Course Name: Watershed Hydrology

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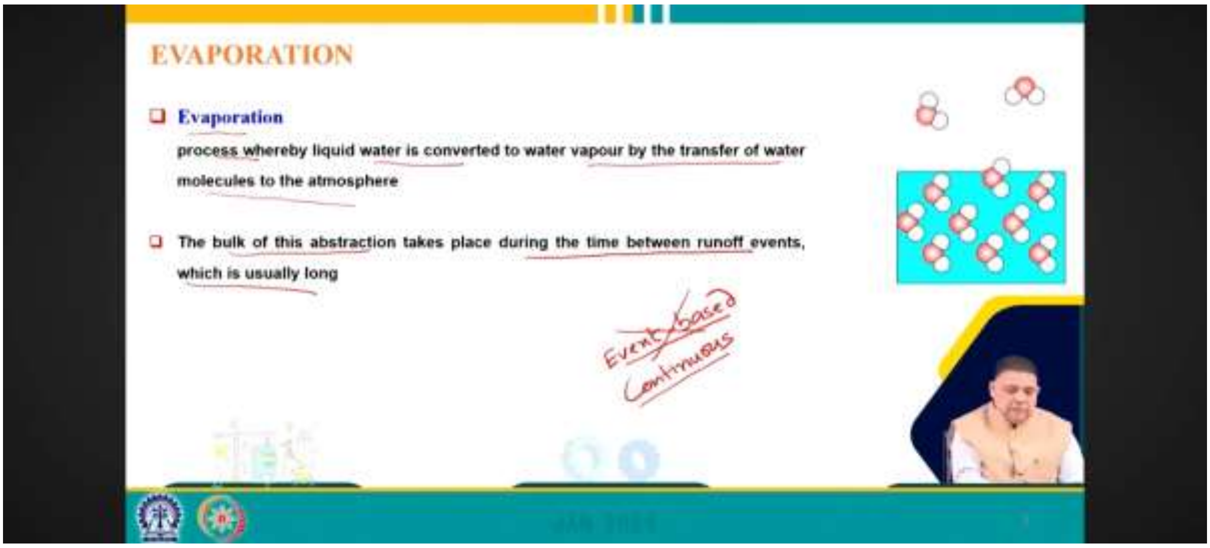
Week: 02

Lecture 07: Evaporation

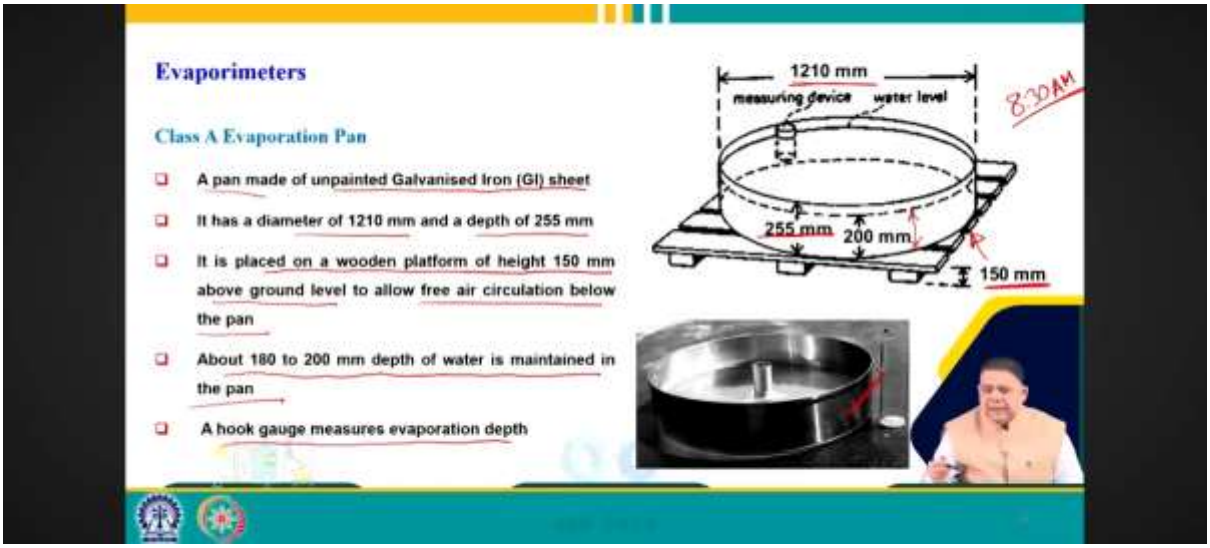
Hello friends, welcome back to this online certification course on watershed hydrology. I am Rajnath Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are in Module 2, Lecture 2, and the topic is Evaporation.

In this lecture, we are going to cover the measurement of evaporation and the determination of evaporation from water bodies.



If you remember from the previous class, we started with abstraction. We talked about various kinds of obstructions and we also defined evaporation as the process whereby liquid water is converted to water vapor by the transfer of water molecules to the atmosphere. We also saw various processes or factors that affect evaporation, with one major factor being Dalton's law of evaporation, where the saturated vapor pressure and air vapor pressure govern the rate at which evaporation takes place.

We also discussed that the bulk of this abstraction takes place during the time between runoff events, which is usually long. We also discussed that there are two kinds of models: event-based models and continuous models. Event-based models only consider a particular rainfall event, and we mentioned that during a specific event, evaporation is almost negligible, which is why most event-based models do not consider evaporation as a component. However, continuous models, which run for a long period of time, do consider evaporation and evapotranspiration because the bulk of the abstraction takes place between rainfall-runoff events. That is where it becomes very important.

