Digital Elevation Models and Applications
Dr. Arun K. Saraf
Department of Earth Sciences
Indian Institute of Technology, Roorkee

Lecture - 15
DEMs Based Surface Hydrologic Modelling- 1

Hello everyone and welcome to Digital Elevation Models and Applications course and also welcome to the 15th lecture of this course. And this topic in on which we are going to focus our discussion is one of the very popular derivative of a digital elevation model which is based on surface hydrologic modelling which we will see how we can use this concept of surface hydrology modeling, using a digital elevation model and can derive various derivatives or various parameters of a terrain.

So, this is a very important and widely used approach to derive various parameters. When we go for this kind of a surface hydrologic modelling basically what we are simulating here is that the flow of water, across a surface or over overland flow of water. And this flow of water we can simulate and by while doing this we derive lot of derivatives from a digital elevation model. One assumption which we will be discussing also that here we choose this surface as a completely insulated surface and; that means, that whatever the water which will come in form of rain over the terrain has to flow on the surface. So, remember this assumption we may discuss again in later part when it comes they are also.

So, basically to model the flow of water across a surface and also as you know that the shape and characteristics of the earth surface is useful in many fields of a study and there this plays very important role that is the surface hydrologic modeling. And also it is important to know that how these things are changing a composition of a area and how it affects the flow of water. And what happens because we want to simulate the conditions that what happens when deforestation occurs or what happens when a forestation is done to the water flow or to the soil moisture conditions.

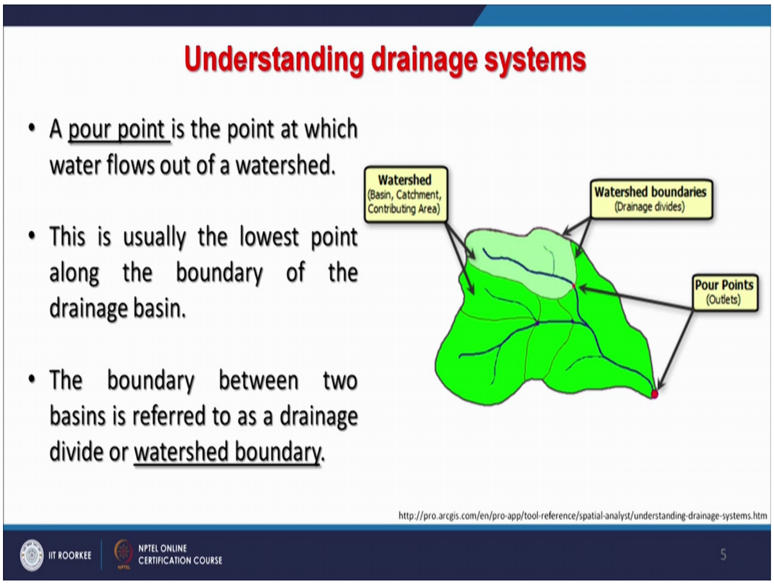
So, these things can also be modeled using our surface hydrologic modelling models you and based on a DEMs and how this can affect that a watershed level catchment level or a basin level that can be because these are the hydrological boundaries the watershed catchment or basin and therefore, generally when whenever we work for a problem which is related with the hydrology then we have to look for natural boundary rather than political boundaries. And also how we can mitigate a problem maybe a soil erosion problem maybe if flood problem or so on, these can also be there also we can use these approaches that is surface hydrologic modelling. There are various applications some of which we will be seeing in this discussion.

So, first before we proceed for a typical surface hydrologic modelling steps which is a sequential processing we would like to understand first the what is basically drainage system is. So, this is the area upon which water falls in a like a watershed boundary and the network through which it will travel to an outlet is referred as a drainage system. So, there is a network of drain lines starting from first order and stream through, second order, third order depending on the size of the basin or a watershed and the water which will come as a input as form of rainfall or precipitation has to flow through this network.

So, where it will flow exactly how it will follow this will depend on elevations and that is why elevation models are used alone for in surface hydrologic modelling to a derive drainage network as well and the flow of water through a drainage system is only a subset of what is commonly referred to as a hydrologic cycle. And because they say it hydrologic cycle encompasses the complete flow of water or movement of water through all processes, but this drainage system the flow of water in a drainage system is just a small part and which, but which is the hydrologic cycle includes precipitation evapotranspiration and groundwater flow. Whereas, in directly in surface hydrologic modelling we cannot handle like (Refer Time: 05:36) and transpiration issues or outputs or in or groundwater flow as well. But the overall this hydrologic cycle will include all these.

Surface hydrologic modelling that is why name says it only take care about the water which is flowing on the surface of a terrain on an area and a assumed assumption is that the every drop of water will flow over that as a surface runoff. So, this has to be remembered here. So, surface modelling focuses basically on the movement of water across a surface overland flow or surface runoff which we talk.

(Refer Slide Time: 06:30)



So, here we are having drainage basin or a one large one is there a watershed boundary is also there and in this schematic we are also having a drainage network and this is the outlet or also called pour point. So, for a larger basin the pour point is going to be here for a smaller watershed or sub basin it may pour point maybe in the upstream area and this says these are the boundaries which we call as a hydrological boundary rather than political boundary. These hydrological boundaries are based on elevations and this is what the surface hydrologic modelling exploits.

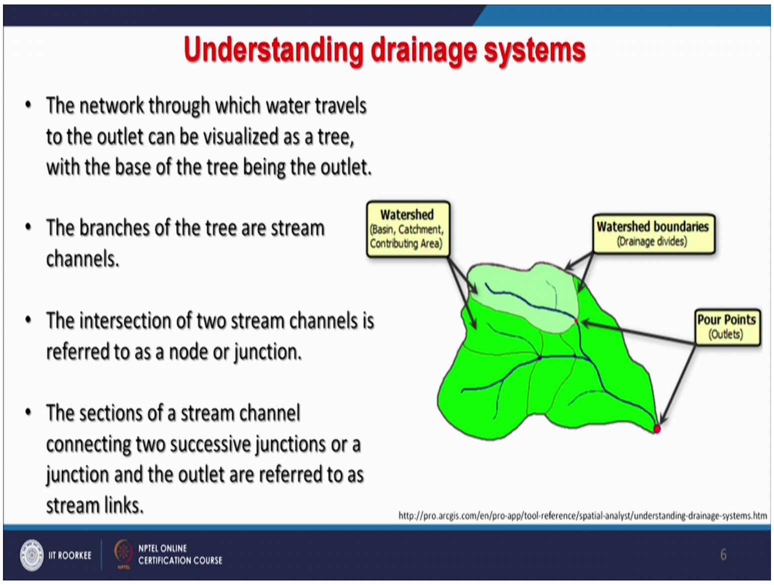
Basically because water will also flow through low elevation areas surrounding maybe you may be having higher areas, but water will flow through the always the low elevation area and to further low elevation areas and therefore, it will create a track and this is that we call as a drainage network. So, the drainage basin is in an area that drains water and other substances to a common outlet. These substances may be sediments, may be nowadays pollutants or other things as well. So, whatever is will flow, will flow through this in this drainage between at that particular outlet where we are deciding that this is going to be our outlet. In this surface hydrologic modelling a user can choose interactively where he is going to choose the outlet and according to accordingly a watershed boundary will be delineated.

