December months for 30 degrees north latitude.

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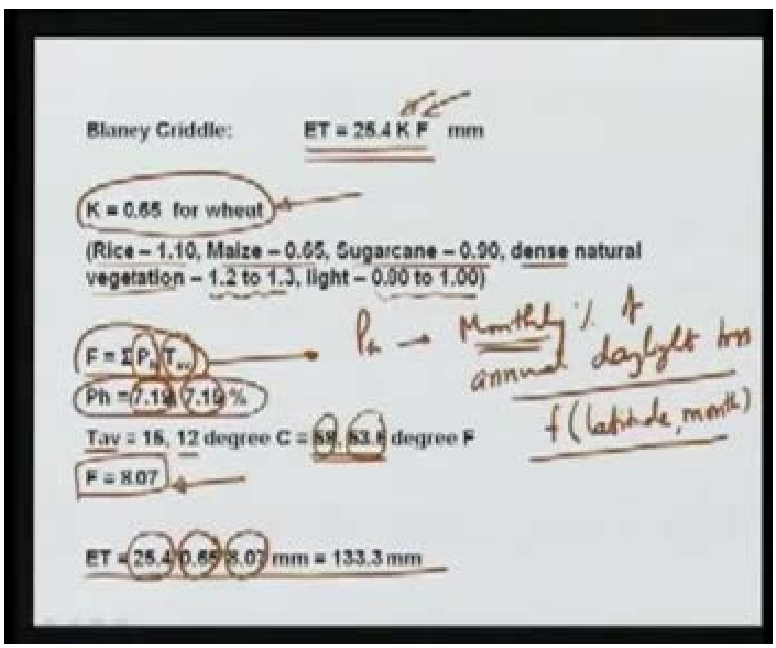

It gives us 133.3 millimetres of evapotranspiration over the two months of November and December.

Similarly if we use the Thornthwaite equation we can write ET equal to 16 La 10 T average over I_t and exponent a. The exponent a as you can see from here is given by another equation which relates it with I_t. I_t is the heat index and it is given as for the whole year summation from 1 to 12 T bar over 5 to the power 1.514 which is this equation. T bar is the average monthly temperature. The heat index can be obtained if average temperatures are given for each month. We have this additional data which should be given to us. This is the mean monthly temperature and this is in degree Celsius; Thornthwaite we are using Celsius. For January you can see that the mean monthly temperature is 10 degree centigrade. November and December are already given to us. But for this method we need to have this whole year data available to us and using this entire data set we can estimate the value of I_t and it turns out to be 96.1; T average by 5 for each month to the power 1.514 summing over all the month. This summation goes from I equal to 1 to 12 as written here. For each month we need to add up all these factors and when we do that we get I_t equal to 96.1. a is a function of I_t. Some constant into I_tq; again I_t square, I_t and a constant term which gives us 2.1.

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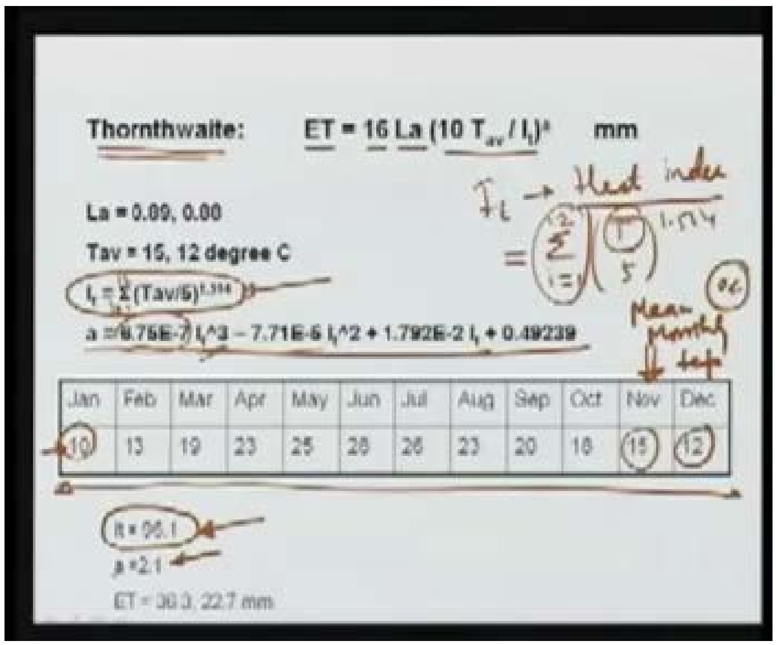

For I_t equal to 96.1 a is given as 2.1 and then the value of L_a is given in table for different latitudes and different months and this is the adjustment factor L_a and for the given latitude of 30 degrees for months of November and December we can see that the correction factor or the adjustment factor is 0.89 and 0.88.

