Water Management
Doctor A. K. Gosain
Department of Civil Engineering
Indian Institute of Technology Delhi
Lecture 10
Crop Water Requirements (Continued)

Let us get back to the same expression of the Penman equation. We were dealing with the various components of this equation and we had looked at what is the vapour pressure deficit? What is the weightage factor? What is the wind function? Only thing which is left is the net radiation.

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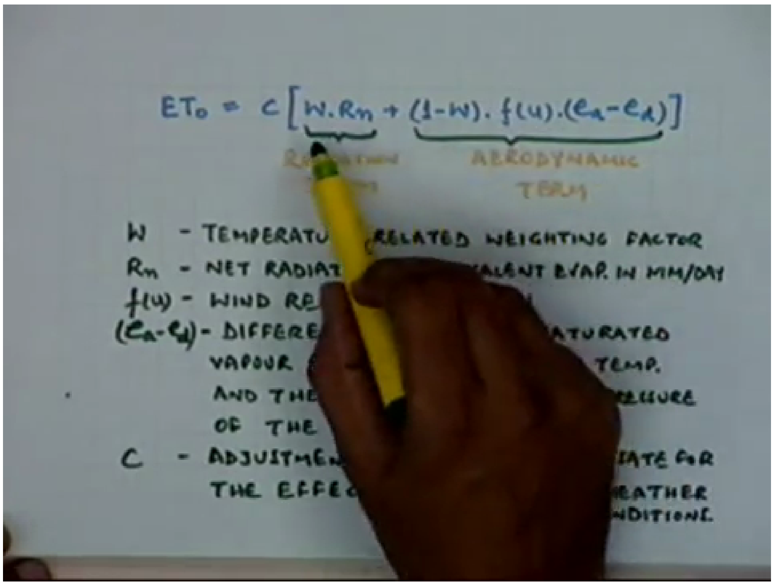

So we will start today with the net radiation. To start with let us see what do we mean by the net radiation? Net radiation is the difference between all the incoming and outgoing radiation with respect to the Earth because this is the source of the energy which is responsible for the evapotranspiration activity.

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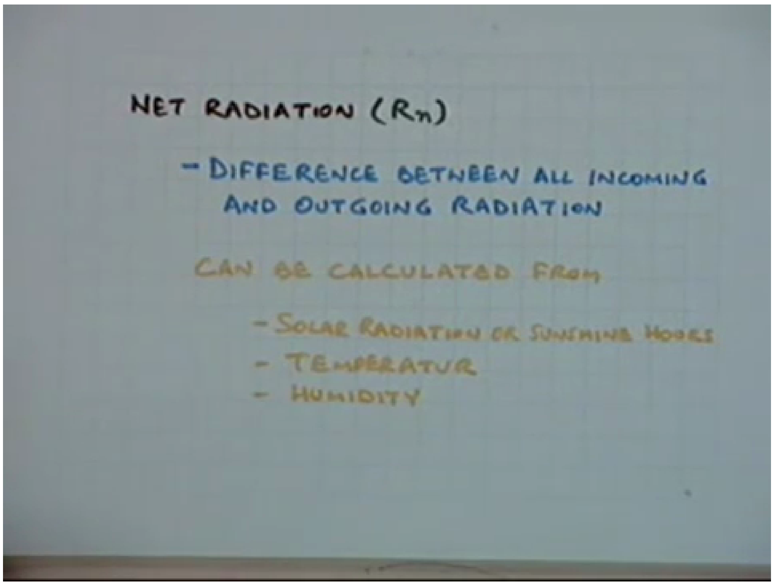

If you look at this figure this gives the various components, the source is the sun here which is say source of the radiation and we have already seen that some part of this radiation reaches the ground surface but before the atmosphere, a part which is reaching the atmosphere which is known as the extra terrestrial radiation which we had expressed by R a, that is something which is fixed, which remains same as long as we are looking at the same period in the year and we are concerned with the same coordinates on the Earth.

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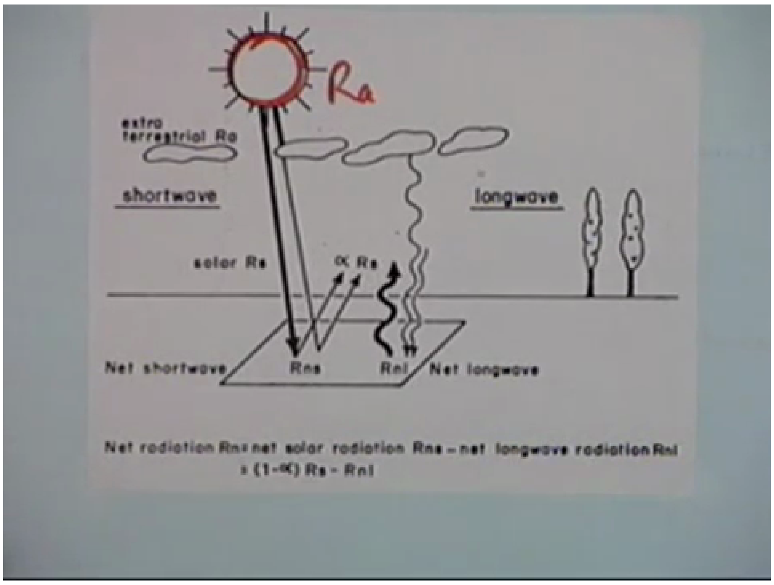

So when we are looking from a particular point on the Earth and for a particular location in other words and also for a particular duration of the year, the amount of R a, the extra terrestrial radiation will remain same. That is the unique quantity. But what happens when this R a approaches towards the Earth? Some part of this R a, some part of this radiation gets absorbed in the atmosphere, some part of that gets scattered. So the part which gets scattered is accounted for in terms of the R s. R s was the radiation reaching the surface.

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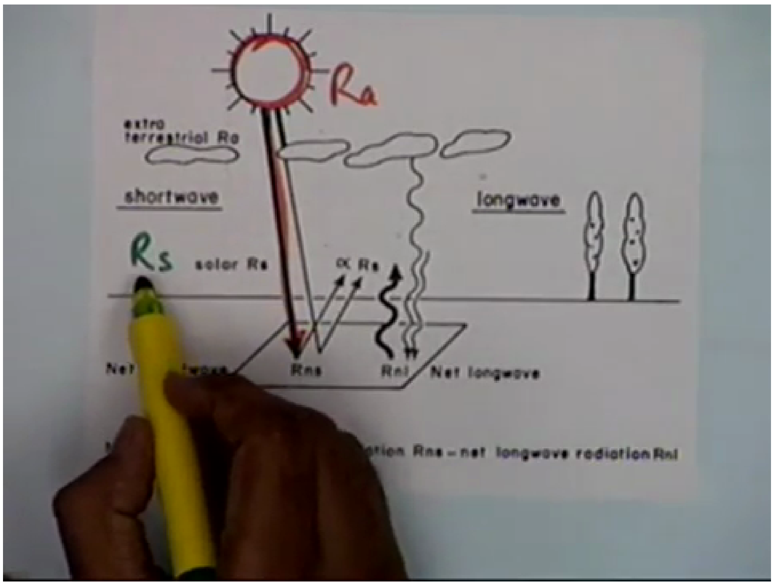

Now this R s is the shortwave radiation which is reaching the Earth surface. A part of this R s, a part of this shortwave radiation is reflected back into the atmosphere and this reflection, how much it will be reflected back into the atmosphere is a function of this quantity alpha, this alpha here which we have mentioned.

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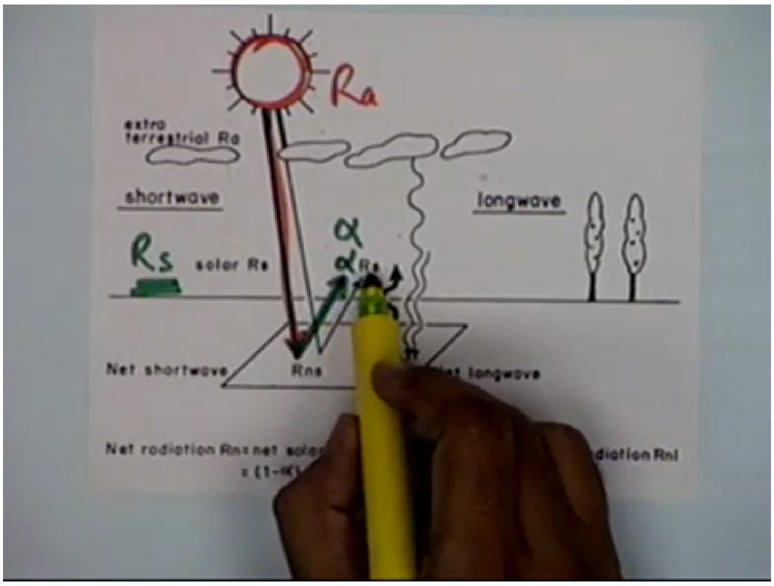

The alpha part of R s goes back into the atmosphere or gets reflected into the atmosphere from the surfaces on which the R s impinges. So it depends on what is the surface which is encountered on the Earth? Was it a water body or was it a cropped area on which the radiation R s impinged upon? Depending on that and depending on the properties of that surface, this alpha will be dependent and this alpha is known as albedo.

You must have heard this term in some course earlier in your undergraduate curriculum. This albedo is the alpha which decides which depends on the reflecting properties of the surface on which this R s impinges.

