Geographic Information Systems
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Lecture-53
DEM based Surface Hydrologic Modelling-1

Hello everyone! and welcome to a new discussion which is surface hydrologic modelling and this is part 1. Of course, the input is going to be the digital elevation model. So, this is also derivative of digital elevation model but through the surface hydrologic modelling, we can create several derivatives. So input is of course digital elevation model but this modelling concept comes from surface hydrologic modelling and again several derivatives we will have.

Starting from like watershed boundary, drainage network and sediment transport, density, yield and wetness index. Many such parameters which we can derive from surface hydrologic modelling. So, we will discuss in two parts so let us start.

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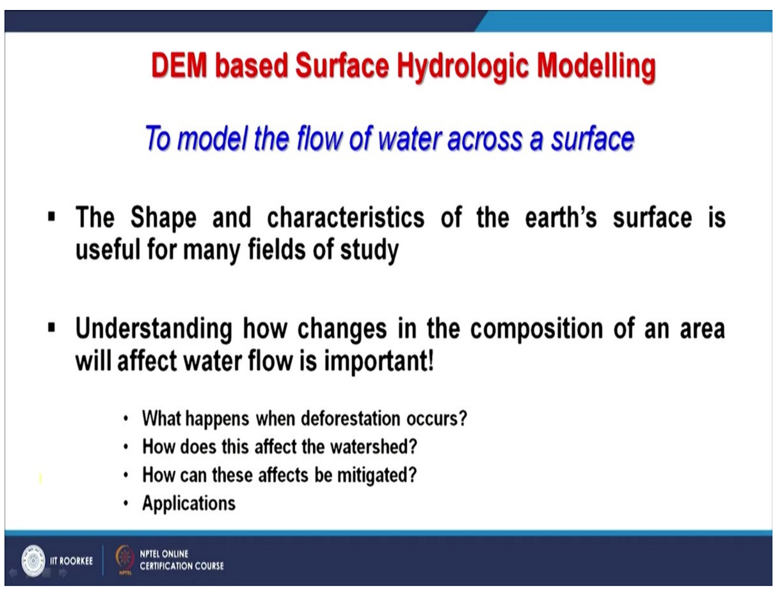

Now as you know that whenever we see word model; here 2 models, one is the digital elevation model and then surface hydrologic modelling. So, model means basically here the surface hydrologic modelling that to model the flow of water across a surface and surface here is digital elevation model. So, we are using one model to model the water flow over the surface and specifically I have used this term over the surface. So, this is important which we will come later in the discussion, why I mentioned over the surface?

Now as we know that the shape and the characteristic of the earth surface is useful in many fields of study especially like in civil engineering, in Earth sciences, in hydrology, in geography also and nowadays in environmental studies. So, these shapes and characteristics of the surface and which model or what is the data which can represent the characteristics, that is the digital elevation model.

And this understanding about the surface characteristics will also allow us to see how changes in composition of an area are taking place or will take place in future? And how water when it flows over the surface, how it creates different features or boundaries like waterside boundary and other thing? Which is of course a topographic boundary as well but the water flow or this plays a very- important role. Drainage network is also developed because of water flow on the surface.

So, we can try and what we will have through the surface hydrologic modelling using digital elevation model to answer certain questions like what happens when deforestation occurs? So, forest creates impediments in the flow of water over a surface. So, if plantation is removed or forest is removed, what would happen to that thing? You recall the very first discussion on GIS in this course; I showed one watershed through two different pictures.

And there I showed that if in one area, the forest is removed; deforestation takes place then what is going to happen to the soil moisture condition in that particular watershed? And in the second scenario it was that if at another place, the same equivalent area of forest is removed then that scenario will change. So, different conditions will bring different results. And many such things can be simulated, modeled, predicted before anything really happens on the ground.

So, your GIS, your Digital Elevation Model and surface hydrologic modelling; all will allow us to predict or see or visualize what would happen if any action is taken on the ground. Now, how does this affect the watershed? I have given the example that if deforestation occurs, it affects the soil moisture condition. And if soil moisture condition is changed, it will bring changes in soil erosion. It will bring changes in groundwater conditions and many other things.

So, any change on the surface of the Earth which takes place in terms of vegetation or drainage or change in elevation, all will bring changes in some way or another, may be immediately or may be after sometime, depends what action is being done on the ground. And also, we can answer through the surface hydrological modelling that how can these effects be mitigated. How we can minimize the impact if at all the development because development should not be stopped, it has to take place.

And the same time, we have to take care about the environment and surface of the land. So how best we can bring a scenario where minimum damage occurs to the environment? So that can also be modelled through the GIS and surface hydrological modelling. And therefore, this combination of digital elevation model and surface hydrologic modelling in GIS has brought many applications which we will see.

Even how these will affect the groundwater conditions or how we can think or visualize the groundwater conditions or changes in groundwater condition can also be there. So, not only in civil engineering, in hydrology, in earth science but in various domains these applications are there. Now before we really go for this surface hydrological modelling, we have to understand how water flows on the surface and how it develops the drainage system because the surface runoff is not uniform throughout the surface of the Earth.

So, it basically develops the drainage system or river network or stream network. So, basically what it means that the area upon which water falls, basically this includes all kind of forms of water. So, in total, we say precipitation and when we see rainfall, it means only water in form of liquid. So, whatever the precipitation which occurs on the surface of the earth, ultimate it will go through or move through the network which is our drainage network and through which it travels to an outlet, that is a watershed outlet or basin outlet.

And entire this thing when it happens, is called the drainage system. So, flow of water through a drainage system is only a subset of what is commonly referred as part of hydrologic cycle because hydrological cycle is big. Even the water which is going through evapotranspiration and then it goes in the atmosphere. It condenses, rain occurs or precipitation occurs. And then again, it flows so hydrological cycle is very big.

But there is a contribution of drainage system to hydrologic cycle. And whatever is the part of hydrologic cycle which also includes as I mentioned precipitation, evapotranspiration and also groundwater flow. Surface hydrologic modelling basically focuses on the movement of water across a surface or over the land. How water will flow? How the surface runoff will occur? Now further in order to develop our basic understanding before we go for real surface hydrologic modelling.

We also have to understand drainage basin or drainage system is an area that drains water and other substances to a common outlet. Now other substances might be your sediments very common other substance, may be pollutants or may be other like wood and other materials. So, all these are carried through this drainage system by the water.

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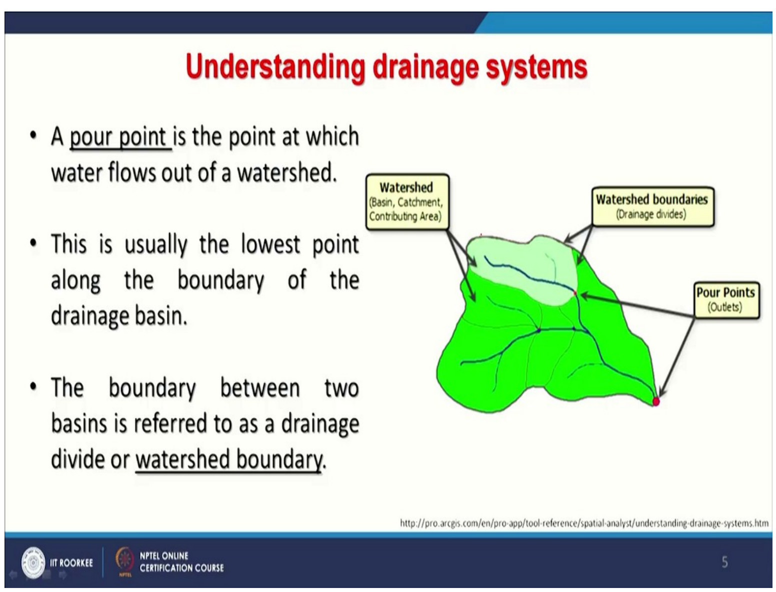

Here some terminology which we will be using so those who are not familiar about this, for them it is fresh but those who know, it is refreshing for them that the important point here is this outlet of the watershed. And this topographic high which is creating a watershed or topography boundary is called basically watershed or drainage divides; it also called drainage divides. Why drainage divide because whatever the drainage network which we are seeing, is all contributing to this outlet.