There are other terms which are used for drainage basins, for example, unlike watershed basin a catchment or a contributing area. And opposed it to this as distributing areas which in civil engineering or in hydrology it is called command area for a canal network or some other thing, so it that is just opposite to our drainage basin or watershed boundary or watershed basin. And this area is basically normally defined as the total area flow to a given outlet of a pour point. So, the outlet is very important where we are choosing the outlet, if we shift the outlet at say this location then we may have a watershed of this much size, but if we go downstream for the choosing the outlet our basin or watershed will become larger and larger.

So, this has to remember the pour point is the point at which water flows out of a watershed. So, again as we have discussed that pour point from where the water will come or whatever the sediments and other things will come and this is usually the lowest elevation point of a along the boundary of a drainage basin. Note, we may not be exactly within lowest point within the watershed, but at the boundary of a drainage basin or watershed boundary and between two boundaries of or between boundaries of two basins it is referred as a watershed divide or watershed boundary as well. So, because topographically it makes a basically a ridge and that ridge will not allow water will allow water to flow either in one basin or one watershed or another one. So, that ridge subset divide and therefore, sometime people call as drainage divide what that also becomes watershed boundary or basin boundary.

Now, the network through which the water will travel to the outlet which is in this say schematic it is soon as he read points as either it is a large one or a smaller one and this network can be visualized as a tree with the base at the tree being at the outlet.

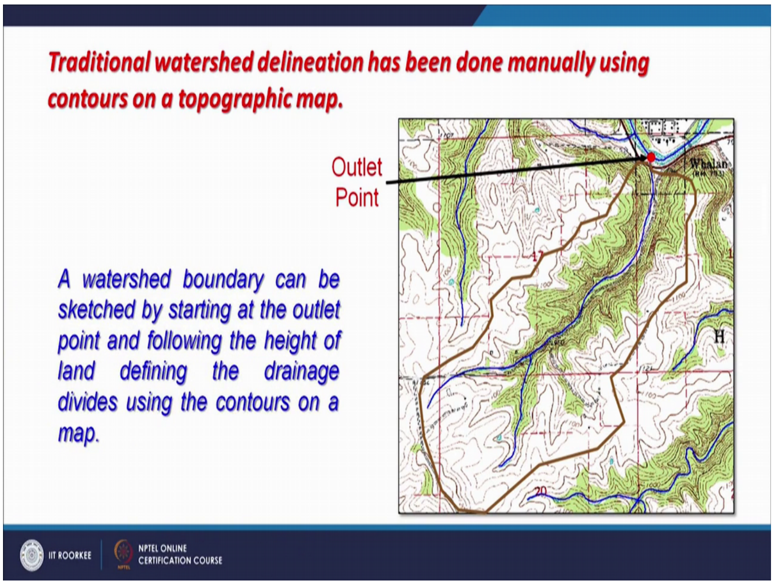
(Refer Slide Time: 10:30)



And they say there are though patterns are there, but we will discuss little later and branches of these trees are a basically these are the stream channels or a these are the drainage lines are there and the intersection of two streams channels is a referred to as a node or junction. So, if we talk in terms of vector data the same concept is used when two vector lines meets then we say node or maybe internode and other terms can be used. Similarly, here that intersection of two stream channels is referred as a node and the sections of a stream channel connecting two successive junctions or a junction and the outlet are referred as the stream links. So, these are important while doing surface hydrology modeling.

Now, here traditionally what we have been doing in order to derive the watershed boundary we used to have topographic maps and in which based on the contours we used to derive or delineate the watershed boundary.

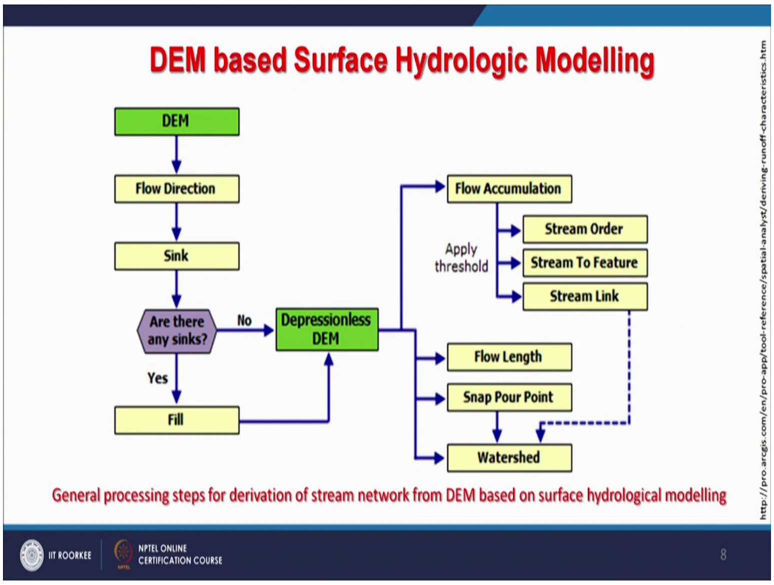
(Refer Slide Time: 12:00)



And this is once we decide the outlet, suppose outlet is decided at this location then delineation will start following the contours which are making the ridge and likewise a watershed boundary can we delineate it.

So, traditionally this is how manually this was being done, that we sketch throughout this thing following the watershed boundary, but in a on a GIS platform using a digital elevation model and employing surface hydrologic modelling we can delineate watershed boundary at any location within our digital elevation model and it is after certain steps of processing it can automatically be delineated if we decide the size of basin.

(Refer Slide Time: 12:23)



So, if we say that I am I want to delineate all watersheds which are having 500 area equal to 500 square kilometer or more then say then through surface hydrologic modelling this can be done automatically for a large area. Whereas, in manual method for individual watershed boundaries have to be delineated.

