Watershed Management

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Module No. # 04

Lecture No. # 13

Watershed delineation Mathematical modeling

Welcome back to the video course on watershed management in module number 4. In lecture number 3 today, we will discuss watershed delineation and watershed modeling. Some of the topics covered today include watershed delineation, various methodologies and steps; watershed modeling and mathematical modeling. Few of the important key words in this lecture: watershed delineation and mathematical modeling.

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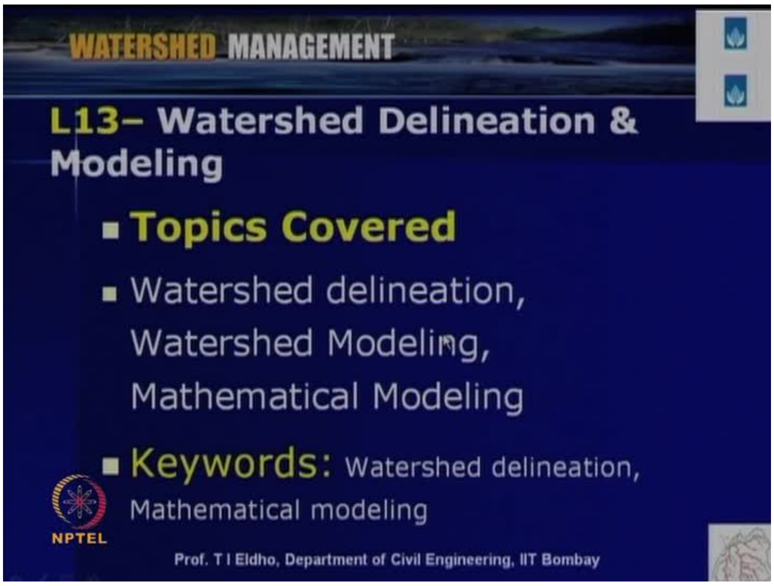

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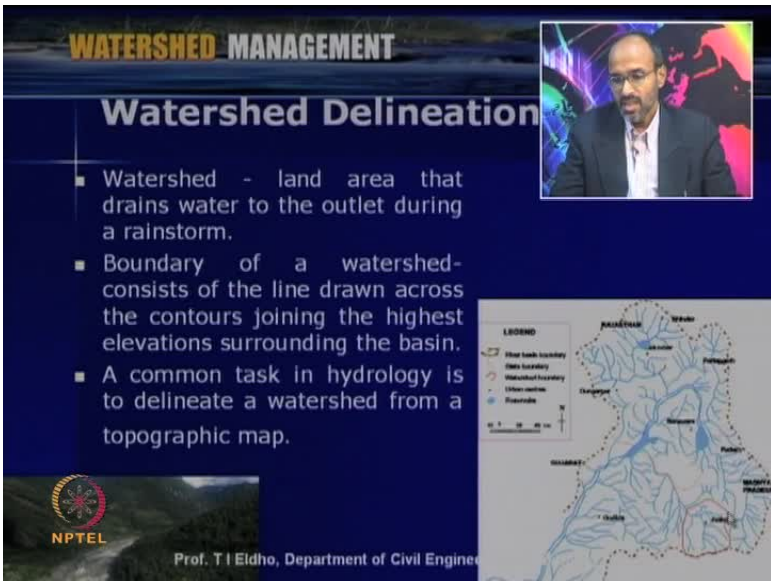

As we have already seen in the previous lectures, watershed is a land or an area that drains water to the outlets during a rainstorm. So, you can see that here in this figure or in this figure, that watershed area is that area that drains water to the outlet during a rainstorm.

So most of the time, say for a given area, for a given village or for a given taluk, we have to identify the watershed before going for the various interventions or before starting the watershed management, or while preparing watershed management plans. So, we have to identify the exact boundaries of the watershed. That is the process called as watershed delineation. Boundary of a watershed consists of the line drawn across the contours joining the highest elevations surrounding the basin.

You can see that if this is a watershed, so this is a district or a taluk or a even a village then, you can see that this is the boundary of the watershed which is a delineated and then for example, this is a sub watershed of this main watershed. Then, you can see that this is our the delineated watershed. So, this is the boundary of the watershed.

A common task in hydrology: so when we when we talk about watershed management or when we go for hydrological modeling, a common task is to identify the watershed or we delineate a watershed from a topographic map. A topographic map or so-called top sheets will be available for a given location. So, we have to identify which is our watershed which is the, what is the boundary of the watershed and then only we go for various managerial pressures or we go for watershed modeling.

So watershed delineation with the topographic maps are very important so the topographic maps, say, gives most of the important information which is the starting points as far as the watershed delineation… So, topographic maps are the fundamentals source of data for delineating and studying the watershed. Depending upon the, say, the country or depending upon the location or depending upon the various say parameters or the organization which is taking this topographic maps or which is making the topographic map, the scale may vary. So, it can go for, say for example, 1 is to 10000; 1 is 20000 or 1 is to 1000000; like that the scale can vary.

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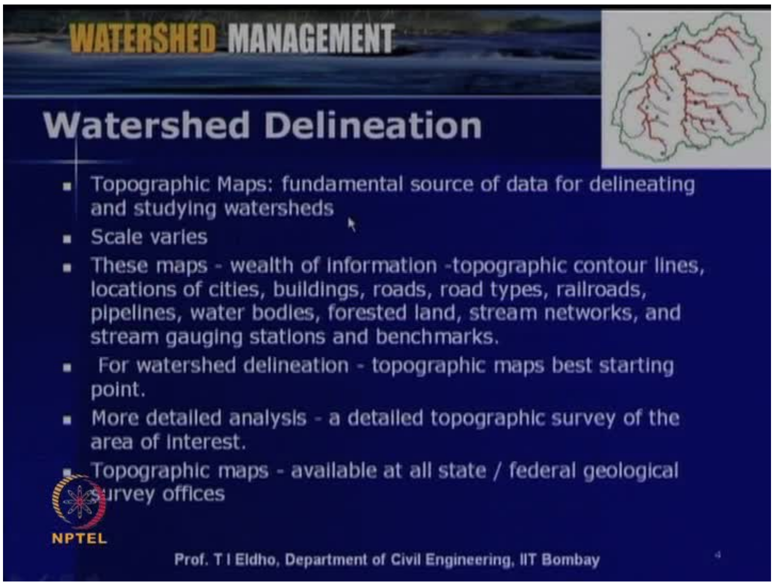

So these maps say, as I mentioned, these maps give a wealth of information. As far as hydrology is concerned, or hydrologists are concerned, the topographic maps are the one of the important map which gives most of the information which we are looking for, as far as hydrological modeling is concerned. The wealth of information like topographic contour lines location of cities, buildings, roads, road types, railroads, pipelines, water bodies, forested lands, stream networks and stream gauging stations and a number of benchmarks. As far as the watershed is concerned, all these details we can directly get from the topographic maps or so-called topo-sheets.

So, as far as say, now we are talking say this topographic maps can be used for various purposes but, now we are discussing the topo sheets. As far as the watershed delineation or identifying the boundary of the watershed and then to go for say, identifying the watershed and go for watershed management plans or watershed modeling.

Say, the watershed delineation topographic maps are the best starting points; so it gives lot of information as already mentioned here. So, from that we can get lot of ideas; say how to delineate the watershed and then various features of the watershed as shown here, like drainage patterns or the lakes or the river. The river flowing through the watershed or the road network, etcetera; a number of information we can directly get through the topographic maps or so-called topo-sheets. So, for more detailed analysis of course, we need to go for a detail topography survey of the area of interest.

So, the starting point is the topo sheets or topographic maps. Then, from that say, once the area is, the location is identified, once approximate of the boundary is identified, we can go to the field and then conduct various surveys which are required as far as a hydrological modeling or the watershed modeling is concerned. So, topographic maps say generally, we can get from the state or federal geological survey offices. So, the survey of India - say for example, in India or say various geological survey; so like that various, the government of federal government or state governments will be having the topographic maps.

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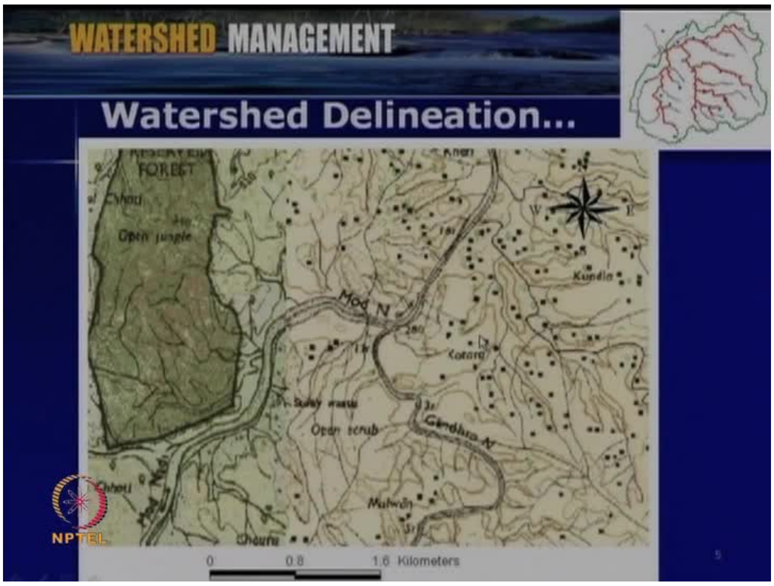

So either we can get through say, by going there or through post or through internet we can obtain the topographic maps for the area. So, this say figure (Refer Slide Time: 06:30) shows a typical say topo sheet or topographical maps. You can see that it gives the land use like a therefore, the reserved forest then the agricultural land and then the rail network, road network then the drainage pattern and then even the location of lakes. So, like that various information we can obtain from a such a topo sheet or topographic map.

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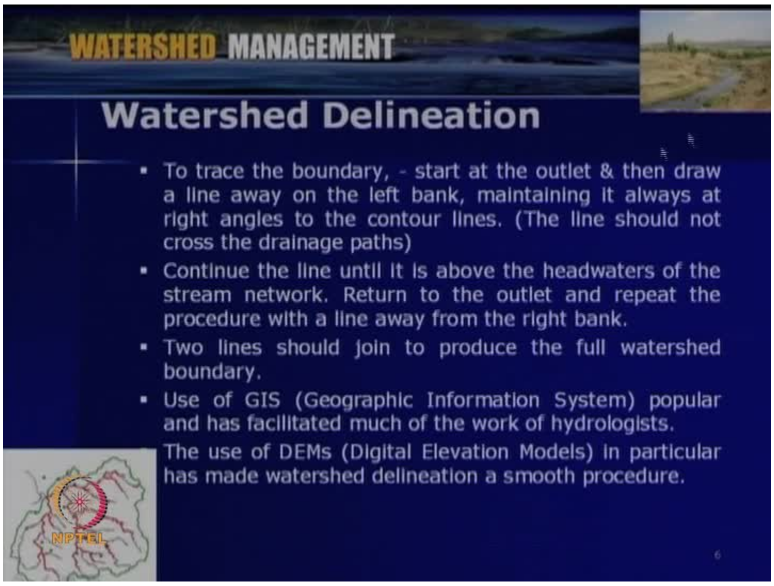

Now, our discussion here is about the watershed delineation. To delineate the watershed, as I mentioned the watershed which is already delineated or, this is a photo of a watershed (Refer Slide Time: 06:57). So, to delineate the watershed first, to trace the boundary that means, we have to trace the boundary of the watershed. We start at the outlets of the watershed so we can identify the outlet of the watershed and then draw a line away on the left bank maintaining it always at right angles to the contour lines. So, always the watershed boundary will be crossing at right angles to the contour lines. The line should not cross the drainage path so that is our main aim. Then continue the line until it is above the headwaters of the stream network; so we can continue on the ridges and then we can say keep on going and then return to the outlet and repeat the procedure with a line away from the right bank.