And interesting part is that one watershed ends, another watershed starts over the land. So, over the entire globe, this is continuous. The size and shape of watershed may change, that adjacent watershed may have a completely different shape and size. But one watershed ends, another starts and all over the land of the Earth, this is true. Now watershed but same time, we also use some other words like basin and catchment.

All are contributory areas. Basically, what they are doing? There whatever the precipitation occurs in this drainage divide or topographic high area which is depicted through this watershed boundaries, whatever the precipitation will occur within the boundary has to come out from this pore point or outlet. There may be some loss of water into the atmosphere through the processes of evapotranspiration or there may be some loss of water into subsurface through ground water.

So, if we exclude those and whatever is surface runoff which will occur which has to come out from this outlet. Now within a watershed, we can also have sub-watersheds like here, it is soon in a light green colour. So, each drainage line or a stream can have its own watershed. For example, I do not do currently the topographic map or this digital elevation model in the background.

But if I decide that this is my outlet then this can be my watershed like this. And if I decide that this is the outlet then this can be my watershed. So, as you go lower and lower towards the outlet, the waterside or sub-watershed becomes larger and larger. And as I go higher and higher in the order of stream. This we say first order of stream, we will have full discussion on this. So, if I decide my outlet is here, this watershed is going to be only this much.

So, within a watershed, we can have many sub-watersheds. Now other common terms for drainage area; I have just mention that watershed, basin, catchment or contributory area. Whenever we use word watershed or catchment; catchment is used in other domain also and can bring some confusion also but when we say watershed, it is the really related with hydrology. And whenever we say watershed, it means we are not talking of very large area.

And when we say basin, we are talking about a very large area. For example, we will say Ganga basin; we will not say Ganga watershed or Ganga catchment. So, there is some difference but there is no quantity attached to this that if a watershed is more than 100 square kilometers, it would be called basin. There is no such classification. So, generally for relatively smaller size, we use words either watershed or catchment.

And when it is a very large area, this watershed then it becomes basin or contributory area also. In a canal system, we will call them a distributary area or command area which is just opposite to the watershed or basin. So, this area that is the watershed area commonly or normally defined as the total area flowing to a given outlet or pore point.

Now pore point, I have just explained that is the point at which water flows out of the watershed. So, it may go out of one watershed but may enter in the larger watershed or a larger piece, till it reaches to the sea. And this water outlet is generally or usually the lowest point along the boundary of the drainage basin. It has to be the lowest so whatever the precipitation occurring will come out through this outlet.

And the boundary between two basins or the watershed is defined as a drainage divide or watershed boundary. So, if this is the boundary and if the rainfall occurs here and surface runoff occurs, it will come out from here. But if rainfall occurs there then there will be another watershed and the outlet might be in this direction so that will come out like this. So, this way comes the outlet. Basically, it is also the precipitation which falls whatever in the boundary will come out through surface runoff.

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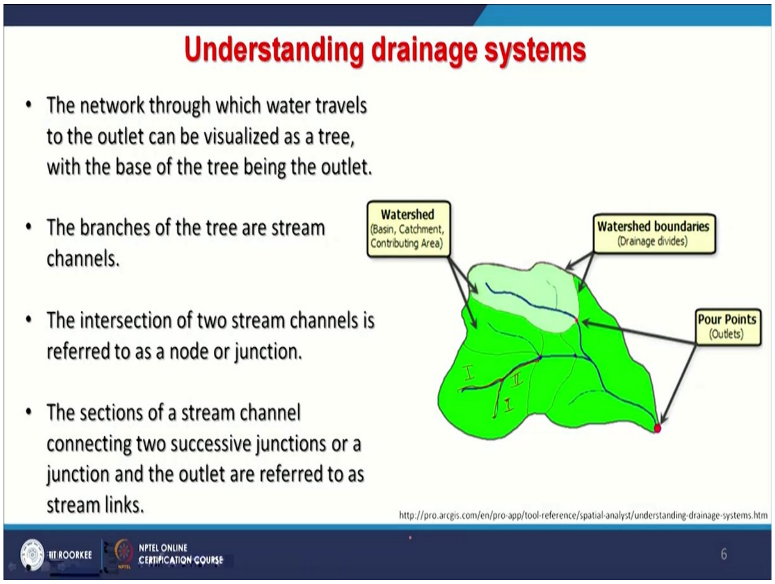

Now this drainage network or stream network which we seen in the form of, generally they are represent in maps in blue lines or black lines. This drainage network through which water travels to the outlet can be visualized as a tree with the base of the tree is at the outlet as you have also seen here. Like what you see that this is my base of tree. And these are the branches which are lower order stream.

Now the branches of the tree are the stream channels and the intersection of two stream channels is referred as a node or junction so in GIS. So here, this may be one stream, say 1st order stream. And this is for also 1st order. Now 2 first order system meets in one scheme, they become 2nd order and likewise we keep adding. So that means the intersection of two stream channels is referred as a node or junction or for downstream, it may become other order.

And sections of a stream channel connecting two successive junction or junctions and the outlet are referred as the stream links. These stream links are very important while deciding order of the streams. So, through surface hydrologic modelling, that derivative can also come that whether streams are following. There are two well-known well-established methods; whether is stream method or Shream method which we will discuss later.

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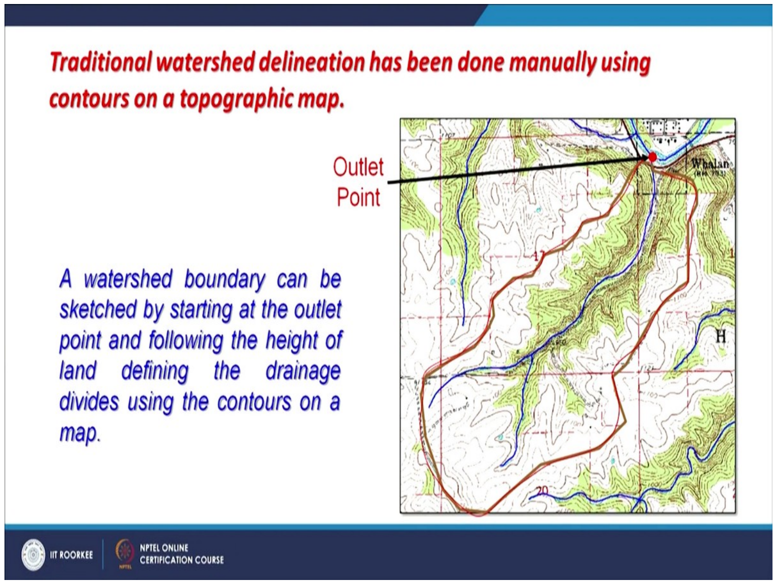

Now as I have been saying it's a topographic divide; watershed boundary also a topographic divide. So, if you see a map which is it topographic map and wherever you are having higher points or contours are having like this or spot heights are also there then, that becomes the watershed boundary. So, using a toposheets and with some care, we can definitely draw a watershed boundary quite easily.

