Geographic Information Systems
Prof. A. K. Saraf
Department of Earth Sciences
Indian Institute of Technology-Roorkee

Lecture-54
DEM based Surface Hydrologic Modelling-2

Hello everyone! and welcome to the next part of surface hydrological modelling discussion. This is my one of the favourite topics because if you recall the definition of GIS, what we had in that after all this development of database and everything, we would like to do the Modelling and this is what we are doing here. So, this is the ultimate and modelling allows us to do the prediction. So, nothing is happening on the ground but we are predicting the drainage network. We are predicting the watershed boundaries and many other parameters which will also see in this discussion.

So, it is the ultimate aim of the GIS project is to model something, present different scenarios for the decision makers and therefore GIS is also a decision support system. Now the next theme or next output of derivative which we derive through the surface hydrological modelling is called the flow length.

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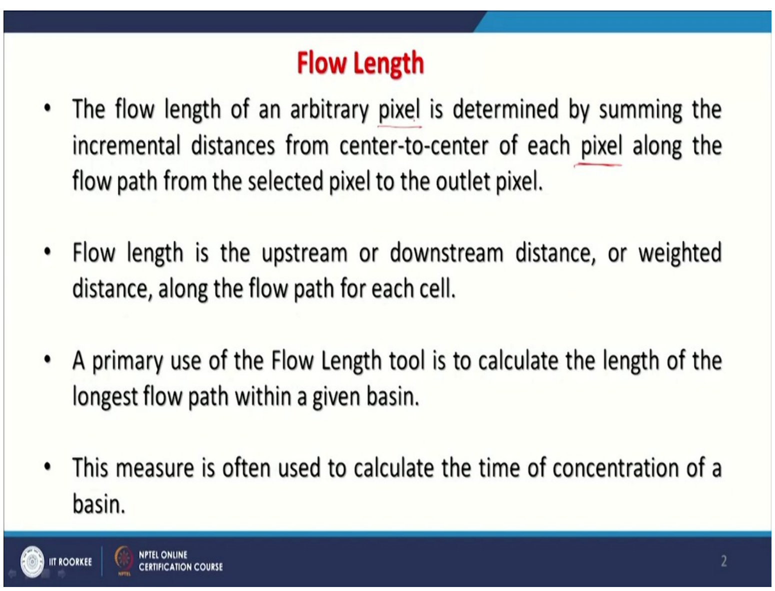

So, flow length is basically an arbitrary pixel which is determined by summing the incremental distance and that distance is from centre to the centre of each pixel or each cell because here, we are using digital elevation model so instead of pixel you can use words cell more appropriately along the flow path and flow path, we have already discussed that is that drainage network, from the selected cell to the outlet cell and this is what we will be doing in the flow length.

Flow length is the upstream or downstream distance or weighted distance along the flow path for each cell. And the primary purpose or use of this flow length tool or flow length derivative to calculate the length of the longest flow path within a given basin because this is very helpful while doing the modelling for the flood. How much time water will take to reach to the outlet or any other location within a basin, that will depend on the flow length.

So, how much distance it has to travel, that we can determine through this step in surface hydrological modelling. And this flow length is often used to calculate the time of concentration of a basin which is directly linked with your flooding forecasting. Also, may be related with sediments flow or maybe some other pollutants because this is after all, time of concentration. How much time it would take to reach a particular location?

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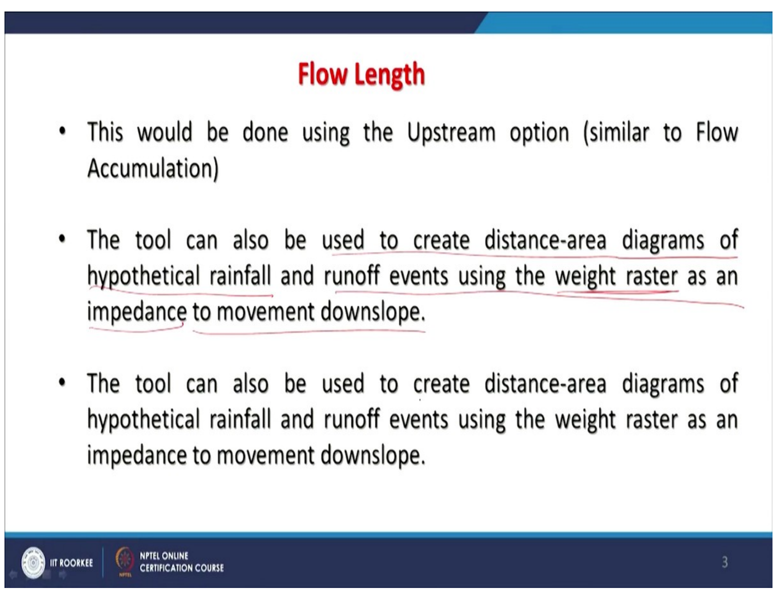

And this flow length will be derived using the upstream option similar to flow accumulation as we do. And this because it’s a sequential processing; surface hydrologic modelling so this is basically 5th step in surface hydrological modelling or this tool can be used to create distance-area diagram of the hypothetical rainfall and runoff events using weight raster as an impedance to the movement of the flow.

And based on the land use conditions, the weight can be assigned or impedance can be estimated and that will allow us to do this modelling more accurately, more realistic. So, this flow length can also be used to create distance-area diagram of hypothetical and down slow.

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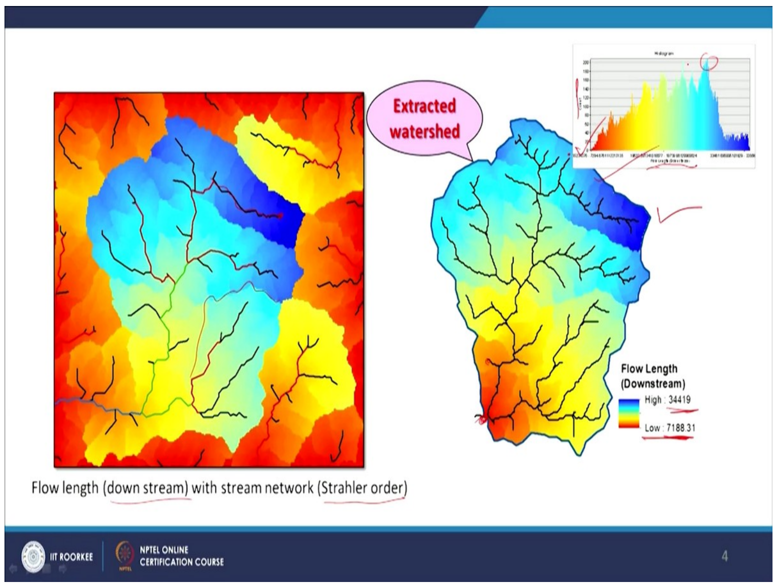

Now, this is the flow length of the same digital elevation model which we have been discussing in this discussion also. Drainage network with stream ordering is also known as a Strahlar stream. And the flow length here as shown in the downstream. So, as you can see that here for example, the values would be very less say in this part. But as we go in the downstream, the length increases. So, therefore for each cell, the changes are occurring. It is not necessary that we always see because it is raster.