We can start from one location and then go back like that and then return. For example, this is in this figure (Refer Slide Time: 07:30). If this our outlet of the watershed, so we can start like this and if the contour lines are also known then, using the topo sheet we can go like this and finally, we can come back so that the watershed is delineated. Say here, two lines should join to produce the full watershed boundary. So this is, if going starting like this and finally, we will be coming back to the end; so that gives the delineated watershed. So, this is the general procedure; say, so-called manual procedure as far as the watershed delineation is concerned but nowadays, a very sophisticated geographical information system software is available like Arc info or ArcGIS or gram plus plus etcetera.

The use of GIS is now very popular and as facilitated much of the work of hydrologists like the watershed delineation, then say making the various maps like a slope map, then digital elevation map or digital elevation model, then land use map, land cover map. So, all these things nowadays, we can easily do with the help of a GIS software. So, the here the use of so-called digital elevation models DEMs in particular, has made watershed delineation a smooth procedure. So, the watershed say, while by using geographical information system we can first generate a digital elevation model using various details so we will be discussing it in the coming slides.

So say, once a digital elevation model is made from that, we can extract the watershed; or we can identify the boundary of the watershed. So, geographic information system is by using GIS; it is much easier to delineate a watershed. Here, in this slide you can see that this is a part of a watershed and these are so-called contour lines.

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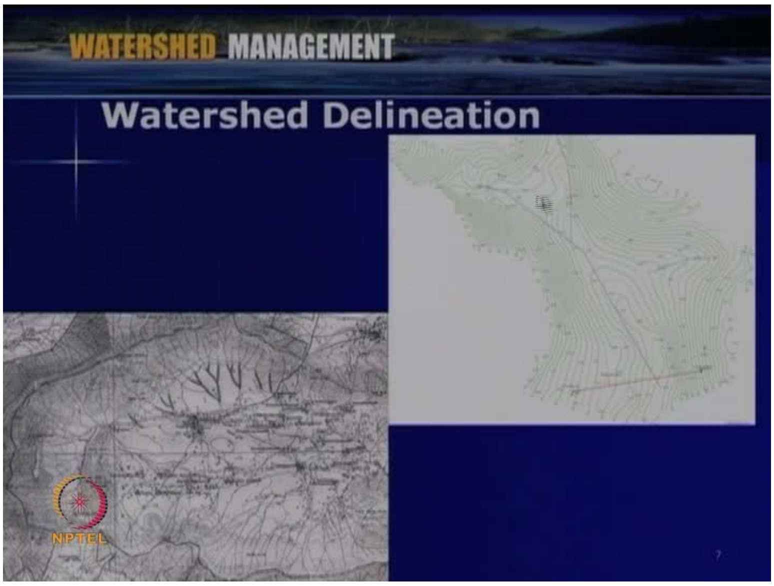

So, this is the drainage system; we can identify say for example if this identified as the outlet of the watershed then we can go as we mentioned either manually or using the GIS software we can delineate the particular watershed. For example, this is another delineated watershed; so these small lines here indicate the contour lines and this is the delineated area or so-called delineated watershed. So, here it is somewhere here is the outlet of the watershed. So, we can either manually delineate the watershed or we can use the sophisticated GIS package for the delineation of the watershed.

Generally, the starting point is a topo sheet or topographic map and then contour intervals are identified; from that we can go ahead with the watershed delineation.

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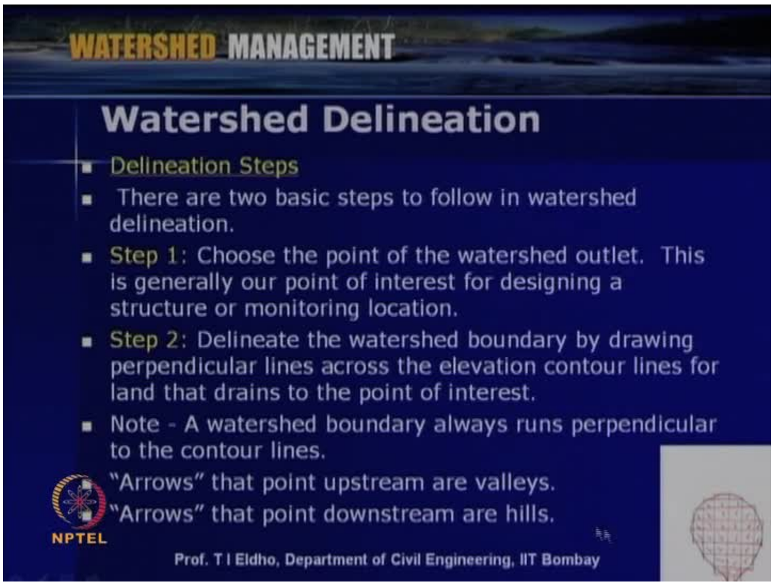

Again, coming back say by manual way, steps to follow in watershed delineation: in step number 1: choose the point of the watershed outlet as I already mentioned and then this is generally our point of interest for designing a structure or monitoring location. For example, if we are going to construct a check dam or if you are going to make a larger dam in a basin then, generally the outlet of the watershed that may be the preferred location as for as such construction is concerned.

So, the outlet we can identify then we can delineate the watershed boundary by drawing perpendicular lines across the elevation contour lines, as we already have seen in the last slide. For lands that drains to the point of interest so that way, we can delineate the watershed. So, here it should be noted that a watershed boundary always runs perpendicular to the contour line. That is the way we say; so that as we mentioned generally, watershed will be represented by the ridges and then an outlet. The ridge we get so that the boundary always runs perpendicular to the contour lines and while doing this process, say for example, arrows that point upstream are always valleys and arrows that point downstream are hills. A certain procedure we can follow while delineating a watershed.

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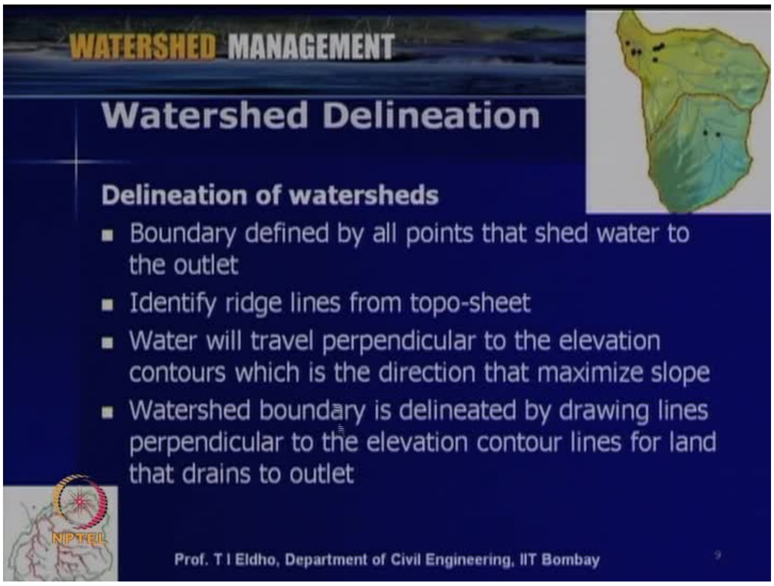

Now, say as far as the delineate watershed is concerned, the boundary defined by all points that shed water to the outlet. Also, I already mentioned say for example, in this figure you can see that if this is our outlet of the watershed, this is the watershed say for example, this say again, a sub watershed also can be there. If you consider this as sub watershed, this is the outlet of the sub watershed and if you consider this as the total watershed then this is the outlet of the main watershed. We can identify the ridge lines from the topo sheet. Then, water will travel perpendicular to the elevation contours which is the direction that maximize slope especially, while doing the manual delineation, we follow the procedure that the water will travel perpendicular to the elevation contours. Then, watershed boundaries delineated by drawing lines perpendicular to the elevation contour lines for lands that drains to the outlet.

So, this is the way we can delineate a watershed using the manual procedure. The manual procedure, say, it will not be always accurate; lot of mistakes can happen. Since, the contour intervals will be most of the time will be very coarse, say may be of 20 meter interval or 10 meter interval, but, to have say, if you are having better contour intervals like say 50 centimeter or 1 meter contour interval then, we can have a better delineation so that is true even in a GIS based delineation also.

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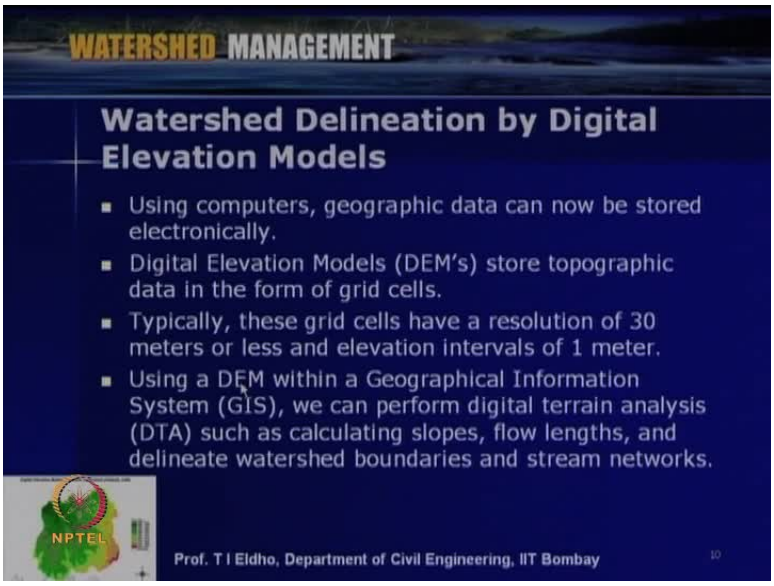

So, now what we have discussed so far is the manual based delineation. Now, let us look into the procedure for say GIS or geographic information system based watershed delineation - watershed delineation by digital elevation models. As I mentioned, we will be generating a digital elevation model based on the given topo sheet. So, the digital elevation model means, at any location that model gives the elevation so that is, we are obtaining through the contour intervals by digitizing the contour intervals and then feeding the details to a geographic information system software.

Using computers geographic data, can now be stored electronically as I already mentioned. Digital elevation models or so-called DEMs stores topographic data in the form of grid cells. So, we can generate the grid and then according to the grid cells only generally the topographic data are stored in the digital elevation models.