But if you are having GIS and digital elevation model, we can do all these things very accurately and automatically through the surface hydrological modelling. So, traditional watershed delineation which we have been doing earlier when we did not have the GIS and digital elevation model like today, by using contours on a topographic map. And watershed boundary can also be as sketch. How you start doing or drawing on a toposheets that first you decide which is going to be your outlet like in this case.

And then you start searching a boundary or that is through your contour line or a ridge and by which then you complete the entire watershed boundary and you come back to the same outlet.

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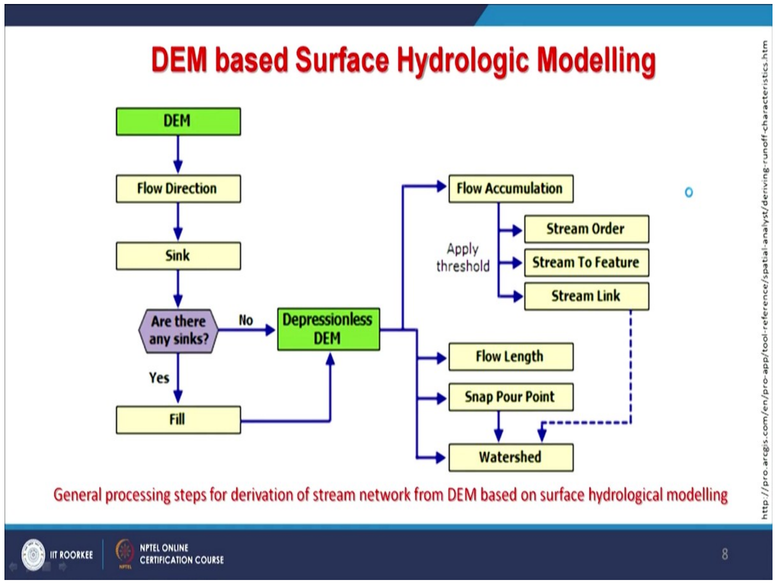

Now, let us discuss surface hydrology modelling. So far, we have developed some basic background about some you know terms which we will be using here. Now this first and the only input basically required initially, is the digital elevation model. Interesting thing here is that surface hydrologic modelling is more or less sequential. So, in that way, it is very simple to understand. And second and most important thing in surface hydrologic modelling is that we are having one assumption; a belief.

Assumption here which is very big assumption. The assumption is that whatever the precipitation will occurs, it has to come out through the outlet. And that means we are assuming that there is no loss of precipitation or no loss of rainwater; neither to the atmosphere through this evopotransmission nor through the groundwater. So, whatever the water even a single drop if it falls in a watershed, it has to come out of your outlet or out of your watershed.

This is the only assumption in surface hydrology modelling. So input is digital elevation model. The first thing which we do generally is we drive the flow direction. Flow direction is more or less like your slope map. Then we identify the sinks. Why sinks because this is what I just mention about assumption. The sinks are the depression artifacts, error within the digital elevation model. So again, a 3*3 kernel will be used. And if any cell is found that water will not flow out of that cell then it is labelled using the surrounding 8 cells values.

And it is labelled, that mean the sinks is filled. And that means the water then will flow otherwise there will be stagnation of water in that lowest cell, out of 8 surrounding cells. So, sink identification has to be done. I will show you some images also or DEM with sinks and then once you have identified the sinks, you are already having one output which is flow direction. Now, you have to fill these things, no problem! There are algorithms.

The software is there and very easily, you can fill the sinks. So, now you are having a digital elevation model which is devoid of sinks or depression which you have already identified and filled them. Now your digital elevation model after this sink fill becomes depression less DEM or sink proof digital elevation model. Now this will go for further processing and the next step to calculate flow accumulation.

Once flow accumulation has been calculated. What exactly flow accumulation is? How and what is flow direction? We will be discussing subsequently within this lecture or in next one. Now using this flow accumulation, one can drive stream order using 2 well established methods. You can drive stream to feature; that means the drainage network in vector form, in polyline form. Also, you can drive stream link which are again very useful for flow modelling point of view.

Further using this depression less digital elevation model, you can calculate flow length. You can also get a snap pore point; that means manually wherever you will click, a watershed boundary can be delineated. And then finally you can for your input digital elevation model just giving the threshold value, you can delineate watershed whichever the present in your digital elevation model.

The only problem which you will face in the boundary area because as I said in the early discussion that one watershed ends, other starts. So, when you are having a boundary or a margin of a digital elevation model, there you do not get the watershed in the adjacent. So only that part will have a limitation, not really error but the limitation. Otherwise within the digital elevation model, you derive watershed of your desired size, that would be decided based on the threshold value and that is basically the area which you give.

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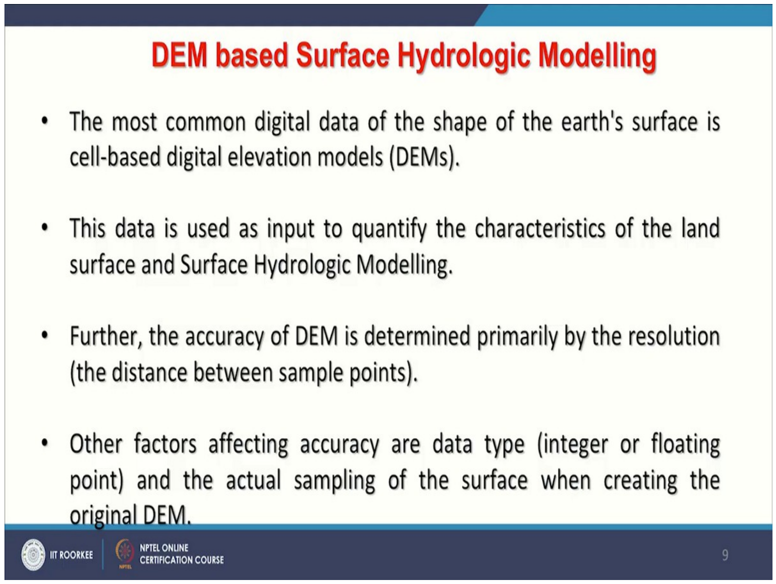

Basically, this surface hydrologic modelling as you must have realized by now, is a sequential model means step by step, you can do it quite easily. Now as you know that the most common input is going to be a digital elevation model. And we have already developed the understanding and this data is used as input to quantify the characteristics of the land surface and how water will flow and that can be modelled through surface hydrology modelling.

Now here the accuracy part will play very important. If your digital elevation model is good; good means quality wise, accuracy wise then obviously you would have better results. This is true in all the cases. Now other factors which will affect our accuracy are like whether your input digital elevation model because it is a grid so you can have a cell value as integer or floating point. Floating point since it is having high precision and therefore the accuracy of your output is going to very high.

But if you are having input of digital elevation model and cell value is an integer that means generally, these are in meters. So, you will have the least count is 1 meter and therefore the accuracy will affect so this depends. If I am creating my own digital elevation model then I should keep the cell value as floating point or real numbers.

