**Watershed Management**
**Prof. T. I. Eldho**
**Department of Civil Engineering**
**Indian Institute of Technology Bombay**

**Module No. # 04**
**Lecture No. # 12**
**Watershed Characteristics**

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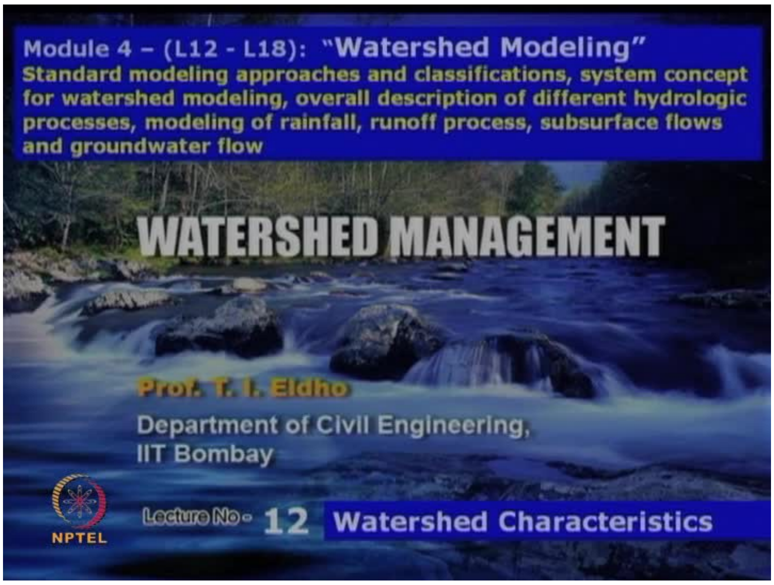


[FL] and welcome back to the video course on watershed management. Today, we will start a new module - module number 4. This module is mainly on watershed modeling. So, the topics covered in this module are standard modeling approaches and classifications, system concepts for watershed modeling, overall description of different hydrological processes, modeling of rainfall, runoff process, subsurface flows and groundwater flow.

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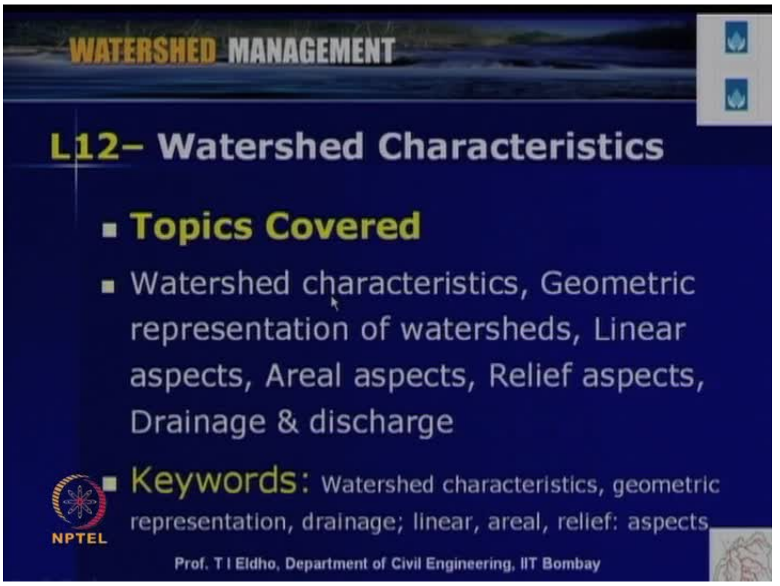


So, in this module, there will be about seven lectures and today in lecture number twelve, we will discuss in this module, watershed characteristics. So, in lecture number twelve - watershed characteristics, we will discuss some of the topics mainly on watershed characteristics, geometric representation of watersheds, linear aspects, areal aspects, relief aspects, drainage and discharge.

Some of the important keywords for today's lecture are watershed characteristics, geometric representation, drainage, linear, areal, relief, aspects. So, we have already discussed about the watershed characteristics in the first lecture itself, when we were discussing about the introduction or introductive aspects on watershed and its management. So, we have seen that when we deal with watershed management, we have to deal with the land, we have to deal with the water and also we have to deal with various resources within the watershed.