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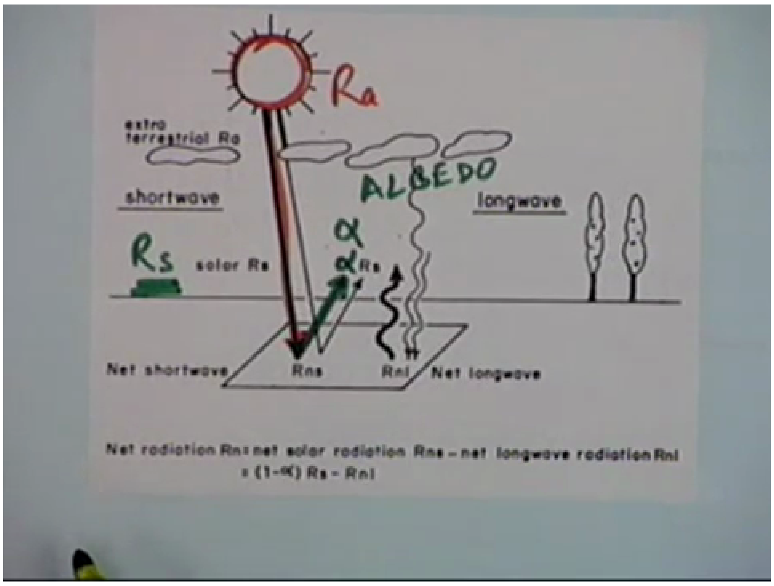

For example if we compare the alpha value, the reflection coefficient will be something to the tune of around 8 or so far water bodies whereas it is up to around 25 for the crop areas. So there is the level difference. That means if you are having a crop area, it will be able to absorb less radiation in the soil. More of this will be getting scattered or getting reflected into the atmosphere.

That is how you can find out what is the net shortwave radiation? So what is net shortwave radiation? the net shortwave radiation R n s we are designating it as is R s 1 minus alpha. That is what is retained.

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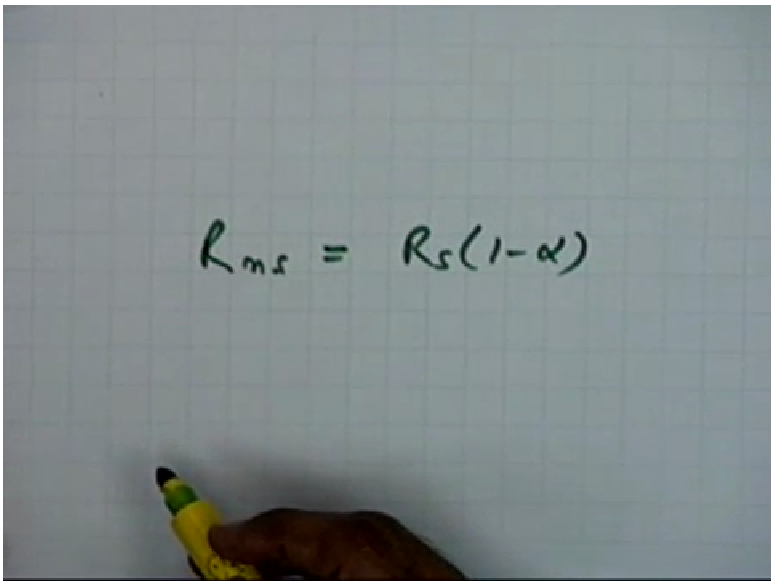

Similarly the other component, we come back to this sketch, there is another component which is the longwave radiation. Now this longwave radiation is a function of what is the status of the atmosphere and what is the status of the Earth surface. There is some long range radiation which is coming from the atmosphere into the soil and there is some component which goes from the soil into the atmosphere and that will depend on the gradient, it will depend on the flux.

What is the flux? What are the conditions of the Earth with respect to the atmosphere? And that is what is accounted for here in the form of the net longwave radiation.

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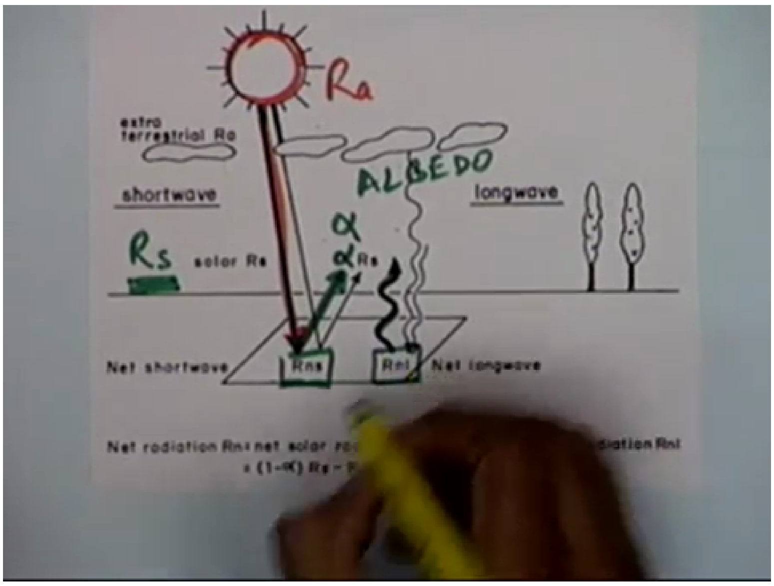

This is incoming from the atmosphere into the Earth surface where as there is some part which is going out. Now the net effect if it is negative, in other words if the outgoing is more than the incoming and in general you will find that the outgoing longwave radiation is much higher than the incoming longwave radiation.

That is the reason that in the end analysis if we look at the net radiation that is the difference between the net longwave and the net shortwave. Since net longwave is the one which is being lost from the Earth that is why we are given a negative symbol to this or the sign allotted to this is the sign here is the minus sign.

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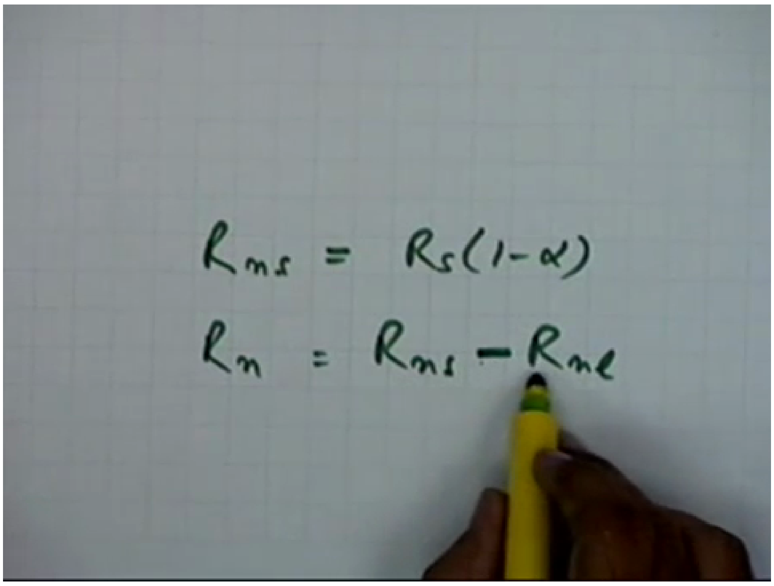

So the net radiation is the difference between the net shortwave radiation and the net longwave radiation. Let us look at the various data which will be involved when you will like to compute what is the net radiation which is available at a particular location. We have already seen this specific relationship where you are relating the solar radiation which is reaching the Earth surface in terms of the extra terrestrial radiation and as a function of the n by N ratio.

Since n by N is the major factor which is influencing how much radiation will be absorbed in the atmosphere, R s is a function of these two major parameters.

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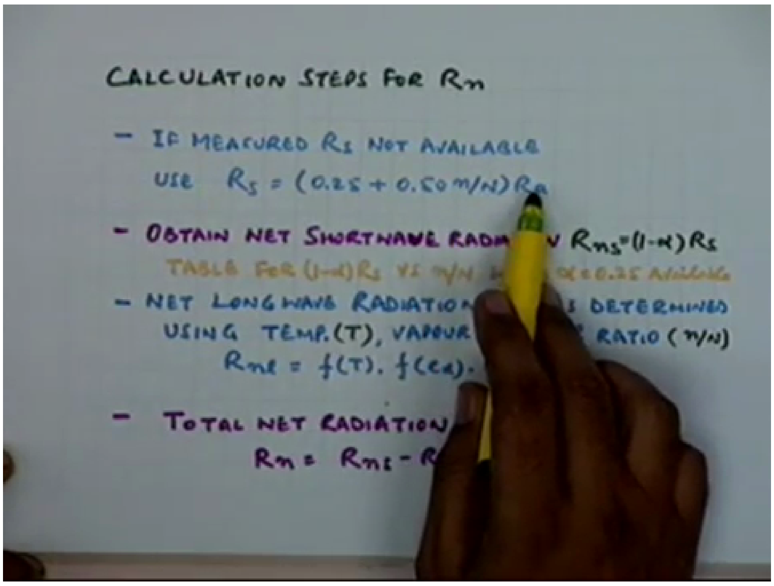

Once you have the R s available then the next step is to obtain the net shortwave radiation which we have said that is dependent on the albedo, it is dependent on the reflective properties of the surface on which the solar radiation is oncoming. And there is a table available which you can look at to convert the R a to R n s which is the net shortwave radiation. You can use this table in which you are assuming that this alpha is having a value of point 25.

So that is an assumption and in general this alpha for most of the crop areas is point 25, is 25 percent what I was mentioning and since when we are computing the evapotranspiration from the crop areas we can ensure that most of the time we are interested in those surfaces where the crop areas are there. Otherwise if we are using this equation for some other areas which are either populated areas or urban areas or water bodies then you can choose appropriate alpha value.