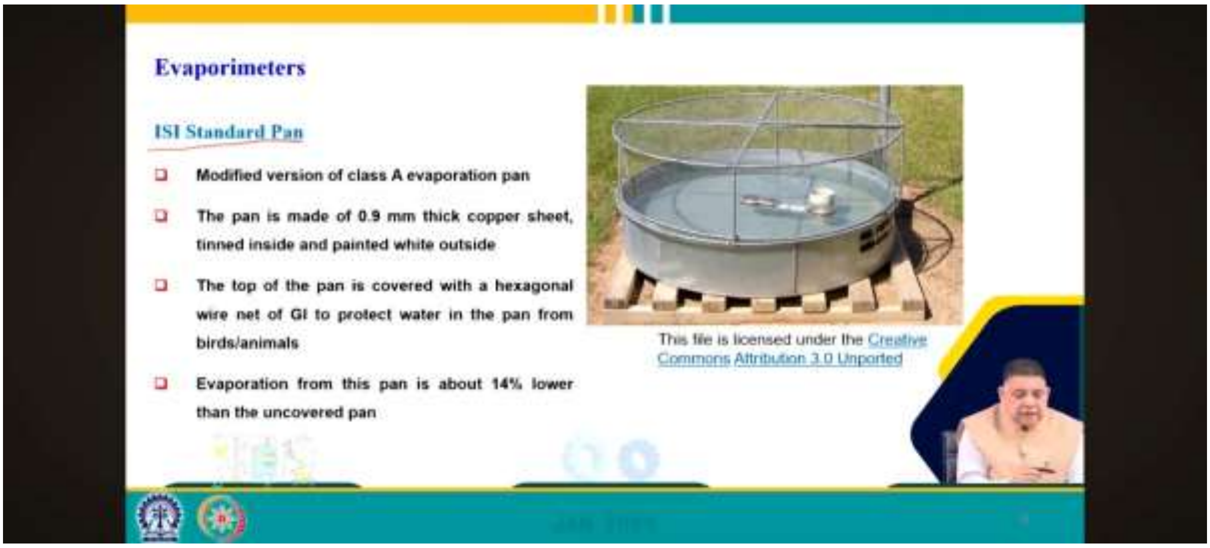


Coming to the measurement of evaporation, typically, evaporation is measured by equipment called an evaporimeter. There are various types of evaporimeters available. A few common ones are Class A evaporation pan, ISI standard pan, Colorado sunken pan, and USGS floating pan, some of which we are going to discuss now.

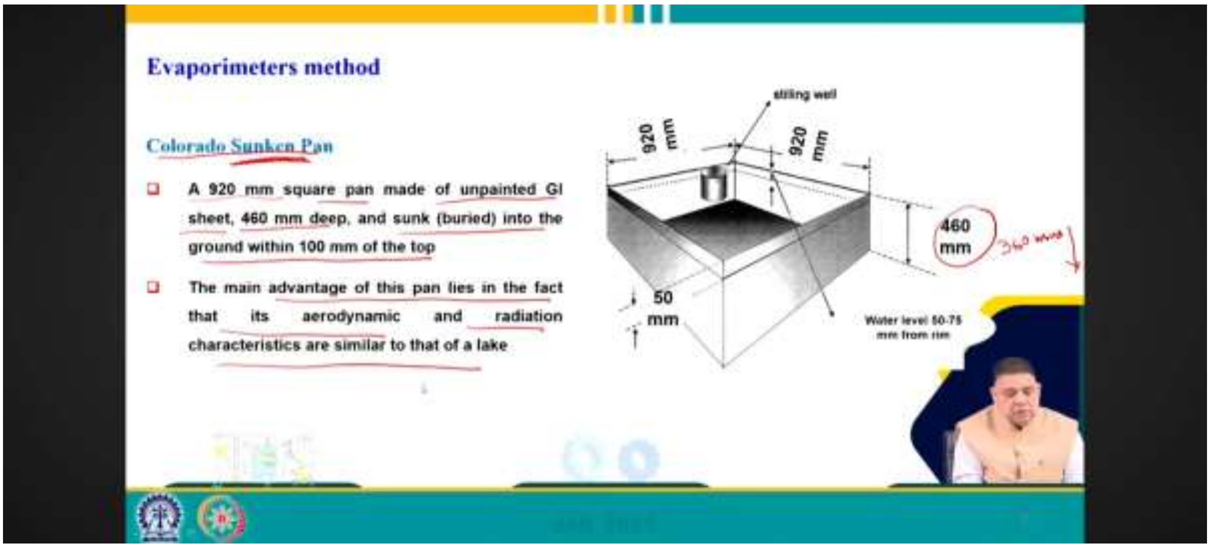
Starting with the Class A evaporation pan, is a pan made of unpainted galvanized iron sheet (GI sheet), and it is cylindrical in shape. It has a diameter of 1210 millimeters and a depth of 255 millimeters. Typically, while installing this evaporimeter, it is placed on a wooden platform of height 150 millimeters above ground level to allow free air circulation below the pan. The idea is to maintain natural environmental conditions while measuring evaporation using this pan. To measure evaporation loss, about 180 to 200 millimeters depth of water is maintained in the pan. A hook gauge is used to measure the evaporation depth.

So, we fill the pan up to a depth of 200 millimeters, and the next day morning at 8:30 am, the evaporation depth is measured. It is worth noting that 8:30 am is the recommended time by IMD (India Meteorological Department) for recording all kinds of meteorological events. This ensures consistency in recording across different hydrometeorological equipment placed in a single location in the hydrometeorological laboratory.

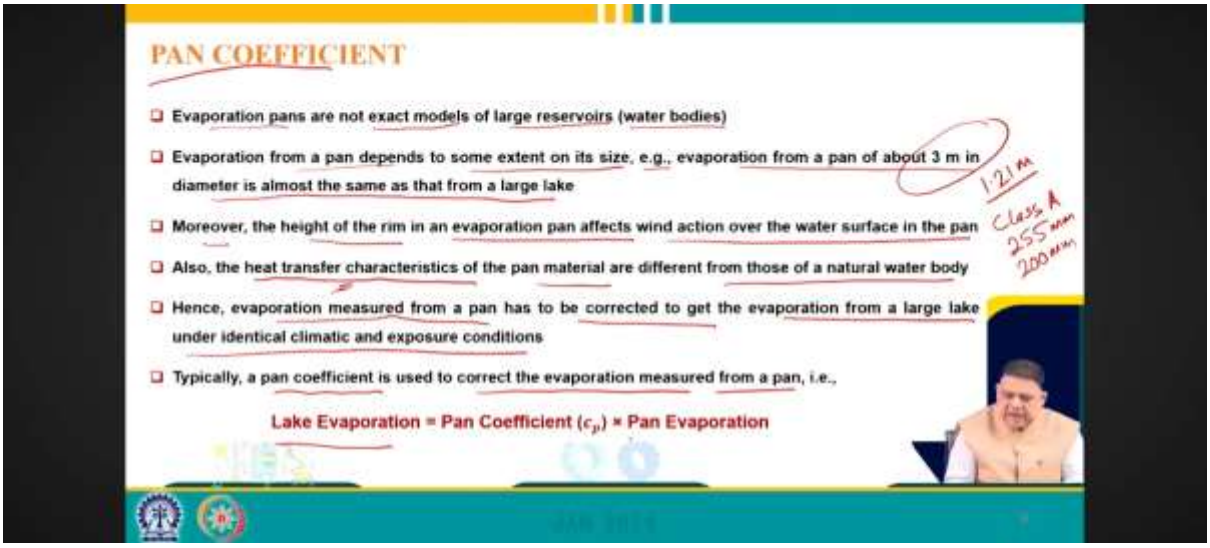
So, that's how the person goes about it. Using the hook gauge, they measure the water level and the loss of water. If we fill it to 200 millimeters initially, with evaporation, the level will decrease, indicating the amount of water evaporated. Then, the water is refilled to the 200-millimeter level, and the recording is checked the next day. This is how we measure evaporation using the Class A evaporation pan. The recorded evaporation value for the previous 24 hours is taken at 8:30 am, like a non-recording rain gauge.