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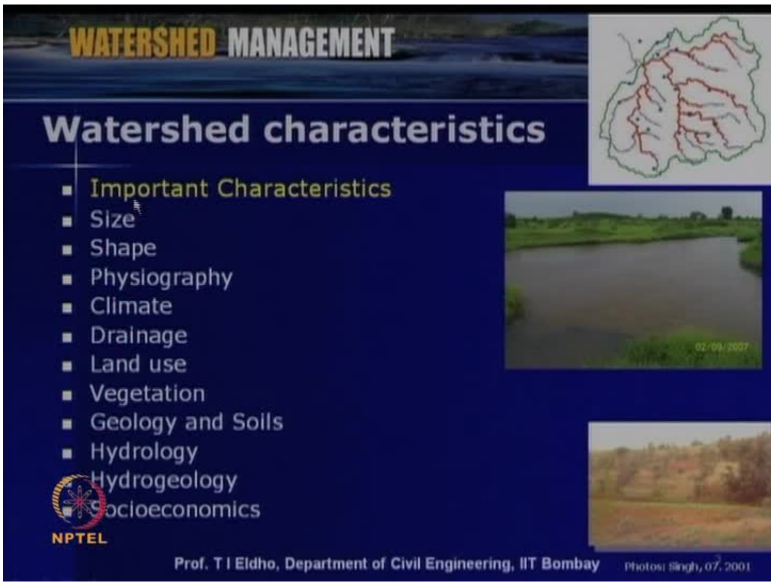


So, there are number of important characteristics which have to be considered, while dealing with watershed modeling or watershed management. Some of the important characteristics I have listed here. So, this includes the size of the watershed; we had a brief discussion about the size in the introductory lecture itself. Then shape of the watershed; what kind of shape, whether it is elongated shape or broad type shape, then physiography of the watershed - so how it is say whether whatever is the various physiographic features within the watershed.

Then climate like the rainfall - say humidity or temperature and various aspects, then the drainage pattern within the watershed so that the flow, the runoff will be accordingly to vary. Then land use – so, what kind of land use is there within the watershed, whether it is forested or whether it is agriculture or whether it is a scrub land and like that, then vegetation – so, what kind of vegetation, whether it is grassland like this or small trees like this.

Then geology and soils - the various hydrological processes taking place within the watershed like infiltration and various other parameters depend upon the geology and soils of the watershed, then hydrology; that is already within the climate aspects like rainfall to runoff and various other hydrological processes and hydrogeology - like ground water and then infiltration and other parameters.

Then of course, the socio economics; when we are dealing with watershed management, what is the nature of the people living in that watershed area and what is their economical background, what kind of work they are doing or what kind of land use are there within that watershed. So, there are a number of characteristics, which we have to identify and then quantify so that many of these parameters we utilize especially, when we say watershed modeling or when we go for watershed management.

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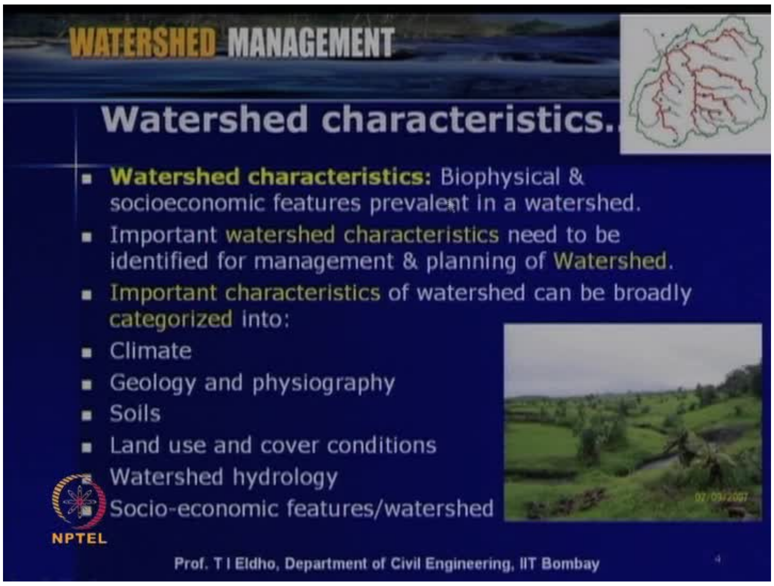