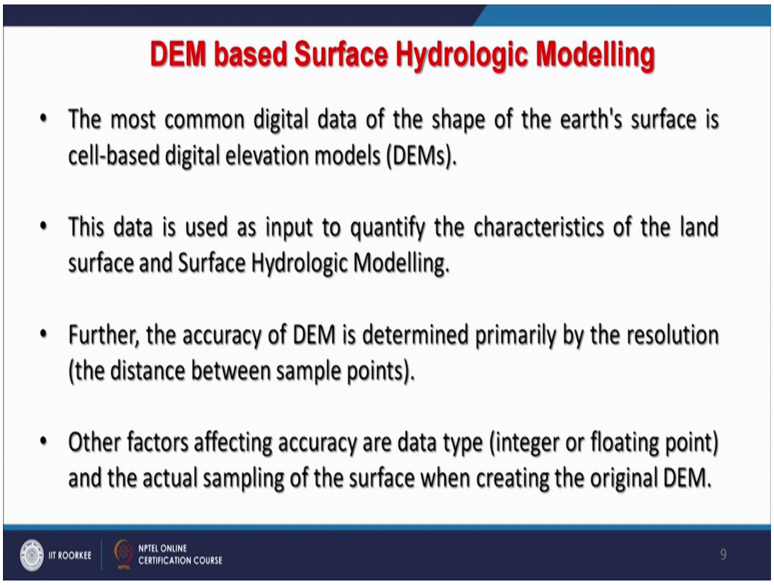
Now, we will go through one by one about this surface hydrologic modelling processes which are there as I have mentioned it is a most of the process are in a sequence. So, we will go one by one. Like first say generally what we do we take a digital elevation model and derive directly flow direction. And again using the same digital elevation model we can we can derive a find out where are the sinks or artifacts in a digital elevation model because digital elevation models may have some errors and why these sinks are identified or depressions local depressions of one cell size or maybe two cell size sinks are or depressions are identified. Because water has to flow on the surface it cannot remain intact or a remain on one place because this is what a in surface hydrologic modeling.

Say it is delineating or it is basically assuming that water has to flow on the surface a surface runoff and therefore, these sinks have to be identified and later these sinks if they are there these have to be filled. And once you have filled and then you are having a depression less digital elevation model. One output we have already created a flow direction and then we are having a depression less DEM.

So, these two outputs will allow us to create one more layer or theme which is flow accumulation and once we reach to this stage which is a very simple very quickly one can perform and can reach to these three products that is flow direction depression less DEM, this depression less DEM and flow direction goes to calculate the flow accumulation. This flow accumulation can be used to calculate stream order, stream and links and other things are therem it can also be used to calculate flow length in the pour point or a snap pour point and ultimately all these processor will lead to took delineate the watershed boundary.

For a entire area in one go depending on the size which we declare or we can choose a pour point or location of a pour point and as soon as we click then automatically the watershed boundary is deleted this I will be showing through few slides. And the basically the most common digital data of the shape of the earth's surface as we know is the DEMs and these DEMs we used and the data is this DEM as a input basically which quantify the characteristics of the land surface and surface hydrologic modeling.

(Refer Slide Time: 16:19)

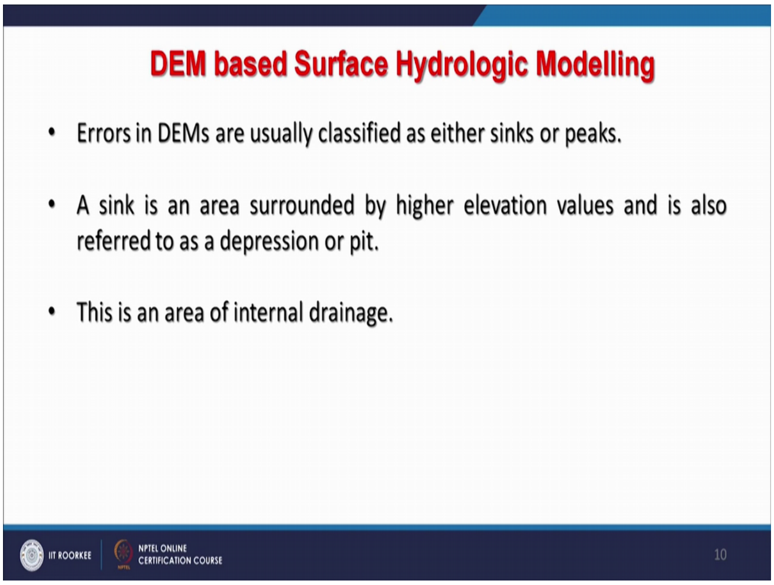


Further the accuracy of DEM it determined primarily by the resolution. So, higher always in for this kind of processing a better or higher spatial resolution DEM would give us the better results and the factors which basically affect the accuracy are the data type that is the cell values of a digital elevation what model whether we are having integer value or real or floating point value they will influence sometimes our results.

But generally in a digital elevation model we are having real values or floating point values and actual sampling of surface where this surface hydrologic model will be performed of a original digital elevation model. So, these things will influence our surface hydrologic modelling outputs.

As you know the errors in DEMs are usually as mentioned I can be classified as sinks depressions or maybe peaks, but for a very small area not very maybe one cell size two cell sizes not more than that.

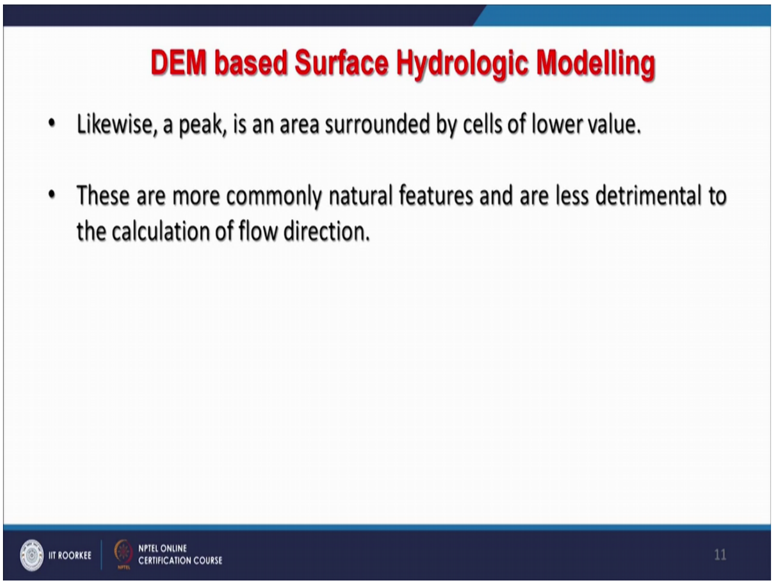
(Refer Slide Time: 17:46)



So, we consider them as and sinks and we identify them in the very first few steps and then fill that those sinks using the surrounding values so that the water can flow throughout the drainage system. So, sink a as I have said that is a higher area surrounded by higher elevation values or in case of depression or in a peak it may be a lower elevation values. And this is the area of an internal drainage because here the surface runoff has to be there and therefore, these have to be filled.

And when we are having a this digital elevation model which is depression less sink filled then it is ready for surface hydrologic modeling, and the you know these are more, these sinks are more commonly natural features may be sometimes depending on the terrain and of course, terrain ruggedness plays very important role, but the none less these will be used while calculating the flow direction.