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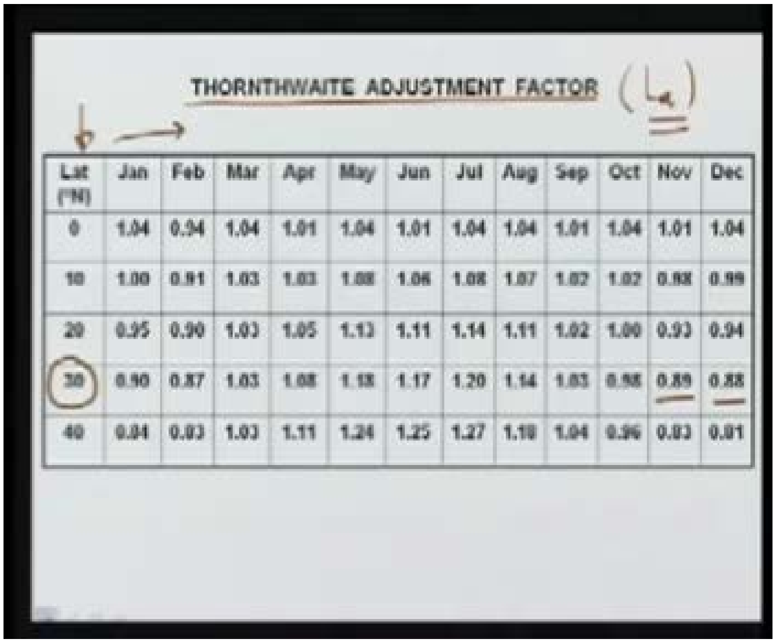
THORNTHWAITE ADJUSTMENT FACTOR (L_a)

Lat (°N)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81

Using this for these two months we can find out the value of ET as 36.3 for November; this is December and this is November; 36.3 millimetres in November and 22.7 millimetres in December. These are empirical equations but there are some theoretical equations also available to find out the evapotranspiration. The most commonly used theoretical equation is the Penman's equation.

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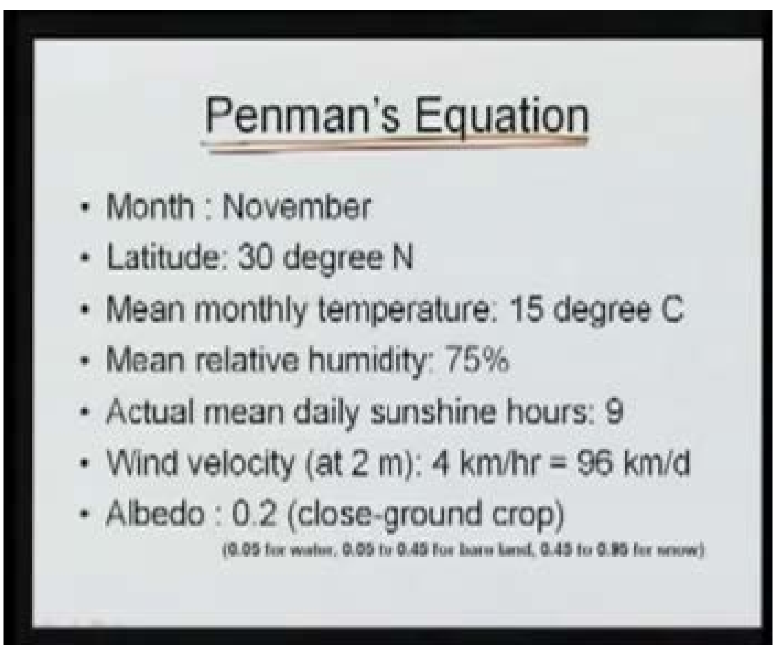

If we look at the Penman's equation it is based on the incoming solar radiation at that particular location and for that particular period of the year. So we need to have some data about what will be the solar radiation coming at different latitudes at different times of the year. There are some tables which are available for this purpose and we will look at a few of those tables which are needed in the Penman's equation which are similar to the other tables which show behaviour with different latitudes and different times of the months. In this case we can look at mean solar radiation in terms of millimetre of evaporable water per day; again for different latitudes and different times of the year we can find out what is the mean solar radiation which occurs at the atmosphere; how much water it will be able to evaporate?

The mean solar radiation is given in terms of millimetres of evaporable water per day. Because evaporation of water requires some energy this millimetre of evaporable water per day indicates what is the energy coming in at the atmospheric level and as you can see for this 30 degrees north latitude in November the solar radiation will be able to evaporate 9.1 millimetre of water per day, in December only 7.9 millimetre per day. At 20 degrees north it would be able to evaporate 11.2 and 10.3 for the months of November and December.