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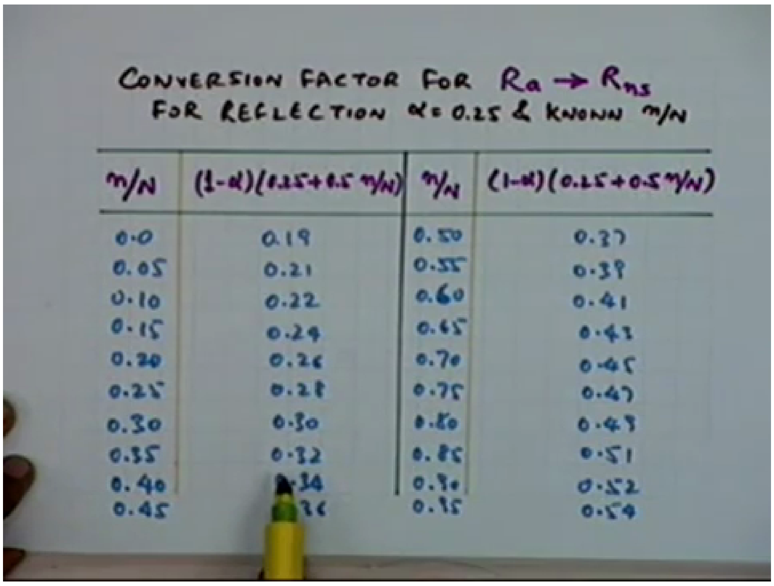

So this table with that assumption that alpha is point 25, this is the relationship which is available and you can find out what is the conversion factor which has to be used and knowing the R a you can directly find out what is the value of R n s which is equal to 1 minus alpha into R s. So that table can directly give you the conversion factor which has to be used for alpha is equal to point 25.

Then once you have the R n s, the only other element is R n l to find out the net radiation and R n l is the long wave radiation which is dependent on many other climatic factors and it has been found that these three elements, the temperature, vapour pressure and the n by N ratio, these are the three elements which influence R n l the maximum. So R n l is found out in terms of these three elements or these three factors have been obtained.

And FAO, the way they have suggested this modified Penman equation, they have converted all those different influencing factors in terms of tables. You can read and directly what is the value of f T? What is the value of the e d and the n by N?

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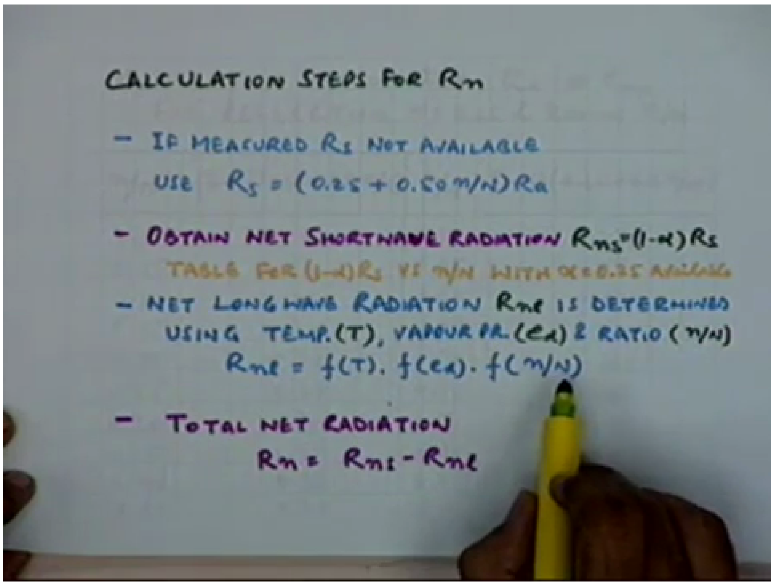

Once you have those values you can directly obtain the R n l value. Let me show you there is the other method also which you can use if you do not have these tables available. But let us first have a look because these tables are giving a procedure which is much simplified. In this particular case this is our table which is giving the effect of temperature on the longwave radiation because how much goes back into the atmosphere is a function of temperature.

So that is a first factor and in this table once you know the temperature you have been given a function which is dependent on T and that value is available here for different temperatures ranging from 0 to 36. You can read the corresponding values of the f T which in turn is dependent on the temperature which is in kelvin and a constant sigma which is available.

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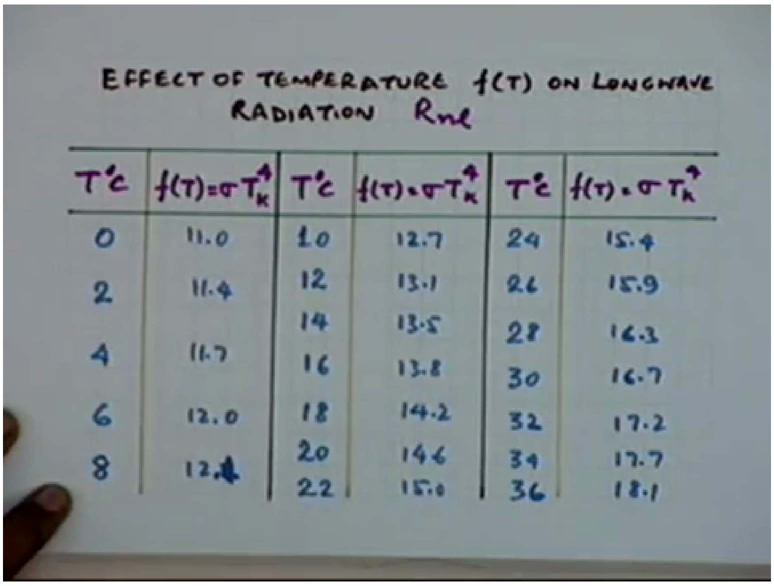
EFFECT OF TEMPERATURE $f(T)$ ON LONGWAVE RADIATION R_{nl}

$T°C$	$f(T)=\sigma T_K^4$	$T°C$	$f(T)=\sigma T_K^4$	$T°C$	$f(T)=\sigma T_K^4$
0	11.0	10	12.7	24	15.4
2	11.4	12	13.1	26	15.9
		14	13.5	28	16.3
4	11.7	16	13.8	30	16.7
6	12.0	18	14.2	32	17.2
8	12.4	20	14.6	34	17.7
		22	15.0	36	18.1

Now similarly the other functions are also available. The function which is giving the variation of f e d which is dependent on the prevailing vapour pressure is given in this particular table where you have the vapour pressure in millibars and this function is the expression used for this particular function point 34 minus point 044 under the root e d.

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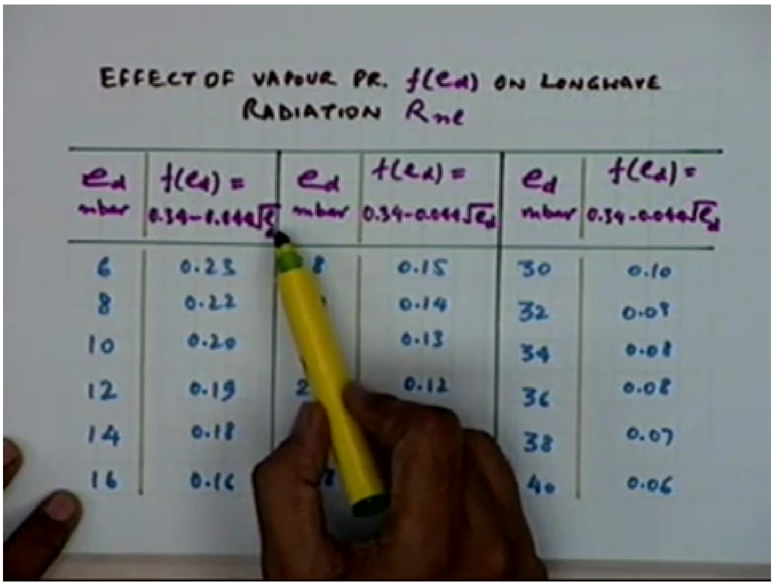

And for these values of vapour pressure you can read the corresponding value of the f e d and in the same manner the other quantity n by N ratio also there is a relationship which has been made available. So once you have the n by N ratio and we know that N is something which is constant for that location and for that particular duration N is something which can be observed. That we have already looked into in the last lecture and once you know the n by N ratio then the value can be read.

So having obtained all these three values, the factors which are deciding factors for the R n l, you can obtain the R n l value and then subsequently you can find out what is the total net radiation. So R n l is the factor dependent on temperature, the factor dependent on e d, factor dependent on n by N ratio and the total net radiation can be now obtained by knowing these two quantities.

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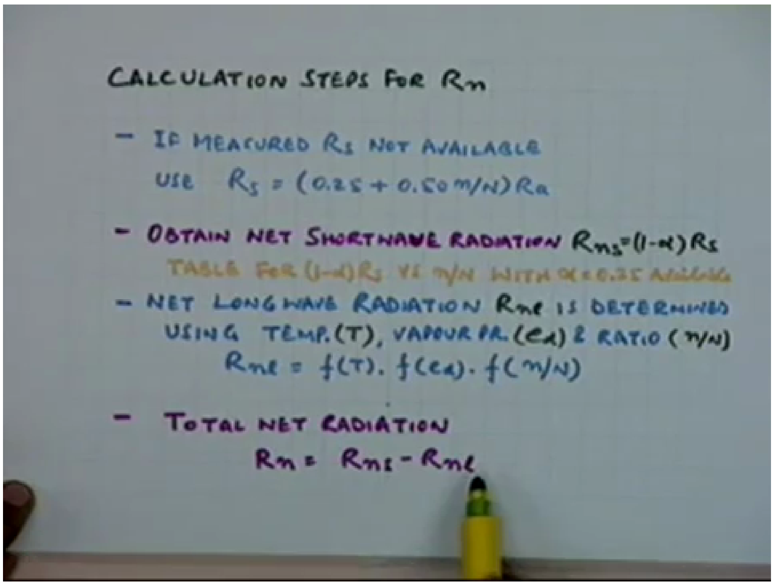

Now I just mentioned that there can be situation where you do not have these tables available or you want to directly go in for equations which if you are not doing this manually you might like to have that in equation form. This is our alternative equation which can give you the value of net longwave radiation and this is in terms of the net outgoing clear sky longwave radiation which is R n l 0 and R s 0 is the daily clear sky solar radiation at surface of Earth.

