Water Management
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Lecture 08
Crop Water Requirements (Continued)

In the last lecture we had starting looking at the various methods of computing reference crop evapotranspiration and we had decided that we will look at all the methods which are proposed by the FAO. We had seen the Blaney Criddle method. We had gone to the various aspects of Blaney Criddle method which are proposed by the FAO. Before we go to the next method which is the radiation method I will like to give you the various nomenclatures which the FAO has used.

In all these methods they have used this climatological nomenclature which helps in putting these climate variables into different categories because whenever the data is not available it was felt that it is better to take a range and a nomenclature is used to express these ranges and that I thought will be better if we at least look at how they have been differentiated? How they have been put in these ranges?

The various major climatological factors. Temperature, mean temperature is used, the mean temperature is the average of maximum and minimum temperature.

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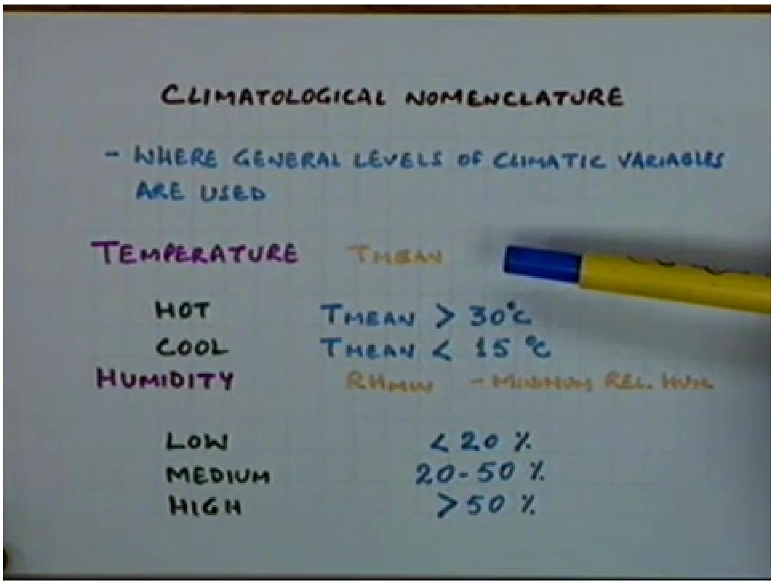

In most of the places you will find that normally the two temperature readings are taken. The temperature is recorded continuously but out of those values which are recorded, two values are picked up, one which is the maximum observed value and the other which is the minimum observed value. The mean temperature is nothing but it is if you have maximum temperature and you have minimum temperature, if you take the average of those two values it is what is the mean temperature.

When the mean temperature is more than 30 degree centigrade then the conditions are known to be hot. When the mean temperature is less than 15 degree centigrade it is called cool condition. Similarly in the case of humidity you will find some methods that require the minimum relative humidity to be used and some other methods require the mean relative humidity to be used.

So, while using the minimum relative humidity these are the various (climatical) climatological levels which has been used, low, medium, high and these are the various ranges of the levels which are associated levels for the minimum relative humidity.

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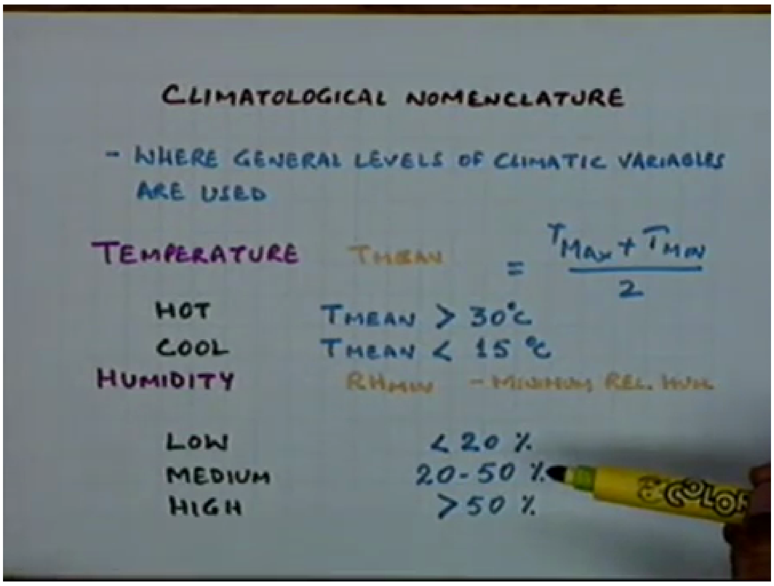

Then the mean relative humidity these four levels have been defined, low, medium low, medium high and high and these are the associated ranges less than 40 percent, 40 to 55 percent, 55 percent to 70 and greater than 70. Similarly the wind, again there are two different units which are used to express the wind conditions. One is in metres per second and the other is when you are using the wind run for the whole day at that situation it is expressed in terms of kilometres per day.

So there is only a conversion factor which is differing the two. In one case again there the wind speed can be instantaneous because when you are observing, you are observing the instantaneous values but then if you average them out over the whole day then you can express them either in the form of metres per second or in terms of the average wind run for the whole day.

What is the wind run in terms of kilometres per day, okay. And these win conditions are expressed in terms of light, moderate, strong, very strong. Most of the time you will find that these conditions are picked up from the weather reviews.

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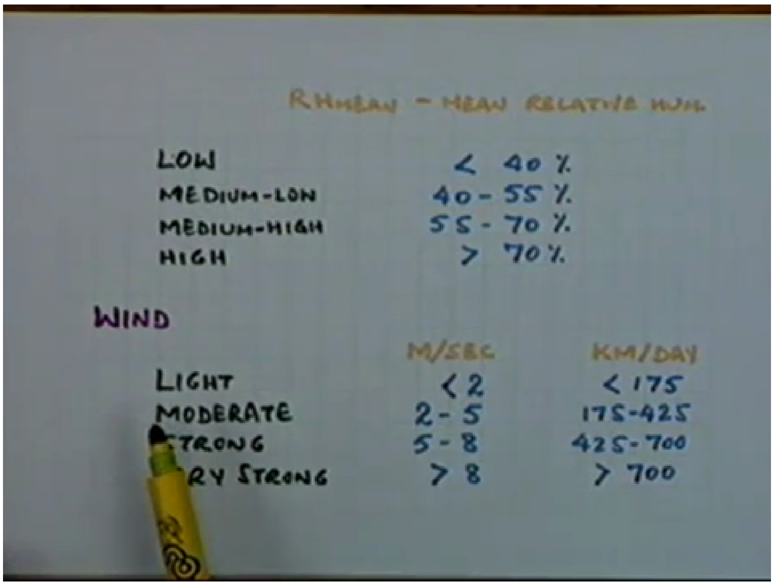

Every area has the published records. Whereas these conditions are used only in those situations where you do not have the actual observed data available and you are using the average conditions which are influencing the evapotranspiration activity to a great extent.

So in the absence of those actual values you are using the average values and since these average values are either average overtime or their values which are representative values for that area is when you look at the weather records, the weather reviews which are normally published by the local meteorological office you will find that they are available on the monthly levels or those records are not in the form of actual data, the instantaneous data. They are in the form of average values.

So these are the average conditions. That is a reason that these average conditions are defined so that you can make use of these average conditions and you can incorporate them while computing the evapotranspiration values. Or for the time being we are discussing only ET not which is the reference crop evapotranspiration value.