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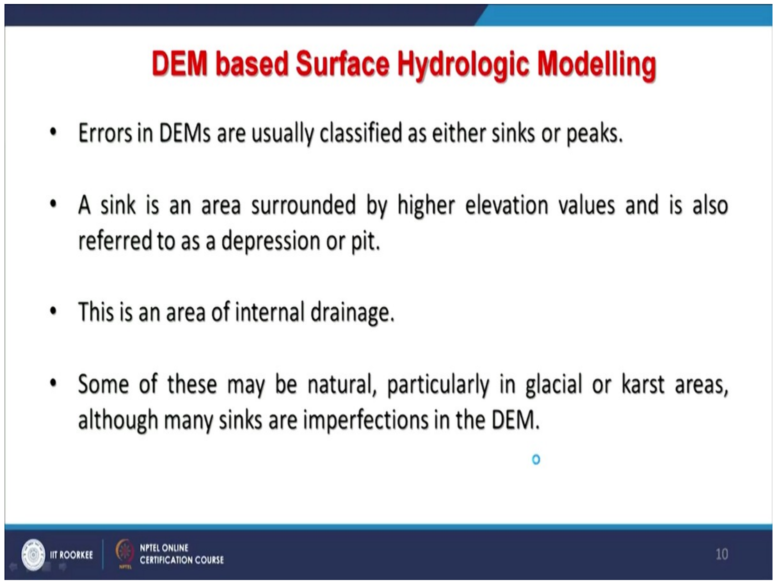

Now this one type of error which can be rectified by first identifying sinks or peaks or depression and then filling them. So, part of the problem is already solved and rest will depend basically on the spatial resolution part. And sink; I have already explained that sink is an area surrounded by higher elevation values and basically 3*3 kernel is used to find out the pit or sinks, depression and the centre cell is analyzed.

If 8 surrounding cells having higher value then the centre cell is identified as sink and later on you fill it. Because if it is not done then it will develop its own internal drainage and then whatever the precipitation which is occurring will not flow on surface as a surface runoff and neither it will come out through the outlet. In many cases you know generally, it will happen that whatever the precipitation is occurring, will form a surface runoff and ultimate will come out.

But there are many natural conditions which may not happen like this. If it is heavily forested watershed, there will be completely lot of delay. It depends on you know, what type of rocks are present, what type of geological structures are present and what type of soils are present, what type of vegetation is present? Any human activities and some other like whether is glaciated or not or snow covered or not, whether it's a karst area or not?

Karst area means limestone terrain because limestone terrain is generally having internal drainage. So on surface, you do not see the drainage but internal drainage. So there, the surface hydrological modelling may not predict as you wish to have because it will not follow that assumption. The assumption is that even a single drop of water if it falls on the surface in a watershed, it has to come out through the outlet.

So, in many conditions, this assumption is not fulfilled but nonetheless in many-2 conditions, it is fulfilled. Even if it is not being fulfilled still, we can exploit and see how it affects the groundwater which we will discuss little later.

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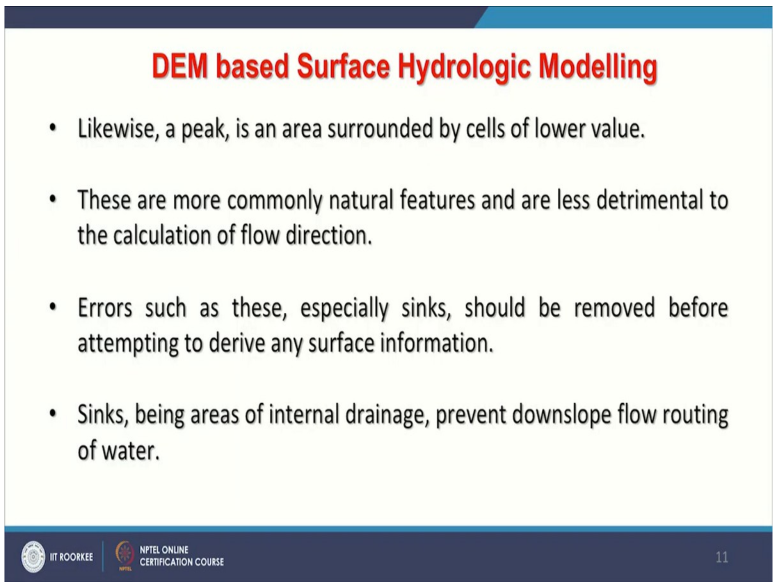

Similarly, when we identify sinks, we also identify peaks but peaks will not affect much in that way. But nonetheless in that process, everything is identified then it is made sure that whatever the water which is dropping on the surface in a watershed has to come out of the outlet. Now this flow direction; that these are the more commonly natural features and the area less determine to calculation of the flow direction.

And errors such as of these like sinks or peaks, should be removed before attempting to derive a surface information or before we go for next step in surface hydrologic model because water has to flow; that is the assumption. Just in one cell, it is become stagnated then it becomes a problem. So, sinks may be areas of internal drainage like I said in case of limestone terrain or can prevent down slope flow routing of water.

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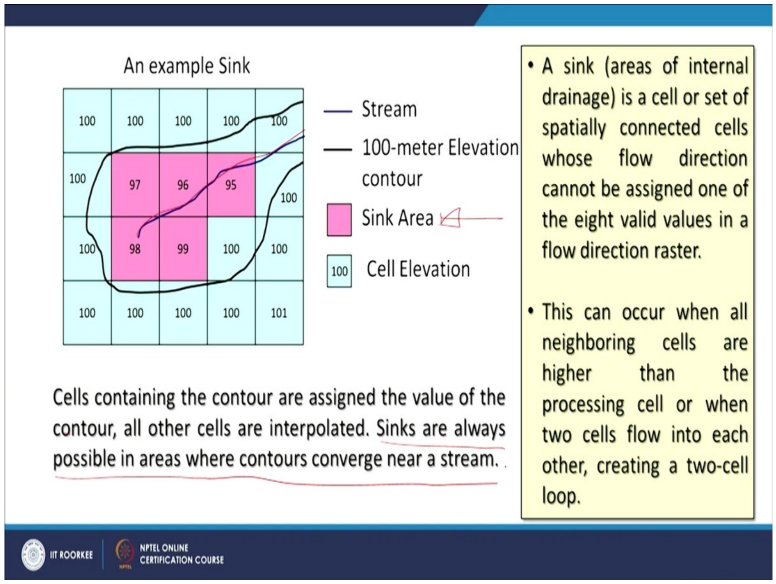

Now here is the example. There may be a single cell representing a sink or depression having multiple cells. In this example, there are 5 cells which are having depression. So, all surrounding cells here are having higher values then these pink-coloured cells. So, we identify them as a sink and rest as you can see the contour lines are also shown here, these are not watershed boundary, remind it. This is contour lines and stream network also shown here.

So basically, cell containing the contour lines and assigned the value of the contour, all other cells are interpolated in a manner that no sink will be there. So, sinks are always possible in areas where contour coverage near a stream. Now sink or areas of internet image is a cell or set of cells which are spatially connected cells and whose flow direction cannot be assigned.

So, for that purpose also, we have to do that part. So generally, in practice what we do that once we take the digital elevation model. First, we do this sink identification and filling then we go for flow direction and flow accumulation and other derivatives; that is always because if there is error, let us remove at the very first stage.

