Sustainable Material and Green Buildings
Professor B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi
Lecture 34
Evapotranspiration: Theory and Models

Right so we will, as we said we will be looking into effect of trees on the environment. Now, one issue which you are not really looking into, the quantification of amount of carbon dioxide which the tree absorbs, this we are not looking into.

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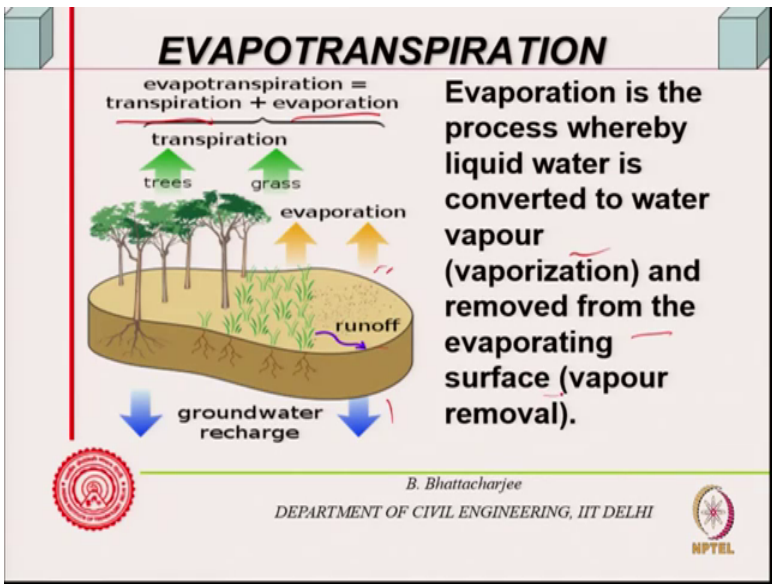

But what we are looking is the, how does it change is the micro climatic features such as humidity or temperature that is what we are looking into. So two things happens with trees actually, the transpiration and evaporation.

So tress basically there be evaporation from the trees and transpiration so we call it evapotranspiration, this process is called evapotranspiration, right. So evaporation takes place from the surroundings around, you know surrounding ground and there is the transpiration from the green tress itself. Both together, you know both together or there will be evaporation from the green surfaces as well and there will be ofcourse some run off, some goes to the ground water, some goes to the ground water, right.

So evaporation is the process whereby liquid water is converted to water vapour and remove from the evaporating surface which could be ground as well as the plain surfaces, right.

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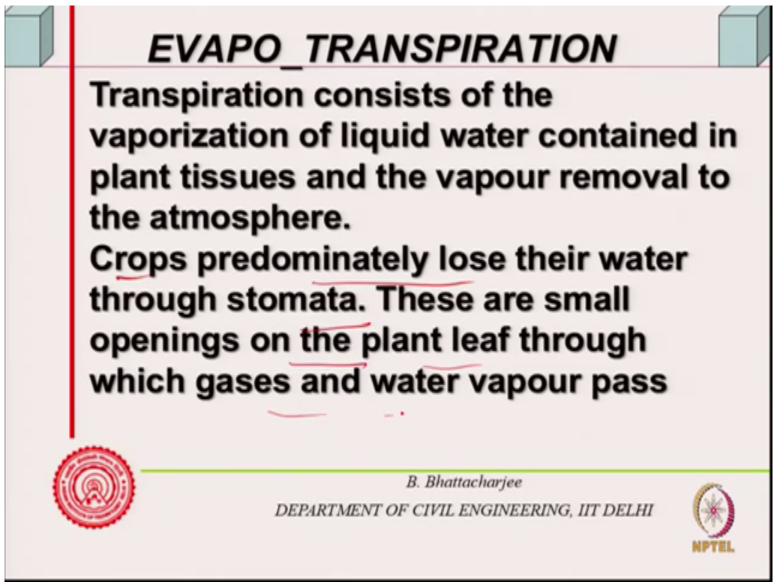

So transpiration consists of vaporisation of liquid water contained in the plant tissues right and the vapour removal to the atmosphere. So in the process, in the biological process, there are water evaporation takes place from the plant and you need water for plant survival, right its nutrients its picks up this from the plant tissues there is water evaporation that tales place. So that we call as transpiration.

So these crops or you say trees even predominantly lose their water through what you call stomata. These are small openings in the plant leaf through which gases and water vapour pass. So there is evaporation from the plant also because the water is needed for carrying the nutrients, right and then water is also evaporated out from the plant surfaces.

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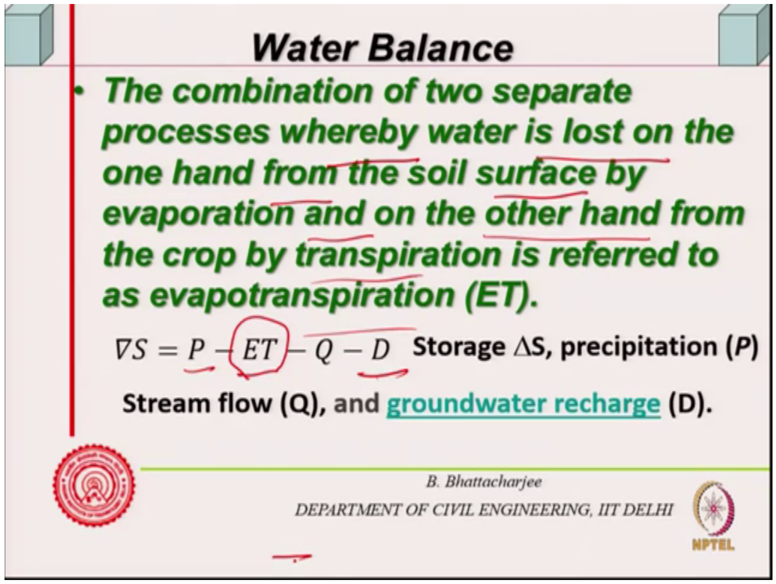

So the combination of these two separate processes where water is lost one hand from the soil surface by evaporation and in on the other hand from the crop of by transpiration is referred as evapotranspiration. So obviously what will be its effect? It will tend to increase the relative humidity, locally and since the evaporation is occurring it will reduce down the temperature, it will reduce down the temperature, right. So we can write it like this delta S is the storage, you know P is the precipitation, the rain or whatever it is and Q is the stream flow run off and then groundwater recharge is D.

So this is what is, so evapotranspiration is this part through which water is lost to the atmosphere but then is thus cooling. While this Q is actually not really much useful in the sense that it straight way runs off. So does not take part in anything else and delta S will be the storage in the ground water system.