So whereas in the case of wind sometimes you might be getting the wind in relative terms that you are having the wind conditions which are light and there might be a corresponding explanation that what are the light conditions? The light conditions are when you can experience the wind on your face. Moderate conditions they will be conditions when paper can blow.

So you might be having some thumb rules to decipher these conditions or there might be some conditions which you can express in terms of the actual happenings and you can designate these general conditions with respect to those occurrences if you do not have the records available in terms of the actual values or the average values. So even that is possible.

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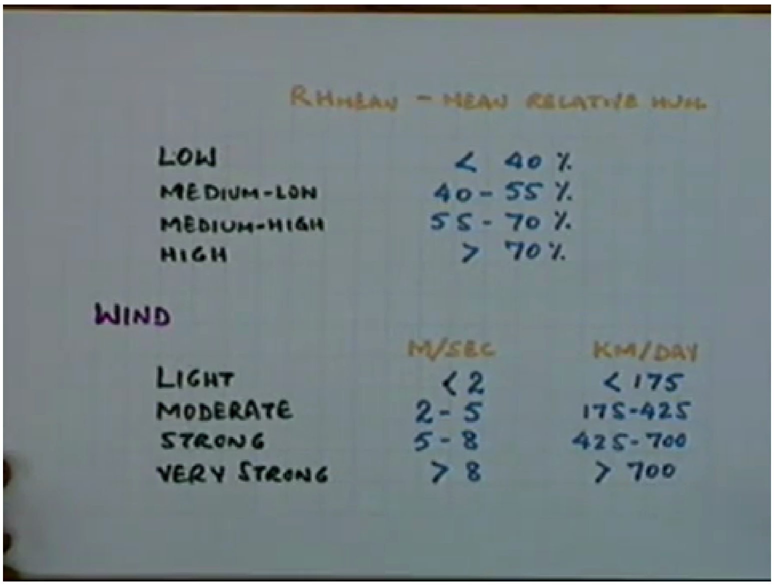

Similarly the other parameter is radiation. The radiation can be expressed in different forms. It can be either in the form of sunshine hours and if it is in the form of sunshine hours it will be the n by N ratio. We will come to these terms later after a while. These three conditions are expressed low, medium and high and these are the ranges. Then cloudiness and if the radiation is expressed in the form of cloudiness then there are two ways by which the cloudiness can be expressed.

There is one system which is known as tenth system and there is another system which is known as Oktas system. So these two ranges are given and these are the nomenclatures low, medium and high and these are the corresponding levels.

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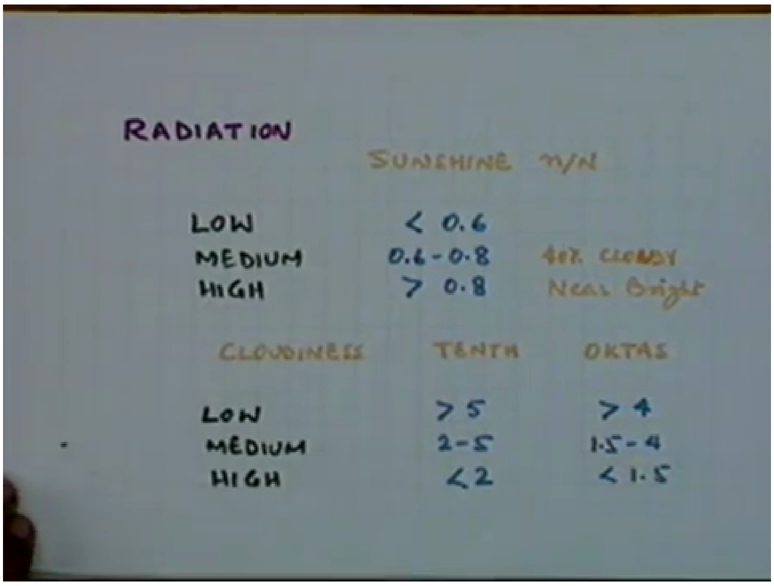

Now next let us come to the next method of calculation of ET not which we had seen that in this method you have the observed data on temperature and sunshine and the radiation data can be used if it is available. If it is not available you can use some relationships for this particular data.

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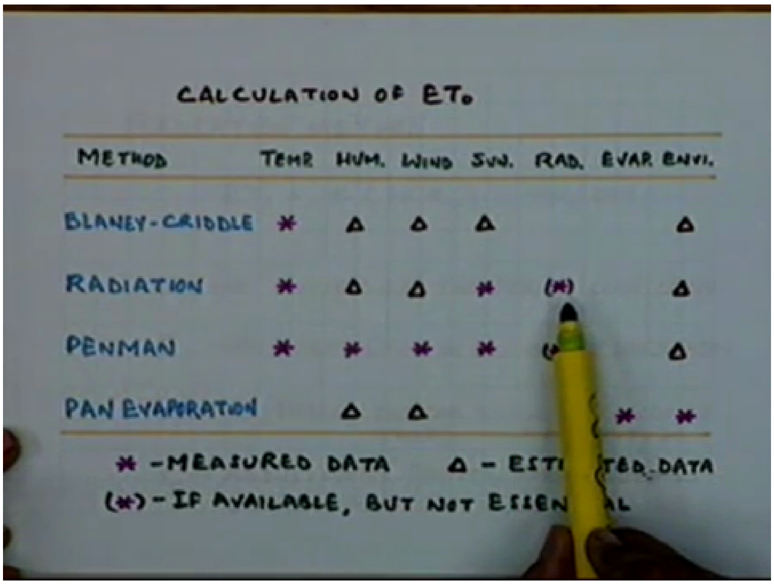

In this method there is an expression which is used to represent the radiation method and this ET not which is the reference crop evapotranspiration for a period under consideration expressed in millimetres per day is a function of R s which is the solar radiation in equivalent evaporation. Solar radiation can be expressed in many forms but in this particular expression the solar radiation is converted into equivalent evaporation expressed in millimetres per day.

And W is the weighting factor which depends on temperature and altitude and C is the adjustment factor which is dependent on the mean humidity and daytime wind conditions.

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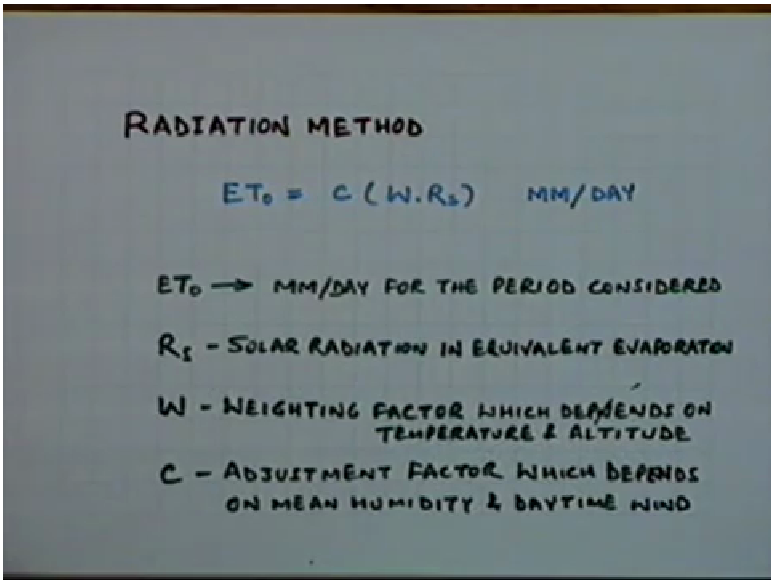

So again you will find that if we compare this with the expression used for the Blaney Criddle it looks the similar expression. In all these methods you will find that a factor has been used which is basically the improvement which has been done on the method. This factor because in all these methods it has been found that there are some of the factors which are very active and they are making lot of difference.

