Course Name: Watershed Hydrology

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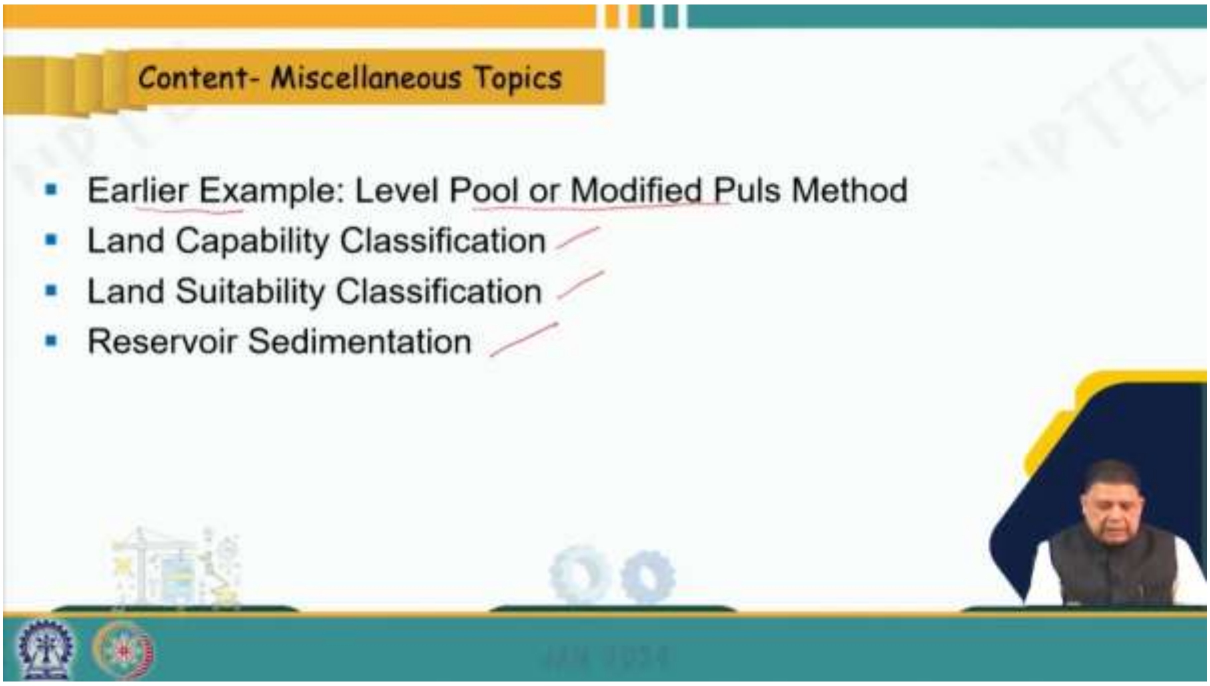
Institute Name: Indian Institute of Technology Kharagpur

Week: 12

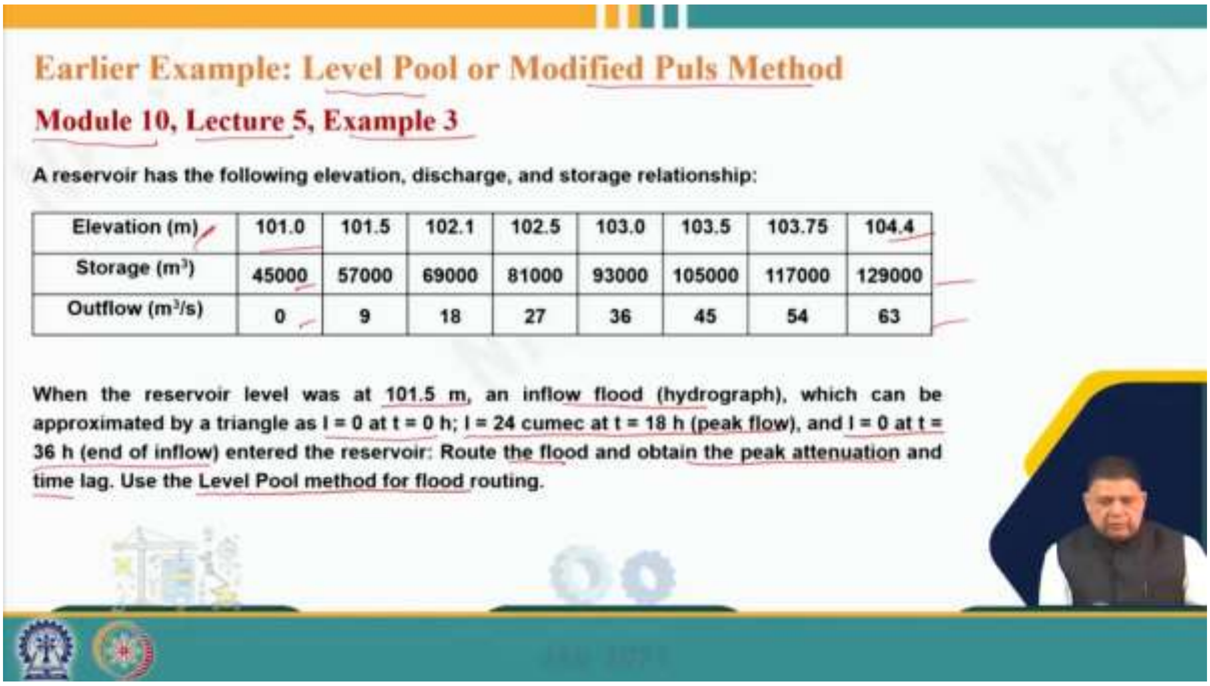
Lecture 57: Miscellaneous Topics

Hello friends, welcome back to this online certification course on Watershed Hydrology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are in Module 12, this is Lecture Number 2, where, as promised earlier, we will be covering miscellaneous topics.

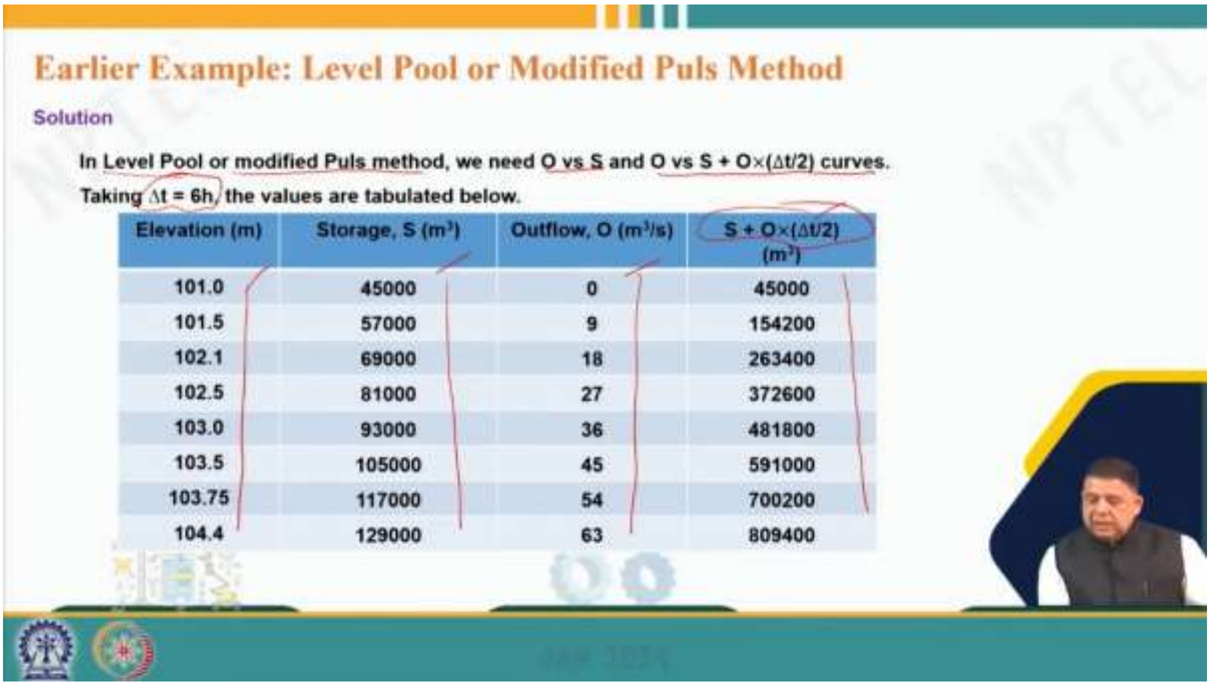
The topics we will cover today, to begin with, are an earlier example where we found some errors and I will provide you with the correct solution. Then, we will delve into land capability classification and land suitability classification, two topics which are very important from an examination perspective but have not been covered in earlier lectures. Additionally, we'll discuss reservoir sedimentation.



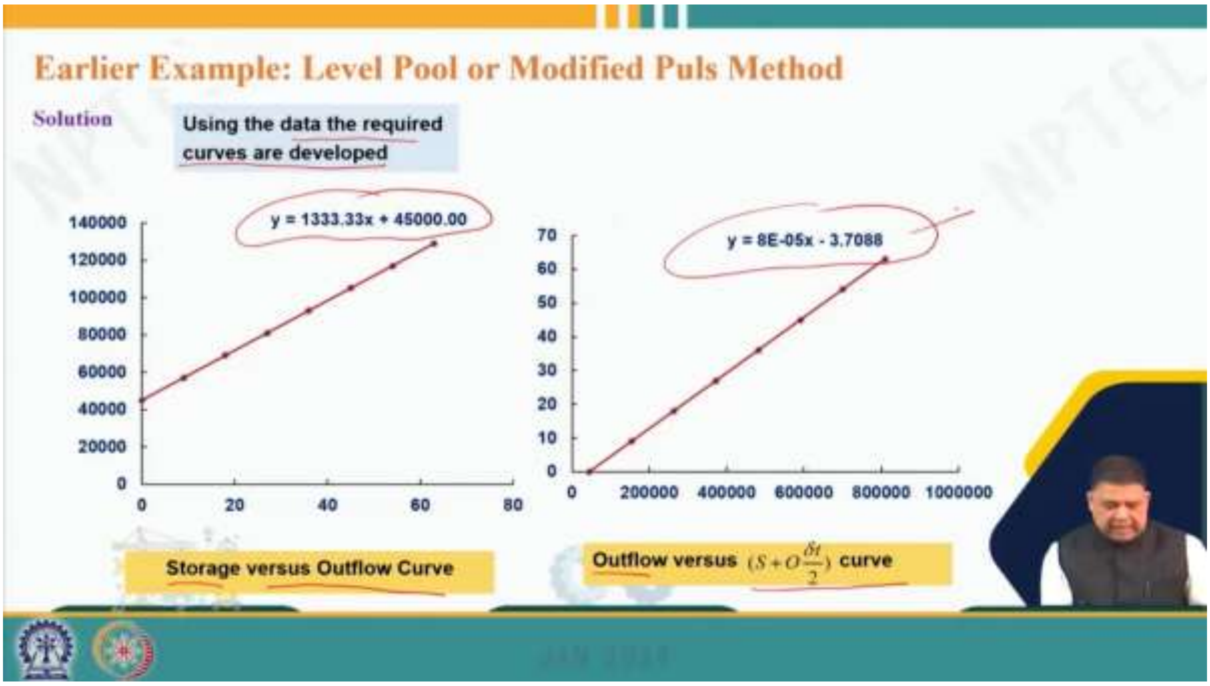
We will commence with an example on the level pool or modified pulse method of flood routing. This problem is extracted from Module Number 10, Lecture 5, Example 3. The problem states that a reservoir has the following elevation-discharge and storage relationship. For elevation values ranging from 101 to 104.4 meters, the storage and outflow values are provided. Furthermore, it mentions that when the reservoir level was at 101.5 meters, an inflow hydrograph, which can be approximated by a triangle with I equal to 0 at t equals to 0, I equal to 24 at t equals to 18 hours (which is the peak flow), and I equal to 0 at t equals to 36 hours (which is the end of inflow), entered the reservoir. Your task is to route the flood and obtain the peak attenuation and time lag using the level pool method for flood routing. We previously attempted to solve this problem, but there was an error in retrieving values from the table. Therefore, I will now re-explain this problem.