So, these watershed characteristics, as I already mentioned earlier, so this watershed characteristics indicate the biophysical and socio economic features prevalent in a watershed. As we have seen, various characteristics are there and these characteristics mainly indicate what is the physical nature of the watershed, what is the biological nature of the watershed and then what are say, hydro geological nature of the watershed and the socio economical features, which are prevalent within the watershed.

So, as I mentioned, we have to identify these important watershed characteristics and then we have to say many of the times, when we go for watershed modeling or management, we have to quantify so that some values for particular parameters like area of the watershed, length of the channel or the slope, all those who have specific characteristics, we may have to give it in say, while doing modeling or while doing the say making the plans for watershed management.

We have seen many characteristics as far as watershed is concerned. So, these characteristics, we can broadly classify or categorize into climate related characteristics, geology and physiography related characteristics, soil related characteristics, land use and land cover conditions, then watershed hydrology and then socio-economic features of the watershed.

So, we have seen many parameters in the last slide. So, those parameters and many other parameters also we can classify into say about say 6 classes like climate, geology, physiography, soils, land use and land cover, watershed hydrology and socio-economical features of the watershed.

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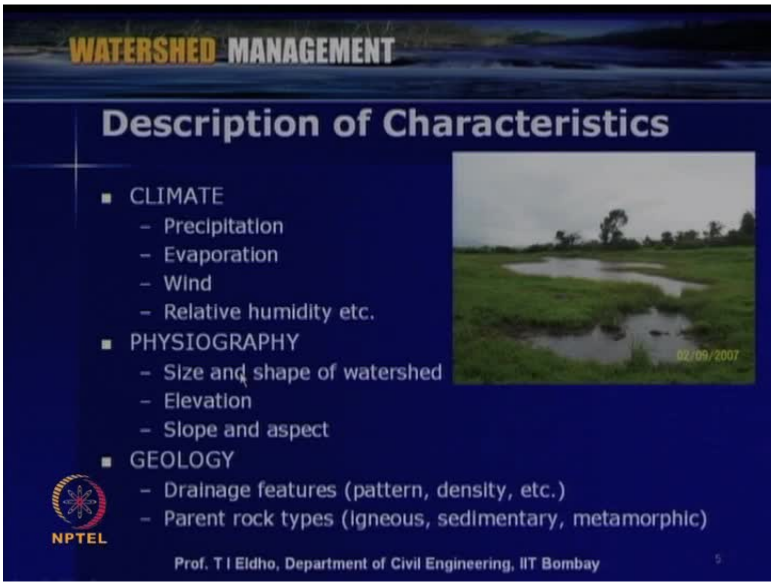


Now, let us see what are the important characteristics within each of these classifications or each of these groups? If you consider climate, as we have seen earlier, when we deal with a watershed management or when we are going for watershed modeling, the important aspect is water availability within the watershed.

Also various climatological parameters like wind, wind velocity or the temperature or the humidity like that. So, the climate parameters mainly include the precipitation; through precipitation or rainfall, there will be runoff and that will be the source of water as far as the watershed is concerned.

Then, with respect to the temperature: so, temperature is another important climate parameter. With respect to the temperature, there will be say, while modeling the watershed, we have to quantify many parameters like evaporation then evapotranspiration and then other climate parameters include wind, relative humidity etcetera.

Now, if we consider the physiography of the watershed, then we can classify say the watershed or the as far as the characteristics of the watershed we can deal with respect to the size and shape of the watershed. So what is a size - whether it is a major watershed or it is a sub watershed or it is a minor watershed or micro watershed like that with respect to size and then what is the shape of the watershed?