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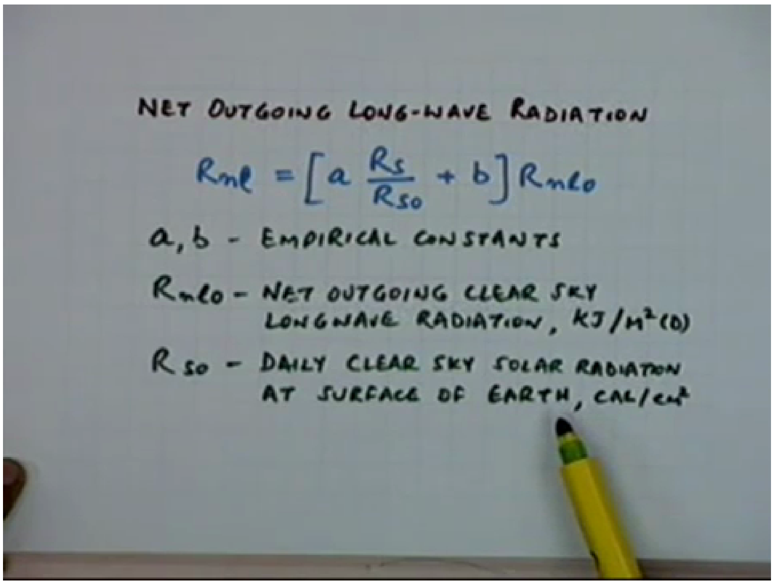

Now these are the two quantities which are using the assumption that the sky is clear that means there is no effect of the clouds. And knowing these two R s, the actual solar radiation which you are getting, so knowing these two quantities you can find out probably you have the empirical constants a and b and these constants are available. We will come to that first let us look at that R n l 0 which is the clear sky net outgoing longwave radiation.

This is expressed in turn in terms of the eta, sigma, T maximum and T minimum whereas eta is the emissivity of the surface which again it is dependent on some further more parameters. We will come to that. Sigma is the same sigma which you have seen earlier in one of the tables, it is the constant. It is known as Stephen Boltzmann constant and its value is 4 point 8895 into 10 to the power minus 3 joules per square metre by kelvin to the power 4. And kelvin as you know is degree centigrade plus 273.

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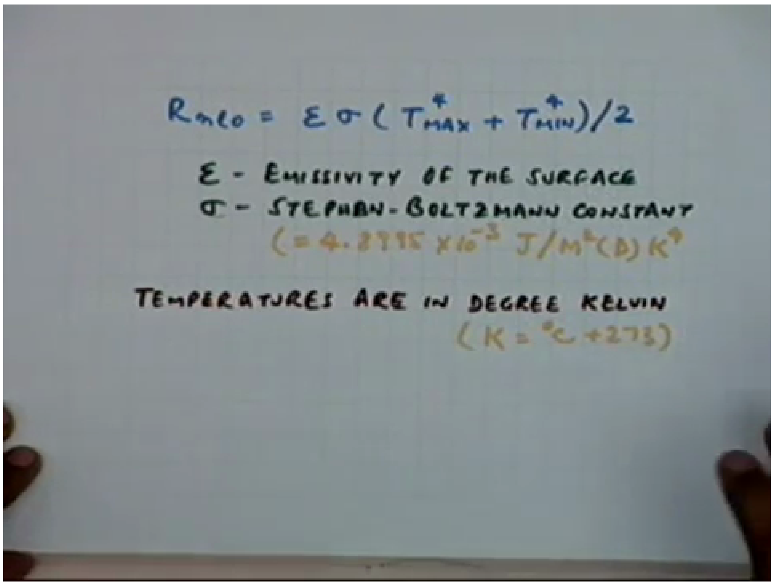

Now this emissivity in turn is dependent on the e S D P which is the saturation vapour pressure at dew point. E S D P we were discussing that in the last lecture the dew point is a point on the psychrometric curve and the corresponding vapour pressure will be the dew point vapour pressure, the saturation vapour pressure at the dew point. So that is deciding what is the emissivity?

Now in many situations if you do not have the dew point and the relative humidity is quite high then you can take the minimum temperature to be equivalent to the dew point temperature. And if you do not have that situation where the relative humidity is not very high then this will not be possible. So in that situation you can use another alternate relationship which uses the mean temperature instead to give you the value of (emissive) emissivity, okay.

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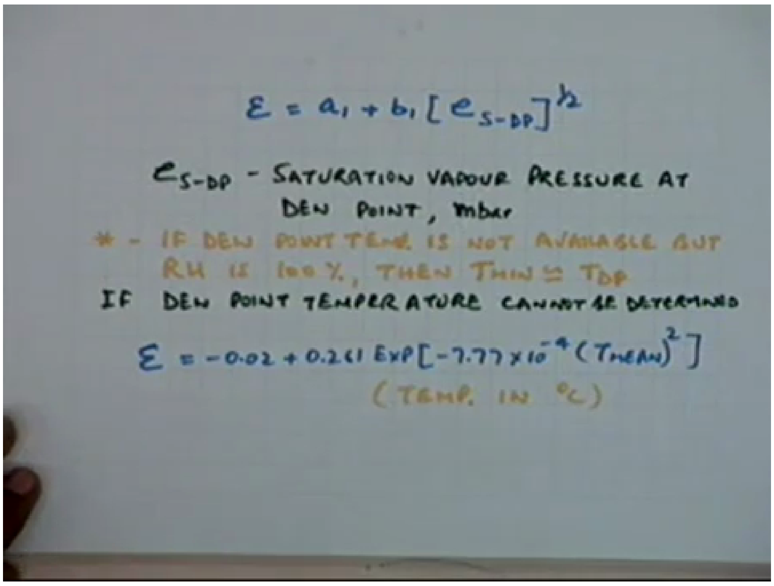

So that means that you have now all the relationships which are needed to find out R n l. The only thing is that there are some other constants which we have seen in these equations, they are not available. The coefficients a, b, a 1 and b 1. Now these coefficients are available in some of the areas. For USA these are the coefficients which are available.

For England a and b is not available but a 1 and b 1 are available. And in general it has been seen that the approximate values they can be approximated to these values for most of the places though there will be some difference.

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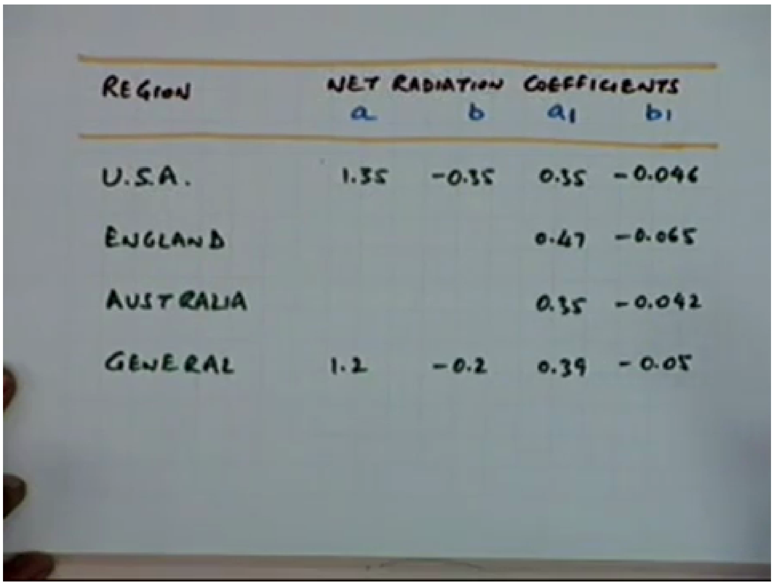

And some more work is needed by the scientist to obtain these values if these relationships have been used because the present relationship which I have given you they are obtained for some specific areas and these values are the values which have been published and they are available. Maybe after some more time the other values will also become available. Now, okay, so as far as the net radiation is concerned we have seen both the procedures.

We have seen how we can use the FAO recommended procedure and the table which have been made available and we can use those tables to find out how much is the net radiation value. So having found out the net radiation all the terms of the Penman equation are now known except this C value which is the conversion factor or the adjustment factor as we know it.

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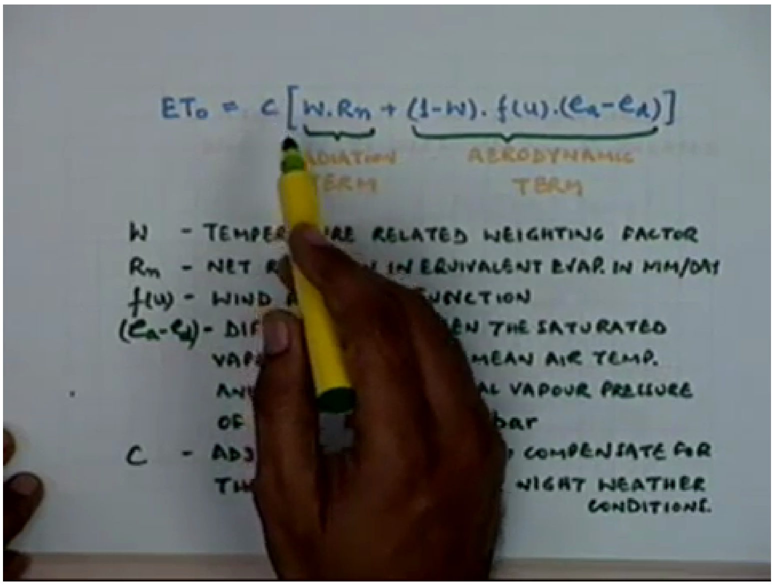

This is the only value which we have not discussed so far but before we discuss that there is another relationship here which I wanted to bring into your notice. Now this is the relationship between the relative humidity, the air temperature and the dew point temperature which can be used in some situations where you want to get one quantity or the other having known some of these quantities. In this the T air is the dry bulb temperature, the T dew point is the dew point temperature and R H is the relative humidity.

Now in this expression if you want to get the maximum relative humidity then you can replace the T air, the dry bulb temperature with the minimum temperature, okay. That will give you the maximum relative humidity and vice versa. If you want to know what is the minimum relative humidity you can use instead of T air that you can replace with the maximum temperature.