So, it is not only along the drainage, the flow length is calculated but for each cell, it is calculated. As you can also realise that these are the boundaries which are being formed here. Ultimately, they may become our watershed boundary, that is a different thing. So, we can extract the watershed boundary as it’s here using some other tools like delineation of watershed. Again, using a surface hydrological modelling deciding this is my outlet.

As you can see here the low values, the coloured values are having a relatively low values as compared to the one which you are having high value. So naturally, the flow length from this point to the outlet is much higher than from this point to this point. So, that will allow us to estimate the time of concentration especially related with water or sediments and we said this that we can prepare a histogram of time length versus that how many cells will contribute.

And that will let us know that you know if this cloud burst happens in this part, then how much time it would take to reach? What would be the flow length, how much travelling time it would require that can be estimated very easily. This is how it is used in the modelling.

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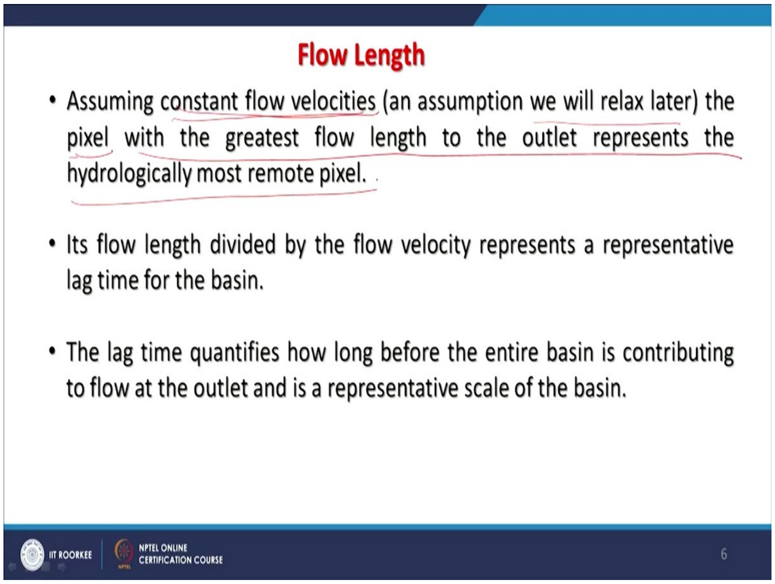

Now downstream flow length; the minimum flow length would be at the pour point/outlet of the watershed and maximum would be the watershed boundary. And generally, the flow length assigned to the outlet cell which is zero. So, whenever there is a precipitation in form of rain, a drop of water landing somewhere in the basin must first travel some distance before it is reaching to the outlet and that will be decided based on how much travel it has done.

So, if we assume that this is constant flow velocities, generally in the modelling, some assumption will always be there. So here if we assume that the velocity through this travel path is the constant which maybe we will relax later, the pixel or the cell with the greatest flow length to the outlet represents the hydrological most remote pixel or remote cell. It's flow-length divided by the flow velocity represented a lag time for the basin.

And the lag time quantifies how long before the entire basin is contributing to the flow because each drain will not reach or each drop of water will not reach at the same time at the outlet. So, there will be some lag time and that too can be calculated using flow length.

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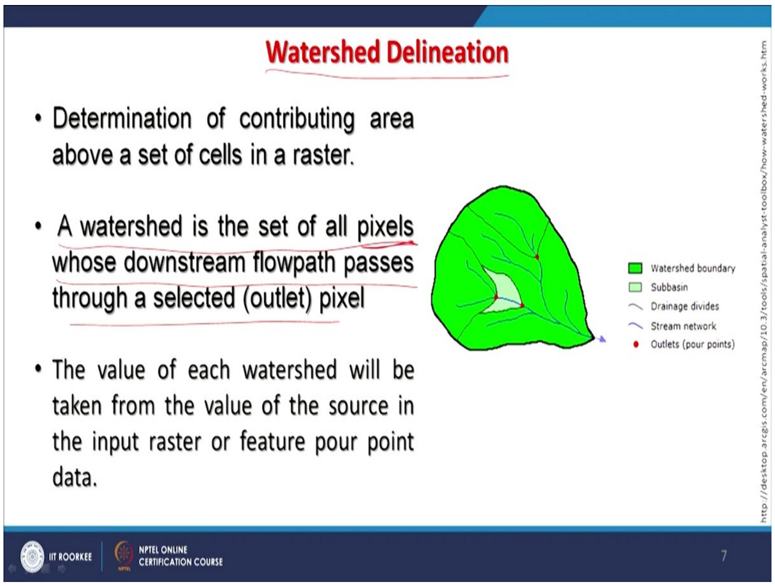

Now the 6th one is the watershed delineation or delineation of watershed boundary which is determination of contributing area above a set of cells in a raster; that is our digital elevation model. So, the only requirement here is to deciding the outlet. Once the outlet has been decided; pour point then the watershed can be delineated using the flow accumulation thing. So, you see if we want to define watershed in terms of surface hydrological modelling point of view then a watershed is the set of all cells whose downstream flow path passes through a selected outlet cell.

And the value of each watershed will be taken from the value of the source in the input raster or feature pour point.

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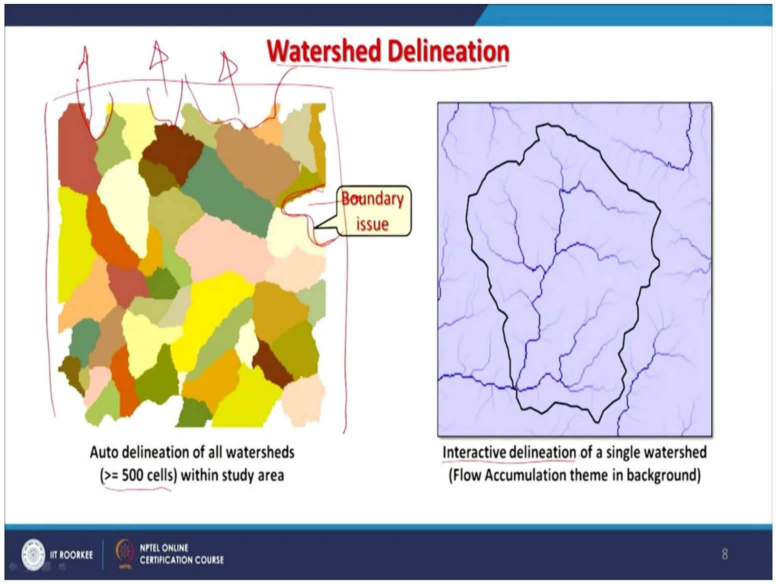

At the same digital elevation model which I was using, the watershed has been delineated and the condition of the threshold value was kept equal to more than 500 cells. So, any watershed which is less than that, has not been identified. One problem I mentioned earlier also in the previous lecture which I am going to repeat that while doing this thing, you will have problems or limitations of this surface hydrological modelling along the boundary or the margins of your input digital elevation model which you can see.