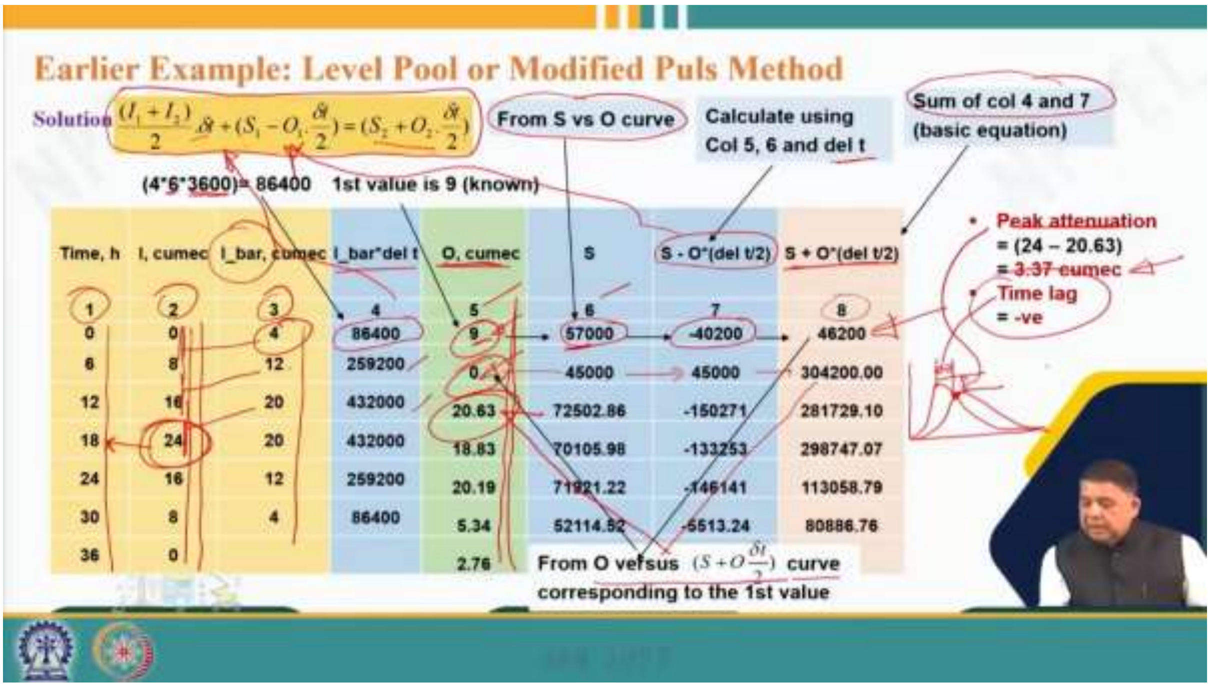
Recall that in the level pool or modified pulse method, we developed two curves: O versus S curve and O versus S + O *Δt/2 curve, which is the modified pulse method. If you remember, for the pulse method, we developed three different curves including another curve of S - O *Δt/2. Here, we assume Δt = 6 hours, and I'll explain why. We've been given a triangle hydrograph that starts at 0, reaches its peak at 18, and ends at 36. Hence, we can have a multiple of 6 to ensure the peak is not missed. This is the rationale behind choosing the Δt value. The provided values include elevation, storage, and outflow. Using the assumed Δt value and the tabulated storage and outflow values, we need to calculate S + O* Δt/2. For different elevations, we have storage values, outflow values, and we will calculate S + O* Δt/2 values in cubic meters.



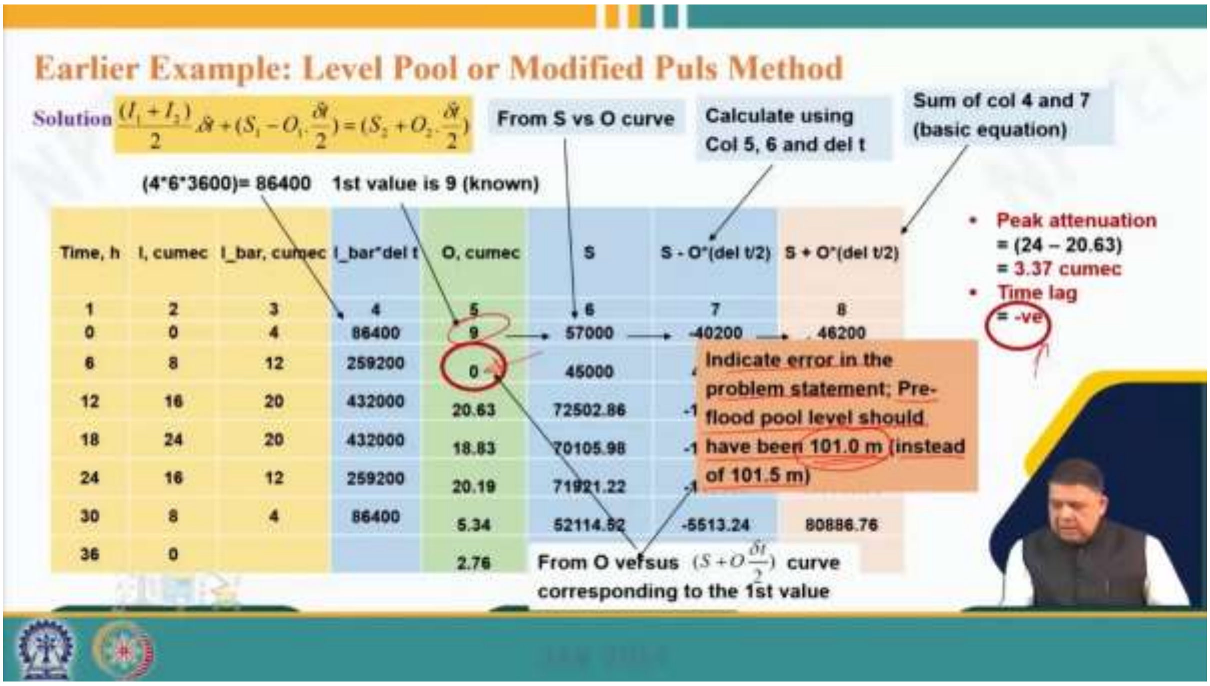
And then, using the data, the required curves are developed. As mentioned earlier, we developed two curves: the storage versus outflow curve and the outflow versus S + O* Δt/2 curve. These values obviously come from the table, and as you can see, they fit a straight line exactly. That's why, using Excel, we have developed the equation as well. Now, obviously, we have two choices. We can directly read the values from the graphs or we can use these equations. Of course, using equations is always preferred because graphical methods always have the possibility of error. However, if you are doing it manually, then you may have to read the graphs, but it doesn't matter.