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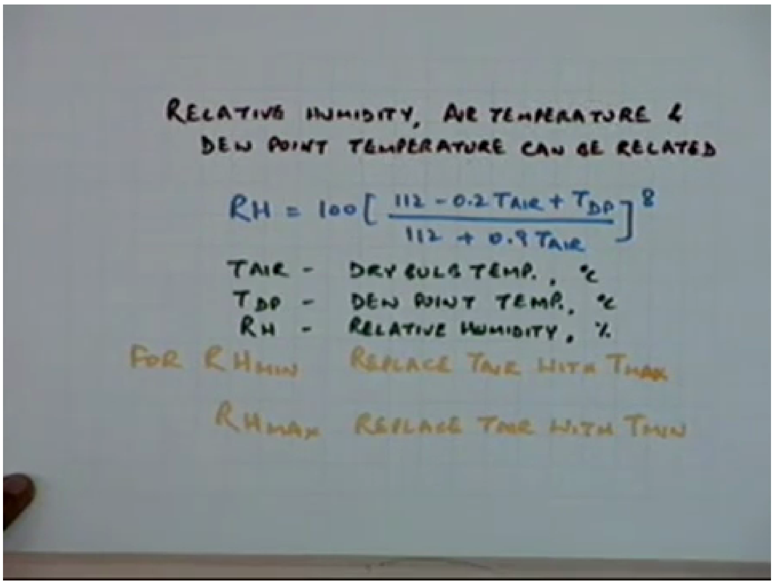

So let us come to the adjustment factor C. First of all why this adjustment factor is needed? The Penman equation as it was developed it was developed for some conditions which are the average conditions. For example these are the major conditions which are used when the Penman equation was developed. Radiation is medium to high so it was catering for the conditions when the radiation is between medium and high range.

The R H maximum is between medium and high and the daytime and the night time wind conditions are such that the ratio is around 2. The moderate daytime wind is double the night time wind. So these were the set of conditions which were used and it was found that whenever some of these conditions change the values which are obtained using the Penman equation they vary a lot.

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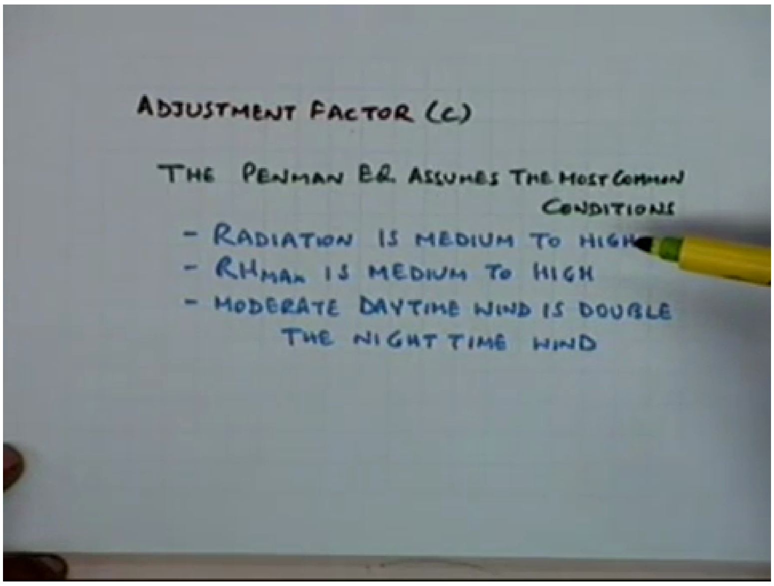

The inaccuracies which are incorporated they are quite large. To account for those corrections or to account for the variation in these factors when they are prevalent in the actual area, the C factor was revised and this is a table which is recommended by the FAO. This table gives the C factor and if you look at this part it is having the R s in millimetres per day and these are the R s values 3, 6, 9 and 12 for different R s, solar radiation values. For R H maximum, this is R H maximum.

This block gives the R H maximum of 30 percent and on this side is the U day in metres per second, varies from 0 to 9. Now for these three combinations for a given R H maximum, for a given R s you have four different values, then you can interpolate.

And for given U day is the daytime wind velocity from 0 to 9 metres per second and another factor which is the U day U night ratio and in this particular case this belongs to a ratio of 4. When the U day U night or the wind conditions of day and night, their ratio is 4 then this part can be used.

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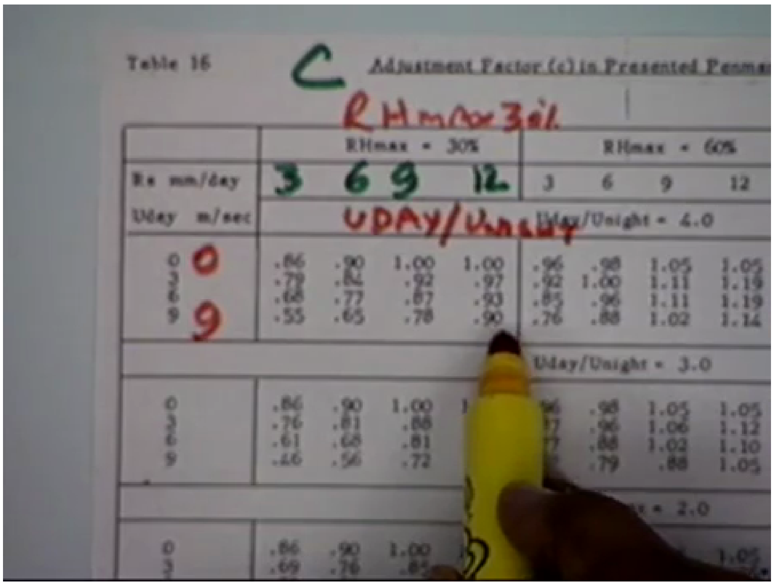

So for these four combinations you have this part and you can find out what is the value of C? Similarly if the R H maximum changes, now here in the next one everything else is same but R H maximum is 60 percent. So the next one is 60 percent and the next one, the third one is with R H maximum of 90 percent.

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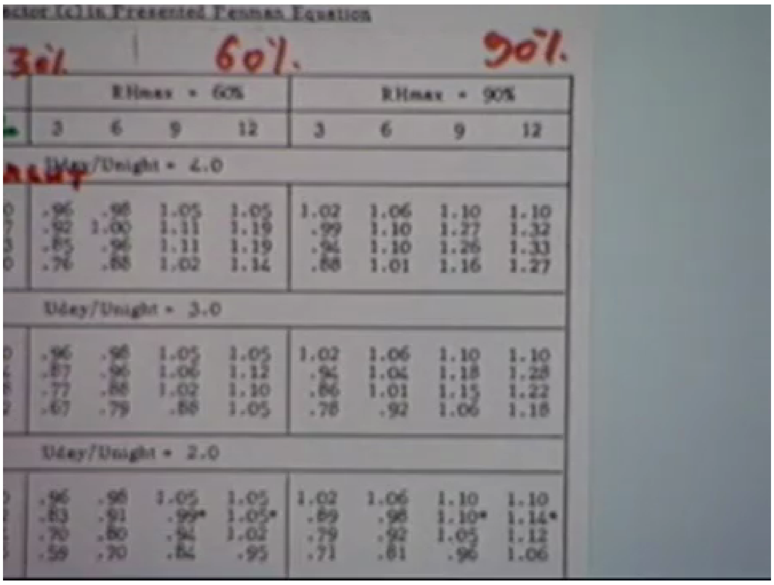

And likewise the other segments are also given where you have the R H maximum is this column 30 percent but here U day U night ratio is 3 in this block. This is R H maximum of 30 percent, this block is 60 percent and this block is 90 percent.

So you can use this table to find out what are the appropriate conditions in terms of R H maximum, in terms of the wind condition, the day and night wind speed ratio and the R s which is the prevalent R s on that particular day and the day wind speed. This day wind speed is taken at 2 metres height again.

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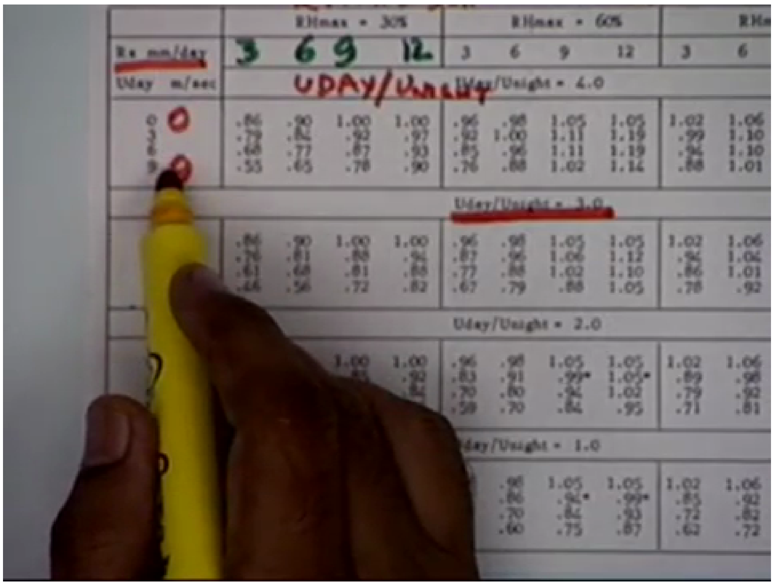

So knowing these you can evaluate what is the coefficient C which should be used? Now if you look at this table you will find that whenever the conditions are closer to the ones which have been used when Penman equation was derived, for example in this particular case you will find that in all the conditions this particular area is having something closer to 1. So this is the R H maximum is 60 percent in this case. The U day and night ratio is around 3.