They might not be making difference in terms of the computation of ET not when the conditions are within the range for which the method has been used or for which the method has been formulated. But when you go beyond those ranges then the method was not performing very well. So, there are few experts or the team which was interested with this particular job.

They have tried to look at all these methods and go beyond their recommended ranges and see how they performing those ranges in those areas in which they were not developed or which were different from where they were developed and that is how they have come out with some recommended additional constraints or additional factors which can be incorporated and some corrections can be made.

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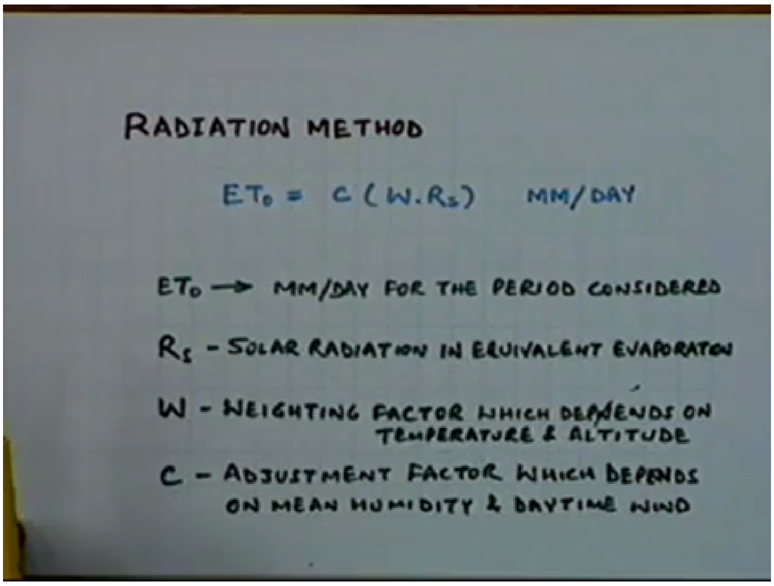

Let us go into the various elements that how do we find out the various elements of this equation? First of all the solar radiation R s. When we want to know R s, R s is basically let me use this, this is the sun. Now from the sun this is what is the cause of the solar radiation.

The rays which are coming and travelling towards the Earth, if this is the Earth, the radiation which is coming up to the atmosphere if this is the level beyond which the atmosphere makes lot of impact then this component is R a, the solar radiation which is approaching the atmosphere, which is reaching the atmosphere.

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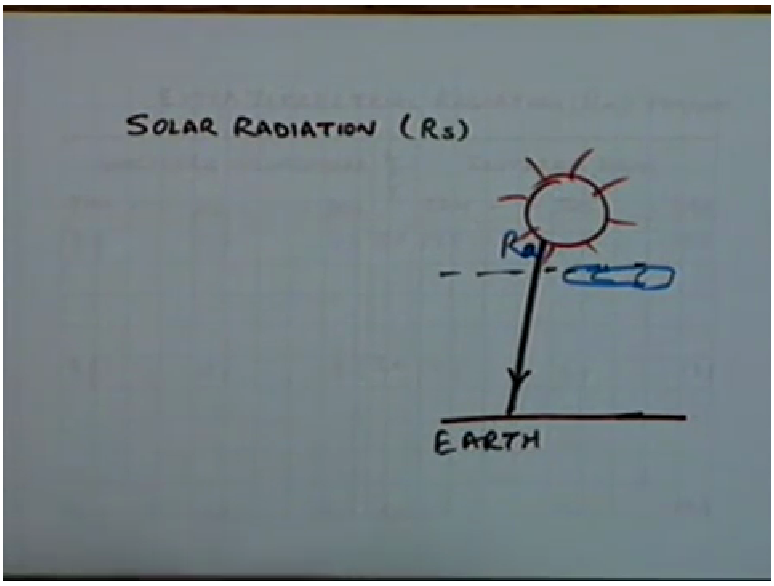

Now this solar radiation R a is basically a function of only two things, one the latitude. What is the latitude of the place which you are interested in? Which you are considering to find out how much is the solar radiation which is coming to that location? And the second is which is the period in question? So the location is defined with respect to the latitude and the hemisphere. Which hemisphere you are in the latitude with respect to the hemisphere will pin point which is the location in question?

And then the variation with respect to the period. So there is a table which is a unique table which is a fixed table which gives the extra terrestrial radiation R a for different locations on the earth and that is the table which is with respect to latitude and the southern hemisphere, northern hemisphere and for different months.

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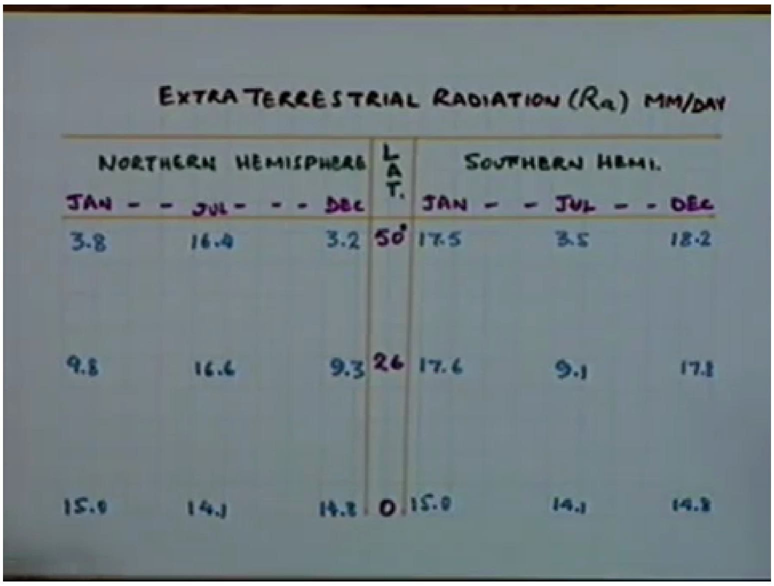

EXTRA TERRESTRIAL RADIATION (R_a) MM/DAY

NORTHERN HEMISPHERE			LAT.	SOUTHERN HEMI.		
JAN - -	JUL - - -	DEC		JAN - -	JUL - -	DEC
3.8	16.4	3.2	50°	17.5	3.5	18.2
9.8	16.6	9.3	26	17.6	9.1	17.8
15.0	14.1	14.8	0	15.0	14.1	14.8

These are some of the values which are picked up just to show you because the table in the full form this is the table which gives the R a value for, this is the latitude, the southern hemisphere, northern hemisphere, January to December, January to December and these are the different values.