Typically, these grid cells have a resolution of 30 meters or less. So, 30 meters is actually very costly but now, with sophisticated packages and if we are having better contour intervals so then we can have very good digital elevation models; say to the order of say 1 meter or even 0.5 meter. So accordingly, depending upon the contour interval and various other parameters, we can get the digital elevation model resolution and then the intervals we can fix accordingly. Say, for example, if 30 meter then we can have the interval of 1 meter or if it is 1 meter the digital elevation model then we can have even 10 centimeters based intervals.

Using a digital elevation model within a geographic information system, we can perform digital terrain analysis. So, we so-called DTA we can get say, much more better information in a very scientific way by using the digital terrain analysis such as calculating slopes flow lengths and we can delineate watershed boundaries and stream networks so this is a say very much now used by most of the hydrologists so if you are having an access to a GIS software and then we are having the contour intervals better contour interval then we can first easily generate a digital elevation model and then we can do various digital terrain analysis. Say for example, this say figure shows a digital elevation model for a sample watershed so, this gives the various the variation of the elevation as far as the considered watershed is concerned (Refer Slide Time: 17:25).

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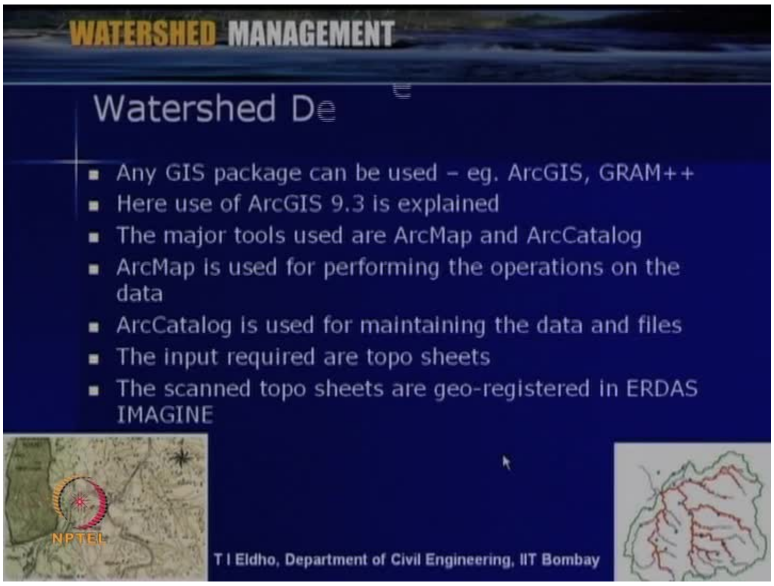

So, the watershed delineation using GIS as I mentioned in a sophisticated way, we can delineate a watershed using the geographic information system. Any GIS package can be used say for example, ArcGIS or gram plus plus or any other say GIS package.

Here, say in the coming few slides I will describe how to delineate a watershed using the package ArcGIS 9.3. ArcGIS is the product of Esri company of United States. The details what is explained here are also given in the websites. How to delineate a watershed? The major tools used are ArcMap and ArcCatalog. So, these are 2 modules given in ArcGIS software. These are the 2 important modules which we utilize for the purpose of watershed delineation. So, Arcmap is used for performing the operations on the data and then ArcCatalog is used for maintaining the data and files.

First we can use ArcMap to do the operations say for example, starting with a topo sheet. A detailed topo sheet and then ArcCatalog can be used to maintain the data and files; so the input required are generally the topo sheets and then of course, the digitized contour intervals. So, say for example, if this is our topo- sheets, first we can scan the topo sheets say for example, in and then geo register. So, geo register is just like a, we can choose 3 typical points and then either using latitude, longitude or for a given particular coordinate system, we can geo register. That process is called a geo register. So, this we can do in a typical software like a ERDAS IMAGINE software. Once it is done, the various locations of the watershed the area considered so that we can easily identify once it is geo registered. So, once geo registered means we can say that the locations of the river or the location of the lakes or various other important features of the watershed, we can identify with respect to the geo registered coordinates by using the scanned topo-sheet.

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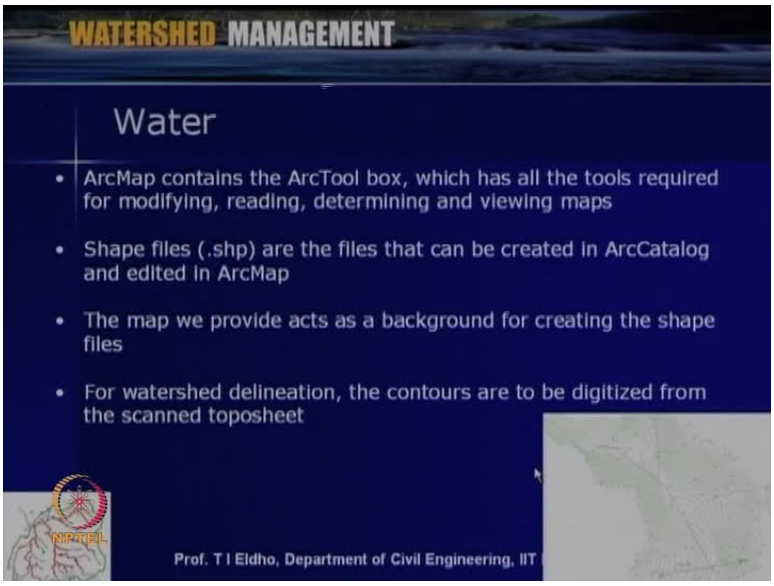

Then we can also say digitize the contour available with within the topo sheet and then that also can be fed to the software. So, then now let us look in to the various procedures which we adopt as far as watershed delineation is concerned. ArcMap contains a tool called Arc tool box which has all the tools required for modifying, reading, determining and viewing the maps. As I mentioned, these details are available in the Esri website so, the viewers can directly go to the Esri website and then get these details and of course, even a tool box is also given. So, from that you can easily say identify how this watershed delineation is done using the ArcGIS software.

So, here say in ArcGIS we generate shape files; so shape files are the files that can be created by ArcCatalog and edited in ArcMap the map. We provide acts as a background for delineating the shape files; so either the topo sheet or the topographic map that we provide that is the background which we are using to generate the shape files say for watershed delineation, the contours are to be digitized from the scanned topo sheet. So, for the given topo sheets say if, I already know the contours we can digitize those contours and then that data we can fit to the software. That way all the… now, after geo registering we know the x and y coordinate or latitude, longitude wise the coordinates.

So the now Once the digitized contours details are given then, the elevation variation also we can easily identify. So, the horizontal x y plane plus the elevation details we can directly get for any location after feeding the data for the geo registered scanned map.

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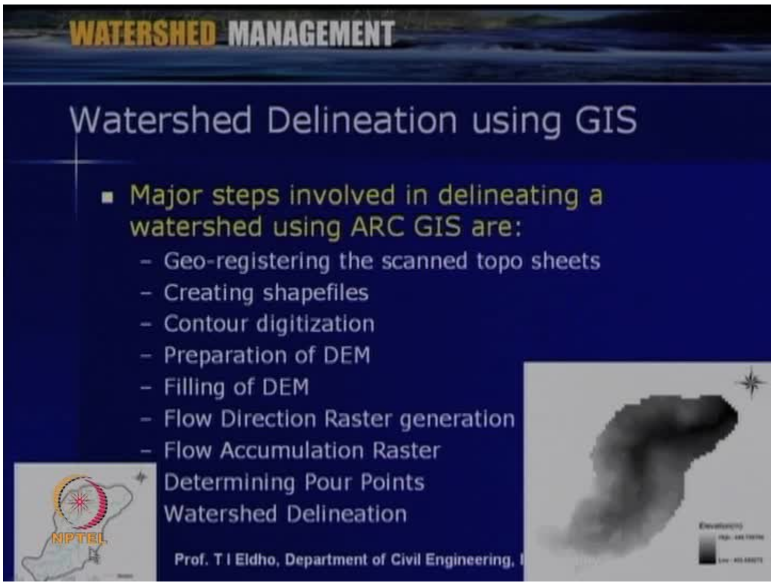

Now, let us look in to the various steps involved in delineating a watershed using the ArcGIS software. So, here in this slide I have listed the various steps involved in the… while doing using the ArcGIS for the watershed delineation.

As I mentioned, geo register the scanned topo sheet, so then, the next step is creating the shape files; then we can contour the digitization; then preparation of the digital elevation model; then filling of digital elevation model; then flow direction using the raster generation; then flow accumulation, raster determining the pour points then finally, the final step is the watershed delineation.

So, this we can in ArcGIS software, we can go step by step and finally, the output will be a delineated watershed and then the digital elevation model. So, using this digital elevation model we can if you do a digital terrain analysis, we can get various other data like a slope map and other kinds of data also can be produced. Say, for example, this is a digital elevation model for so-called BANHA watershed and this is the delineated watershed for which the drainage network also shown.

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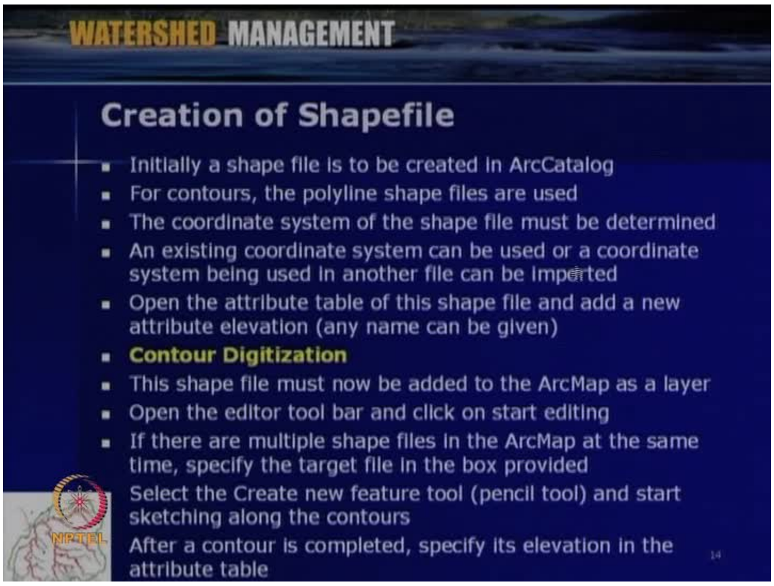

Now, let us have a look in to the step by step procedure. What is discussed in the last slide? So, here first one is the say once the geo registering and scanned topo sheets is done then, the next step is creation of the shape file. So, initially a shape file is to be created in the ArcCatalog in the ArcGIS environment. Then, for contours the polyline shape files are used. The coordinate system of the shape file must be determined; an existing coordinate system can be used or a coordinate system being used in another file can be imported.

Open the attribute table of this shape files and add a new attribute elevation so we can use any name. Say, for the considered shape file so this is the first step is the geo registering and the scanned topo sheets; second step is creating the shape files so the shape files can be created by using this steps in the ArcGIS software.