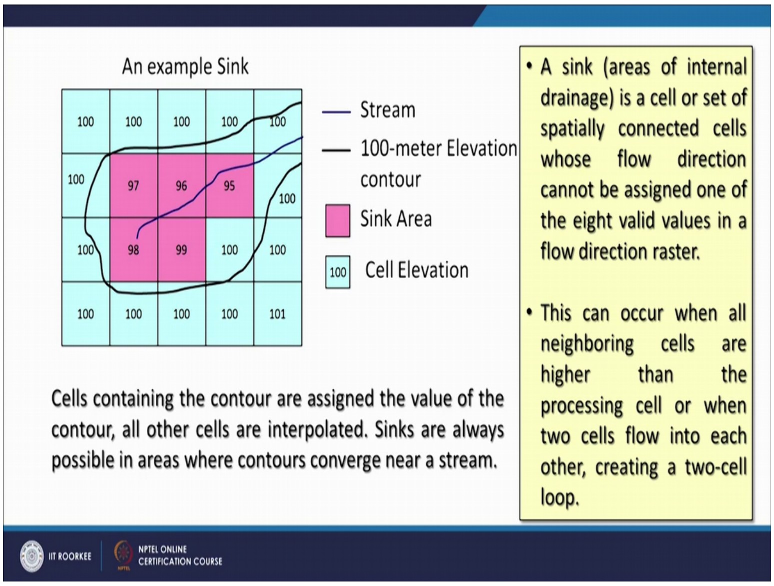
(Refer Slide Time: 18:44)



So, that is why in the flow chart flow direction has been calculated first. But sometimes people first go for depression less creating a depression less DEM and then derive the other parameters that is also possible.

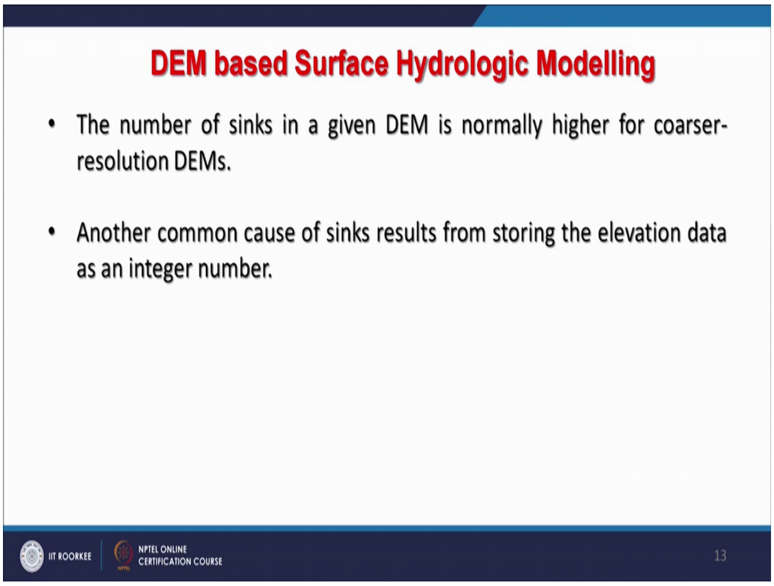
So, these have to be removed or these have to be filled with surrounding values and once say it is done then we assume that now water will flow over land or as a surface runoff and this is one example of sinks it here that there are 5 cells which are having values lower than the surrounding so we can these we can fill so that this depression is removed.

(Refer Slide Time: 19:36)



But generally through my own experience I have seen the sinks are of not this much size. They are generally of just 1 or 2 pixels maximum and as said that the sink are the areas of internal drainage and we have to get rid of these internal drainage to allow water to flow over the surface and these sinks can occur when all neighboring cells are higher than processing cell or maybe lower in case of a peak in a digital elevation model, but this peak is just 1 or 2 cell size.

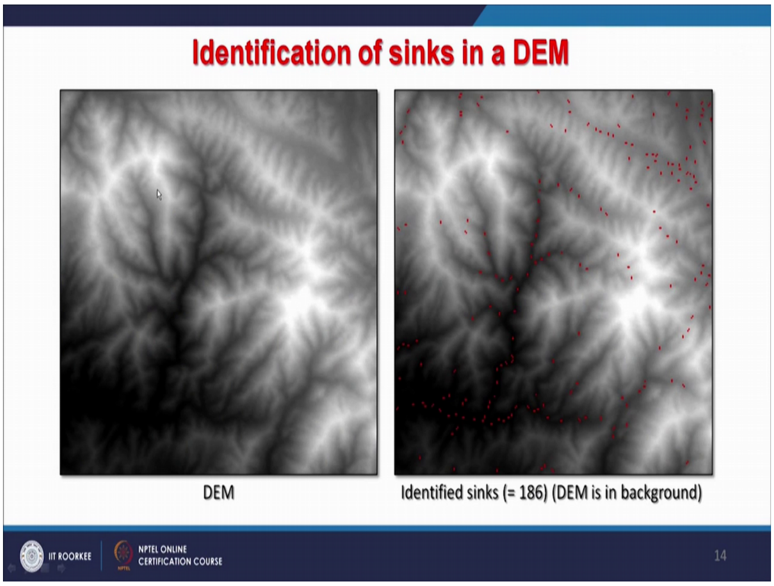
(Refer Slide Time: 20:24)



So, number of sinks in a DEM is normally higher for coarser resolution DEMs because a coarser resolution DEMs may have more errors in for most sinks as compared to relatively higher spatial resolution. And now instead of 90 meter a spatial resolution which we used to call as a coarser resolution most of us have started using 30 metre or higher spatial resolution. So, this issue of sinks have become little less or less problematic in our surface hydrologic modeling. Another cause of this sinks results from storing the elevation data as integer number. So, by mistake if a data has been stored then the because integer numbers will not allow the values it means one least count will be there and that that is why it may create some sinks.

So, generally as I have mentioned already that a digital elevation cell values are generally stored as a real values rather than integer values. So, this care has to be taken before we put a DEM through the surface hydrology modelling and as we know that these things can be avoided once we get a digital elevation model of our area of interest first we should study visually otherwise look the minimum values maximum values and the cell values whether they are integer and real once that is done then we can proceed for surface hydrologic modelling. So, depending on the spatial resolution as a in this example as that increases as much as 5 percent for a 3 arc set second, DEM that it means ninety meter resolution DEM.

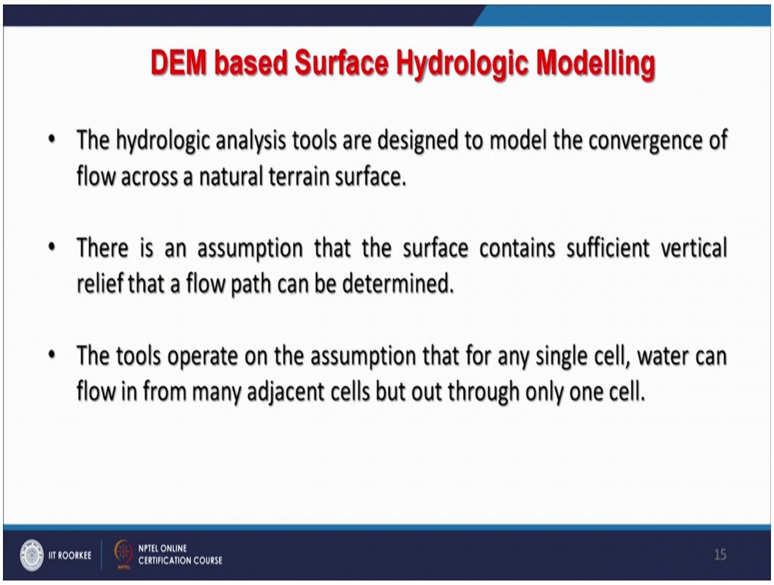
(Refer Slide Time: 22:32)



The example is here that the same digital elevation model which we have been using throughout this course the subset of that DEM is shown on the left side and when this DEM was subjected to sinks or sinks identification this is how these number of sinks have been identified only 186 cells which have been found having values lower than the surrounding values or values a having very significant higher values. So, generally these are the depression local depressions which we need to remove, or filled and once that is done then we can proceed for next step of surface hydrologic modelling.