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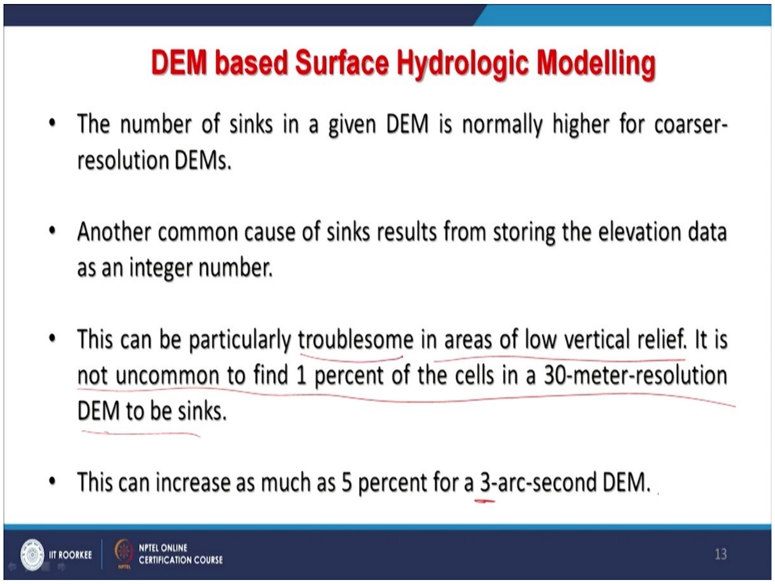

Now the number of sinks in a given Digital elevation model is normally higher for coarser resolution DEM. So relatively if you are having a course resolution digital elevation model, the area which will be covered by these sinks is going to very high. And in a high spatial resolution digital elevation model, it is just a reverse case. So, in this case for surface hydrological modelling if choice is there, it is always better to go for relatively high spatial resolution digital elevation model.

But as when we have been discussing the quality of a digital elevation model, we also discuss that high spatial resolution does not always mean a high accurate digital elevation model. So, this one has to also remember. Another common cause of sinks in a digital elevation model results from storing the elevation data as an integer number, not as a real number. And this can be more troublesome in areas of low vertical relief; that means the area which do not have many undulations and you may have problem.

Now it is not uncommon to find 1% of cells in a 30-meter spatial resolution DEM to be sinks but 1% is nothing in that sense. Now, this percentage can increase by multifold if we are having a 90-meter; that means 3-arc second equal to 90-meter roughly and 1-arc second equal to 30-meter so 3-arc second digital elevation models.

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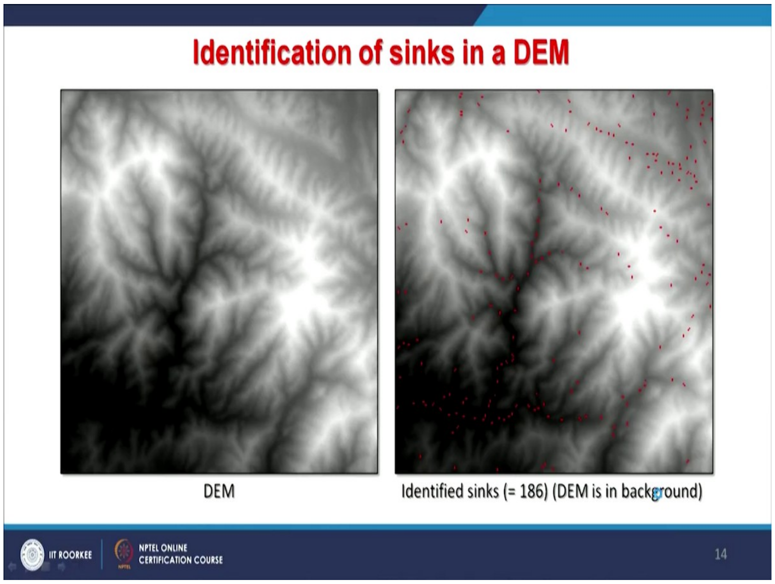

Now I am having an example on the same digital elevation model which we have been using throughout this course. So, this is the DEM and when DEM is subjected for identification of sinks. You can see the red dots; sinks have been identified. Some are single cell; some are having set of cells. So, identify sinks here. The total number is 186 whereas digital elevation model total number of cells are 99 time more than this roughly.

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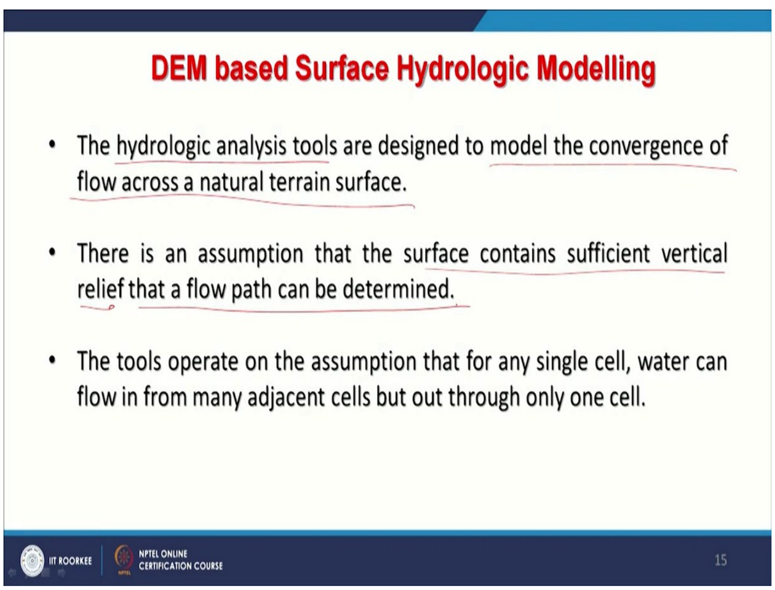

Now once we have filled the sinks then we come to the next step and that is your flow accumulation or before that flow direction. So, these tools; hydrologic modelling tools or hydrologic analysis tools basically have been designed to model the convergence of flow across a natural drainage system or terrain. And the assumption which I have already mentioned is that there the surface contains sufficient vertical relief that a flow path can be determined.

Whatever is falling in form of precipitation has to flow and it will create own path through a drainage network, in the form of drainage network. And these software tools operate on the assumption that any single cell, water can flow in from many adjacent cells but out through only one cell.

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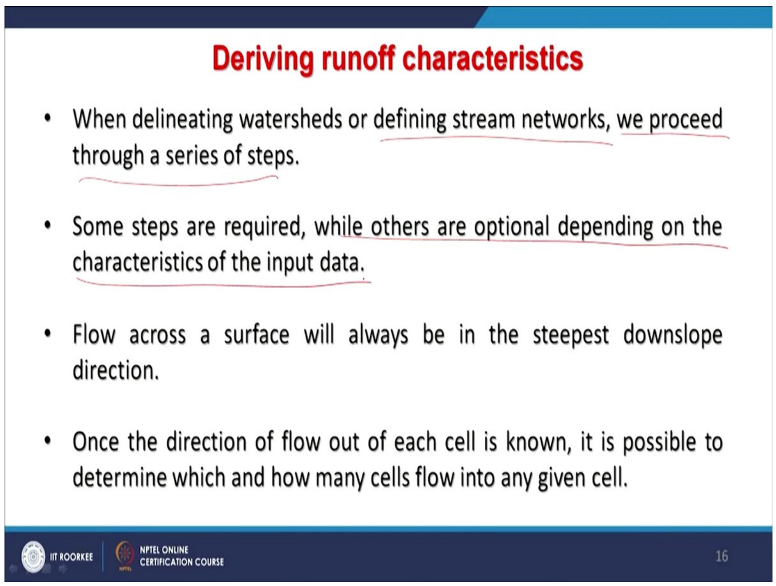

Now when we go for the delineation of watershed using surface hydrologic modelling or defining stream network, we process through a series of steps. That is why I said earlier that surface hydrologic modelling is a sequential modelling. So, series of steps; one by one, we will go. Some steps are required while others are optional depending on the characteristics of the input data and whether we really required those outputs or not.