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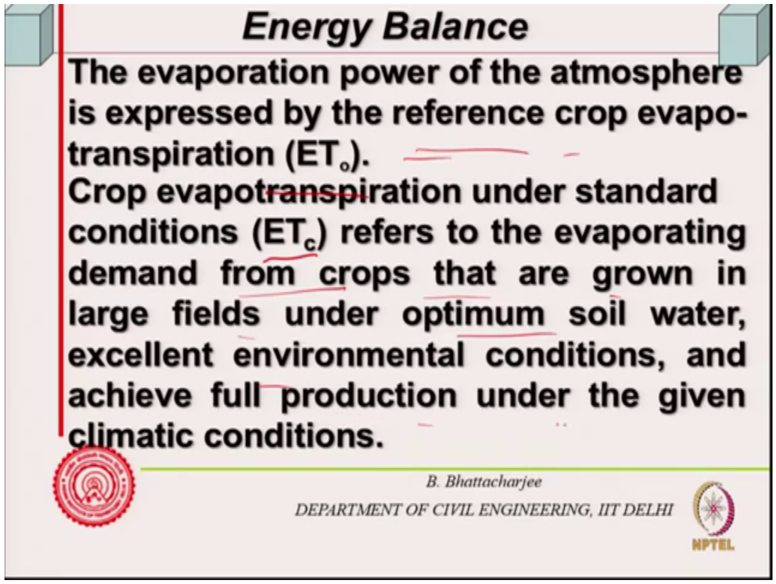

So evaporation power of the atmosphere is expressed by what is called reference crop evaporation, evapotranspiration. Now this has been modelled. So you can actually model this process for agriculture engineers actually they have done it actually.

So they take a crop preference, you know crop evapotranspiration as if we shall this, this model if you can apply, for example you can actually compute as we shall see, what is the likely relative humidity change because of the trees around this place, the example I will have is of Humayun's tomb, where there are plenty of trees around the monument and it showed there is the reduction in the temperature compared to measured temperature in one of the station, atmospheric station like that of Safdarjung airport which is not very far off. Measured temperature is lower but measured relative humidity is higher, relative humidity is higher. So this is the whole purpose, purpose is to see basically what is the physics or physical mechanism behind these kind of thing? So that you can actually look into any other places as you want.

Now agricultural engineers have actually used this kind of concept before for the purpose of crops, so the idea is borrowed from crop right, so crop evapotranspiration they define something called standard or reference crop condition for which the standard evaporation is ET 0 (plus) right. Now crop evapotranspiration under standard condition refers to the evaporating demand from crop that are grown in large field under optimum soil water condition and excellent environmental condition. So and achieve full production under the given climatic conditions.

So basically for most conducive condition for standard crop, this has been established and then for any other crop and any other condition you have some multiplying factors to find out the amount of evaporation say millimetre per day or whatever it is.

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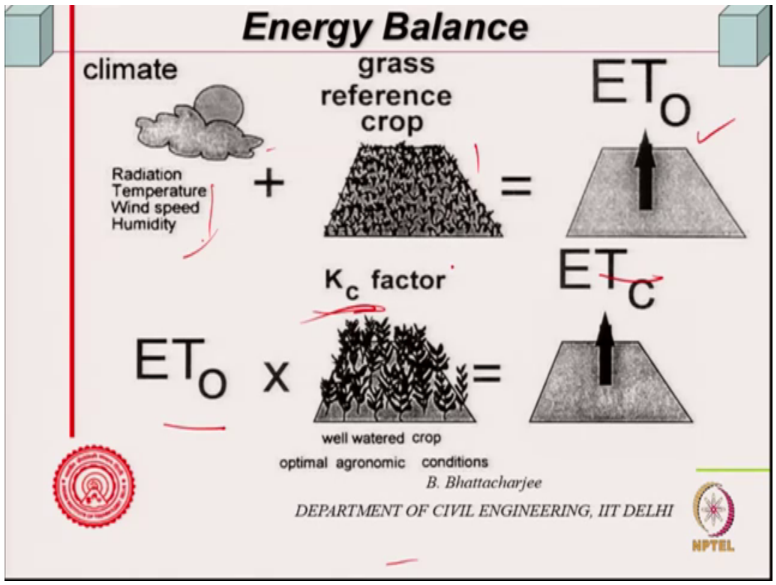

So if you look at first, you know both energy balance as well as the, so basically this is the precipitation radiation temperature wind speed humidity. Now reference crop is a special type of crop with a given height and leaf condition which is well water grass as if you see, you know. And later on it is (12) it is actually 12 centimetre high and that is what we call is standard condition under which we define as evapotranspiration 0, I mean oh you know subscript.

So basic standard, this is multiplied by factor. So ET0 multiplied by a factor for well watered other crop not the grass then you get ET c, so there is the standard one.

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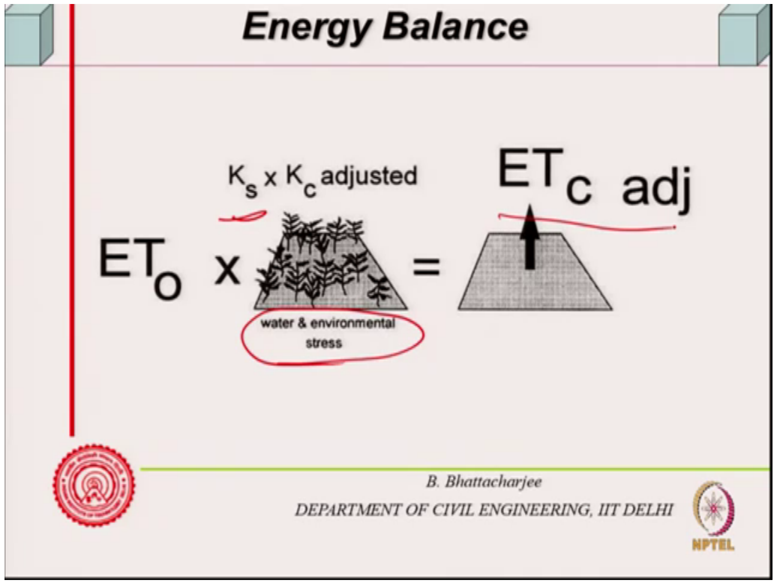

In fact for type, given type of crop and then if water and environmental stress is there, that means water is not optimal or right kind of you know well watered optimal (you know) agronomic condition. If it is not that then you multiply by another factor, so this is ET c adjusted, you know that is just how it is. So for you know for crop this is done, right.