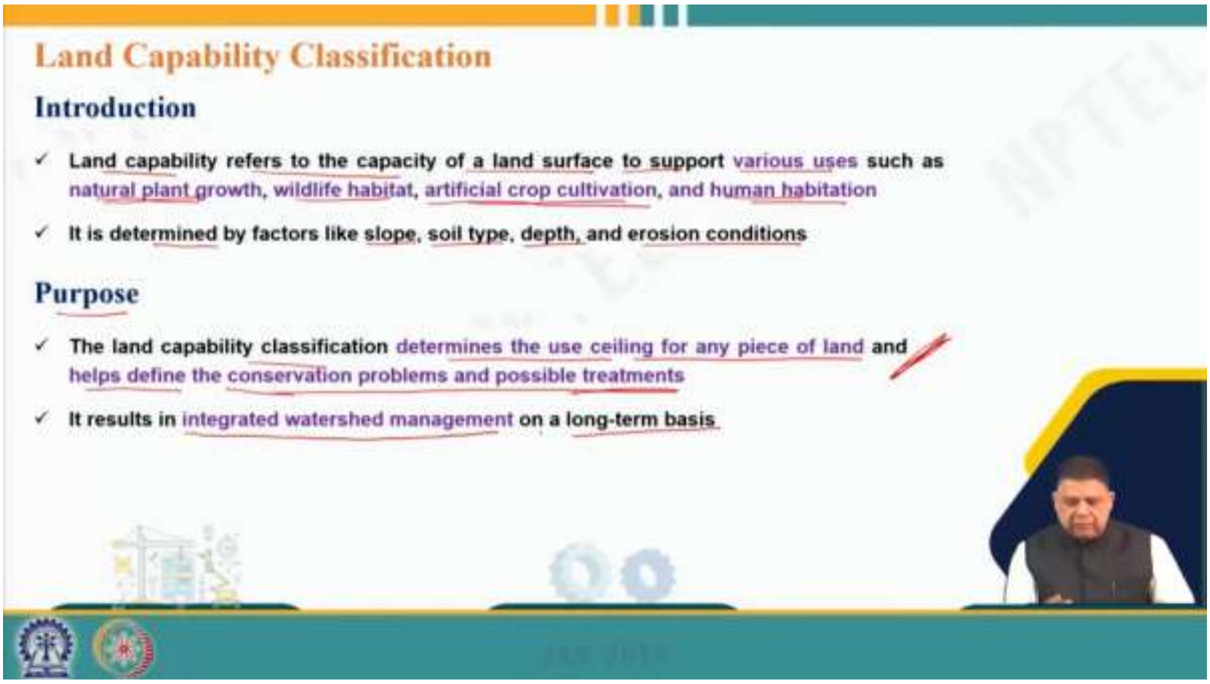
Now, after this, we enter the table. If you remember, in the modified pulse method or even the pulse method, we use this form of equation, the routing equation, that is, I1 plus I2 by 2 delta t, which represents inflow, then S1 – O1* Δt/2, and then S2 + O2* Δt/2. This is the curve we just developed, the S plus O delta t by 2 curve. So, now, for different times, they are put in column number 1, and inflow values are put in column number 2. Obviously, using these inflow values, we can calculate the average inflow, that is, I1 plus I2 by 2, and these are the values. So, 0 and 8 average is 4, 8 and 16 average is 12, 16 and 24 average is 20, and so on. These are the values we have calculated. Because we need to calculate I1 plus I2 by 2 times delta t, obviously, the delta t value, we know that we have used 6 hours. Of course, we have to convert that into seconds. So, this value, I bar times delta t, will be 4 times 6 into 3600. So, we get a value of 86,400. That is the first value. Then, accordingly, 12 times 6 times 3600 will give us 20 times this will give us this, and so on. So, we can calculate all the values. This is the first term on the left-hand side. Then, the first value of outflow, O, is known because we have been given that the flood enters the reservoir at 101.5 meters, and from the curve, we get, or even from the given table, we know that the outflow value is 9 at that elevation. So, that is the first value of O. And once we have the value of O, then from the S versus O curve, corresponding to this O value, we can read the S plus O value. From the S versus O curve, corresponding to O, we read the S value. And then, once we have S and O and delta t, we calculate S minus O times delta t by 2 using column 5, column 6, and the delta t value, which we have assumed is 6 hours. So, that value, we can calculate and it comes out to be minus 40,200. And then, we have the last column, S plus O delta t by 2. Obviously, from the basic equation, you know that S minus O delta t by 2 is the second term, and this one is the first term. So, the sum of column 4 and column 7 will give us column 8. Column 8 is the sum of columns 4 and 7. So, column 4 and column 7 will give us a value. The first value we get is 46,200, but then using this value, we can go and we have already developed the O versus S plus O delta t by 2 curve. So, using this value from this curve, we can read the value of O. However, there is a problem here. What we are getting is that for this S plus O delta t, the next value is lower than the first value we started with, which typically does not happen. So, this is the value we get, but let's say that we are getting this value of O or whatever value we will get, and then obviously, again, it becomes a repetitive process. Corresponding to this O, we have to read from the S versus O curve, we read S, then we calculate S minus O delta t by 2 because O is 0. So, obviously, this term becomes 0. So, it is the same as S, then the sum of column 4 and column 7 will give us this value. Then again, we will read from an O versus S plus O delta t by 2 curve, we will read the O value, and this process continues. This is how we will get column number 5, which is the outflow value which we are interested in. So, column number 2 is the inflow curve, column number 5 is the outflow curve we can plot. Because we have to find out peak attenuation, peak attenuation means the difference in peak. So, here the peak value is 24 for inflow and 20.63 for outflow. That means, the attenuation is 3.37 cumecs, that is the peak attenuation from the inflow and outflow graph. And if a time lag occurs, the peak inflow occurs at 18 hours, but the peak outflow here is occurring at 12 hours. That means the time lag becomes negative. But you remember, every time we plotted the curve, we always plotted like this: this is the inflow hydrograph, and then the outflow hydrograph will be like this. This is the typical peak of the outflow hydrograph, typically this is the point it intersects the inflow curve, but here, so there is a peak attenuation and there is a time lag, this is time lag and this value is peak attenuation, these are the two, but here it is becoming negative,



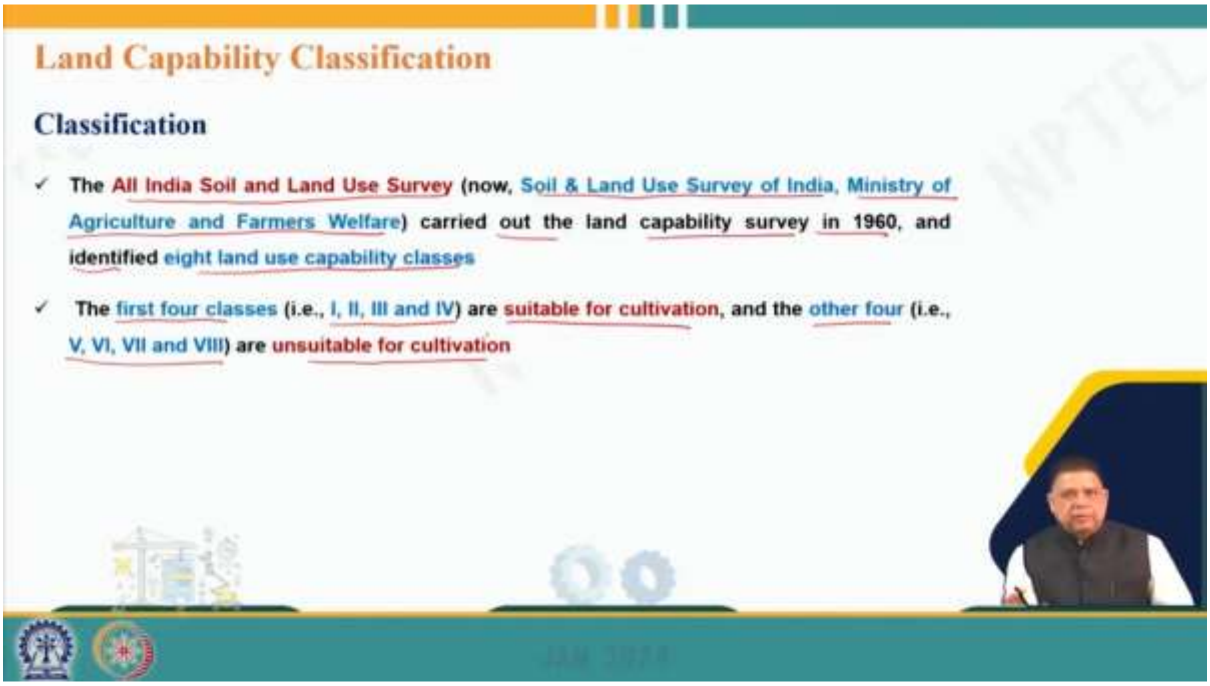
And that is because our, it indicates a problem error in the problem because of the simple reason that we got. So, if we erase all first and then we start again, so that means the problem is that these values, the first problem, okay. So, the problem is as we discussed that because of this change, we got a value of 0 which should not have happened. So, because of this 0, we are getting this, indicating an error in the problem statement. The pre-flood levels should have been 101.1 meters instead of 101.5 meters. So, then in that case, we would have started with a 0 value, and then we would have got some positive value, a higher value in the next iteration, and so our value would have been better. So, because there is a problem in the statement itself, there is an issue, but keeping numerical value aside, this is the procedure we will use for solving the problems. So, the first value will be read from the given data, and then the rest of the things will be coming from calculation. So, this problem unfortunately has some issue, so that is why we are having the problem.



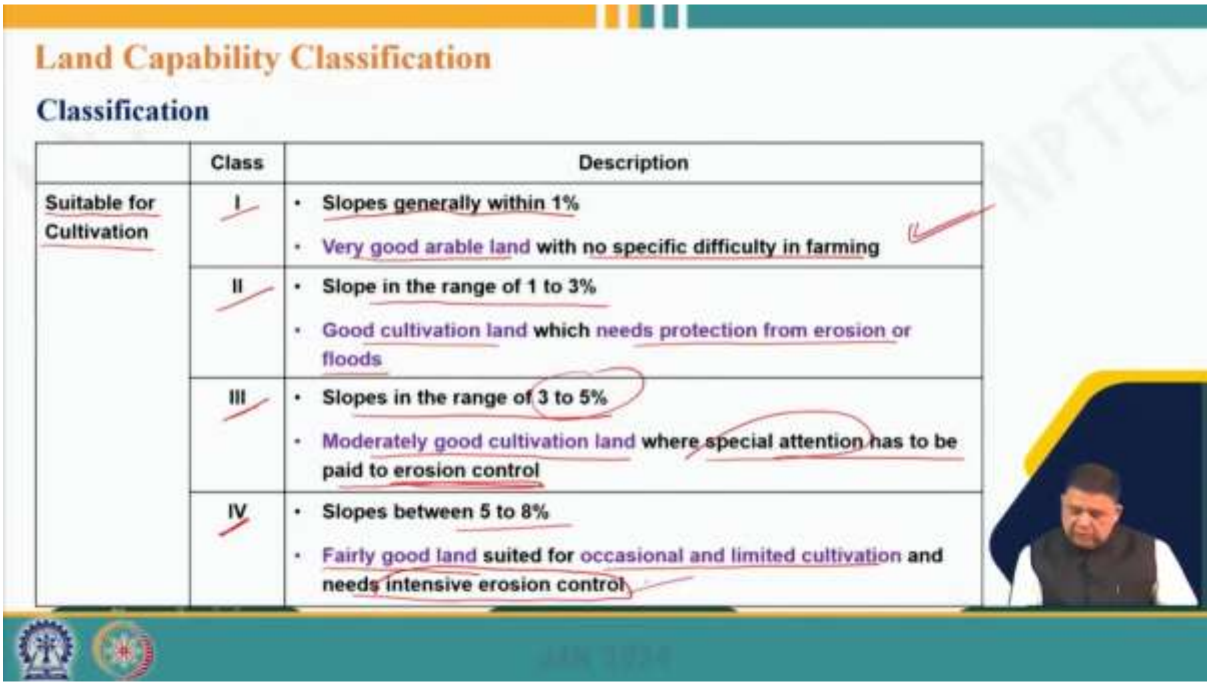
Now, we go into the second aspect of it, and that is land LUCC, land capability classification. So, land capability refers to the capacity of a land surface to support various uses, such as the nature of plant growth, wildlife habitat, artificial crop cultivation, and human habitation. Basically, land capability classification aims at classifying lands according to their capability for supporting particular activities. For example, a particular class may support artificial crop cultivation, human habitation, or plantation. So, the capability of the land is taken into account while classifying it, and it is determined by factors like slope, soil type, depth, and erosion conditions. These conditions decide whether a crop is suitable for cultivation, plantation, or other purposes. That's what land capability classification means. The purpose is obvious; land capability classification determines the best use for a piece of land and helps define conservation problems and possible treatments. In this way, we know for what purpose each piece of land could be used and what associated problems, especially concerning soil conservation, exist and what possible treatments can be applied. Thus, by keeping an eye on the capability of the soil and its issues, we can take remedial measures, resulting in integrated watershed management on a long-term basis.



