Advanced Hydrology
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Lecture – 15

Good morning and welcome to the next lecture of a video course on Advanced Hydrology. In the last class we looked at some methods of calculating a special average rainfall given the rainfall data at many rain gauges in a catchment. We looked at four methods, first one was the simple arithmetic average method, second was the Thiessen polygon method, the third one was the Isohyetal method and then the last one was the distance reciprocals squared method. Then we moved on and we looked at when important concept of thunder storm cell model, in which we derived the expression for rainfall intensity coming out of a steady state thunder storm cell; in which the rainfall is occurring through some convective patterns. What we will do today is, we would leave the rainfall at this time and we will move to the new topic in this chapter on evaporation.

In the evaporation, what we will do is look at the definition, the factors effecting evaporation and then how we can estimate the evaporation; its importance and then how we can estimate it using various methods. So, I would like to get started with the definition of evaporation, how do we define evaporation? I am sure all of you may have seen evaporation as a process in your earlier classes. It is a process of change of phase of any liquid into the gaseous state, right and there are certain conditions to that. So, let us look at the definition first and then we will move to the physical process.

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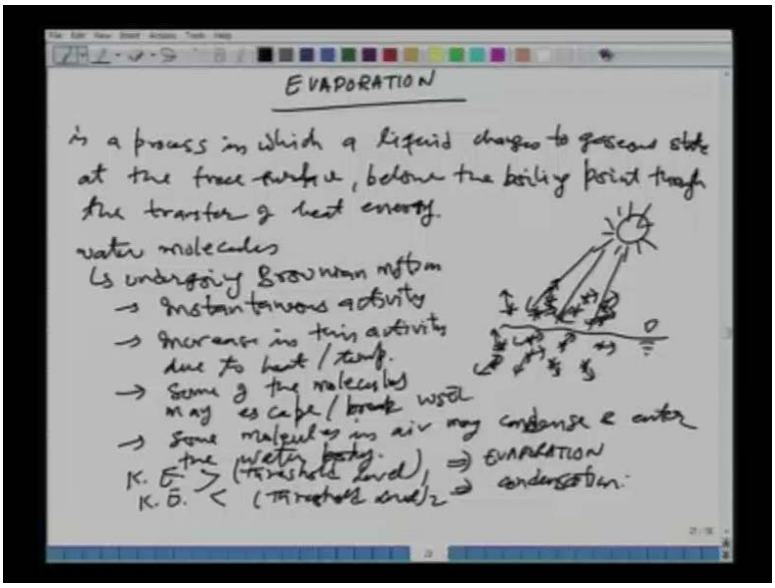

So, we are starting the new topic on evaporation. And how do we define it? Well, it is a process in which a liquid changes to gaseous or vapor state. That is the very simple definition for lemon, but then there are certain conditions. At the free surface of the liquid and the condition is below the boiling point, below the boiling point through the transfer of heat energy. So, the two conditions are that, it is the temperature is below the boiling point in the liquid and there is a heat which is being imparted to the substance or to the liquid. In our case we will be talking about mainly water; water will be our new liquid and the heat energy that will be provided, it will be provided by the sun. And as hydrologist or engineers, we are interested in finding out the evaporation or estimating evaporation from the water bodies; such as our reservoirs and lakes, and rivers and so on.

So, what I would like to do is look at the process, all right; why is the evaporation taking place and how it is taking place? So, we are talking about the heat energy which is provided by the sun. So, you have the sun shining and then you have some water body; it may be lake or a reservoir or river or anything. What happens is that you have this heat energy coming in the water body; you have these water molecules close to the water surface. And as you know they are undergoing Brownian motion, all right; they are constantly or instantaneously moving in any direction. Close to the water body or close to the water surface elevation, also there is moisture or water molecules in the air. They are also undergoing or constantly undergoing this Brownian motion, all right; in all the directions, all right.

So, you have this water molecules undergoing Brownian motion and they have some what is call instantaneous activity. So, what do you think will happen to this instantaneous activity or the Brownian motion; as the heat is being imparted to them, all right. Any molecule which will posses certain level of energy all right and if we increase that level of energy this activity or the Brownian motion will tend to increase, all right. So, there is an increase in this activity due to or with heat or the temperature; in this process the temperature of the liquid also go up. So, as a result of that, what may happen is; some of the molecules, some of the water molecules may escape or basically break the water surface elevation and go into the atmosphere, all right. Because they may possess your sufficient energy, all right; so that they break the surface tension forces which are there at the water surface elevation and then they may enter into the air.