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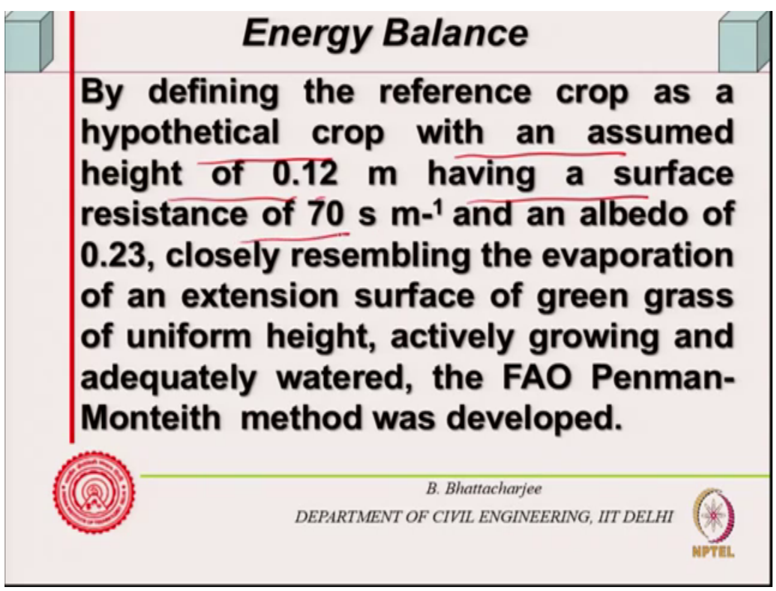

So by defining the reference crop as a hypothetical crop with an assumed height of 0.12 meter, that means 12 centimetre and heaving a surface resistance, now I think I will come to the statement later on, let us look at this diagram.

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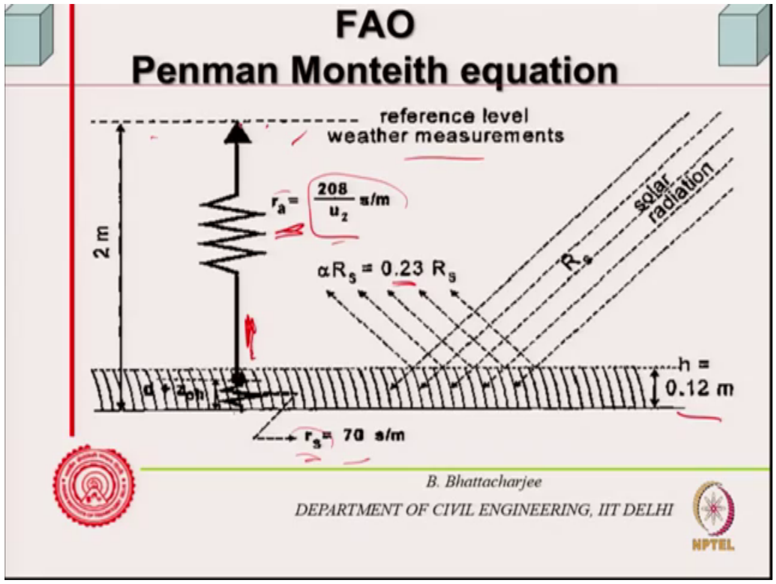

Let us look at this diagram, something like this. I have this height of the crop, grass 12 centimetre, solar radiation falls onto it and this is our albedo, part of it goes out, you know so this is what is falling solar radiation will falling onto it. Now there is evaporation occurring from here, so there is resistance offered, there is a resistance offered which is in one over velocity term. So velocity is meter q per meter square, velocity is nothing but flow per unit area, right, so one over that flow is a resistance that sort we are talking of.

So there is resistance offered here and this resistance to this evaporation because this is flowing, vapour is flowing, so reference level weather measurement is done at 2 meter height. So temperature, relative humidity etc measured at 2 meter height for 12 centimetre or 0.12 meter crop and there is one resistance here as well which is assumed to be 70 second per metre, one over velocity. So this is you know this from experimental observation they would have found out and this resistance from here to there is actually resistance of the air. This is resistance of the crop air itself and this is given as 208 divided by velocity where air velocity.

If the air velocity here is high, obviously more evaporation would occur, resistance will be less. So that is how it is done.

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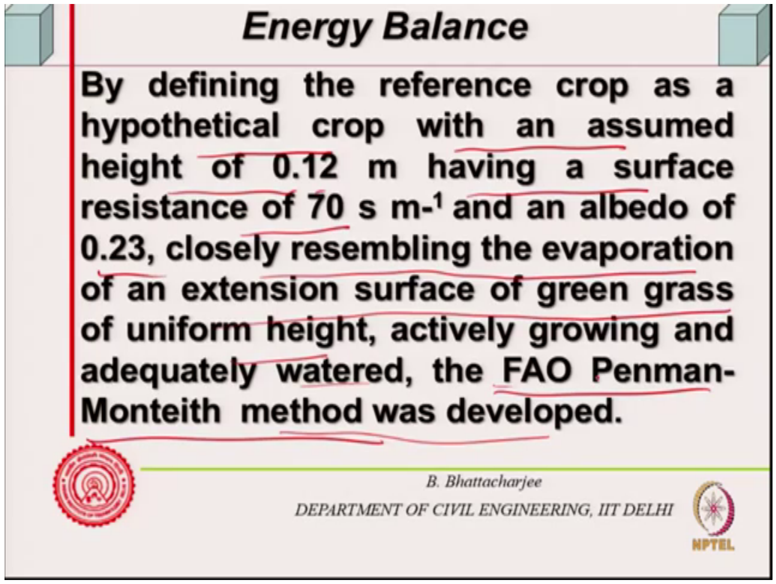

And albedo is taken as 0.3 , closely resembling the evaporation of an extension surface of green grass of uniform height actively growing in adequately watered, the you know FAO Penman Monteith method is developed based on these actually. So this model right, federal agricultural organisation because it is U.S American Society of Civil Engineers they did it. So this model was developed based on this, model was developed based on this for reference crop with measured you know accepted resistance value from the soil to the crop and resistance value from crop to the 2 meter standard height, right, so this is what it is.