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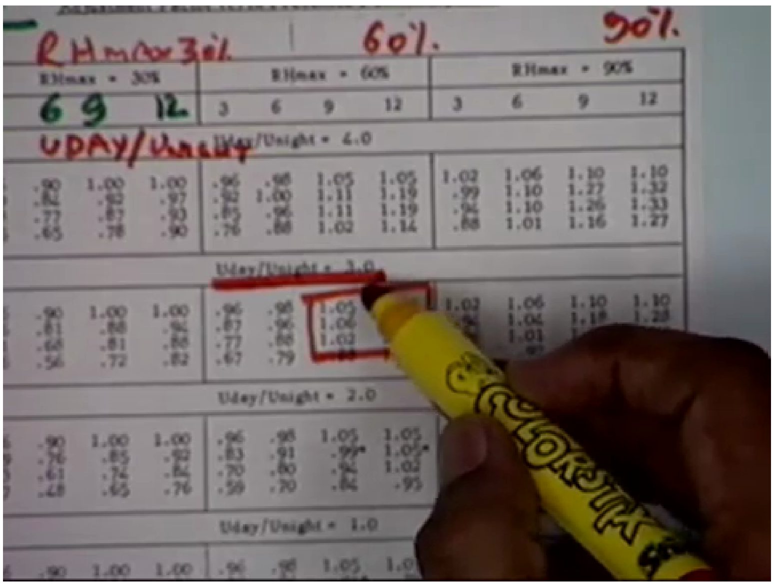

If you look at the next one when it is 2 we are still closer to 1. It is point 99 and 1 point 05. So these C values are very much different, in this particular case they are even point 46 when the conditions are which you have the U day, the velocity is very high, it is 9 and the maximum relative humidity is very low.

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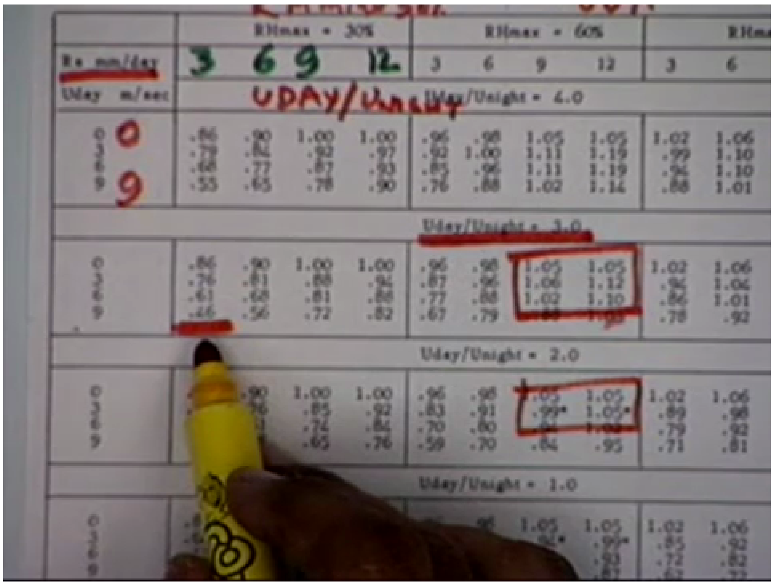

So in that case a coefficient or a factor which is almost close to 50 percent that has been used. That means you are getting a value from the Penman equation which is very high. So it is over simulating the conditions and that is why you need a factor to bring it down. So with that we have seen in detail what are the various ways of calculating the reference crop evapotranspiration.

There is only one more method which is a different method which is the Pan evaporation method which if I again bring out the old slide, we have covered these three methods. The fourth method was the Pan evaporation method in which you only needed the evaporation data and the data on the environment that where the Pan is situated? What is the environment closer to the Pan? And you can use the data on the humidity and the wind if it is available otherwise you can use the estimated data.

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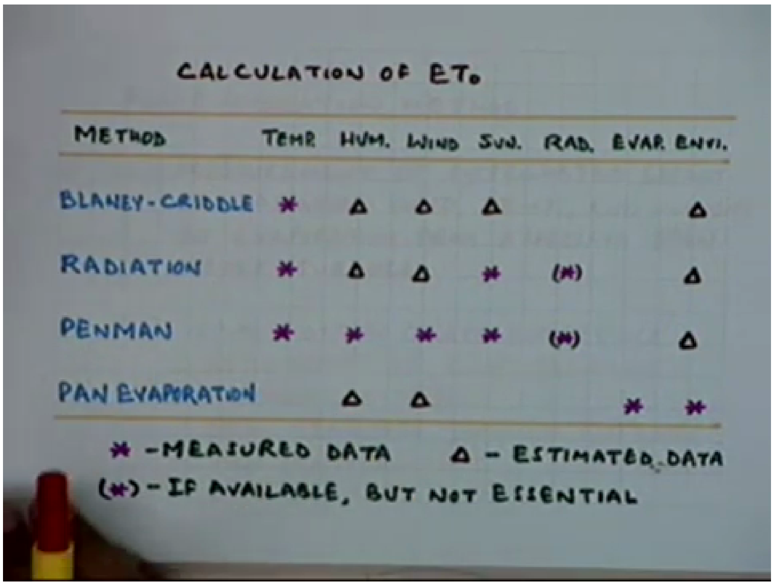

Let us look at first of all what is a Pan? This is a very simple instrument which is nothing but is a vessel which is a circular vessel and the diameter, they are different Pans which are available in literature. In different countries people are using various types of Pans but I am trying to give you one Pan which is quite popular. It is known as US weather service class A Pan. It is 121 centimetres in diameter. The depth is 25 point 4 centimetres.

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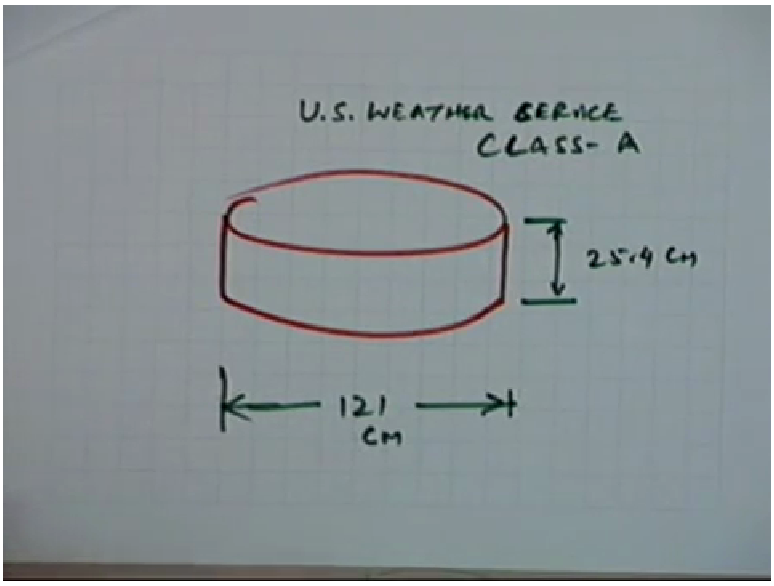

Now what you do is that you fill this with water and the depth up to which you normally fill the water, this depth should be maintained in such a way that the fluctuations are within around 5 to 7 point 5 centimetres. From the rim of the Pan you can go maximum up to around

7 point 5 centimetres. So what you do is that you keep on pouring water regularly, the known quantities of water so that you know that what is the depth at that time.

You keep record of what was the depth at a particular time of the reading. When the reading was taken what was the depth? How that that has been depleting in time that is what will give you that how much is the lost water because of evaporation activity? And then you again fill it up to the desired level. That means you are within this range and again that process goes on.

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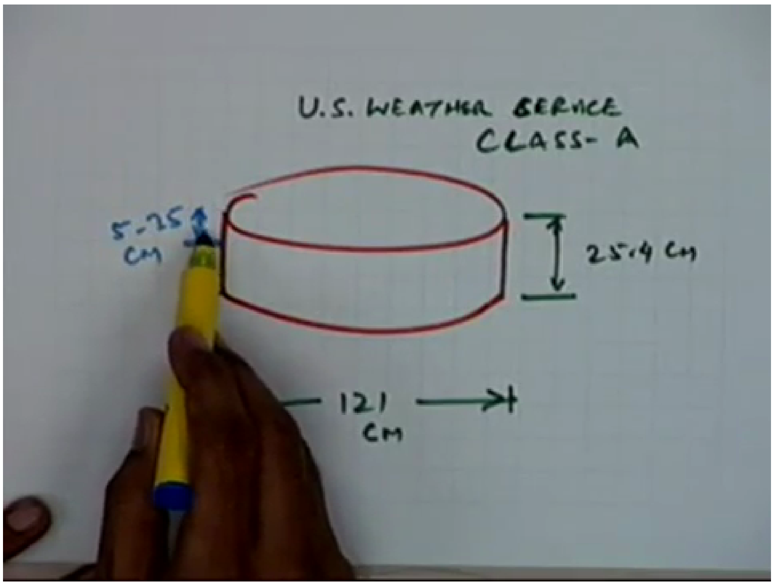

The other requirements are, there are some requirements for placing this Pan that it should be placed on some platform, that can be a wooden platform on which you can place this so that there is lot of air which is passing through and the ground surface temperature is not affecting the temperature of the water. But there are different types of Pans.

There are Pans which are known as Sunken Pans which are buried inside the ground and there is a Pan which is known as the Colorado Sunken Pan. There are Pans which are even floated inside the lake. So you can install on a float. What happens is that it depends where you are making the observations? Suppose you are making the observation in the lake and you want to know what is the lake evaporation?

Now if the lake is there, suppose you have this lake and you have installed the Pan somewhere here. Now this Pan will be able to give you a reading which is much different than if you install the same Pan on the ground because of the fact that if the evaporation activities taking place on the lake then what you are getting here, the water vapours which are making this air saturated, that activity is much different because now with the knowledge which you have gained you can see that this air will be very saturated.

It will be having a lot of moisture available in its air mass in comparison to this air where you have only the water surface in this very small body and there can be the wind which is regularly replacing this air mass which is somewhere in this area.