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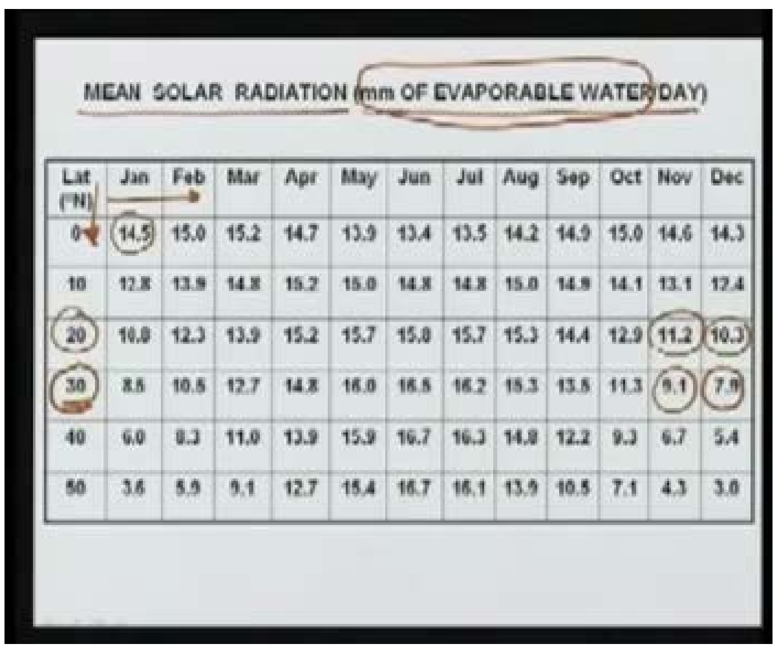
MEAN SOLAR RADIATION (mm OF EVAPORABLE WATER/DAY)

Lat (°N)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	14.5	15.0	15.2	14.7	13.9	13.4	13.5	14.2	14.9	15.0	14.6	14.3
10	12.8	13.9	14.8	15.2	15.0	14.8	14.8	15.0	14.9	14.1	13.1	12.4
20	10.8	12.3	13.9	15.2	15.7	15.8	15.7	15.3	14.4	12.9	11.2	10.3
30	8.6	10.5	12.7	14.8	16.0	16.5	16.2	15.3	13.5	11.3	9.1	7.9
40	6.0	8.3	11.0	13.9	15.9	16.7	16.3	14.8	12.2	9.3	6.7	5.4
50	3.6	5.9	9.1	12.7	15.4	16.7	16.1	13.9	10.5	7.1	4.3	3.0

The other thing which we need for most of the theoretical equations is the sunshine hours per day, the mean potential sunshine hours per day. The actual sunshine hours will be different depending on the cloud cover on that day but this is the potential sunshine hours per day and this will depend on the latitude and the time of the year. At the equator this value does not change with the time of the year. It is 12.1 hours of sunshine every day expected on the equator throughout the year. For 10 degrees north latitude again winter months; since we are talking about northern hemisphere January, February, November and December are the winter months. The sunshine hours are smaller during this time and then they become larger during the summer months. That trend you can see here also smaller number of daylight hours, sunshine hours, in the winter months and large number during the summers.

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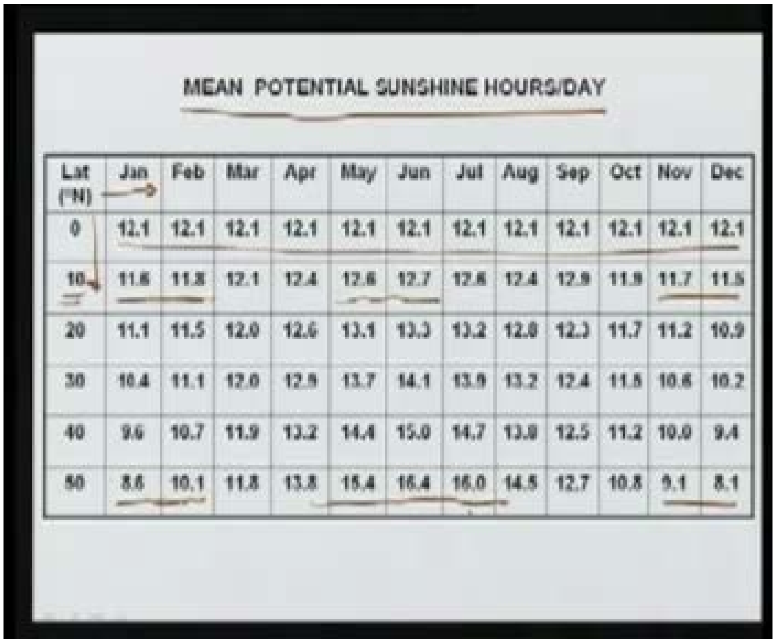

MEAN POTENTIAL SUNSHINE HOURS/DAY

Lat (°N)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
10	11.6	11.8	12.1	12.4	12.6	12.7	12.6	12.4	12.9	11.9	11.7	11.5
20	11.1	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
30	10.4	11.1	12.0	12.9	13.7	14.1	13.9	13.2	12.4	11.5	10.6	10.2
40	9.6	10.7	11.9	13.2	14.4	15.0	14.7	13.8	12.5	11.2	10.0	9.4
50	8.6	10.1	11.8	13.8	15.4	16.4	16.0	14.5	12.7	10.8	9.1	8.1

These two tables mean potential sunshine hours and mean solar radiation. They would be helpful in obtaining estimates of evapotranspiration using the theoretical equations. In the Penman's equation the equation which is given for finding out the evapotranspiration involves solar radiation. In the equation which is given by Penman the potential evapotranspiration would be some factor A times Hn; this is the radiation. Again another factor gamma, Ea is the evaporation and weighted by mean of the weights A and gamma and then divided by total value A plus gamma.