The next evaporimeter commonly used is the ISI standard pan. It's an Indian version, essentially a modified Class A evaporation pan. The dimensions, like the diameter (1.21 meters) and depth (255 millimeters), remain the same. However, this pan is made of a 0.9 mm thick copper sheet, tinned inside, and painted white outside. This change is to minimize heat losses, as environmental heat can affect the measurements. Additionally, the top of the pan is covered with a hexagonal wire net of galvanized iron to protect the water from birds and animals. This ensures that losses due to animal consumption are not counted as evaporation. The evaporation from this pan is about 14 percent lower than from the uncovered pan, thanks to this covering.



Another important type of evaporimeter is the Colorado sunken pan. Unlike the circular pans we discussed earlier, this one is square, measuring 920 millimeters on each side. It is made of unpainted galvanized iron sheet and is 460 millimeters deep, with around 360 millimeters buried or sunk into the ground, hence the name "sunken pan." Its advantage lies in its aerodynamic and radiation characteristics, like those of a lake. Being buried helps maintain these characteristics, affecting evaporation. Water is filled up to a level of 50 to 75 millimeters from the rim, and changes in water level, indicating evaporation loss, are measured using a stilling well.

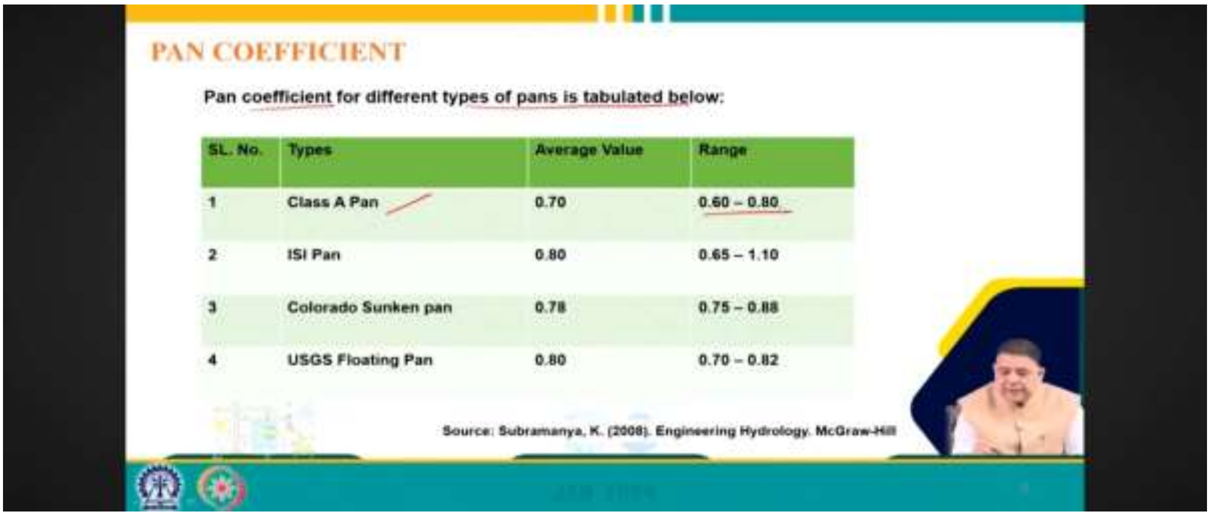


Now, let us talk about the pan coefficient.

So, basically, the evaporation pans we discussed just now are not exact models of large reservoirs or water bodies, as we can visualize. Large water bodies have different shapes, sizes, and appearances compared to the circular or rectangular evaporation pans we discussed. So, evaporation from a pan depends to some extent on its size. For example, evaporation from a pan about 3 meters in diameter is almost the same as that from a large lake. Experimentally, it has been seen that if the pan size is kept equal to 3 meters in diameter, it will probably give a similar value of evaporation as from a large water body or lake. However, as we discussed earlier, the recommended size is only 1.21 meters, which is about one-third of the optimal size. This disparity affects the representativeness of the evaporation value obtained.

Moreover, the height of the rim in an evaporation pan affects wind action over the water surface in the pan. For instance, in the case of a Class A pan, the water level is initially 55 millimeters below the rim of the pan. This creates a gap between the wind movement and the water level, which affects the evaporation rate. Additionally, the heat transfer characteristics of the pan material differ from those of a natural water body. Whether using a galvanized iron sheet or a copper sheet, the heat transfer properties are distinct, which further impacts the evaporation value obtained.

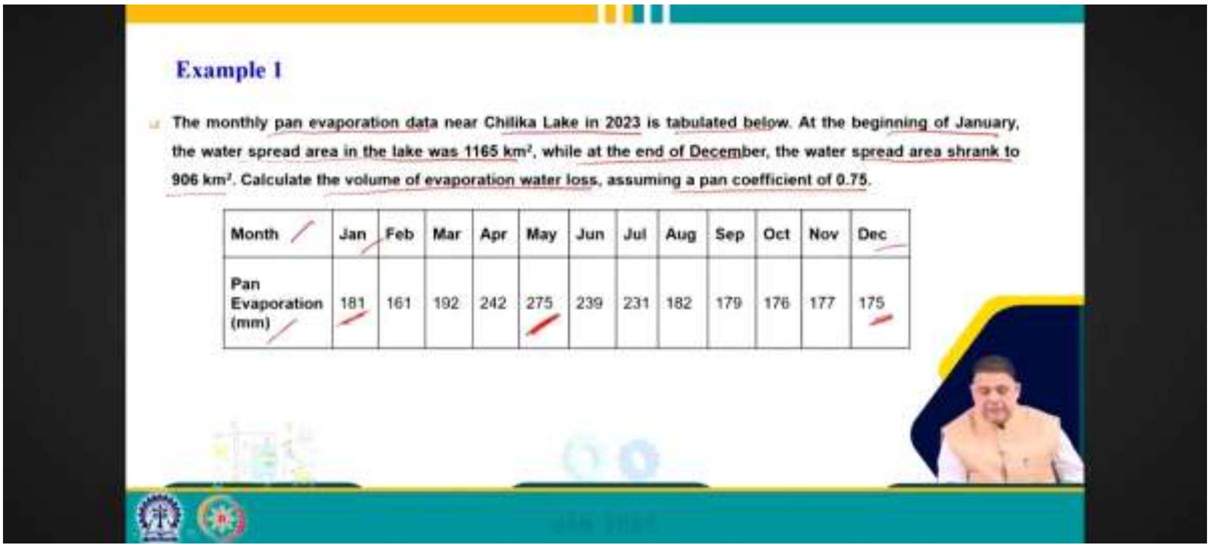
Hence, evaporation measured from a pan needs to be corrected to obtain the evaporation from a large lake under identical climatic and exposure conditions. This correction is done using a pan coefficient, denoted as Cp. Lake evaporation is calculated by multiplying pan evaporation by the pan coefficient.