So, this is process of evaporation in which the water molecules are breaking away and they are from a liquid state they are getting converted into the gaseous state. Now, this couple of concepts I would like to look at here; before I go to that, at the same time we may also have some molecules in the air or in that atmosphere may condense may condense and enter the water body. So, it is a two way process; sometimes may be due to the change in climatic conditions and the net escape of water is what we define as the evaporation.

All right, so let us look at the two concepts; one is the when the kinetic energy of the molecules water molecules which you know the possess, if it is more than certain threshold threshold level. And let me call this threshold level 1, all right. If the kinetic energy increases and if it goes beyond a certain level 1 threshold level, then you will have evaporation, and on the other hand if the temperature goes down for some reason, all right and the kinetic energy reduces below some other threshold level, then you will have condensation. So, the other aspect is if the kinetic energy or the water molecules is less than some other threshold level; let me call it 2; then you will have condensation.

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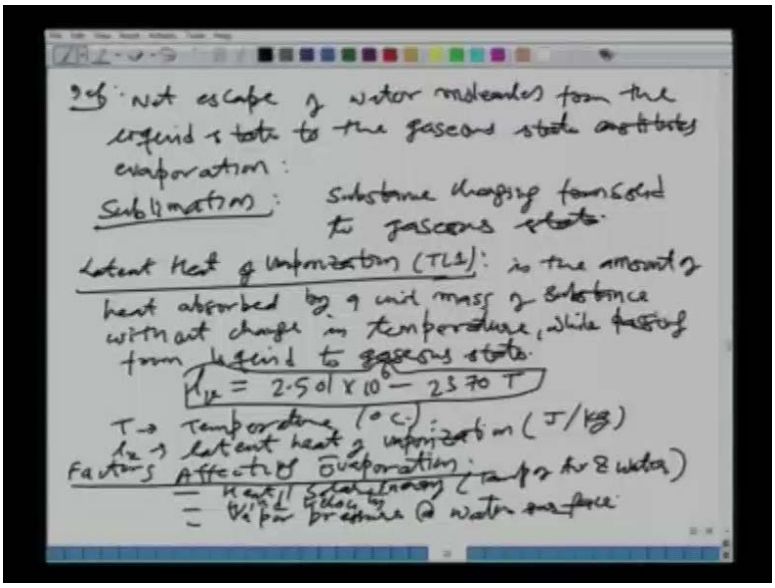

So, then how do we define or we give another definition we can say for evaporation is the net escape of water net escape of water molecules from the liquid state to the gaseous state constitutes evaporation. See that any substance is going from one state to the other all right, in this case liquid to gas all right and that we are calling as evaporation. Sometimes, it may so happen that a substance may evaporate from a solid state. You may see that from the mountain tops, you have the snow and ice covers and there may be evaporation taking place, what is that called? That is actually called sublimation; we have a different name for that process, sublimation. And in sublimation what do we have? We have the substance of which is water in our case changing from solid to gaseous state. So, this is as per as the basic concepts about this evaporation is concerned.

Now, we will look at we had defined or looked at this two threshold levels. Thus, anyone of you have any idea what this threshold levels are? Well, one of them is what is called the latent heat of vaporization; so let us look at that. Latent heat of vaporization, all right, and this is nothing but your threshold level 1, all right; if the heat energy or energy possessed by the water molecules becomes higher than this that is when you will have evaporation process starting or occurring. Now, what is latent heat of vaporization? I am sure all of you know or understand this, but we will quickly look at its definition.

Is the amount of heat absorbed by a unit mass of unit mass of substance without change in temperature while passing from liquid to gaseous state. So, it is the amount of energy,

heat energy any substance will consume, all right of unit amount. That is unit mass all right, without undergoing any temperature change all right while going from one state to the other. That is the basic definition of your latent heat of vaporization which I am sure you have studied earlier in your physics classes.

There is an expression we will not look at its derivation. It is given as latent heat of vaporization l v as 2.501 times 10 to the power 6 minus 2370 T. So, in this equation your T is your temperature and is degree centigrade of your substance and l v, as you see that this is an empirical equation with constant so these constants will take care of the units themselves. So, this is the latent heat of vaporization and the units will be joule, joules per kilogram. So, if you use this equation all right, if you know the temperature of the water body you can find out what will be the latent heat, required for water to starting elaborating.