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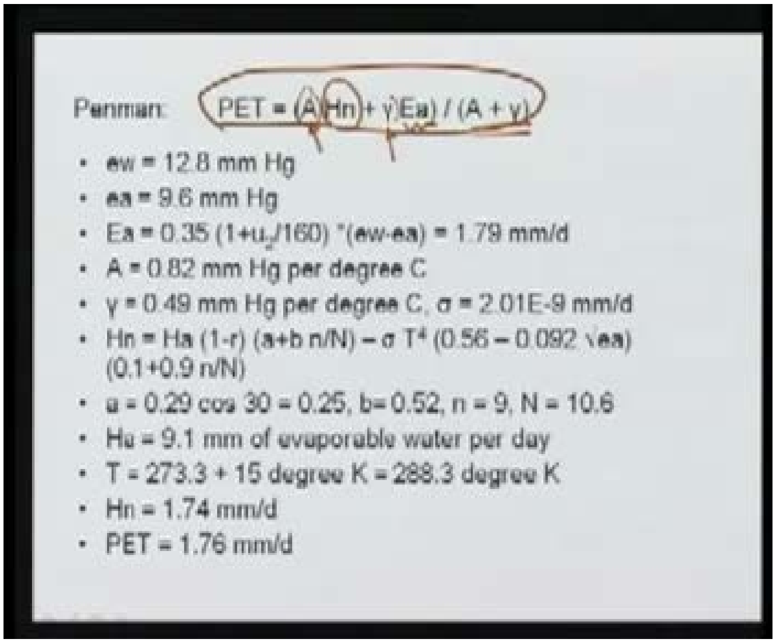

The data which is given in this example is that for the month of November at latitude of 30 degrees north. Mean monthly temperature is given as 15 degrees centigrade and in this case let's take the mean relative humidity as 75% and actual mean daily sunshine hours for the month of November are taken as 9. Potential sunshine hours are larger than this. But actual daily sunshine hours are only 9 because sometimes there may be cloud covers. Wind velocity is measured in this case at 2 metres above the surface and was found as 4 kilometres per hour. But in Penman's equation we need the velocity in kilometres per day. So we converted into 96 kilometres per day.

There is an albedo required in the Penman's equation which is the reflectance of the surface. It is given that this area is very close to ground crops which have albedo of 0.2. It is the reflectance of the surface. So 0.2 is taken as the albedo. If we have water we have 0.05 albedo. For bare land it can vary from 0.05 to 0.45 and for snow it can go as high as 0.95. But in this case albedo is given as 0.2.

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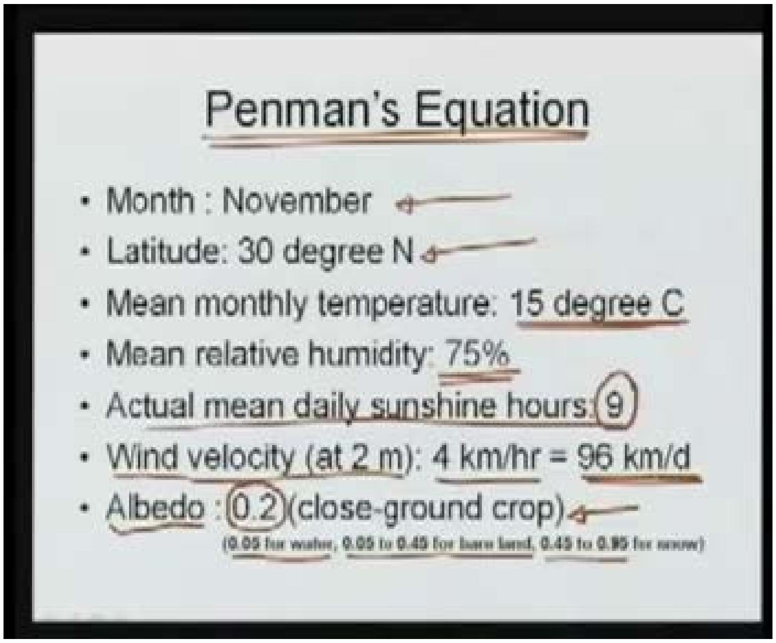

In the Penman's equation we would need the quantities; as we have seen the albedo is given as 0.2, net radiation we want at the atmospheric level, we also want a psychometric constant which is taken as 0.49. Then there is one more term which we require, the slope of the saturation vapour pressure curve. This also depends on the temperature. If you take a temperature of 15 degrees centigrade the saturation vapour pressure is 12.8 and the slope of the curve is 0.82.