Because remember one watershed ends, another starts. So here, we do not have a continuous digital elevation model for the entire globe, only a part of here. So that means this area will contribute to some other outlet, not here but some outlet may be like this. And therefore, it is not part of this basin and therefore it has not been delineated. Similarly in all boundaries areas so that means the water will flow out from like this, from the same here also.

So, if you are working for a real project, it is always good to take large area. This I have been also telling in case of interpolation or any other thing. Take little larger area so then later on, you can make a subset. Otherwise, you may have this kind of limitation of surface hydrological modelling. So, boundary issues will always be there. Anyway, interactively also you can delineate the watershed with choosing a you know, single watershed has been used by choosing an outlet or pour point here.

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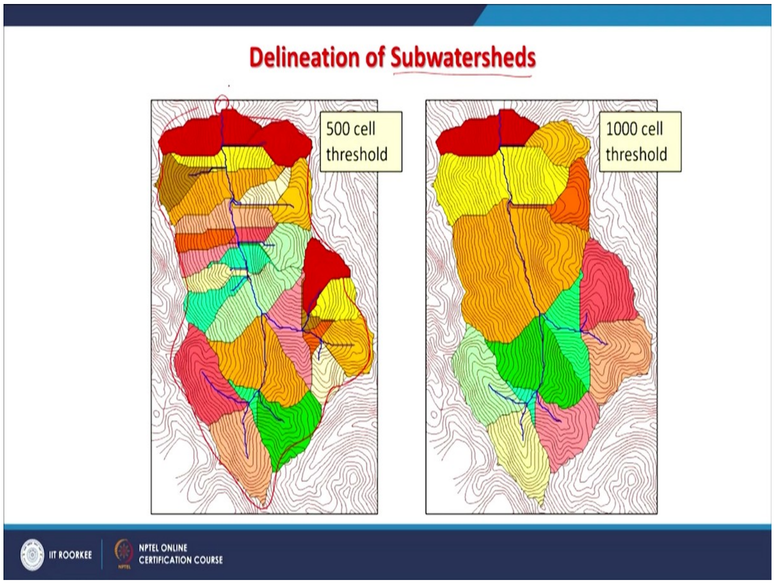

And of course, in the background, your flow accumulation which is the basic thing required for deletion of watershed was shown there. Now delineation of sub-watershed can also be done. Here also that these can also be considered sub-watersheds which are small but if this is the outlet, these are the sub-watersheds and overall, this is the watershed for the entire input area. That means a large watershed can have many sub-watersheds.

Or you can say each stream segment will have its own watershed. Threshold value was kept here 500 cells. If I change the threshold value to 1000 then number of watersheds will be reduced, however their areas will increase. So many watersheds which were different here like this, there are still there but here, they all have been merged in small-2 one because I put the condition more than equal to 1000 cells. So, if this is the condition, small watershed will disappear.

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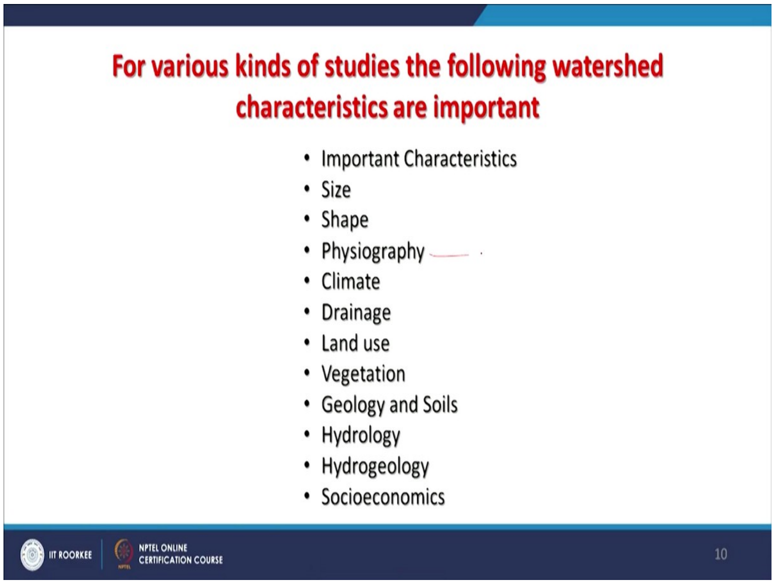

Now there are other uses of watershed characteristics which we can utilized for example important characteristics for this thing like size, shape of watershed, Physiography of the watershed, climate, physiography will include minimum, maximum, what are the slopes and other thing. For climate studies, for drainage studies, for land-use studies, for vegetation, for geology and soils, hydrology, hydrogeology and believe me, this is not exhaustive list.

So, there can be many other things which we can use or we used for watershed characteristics. We are used for different studies. Now once you have delineated watershed or ask a system through surface hydrological modelling to delineated watershed automatically by providing this threshold value, many other parameters related to watershed can also be derived automatically.

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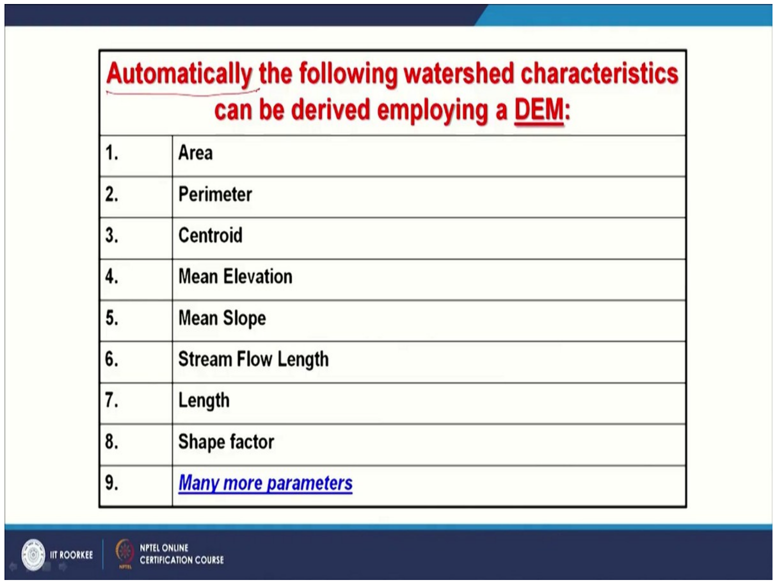