Then next one is the contour digitization; so this shape file must now be added to the Arc map as a layer open the editor tool bar and click on start editing. If there are multiple shape files in the ArcMap, at the same time specify the target file in the box provided and then select the create new feature tool and start sketching along the contours. So, that is the procedure which we adopt for the contour digitization.

After a contour is completed specify its elevation in the attribute table. So, first one is the digitization of the topo sheet; second one is the creation of the shape file and then we can digitize the contour within the software itself, ArcGIS itself and then so that now we are having the contour details with respect to the say the topo sheet shape file.

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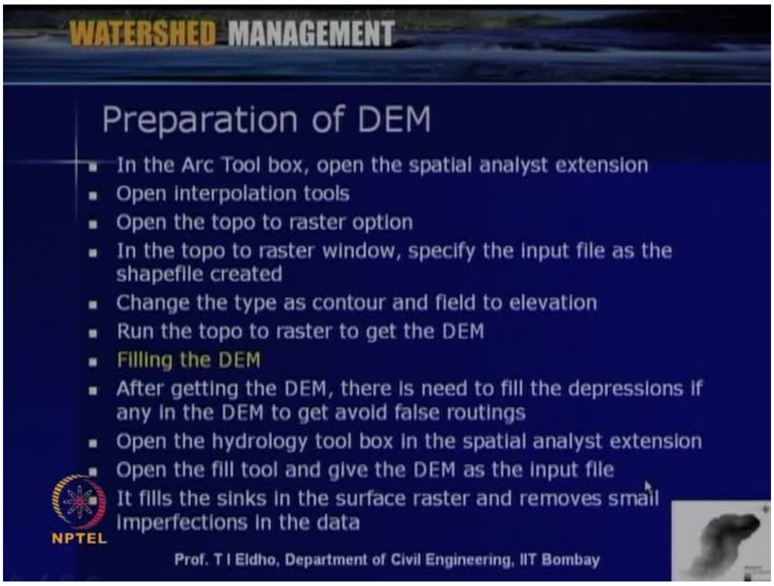

So, then the next step is the preparation of the digital elevation model. So, the steps are listed here in the Arc tool box; open the spatial analyst extension, open interpolation tools, open the topo to raster option then in the topo to raster window specify the input file as the shape file created.

Now, change the type as contour and field to elevation; so then run the topo to raster to get the DEM. Now, using the scanned topo sheet then the shape file and then also the details of contour; we are now making the digital elevation model these steps are mentioned here.

Now, once the digital elevation model say for example, from the BANHA's I mentioned watershed this is the digital elevation model. So, once the digital elevation model is made then, we have to do certain steps. So, that is so-called filling the digital elevation model. So, after getting the DEM there is need to fill the depressions if any in the DEM to get avoid false routings.

So, you can see that depending upon the contour intervals if verifying contour intervals are available then, most of our problem will be solved. But, if there is only coarse contour interval is available like a 10 meter interval or 20 meter interval then whatever the digital elevation model, what we get we are not able to completely or correctly represent the various elevation variations within the watershed.

So, here we can go for a filling the DEM. Here, what we do, open the hydrology tool box in the spatial analyst extension then open the fill tool and give the DEM as the input file. So, it fills the sinks in the surface raster and removes small imperfections in the data. So, we can see that depending upon their case, if there is a drastic change with respect to say due to various the given data then, this will be the filling operation; will rectify this so that we are having a better digital elevation model.

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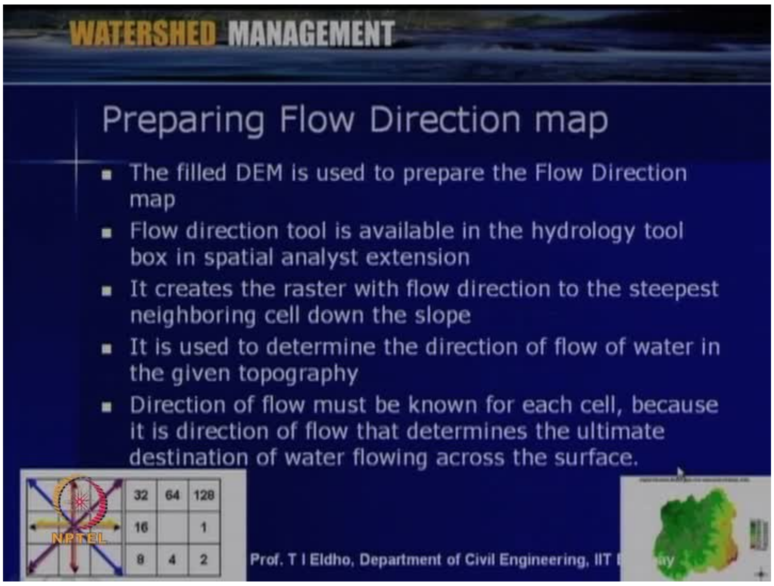

Now, then one next step is preparation of the flow direction map. So, the filled DEM digital elevation model is used to prepare the flow direction map. We can see that if we are now representing the digital elevation model with respect to a grid like this, we should know how the flow is going from one cell to another cell. So, we can have different options like either downward or to right to the left or to the up or say, in 45 direction like this; so different options are available.

So we have to identify depending upon the elevation variation we have to identify how the flow is taking place so the filled DEM is used to prepare the flow direction map flow direction tool is available in the hydrologic tool box in spatial analyst extension it creates the raster with flow direction to the steepest neighboring cell down the cell so that the flow will be in the direction of the say reducing contour so it is used to determine the direction of flow of water in the given topography. So, direction of flow must be known for each cell because, it is the direction of flow that determines the ultimate destination of water flowing across the surface.

So, we can see that now say, as far as the watershed is concerned, say we are now for example, if you are going for modeling like rainfall to runoff modeling. Then, we should say we have to identify how is the over land flow is taking place within the watershed and that over land flow is now joining the channel flow; so that channel flow finally we have to route to the outlet of the watershed.

So, now when we are representing the watershed with respect to agreed and then, now the we have already having the digital elevation model, now we have to identify how the flow will be taking place within the watershed. Especially, overland flow so that overland flow we have route through from one cell to another cell and finally, that cell will join to a channel. So, that direction is very important; the direction of flow determines the ultimate destination of water flowing across the surface.

That weight is very important say for example, if this is the considered watershed and this the outlet of the watershed and this is our digital elevation model, you can see that here various features we are representing with respect to the surveys raster ways representation and then, say this color indicate how the variation of the elevation within each cell. and so that From that we can easily identify how the flow will be taking place and that gives an indication and this helps in our hydrological modeling.

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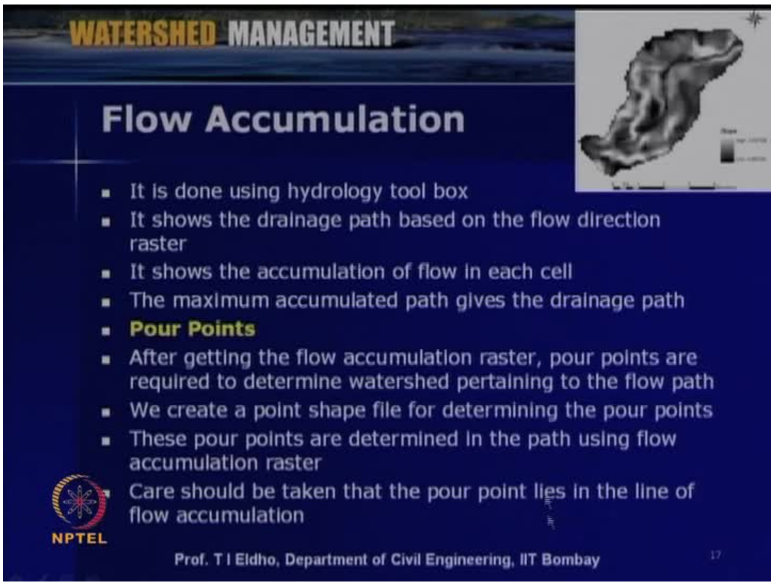

Next step is flow accumulation; it is done using the hydrology tool box. It shows the drainage path based on the flow direction raster and it shows the accumulation of flow in each cell. The maximum accumulated path gives the drainage path. So, this is say for example, this figure (Refer Slide Time: 31:25) shows a slope map which is obtained from the previous digital elevation model which has shown in one of the earlier slide. So, from that we can get the slope map. This slope map also is an indication of how the flow will move as far as the watershed is concerned. Now, say here we will identify the so-called pour points. These pour points actually that show how the flow direction or say, pour points are the points where the lowest elevated point so to which the water be finally flowing.

So, the pour points we identify and then we give it in the software. After getting the flow accumulation raster, pour points are required to determine the watershed pertaining to the flow path. So, we create a point shape file for determining the pour points. So, these pour points are determined in the path using flow accumulation raster. We should take care that the pour points lie in the line of flow accumulation; so the pour points determine the flow path and based up on that only finally the watershed is delineated using the digital elevation model.

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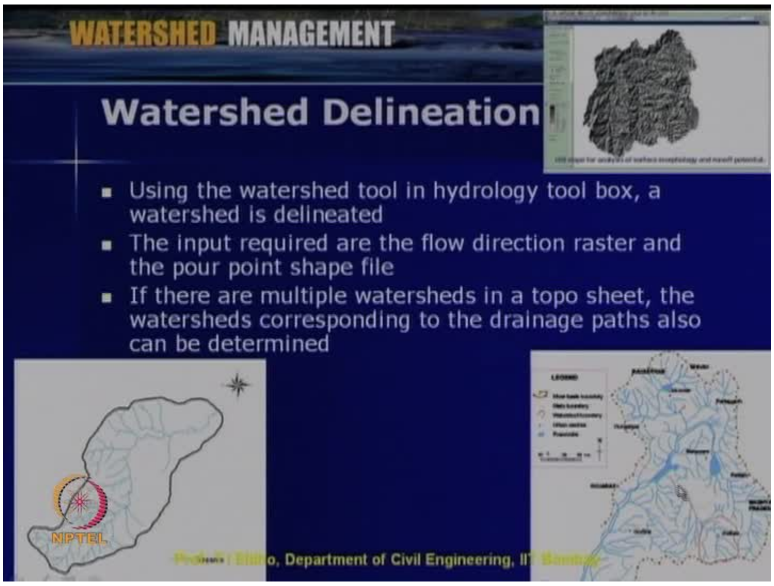

This is the digital elevation model which we mentioned. We can identify the pour points depending upon the various cells or various grid which we consider and then finally, we can identify the various pour points and then from that we can extract the watershed. Finally, after doing this operation now, we are ready to get the delineated watershed. So, using the watershed tool in the hydrology tool box, watershed is finally, we delineate the watershed so if there are the input required are the flow direction raster and the pour point shape file as I already mentioned in the previous slides, so if there are multiple watersheds in a topo sheets, the watersheds corresponding to the drainage paths also can be determined.

So, this is now say for example, for this BANHA watershed this is the finally delineated watershed. This, is the outlet of the watershed; so the delineated watershed gives the boundaries of the watershed, the drainage pattern in the watershed and so this we can directly utilize for various hydrological modeling as far as the watershed is concerned and that we finally utilize as far as the watershed's management is concerned.