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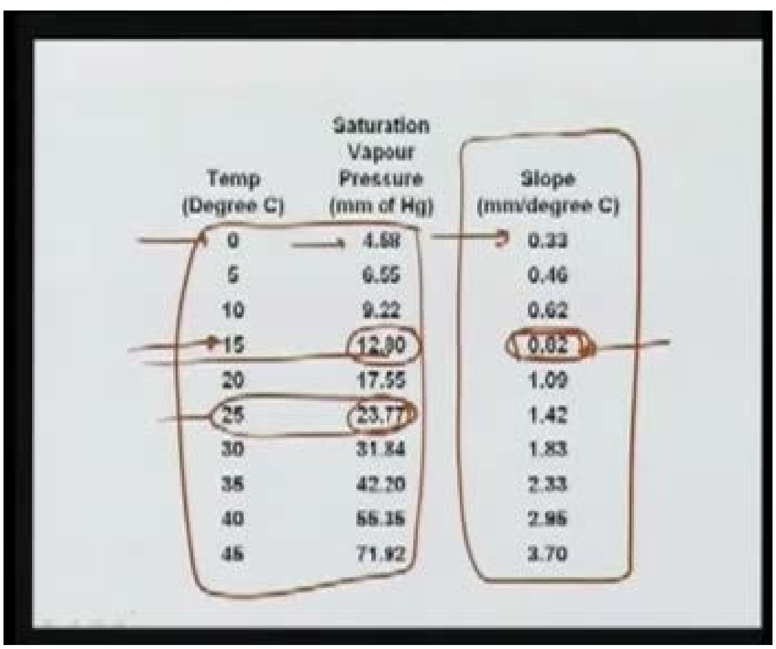

Temp (Degree C)	Saturation Vapour Pressure (mm of Hg)	Slope (mm/degree C)
0	4.58	0.33
5	6.55	0.46
10	9.22	0.62
15	12.80	0.82
20	17.55	1.09
25	23.77	1.42
30	31.84	1.83
35	42.20	2.33
40	55.35	2.96
45	71.92	3.70

This shows the saturation vapour pressure and the next curve shows the slope of the saturation vapour pressure curve in terms of millimetre per degree centigrade and for different temperatures we can find out its value.

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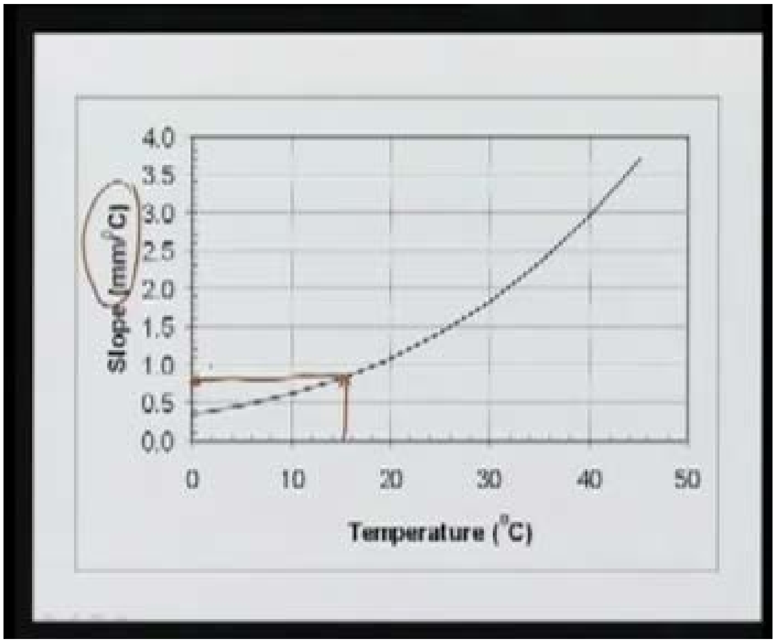

In this case for a temperature of 15 degrees Celsius the values which we will be using will be 12.8 millimetre of mercury pressure, saturation vapour pressure e_w and 0.82 as the slope of the curve. The other thing which we need is the amount of solar radiation available and if we look at the month of November for different latitudes we have these values of mean solar radiation. This tells us that using these tables and the values of the coefficients we can estimate or find out the values of different parameters in the Penman's equation. We will look at the example. The month is November and latitude is 30 degrees north. Using these data we can obtain from the table which we have shown that Ha is 9.1 millimetre of evaporable water per day. This we have seen function of latitude and month. The table gives us the available radiation as 9.1 millimetre. e_w also we have seen for the temperature of 15 degrees was 12.8 millimetres of mercury. The relative humidity given in this case is 75% percent. The actual vapour pressure will be 75% of the e_w which is obtained as 9.6.

e_w and e_a can be obtained from the temperature and the relative humidity data. The evaporation for the Penman's equation is given by this equation 0.35, wind velocity term and the saturation deficit term. u_2 means the wind velocity at 2 meters. In this case the velocity is given as 2 meters. We don't need to use the height correction and therefore we will be using 96 kilometres per day as the velocity. Using 1 plus u_2 by 160 the wind velocity term, saturation deficit term multiplied by 0.35 we get e_a as 1.79 millimetres per day. The slope of the saturation vapour pressure curve again we have obtained from a temperature of 15 degrees and it was obtained as 0.82. That is the value of A. A is the slope of e_w versus t curve and this is in millimetres of mercury per degree Celsius. The value is obtained from the table as 0.82. So A is also obtained. Psychometric constant gamma is 0.49 millimetres of mercury per degree Celsius. That value is almost a constant.