Automatically the following watershed characteristics can be derived employing a DEM:

1.	Area
2.	Perimeter
3.	Centroid
4.	Mean Elevation
5.	Mean Slope
6.	Stream Flow Length
7.	Length
8.	Shape factor
9.	*Many more parameters*

So, automatically you can derive for example area of watershed you can calculate, the perimeter of the watershed, the centroid because it’s a polygon so you will get area. You will get centroid. Also mean elevation, mean slope, highest elevation, lowest elevation; that is all going to be always pour point. And then stream flow, stream length, shape factor; Shape factor plays very-2 important role in your flood modelling.

Because if watershed is having a shape something like this and this is drainage network, that means there will be lag time more and that means if water is falling all over this catchment like this or watershed like this then the water which will fall here, will come out first of this outlet. Whereas water which will fall here or precipitation which will occur here will come out last. Therefore, there will be lag time that water falling within that basin, will come out at different times. Flow length is different.

But if watershed is having a circular shape and outlet is like this and drainage network is something like this then what would happen that every stream will contribute to the water almost same time here and then there will be flooding in this part. Therefore, the shape of watershed really matters lot for flood monitoring. And of course, then other related things like sediments and other things will also come.

So, it is very using surface hydrologic modelling to derive all other parameters which are required for various studies of watershed. So, this is again not exhaustive list. Many more parameters can also be derived.

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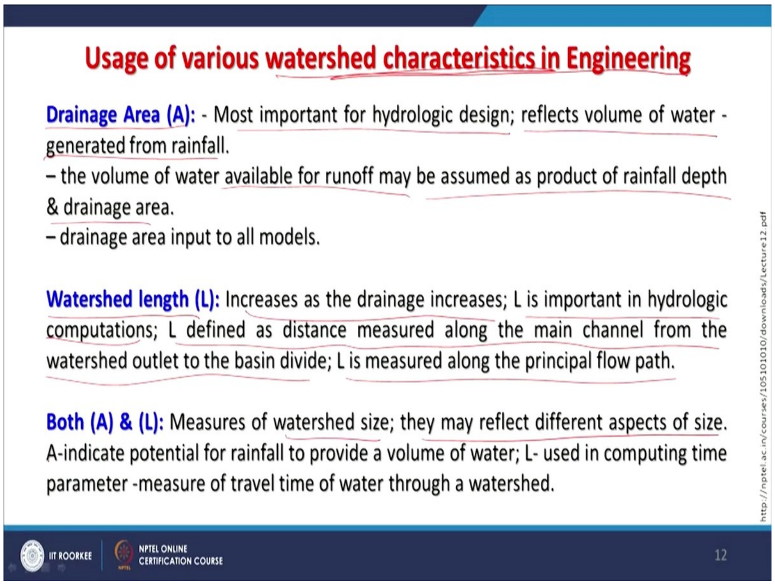

For example, watershed characteristic which are used in engineering or in sciences like earth sciences, hydrology. Like drainage area, again very important. Then that is the area which is being covered because most important for hydrologic design; reflex volume of water generated from the rainfall. The volume of water available for run off may be assumed as the product of rainfall and drainage area.

Drainage area input to all models which is always required. Now watershed length; that is increases as the drainage increases so L is important in hydrology computation. The L defines a distance measured along the main channel from the watershed outlet to the basin divide. And this L measured along the principal flow path as I shown earlier through the shape of watersheds. And then both A and L measures the watershed size. They may reflect different aspect size.

A delineated potential of rainfall to provide a volume of water. L used to compute the time parameters; measure of travel time of water through a watershed.

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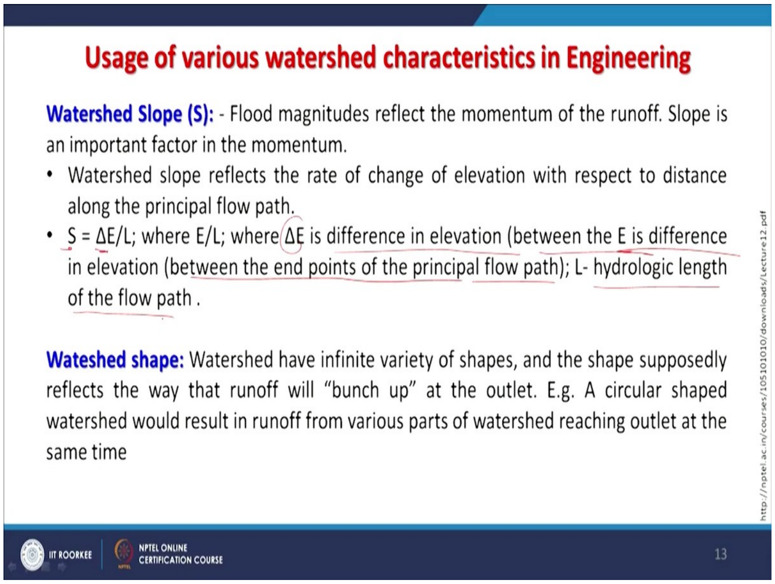

Watershed shape, I have already discussed which plays a very important role in flood magnitude assessment and then of course, the slope will also play a very important role. And here we can utilize this one like $S = \Delta E/L$ and whereas E/L, the ΔE is the elevation difference between the endpoint and the principal flow path and L is the hydrologic length of the flow path.

And watershed shape which is also very-2 important. We have already discussed this because bunching of water should not happen within one watershed. Though this is a natural boundary, we cannot change. But if impedance can be provided then all the water which is falling over watershed will not reach at the outlet at the same time or will not get concentrated in one area of watershed at the same time.