Especially, shape is very important. According to the shape, the runoff characteristics within the watershed will change, then another important physiographic parameter is elevation. So, you can see that the watershed say in the within the watershed, the elevation or the various the slope is changing from one location to another location.

So, the elevation According to elevation, we can identify the contours of the watershed and then we can say see various parameters related to that and then slope and aspect. Slope is of course, with respect to the elevation aspect of the various points within the watershed. Then aspect means it can be linear aspects, areal aspects or the say the height related aspects. These details, we will be discussing later.

Then another important characteristic is related to geology like the drainage features, then pattern, density etcetera. Then what kind of rock is there within the watershed, say what is the nature of the rock, whether it is igneous, then sedimentary or metamorphic, what kind of rock is there, like that geological parameters are also very important when we deal with the watershed modeling or related to watershed management.

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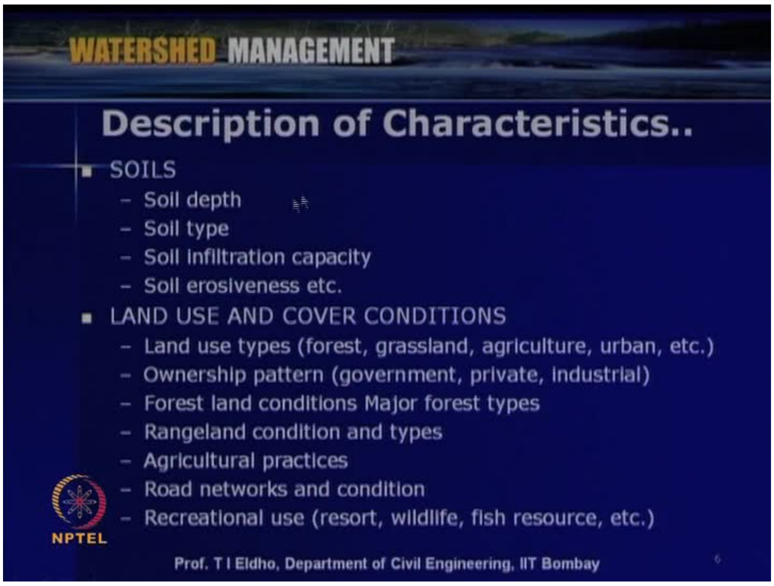


Now, as far as soils are concerned, within the watershed, what is the depth of the soil? So, that is very important since accordingly, the agriculture activities or accordingly, the filtration parameters will vary.

Then what is the type of soil, whether it is sandy type soil or the loamy type or the clay type, what kind of soil. Then soil infiltration capacity; so, we discussed earlier that in the rainfall runoff process, infiltration is one of the important parameter, which is controlling the runoff process. So, we have to identify the infiltration capacity of the soil within the watershed.

Then soil erosiveness: we have already seen earlier the erosion sedimentation problems within watershed. Depending upon the nature or soil and other parameters, there will be more or less or what type of erosion problems can be there within the watershed. Finally, the land use and land cover conditions: so, land use say accordingly the say For example, many parameters like man use reference coefficient or the agricultural pattern, all those things will be according to the land use and land cover. So, land use types like forest, grassland, agricultural land, urban land etcetera, then the ownership pattern say the land is concerned, whether it is government land, private land, industrial land, accordingly, the various things what we can do within the watershed, it will vary.

Then forest land conditions, whether it is major type of forest or we say what kind of whether thick forest or thin forest, then rangeland condition and types, then agricultural practices within the watershed, then say whether there are roads in the watershed like road network and what are the conditions of that road, then recreational like resort, whether the watershed area is used for resort purpose, wildlife, fish resources etcetera. So, these are some of the important aspects or important characteristics, which we have to consider as far as land use and land cover conditions are concerned.