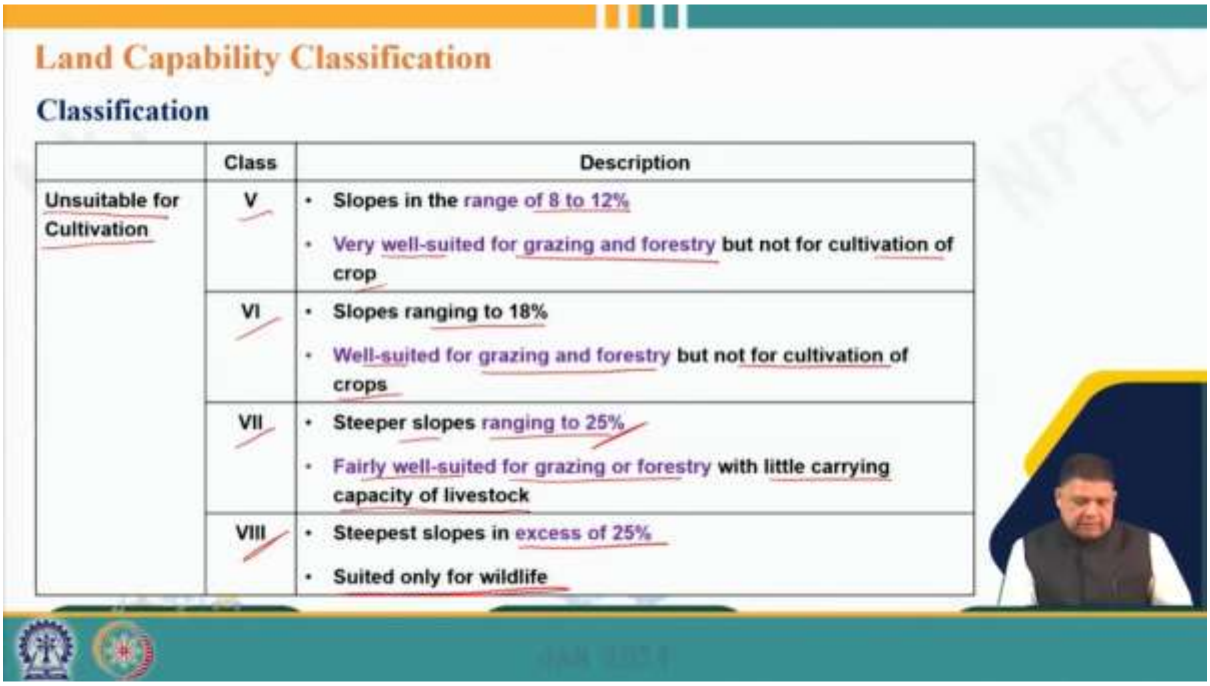
Now, coming to the classification itself, the All India Soil and Land Use Survey, now known as the Soil and Land Use Survey of India under the Ministry of Agriculture and Farmer Welfare of the Government of India, carried out the land capability survey in 1960 and identified 8 land use capability classifications. These classifications follow the ones given by the USDA with some local modifications. The first 4 classes, labeled as class I, II, III, and IV, are considered suitable for cultivation, while the next 4, class V to VIII, are deemed unsuitable for cultivation. So, broadly, we classify them into 2 categories: the first 4 classes are suitable for cultivation, and the next 4 classes are not.



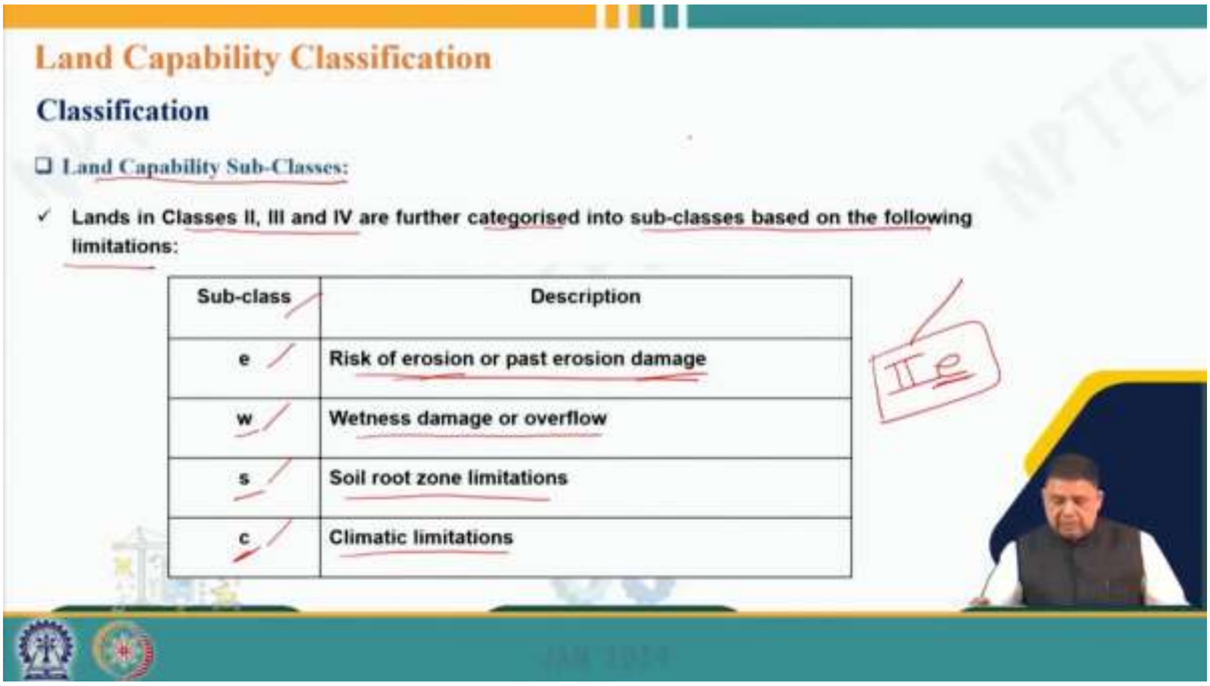
Now, let's delve into the description of various classes, starting with the lands suitable for cultivation, which are class I to IV. Beginning with class I, the land slope is generally within 1 percent, indicating flat land, which is excellent arable land with no specific difficulty in farming. It's fit for cultivation, with no identified conservation or other problems. Moving to class II land, where the slope ranges between 1 and 3 percent, it's good cultivation land but needs protection from erosion or floods. So, some protection is required from the perspectives of floods and soil erosion. Then we move to class 3, where the slope ranges between 3 to 5 percent, and it is moderately good cultivation land where special attention has to be paid to erosion control. Of course, if the slope increases, erosion becomes an issue. So, when we go to class 3, where the land slope is 3 to 5 percent, we have to pay special attention to erosion control. Next, we move to class 4, the last class suitable for cultivation. Here, the slope ranges between 5 and 8 percent, and it is fairly good land suitable for occasional and limited cultivation, but it needs intensive erosion control. Obviously, the terminologies are important here. The first classification is based on the slope: 1 percent, 1 to 3 percent, 3 to 5 percent, and 5 to 8 percent, comprising 4 classes. Class 1 is free from any kind of erosion, class 2 needs a little bit of protection against erosion and floods. Class 3 is moderately good for cultivation, requiring special attention from an erosion control point of view, and class 4 is good land but requires intensive erosion control. These are the 4 different classes suitable for cultivation.



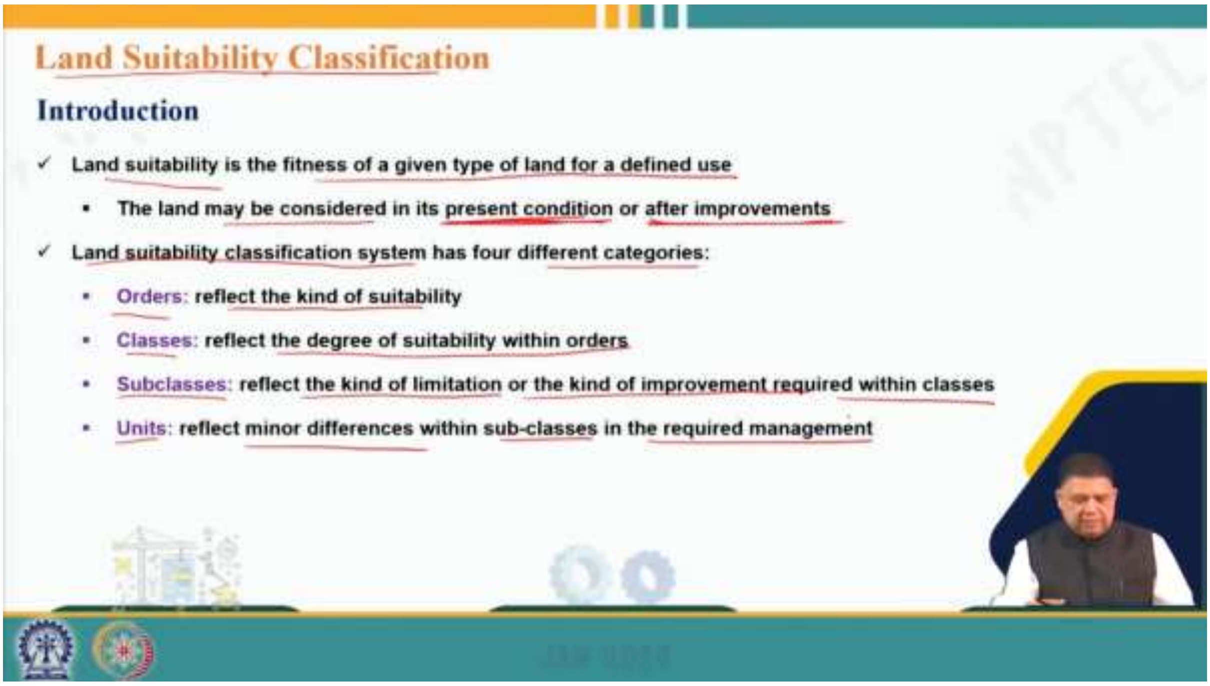
Moving on to the next 4 classes, class 5 to class 8, which are unsuitable for cultivation, slope is again the guiding factor. Class 5 means the slope ranges between 8 and 12 percent; it is well suited for grazing and forestry, not for crop cultivation. Then we move to class 6, slopes ranging from 12 to 18 percent, well suited for grazing and forestry, but not for crop cultivation. Class 7 indicates steep slopes ranging from 18 to 25 percent, fairly well suited for grazing or forestry, with limited capacity for livestock. Finally, class 8, steepest slopes in excess of 25 percent, suitable only for wildlife, not for any kind of cultivation, forestry, or grazing; it's designated for wildlife management only. These are the 8 classes, 4 suitable for cultivation, 4 unsuitable for cultivation.