All right, so this is as far as the very simple basic concepts about the evaporation, and latent heat is an important, you know physical property of the fluid which we will be using when we derive the expressions. Now, what we will do is, we will move on to the factors that affect the evaporation, all right. When we say the factors affecting evaporation, it may be the rate of evaporation or the total volume of evaporation. So, we will look at combined factors and will call them it may be physical factors; you know fluid properties as well as the climatic conditions.

Factors affecting evaporation, why it is important to understand the factors that affect a particular phenomena? Well, if you need to calculate or estimate somehow its value of that particular physical variable evaporation in this case; we need to know what are the physical, other physical variables that impact or that affect its value, all right. So that what we do; we list them out how many of them are there, which one is you know affect the most and we can prioritize them and then we will select some dominant factors which will affect evaporation, all right. So that we can monitor those factors, may be observe them; you know using instruments we can measure those values. And then we calculate the final output which is evaporation, all right.

So, what I will do is we will look at all the factors which are responsible for evaporation; first one of them, in the definition we had said that the cause of the evaporation is what? It is the heat energy provided by the sun. So, the first and the foremost you know factor

that affect the evaporation has to be the heat. The amount of heat or the solar energy which may vary from place to place, which may vary from you know within a day, you know from morning till afternoon till evening and so on. So, the amount of heat or the solar energy which a water body is receiving all right, that will dictate its temperature and that will dictate the amount of evaporation. So, the heat or the solar energy and which is related with the temperature of your air as well as the water body all right.

What is the other factor, other factors? One is the heat energy, fine. Well, what happens to the water vapor after it has been evaporated? Let us consider the two cases; in one case all the conditions are same. The other one also you have the same condition except that there is wind blowing in one case. Where do you think you will have more evaporation? Obviously, the place where there is a constant wind blowing. So, what happens? Actually the overall evaporation losses is that, water molecules become vapor initially and then due to the wind action they are carried away or taken away from the water body or your lake or your reservoir.

So, wind velocity, higher the wind velocity higher will be the rate of removal of this water vapor above the water body. So, wind velocity becomes a an extremely important factor in determining the loss of evaporation, loss of water due to evaporation from lakes. So, I am going to write the wind velocity. What else? Why does the evaporation take place? We have looked at the physical phenomena as far as the water molecules are concerned. Let us say water starts to evaporate, all right and then let us say there is no way. For example, after sometime you will have more and more moisture in air. The water keeps evaporating; all right in the moisture there may not be any more capacity to hold any more moisture.

So, the other factor that depends is the difference in the vapor pressure, the current vapor pressure and the what is called the saturation vapor pressure. So, vapor pressure is an important parameter, vapor pressure at the water surface, which is a measure of the humidity in the atmosphere. You may have noticed that on the days when we have higher humidity, you will have less evaporation. Why? Because of higher evaporation sorry for higher you know humidity or moisture in the atmosphere, you will have higher vapor pressure. And the deficit between the saturation vapor pressure and the current vapor pressure will be small, all right; that is what is the driving force. Many of the empirical equations you may have seen earlier, always involve in expression which is e s

minus e a. So, it is basically the current humidity conditions measured in terms of the vapor pressure.

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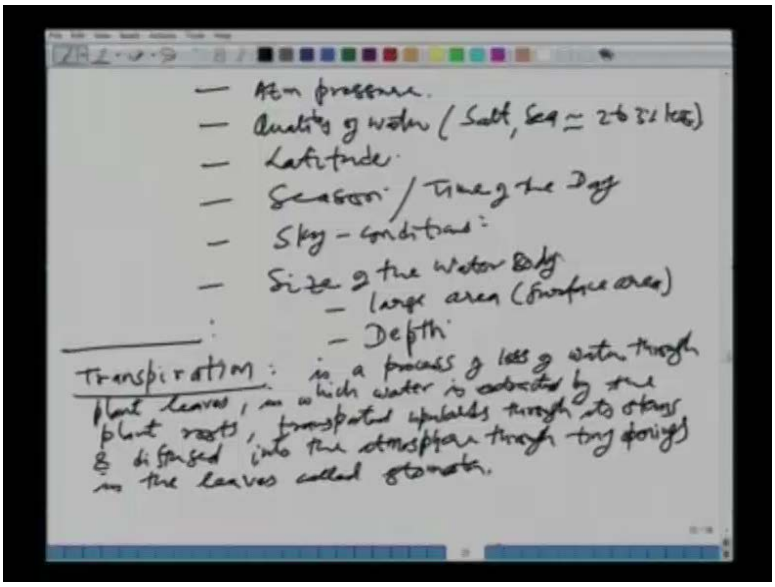