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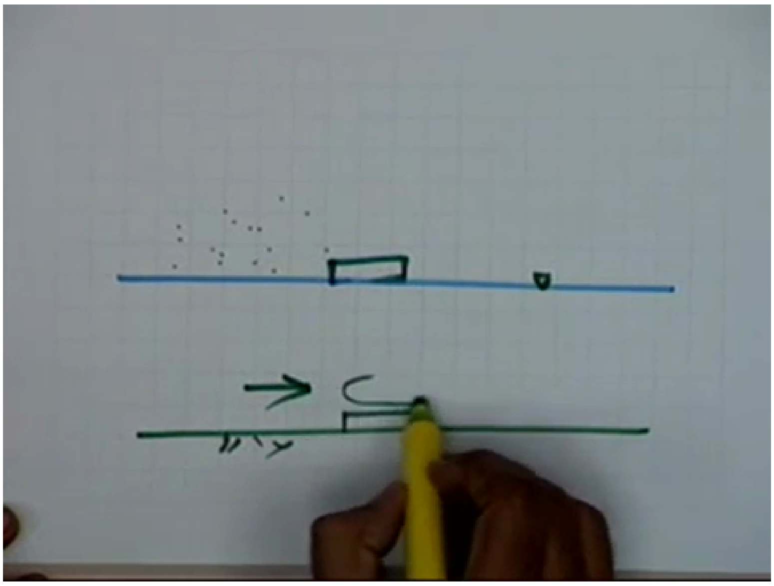

Now with that replacement this air is always the air which is over this particular Pan will be much drier. It will be having much more absorption capacity with the result the evaporation which will be taking place from the Pan on the ground will be much higher than the Pan on the lake surface. So that variation can be there. You will find that depending on the type of the Pan, depending on the environment, in this case this is what is the environment.

The environment in this case is different because one is inside the water body, the other one is on the land surface. Similarly if there will be a situation where you have some cropped area here, this is having the air coming over the top of some crop area. That will have its own impact on the evaporation activity at this place.

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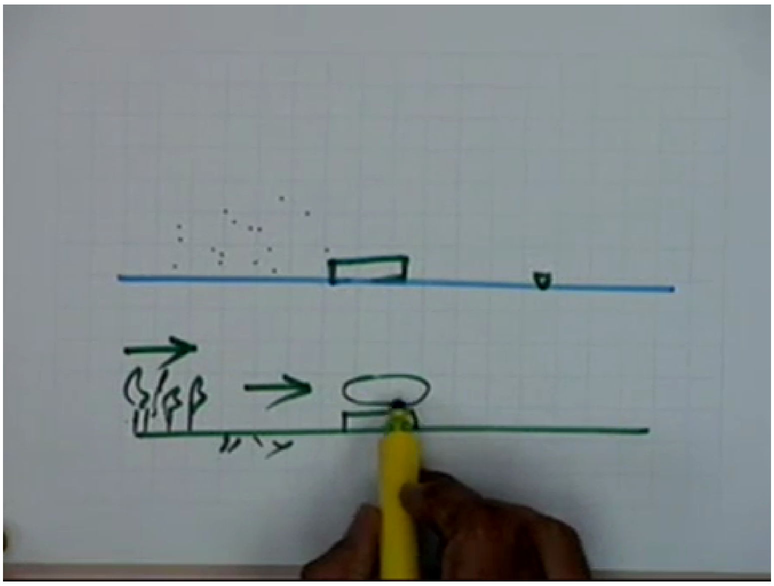

So all these things will define the environment but what we are looking at right now is that the FAO has assumed that they will be only considering that the Pan in the question is the US class A Pan and using that Pan the relationships have been developed. So they have also given some conversion tables that if you have some other Pan how you can convert? How you can use the factor which will convert the reading of that Pan into a equivalent class A Pan?

This is the expression which is used to get the ET not reference crop evapotranspiration and it is a function of E Pan that is the Pan is reading. It is the Pan evaporation in millimetres per day and it represent the value over the period which you are considering. If you are considering a month then what is the evaporation in millimetres per day over the month, the average value? And K P is a Pan coefficient which has to be used. This Pan coefficient is a function of climate and the Pan environment.

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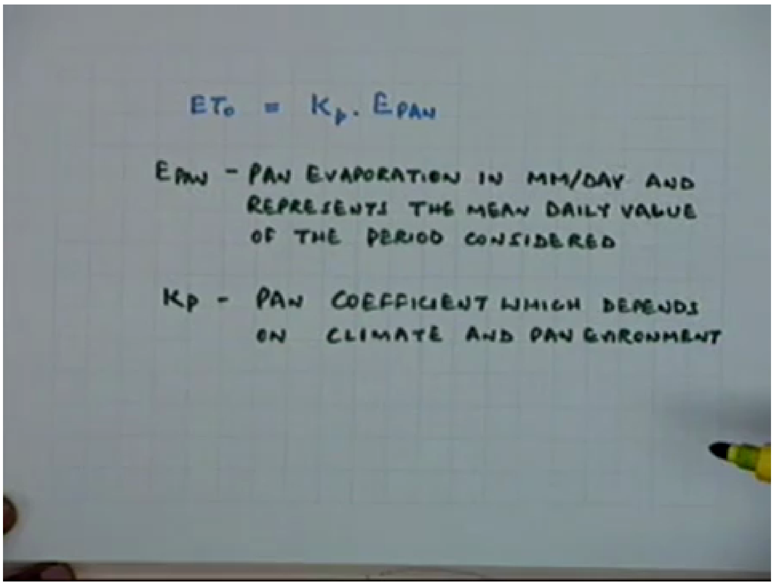

It is a very simple equation as we have in the other cases. The only question is this is what we are observing. E Pan is what we are observing in the observatories or whenever the Pan is installed. Only K P has to be evaluated which needs some further information.

Now to incorporate the environment to find out what is the environment there are two cases which have been defined. One case, case A in which this is the place where the Pan is. Now this case deals with that situation where you have the green crop on the windward side in the near immediate vicinity of the Pan.

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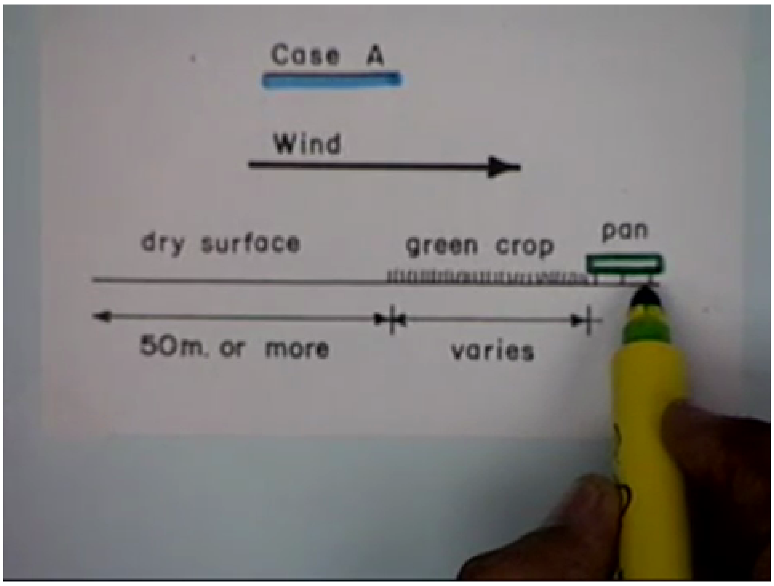

So there are relationships which have been developed to find out what will be the impact of this fetch of the green crop. That means the extent can vary. If this varies what will be the impact? So there is one parameter, what is the fetch of the green crop which is then followed with the dry surface. And other case is the other possibility that if you have the Pan installed in an area in which it is having the green crop area which is much away from the Pan location and in the immediate vicinity the dry surface is available.

How much is the extent of the dry surface that is again is a variable which will be taken care of. But in both the cases it has to be ascertained that the windward side has to be known and the climate or the environment will be dependent on which is the windward side, okay.

If the windward side changes, your environment might change because what happens the wind direction is what is responsible for knowing whether the air mass which is coming over the Pan or which is passing over the Pan what is the condition of that air mass because that is what is going to govern the activity of the evaporation.

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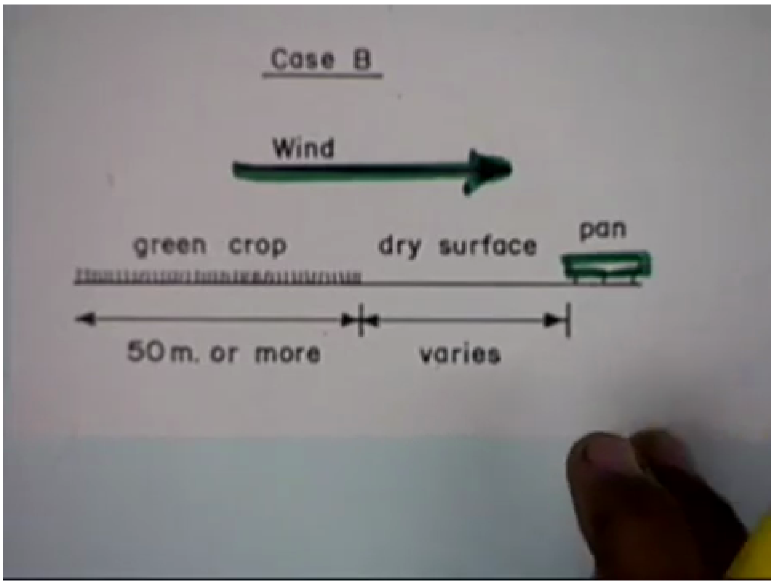

Now having known this then the K P has been, this particular table is very small so I will try to explain what are the various variables which have been considered here. Now to find out the K P value from class A Pan that is the condition. This is the case for case 1 or case A. The various things which are considered here are what is the value of R H mean in percentage and there are 3 cases which are given when R H mean is low, when it is medium and when it is high. In the case of low it is less than 40 percent, 40 to 70 percent and greater than 70 percent.