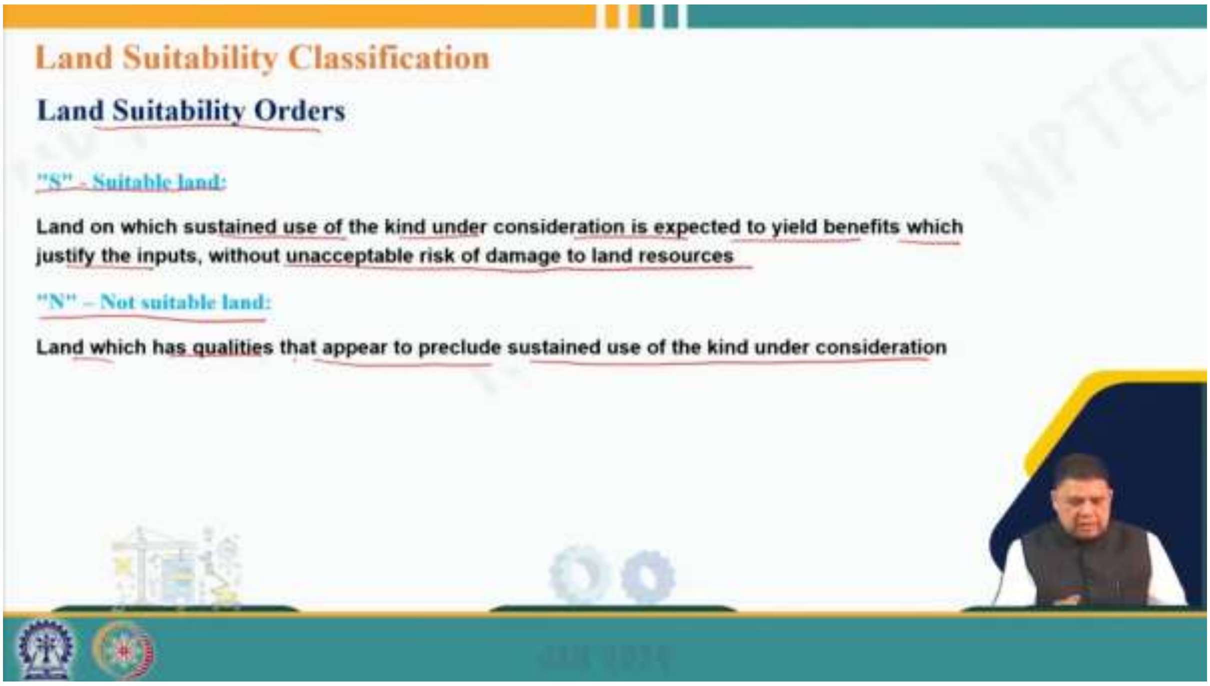
Within the land capability classes, we also have certain subclasses identified, applicable to classes 2, 3, and 4 only. Classes 2, 3, and 4 are further categorized into subclasses based on limitations. So, besides slope, they were classified from good for cultivation to less suitable. Subclasses are identified by letters like e, w, s, and c, describing the type of subclass. e indicates the risk of erosion or past erosion damage, w denotes wetness damage or overflow, s indicates soil root zone limitation, and c represents climatic limitations. For example, if we have a class 2 land, we can append a suffix "II e" to indicate that it's a class 2 land with a subclass where there's a risk of erosion or past erosion damage to that land. We also use a prefix to clarify the type of problem associated with the land. So, obviously, we can think about proper care of this type of soil.



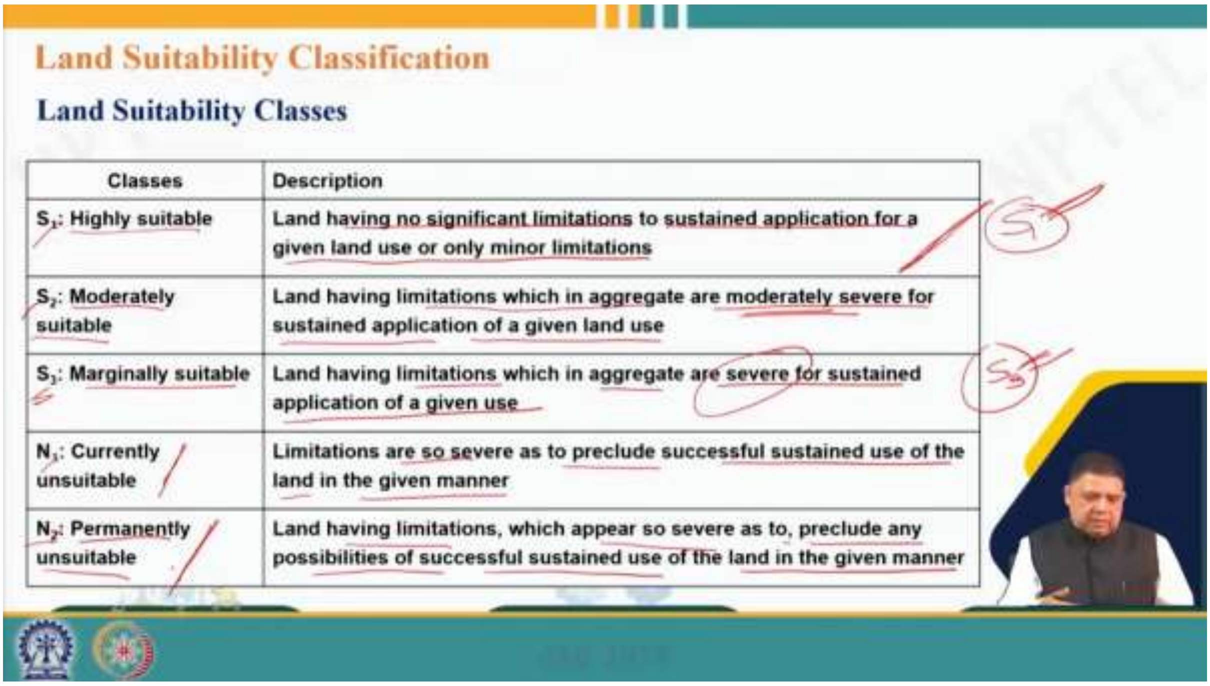
Then we delve into land suitability classification. Land suitability is the fitness of a given type of land for a defined use, though very similar to the first class we discussed, which was about capability. Here, we are talking in terms of suitability for a particular use. Land suitability classification considers land in its present condition or after improvement. So, both conditions could be there, the existing condition, and even if you have taken some kind of measures to take care of the problems associated with the soil, then also it can be considered. A land suitability classification system has four different categories. The first is orders, which reflects the kind of suitability. Classes reflect the degree of suitability within orders, and subclasses reflect the kind of limitation or kind of improvement required within the classes. Then units reflect minor differences within subclasses, requiring management. So, it's like a tree; you start with the order, then within the order, there are classes, subclasses, and units. Basically, this is the kind of classification we make.



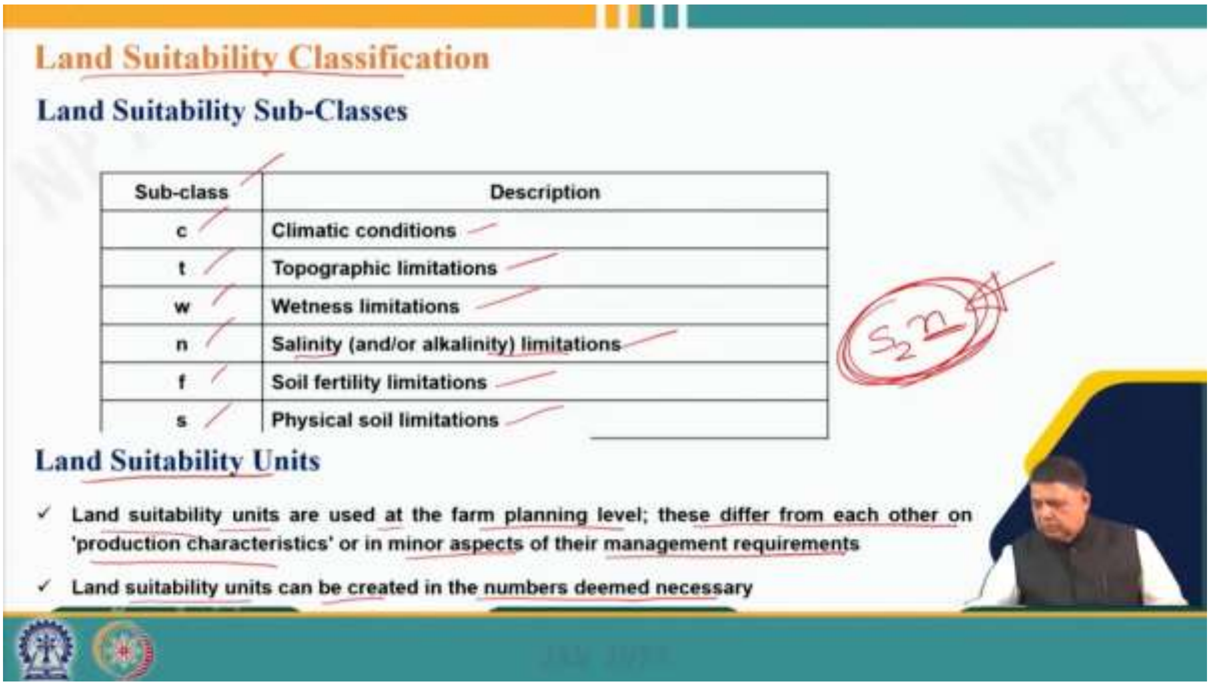
Now, regarding orders, we consider S suitable land and N not suitable land. Suitable land is where sustained use of a kind under consideration is expected to yield benefits that justify the inputs without unacceptable risk of damage to land resources. So, if land is suitable for cropping, it means it will be beneficial to go for cropping on that particular land. On the other hand, land categorized as not suitable has qualities that appear to preclude sustained use of the kind under consideration. If you opt for cropping on such land, you may incur losses or even damage to the soil itself and the environment. That's the classification.



Moving on to classes, there are S1, S2, S3, and N1, N2. Suitable lands are in three categories, and non-suitable lands are in two categories. S1 denotes highly suitable land, where there are no significant limitations to sustained application for a given land use or only minor limitations. If your intended use is agriculture and the soil type is S1, it means you can go for cultivation without hesitation, with no identified issues as such, maybe just minor limitations. Then we have moderately suitable, S2, which refers to land having limitations that, in aggregate, are moderately severe for sustained application of a given land use. So, of course, there are issues, but they are moderately severe, and then S3 is marginally suitable, meaning land having limitations which, in aggregate, are severe for sustained application of a given use. So, if you compare S1 versus S3 for agriculture, S1 poses no issues, but S3 has severe limitations. You have to be careful about that. Similarly, N1 denotes currently unsuitable land, where limitations are so severe as to preclude successful sustained use of the land in the current condition. However, there's a scope that if corrective measures are taken over time, it may be usable. On the other hand, N2 is permanently unsuitable, meaning land having limitations so severe as to preclude any possibility of successful sustained use of the land in the given manner. N2 type of land can never be used for a particular purpose you are defining. That's how you define the clauses within the order.