SL. No.	Types	Average Value	Range
1	Class A Pan	0.70	0.60 – 0.80
2	ISI Pan	0.80	0.65 – 1.10
3	Colorado Sunken pan	0.78	0.75 – 0.88
4	USGS Floating Pan	0.80	0.70 – 0.82

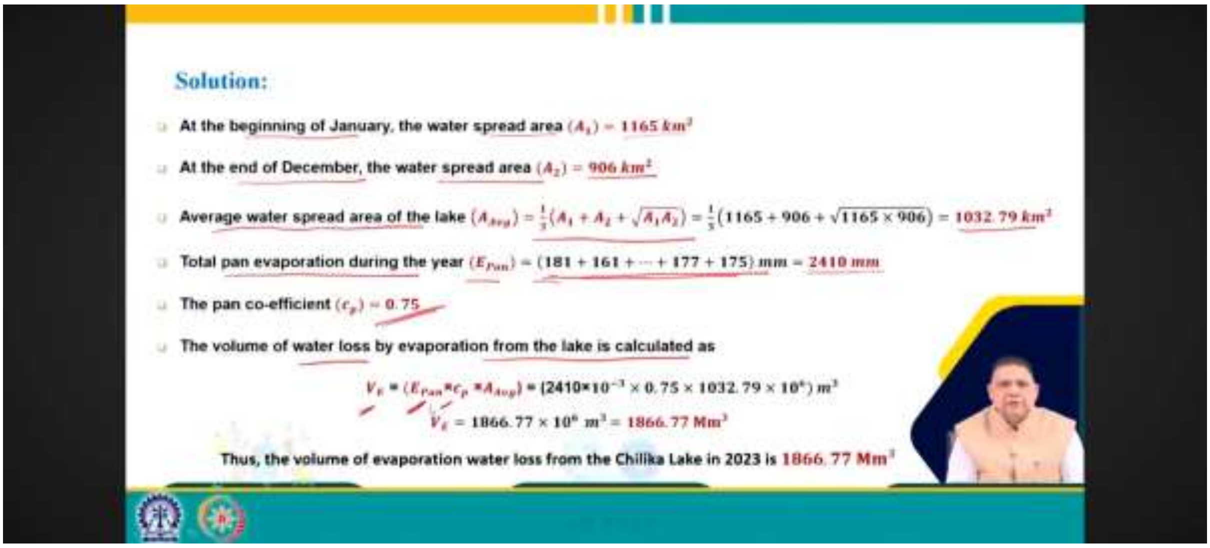
The table provides the pan coefficient for different types of pans. For example, for a Class A pan, the coefficient ranges from 0.6 to 0.8, with an average value of 0.7. Similarly, for a Colorado sunken pan, the coefficient ranges from 0.75 to 0.88, with an average of 0.78. Depending on the type of pan used, the measured evaporation value needs to be corrected accordingly.

Now, let us consider an example.

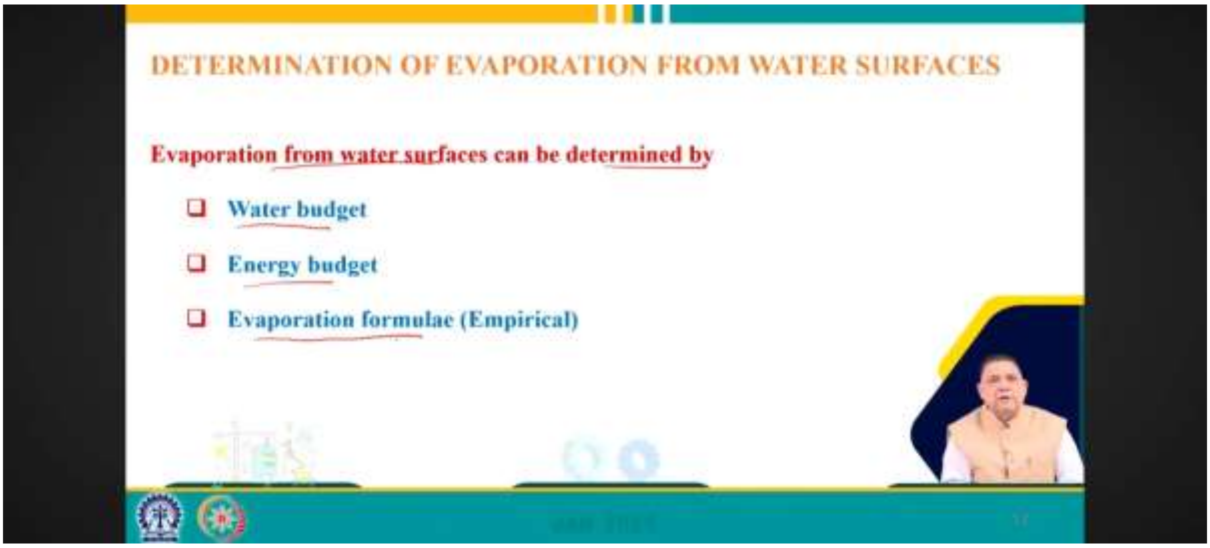


The total pan evaporation loss during the year, or Epan, is obviously the sum of evaporation values measured over 12 months. Remember in the table, we have been given the values right from January to December, and we also saw that the value was highest in the month of May.

So, we must sum those values, and that comes out to be 2410 millimeters. The pan coefficient value is also given to us, that is 0.75. So, the volume of total water loss by evaporation from the lake can be calculated by this simple formula. You remember Epan times Cp will give us the evaporation value in-depth, and then if you multiply it by the average area of the lake, we will get the total water loss. That is what we are doing here.