Now, this analysis or surface hydrologic modelling basically is designed the concept is based on this the convergence of flow across a natural terrain surface this has to remember that the water has to flow over the surface and this assumption as I have been mentioning that this assumption basically is that the surface contains sufficient vertical relief that if flow path can be determined. So, you have to have a sufficient change in elevation and therefore, the water can flow.

(Refer Slide Time: 24:04)

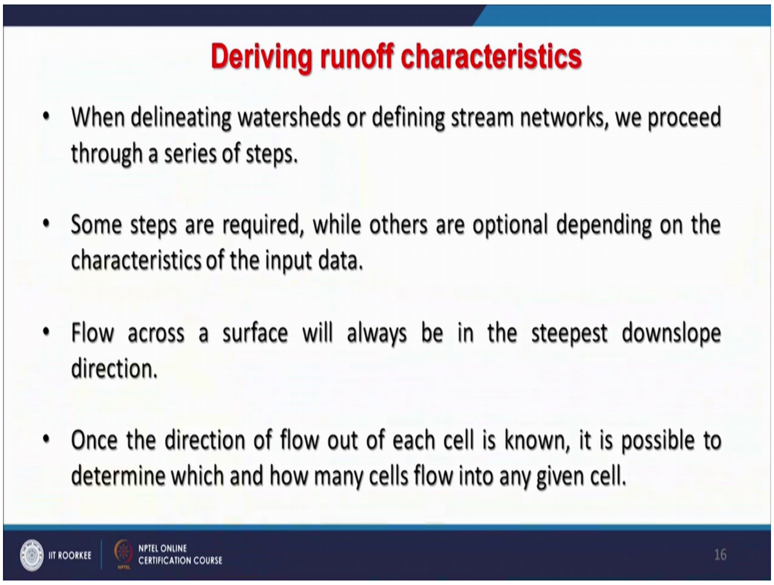


And the tools which we use in different GIS platforms and they operate on this assumption that any single cell the water can flow in from many adjacent cells, but through only one cell.

So, there may be various cells, may be having lower value elevation values, but it will flow through only that cell, a single cell which is having among the surrounding cells the minimum elevation values. And when we delineate these water sets or defining a stream network we proceed through a series of steps as soon through the flowchart some steps are required some other are optional depending on the characteristics of input data and also depending on what we are going to achieve through this say surface hydrologic modeling. Because somebody may be looking only up to drainage network and not looking for stream modelling or may not be looking for watershed boundary.

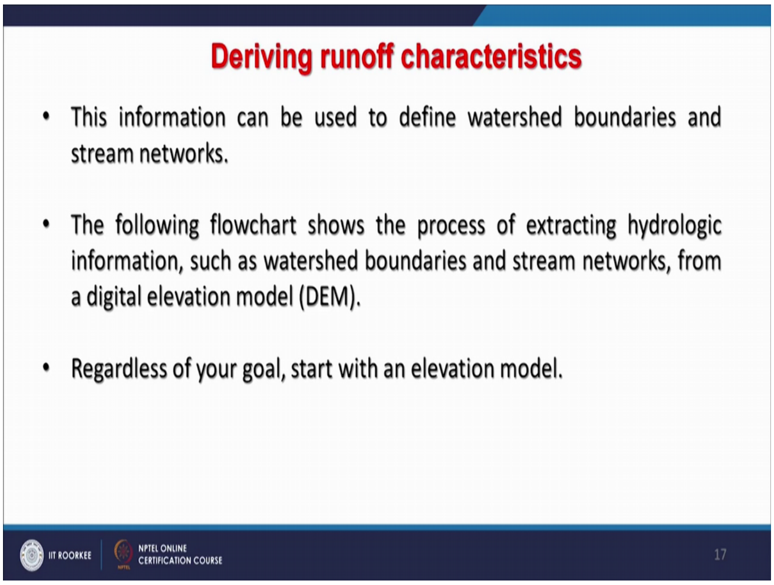
So, depending on that we go for a steps flow across a surface will always be in the steepest down slope direction. This we know is a very simple fundamental thing, is the basic thing.

(Refer Slide Time: 25:14)



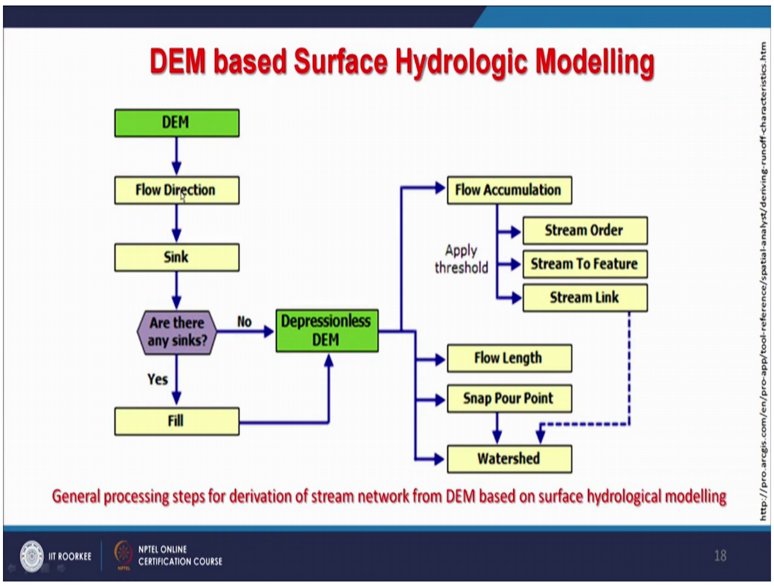
Once the direction of flow that is why the first step here is to calculate the flow direction. So, once the direction of flow out of each cell is known, it is now possible to determine which and how many cells flow into that given cell and that will decide the flow accommodation. So, the first after depression that or even before that the flow direction has to be calculated. So, both approaches are available based on the depression less or own and the original DEM the flow direction can be calculated, but for flow accumulation it depression less DEM has to be there. And the information can be used to define watershed boundaries and stream networks that is the flow accumulation information.