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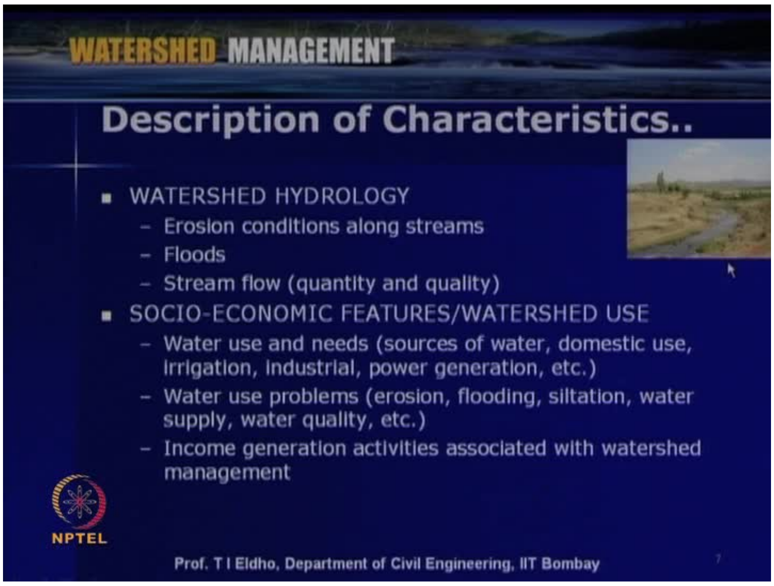


Then as far as watershed hydrology is concerned say Another important classification is watershed hydrology. So, we have to see with respect to the hydrological aspects of the area.

What are the erosion conditions along streams, you can see that this stream is say too much eroded on the banks so that accordingly, the various conditions within the watershed will vary. And then whether say With respect to rainfall whether any flooding problems is within the watershed and how much is the quantity of say runoff taken place within a stream like this – so, quantity and quality. So, these are some of the important characteristics, which we have to consider as far watershed hydrology is concerned.

Finally, the socio-economic features of the watershed: as far socio economic features are concerned like your water use and needs, as far as the people living in the watershed, then water is concerned like what are the sources of water, then what are the uses of the water like domestic use or irrigational, industrial or for power generation purpose etcetera. Then water use problems: so when the with respect to the usage of water within the watershed, whether say with respect to the conditions available within the watershed, whether there can be problems of erosion or flooding or siltation, then as far as water supply, the domestic supply or industrial supply, then what is a condition of the quality of the water, like water quality.

Then another important aspect which we have to deal always is the economical aspects. That means, the income generation activities associated within the watershed. As we have discussed earlier, in any of the watershed management programs the economical status of the people or the income generation facilities available within the watershed, whether it may be through agriculture activities or it is through various mining activities or whatever kind of activities which are possible within the watershed. So, that is also an important characteristic like economic characteristics, which we have to consider, when we go for a watershed management or watershed modeling.

So, now, with respect to the various watershed characteristics, which we have considered some of the important characteristics, we will be discussing in detail, since these characteristics are very important especially, when we go for watershed modeling. Modeling means it can be rainfall to runoff modeling or ground water modeling or many of the other processes that are taking place within the watershed.

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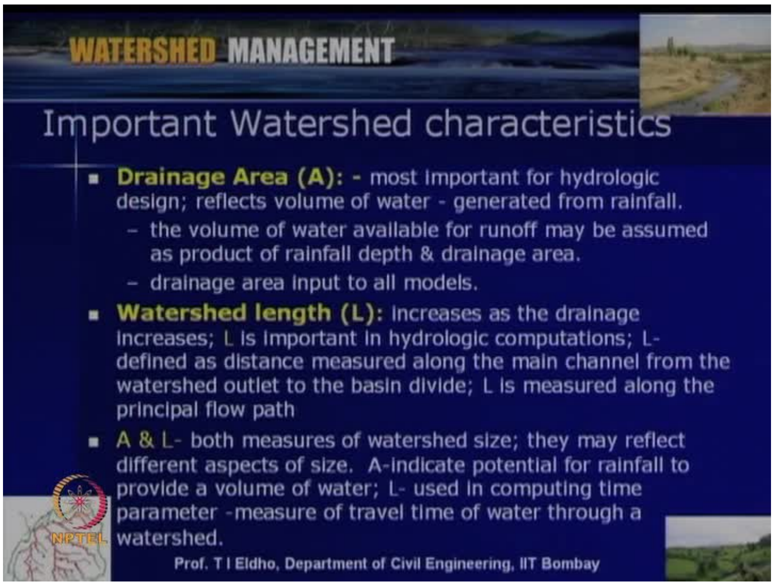


So, let us have a brief look into the important watershed characteristics, what are their definitions and where you will be utilizing as far as the watershed modeling is concerned. So, first one is the drainage area of the watershed.