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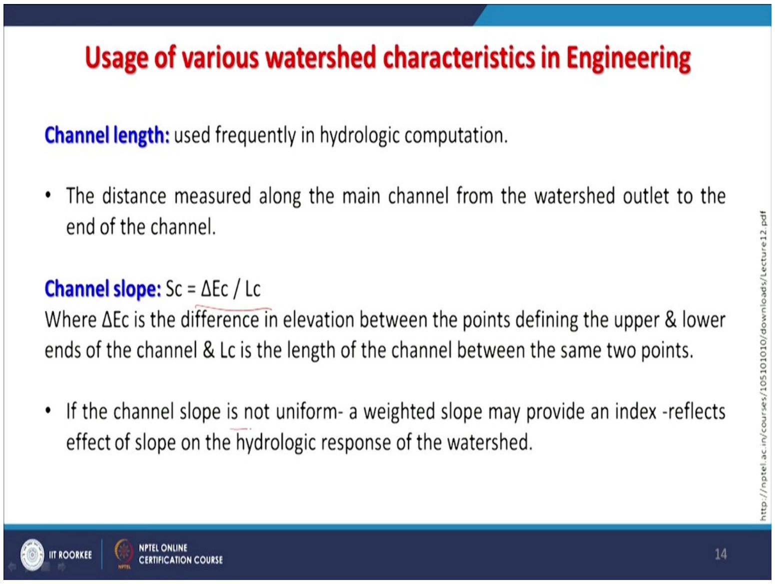

Channel length also used in hydrology computation; that is the distance measured along the main channel from the watershed outlet to the end of the channel. Channel slope is also very important which can be calculated like this. And if channel slope is not uniform; naturally, generally it is not. In nature, it is not. There might be rapids, there might be a flat part and so on. So, a weighted slope may be provided an index, that is why the channel slope is very important. The effects of slope on the hydrologic response of the watershed. Each parameter will play their own important rules.

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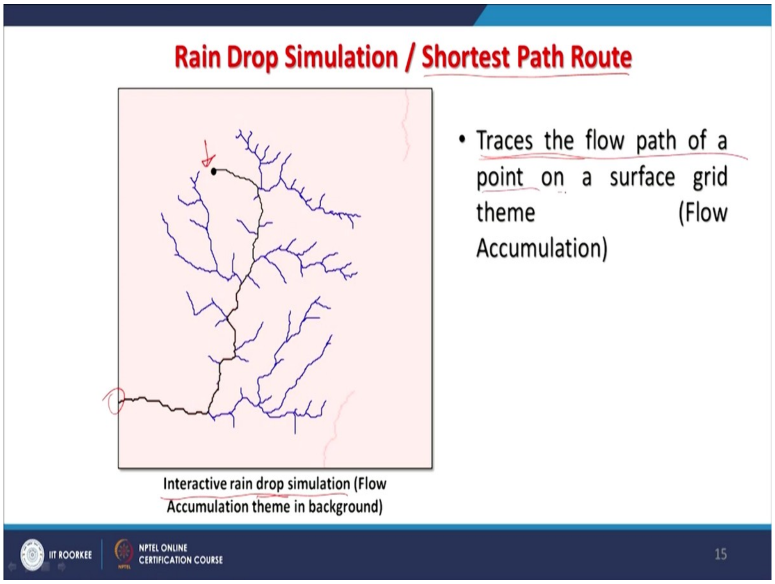

Now there is also automatically you can delineate the drainage network through a raindrop simulation or also it is called shortest path routing. If I drop a single drop of water like this here then over a flow accumulation theme, it will show that which path it will follow to come out of this outlet. So, this you can do it once you are having flow accumulation theme as a drop simulation. Now major use of this in related with point source pollution studies or also in use for estimating for groundwater recharge or other things.

That which stream will take and of course the time and length, everything can be then measured because every data is here itself. So, once you know the velocity, the time can also be calculated. What is basically rain drop simulation that is the traces of flow path of a point on a surface grid theme. The input is flow accumulation. As I have already mentioned very-2 useful for point source pollution studies.

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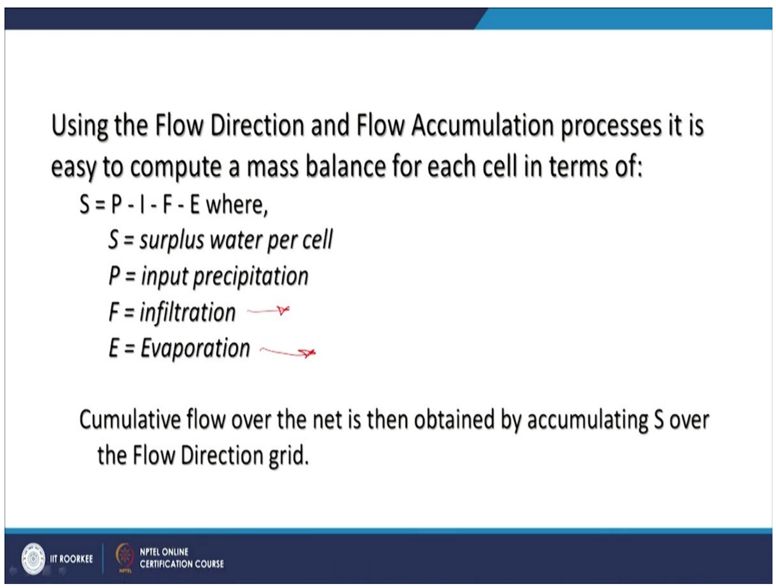

So, employing two themes together; flow direction and flow accumulation processes, it is easy to compute a mass balance of each cell in terms of S = P - I - F - E where S is surplus water per cell, P is the input precipitation, F is an infiltration and E is evaporation. Because more the realistic picture you want in modelling or better protection, you have to bring other losses of the water.

And here it is coming in from evaporation or evapotranspiration which is going to the atmosphere. Infiltration which is going downward towards the ground water and of course input is also there. So, this accumulated flow over the net is then obtained by accumulating S over the flow direction grid, this S.

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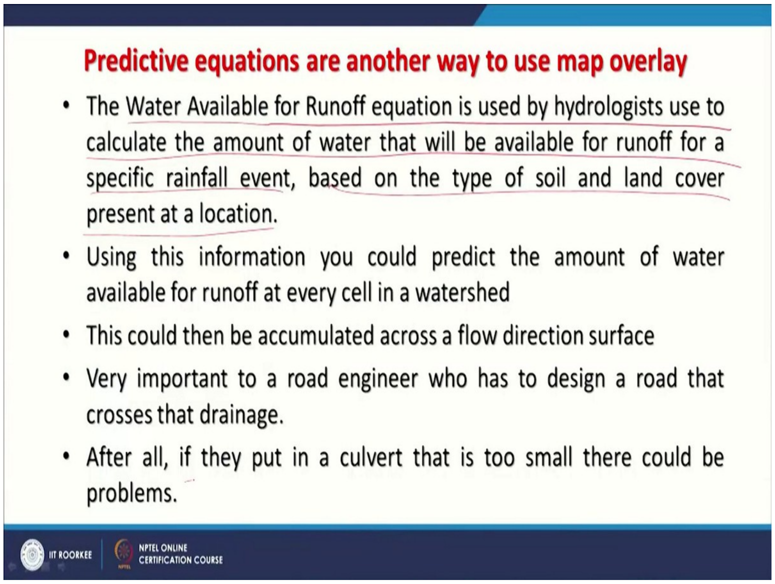

Now predictive equations are another way to use for map overlay depending on for what purpose. If I want to calculate the water availability for run off equation is used by the hydrologist to calculate the amount of water that will be available for runoff for a specific rainfall event, based on the type of soil and land cover present at a location. And this information can also be used to predict the amount of water available for runoff at every cell in a watershed.