Let us move on there are many other parameters of factors we can list out here and some of them may be interrelated to each other. So, I will write the atmospheric pressure which may vary from place to place although very slightly, but the atmospheric pressure will also dictate the amount of evaporation that is taking place. What about if you consider two cases in which, let us say you have two lakes. One of them is consisting of fresh water all right, it is a pure water; the other one may have some minerals or you know some salts or you know some kind of impurities, all right. Do you think the amount of you know evaporation will be same? No, the existence of this minerals and impurities in the water will affect the amount of evaporation from that particular water body.

So, the quality of water is also an important parameter or factor that will affect the amount of evaporation. For example, as we all know the sea's water is very salt, all right. From there the evaporation is approximately 2 to 3 percent less as compared to evaporations from the fresh water body having similar climatic conditions. So, the quantity the quality of water also affects the evaporation. What about the latitude? The altitude of your water body itself will have some bearing on the amount of evaporation, because the amount of heat energy that is received will vary as a function of the altitude.

So, the evaporation from the hilly areas may be different than the evaporation in the lakes in the planes. So, altitude also impacts the rate of evaporation.

How about the season? Will the evaporation be same throughout the air? No, it will depend up on the season; in winter's it will be less, in the summer's it will be more; again, some of these more factor are interrelated to each other. Also, we can say the time of the day. If you look at the hourly variation during the day of your evaporation, you will notice that evaporation will be maximum in the afternoon close to 1 p m 2 p m and the sun is beating down, alright. Early mornings and in the nights you will hardly have an evaporation very little. So, it the depends up on the time of the day as well. Other one is let us say the sky conditions even during even during the summer months, if you have cloudy conditions; you may not be receiving sufficient heat because of that cloud cover. And because of the less amount of heat you will have less amount of evaporation taking place. Another important factor is the size of the water body.

What do we mean by the size of the water body? Let us say you have two lakes; same climatic conditions in two different catchments. One has large area, surface area all right other is the small surface area, which one will have you know more loss of you know water due to evaporation? Obviously, the one with the larger surface area, that is as far as the surface area is concerned, how about. So, this was about the surface area actually I should say; larger area will have higher evaporation, what about the depth of the lake? You have two lakes one is shallower and other is deeper. Where do you think evaporation will be more? If you think about it the shallow lake has less capacity to store the heat. So, the heat storage capacity of a shallow lake is small as compared to the deep lake. So, you would you now think that the amount of evaporation losses from a shallow lake will be higher as compare to the deeper lake.

So, you see that these are some of the factors that affect the evaporation all right either the evaporation rate or the total volume of water loss due to evaporation in a particular period of time. So, we have combined all these methods. And there are many methods which will account for some of these factors, all right. And in this chapter we will look at some of the methods, how to calculate or estimate the evaporation. Now, before we move on to that, let us look at couple of you know associated physical processes, all right. And first one of them is what is called transpiration.

What is transpiration? Transpiration is also the loss of water from the catchment to the atmosphere. How? Through the vegetation, all right. And where is the water coming from? It is not the surface water. The loss of water through the vegetation leaves and through the stems coming from the route zone or it is the subsurface water which is the being lost to the atmosphere to the vegetation. So, if you want to define it, we can do it like this. Is a process of loss of water through plant leaves in which in which water is extracted water is extracted by the plants roots, all right gets transported. The water will talk about transported upwards through its stem or branches and diffused into the atmosphere into the atmosphere through tiny openings; very small openings, through small openings in the leaves which are called stomata.

So, what you have is in the subsurface zone there is some soil moisture, there is some water; it may have been to some rainfall or some other reason. And if they have vegetation and the sun comes up and what we what happens is, the plants have the capacity to extract this water, all right. This water gets from the roots, it goes into the stem and through the branches and to the leaves and in the leaves you have very tiny holes which are called stomata. And through which the water loss takes place are which is called the transpiration. We will not go into the too much of detail of this process.