And flow across a surface will always be in the steepest down slope direction. So whichever the cell is having more difference in terms of elevation, there the water will flow from the centre cell when we think in terms of that 3*3 kernel. Once the direction of flow is decided out of each cell in the known, it is possible to determine which and how many cells flow into any given cell. So, each cell has to flow out but in how many cells will flow out in one cell that will be also determine through flow direction.

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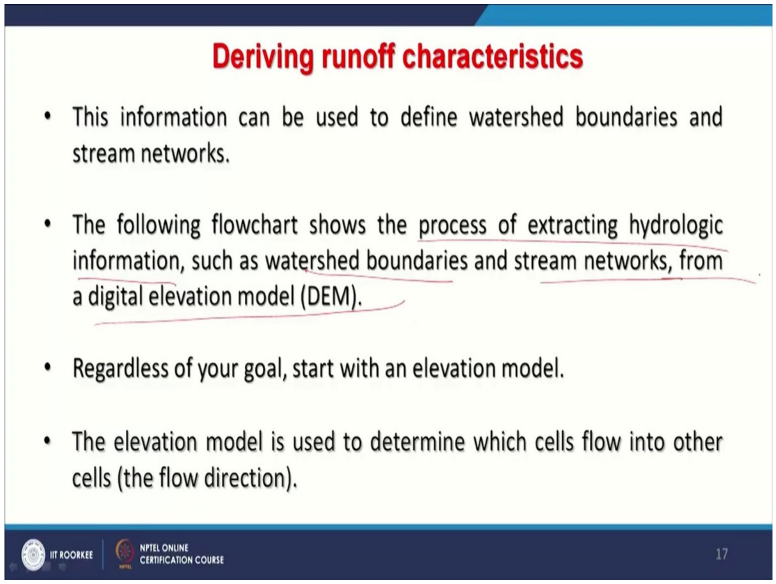

And the information then can be used to define watershed boundaries and stream network. So, these are 2 derivatives through the surface hydrological modelling, very popular one or you can say 1st order derivatives. So, the flowchart which we have discussed, again I am going to show which shows the process of extracting hydrologic information such as watershed boundaries, stream network through using a digital elevation model.

Whatever the purpose of using this surface hydrological modelling, the start point has to be always as a digital elevation model and identification of sinks and filling of the sinks. So, elevation model or DEM are used to determine which cells flow into other cells; that is flow direction. This is the flow direction which I am talking.

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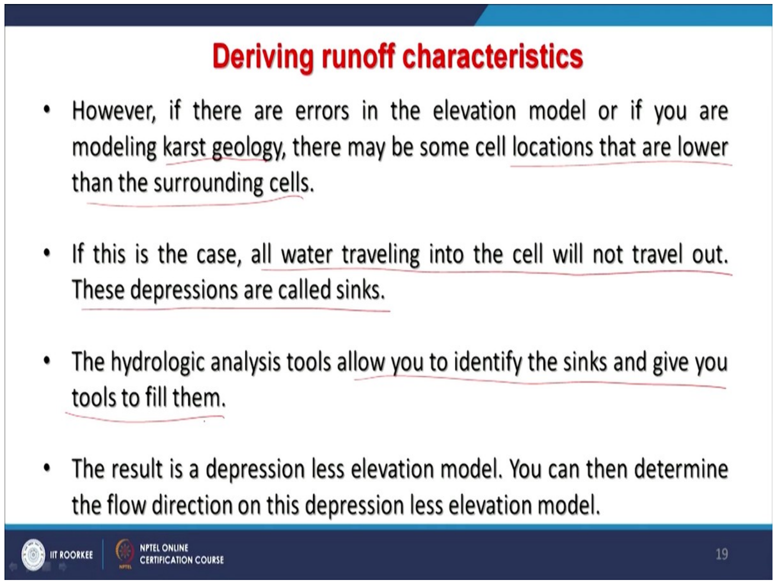

Now if there are errors in the elevation model which we have also touched upon this issue then like maybe a limestone terrain; a karst topography or karst geology, there may be some cell's locations that are lower than the surrounding cells and internal flow might be there. So, there is a limitation of surface hydrologic modelling; that means in those conditions, the surface hydrological modelling will be failed because the assumption is here that each and single drop of water has to flow as a surface runoff and has to come out of a watershed.

And if in case of karst topography, all water traveling to the cell will not travel out and if that does not travel out then the surface hydrology modelling will not work. So, our tools; this surface hydrologic modelling tools which are available in most of the popular GIS software will allow you to identify sinks and give you tools to fill them. I have shown the examples also. And ultimately then you will have a depression less elevation for further processing

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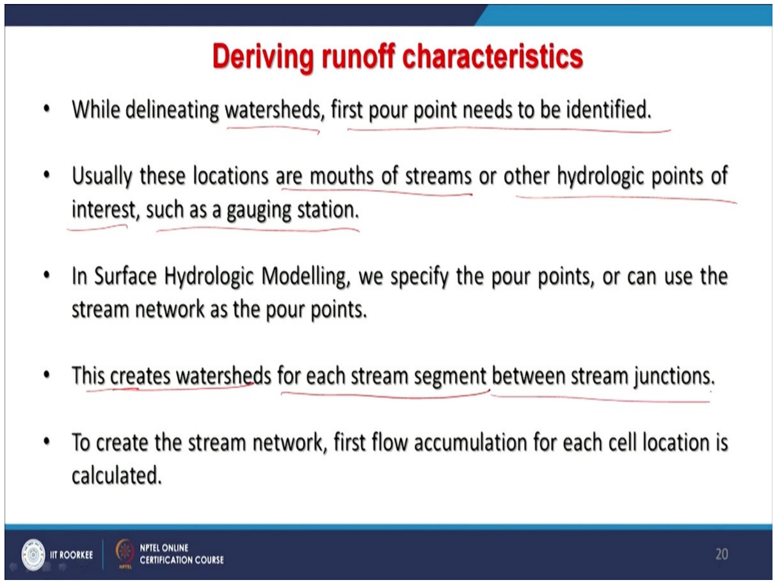

Now one of the derivatives of the surface hydrologic modelling using the digital elevation model is delineating a watershed; that is the first pour point needs to be identified for that. And usually these locations pour points, outlets are the mouth of the streams or other hydrologic points of interest such as gauging stations. So, in the beginning of this discussion when we have been discussing about this part, the terms which we going to be used about watershed, there we have already discussed this part.

And in this surface hydrologic modelling, once the pour point has been identified then the system will automatically delineate the watershed. Of course, stream network and other things will also be done. And this creates the watershed once you have selected a pour point for each stream segment; that means sub-watershed, you can go to a single stream between the stream junctions. And to create the stream network, the first flow accumulation for each cell location is calculated.