Now, say if there are multiple watershed; say for example, if this is a watershed which main watershed and there are many sub watershed like this then say the watershed corresponding to the drainage paths also we can determine and then finally the various sub watersheds also we can identify or delineate the process. So, this way now the watershed delineation is concerned either we can use the manual way or we can use the using GIS or the say the ArcGIS or any kind of software as we mentioned.

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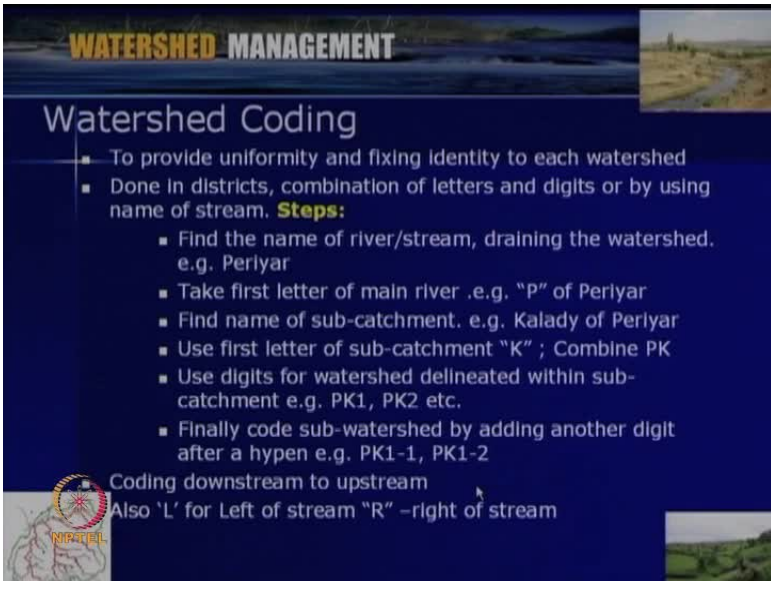

So now Further, once the watershed is delineated say when we are dealing with large number of watersheds, we have to say represent say each watershed; that process is so-called watershed coding. So, watershed coding, it is used to provide uniformity and fixing identity to each watershed.

So when Say for example, country like India is concerned, if you have to identify while going for watershed management if you can identify particular watershed, so that will be very good since we can get various data or various details from various sources for the given watershed. That process is called watershed coding. This provides uniformity and fixing the identity of the watershed. So, the watershed coding is done in districts say in combination of letters and digits or by using the name of streams. This varies from country to country; so, here I explain the steps we adopt say for example in India as prescribed by the central water commission.

The steps are listed here: first step is finding the name of the major river or stream draining the watershed; say for example, a river so-called Periyar in Kerala; we can identify the river so-called Periyar. Now, take the first letter of the main river; say here Periyar means P then find the name of sub-catchment say for example, if a small catchment say in Kalady, say this is a sub-catchment for Periyar then, we can use that word as the next word; so use first letter of sub-catchment K. We can combine this P and K so that we are forming P K; then use digits for watershed delineated within sub-catchment. say for example, sub-catchment 1, sub-catchment 2, like that. We can now code it as PK1, PK2, etcetera. Now, finally code sub-watershed by adding another digit after a hyphen; so PK-1 hyphen 1, PK-1 hyphen 2, so like that the various sub-watershed we can identify within that watershed.

Now, say the coding is generally from downstream to upstream; so that is the general way of watershed coding. Also, we can use left L for left of stream, R for right of stream. So, if this is the river passing then left and right, that way also we can code.

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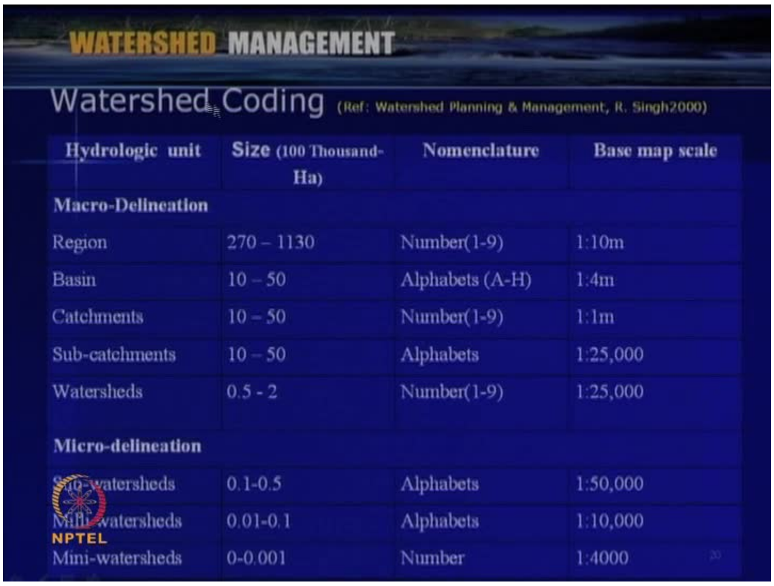

This is the procedure which we adopt for watershed coding. So, watershed gives… it is much easy to identify which is the watershed and then accordingly, we can obtain number of data sets for that given watershed and now say for example, while doing using the or doing the watershed coding, this is taken from the book of Ranaveer Singh, Watershed planning and management.

The hydrological unit we can represent and then, what is the size of the watershed? then various nomenclature, what we generally use and then what is a base map scale? So, that is given here, say for example, if you are going for Macro-Delineation large scale delineation then the region say it can vary from say 270 to 1130 100 thousand square hectare. So, then we can use nomenclature like number 1 to 9 and scale may 1 is to 10 million and say basin wise it can go from 10 to 50 100 thousand hectare so the alphabets we can use say for example A to H alphabets and where the base map scale may 1 is to 4 million and then we can have catchments like 10 to 50 100 thousand hectare and then numbering is 1 to 9 and then the these base map scale can be 1 is to 1 million. So sub-catchment 10 to 50 and then alphabets, we can utilize so the scale can be 1 is to 25000 and then watershed it can vary from 0.5 to 2 100 thousand hectare and numbering can be done 1 to 9 then the base map scale can be 1 is to 25000.

So, then if we are going for micro delineation we can have like sub-watersheds milli-watersheds or the mini-watersheds. The area is described here and then we can use alphabets or number and the scales are also mentioned in this scale.

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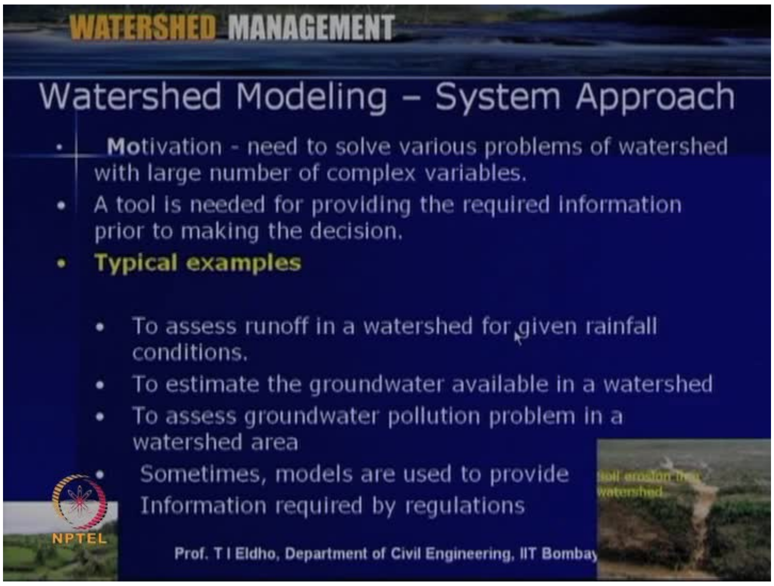

Now, this is about the watershed delineation and then the watershed coding. Now, say second part of this lecture is on modeling; so-called watershed modeling so generally, say once the watershed is identified delineated then, before going for watershed management practices of making plans, we can various processes like hydrological processes and other processes, we have to go for modeling. So, we will discuss generalized steps as far as the modeling is concerned before going to the specifics of watershed modeling.

So, the modeling is, say main motivation is a need to solve various problems of say for example, for watershed with a large number of complex variables. We have already seen that there are number of variables we have to deal starting from rainfall to runoff. Then, various hydrological processes like infiltration, evaporation, transpiration, then interception like that. So, we have to… so this is a very complex procedure and then number of complex variables to be involved in this modeling aspect. We need a tool to provide the required information prior to making the decision say for example, if you are going for a watershed management plan then it is better to do some modeling like a rainfall to runoff modeling or groundwater modeling like that various hydrological processes modeling.

So, say the motivation is to solve various problems as far as the watershed is concerned. Typical examples like, to assess runoff in a watershed for rainfall conditions then to estimate the groundwater available in a watershed to assess groundwater pollution problem in a watershed area. These models generally, either we can use in preparation of the plans watershed management plans or we can use to get the information that are required for the various regulations.

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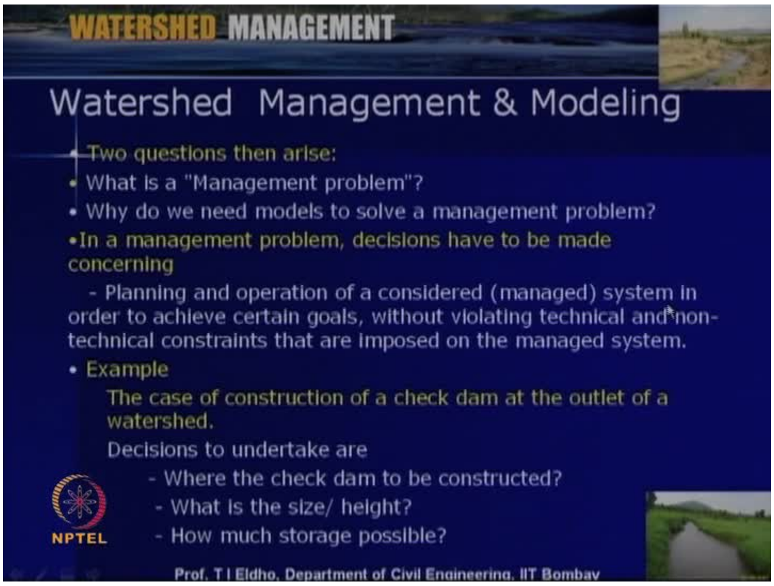

That the way we go for modeling now say, watershed management and modeling so generally 2 questions arise as far as the watershed management is concerned. So, the question is what is a management problem? Whether we are dealing with the water problem within the watershed or what kind of problem we are going to deal. Then, why do we need models to solve such a management problem? So, as I mentioned say when we are dealing with rainfall to runoff, it is very complex process. We have to deal a number of processes what is taking place from rainfall to runoff so that is why we need models.

So, in a management problem decisions have to be made concerning planning and operation of a considered or so-called managed system. We go for a system approach or systematic approach based upon the delineated watershed; so our system here is the delineated watershed. So, in order to achieve certain goals without violating technical and non-technical constraints that is imposed on the managed systems.