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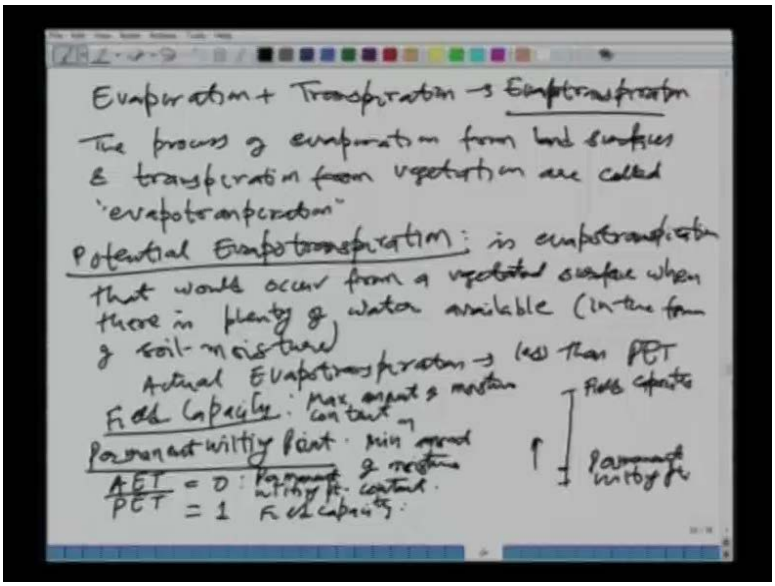

We combine the evaporation; the term evaporation and transpiration and in hydrology a combined term is called Evapo-transpiration. So, evaporation of the water from the soil

surface, surface water, the lake and catchment in general and the transpiration; that is the loss of water with from the root zone, all right. If we combine all of that, that basically quantifies the loss of water, all right to the atmosphere. So, there is a single term we try to find out or estimate which is called the Evapo-transpiration. So, as far as the engineering point of view is concerned or the hydrologist's point of view is concerned, they are concerned in estimating how much will be the water loss, all right. So, we do that and that so that we can plan our water resources management activities accordingly. And Evapo-transpiration is also important as you all know in the agricultural practices.

The process we can define this as the process of evaporation from land surfaces from land surfaces and transpiration from vegetation are called or collectively called you can say Evapo-transpiration. Combining with the all the two processes; if you see that the transpiration or the Evapo-transpiration will depend upon the vegetation density or the forest cover in a particular catchment. Higher is the forest cover, you will have higher percentage of water getting will lost due to transpiration, all right. And in the urbanize catchment you will have very little of your transpiration losses, but the contribution from the evaporation will be more. But we combine both of this and we termed it as Evapo-transpiration.

Now, related to the Evapo-transpiration, we have a term called actual Evapo-transpiration and potential Evapo-transpiration. And I think you understand the difference; we will define the potential Evapo-transpiration first. As the name suggests what is the potential Evapo-transpiration? Well, like we had discussed for the infiltration process, the potential infiltration we had said is the maximum amount of infiltration that can occur, given there is sufficient amount of water that is available. So, similarly, the potential Evapo-transpiration is the Evapo-transpiration losses that would occur when you have lots of water available for evaporation or Evapo-transpiration. So, there is no scarcity of water in the catchment, all right; what we will be the evaporation at that point of time. So, that is what is called the potential Evapo-transpiration.

So, it is the Evapo-transpiration Evapo-transpiration that would occur from vegetated surface when there is plenty of water available mainly in the form of in the form of soil moisture in the roots zone. Yeah, that is what is the potential Evapo-transpiration. So, what is the actual Evapo-transpiration then? The amount of soil moisture or the water available in the catchment will not be maximum the all the time, all right. You will have

the catchment, moisture conditions will be certain fraction of the maximum possible moisture that the catchment can store. So, depending upon that the actual Evapo-transpiration will be corresponding to the existing or the current soil moisture conditions. So, the actual Evapo-transpiration will be obviously less than the potential Evapo-transpiration.

Here, I would like to discuss this two concepts; one is called the field capacity; those of you who are in agriculture sector. The amount of moisture in the subsurface zone or the soil can be characterized or will vary between two limits. One of them is the field capacity; what is field capacity? It is the maximum amount of moisture content, it is the maximum amount of moisture content the soil can have, all right. So, that is why this is the field capacity which is the highest all right. We are looking at moisture content as we go up in this chart. And then you have the minimum one or which is called the permanent wilting point.