In the Penman's equation, ….. (00:43:58) constant and the value which is taken is 2.01 into 10 to the power -9 millimetres per day. The Stefan-Boltzmann constant is used here sigma T to the power 4; T is the temperature in degree Kelvin. T as we have written here for a temperature of 15 degree Celsius we have to add 73.3 and we get the T of 288.3 degree Kelvin. There are some correction factors here a plus b n by N and 0.1 plus 0.9 n by N. These correct for the actual number of sunshine hours compared to the potential sunshine hours. In this case the potential number of sunshine hours for the month of November at latitude of 36 degrees North can be obtained from the table and the value which is obtained is 10.6 hours. This means that we can have a maximum of 10.6 hours of daylight in that period on that latitude but the actual number n is only 9. This may happen due to a number of reasons. Some days may be cloudy so sunshine hours are limited. Because of this number of actual sunshine hours being less than potential hours we have these correction factors a plus b n by N here and 0.1 plus 0.9 n by N here in which a is related to the latitude as 0.29 cosine of the latitude, in this case 30 degrees and it comes out to be 0.25. b is constant equal to 0.52; r is the albedo given as 0.2. Ha available solar radiation that we have seen will depend on the latitude and the month and from the table we have seen the value as 9.1. In this equation all the terms are known and we can find out the net radiation in terms of evaporable water per day as 1.74 millimetre per day.

As we can see here Ea and Hn both have been obtained. In this case they are very close. Hn is 1.74 and e_a is 1.79. In this case the relative magnitude of A and gamma will not really matter because these two values are very close. Whatever weight we assign to individual values will not affect the calculation very much but still if we use A and gamma as weights we get potential evapotranspiration as 1.76 millimetres per day. For the month of November at latitude of 30 degrees North we can expect if the actual sunshine hours are 9 per day on an average and relative humidity is 75% then we can expect for a wind velocity of 4 kilometres per hour and for an albedo of 0.2 that the potential evapotranspiration from that area would be 1.76 millimetres per day.

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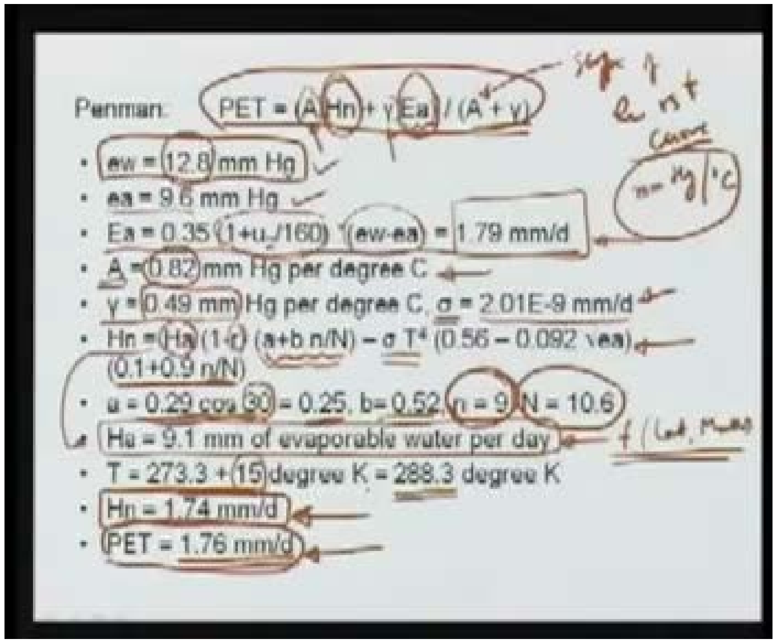

Using either the theoretical equation where Penman's is the most common or some empirical equations for example Thornthwaite we can find out what is the potential evapotranspiration from that area. Knowing the initial abstraction and the potential evapotranspiration the only other abstraction which we need to look at is the infiltration. Infiltration depends on the soil type and as we have seen there are some curves which relate the temporal variation of infiltration rate. Infiltration rate will be very high at the beginning of the storm and as we move further in time infiltration rate will decrease because the soil has become more saturated. The soil may also become compacted because of the impact of the raindrops. Generally the infiltration rate will decrease with time. There will be some rate here at time zero, there will be some rate here at infinity and then an exponential decrease is specified as the change of infiltration with time. But it becomes very complicated to estimate these parameters f_0, f infinity and there is some rate here which is like e to the power –kt; finding out this K also becomes complicated.