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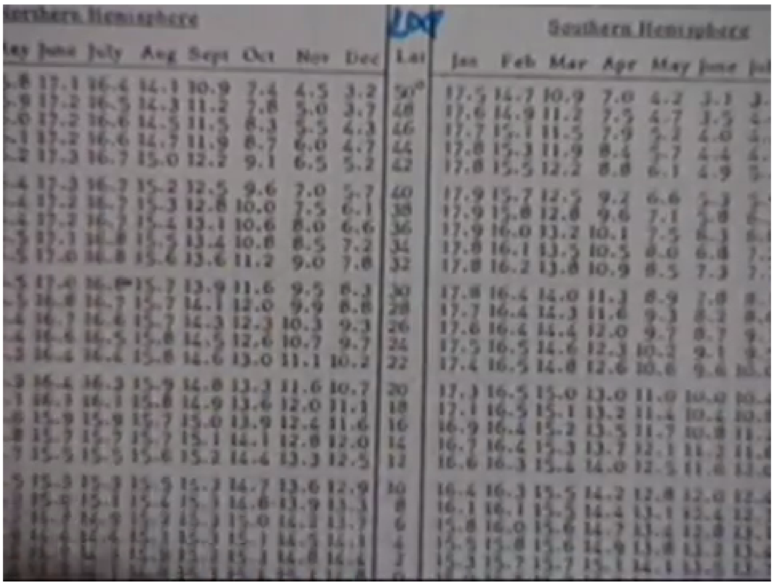

Northern Hemisphere								Southern Hemisphere					
June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June
17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1
17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5
17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0
17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4
17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9
17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3
17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8
17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3
17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8
17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3
17.0	16.8	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8
16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2
16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7
16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1
16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6
16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0
16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4
15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8
15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2
15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6
15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0
15.0	15.1	15.4	15.1	14.6	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	15.8	16.0	15.6	14.7	13.4	12.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	15.5	15.8	15.6	14.9	13.8	13.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	15.3	15.7	15.7	15.1	14.1	13.5

So once you know the latitude, you know in which hemisphere it is, you can use this table to find out how much is the solar radiation approaching the atmosphere? Okay. So once R a is known this is the maximum radiation which can come, which can reach the earth at a particular time for that specific location. This remains fixed but what happens, some part of this radiation is absorbed by the atmosphere.

So it depends on the condition of the atmosphere, it is a function of atmospheric conditions how much of this radiation will get absorbed and how much will be scattered? So there is a part which is reaching the Earth surface. That is known as the R s.

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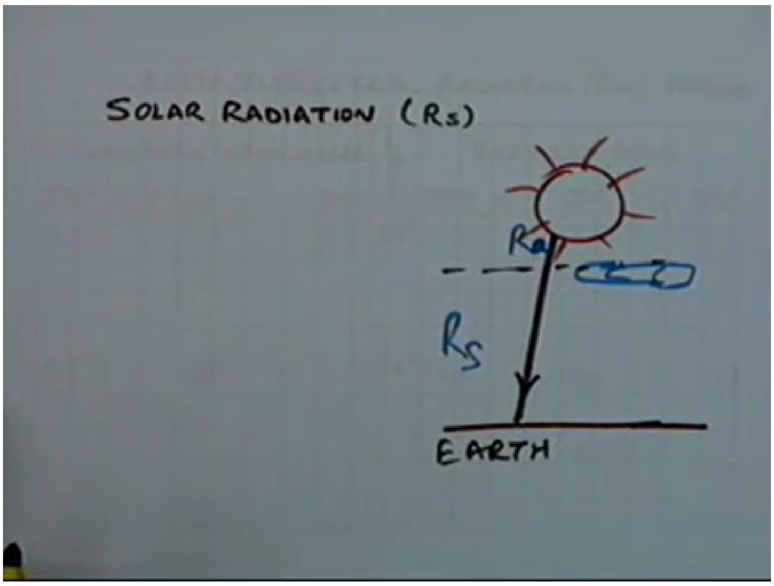

That part is known as the solar radiation and it can be directly measured it is fine otherwise it can be obtained from this expression where you are using the sunshine ratio. This n by N is a sunshine ratio which is expressed as the ratio between actual measured bright sunshine hours and maximum possible sunshine hours. Now this maximum possible sunshine hours again as we have seen in the previous lectures that this is something which is fixed.

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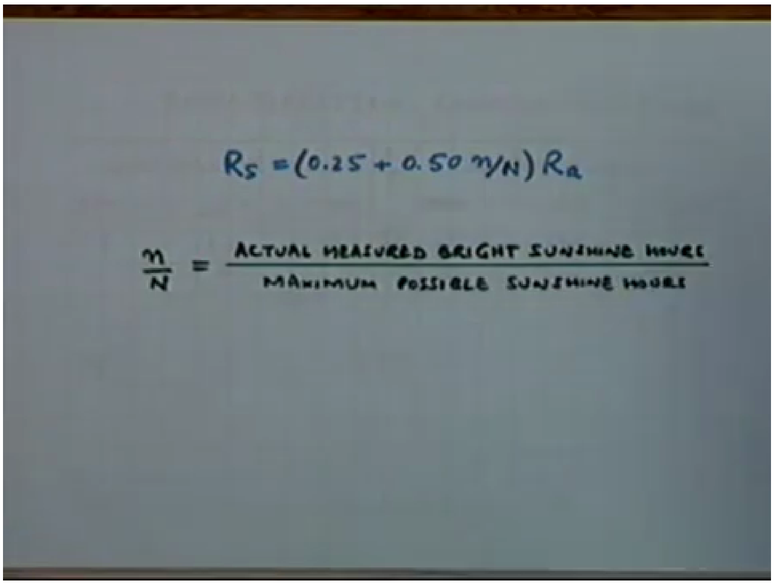

The maximum sunshine hours again is a function of which location and what time of the year? So there is a table which gives the mean daily duration of maximum possible sunshine hours at different latitudes and for different months and this table give you a value which is N value which is the maximum possible sunshine hours which is the difference between the sunrise and the sunset which remains fixed.

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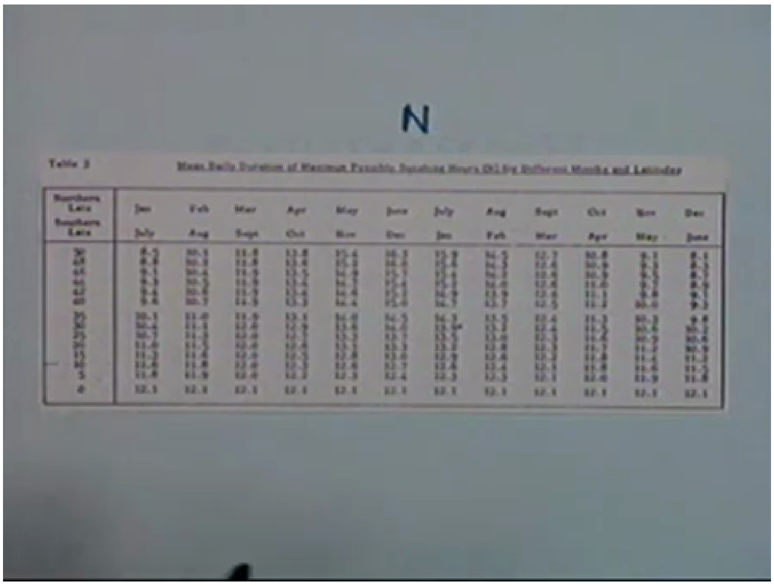

So it is independent of whether it was cloudy or it was not cloudy you are looking at if there is no cloud then what is the possible number of sunshine hours? That is what is given by this table. And this small n which is used here is the actual measured bright sunshine hours.

That is basically there is a possibility that if the sunshine is not or the solar radiation is not reaching the Earth surface it is because of the fact that there is some cloud prevalent at that particular location. So the activity of evapotranspiration will be totally influenced by the number of sunshine hours which were prevalent at that particular time or during that duration.

If you are taking a particular month in that month how many sunshine hours were there and how many sunshine hours were possible that ratio is used to find out what is the solar radiation which is reaching the Earth surface? Okay. So once you know what is the R s in which you have taken into account the effect of the clouds, for how long the clouds were there? To find out the small n value there are various ways by which you can know what is the n value?