The permanent wilting point is what? It is the minimum amount of moisture content the soil can hold. So, what will on this graph let me say that this is permanent wilting point. What will happen when the soil moisture conditions in the catchment drop below the permanent wilting point? Well, the vegetation will start to feel the stress and they will start to die or wait under pressure. So, the moisture condition actually varies between the permanent wilting point, which is the minimum soil moisture conditions and the maximum one. So, depending upon that if we look at the ratio; that is your actual Evapo-transpiration divided by the potential Evapo-transpiration. Actual divided by potential will be equal to 0, when will that occur? When the moisture conditions in the catchment are equal to the permanent wilting point. So, they will be hardly any water. So, they will be no actual Evapo-transpiration.

So, this is at the permanent wilting point. When the moisture conditions are at the permanent wilting point and it will be equal to 1 at the field capacity. And as you know normally the soil moisture condition will be between these two limits. So, the ratio of the actual Evapo-transpiration to the potential Evapo-transpiration will be between 0 and 1. So, now we will look at the methods of estimation of evaporation. When we look at these methods, there are many kinds of methods of course; and we can classify them into three different kinds.

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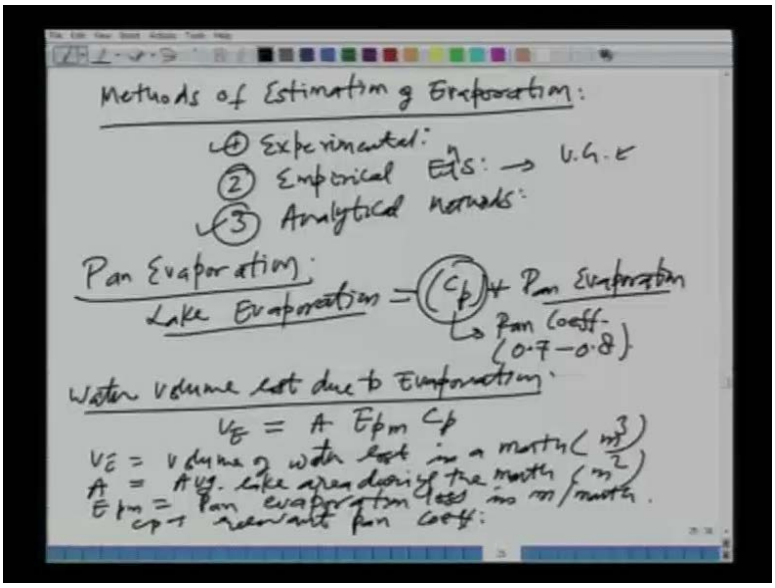

So, let us start looking at methods of estimation of evaporation. And as I said there can be three different types of methods; all the methods can be divided into these three. First one is we will say the experimental; this actually is true for any hydrological process. In the experimental method, what do we do? We try to measure the that particular hydrologic process. So, what we do is we can set up certain instrument in the experimental method and then just directly measure the evaporation losses. We will look at you know one of them. Then they have another category of methods called empirical equations. These empirical equations or empiric empirical methods are the methods developed by many researchers or people over the years, all right which are based up on certain observations, certain in data they have taken after conducting experiments and then fitting certain kind of relationships, all right.

All though, it is said that these empirical methods do not have any strong or you know physical incorporation or the knowledge of you know physics about that particular process. However, although the loss of physics are not applied, but still there is some knowledge or some understanding of the factors that affect that particular process or some knowledge of the concepts are actually involved in that. So, I am sure you may have looked at some of these empirical equations of estimation of evaporation. We will not do that in this course actually; we will be looking at the experimental method and then we will look at, this you have already done in your UG classes. So, I will not look at

that or maybe I will look at couple of equations after we are done with the third category of methods which is called the analytical method.

Analytical methods in which what we do is we make certain assumptions, we look at all the forces that are acting, all right we use our Reynolds transport theorem. And then we try to find out the expression of calculating the evaporation using the laws of physics. What do we mean by the laws of physics? Certainly, will use the continuity equation, we will use the energy equation and so on. So, in this course what we will do is you will look at two methods on the analytical methods among this and one experimental which is very straight forward actually. And then if the time permits will come to this empirical equations.

So, the first of all let me look at this experimental method which is nothing but what is called the pan evaporation. In the pan evaporation method, as you all know what is done is many mythological societies have developed some standard pans, all right. It is just a utensil in which we put certain amount of water and this utensil is put right next to your installed or closed to a lake or a reservoir or some water body at which we want to estimate the evaporation. And then what is done is understand the conditions, the loss of water all right loss of level of water in that evaporation pan is measured. That gives you certain indication of how much water loss is actually taking place in the lake or in your reservoir.