And this could then be accumulated across a flow direction surface. And very important to the road engineers who has to design a road that crosses that drainage because in flood events, the minimum damage or no damage should occur and therefore in the design while designing this thing, either small bridges or culvert or whatever, these things should be kept in mind. After all, if they put in a culvert then too small there could be a problem.

So, if estimation has been done properly through surface hydrological modelling, then a proper design of culvert will come or a bridge.

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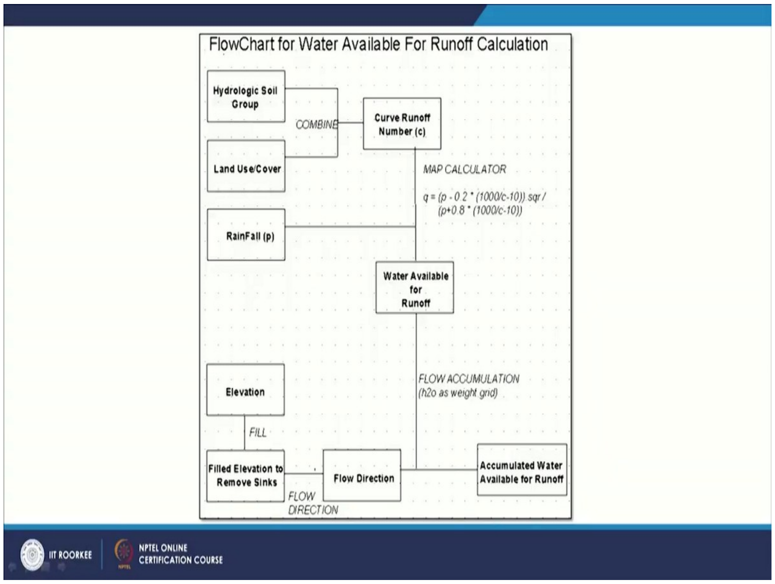

Now how you will calculate the availability of water for runoff calculation which accurately if you want then you have to bring the hydrological soil groups as one of the inputs, land use land cover map, rainfall precipitation data and all these will be combined then you will have the curve runoff number, surface runoff number (SCN) method. And then you will have the water available for runoff and your elevation; that is the digital elevation model, filled depression sinks, flow direction which is also combined and finally you come to the accumulated water available for runoff.

So, these calculations are very-2 important from flooding or other modelling point of view. There may be many other types of hydrologic variables that can also be generated using digital elevation model. In this course and in limited time, we have touched only few. When we started discussing digital elevation model, at that time, I mentioned that digital elevation models and satellite images are storehouse of information.

As we are moving and advancing, we are taking out many-2 other information's from these two major sources.

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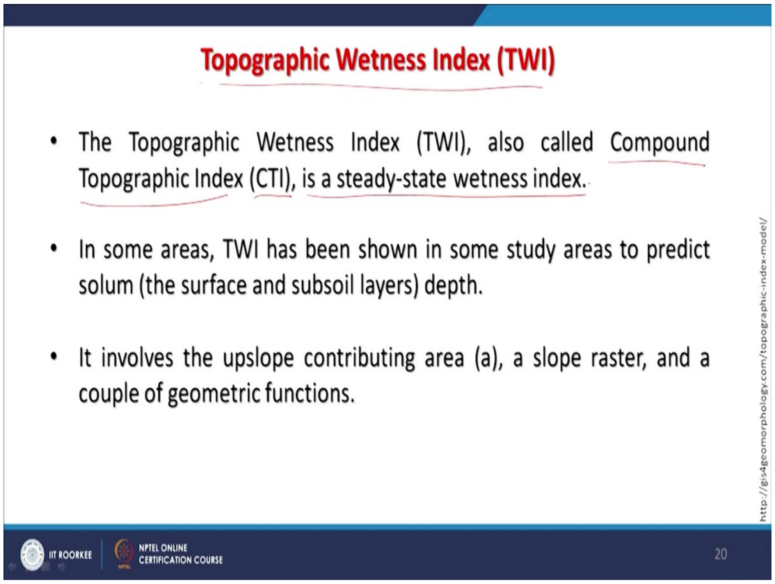

Flow direction grids are basis for a wide range of dynamic modelling tools where we keep changing as per the prevailing conditions, current condition, things can be. Now another derivative which is again important which is topographic wetness index; TWI. Again, it's an output of surface hydrological modelling using a digital elevation model which is also called as compound topographic index; CTI, it is a steady state wetness index.

And in some areas, this TWI; that this topographic wetness index has shown in some studies areas to predict SOLUM (the surface and subsurface soil layers) depth. And it involves the upslope contributing area; that is a, slope raster. Of course, you are already having a slope map and derive through a digital elevation model and a couple of geometric functions.

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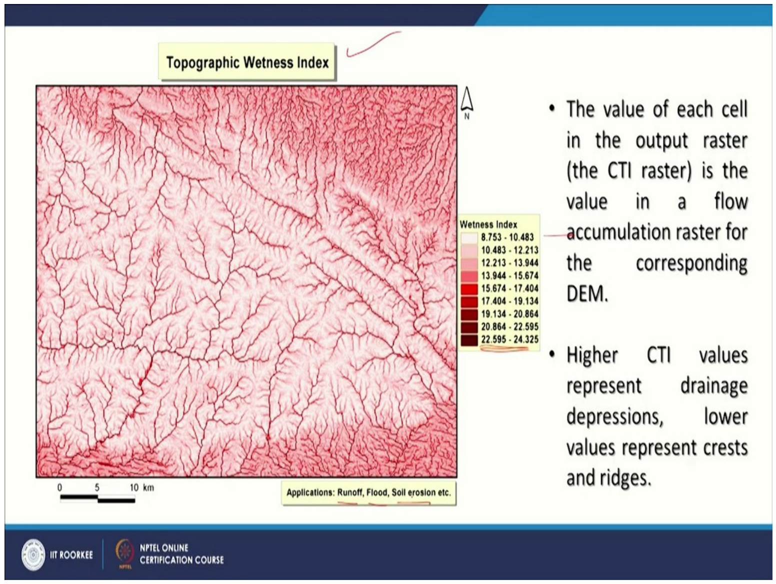

This is the output based on the same digital elevation model about that topographic wetness index. As you can see that darker here; the main higher order stream, you are having this wetness much high, naturally. And there are areas where the values are very less which are shown here in light pink colour. Application areas of topographic wetness index are runoff, flood, erosion etcetera. So, when you calculate the topographic wetness index, the value of each cell in the output raster of topographic wetness index or CTI is the value in a flow accumulation raster for the corresponding DEM.