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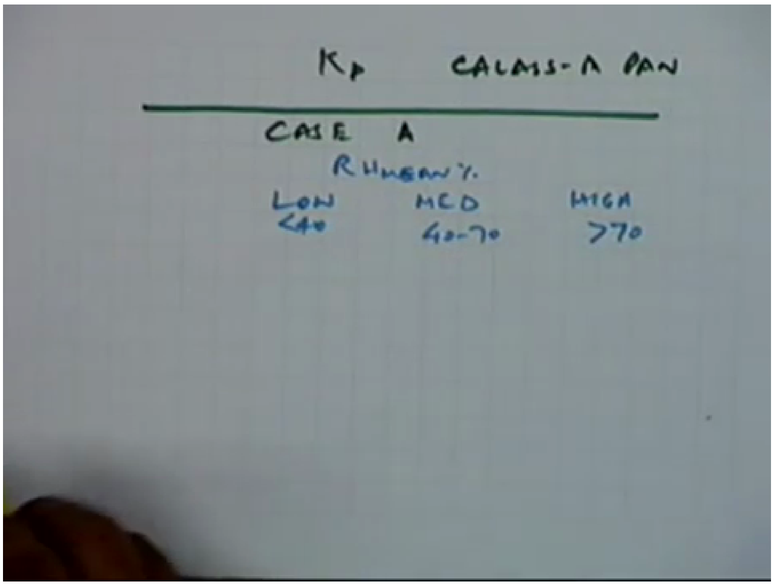

Then we have wind which is expressed in kilometres per day. We have the conditions which are the light wind, moderate and strong, very strong. We had covered these things in the beginning when we had looked at the nomenclature that what are the various ranges. When we talk of light, light was less than 175 and this very strong was greater than 700 kilometres per day.

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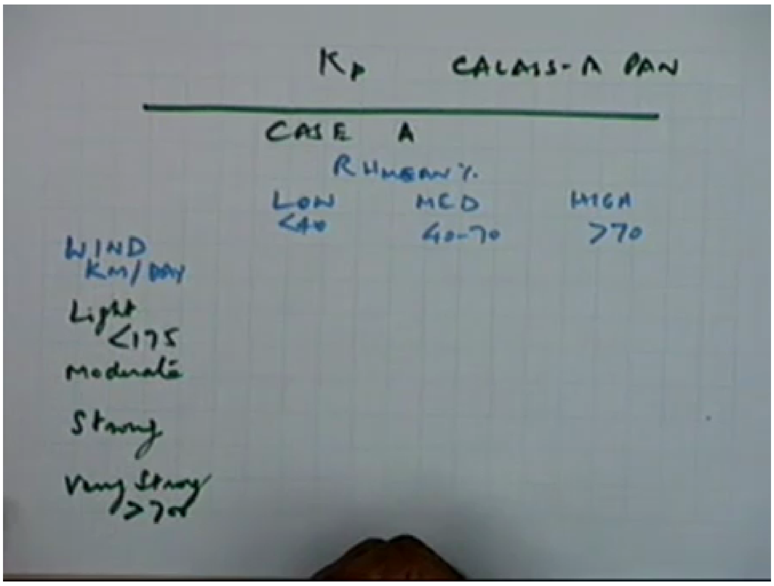

Then another parameter which was introduced was the windward side distance of green crop in metres. That is what we were saying that this can be variable. So there are four different levels when this is around 1 metre to 10 metres, 100, 1000. So these values now are the values of K P for different levels, point 65, point 7, point 75. Similarly when it is very high it is point 75, point 85, point 85, point 95. So in between you have the other values.

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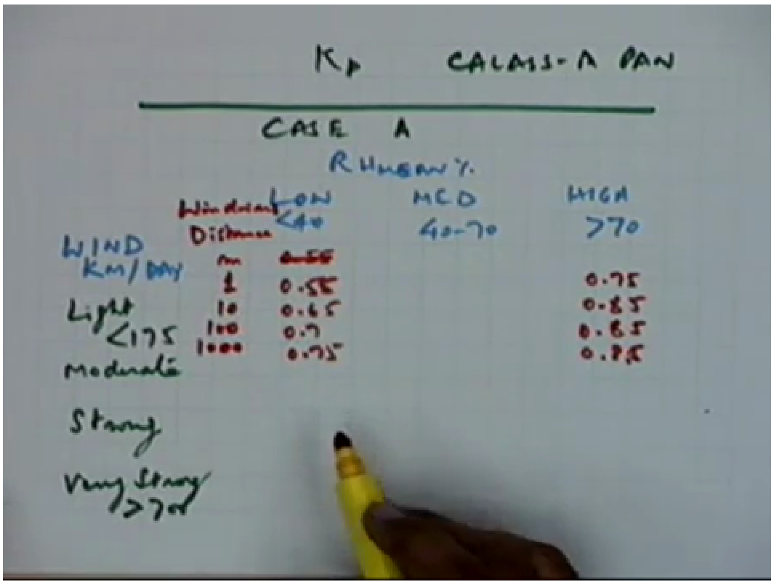

Now this is what is given in this table. That is what this table is about. This table gives for case A all these K P values. Similarly for case B here, all these K P values for different fetch. This is the fetch in case of case B and again for the low, medium and high R H mean value as well as for conditions which are light wind. Now this belongs to the light wind conditions, this belongs to the moderate wind and the next one strong wind, very strong wind.

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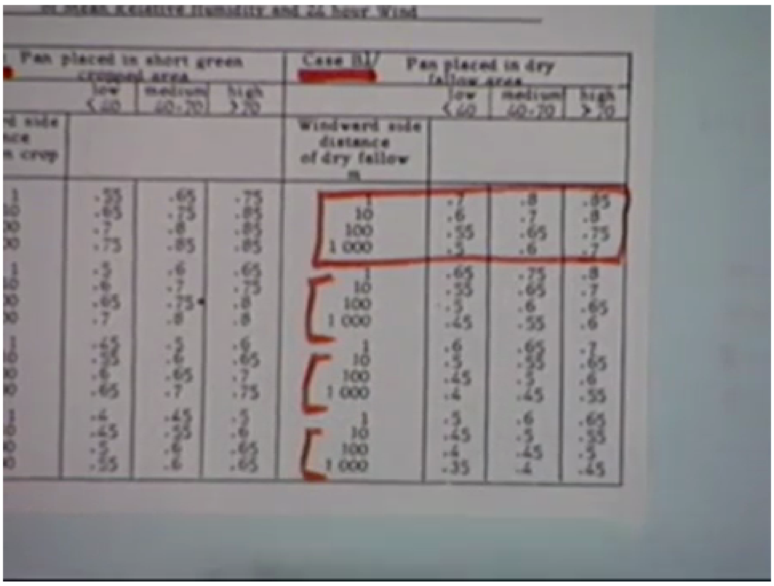

Pan placed in short green cropped area: low <40	medium 40-70	high >70	Case B: Pan placed in dry fallow area — Windward side distance of dry fallow m	low <40	medium 40-70	high >70
.55	.65	.75	1	.7	.8	.85
.65	.75	.85	10	.6	.7	.8
.7	.8	.85	100	.55	.65	.75
.75	.85	.85	1 000	.5	.6	.7
.5	.6	.65	1	.65	.75	.8
.6	.7	.75	10	.55	.65	.7
.65	.75	.8	100	.5	.6	.65
.7	.8	.8	1 000	.45	.55	.6
.45	.5	.6	1	.6	.65	.7
.55	.6	.65	10	.5	.55	.65
.6	.65	.7	100	.45	.5	.6
.65	.7	.75	1 000	.4	.45	.55
.4	.45	.5	1	.5	.6	.65
.45	.55	.6	10	.45	.5	.55
.5	.6	.65	100	.4	.45	.5
.55	.6	.65	1 000	.35	.4	.45

So you can use these for finding out what is the value of K P and once you know the K P value you can then find out what is the ET not using the Pan equation. So with that we have seen all the four methods. We have seen what are the various data requirements? How the method has to be used?

What are the other assumptions used in these methods? And with that we close this particular section of the topic where we were trying to find out the ET not and we were trying to look at the effect of the climate on the crop water requirements.

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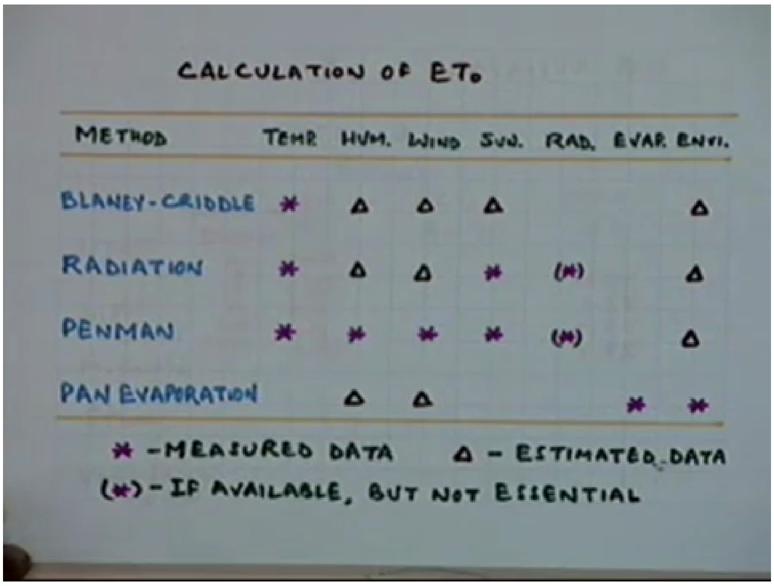

So we have only seen the first impact that what is the impact of the climate on crop water requirements? And for that purpose we try to define a reference crop which is grass in the present case though there is another crop which is alfalfa which is also used as reference crop. So easy material because we said in the beginning that any crop which does not vary in its growth much that can be used as reference crop.

So in the next class we will start with how we go to incorporate the effects of the crop characteristics into the crop water requirements? How we evaluate the crop water requirements? That is the remaining portion we will look at. Any question?