There can be various constraints; some of the constraints can be technical; some of the constraints can be non-technical. For example, the case of construction of a check dam at the outlet of a watershed. So, say what we can do for example, if this is the outlet of the watershed and we are planning to construct a check dam. We should know what should be the size of the check dam and then where the check dam to be constructed then what is the size? What is a height and how much storage is possible? So, for this all this we have to rely upon modeling since, it is a very complex process say since we are dealing with a nature, so we have to deal with various parameters various variables in a complex environment; so that is why we need a models.

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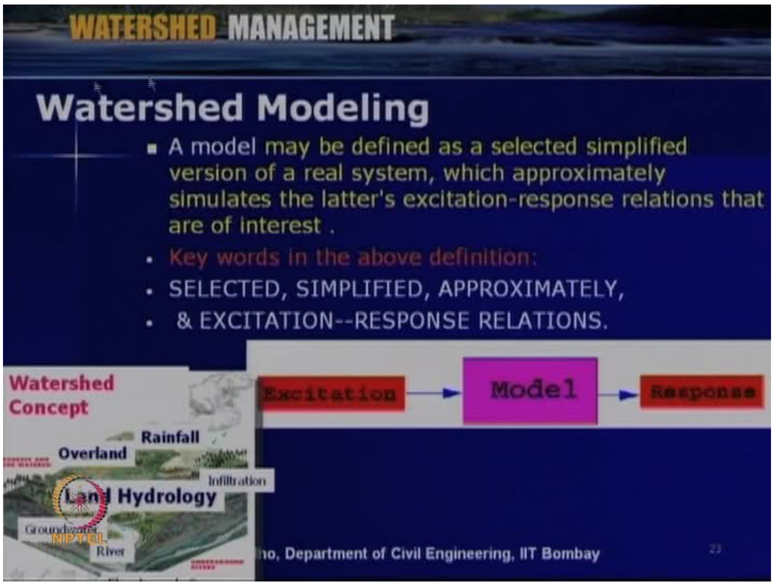

Now, say when we go for watershed modeling; so the question comes what is a model? A model may be defined as a selected simplified version of a real system which approximately simulates the latter’s excitation response relations that are of interest. So, here we can see that definition is we have say the watershed, so-called watershed that is we are have already selected… the system is selected. Now, we put number of simplifications; since all the time we may not be in a position to get the entire complex system. So, we go for some simplifications then the… but, it is still represents the real system and then this, we go for the simulation of the latter’s excitation-response relations. Say, for example, now say from here the rainfall is taking place. As I mentioned we want to identify how much is the runoff possible for the given rainfall.

Rainfall is the excitation and runoff is our the response; so that way we go for modeling say for the watershed modeling. So, the keywords in this definition are the selected, we select the watershed; then we simplified. We simplify by assuming putting various assumptions then we approximate some of the parameters that is approximately then excitation. For example, watershed modeling excitations the rainfall then, what is the response? Response here is the runoff; so excitation; then we will be having a model; then that model use the response, so the rainfall to runoff.

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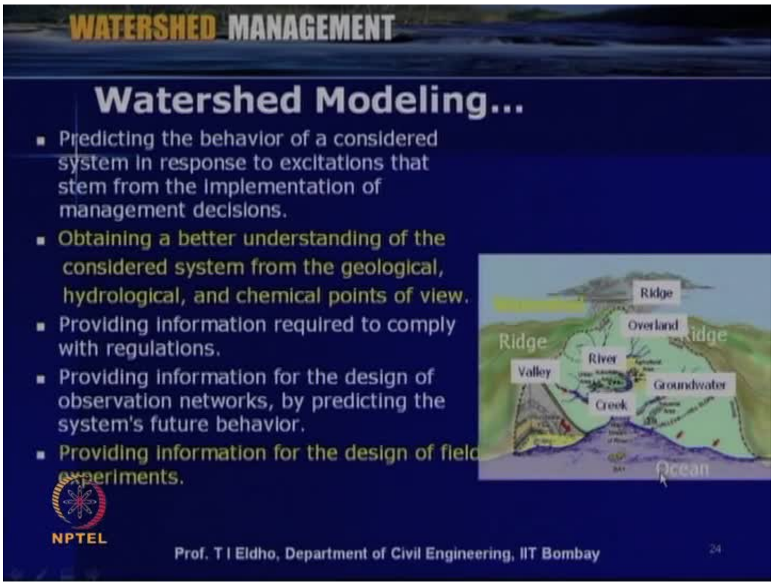

So, model means that is the… for the given rainfall we want to identify, how much is the runoff. So, the runoff is the response; rainfall is the excitation and while running the model we get the runoff. Now, as far as watershed modeling is concerned, we go for prediction of the behavior of a considered system or so-called watershed in response to excitations that stem from the implementation of the management decisions.

As I mentioned, it can be for various plans making or various management decisions or for the regulatory measures; so, we have to get the various aspects. Now, obtaining a better understanding of the considered system from the… we have as far as watershed is concerned, we are trying to get from the geological, hydrological and chemical point of view. As far as the water is concerned, then provide information required to comply with regulations for to obtain the various regulations. Say for example, how much water can be taken from the given dam or say from that aquifer? How much water can be drawn?

So, like that then providing information for the design of observation network by predicting the system's future behavior; that can be another cause for watershed modeling; then providing information for the design of field experiments; so like how much should be the height of a check dam? Like that, various experiments we can do for a given watershed.

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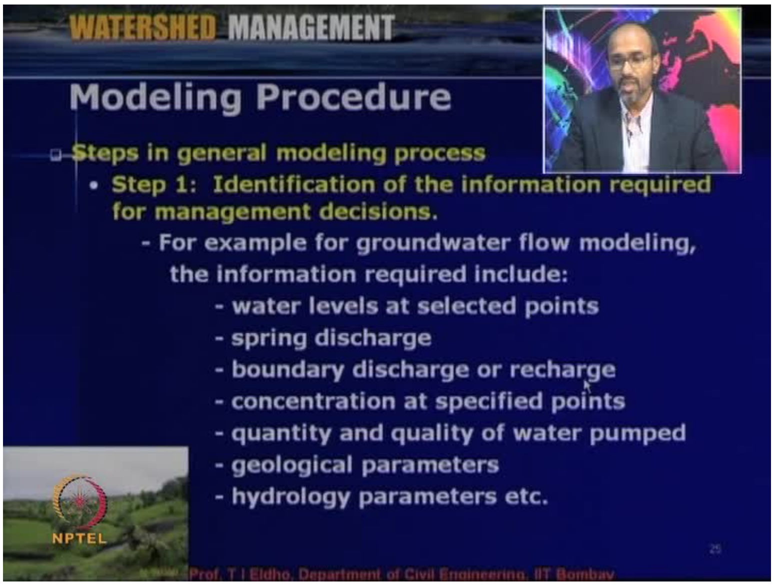

Now, say let us look quickly through what are modeling procedures. Say, number of steps are there while going for a detailed watershed modeling so, the general within a general modeling framework. Here, we will discuss the step by step procedure; so the first step is say now say for example, what we are looking for? We are looking for a say, if we are the consultant and a client is coming to you and then you have to say the client know what he is looking for but he does not know how to get it but, he has some data and some information.

So, as the consultant or as the engineer or as the scientist who are dealing with this problem, first step is step number 1 is identification of the information required for management decisions. So, the problem is known; the objectives are already clear; so to meet to get, to go to that objectives we will be… we can identify what are the information required for the modeling. For example, for groundwater flow modeling - the information required include water levels at selected points, spring discharge boundary discharge or recharge then, concentration at specified points and quantity and quality of water pumped geological parameters hydrology parameters etcetera.

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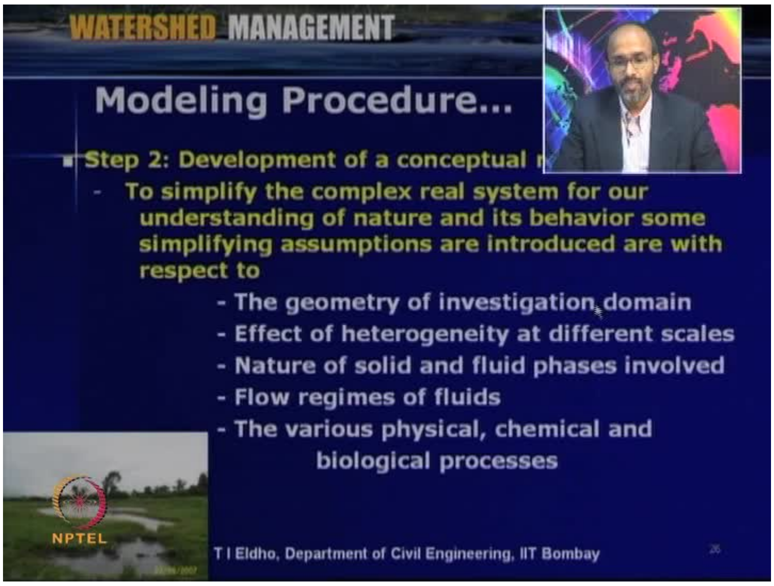

So, this is step number 1; we identify the various information required to achieve the objectives which we have already set in our modeling. now the second step which is the most important step in modeling or say called watershed modeling which we are discussing today, is development of a conceptual model. So, we now understood what are our objectives and now we have already, we have already collected the various data either based upon the data given by the clients or by going to the field or from various sources.

Now, the next step is say we have to conceptualize the problem or we have to develop a conceptual model. Actually, this is the most important step that where an engineer's service or a scientist's service is required. So, we have to put lot of illusions; we have to put lot of assumptions and then come up with a conceptual model that may truly to certain level, that will represent the real nature of the problem. So, what we are doing in development of conceptual model is to simplify the complex real system for our understanding of nature and its behavior; so that, we put some simplifying assumptions with respect to like the geometry of investigation domain. Say, for example, a 3 dimensional problem we assume as 2 dimensions; or a 2 dimension to 1 dimensions or effect of heterogeneity at different scales.

Say, for example, the hydraulic conductivity varying from one location to another location; but, we considered various zones; so average hydraulic conductivity. The nature of solid and fluid phases involved depending upon the problem then flow regimes of fluids then the various physical chemical and the biological processes so this way in step number 2 we make a a conceptual model or we develop a conceptual model.