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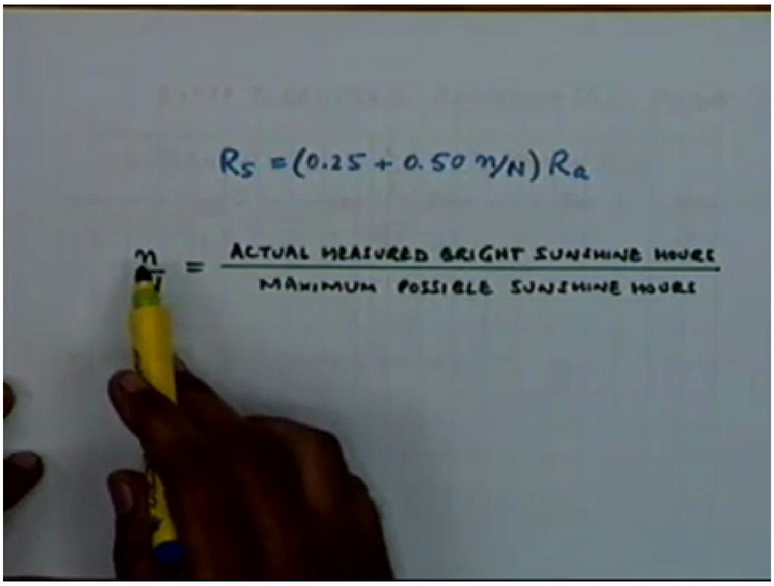

There is an equipment which is quite often used which is known as in general the sunshine recorder. The Campbell Stokes sunshine recorder is equipment which is quite often used to find out how much is the number of hours which were actually sunshine hours in a particular day and the way it is done is that use a strip of paper and you have a ball through which you let the rays of the sun pass. The paper is attached behind this ball.

So it has the same effect as when you take a lens and burn the paper, it has a similar effect. So depending on for how long the sunshine was available it will have the paper burnt for that duration. So it can be calibrated and at the end of the day you can find out what is the length of the paper which is (())(24:59) and accordingly you can find out what is the n value?

So the actual sunshine hours you can make a measurement on those sunshine hours using this. The cloudiness can be expressed in the form of Oktas or tenths. So this is the relationship between n by N ratio and cloudiness.

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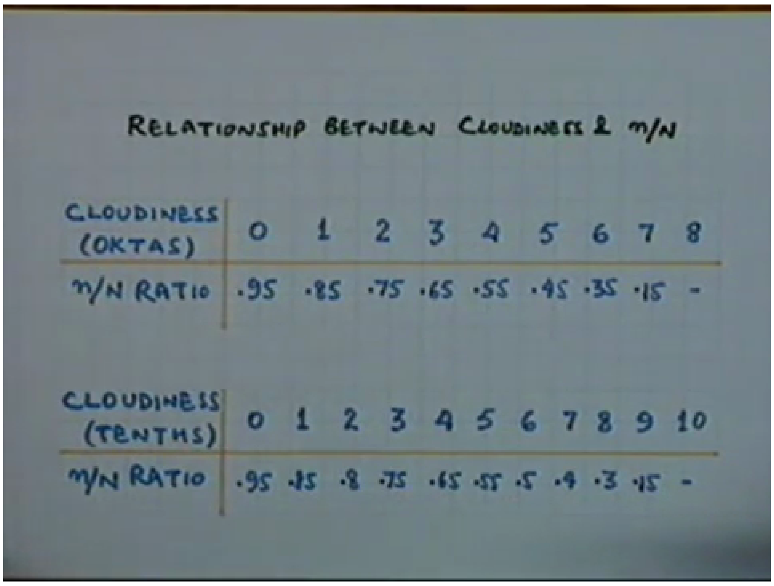
RELATIONSHIP BETWEEN CLOUDINESS & n/N

CLOUDINESS (OKTAS)	0	1	2	3	4	5	6	7	8
n/N RATIO	.95	.85	.75	.65	.55	.45	.35	.15	-

CLOUDINESS (TENTHS)	0	1	2	3	4	5	6	7	8	9	10
n/N RATIO	.95	.85	.8	.75	.65	.55	.5	.4	.3	.15	-

If you have the cloudiness available instead of n by N ratio or the sunshine ratio then you can convert that cloudiness into the equivalent sunshine ratio so that you can use it in the equation to find out the ET not. And this relationship or this conversion again is available in FAO 24 at publication on crop water requirements. All this material which I am using you can refer to crop water requirement publication or the research paper on irrigation and drainage division by FAO.

There are given all these relationships and all these details in a very elaborate manner. Next let us have a look at the weighting factors W because in the equation ET not is equal to R s into W into C. That is what we have the relationship. So we have looked at R s, the solar radiation. W is the weighting factor which is used to differentiate the impact of temperature and altitude on ET not.

So this table you have the temperature, this is the temperature given on this side from 2 degree centigrade to 40 degree centigrade and for different altitudes and the altitude varies from 0 to 4000.

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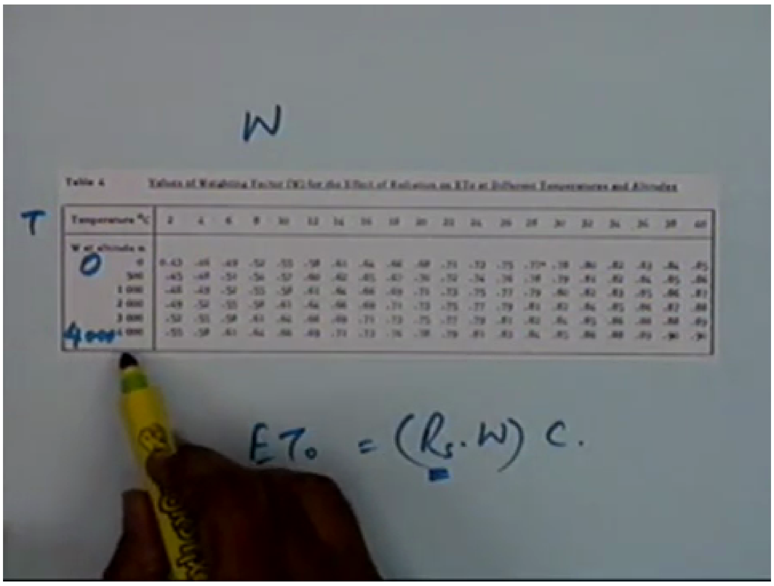

The values of W are given here. You can see here that as we go closer to higher temperatures, the factor is approaching 1. That means the conditions under which the radiation equation has been used or has been formulated as such it was more near such conditions, this area where it was closer to 1 where the temperatures are slightly higher on the higher side and even the altitudes are also somewhere in this range from 500 metres to around 2000 or 3000 metres.

In this zone where the values can even go t point 43 when the temperature are 2 degrees centigrade that means the lower the temperature it was felt that it was giving very high results. It was over stimulating the values which you were getting they were much more than the actual values. That is why a weighting factor of almost half or less than even point 5 has been recommended.