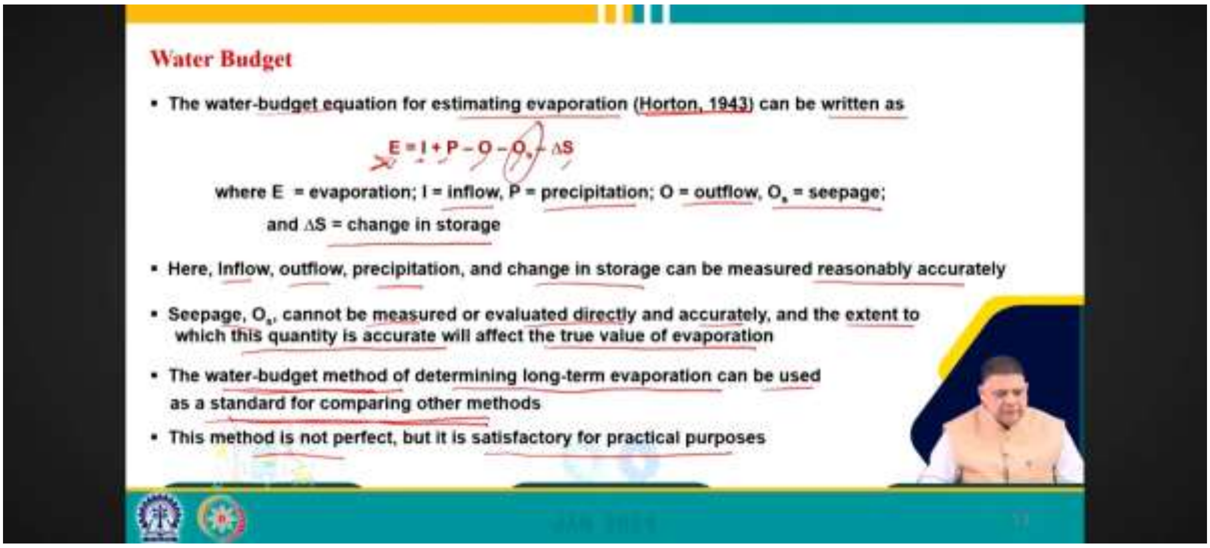


Epan value is 2410 millimeters. So, for units, we put everything in meters, and that is why it is written here as 2410×10^{-3}. The pan coefficient value is 0.75, and the total square kilometre area also needs to be calculated in square meters. So, that is why we are multiplying the obtained value by 106106. So, that is the total volume we get in cubic meters, and that is what we get 1866.77×10^{6} cubic meters, or we can write 1866.77 million cubic meters. So, the volume of evaporation water loss from Chilika Lake in 2023 is 1866.77 million cubic meters. That is the answer to this particular question.



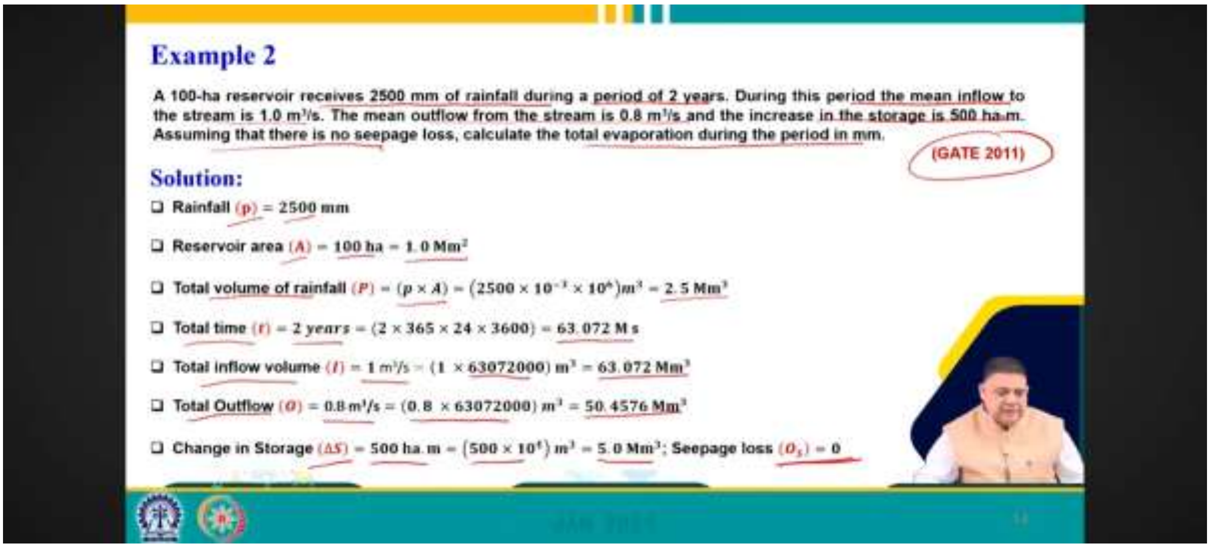
Now, let us go into determining the water body. Up till now, we are talking about the measurement. Now, we have also indirect ways of determining the evaporation from water surfaces, and that is what we get into.

So, let us talk about that. Evaporation from water surfaces can be determined in different ways, whether using a water budget, energy budget, or using empirical evaporation formulas. We will see a few of them here.