So, this is virtually the fourth step. The first step is to identification of sinks, filling of sinks, flow direction, now flow accumulation. Now in case of flow direction, how it will look in terms of digital values?

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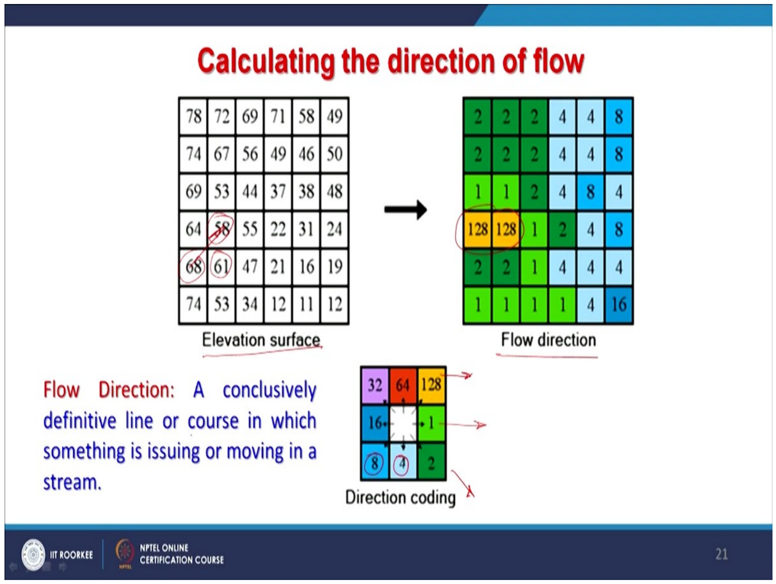

So here we are having a input digital elevation model. Here we are having this 3*3 kernel and a coding system. So, for each direction, we are having code 1. Though, it is a number but it is a code that means we will not do any arithmetic operations over the codes. For the southeast direction; The code is 2. For south direction; code is 4 and for southwest direction; 8 and likewise. So, when this 3*3 kernel moves all along over a digital elevation model, this is how it will have a flow direction.

So, 128 means it is flowing in the northeast direction. Now, let us see for these cells that here this is 58 and this is 61 and 68. So, 68 is very high among these so this will flow in this direction; that is in the northeast direction. Similarly, we can understand the others. So, flow direction while calculating, we use this concept of 3*3 kernel using codes. So, flow direction a conclusively definite line or course in which something is issuing or moving into a stream.

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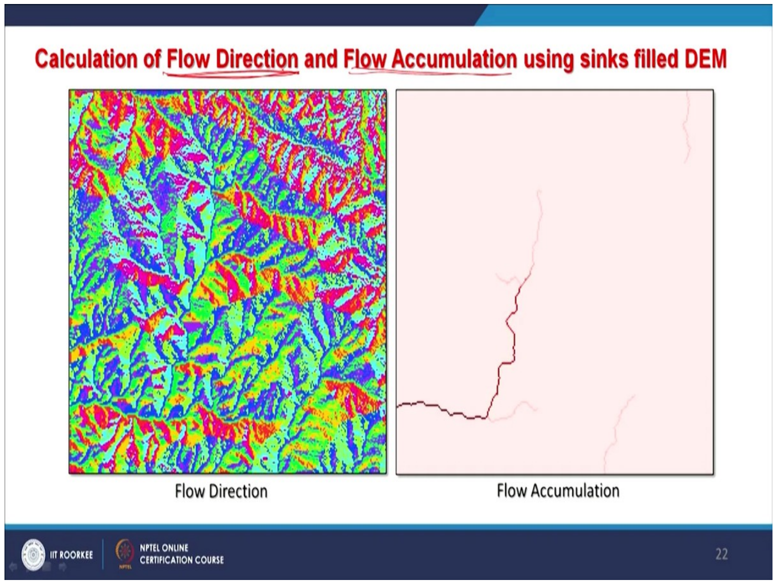

Now on the left side, you are saying a flow direction derivative through surface hydrologic modelling and on the right side, you are seeing flow accumulation. Though here, you may feel that only few lines in form of drainage are visible, rest is not there but each cell is having a value which you can check while zoom it and using identification tool. So that is why I said earlier also that the flow direction is more or less like an aspect map; very close to that concept.

But the coding part is little different because these numbers are required, not the northeast, southwest. These numbers are required in different calculations so that is why the coding system has been adopted for flow direction.

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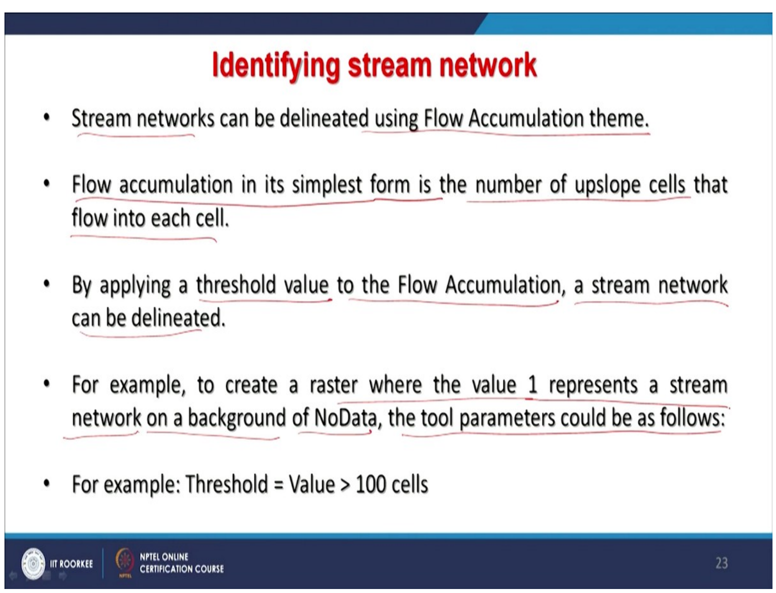

Now a stream network can be delineated using flow accumulation theme which is the fourth derivative. And flow accumulation in its simplest form, we can say that the number of upslope cells that flow into each cell because stream network will be decided based on the number of upslope cells. And by applying a threshold value that if 100 cells or 1000 cells are flowing from outlet, that becomes my pour point and then watershed boundary or drainage network can be delineated.

So, by applying a threshold values in terms of number of cells to the flow accumulation output or theme, a stream network or a watershed boundaries can be calculated. And for example, to create a raster where the value of 1 represent a stream network on the background of Nodata and the tool parameters could be as follows that for example threshold value equal to or more than 100 cells.