As far as a watershed is concerned, the area of the total area of the watershed is a most important factor. So, the drainage area is the most important, as far as the hydrological design is concerned. when we deal with especially, with various Land is one of the resource and then with respect to water also, we have to deal with how much is the area of the watershed, so called drainage area.

So this drainage area reflects the volume of water generated from the rainfall. If for example, if 100 mm of rainfall takes place within a watershed, we can identify how much is the volume of water available with respect to this 100 mm rainfall by considering the drainage area. Normally, what we can do, the volume of water available for runoff may be assumed as product of rainfall depth and the drainage area. So, this is a simple calculation, but that may not be so accurate, but, say generally we can take it as the depth of the rainfall or depth of water available multiplied by the drainage area, that will be the volume of water available for runoff within the watershed. Of course, various losses will be there so that we have to consider with respect to the rainfall available or so called excess rainfall, then another important characteristics which we have to consider especially watershed modeling is so called watershed length.

So watershed length is defined as the distance measured along the main channel from the watershed outlet to the basin divide. So, you can see that if this is the watershed, which we consider, here is the basin divides and if somewhere is the watershed outlet then so this is the length from the watershed divide to the outlet. So, that is the definition of the watershed length. You can see that this watershed length increases as the drainage increases. So, that is obvious, when the drainage increases, the watershed length also increases.

So, this is one of the important aspects as far as the hydrology computations are concerned, since the time of concentration and then runoff generation depends upon the watershed length. Then this watershed length L is measured along the principle flow path. If this is the main channel available within the watershed or in this watershed, this is the main channel, then say the watershed length is measured along the principle flow path. So, while going for watershed modeling, this drainage area A and watershed length L both are measures of watershed size. So, what is the watershed size? That depends upon the drainage area and the watershed length.

So, this A and L, they may reflect the different aspects of the size of the watershed. As we have discussed, they indicate the potential for rainfall to provide a corresponding volume of water and L is used in computing the time parameter. As I mentioned, time of concentration or the time required for water to reach from the divide - water divide to the water outlet, it is a measure of travel time of water through a watershed. So, two important parameters as far as the watershed modeling is concerned: these parameters are drainage area and the watershed length.

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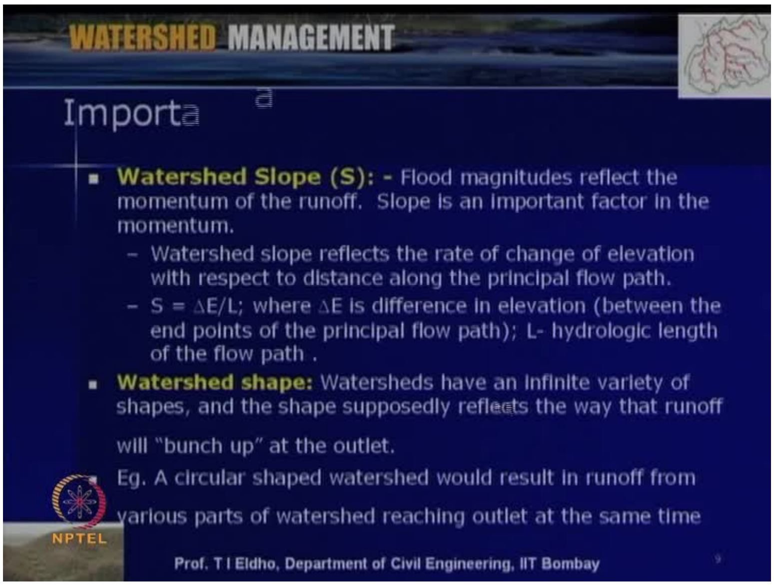


Then some other important parameters like a watershed slope. so the slope according to the slope say When the precipitation takes place, the runoff will be evolved according to the watershed slope. So, the flood magnitude reflects the moment of the runoff. So, slope is an important factor in the momentum.