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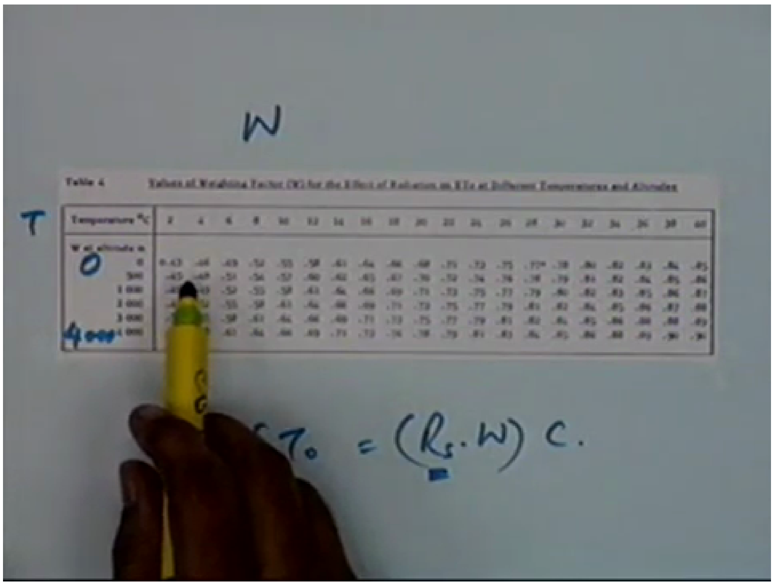

Now coming to the last factor which is the correction factor small c, again a table has been recommended. A graphical four different figures have been recommended where only two parameters are now used. One is the mean relative humidity, this is R H mean. Is it visible or I will write here. This particular mean relative humidity is medium to high, 55 percent to 70 percent in this figure and when the R H mean is greater than 70 percent then this figure is recommended.

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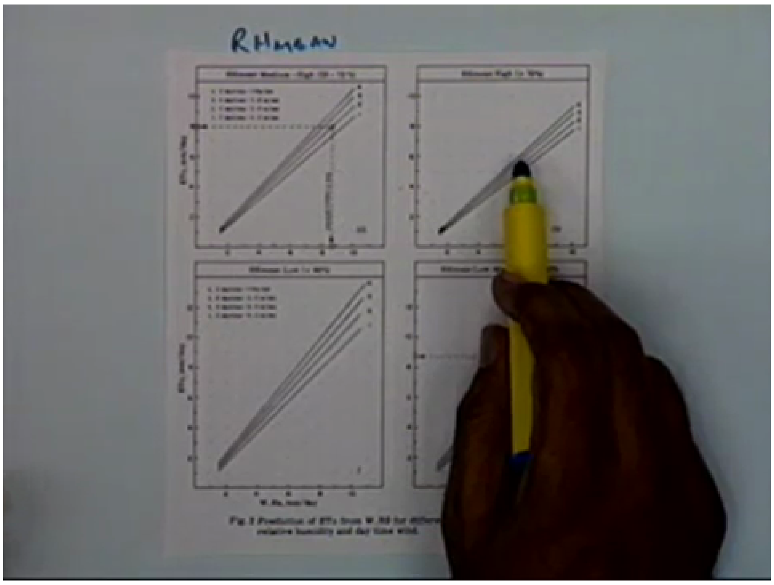

Again in constructing all these figures again the stepwise regression analysis has been done and that is how these figures have been obtained by taking each individual parameter into consideration and looking at its impact. The other parameters which are used are the daytime wind conditions, the daytime wind speed and there are four different wind speeds which have been taken, 0 to 2 metres per second, 2 to 5, 5 to 8 and greater than 8 metres per second. So these four are represented by this number 1, number 2, number 3 and number 4, these curves.

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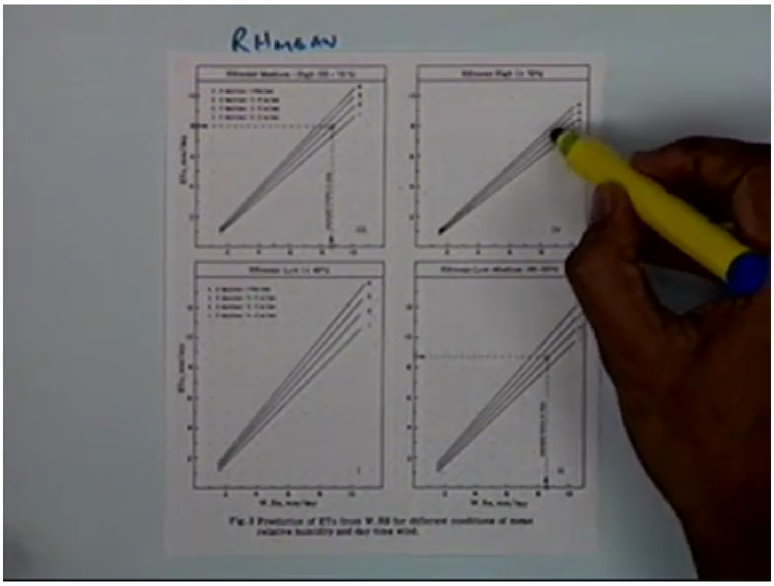

And depending on these two parameters the relative humidity which is the mean relative humidity and the wind conditions the value of c has been recommended. So on this side you have this is basically W into R s . The W into R s once you find W into R s after finding out each individual item you can look at what is the mean value of relative humidity.

That can be found out and then you can find out which is the relevant figure. If the relative mean humidity is high, use this. If it is medium high, use this. If it is low then this figure is valid. If it is low medium, this figure is valid.

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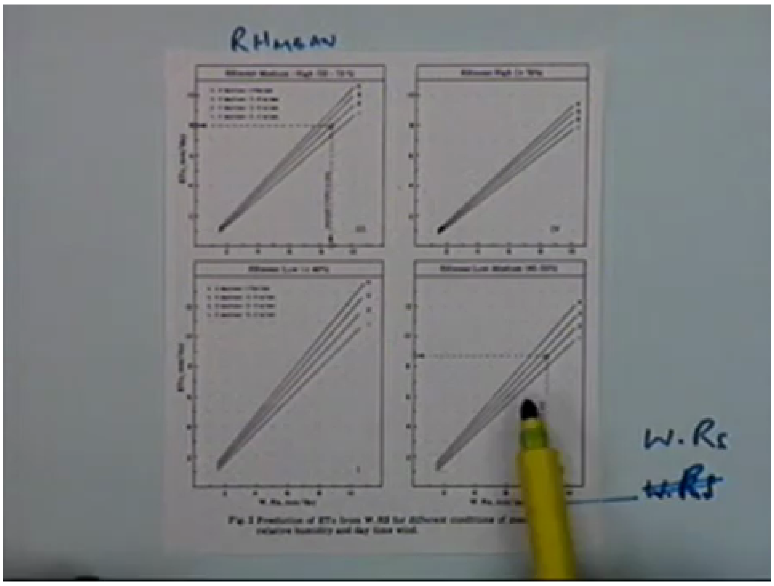

Then you can find out what is the u daytime wind condition, the u day time and which particular condition is valid accordingly choose the appropriate line and then you can find out what is the value of ET not? So having W into R s value available and after knowing which is the corresponding R H mean which has to be used along with the wind conditions you can directly use this. Go up in this direction, if 2 is the u day condition then move horizontally and this value, the value can be read, this value is ET not in millimetres per day.