And higher CTI or TWI means that values represent the drainage depressions. Obviously, these are the drainage lines which are so near in the dark maroon colour. Lower values represent the crest or ridges as you can see. If I draw here then roughly, these are the ridges which are here.

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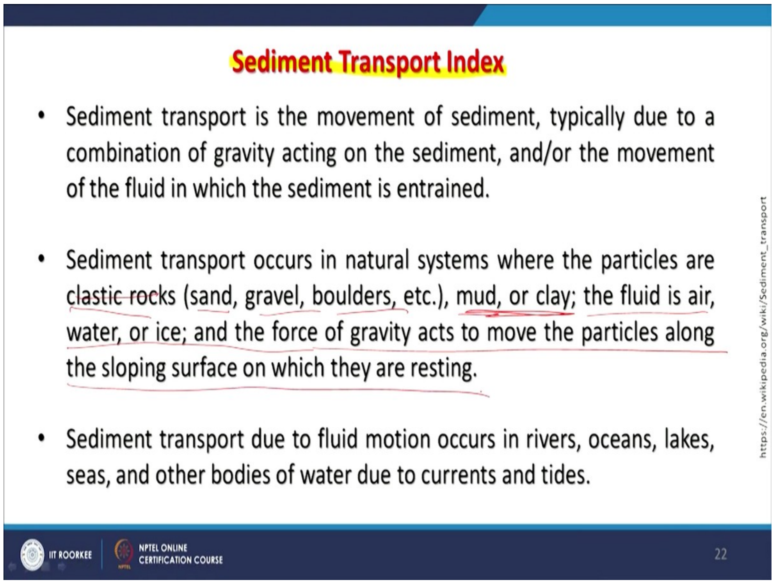

Now another derivative is the sediment transport index which is a movement of sediment typically due to a contribution of gravity action on the sediment and/or on the movement of fluid in which the sediment entrained. The sediment transport occurs in natural systems. So, in a natural drainage system, there will be some sediment. The density or turbidity may very but there will be some particles in suspended form or may role along the stream.

So, where particles are clastic-rocks (sand, gravel, bolder etcetera) or can be very fine one; mad or clay or the fluid in the air, water or ice force the gravity acts to move the particles along the sloping surface on which they resting. Sediment transport due to fluid motion occurs in rivers, oceans, lakes, seas and other bodies of water due to current and tides. In almost along water bodies or at the margins of water bodies, this transport of sediments can be visualized.

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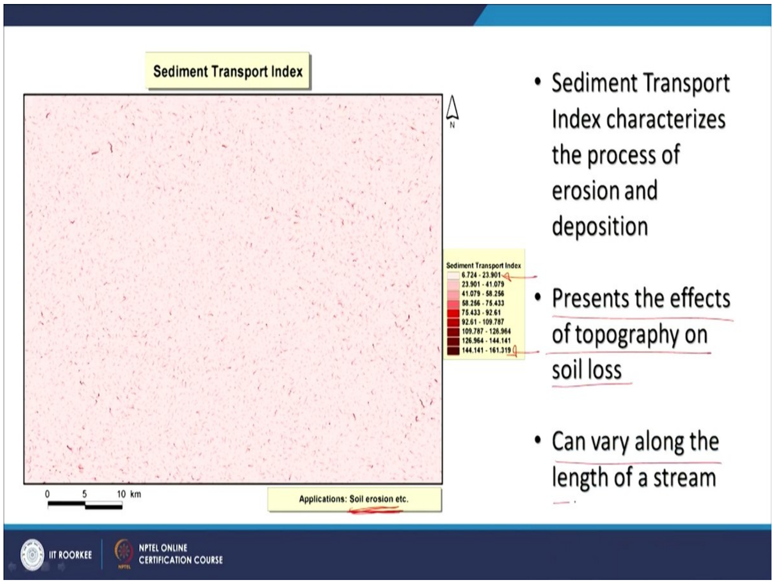

Now this sediment transport thing which is again the same input digital elevation model, you are seeing here. Light coloured one are showing the less index value and where the dark one is showing the high index value. And application of this is mainly in the soil erosion studies. So, sediment transport index characterizes the process of erosion and deposition. So, wherever you are seen all these dark areas, basically they are indicating the depositional area. So, presence the effects of topography on the soil loss and can vary along the length of a stream, of course.

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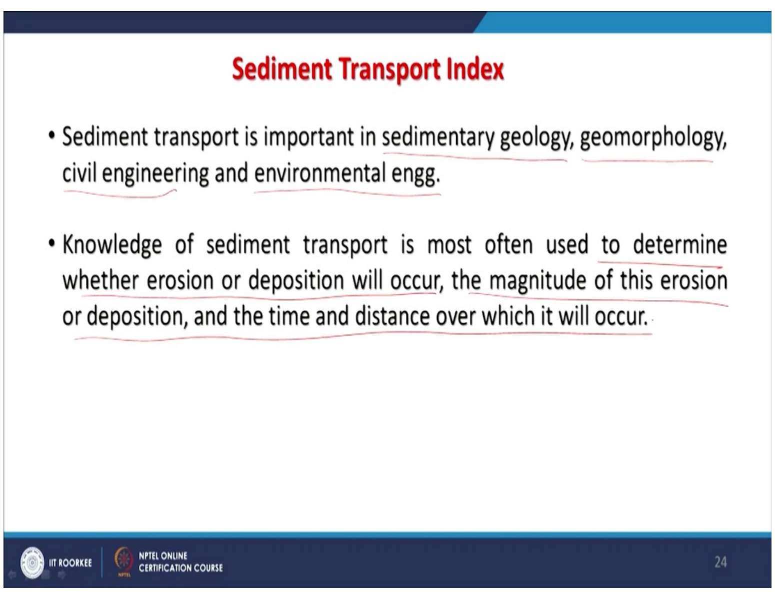

So, this STI; that is Sediment Transport Index is important in manage other studies including in sedimentary geology of part of earth sciences, geomorphology. Geomorphology and civil engineering; there is a link especially in hydraulics civil engineering with the geomorphology.

And also in the environmental engineering, the sediment transport, plays very-2 important role. So, this knowledge of about the basin or watershed if we are having about the sediment transport can be used to determine whether the erosion and deposition will occur.