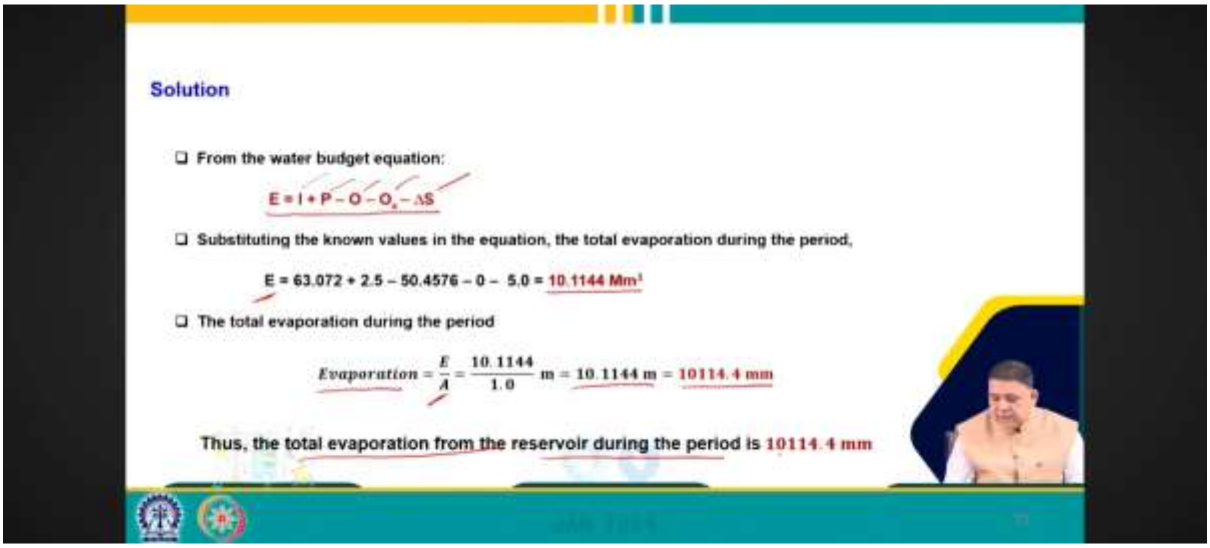


Now, coming to the water budget, the water budget equation for estimating evaporation, which was given by Houghton in 1943, can be written as $E = I - P - O - OS + \Delta S$. That means, for finding out different abstractions, we can write this equation in different forms. This, for evaporation, is the form given by Houghton in 1943. Now, in this equation, inflow, outflow, precipitation, and change in storage can be measured reasonably accurately. However, seepage OS cannot be measured or evaluated directly and accurately, and the extent to which this quantity is accurate will affect the true value of evaporation.

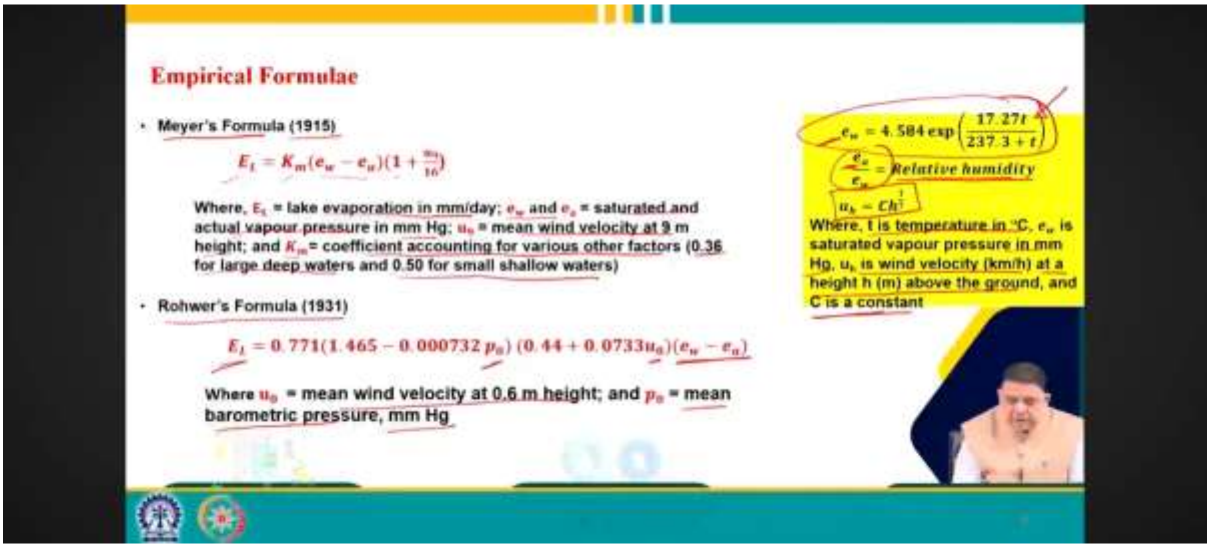
So, basically, as you can see, it clearly says that out of 5 variables, 4 can be determined effectively, but *OS* we must depend on indirect methods. If we can estimate or determine this value effectively, then we can get a reasonably good estimation of evaporation using the water budget equation. This water budget method of determining long-term evaporation can be used as a standard for comparing other methods because, although this method is not perfect, it gives satisfactory values for practical purposes. This equation provides a practically useful value of pan evaporation for long-term evaporation. That is why many times we may use this water budget method as a standard for comparing evaporation found by using other methods. So, we saw that we have different other methods of determining evaporation. So, the water budget method can be used as a reference point for determining evaporation.



Now, let us take an example: a 100-hectare reservoir receives 2500 millimeters of rainfall during a period of 2 years. During this period, the mean inflow to the stream is 1 cubic meter per second, the mean outflow from the stream is 0.8 cubic meters per second, and the increase in storage is 500-hectare meters. Assuming that there is no seepage loss, calculate the total evaporation during the period in millimeters. This question was asked in the 2011 examination. So, coming to the solution, different things are given to us: rainfall is given as 2500 millimeters; the area of the reservoir is given as 100 hectares, which is 1 million square meters. The total volume of rainfall, because it falls on the reservoir area, is $P \times A$, which comes out to be 2.5 million cubic meters. The total time given is 2 years, so that means we can convert that into seconds, which comes out to be 63.072 million seconds. The total inflow volume given is 1 cubic meter per second, so obviously, to get into volumetric terms, you must multiply it by the time in seconds. So, the total inflow comes out to be 63.072 million cubic meters. The total outflow is 0.8 million cubic meters per second, so obviously, that has to be also multiplied by the time, 2 years, or 63.072 million seconds. So, this value comes out to be 50.4576 million cubic meters, and the change in storage is given as 500-hectare meters. Again, we must convert the units to proper units in meters, so that comes out to be 5 million cubic meters, and the seepage loss value is mentioned as 0. So, the most complicated component is set at 0.



From the water budget equation, we know $E=I+P-O-OS-\Delta S$. We know the values of I, P, O, OS is 0, and ΔS. So, putting those values, we can get the value of E as 10.1144 million cubic meters. That is the total volume, but we have been asked to answer in millimeters. So, for the total evaporation depth during the period, we must multiply the total evaporation volume by the area, and then we get a value of 10.1144 meters or 10114.4 millimeters. So, the total evaporation from the reservoir during the 2-year period is 10114.4 mm. That is the answer to this question. It is a very simple question based on the water balance equation.