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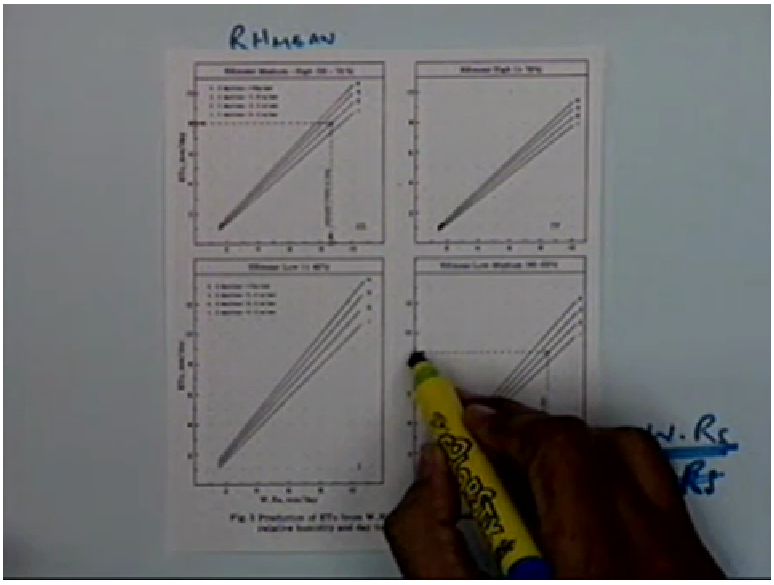

If you do not want to use the graphical presentation then this can be converted into some tables which can be used in a computer system. only thing is that you have to interpolate between the two values. So the linear interpolation can be done if you get a value which is in between the two values because then you will have to give all these points in the form of either equation or in terms of the actual values for different levels.

So if you give in terms of the actual values in the form of the table then you will have to have incorporate interpolation procedure and that can also be done. So it is not difficult, the packages are available where the interpolation is resorted to. You do not have to actually use these figures. These figures can be converted into equivalent tables or in the form of some equations which can be directly used. But if you are doing it manually then it is much easier to use these graphical figures.

Now with this the method on radiation is taken care of and this method again gives reasonably good results and it depends on whether you have the data available which is the required data. Now coming to the next method which is the Penman method, this method is the most efficient and most accurate method. But at the same time it requires a very large amount of data.

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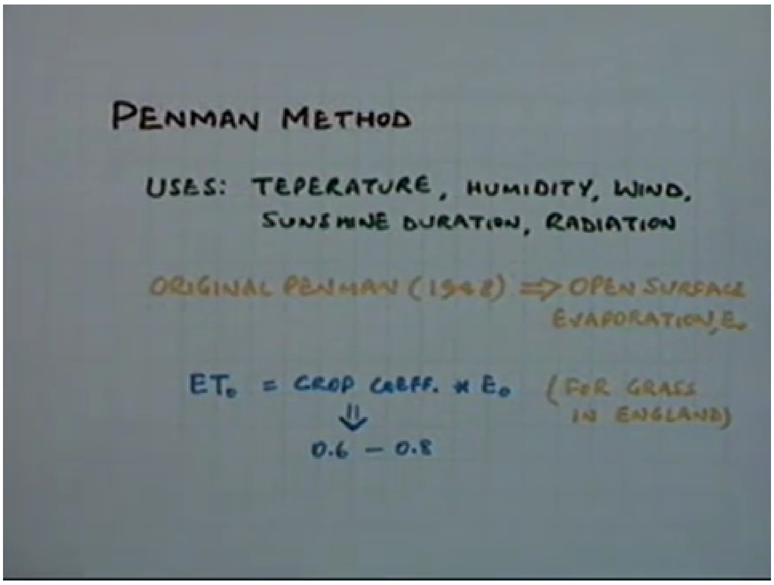

If we again go back to the same figure, what is the data which is required for the Penman method? You will see that it requires the data on temperature, humidity, wind conditions, sunshine data and as well as the radiation data.

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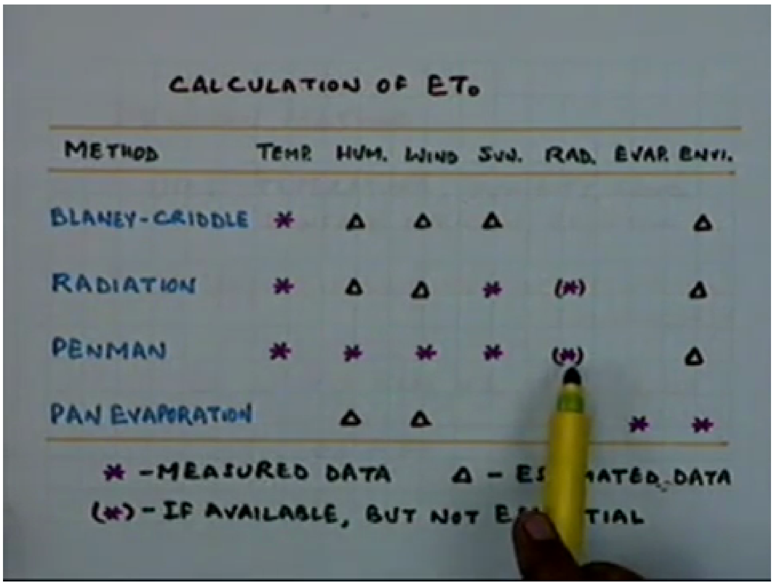

This method was put forward by Penman in 1948 and at that time the method was basically introduced to find out what is the open surface evaporation. Later on it was felt that the same method can also be used for evapotranspiration because basically the factors which affect evaporation is the same factors which affect the evapotranspiration also.

So when you talk of evaporation from water bodies that is something which is the potential evaporation from the water bodies as when you say potential evaporation what we are saying indirectly is that there is no dearth of availability of moisture or we are saying that there is no constraint on the availability of moisture. That is why from water bodies whenever you say evaporation it is always at the potential rate.

Whereas the other thing is not true if you are talking in terms of the evapotranspiration from the soil surface or from the land. It is not always at the potential rate because it is dependent on what is the availability of moisture in the root zone depth. So when you say evapotranspiration though in all these equations which we have seen so far, in all these methods which we have treated so far, we are making an inherent assumption that there is no dearth of moisture availability.

There is no constraint on the moisture availability. That is why the ET not which we are trying to find out, the reference crop evapotranspiration, it is the potential value, it is the maximum value which can take place in those circumstances or in those conditions.

So to find out the grass evapotranspiration and that is where I think I am not sure but I think maybe that is the situation in which the grass was thought of to be used as reference evapotranspiration medium where this was done in England and the Penman equation was used to find out what is the evapotranspiration from grass.

It was found that by just multiplying the E not which is the open surface evaporation given by Penman, if you multiply that by a crop coefficient ranging between point 6 to point 8 you can get the evapotranspiration of the grass.

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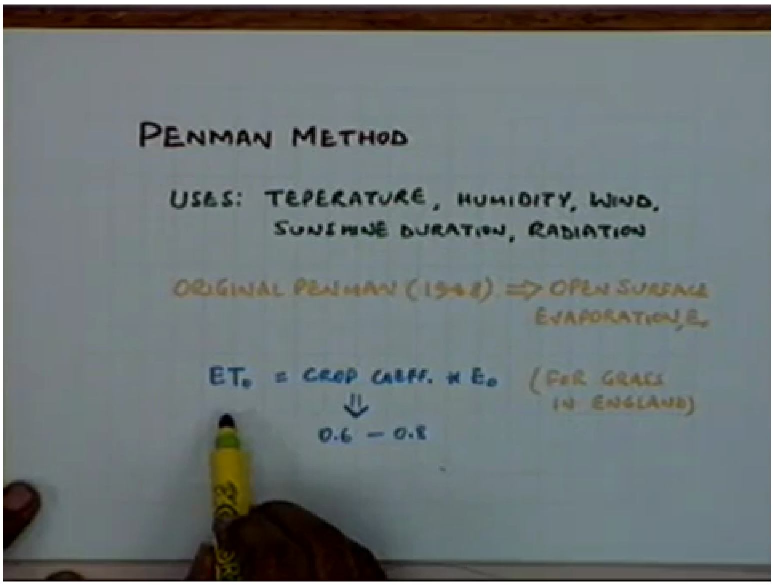

But at the time of this inter comparison or the FAO team when they look at the Penman method again they found that it is really very difficult to find out which crop coefficient should be used. In some situations point 8 was quite a satisfactory value but in some situations point 8 was not. It was giving quite high estimates. So they have used all this information in giving a revised form of Penman method. The method remains same, only they have introduced a revised wind function which we will just discuss.