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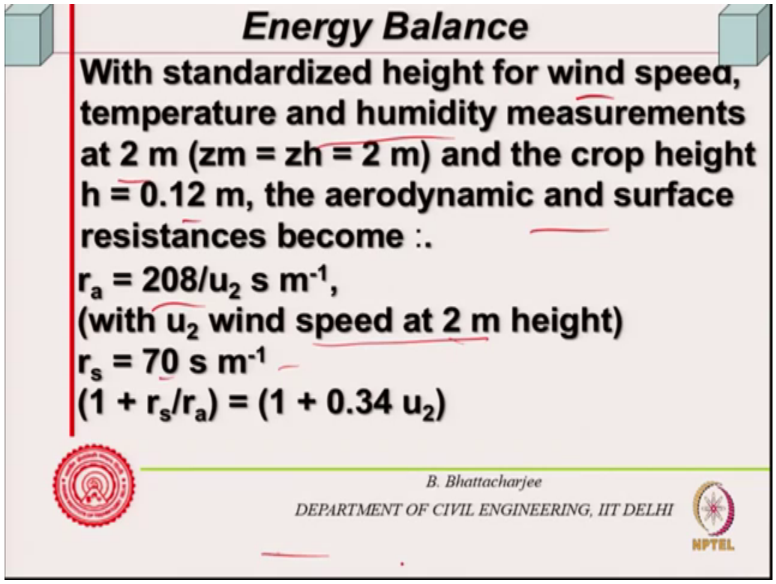

So standardised height for wind speed, temperature and humidity at 2 meter and crop height of this, the aero dynamic surface resistance has become. So first is a resistance, another is aerodynamic resistance, so rs and so ra is taken as 208 by u2 as shown in the diagram and the ut is the wind speed at 2 meter height and rs is 70, so this ratio is useful somewhere see shall see that resistance, you know 1 divided by 1 plus resistance of these two.

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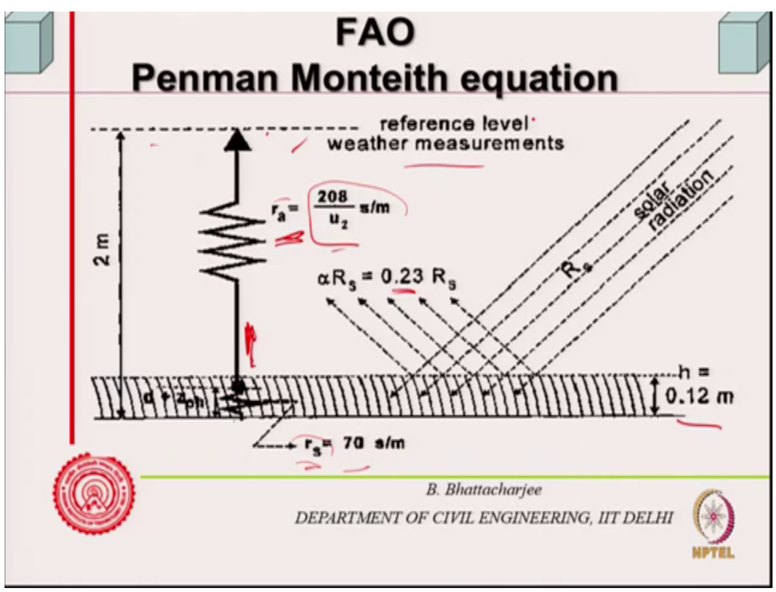

So this is, this is Penman Monteith model actually, this is a Penman Monteith model. So this model can give you the evapotranspiration under standard condition, write it can give you under standard condition and once you know the standard condition for your type of crop which is also they have listed down for what sort of crop what should be the factor k and then you can apply that and then find out, right. Okay, so this is the basic principle.

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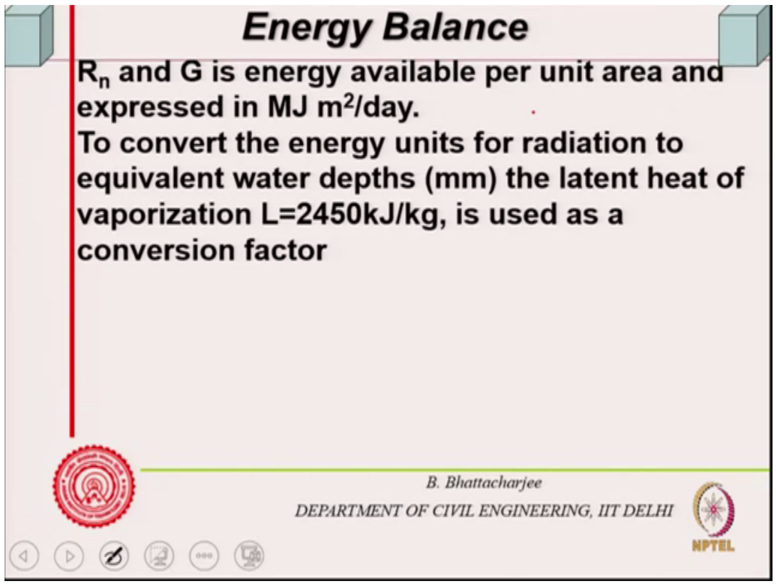

So right so this is what I said and Rn that is the normal radiation, we are using Rn here, I mean they are using Rn, the name notation kept it. Rn is the normal radiation, G is a energy available per unit area and expressed all these are expressed in Mega Joules power metre square per day you know.

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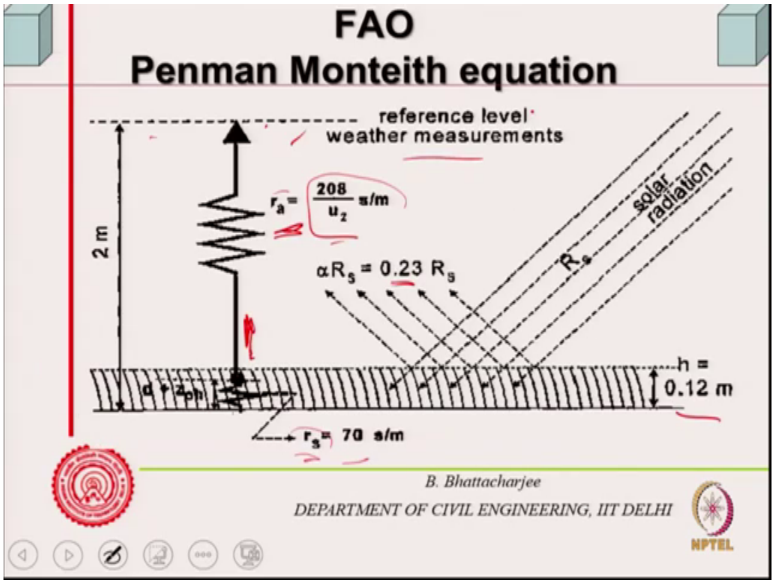

So if you look at it in this diagram this is the normal radiation supposing I am calling it Rn, here ofcourse is shown as Rs as solar radiation.