(Refer Slide Time: 26:09)



And the fall these the chart which I am going to show are having this information watershed boundary, stream networks from a digital elevation models and we start with always whatever is the you know ultimate aim or ultimate derivative which we are targeting, we have to start always with a digital elevation model. And this is based on in which cell the water will flow from which cell and this will decide basically the direction. So, this is a repeat flow direction that the flowchart which is here that we will after having a depression less DEM, then a flow accumulation theme is calculated.

(Refer Slide Time: 26:54)



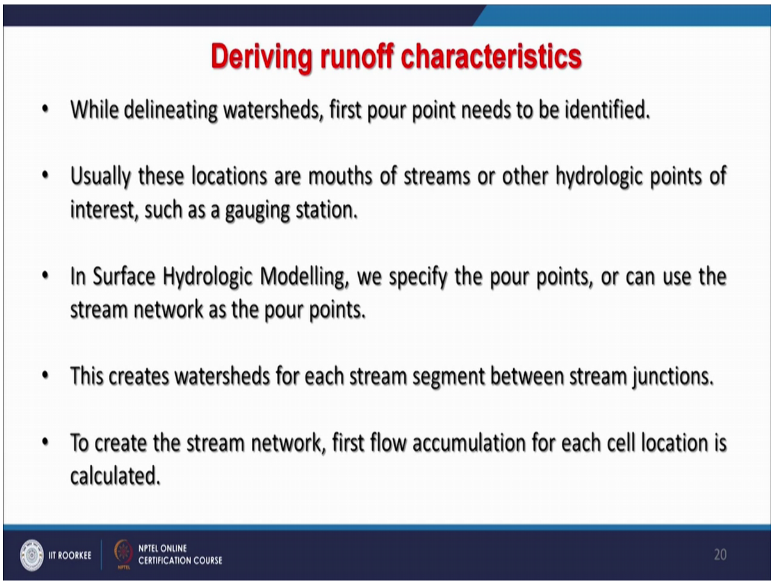
This theme as mentioned can be used to derive a stream network stream order or stream to features means say from raster to vector here or a stream link files which can be used and later on in case of watershed boundary delineation and other in between parameters can also be derive.

So, like deriving runoff characteristics of from of a DEM, of a terrain through a surface hydrology modelling. So, if the error part we have already discussed that the if there are errors in digital elevation model or if you are modelling a cost geology; that means, the terrain which is representing a limestone terrain and you know there are we are having, these a limestone related log rocks and then one has to take care because we may have a large sinks there otherwise generally we do not have this problem. So, they because you may have these lower areas and generally in and this cost topography or cost geology we do not have this in calcareous terrain, we do not have surface drainage.

So, only subsurface drainage network is there, but a say very not a common phenomena and if this is the situation, then probably the surface hydrologic modelling will not work, but otherwise in most of the cases there is should not be any problem about this. So, when we go for depression remove the depressions or depression less elevation model then we can also later on derive the flow direction, followed flow accumulation and so on so forth.

While delineating watershed boundaries first pour points need to be identified that we have already discussed. Then these locations are mouths of streams or other hydrologic points of interest such as gauging stations and in surface hydrologic modeling we specify pour points while delineating a watershed boundary and one can use the size of give a threshold that if a 500 and cells or 5000 cells or a square meter area its contributing then I want to delineate. So, likewise the drainage network and everything can be determined.

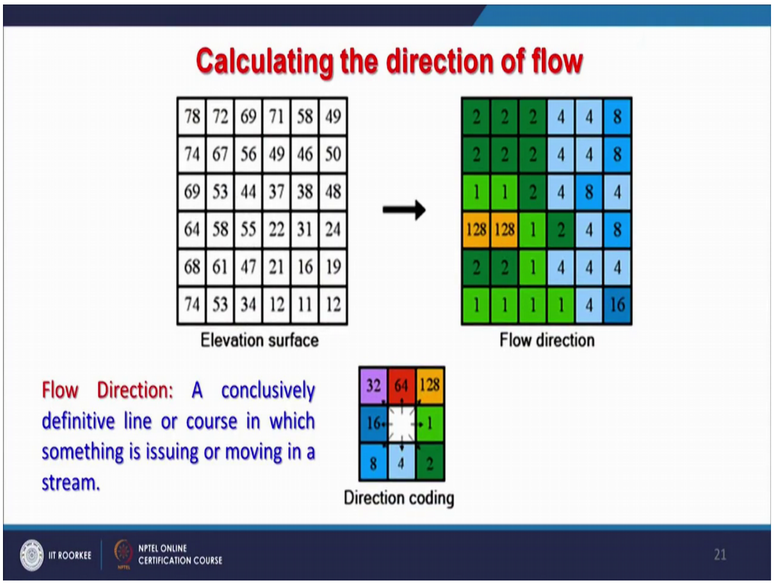
(Refer Slide Time: 29:25)



And this to create the watershed for each stream segment between stream junction, so stream link information is also becomes very important. Once the drainage network has been derived then we can use for other things. So, in order to create a drainage network after the flow direction the next thing is flow accumulation for each cell is calculated.

If we look on the cell base is how flow direction the one major theme which we derive is a so on the left side top left basically we are having a elevation digital elevation model of a very small area is shown here and, when we create a flow direction we follow a scheme generally this is the scheme for coding. So, these are not basically elevation values these are the codes of flow direction.

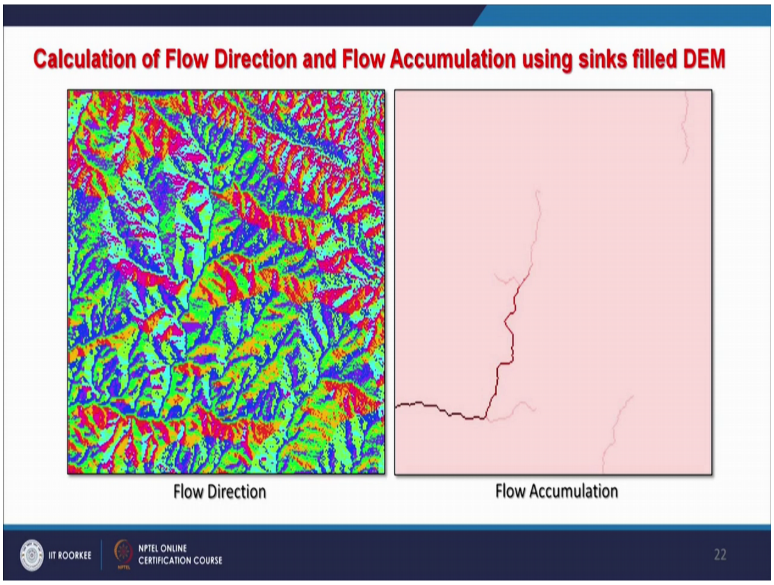
(Refer Slide Time: 30:27)



So, when a when a cell is will allowing water to flow towards the east then the code 1 is given, when it is going for south east direction then code 2 likewise when it is going for north direction then code 64 is a sign and if it is going for northeast direction then 120. So, it is in a particular digital elevation model may not be necessary that all codes will be used.