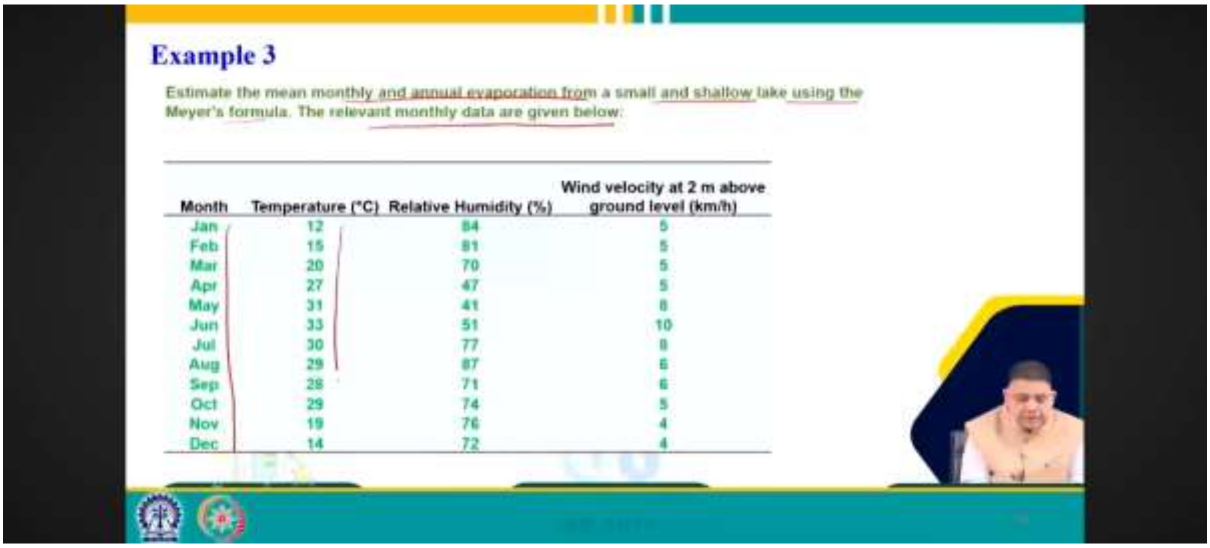
Now, we come to empirical formulas, and the first formula we discuss is Meyer's formula, which was given in 1915. According to Meyer's formula, $EL=K_M\times(E_W-E_A)\times(1+U_9/16)$, where E_L is the lake evaporation in millimeters per day.

E_W and E_A are saturated and actual water vapor pressure in millimeters of mercury, U_9 is mean wind velocity at 9 meters height, and K_M is a coefficient that accounts for various other factors. Its recommended value is 0.36 for large, deep waters and 0.5 for small, shallow water. So, depending on what kind of water body you are dealing with, you must change the coefficient.

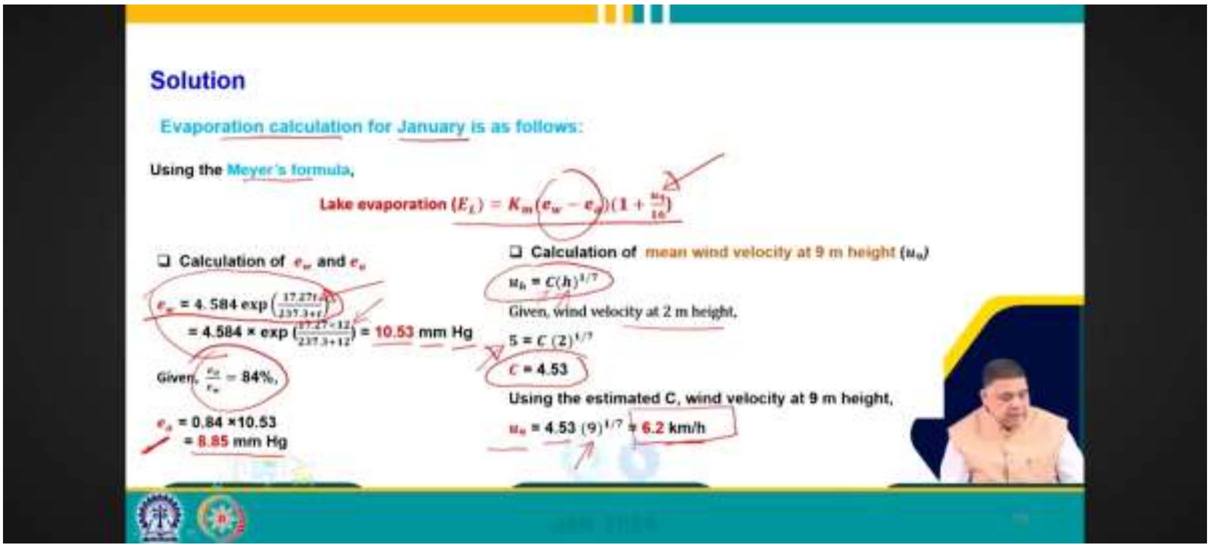
Before going to the other formulae, here we also have empirical relationships for estimating Ew, which is the saturated vapor pressure.

Now, saturated vapor pressure in millimeters of mercury can be obtained using this relationship, which is a function of T_e, where T_e is the water temperature in degrees Celsius. So, if you know the water temperature, you can find out the value of e_a and e_w. We also know that relative humidity e_a by e_w. So, once we know e_w and if we have a measured value of relative humidity, we can find out the actual vapor pressure too. Similarly, for wind velocity, wind velocity at any height h can be found out using this relationship: $u_h = CH^{1/7}$, where u_h is wind velocity in kilometers per hour at a height H meter above the ground, and C is a constant.

Another important formula used for finding out evaporation is Rohwer's formula, which was given in 1931. According to this, E_L is a function of e_a, e_w, and e_a. Here, P_0 is a new term which is the mean barometric pressure in millimeters of Hg, and u_0 is the mean wind velocity at 0.6 meters height. In Meyer's formula, the wind velocity at 9 meters height is used; in this case, it is 8.6 meters height, which is very close to the ground.