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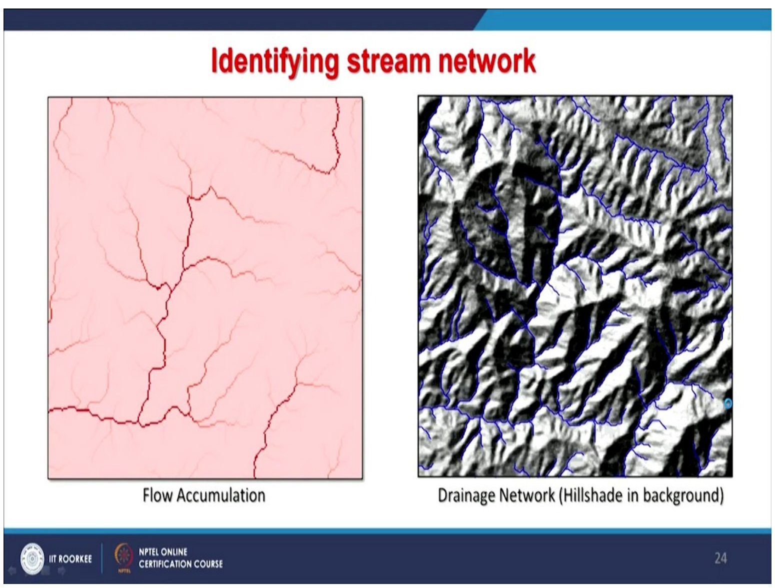

So, this is what it has been done. Once it is applied, now flow accumulation, you are seeing lot of drainage there. And using that I can identify this drainage so from raster, I can convert into the vector. So, the blue lines which you are seeing and in the background, you are seeing shaded relief model which is again derivative of digital elevation model. These blue lines are vector drainage network which has been derived through the same DEM through the surface hydrological modelling where the threshold value was kept at 100.

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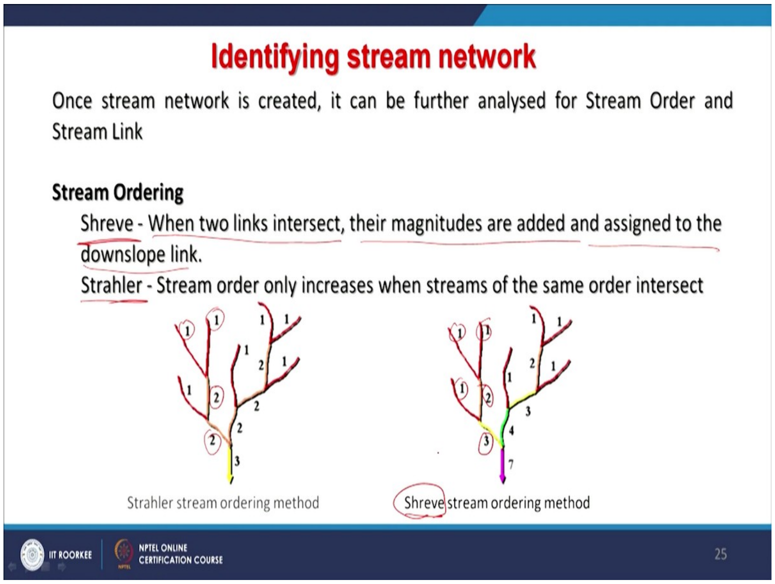

Now once the stream network is created, it can further be analyzed for stream order and stream links which are again useful in some other modelling. So, for stream ordering, Shreve methods and Strahler methods; 2 methods are well established. In first method when the two links intersect, their magnitudes are added and assigned to the down slope link like here.

This is the Shreve; the first method. So, 1st order, 1st order, it becomes 2nd order. 1st order and 2nd order, it becomes 3rd order. This is the Shreve method, the first one. And the second one is Strahler method where are the 1st order, 1st order of course become 2nd order but 2nd order and 1st order will remain 2nd order. And when two 2nd order streams meets then it becomes 3rd order, not the 4th order as in case of here.

So, there is only little different but the Shreve order is very simple and this is most popular. However, in good standard GIS software, both stream ordering schemes have been implemented. So, whichever you like most, you can use them.

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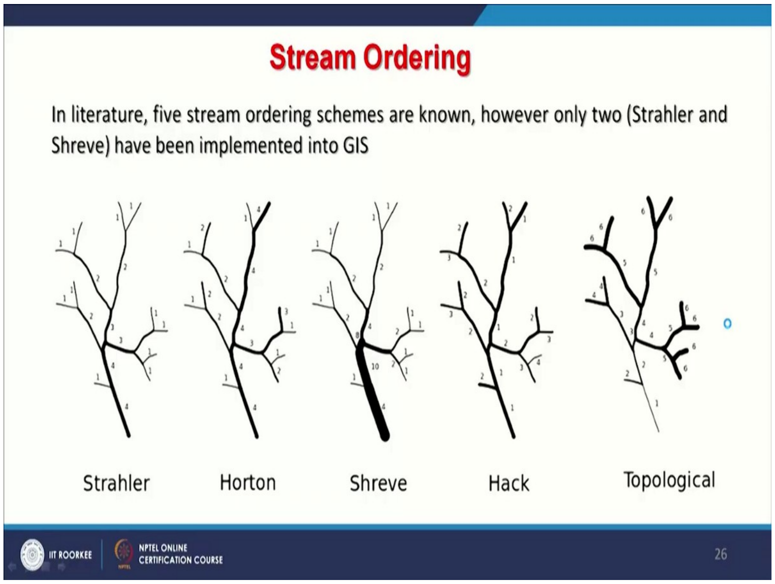

Now stream ordering as you can see there are other methods also. Apart from the Strahler and Shreve, there are methods; Horton. Horton is worked lot on in this because you have also seen new algorithm first slopes, aspect and other things. Hack method and of course a topological method; that is based on the topology. So, in literature, you may find 5 stream ordering schemes are known however as I have mentioned the in software's, only either Strahler or Shreve or both have been implemented, not many.

Personally, my choices for this Shreve method which I find is very simple. After all, we have to give some order. So let us take the very simple example.

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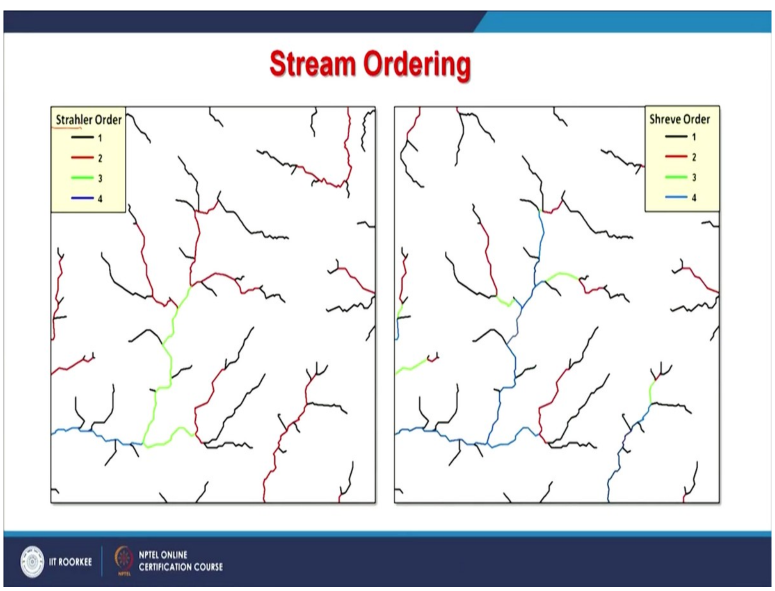

Now stream ordering has been done. The drainage network I showed which had the background of shaded relief model. Here stream ordering has been done. You can check using the Strahler method and for the same drainage network, it has been done for the Shreve. So, for example say this is 1st order and then there is also a small one so this will become the 2nd order. And then 2nd order, 1st order becomes the 3rd order. 3rd order and one more become the 4th order and likewise, you go.

So, in this example, only you are having pour waters. So, this is one you know like watershed boundary which we will discuss later. Stream ordering, stream network can be deriving. So, these are the few outputs which we get through surface hydrological modelling. Further output and further discussion, we will have in the next part. With this I end. Thank you very much.