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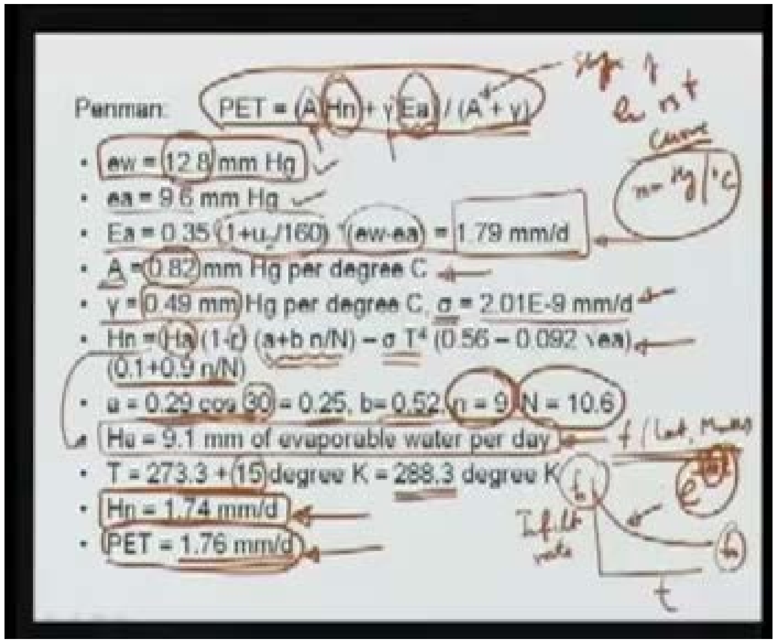

There are some simple methods which can be used to estimate the infiltration loss. The infiltration indices in a way represent an average value of the loss. The most commonly used index is the phi index and what it means is some kind of average loss from the precipitation. If we are given a storm hyetograph, for example a storm may look like this, intensity may be millimetre per hour and time in hours. We may be given that rain occurs with this intensity and this temporal variation and we may be given runoff. Knowing the amount of rain and the amount of runoff we can estimate what are the losses and using those losses we can estimate what is the average loss expressed in terms of phi index.

Let's take an example in which the precipitation of 88 millimetre occurs in 8 hours as shown in this table. From 0 to 1 hour the intensity is 4 millimetres per hour. Similarly 1 to 2 is 8 and 7 to 8 intensity is 5. If we add all these up we get 88 millimetres of precipitation. It is also given that because of this rain there is a 46 millimetre of runoff and a total loss of 42 millimetre takes place for this particular event and when we say this loss this includes all losses. So everything else goes as runoff. Now in order to find out the phi index what we need to do is draw a line here such that the area above this represents runoff and the area below this represents the loss. Then this value is called the phi index.

How to compute this phi index? Basically we want the total precipitation and runoff so that we can find out the losses and then we have to adjust this line in such a way that the area below that is equal to loss. So in this case we can say that the average loss is in 8 hours; we have loss of 42 millimetres. The average loss is 5.25 millimetres per hour but if we look at the table we can see that for the first period and the last period, rainfall intensity is smaller than 5.25. First period is only 4, last period it is 5. So in the first period and the last period the losses cannot be 5.25 because the losses are limited to the amount of rain. Whatever rain is falling all of it can be lost but no more than that. So what we have to do now is one more iteration in which we assume that in the first hour the loss is 4 millimetres in the 8^{th} hour the loss is 5 millimetre and in other 6 hours we have to find out what will be the loss. We can say that a loss of 42-4-5 will be in 6 hours which means that a loss of 33 millimetres in 6 hours giving us average loss of 5.5 millimetres per hour and all the other values are higher than 5.5. Therefore we can say that phi index is 5.5 millimetre per hour.

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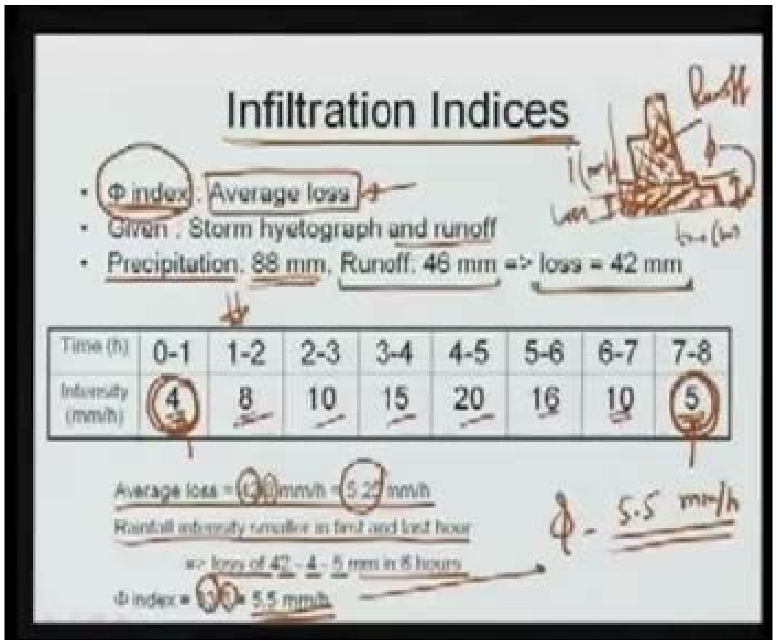

In this way we can obtain the value of an average loss over the entire period. If we look at the hyetograph and let's say that the phi index is somewhere here then we can say that this t_e will be the duration of effective rainfall or excess rainfall. This rainfall is what is contributing to the runoff and the rest is lost to infiltration, evaporation and abstraction.