Let us first have a look at basically what is the difference between the Penman method in comparison to the other methods? In the Penman method two terms have been used in the Penman equation. One is the energy term and the other is aerodynamic term because it has been seen that whenever you are trying to estimate the evapotranspiration activity at a particular location, in some situations it is the radiation term or it is the radiation which is more prevalent.

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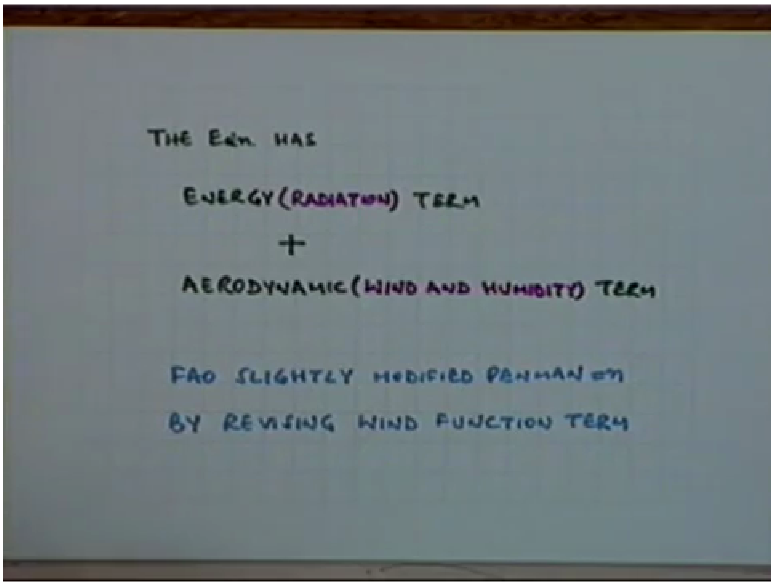

For example if the conditions are very calm, the weather is very calm, you will find that the energy term will become very important because the activity of evapotranspiration will be dominated by the radiation which is prevalent at that particular location. On the contrary there are some situations where you will find that if the conditions are very windy, if the conditions are such that the wind and humidity they are influencing the evapotranspiration activity then the aerodynamic term will be more predominant.

So it is the combination of these two terms which will be in a position to approximate or simulate the conditions in a better manner. The level or the extent of their involvement is a function of the actual conditions. So if you have a equation which can take into account both these factors then that equation will be more useful, it will be more accurate and that is the reason that the Penman equation has a better chance of performance or its results are much better in comparison to the other equations.

Let us try to look at the equation as recommended by FAO which only has slight modification only in the form of this wind function and this C factor has been introduced. This is the equation in which this W into R n component is the radiation term and this part is the aerodynamic term whereas this part is the radiation term.

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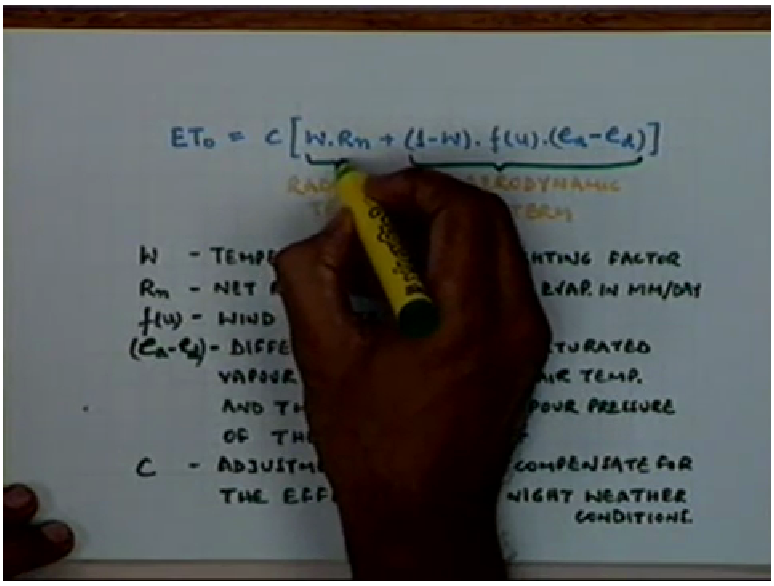

Looking at the various elements of this equation W is the temperature related weighting factor, R n is the net radiation in equivalent evaporation expressed in millimetres per day, f u is the wind related function, E a minus E d term is the difference between the saturated vapour pressure at mean air temperature, that is E a.

E a is the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air which is E d. Both expressed in millibars. And C is the adjustment factor as we had mentioned earlier also. This adjustment factor compensates for the effect of day and night weather conditions.

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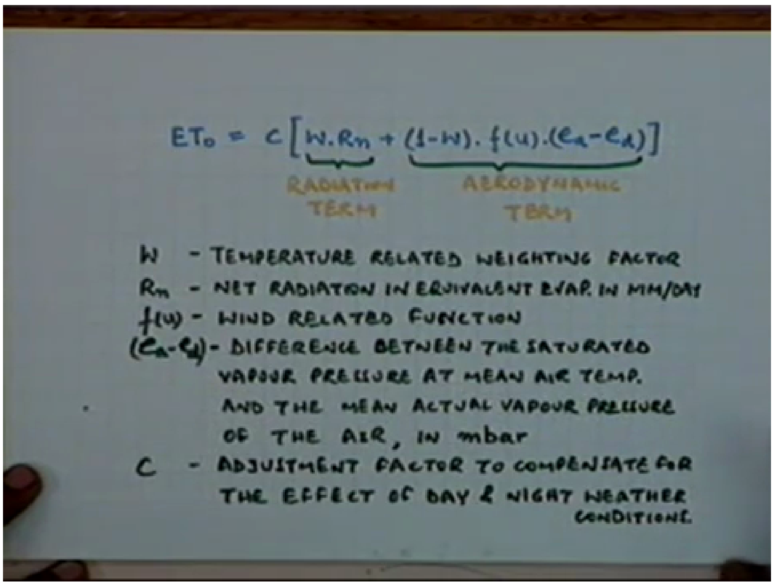

Now how we can compute each of these terms that is what is our next question and that is where you will find that if you will ultimately look at this whole procedure you will find that this is quite a laborious thing, the number of terms which are involved and these also in turn involve many other terms which have to be looked at.

But at the same time method has been made quite simple by providing the various relationships in the form of either the graphical representations or in the form of tables and we will have a look at all those things in detail.

So we will try to take each of these elements one by one and try to look at what is involved in computing those individual elements and which are the various tables which are available? I think we should leave that to the next class because if we will start that we will not be in a position to finish.