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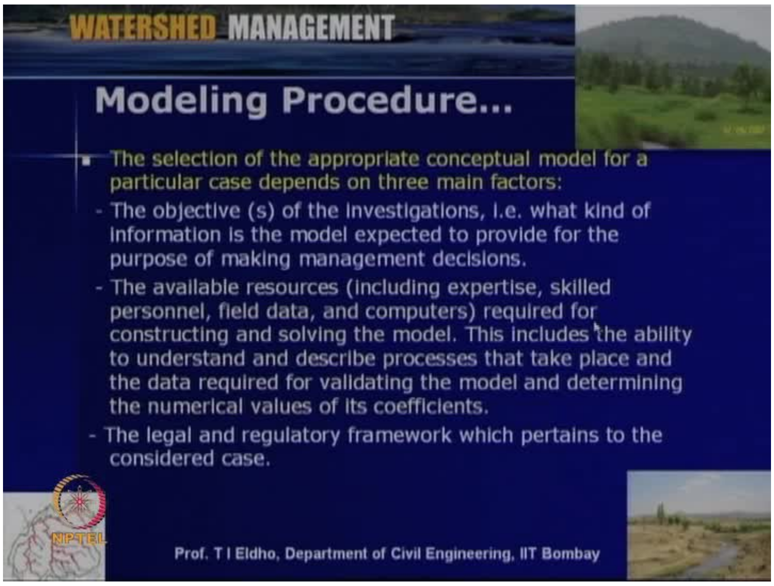

So, while doing this conceptualization, the selection of the appropriate conceptual model for a particular case depends on generally on 3 main factors like the objectives of the investigations: what are your objectives? Then, what kind of information is the model expected to provide for the purpose of making management decisions; then, the availability of resources. So, what kind of data is available including expertise, skilled personnel, field data and computers required for constructing and solving the model? Then, this includes the ability to understand and describe processes that take place and the data required for validating the model and determining the numerical values of its coefficients. Then, the legal and regulatory framework which pertains to the considered case; so, these are some of the issues which we should look in to while constructing or while developing a conceptual model.

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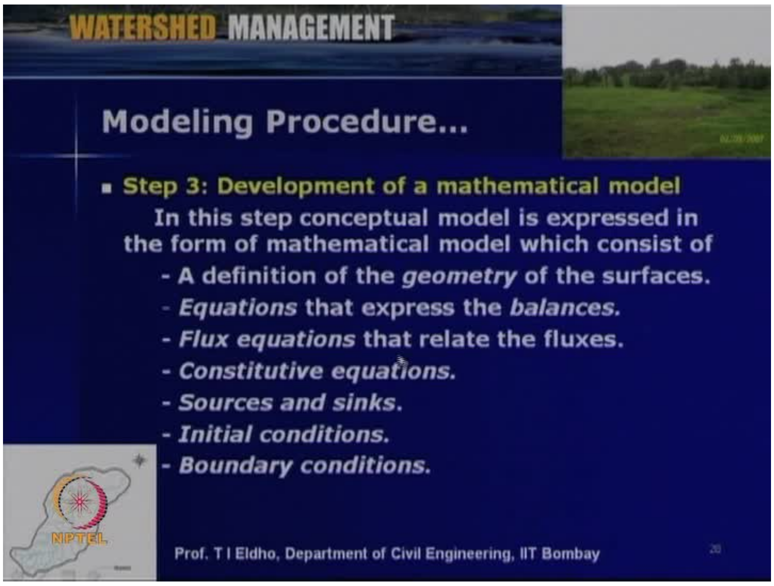

Now, the conceptual model is ready. So, as I mentioned this is the major part of… major say the major role of an engineer or major role of a scientist, to conceptualize the problem. So, once your conceptual model is of good quality, good conceptual model then it is much easy to solve your solve the problem. So, now next step is number 3: development of a mathematical model. In this step, the conceptual model is expressed in the form of a mathematical model which consists of a definition of the geometry of the surface or the surfaces; then equations that express the balances like conservation of mass conservation of momentum; conservation of energy like that ;then flux equation that relate the fluxes; constitutive equations sources and sinks initial conditions boundary conditions.

So, now as I mentioned the watershed model is a watershed is very complicated say, the system; so, it is not possible to have simple models like analytical models or simplified empirical equations. So, we need to generally, most of time, we have to go for complex distributed models; the distributed model means, based upon the conceptual model. Depending upon the problem we can develop a mathematical model.

Mathematical models generally, it constitutes the governing equations. What kind of things we are going to do? Depending upon your objectives we can define the governing equations; we can define the boundary conditions; we can define the initial conditions and then various sources sinks like ground water pumping, ground water recharge or the rainfall conditions or with the withdrawal of the water from the river. So, like that, so that is the essence of the step number 3 that means development of a mathematical model. Then once the mathematical model is developed, so either you can develop Eurone model.

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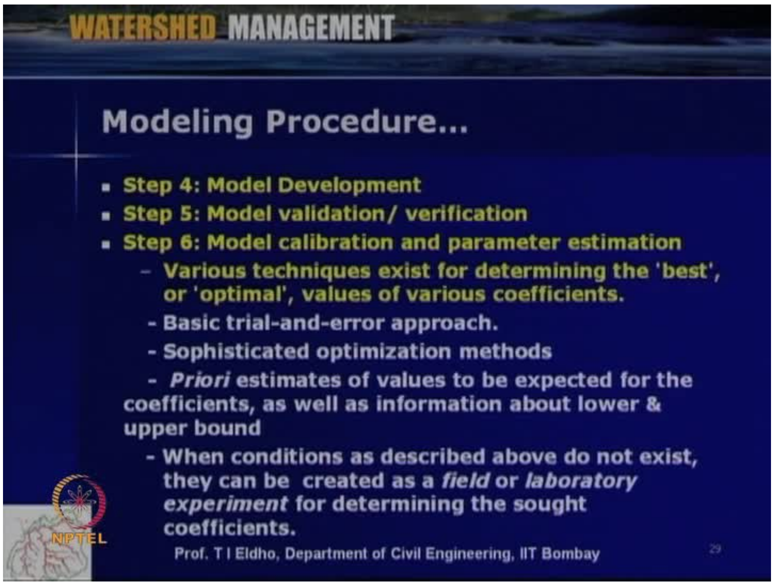

In step number 4, if you have the expertise you can go for Eurone model or you can also buy the available model from the market. So, that is so-called the step number 4 model development. Then, step number 5 we have to generally validate or verify the model with respect to the available data or with respect to various verification with respect to analytical solution. So that is step number 5 model validation/verification and step number 6 - model calibration and parameter estimation. You can see that especially in watershed modeling, a number of coefficients or number of parameters we have to identify based upon the available field data. Since it is so complex we have to identify some of the parameters; so that is model calibration and parameter estimations. So, here so we can various methodologies are there like, a basic trial and error procedure; then sophisticated optimization methods or priori estimates of values to be expected for the coefficients as well as, information about the lower and upper bound.

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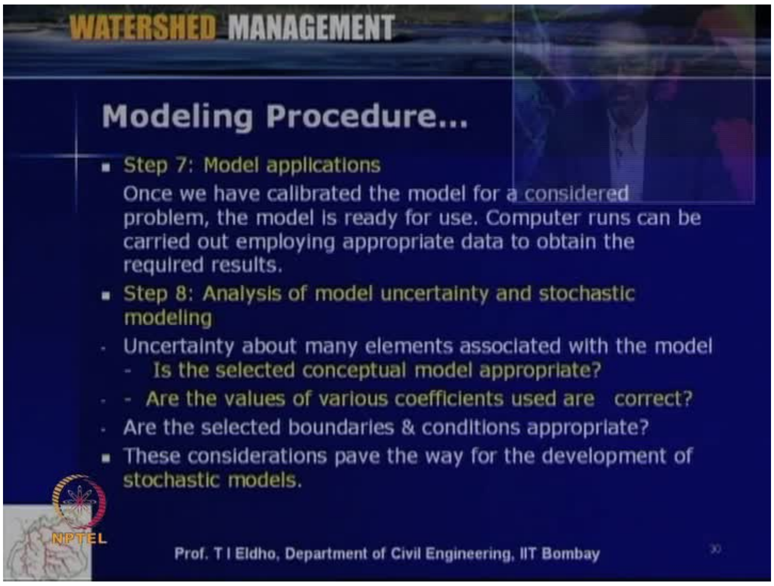

We can identify what are the lower and upper bound; so from that we can obtain the best values. When conditions are as described above do not exist, they can be created as a field or laboratory experiment for determining the sought coefficients. So, this is the step number 6 and step number 7 - the invert model applications. According to our requirement we can go for model applications and then step number 8 we can analyze various model uncertainty and stochastic modeling. So, uncertainty about many elements associated with the model like is a selected conceptual model is appropriate.

Are the values of various coefficients used, are correct or are the selected boundaries and conditions are appropriate? These considerations pave the way for the development of stochastic model. Depending upon what kind of objectives we can further go ahead with a stochastic model or a deterministic model. So, these things we will be discussing later when we discuss the various watershed models.

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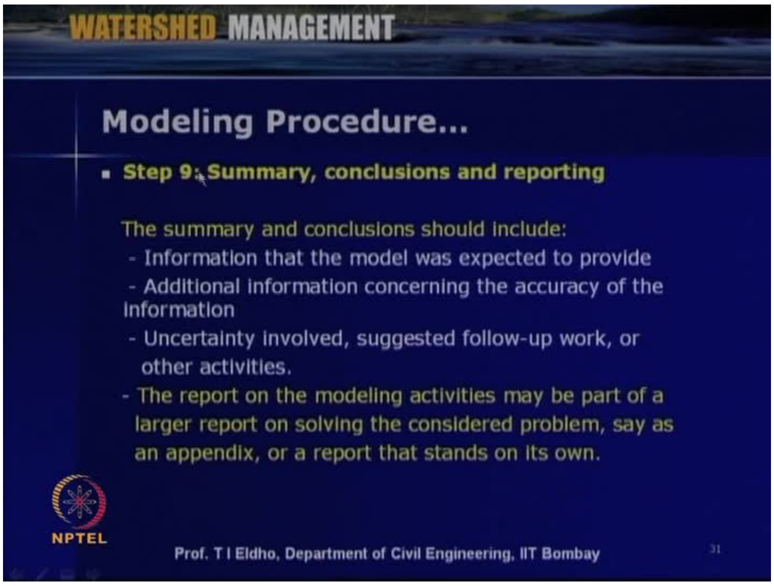

Finally, in step number 9, we can say once the model is run and the applications we got various results and then we can come up with the conclusions based upon the results. So, step number 9 - summary conclusions and reporting so the summary and conclusion should include information that the model was expected to provide additional information concerning the accuracy of the information. Then, uncertainty involved suggested follow up work like that and the report on the modeling activities may be part of a larger report. On solving the considered problem say, as an appendix or a report that stands on its own.

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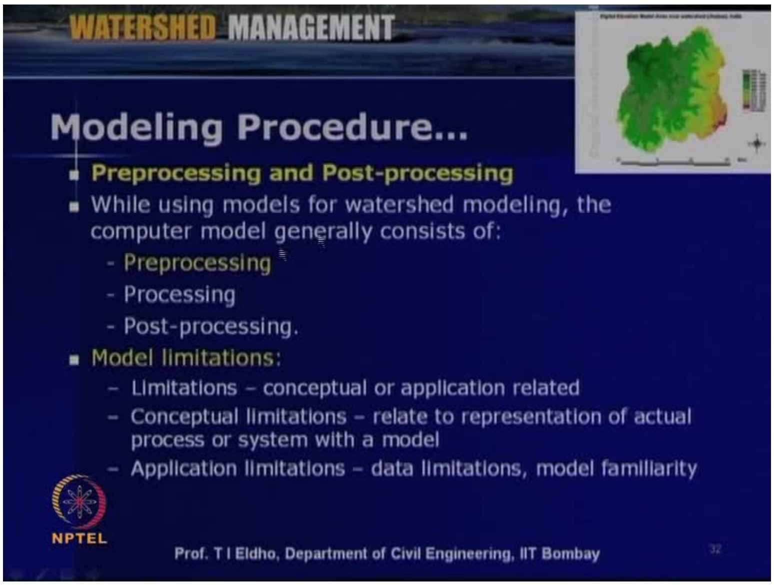

Generally, in modeling procedure there will be 3 steps; in watershed modeling also one is preprocessing. So, we collect the various data required for modeling and then processing that means, we develop the model and we run the model and then last is post-processing. So, once we get the results we analyze those results and then we make various representations in terms of tables, graphs or animations. So, that is preprocessing, processing and post-processing and then models are not always…, it may give the complete answer. So, there are limitations for model, like limitations, like conceptual application related. Then, conceptual limitations like when we conceptualizing 3D model to 2D model; then application limitations like the models runs will be depending upon the data; then say what kind of accurate data; accordingly, we will be having better models.