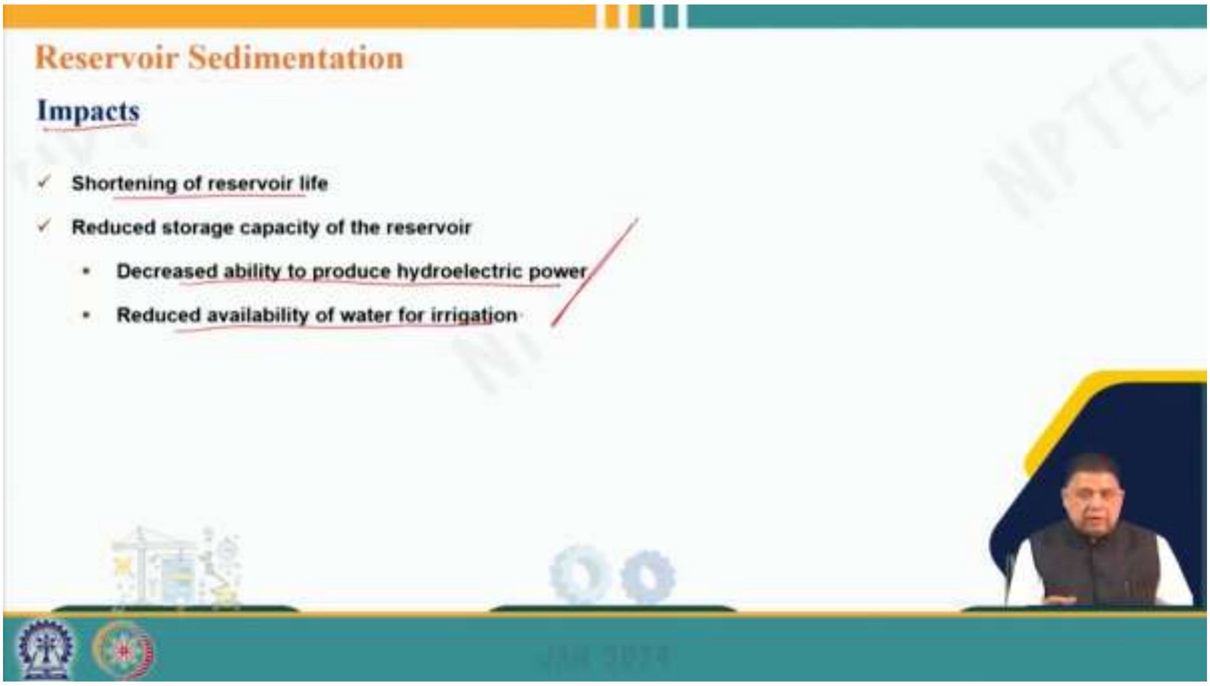


Then, of course, we have subclasses, similar to the subclasses in land capability, that we use. c, t, w, n, f, and s represent climatic conditions, topographic limitations, wetness limitations, salinity or alkalinity, soil fertility, and physical soil limitations, respectively. So, if we say S2N, it means salinity or alkalinity is a problem, and you have to be careful. Lastly, land suitable units are used at the farm planning level. These units differ from each other in production characteristics or minor aspects of their management requirements. Land suitable units can be created in the number deemed necessary. If you identify that your land on the farm is overall S2N category, salinity and alkalinity levels could be different in different parts of the farm. Then you will create these units; there could be 4 or 5 units where salinity is high or low, and accordingly, the measures required will differ. This is how it works. We have orders, classes, subclasses, and units as far as land suitability classification goes. With this, we conclude this classification.

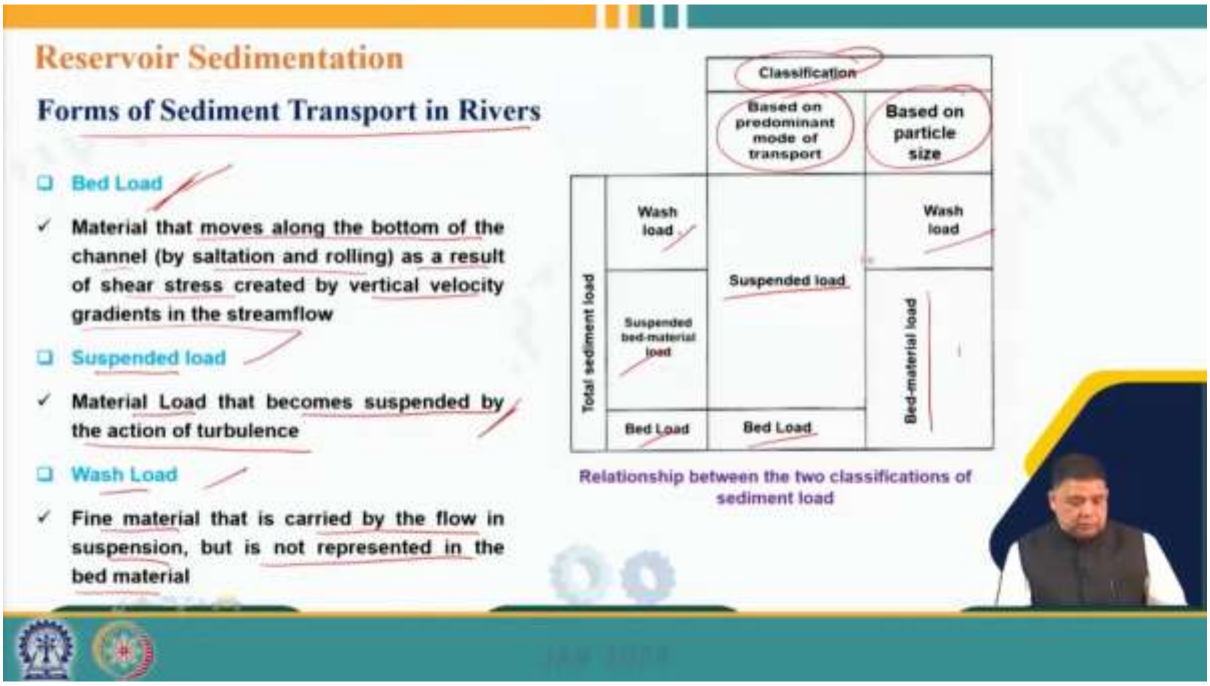


Now, we delve into reservoir sedimentation, yet another very important topic which has not been covered. The name itself suggests that we are focusing on sedimentation of the reservoir or the filling up of the reservoir capacity due to sedimentation. We know that rivers transport huge amounts of sediments, sometimes beneficially like the deltas, alluvial fans, or levees, which are created because of this movement of sediments through rivers. However, reservoir construction impedes sediment flow downstream, causing sediment accumulation within the reservoir. This is an issue we know, and that's why we are careful, because despite varying sedimentation rates, all reservoirs usually lose water storage capacity as sediment occupies water storage space. And we know that while we discussed earlier that while designing reservoirs, we use the consistent concept of storage zoning. A part of the reservoir referred to as dead storage is already provided based on some assumed sedimentation rate over the life of the structure. This will be the sedimentation expected, and because of that, dead storage is provided. As long as the sedimentation rate is such that only the reservoir sediments will fill the dead storage, that is not a problem. But the problem arises when it exceeds. According to the International Commission on Large Dams report, ICOLD, 2009, the global average sedimentation rate and storage loss is around 0.96 percent annually. Most reservoirs are losing 1 percent of their storage annually because of sedimentation. That is a major challenge.

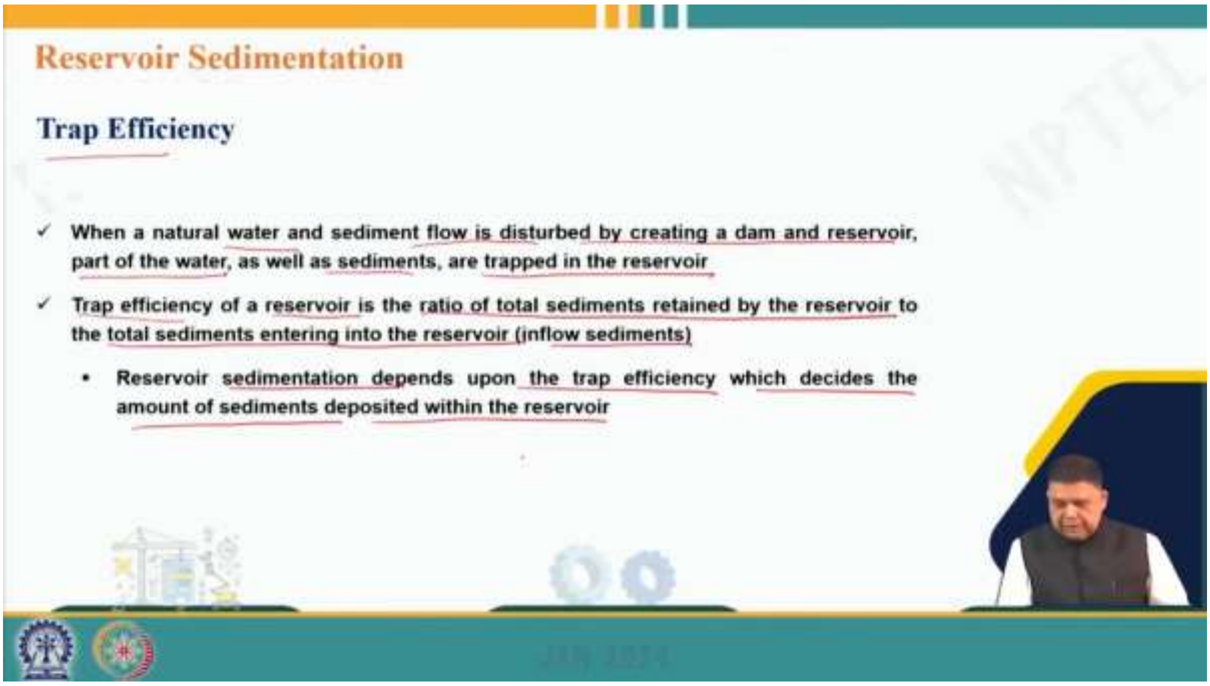
Of course, the impacts of sedimentation are known: reservoir life will be shortened because if the capacity is filled up, it will not serve the purpose for which it was meant. Additionally, there will be a decrease in the ability to produce hydroelectric power and a reduction in the availability of water for irrigation. The life of the structure will be decreased, and it will not be able to meet its intended purpose.