So, it is very simple method actually. So, I will not go into the details. So, the method we use is the lake evaporation; is equal to you say a certain co-efficient; it is called c p is the pan coefficient, times the pan evaporation. So, we install a standard pan, all right close to a water body. We measure how much is the water loss; let us say in a day or in a month it could be, the time units can be anything depending upon our needs. And then each evaporation pan comes with what is called this C p or it is pan co-efficient. And its value is usually between 0.7 to 0.8. So, you measure this; this value is known to you. So, you can find out what will be the lake evaporation all right.

Then, once we have calculated the lake evaporation we can find out or using the pan evaporation we can find out, what is the water volume lost due to evaporation. It is a straightforward in equation in which you find out the volume lost due to evaporation; first let me give you this and then I will define this term. Area times E p m times C p

where V E is the volume of water lost V E is the volume of water lost let say in a month may be in meter cube or other suitable units. A, let us say is the average lake or reservoir area during the month surface area that is; it will be obviously in square meters. E p m is the pan evaporation loss pan evaporation loss in meters per month. And C p of course, we have defined as the relevant pan co-efficient. So, it is basically you can measure the evaporation in the length units in a particular time duration which is month in this case. And then you can find out what will be the total volume of water lost from that lake or reservoir; so that you can plan according to this.

The main advantage or the objective actually of the evaporation studies is to estimate how much water will not be available for supply, all right. We constructed dam across a river and then assuming a certain level or the flows coming in, you cannot plan for the all the flows that coming in. I cannot convert them volume, all right; because they are going to be evaporation losses. Now, what I do is I normally like to give an example which demonstrates the importance of evaporation studies. Sometimes it is not possible to appreciate the importance without having to or without looking at the numbers. So, what I would like to do is I will take up a very simple example of how much water can be lost due to evaporation under Indian conditions, all right. I will take the data from a particular state and then try to demonstrate the how important this evaporation studies are.

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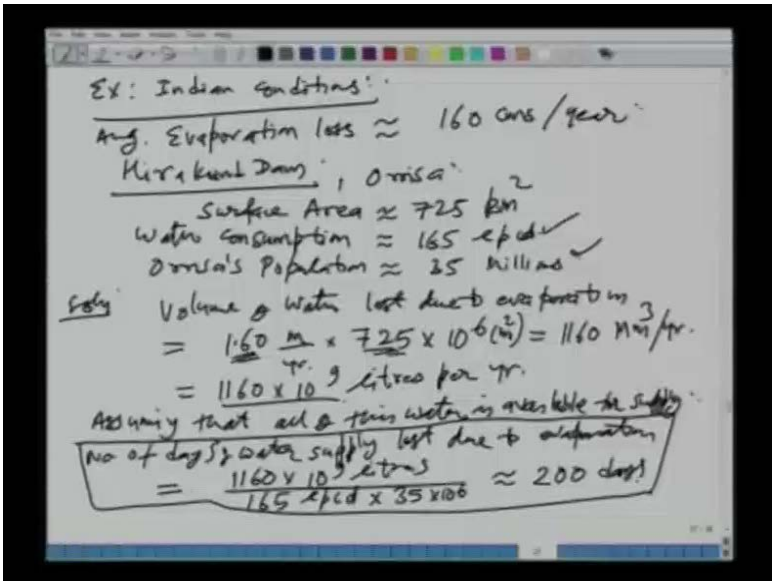

So, I am looking at the example of evaporation studies for Indian conditions. So, let me see the for Indian conditions, the average I am going to have to assume certain data here; which you may not have seen or you not seen. But you can take it this data are taken you know from India mythological department and also you know certain some reasonable assumptions have been made. So, the evaporation lost for Indian conditions are of the order of 160 centimeters per year. And I am going to take the example of Hirakund dam. Where is the Hirakund dam or Hirakund reservoir? It is in the state of Orissa; it is in Orissa and it surface area is approximately 725 square kilometers. The other data that is given to us is the water consumption; the average water consumption for Indian conditions is 165 lpcd. What is lpcd it is liters per capita per day? It is the average consumption of water for the residency or the population.