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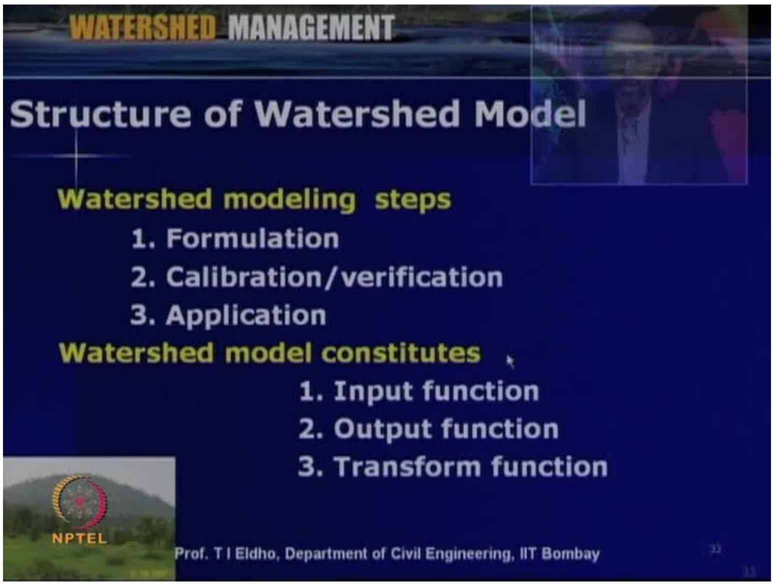

Finally, in this final slide say when we are going for watershed model, we formulate the problem; the steps are formulated; the problem then we calibrate or verify and then next is applications and then, watershed model constitutes the input function like in the case of watershed rainfall; then output function, output runoff then transform function; the various hydrological processes taking place.

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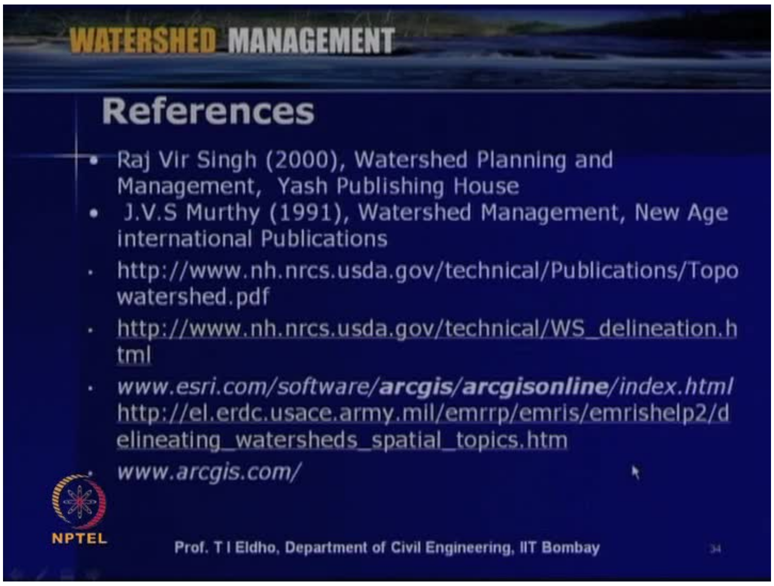

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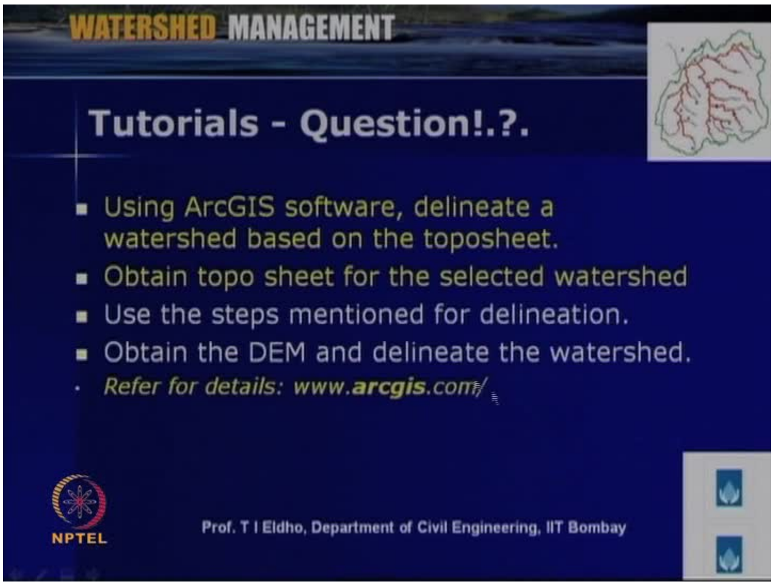

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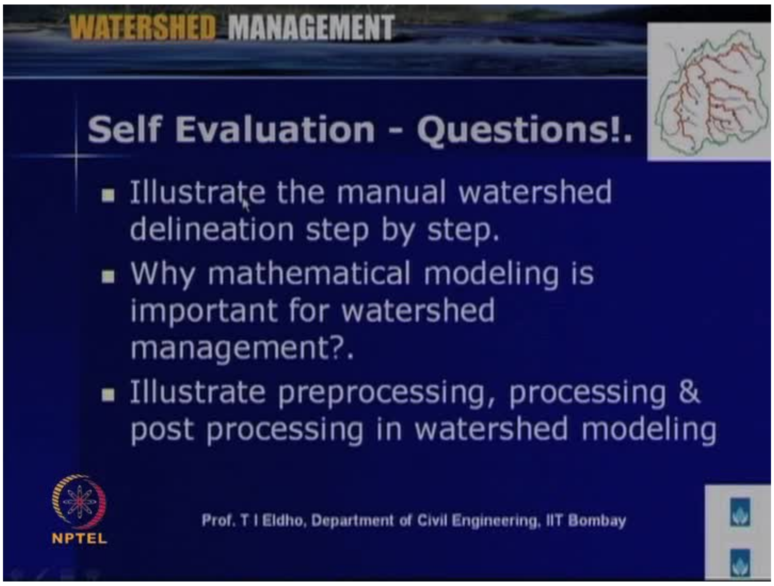

These with respect to this we will be discussing further on the hydrological processes and modeling in the coming lectures. So, before closing this lecture various references used in this lectures, lecture is listed here and then tutorial questions like using ArcGIS software delineate a watershed based on the topo sheet. So, you can obtain topo sheet and then digitize and we can follow the steps given as in the ArcGIS; as given in this website and 3 self-evaluation questions, illustrate the manual watershed delineation step by step; why mathematical modeling is important for watershed management then illustrate preprocessing, processing and post processing in watershed modeling.

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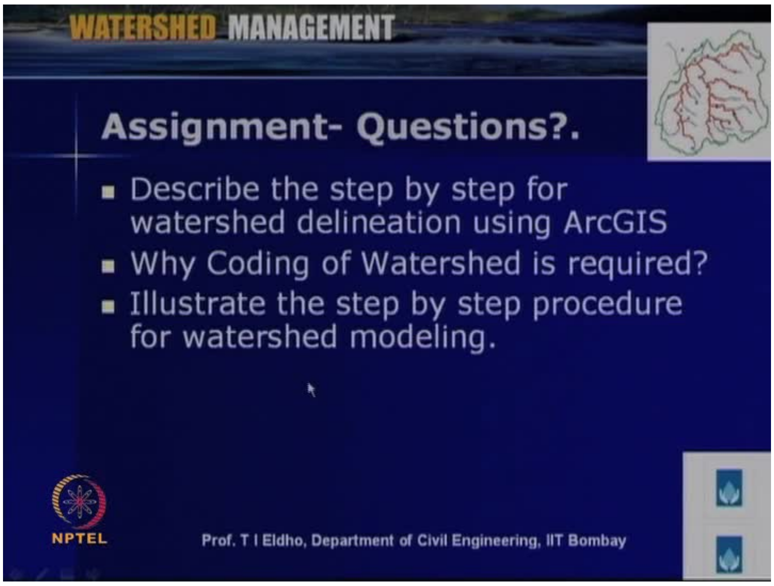

Then 3 assignment questions describe the step by step procedure for watershed delineation using ArcGIS; why coding of watershed is required; illustrate the step by step procedure for watershed modeling. So, all these we have discussed in today's lecture.

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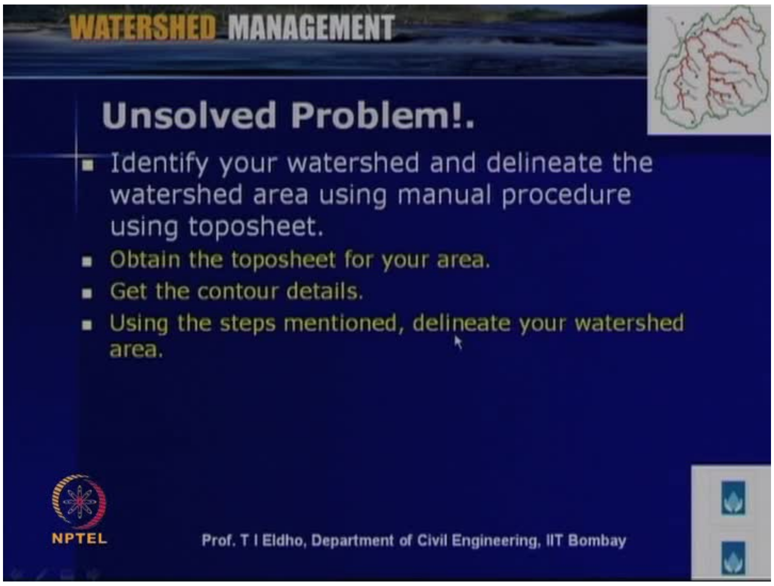

So, for your watershed has an unsolved problem; you can identify your watershed and delineate the watershed area using manual procedure, using a topo sheet. So, we can obtain the topo sheet and then get the contour details and then the step as mentioned in today's lecture you can delineate your watershed. So, in the next lecture we will be discussing about the further the various hydrological processes and then the hydrological models we will be discussing in the coming lectures; thank you very much.