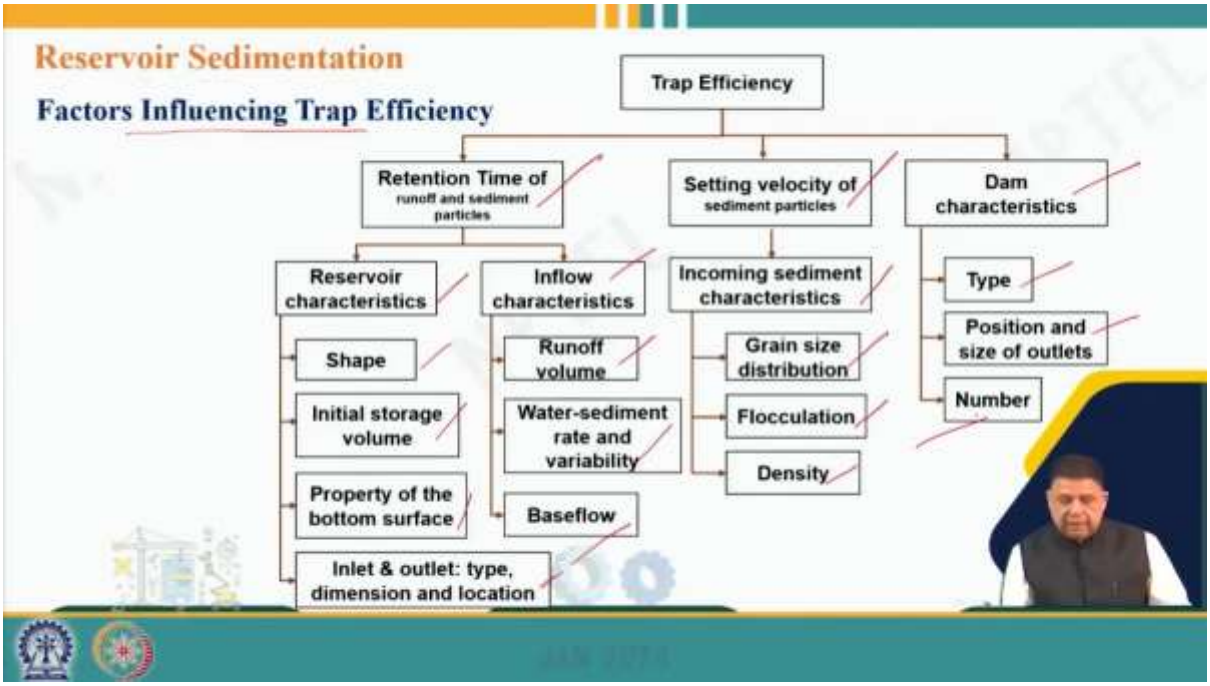
The forms of sediment transport in rivers are well understood. Sediments move either as bed load or suspended load or wash load. Bed load refers to materials that move along the bottom of the channel by saltation or rolling as a result of shear stress created by vertical gradients. Suspended load refers to material that becomes suspended by the action of turbulence, mainly fine particles only. Wash load refers to fine particles that are carried by the flow in suspension but are not represented in the mud material. Based on transport, they can be further classified as suspended load and bed load, and based on particle size, they could be wash load and bed material load. Typically, we use the classifications wash load, suspended load, and bed load. These three are identified.



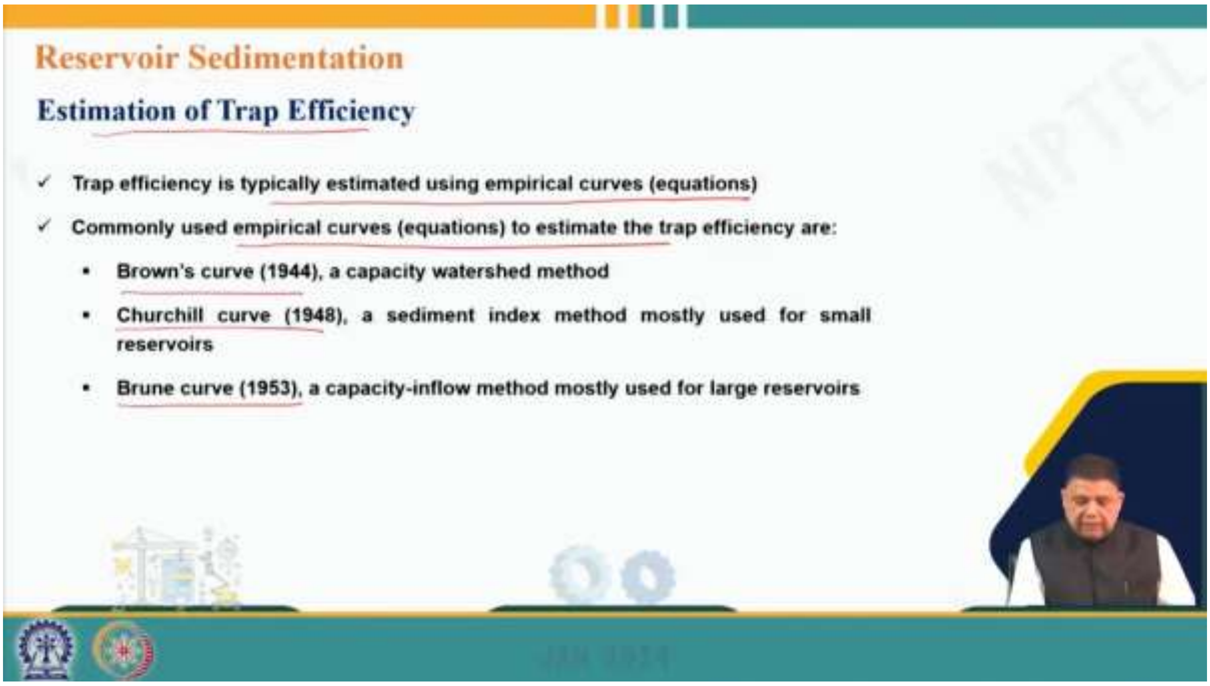
Then comes the trap efficiency. When natural water and sediment flow is disturbed by creating a dam or reservoir, part of the water as well as sediments are trapped in the reservoir. The trap efficiency of a reservoir is the ratio of the total sediments retained by the reservoir to the total sediments entering the reservoir, that is, the inflow sediments. If X amount of sediment is coming into the reservoir and a certain percent of that is retained, then that becomes the trap efficiency. So, reservoir sedimentation depends on the trap efficiency, which decides the amount of sediments deposited within the reservoir.



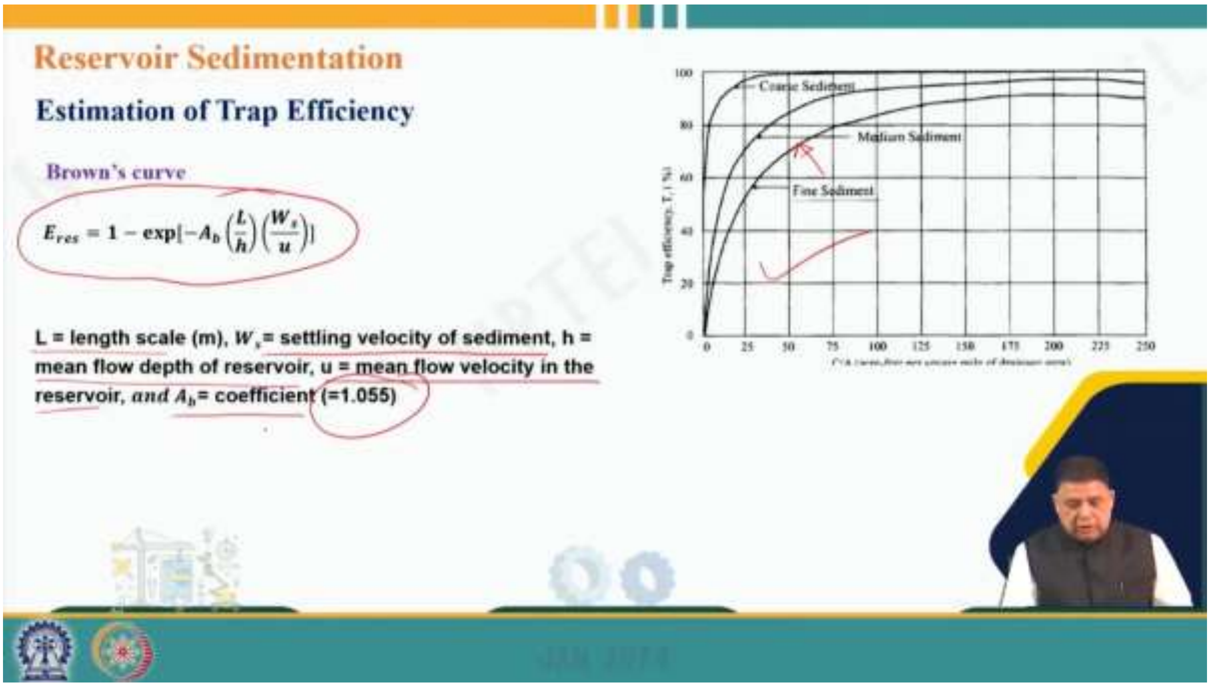
Factors that influence the trap efficiency include retention time to runoff, sediment particles settling velocity, dam characteristics, retention time of runoff, reservoir characteristics, and inflow characteristics such as shape, initial storage volume, properties of the bottom surface, inlet type, and inflow characteristics like runoff volume, water sediment rate, and variability in base flow. On the other hand, sediment velocity, incoming sediment characteristics like grain size, flocculation, and density, and dam characteristics including type, position, size of outlet, and number are also crucial.



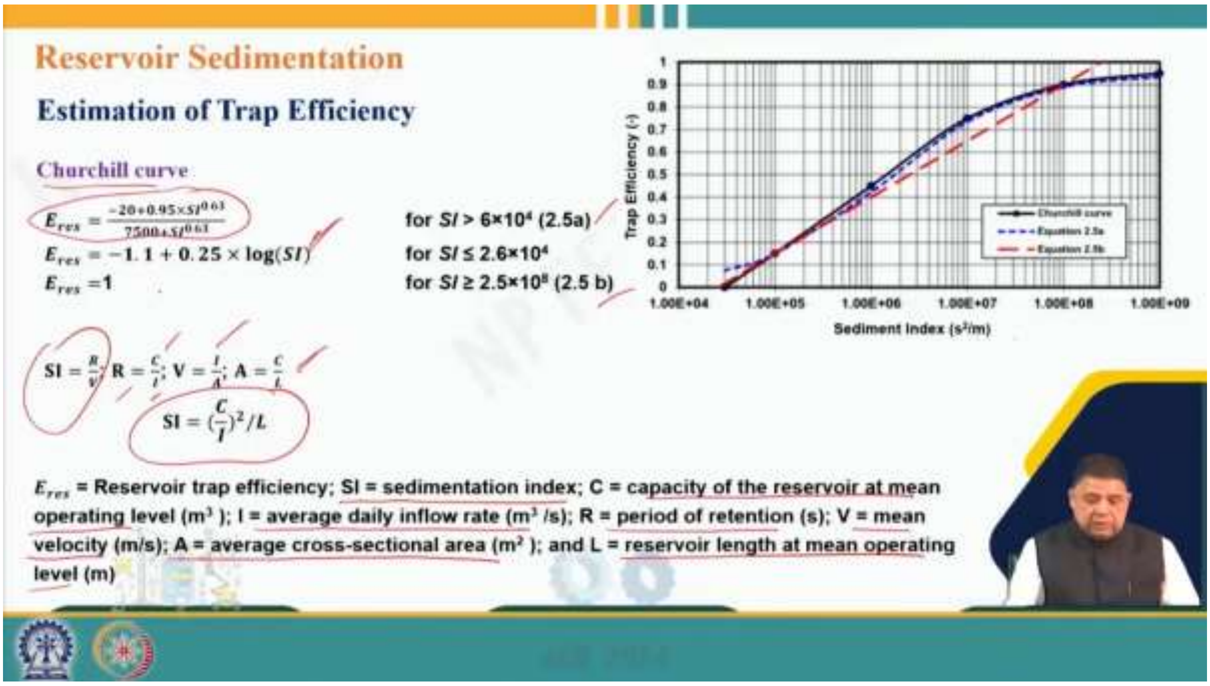
As for the estimation of trap efficiency, it is typically done using empirical curves or equations. Commonly used empirical curves include Brown's curve from 1944, Churchill's curve from 1948, and Brun's curve from 1953, each associated with its own set of equations.