So, what I would like to do is given this data, we can find out how much volume of water will be lost in a year from this you know Hirakund dam. And then if that water could have been saved somehow, for how many days we can the feed the whole state of Orissa with the water. So, if you want to do that you will need Orissa's population and as I said we are making some reasonable assumptions is about 35 millions. All right, so with this data let us start looking at what will be the volume of water lost due to evaporation? If the average evaporation lost is that much, all right. So, it will be 1.60 which is meters per year of course, times how much is the area? Well, area is 725 square kilometers and then you need to multiply this by 10 to the power 6. So, it will be this is n square meters.

So, the final answer that will come out will be what? It will be in meter cube per years. So, it will be 1160; I will say million meter cube per year, we can convert this into liters, all right; 1000 liters make 1 meter cube. So, this will be 1160 times 10 to the power 9, all right. So, we had multiplied this equation by 1000, it will be liters per year. So, at this rate from this surface area the total amount of water that is lost in a year is approximately this much. Now, assuming that all of this water is available for water supply assuming that all of this water is available for supply or water supply for the state, for which the average consumption is given as 165 liters per capita per day. And the Orissa's population is given as 35 million people. Then the number of days the water supply number of days; I should say of water supply lost due to evaporation, will be how much? How can we find it? Well, total volume of water divided by the rate of consumption.

So, it is 1160 times 10 to the power 9, it is liters and we are talking per year so let me not write that. And then divided by 165 which is the liters per capita liters per capita per day lpcd times the population which is 35 times 10 to the power 6. So, per capita will be taken care of and then you have the answer that will come out, you can convert into the days; it will be approximately 200 days. So, what you have is if you can somehow save this water from evaporating, you can supply the water for the whole state of Orissa for approximately 200 days in a year.

So, that demonstrates or that tells us the importance of evaporation studies. Due to this there have been many attempts, scientists have tried to you know attempt to reduce this evaporation lost. And there are many methods which people have to tried; it may be putting the chemical films or flow or any kind of experiments have been conducted in which the reduction of the evaporation losses has been attempted. However, those methods are very costly; they are not very cost effective and the reduction in the evaporation has not been as much. All right, so this is the example about the importance of evaporation.

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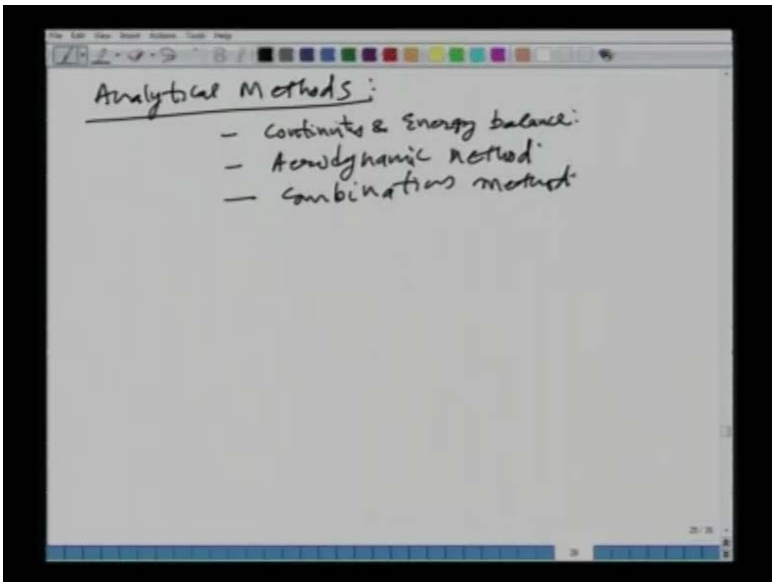

Next, what we would like to do in this case look at the analytical methods. And among the analytical methods as I said we will look at two methods, all right. One of them is based on the continuity and energy balance method. So, in the first method what we will do is we look at the continuity equation and the energy equation, the Reynolds transport

theorem applied to a certain control volume we will take. And the second one, so this method will mainly be taking care of the heat energy, all right. And the second one is what is called the Aerodynamic method; Aerodynamic method in which we will consider the aerodynamics over the water body or the water surface elevation, all right. What is how is the process of evaporation taking place and how the winds are removing this evaporated water, all right. So that is what is the aerodynamic method?

And, then these two methods account for different factors that affect the evaporation. So, what we will do is towards the end we will look at the combination method combination method. We will look at method in which we combined these two methods which will actually be the most accurate one. So, I think I am running out of time today. So, I would like to stop here and in the next class we will start looking at these analytical methods.