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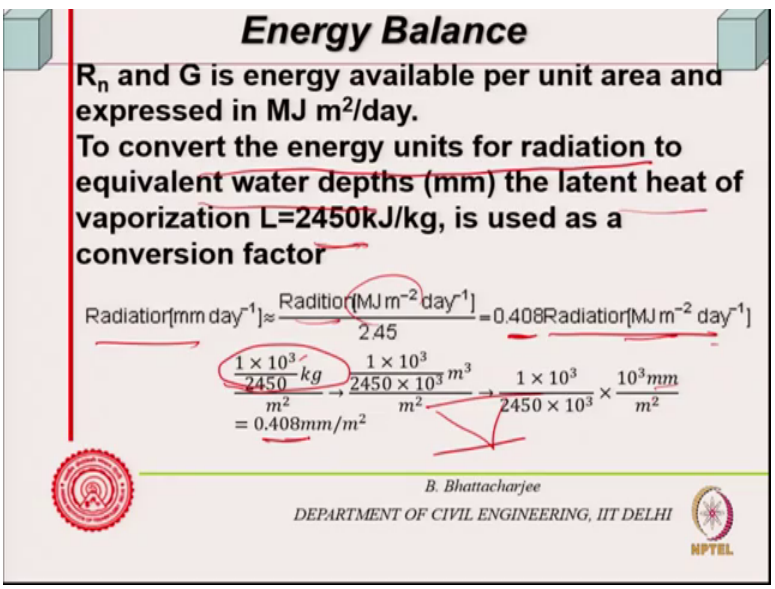

So this and G is the energy available per unit because some of this radiation will be reflected back, some will be available because when the evaporation is occurring energy must come, latent heat of evaporation must come. So if radiation is known to us, some this of this energy will be actually absorbed for evaporation purpose will be consumed for evaporation purpose and some we, will be anyway you know, some will be reflected back and you know we will go on heating and things like that.

So to convert the energy unit for radiation equivalent of water depth, so you want to find out how is the water depth, right? The latent heat of evaporation is taken as 2450 kilo joules per kg, so radiation, corresponding to radiation in mega joules per metre square per day. I want to find out how much is a evaporation corresponding to the radiation in millimetre per day. Because it will be evaporating from the some depth, right. So radiation mega joules per day divided by 2450 latent heat of evaporation.

So if I know the total energy coming in this divided by latent heat of evaporation will give me the quantum of water that can evaporate from the radiation received quantum because after all if the evaporation is to occur the sunlight is also needed, you know the energy is needed in order that evaporation takes place, right.

So if mega joule pass metre square per day is the amount of radiation this divided by 2450, 2450 this is in kilo joules per kg divided by 1000, will be this is how it is, you know. So this divided by, this is mega joules, I multiply by 10 to the power 3 I get kilo joules and this 2450, so that much kg of water will be , this multiplying factor I am trying to find out, I am trying to find out a multiplying facto, this value multiplied by the radiation. So whatever radiation I get multiply by factor that is what will give me millimetre per, per day.

So radiation is this, is in mega joules per metre square per day multiplied by 1000 divided by 2450 that much kg of water or moisture will evaporate, this multiplied by for 1 unit mega joule per metre square per day. For unit mega joule square per day, this much kg of moisture will evaporate, right. So per metre square anyway this is per metre square so mega joules to kg per metre square will come per day.

Now this multiplied by 10 to the power 3 because I want to convert this metre into, this is, this will be kg, kg divided by meter thousand will give me in meter cube because density of water is 1000 kg per meter cube. So this will give me meter depth of water that will be actually evaporating for the amount of radiation that is coming in per unit radiation. Now this if I will get, I get something like this 10 to the power 3 metre you know so millimetre if I want to convert I will multiply this factor by 10 to the power 3.

So I get 1 by 2.45 which is 0.408 millimetre square per meter square, so for unit radiation, unit mega joules per meter square per day, the amount of water which will evaporate is 0.408 thickness if it is fully saturated, if it is fully saturated 0.408.

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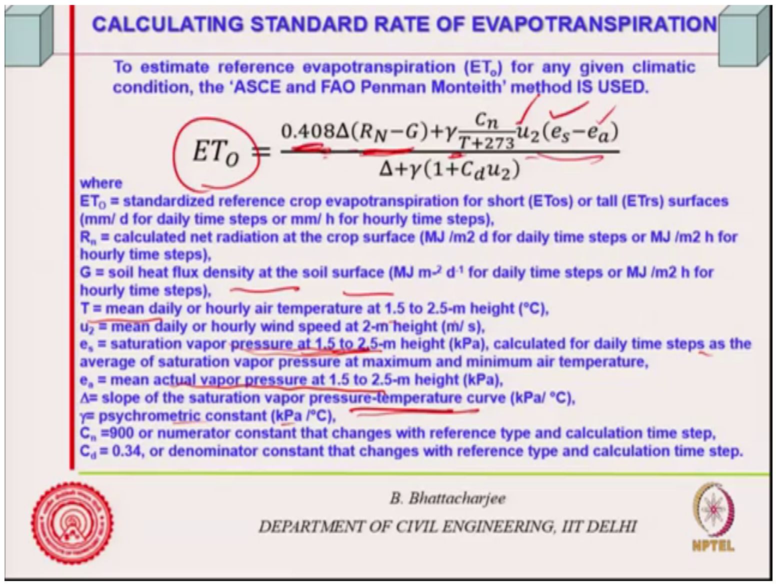

Now this comes into the equation actually, this comes into equation, you see this is408, now it has got two component as you can see the equation. There is the (standard) standardized reference crop evaporation, this is what they have developed this equation, so this is Rn is the amount of radiation that is coming in, G is going out into the ground.

So G is the solved fluxed density, whatever is absorbed by the soil, Rn is the total coming out per unit area, a part of it will be absorbed by the soil. Remaining radiation multiplied by 408 is a millimetre per day but evaporation also requires you know vapour pressure difference. Evaporation will occur depending upon relative humidity or vapour pressure difference. Because if the vapour pressure difference is not there evaporation cannot take place. This is fully saturated, so this is the slope of the saturation vapour pressure temperature, right.

So slope of the saturation because moisture is saturated and there the evaporation is occurring at a given outside temperature. So this is, this gives me, this will be you know, second part (()) (18:09) velocity, second part, so this is the evaporation that is occurring at the surface itself, at the plant surface itself and this is related to the velocity somewhere above if the, depend upon the resistance also the pressure difference between that point and the top surface, 2 metre, at 2 metre.

So ES and EA saturation vapour pressure at one point 5 to 2 metre height, 2 metre height now I am considering.