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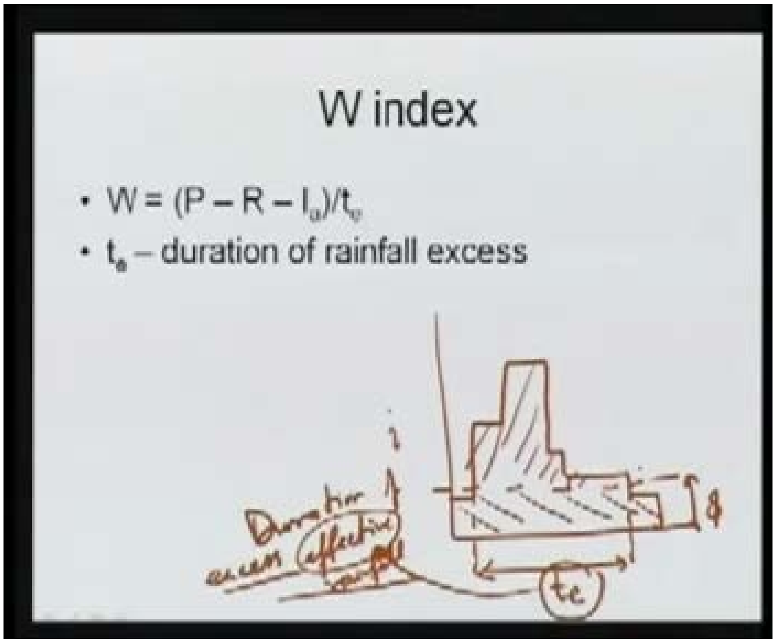

The six here represents the effective t or the time of excess rainfall. So phi index is very commonly used to estimate the average loss. There are some other indices also. There is a W index which is given as precipitation minus runoff minus initial abstraction divided by the duration of rainfall excess but phi index is little more common. There are some other methods also of estimating phi index. After getting the phi index we can prepare a table like this which shows for different times what is the excess rainfall? That means after taking care of the losses what is the additional amount and in this case if we look at this table this 4 is completely lost; out of this 8 we have a loss of 5.5 millimetres. All the other values we subtract 5.5 except the first and the last that becomes zero and a sum of all these will turn out to be 46 millimetres.

Central water commission, CWC of India has given an equation by correlating the runoff with rainfall. If rainfall of I centimetre per day occurs in 24 hours, the runoff can be correlated by alpha I to the power of 1.2. Alpha depends on the soil type; 0.2 for sandy and 0.45 for clay.

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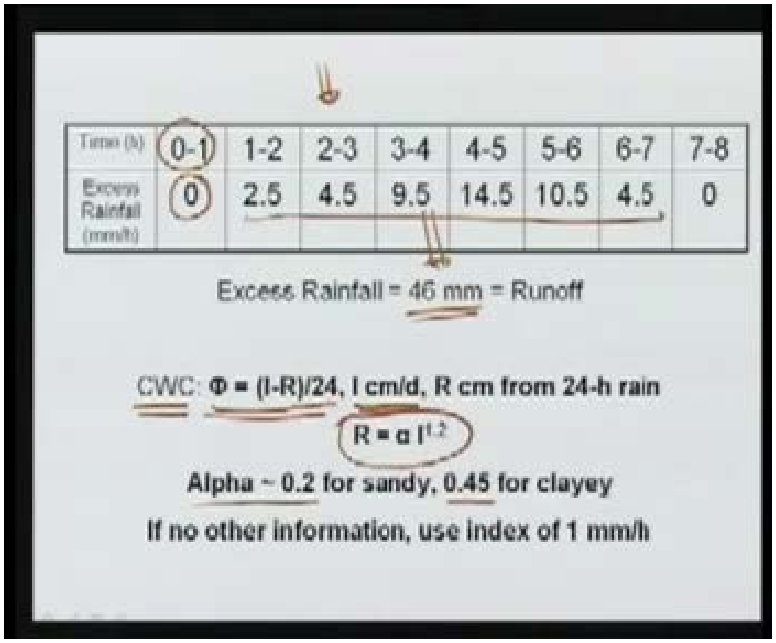

We have a higher runoff for clay soils and then phi index can be defined as I minus R divided by 24 and can be used to estimate the effective or excess rainfall duration.

In today's lecture we have seen various abstractions and how to compute them. We have looked at the initial abstraction, the evaporation, evapotranspiration and infiltration. We have looked at various empirical and theoretical methods to obtain an estimate of these parameters which can be used to find out how much percentage of rainfall will be lost and how much will go as runoff which is our main part of interest as to how much runoff will occur due to a particular storm effect.