Same thing here in this example there are few codes like in the 64 code, 32 code and these codes have not been used whereas, the code 1 2 4 and 128 16 have been used; that means, the flow in these directions within this example DEM are there, but in other directions like in north direction northwest direction there is no flow is there. So, it is not necessary that all codes within a given or as a DEM will be given these all codes there it depends on in which direction the flow is going to flow from water is going to flow from one cell to another cell. So, flow direction conclusively a definite line or course in which something is issuing or moving in a stream.

(Refer Slide Time: 32:17)

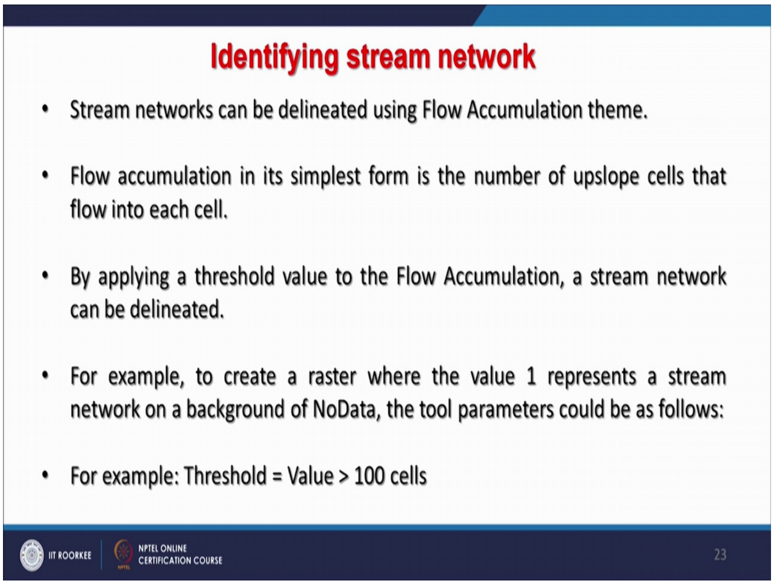


And when we see in form of the same digital elevation model and a really large file instead of just on cell based cell based as we have been seeing in previous slide. Here this is the DEM which we have taken an example DEM throughout this course and the flow direction has been determined.

Sometimes you one may feel the flow direction looks more close to slope map. In fact, yes say in some way, but basically the course have to be taken care because their course there are different then here otherwise the output may look similar in that sense, but we cannot equate directly. So, codes have to be taken care because these codes are later on used while calculating flow accumulation. So, this flow accumulation map is here. So, this is showing the major drainage and of course, if I on a GIS platform if I click directly say here then automatically a watershed boundary will be delineated. So, they say in this flow accumulation flow direction and flow accumulation generated using a filter DEM in this particular example.

Now, how to identify stream network? For a stream network the theme which will go as input is of course, the flow accumulation theme and here it is that we have to define a threshold value that how many cells will contribute for outlet and based on that the stream network will be driven. So, flow accumulation in its simplest form is the number of upslope cells that flow into each cell.

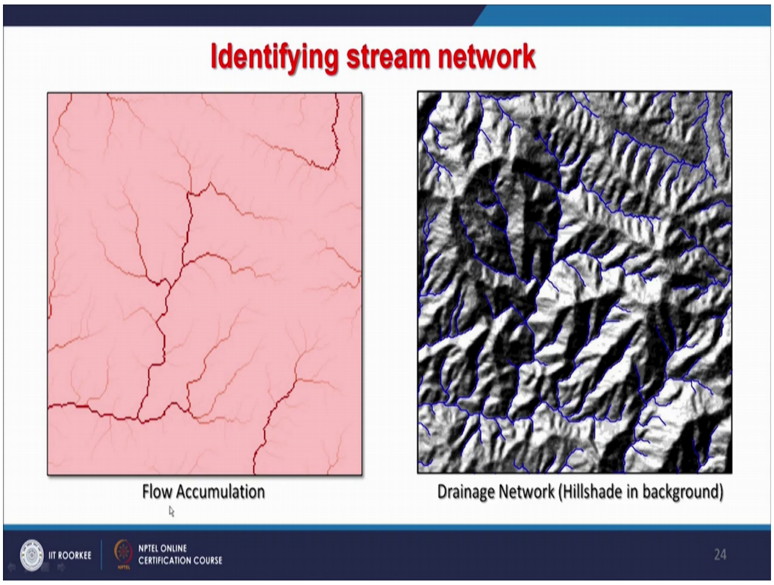
(Refer Slide Time: 33:57)



So, if I take example here, these at this location the maximum number of cells will contribute at this location, but if I go here then relatively I will have less number of cells which will be contributing at this pour point. So, this is what it is meaning is that the flow accumulation in a simplest form is the number of upslope cells that flow into each cell and therefore, the values will be also accordingly. So, at higher elevations say near watershed boundary you will have a very small flow accumulation value whereas, at pour point or at the in this particular example at the edge of our watershed from where the water will go out of my study area the flow accumulation value is going to be very high, because it is declaring the upslope cells which are which are going to flow into each cell.

And by applying this threshold value to a flow accumulation theme a stream network can be delineated. And likewise I will just show you that for example, if I to create a raster where value one represent a stream network on a background of no data the tools parameter could be as follows. That for example, I can decide that the threshold value is more than equal to say 100 cells; that means, that if a 100 cells or more are contributing then start delineate in drainage network from there itself because I cannot have one each cell if I go and reduce this value then two dense drainage network will be delineate it which will not be close to natural drainage one network which we see on the ground or through a topographic map. So, this threshold value has to be judiciously chosen. So, that at least some comparison can be made.

(Refer Slide Time: 36:29)



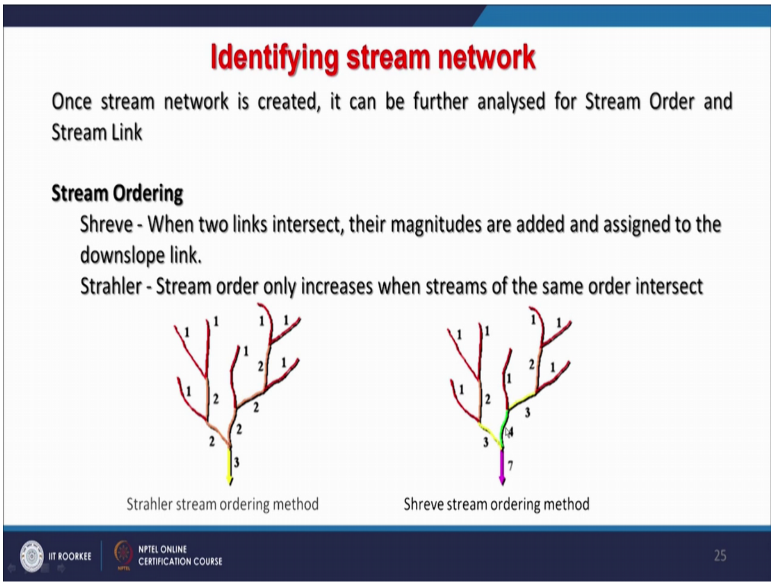
Here flow accumulation is say, is there and what we are seeing here the drainage network in form of blue lines and in the background a hillshade has been put here just too. So, that how if this becomes the watershed boundary and at this outlet as you can see and the drainage is just going through here likewise.