So first stage is at the surface itself evaporation will occur, 12 centimetre thick moisture, I mean grass where the evaporation will occur and that would occur because of the radiation coming in minus the radiation that is going into the ground. That would cause evaporation, second thing is after that also further evaporation will proceed from there to the 2 metre height depending upon the relative humidity at the 2 metre height, so it is taken as 1.5 to 2 metre height, you know at T mean temperature at, T is coming T would be coming here, that is an absolute term and gamma is again the, gamma is cyclometric constant related to vapour pressure difference to moisture content, you know.

KPa, Pressure I mean vapour pressure to per degree centigrade, so this is, I do not think I have talked about the cyclometric chart earlier in this in the course, but does not matter, we will not get into that details but what we understand is in a cyclometric chart absolute humidity, relative humidity, you know dry out temperature or temperature these are all related to cyclometric chart, you know different degrees of saturation what you call a different relative humidity, slope of that curve is you know used.

So here this is the saturation vapour pressure at 2 metre height, so you take from 1.5 to 2 meter height. Calculate it for daily time step because if you will do it for 24 hours so you will do it, assuming that it is the kind of constant over a period of time, every hour or every half an hour or every 2 hours and it will depend upon you know will calculated for daily time step. Mean actual vapour pressure, so this is the actual pressure, this is the saturated vapour pressure at that height. UT is the velocity because that causes the evaporation from the second stage, so first stage is we saw you know this part 408 Rn etc deals with, 40 Rn etc-etc deals with this situation.

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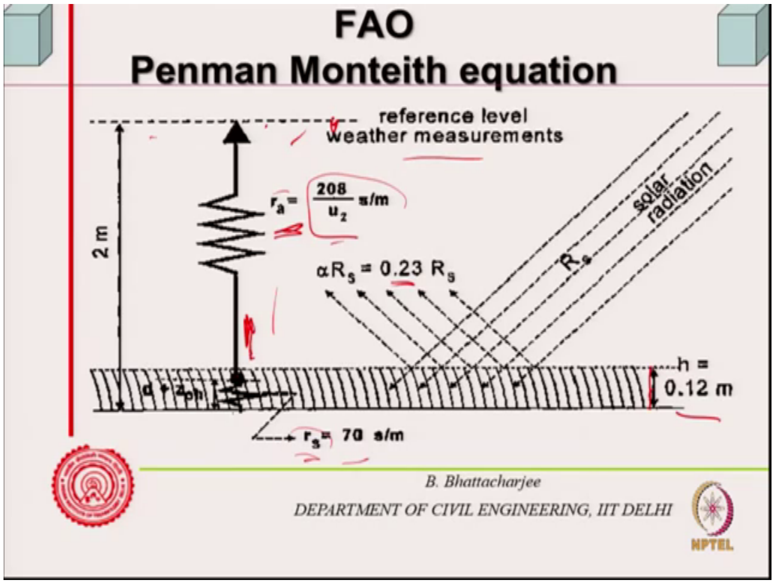

It deals with here evaporation at this level and this portion is the second part so the , we are taking the saturation pressure here and the actual pressure there, so that difference will cause evaporation occurring at you know from here to there evaporation occurring, right. So that is the 2 part of this equation, that is the two part of equation.

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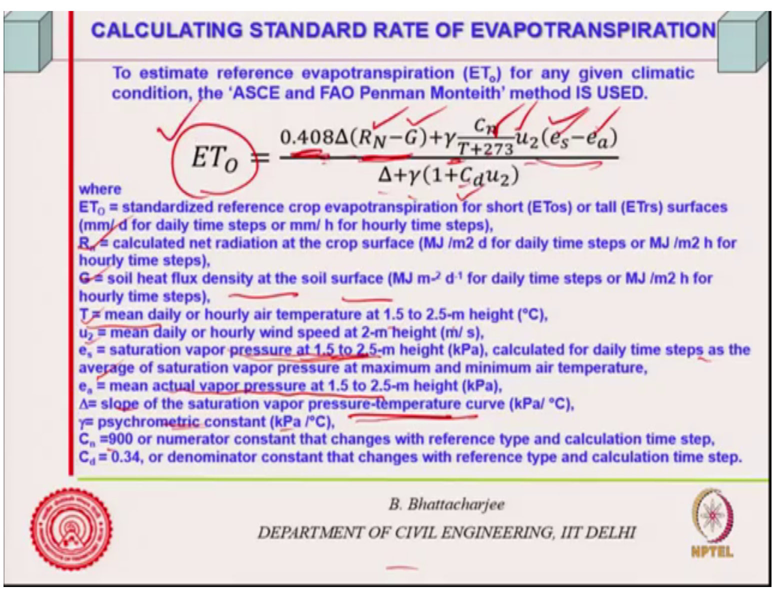

So this is a constant and this is another constant. Now this divided by the cyclometric constant and ratio of these two resistance is, ratio of these two resistance is, so we can that this is the radiation falling in direct radiation, G is the soil heat flux, the amount of heat radiation going through the soil, T is the mean temperature at two metre height, you know this is where it is coming, this is saturated vapour pressure at to 1.5 to 2 metre height. This actual air pressure, vapour pressure at 1.5 to 2.5 metre height, this slope of saturation line and this cyclometric constant, these are some constants depending upon time step you take for calculation because you will calculate at different times assuming time step to be constant.

During that period of time, how much evaporation has occurred? So it was, and then sum it up for the whole day, millimetre per day, that is what you will be interested in and this values can be 34, ideal condition or can be some other velocity. So you see one can find out the ET 0.

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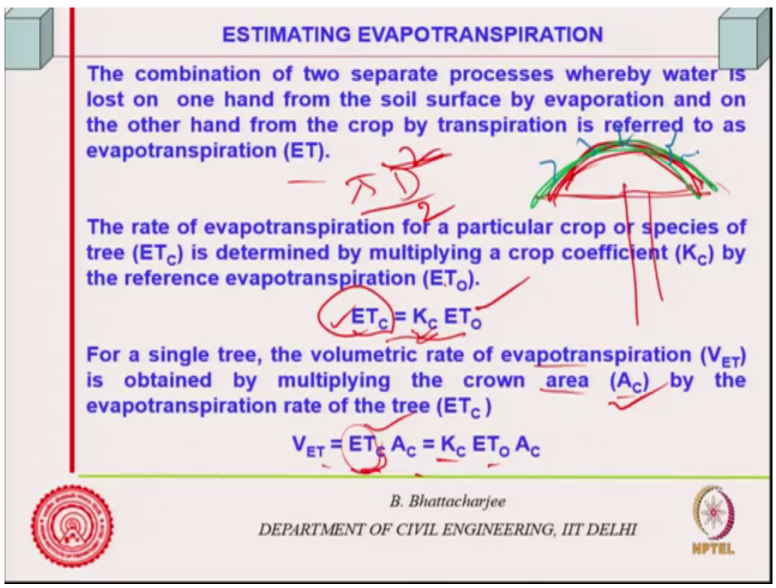

Then K values are available on table, K values are available on table you know K values are available on table, so this separate processes whereby water is lost on one hand from the soil surface by evaporation and on the other hand from the crop by transpiration that is what it is and this Kc.