And the magnitude of this erosion, deposition and the time and distance over which it will occur. Suppose on a Himalayan terrain, you are having a large reservoir for example Tehri reservoir. Now, you would like to estimate that what kind of sediment will be coming in the reservoir because you know that more the sediment will come in the reservoir and settle down, it will reduce the storage capacity of the reservoir.

And ultimately, it will reduce the power production from the reservoir. So, estimating sediment transport is very-2 important from that point of view.

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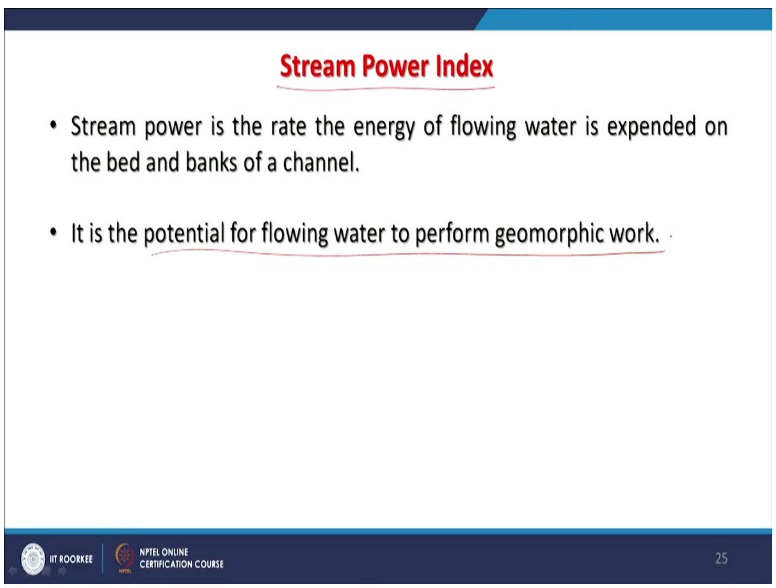

Stream power is another product which is the stream power index which is the rate the energy of flowing water is expended on the bed and banks of the channel. How powerfully? What is going to be the velocity or power of flow along the stream or in the margins or on the banks? And it is the potential of flowing water to perform geomorphic work. Geomorphic work; the basic work are erosion and deposition which create different landforms. And stream power can be calculated again using a digital elevation model, that is also one of the derivatives.

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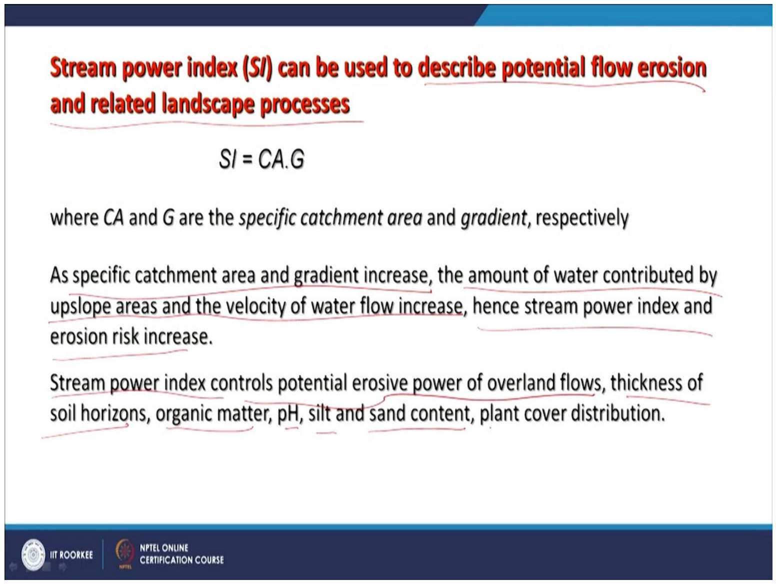

Now steam power index or we can also call as SI can be used to describe potential flow erosion and related landscape processes. This can be calculated SI = CA * G whereas CA and G are the specific catchment area and gradient repeated respective. So, a specific catchment area and gradient increase the amount of water contributed by the absolute area and velocity of water will also increase.

So, there is a direct relationship. Hence stream power index and erosion risk increases. Whereas the stream power index controls potential erosive power of overland flows, thickness of the soil horizons, organic matter, pH, silt and sand content and obviously plant cover distribution that will create impedance. So, for a realistic picture, everything has to be included including land use and forest cover and vegetation. Of course, slopes play also very important role and soil type and geology and another thing.

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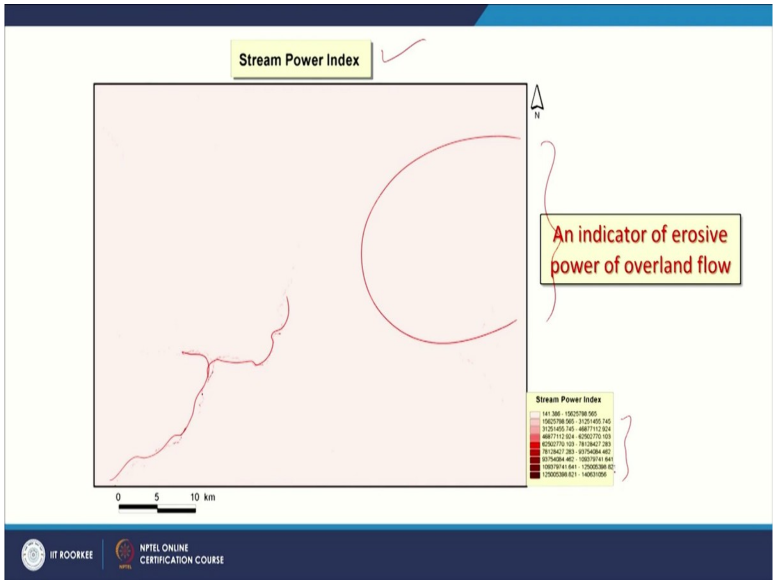

Now this is again same digital elevation model was subjected to stream power index. You can see that here; the steam power is very much high relative to other parts of this watershed. Here when we are saying visually, we are finding here that this area is having almost same value, it is not true. There are values which are varying if you zoom it and use an identification tool, you would find that each cell is representing a different stream power index.

So basically, stream power index is an indicator of erosive power of overland flow; that is surface runoff. That means we can drive lot of derivatives from digital elevation model. It depends on for what application I am working? If I am working for say for example soil erosion study, I will involve those kinds of derivatives. If I am working for this flood monitoring or flood forecasting then I will use those parameters.

But the input is one; digital elevation model basically and in order to have more realistic thing or modelling, we may include some other themes or inputs like land use, land cover and so on. So, this brings to the end of these two parts of surface hydrologic modelling discussion. With this, I end. Thank you very much.