If I have chosen a very small value as through cell threshold value then too much drainage lines would have been delineated and some though the system will calculate, but they may not be close to realistic, means you will not see on the ground really or on a even on a large scale topographic maps. So, it is always one has to be careful while choosing the threshold value. So, here in this particular example the threshold value was equal to a greater than 100 cells. So, once we choose or one may go for instead of number of cells one may decide based on the area and accordingly it has to be given.

Once the stream network is created it is further analyzed for a stream order or a stream links. So, as I have mentioned in the beginning that say you know sequential processing we started with digital elevation model, we filled the depressions we calculated the flow direction, we calculated then using the flow direction, we calculated the flow accumulation once the flow accumulation is there, we apply a threshold value and calculate it and determine the drainage network. Now once drainage network is there then this we can use to derive two products one is a stream order and a stream links. Stream links is used later on, but a stream order there are a different stream schemes by exists the most popular one are the Shreve given by a scientist or geomorphologist Shreve and Strahler, Strahler.

So, these two is and stream ordering schemes have been implemented and on into GIS softwares and within this surface hydrologic modelling and there are slight changes in this we will see the differences in this that in this Strahler the let us take the later one first.

(Refer Slide Time: 39:00)



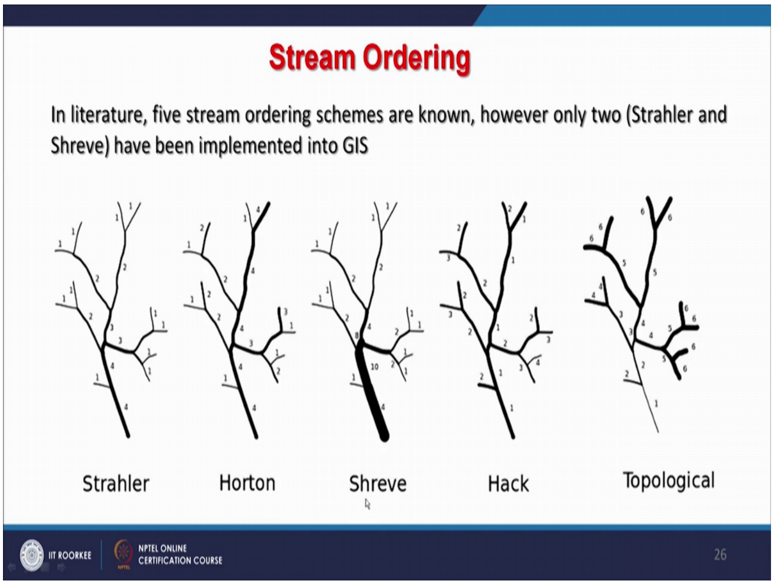
So, its Strahler stream order only increases when he streams of the same order intersect. What does it mean? That when I am having order one a first order stream, first order stream when these two meets then it becomes second order. When second order and first order and these meets then still it remains second order. So, once say we are having two second order streams then only it becomes the third order. This is Strahler scheme of ordering, stream ordering.

Now, if we go for this first the Shreve when two links intersects their magnitudes are added and assigned to the down slope link it is a kind of addition. Example here for the same schematic a drainage network that one first order first order meets it becomes second order, then second order in first order meet it becomes third order in the down slope side. W hen this happens first order and third order meets it become fourth order, then third order and fourth order meet becomes seven order.

So, in Shreve ordering, in Shreve ordering what we are seeing that at the outlet we are having 7th order whereas, in case of Strahler it is just third order though the drainage network is same because of two different way of ordering streams are there. So, both options generally have been implemented in popular GIS softwares depending on our requirement we can choose, but this one becomes more on Shreve one become becomes very easily understandable and it is therefore, very much popular.

Now, stream there are other stream ordering schemes are available in literature some of them have also been implemented on GIS, so five popular one are shown here two we have already seen, Strahler and a Shreve stream ordering.

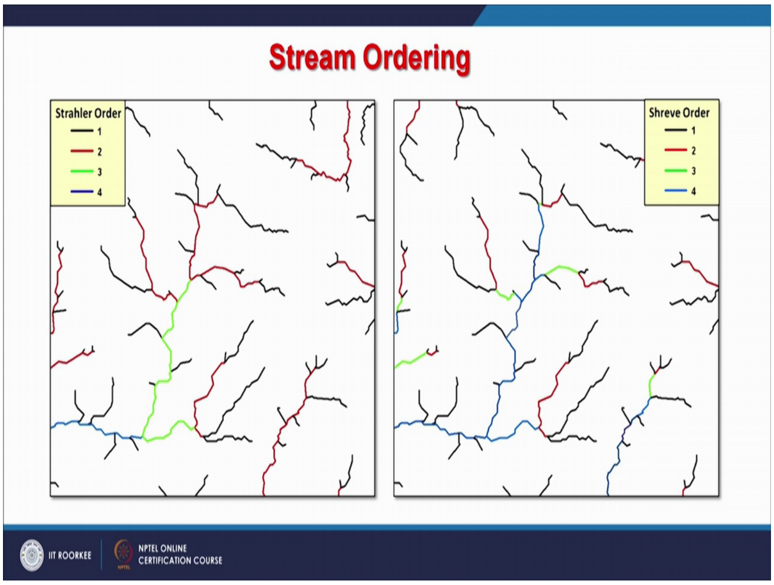
(Refer Slide Time: 41:07)



Then there is a Horton stream ordering scheme, there is a Hack stream ordering scheme and there is a Topological stream ordering scheme. Different schemes are there, one can follow anyone or the most popular one which is the Shreve one, and these are the two which are most popular.

Now, if I take our example digital elevation model on which we have generated our this flow direction and then later flow accumulation and then stream network. Once we put this stream network for this Strahler order stream then this is what the output we get.

(Refer Slide Time: 41:51)



For our example digital elevation model and if we it is subjected for a Shreve order then this is how it looks. Though the drainage network overall drainage network is the same, but when we apply two different stream ordering schemes then we get slightly different results here.

So, depending on your requirements one can choose any one of these ordering streams. So, this brings to the end of this discussion this is, this says in the surface hydrologic modelling is in two parts. The first part we have discussed, in next lecture we will be discussing the second part of surface hydrologic modelling. So, we will be discussing few more derivatives which will be coming through the surface hydrologic modelling using a digital elevation model.

Thank you very much.