So the Kc value is we know for different types of crop, assume or plants. For assuming the plants, we can assume a plant, supposing it is 3, a hemispherical surface, right approximately because tree lives generally from that kind of an umbrella shaped thing. So you can approximate this to a say 5 meter radius, 5 meter diameter or 10 meter diameter, etc-etc. And for the given type of plants you have not really cropped, the multiplying factor will vary and thus whole list is available for different types of plants.

For example, I mean for trees, supposing you want to convert it into trees of the kind of you know like a, like a banyan tree, the values are available. So these values people have actually obtained the botanical, you know people botanical backgrounds and things like that or agricultural background they have, so this you can multiply. Standard one you calculate out and this is what you find out, right. Now for a single tree the volume of rate of evaporation is obtained by multiplying the crown area, so this is the crown area.

The crown area will be simply Pi D square by 2 because we assume it to be hemispherical right, hemispherical right, okay, it is Pi D square by 4 Pi r square, so Pi D square, so Pi D square by 2, that is what it would be. So crown area by the you know so you get ET c standardised value ET c multiplied by crop factor and moisture factor and all those, so volume of you can actually find out Kc ET c Ac right.

So for example, the example case that we will take later on Humayun's tomb let us say, where one could count the number of trees, if you see that I have some Google photograph of the same I will show you. The actual tomb is there, surrounding that there are number of trees of different sizes, some 5 meter, some 10 metre, so one could count them and once you have counted them for the whole day you will find out how much is the moisture that will evaporate from the tree top, from the crown.

So that is given by this formula, now you cannot do hand calculation may not be very easy, remembering the formula also may not be very easy, remembering the formula is not very easy but you can write in excel sheet, so easily you can actually calculate it out. Now once you have calculated that what you have found out, the evaporation that is occurring, evaporation that is, evaporation that is occurring here, you know evaporation that is occurring actually, evaporation that is occurring at this level.

Now this will not remain there, this will get distributed, all over the space. So you have a kind of a space that you are concerned about, considered that total space, it will be a 3 dimensional space could be a rectangular parallelepiped because there the number of trees and then you want you want to find out what would be the relative humidity at every element in that area, right, so that you can do.

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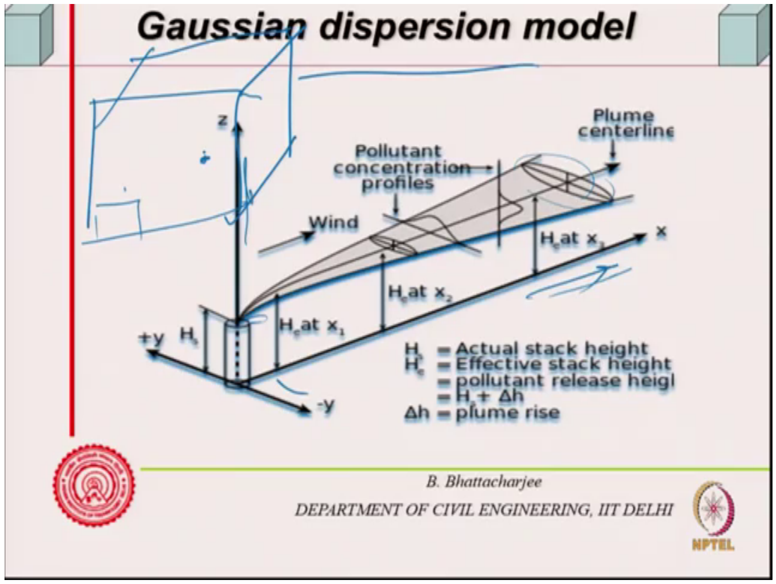

Now this can be done using what is called Gaussian dispersion model which people in air pollution use, you know when they have steady situation of a chimney let us say say vertical one, a chimney, the pollutant or smoke moves along, it is assumed that it actually moves in a with circular cross section, it expands and moves in a circular cross section. So if you look at the direction of movement, take a normal path I mean normal direction, it will be circular cross section.

And you assume that in all, both the direction it is normally distributed, the concentration is maximum at the centre and symmetrically distributed about the centre like Gaussian distribution, okay. So this is Gaussian dispersion model, that is what it is, so pollutant concentration so in our case this can be our tree with the height Hs, this is x direction, this is z direction, this is y direction for you know for a given tree and therefore at a given distance, given height compare to this or given distance in x and y direction using Gaussian dispersion model we can find out what will be the moisture content, right.

For a 3 dimensional box kind of an area where this might be my tree height and the number of trees and that I find out at any point I can find out the moisture content form a single tree. I can sum up for all the trees to find out what is a, you know how much will be the dispersion of the moisture vapour from the tree to that from all the trees I can find out. Now this moisture vapour actually you know would reduce down the temperature because it would be taken the latent heat of evaporation.

So on an average basis total temperature reduction you can find out because the amount of moisture that is evaporated sum total of all of them, divided by latent heat of evaporation will be the average temperature change in the whole space right, average temperature change in the whole space. And the moisture that is added actually changes the relative humidity, will change the relative humidity, right, so that is what it is.