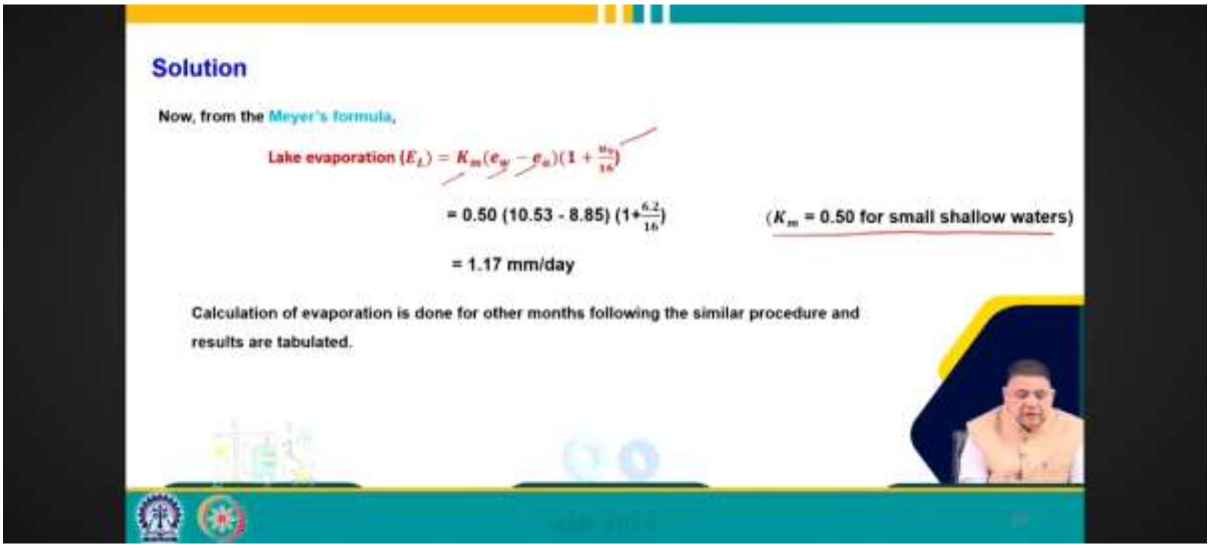
Let us take an example: estimate the mean monthly and annual evaporation from a small, shallow lake using the Myers formula. The relevant monthly data are given below. For different months, January to December, we have been given the temperature in degrees Celsius, relative humidity values in percent, and wind velocity at 2 meters above the ground in kilometers per hour. So, to find out, we must calculate for all months, and then we can sum up to get the annual evaporation from the water body. Remember, it is a small, shallow lake, and if you remember, the coefficient value is changed from a small, shallow to a large, deep lake. So, evaporation, let us say evaporation calculation for January month. Meyer's formula we know is E_L is given in this form.



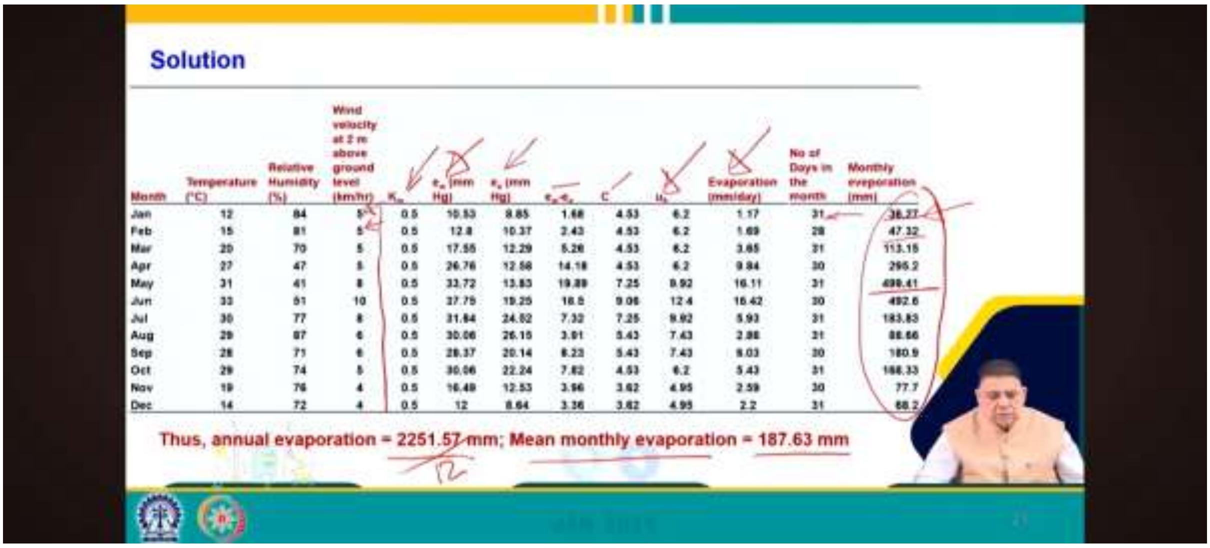
So, obviously, the first thing we must calculate is E_W and E_A. E_W is related to T, and we saw this is a relationship that relates E_W to T. Because we have the temperature given in degrees Celsius, we can put the values.

For example, in January month temperature is given as 12 degrees Celsius. So, we can put this value and get the value of e_w as 10.53 millimeters of Hg. Also, we have relative humidity data provided, that means e_a by e_w is provided. So, once we know e_w, we know relative humidity. So, we can also find the value of E_A, which is 0.84 times E_W, which comes out to be 8.85 millimeters of mercury. Now, this part is taken care of; the other thing that we require is wind velocity at 9 meters height U_9, and we also know the relationship that u_h at any height h can be calculated provided we know the value of C.

So, now we have been given wind velocity at 2 meters. For example, January wind velocity is 5 kilometers per hour at a 2-meter height. So, by putting the known value, we can find out the value of this coefficient C, which comes out to be 4.53. Now, for 9 meters, we can again use this relationship by putting the values of C and H=9. So, this value C and 99, and then we can find wind velocity at 9 meters is 6.2 km/hr.



And, we know that the K_M value recommended for small shallow water is 0.5. So, that means, we know all K_M, we know e_w, e_a, we know u_9. So, by putting these values, we can find out the lake evaporation, which comes out to be 1.17 millimeters per day for the month of January.



Similarly, we must calculate evaporation for all other months following the same procedure, and then we are directly tabulating the values here. So, that means, K_M value remains constant; these values were given up to this point, these were given to us this side. So, K_M is, of course, constant. e_w already we saw we can calculate in terms of temperature which is given for every month. Relative humidity is given, knowing E_W and relative humidity, we can find out e_a. The difference we can find out, the value of C we can determine because at 2 meters we have been given wind velocity. So, obviously, whenever the same value with the C value is the same, if the velocity changes, the C value will change. Once we know, we can also get the 9-meter velocity. So, putting all the values in Meyers' formula, we can calculate evaporation millimeter per day for different months, and then also we know the number of days in the month.

So, by putting and multiplying that, we can get the monthly evaporation value, which comes out to be. So, for different months, it is January 36.27, February it is 47.32, and of course, in the month of May, it is the highest, 499.41, and so on. And total evaporation value, of course, will be the sum of this column, will be the total annual evaporation, which comes out to be 2251.57 millimeters. And the mean monthly evaporation, that is if we divide this value by 12, then the mean monthly evaporation comes out to be 187.63 millimeters. So, this is how we can either measure evaporation or we can determine it either by using water budget method or by empirical formulas, and we can use that then use that for any other purposes during hydrological water balance modelling.

And with this, we come to the end of this lecture. Thank you very much. Please give your feedback and raise your doubts or questions which can be answered on the forum. Thank you very much.