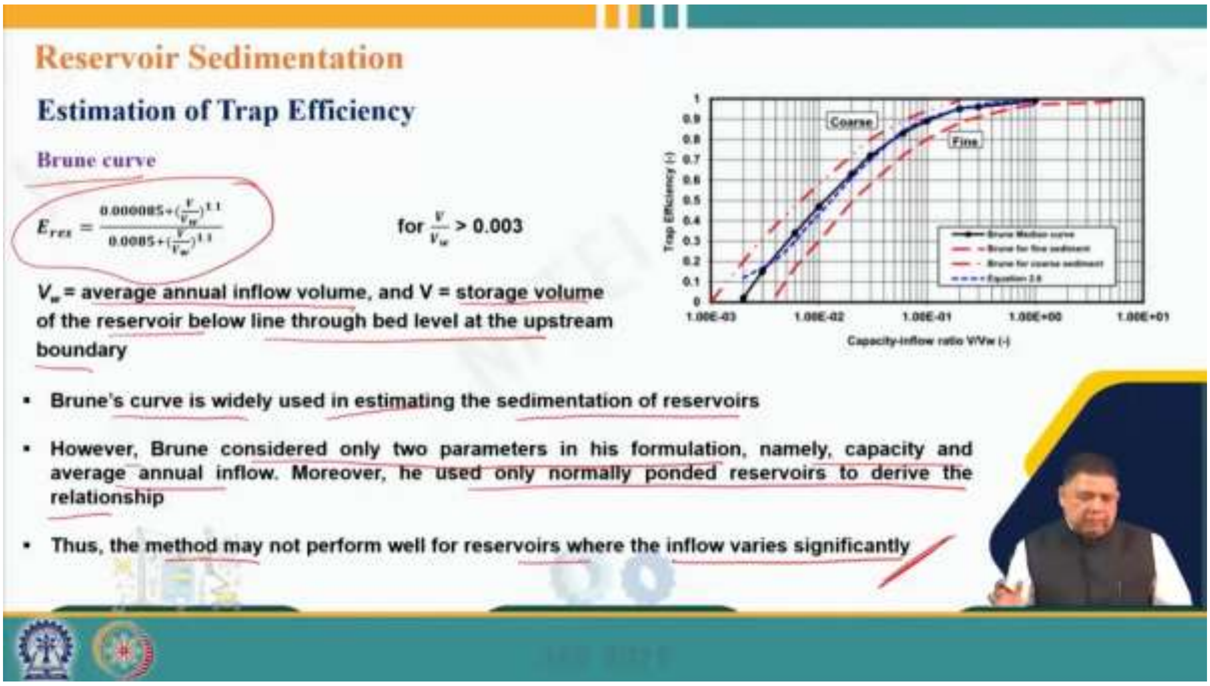
Brown's curve divides sediment into three categories: fine, medium, and coarse, with variables such as length scale (L), sediment settling velocity (WS), mean flow depth of reservoir (H), mean flow velocity in the reservoir (U), and a coefficient (AV) whose value is typically 1.055.



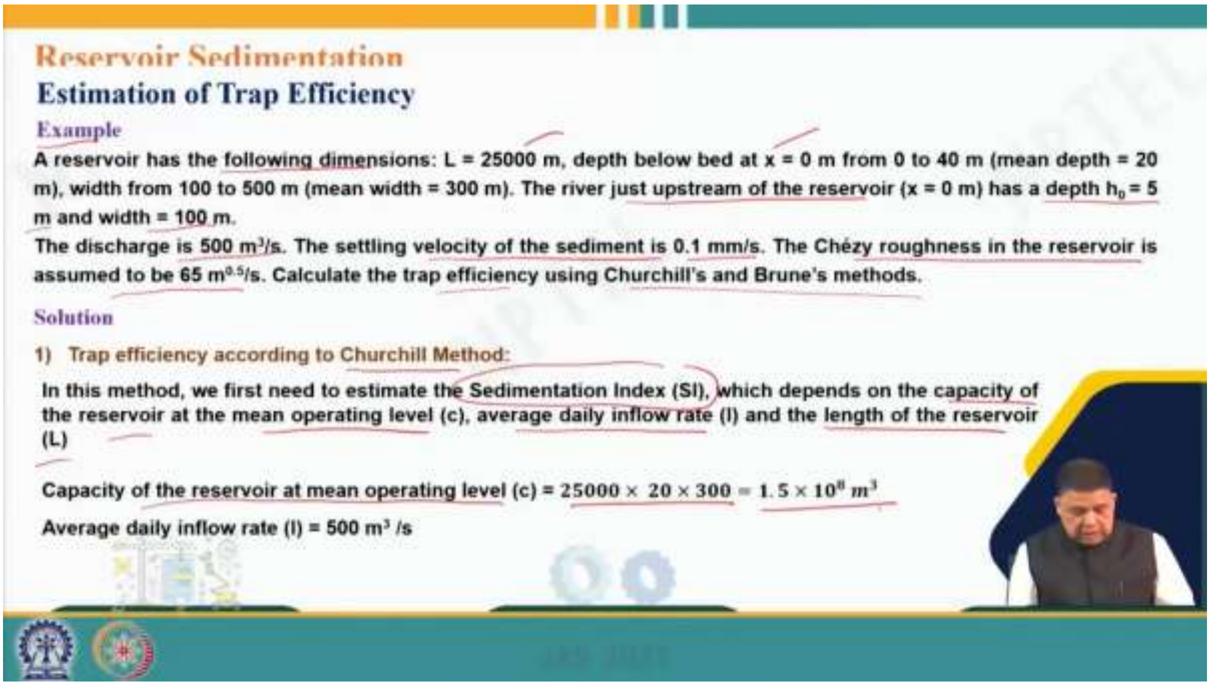
Churchill's curve involves a sediment index (Si), which is calculated using reservoir capacity at mean operating level (C), average density inflow rate (I), average cross-sectional area (A), and reservoir length (L).



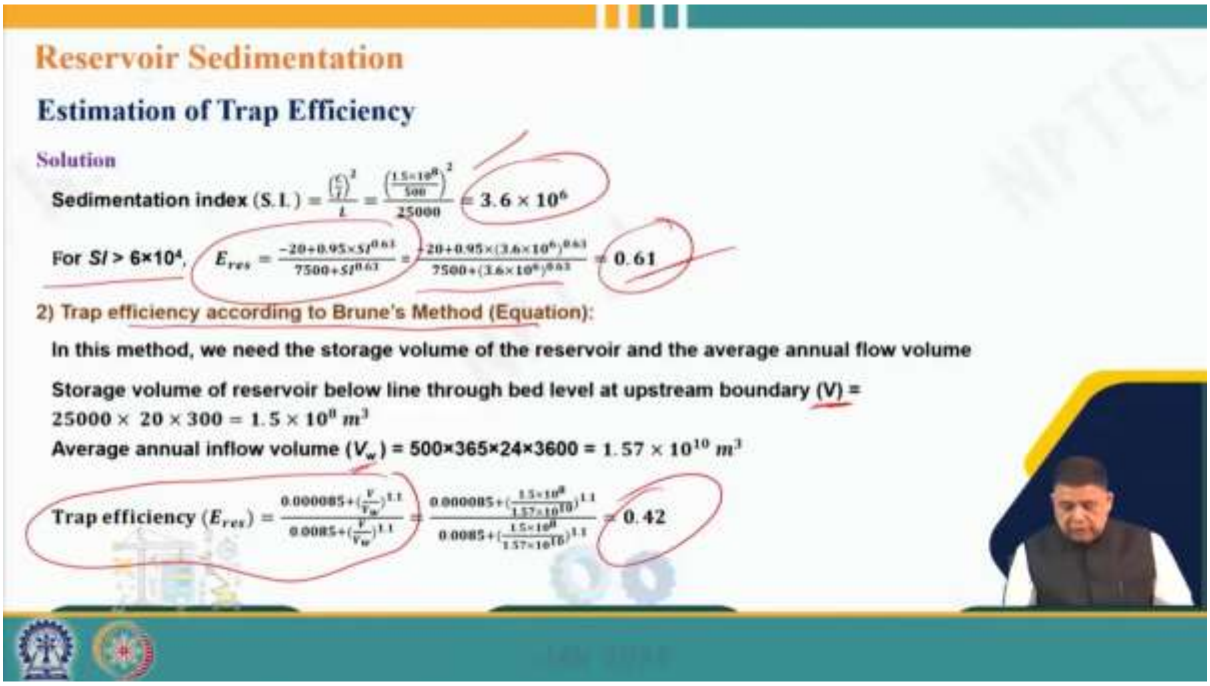
Brun's curve, on the other hand, considers variables such as average involved inflow volume (Vw) and storage volume of the reservoir below the line through bed level at the upstream boundary (V). Brun's curve is widely used for estimating reservoir sedimentation, but it has limitations, particularly for reservoirs where the inflow varies significantly. Despite this, it remains the most commonly used equation.



Let's conclude with an example: A reservoir has the following dimensions—length, depth below the bed, and different elevations. The river just upstream of the reservoir has a depth (h0) of 5 meters and a width of 100 meters, with a discharge of 500 cubic meters per second. The settling velocity of sediment is 0.1 millimetre per second, and the change in roughness in the reservoir is assumed to be 65 meters to the power half by S. Calculate the trap efficiency using Shirley Churchill's and Brun's method. So, of course, in Churchill's method, we first need to estimate the sedimentation index, which depends on the capacity of the reservoir, the mean operating level, the average daily inflow rate, and the length of the reservoir. Given the values provided, the capacity of the reservoir at the mean operating level can be calculated, which comes out to be this. The average daily inflow rate is also given.



Thus, the sediment index can be calculated, resulting in 3.6 x 10^6. If this value is greater than this, then this equation is used, yielding a 61 percent sedimentation trapped using this method. Now, if we turn to Brune's method, then obviously, we need to calculate the straight equation V and Vw. Estimating V and Vw in this method results in 0.42, which translates to 42 percent. As you can see, there is a marked difference between the trap efficiency obtained by the two different methods. However, as mentioned, Brune's method is the most popular.



With this, we conclude this lecture. Thank you very much. Please provide your feedback and feel free to raise any questions or doubts you may have, and we shall be happy to address them on the forum. Thank you.