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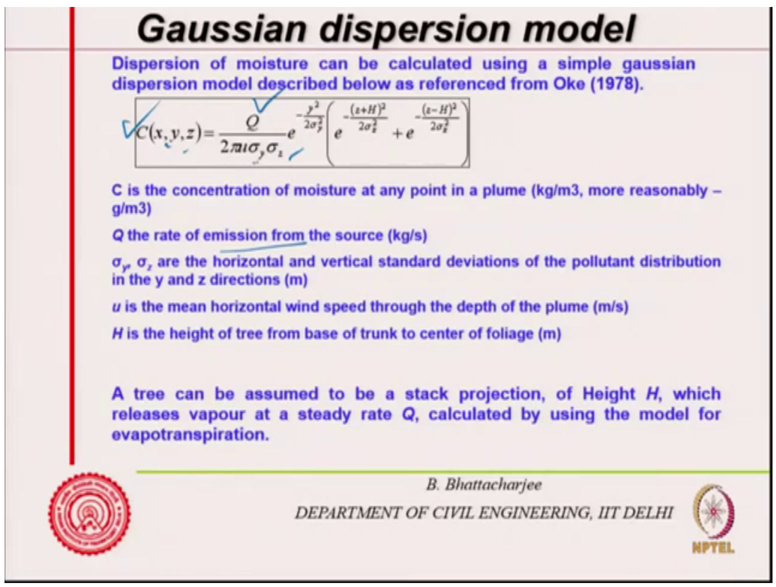

So Gaussian model is applied and the formula is something like this concentration or in our case it will be mass of the moisture per unit volume, at any point x, y, z in any point in this three dimensional box is given by Q is the rate of the emission from the source that is from my tree crown of the tree , that I have already calculated using Penman Monteith model, these are standard deviation

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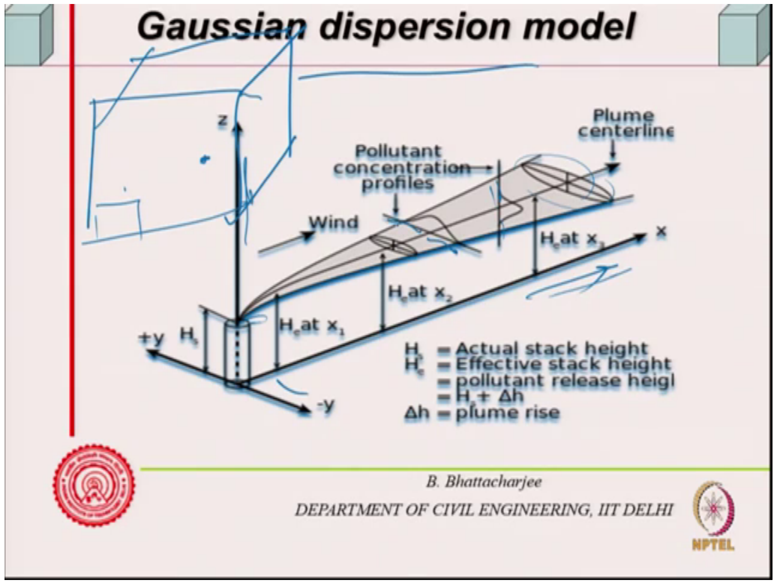

That means you know this spread on in xn, y direction , this will be 3 sigma, this will be 3 sigma, this will be 3 sigma, this will be 3 sigma, this will be 3 sigma x and y direction.

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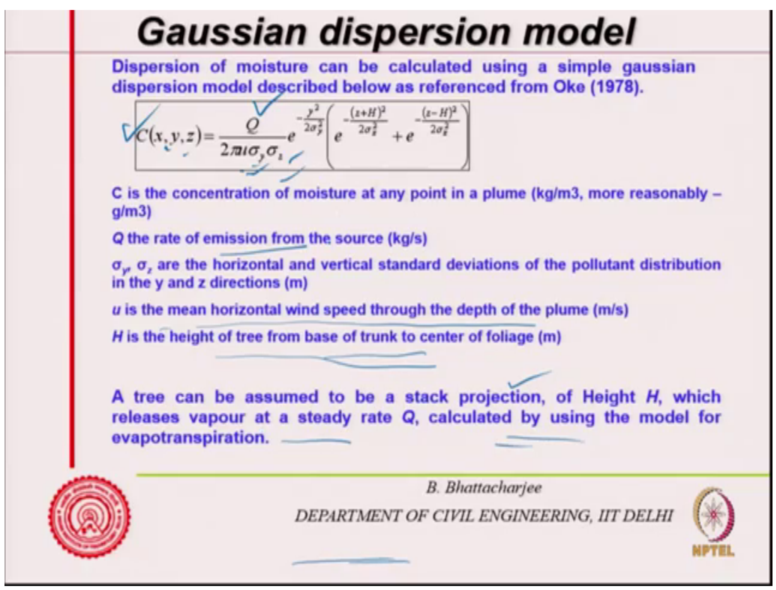

So the spreads these values are actually available, values are available for different types of pollutants how they will spread actually this are available. So sigma x, sigma z, U is the air velocity mean horizontal speed to the depth of the plume. Horizontal air speed, right given a direction of movement and this is z is a, z is a height in z direction, h is a, h is a height of the tree from base to trunk. Base of trunk to the centre of the foliage that means half of the crown you know centre of the foliage you will take.

So you can assume the tree to be a stack projection of height h which increases vapour at steady rate, so this valid for steady state situation. Constantly evaporating at the same rate, moisture is constantly evaporating at the same rate, right. So this valid for situation which releases vapour at steady rate, calculated by using the model for evapotranspiration and once you have done that, that any point you can find out, right you can find out any point you can find out.

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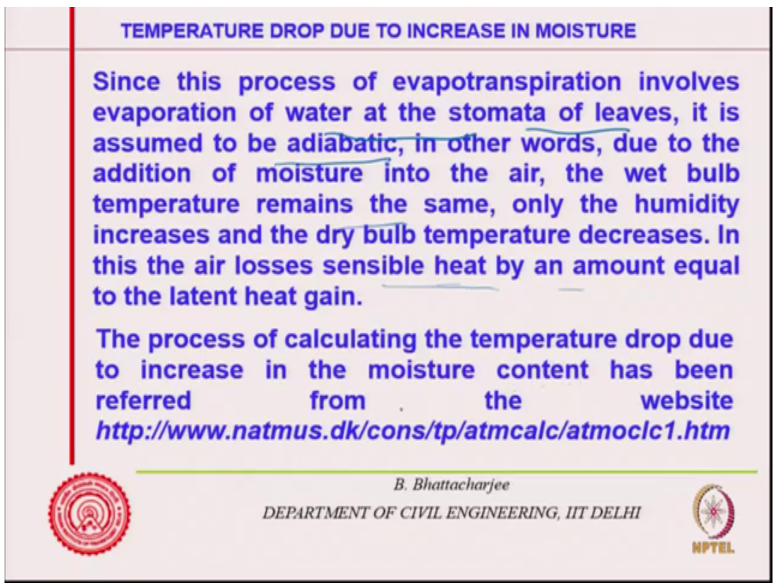

So will just look at this, since this process of evapotranspiration involves evaporation of water from stomata of leave is assumed that it is to be adiabatic into the air, the wet bulb temperature remains same because at saturation the wet bulb temperature will be evaporating, only the humidity increases that is what we are saying and in this they are loses sensible heat and the amount of equal to the latent heat gain. The process of calculating etc okay so one can obtain from this website the, you know the model