According to the slope of the say you can see that depending upon what is the slope so here you can see that a steep slope as far as this watershed is there concerned say According to the slope, there will be more momentum as far as the runoff is concerned and watershed slopes reflect the rate of change of elevation with respect to distance along the principal flow path.

So for the watershed concerned If this is the principal flow path, accordingly, the watershed slope reflects the rate of change of elevation. So, the slope S is equal to delta E by L, where delta E is the difference in elevation - that means between endpoints of the principal flow path and L is the hydrologic length of the flow path.

So, if this is our concerned watershed, so S can be defined as say if this is our main channel so here what is the height here and what is the outlet height and then we can identify what is the difference in elevation between these two points and then we can identify what is hydrologic length. So, slope will be - watershed slope will be delta E by L.

Then another important characteristic is watershed shape. So, watershed shape have an infinite say As far as watershed shape is concerned, there can be infinite variety of shapes. It can be broad type or elongated type or somewhat circular type. So, there can be number of types of shapes and a shape supposedly, reflects the way that runoff will bunch up at the outlet.

So, you can see that if there is a narrow shaped watershed, then the runoff will be much say, it will take small period of time, but if it is a broad type watershed like this, more time for that all this say the runoff will be bunching up at the outlet. So, watershed shape is an important parameter.

So, say For example, a circular shaped watershed would result in the runoff from various parts of the watershed reaching outlet at the same time. So, the shape is very important whether it is say somewhat circular type or the broad type or rectangular type or square type or narrow elongated type. Accordingly the various Especially, when we are going for watershed modeling, accordingly, the runoff process the say for example, time of concentration would vary or say the total runoff will vary according to the shape of the watershed.

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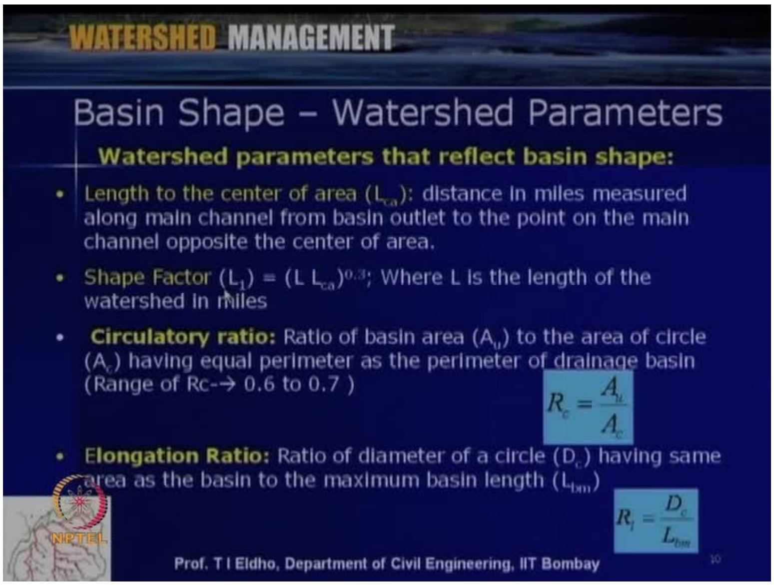


Now, as far as the watershed shape is concerned, there are number of important parameters, which we have to consider. So, basin shape and related watershed parameters. So, the watershed parameters that reflect the basin shape include the length to the center of area. That is the distance say in miles or kilometers measured along the main channel from the basin outlet to the point on the main channel opposite the center of area. So, this is the definition as far as length to the center of area of the watershed is concerned.

This depicts one of the character the parameter as far as the basin shape is concerned. Then another important parameter is shape factor. We can define the shape factor as L into L ca to the power 0.3, where L is the length of the watershed in miles and L ca is the length of center of area. So, as shown here, shape factor is equal L into L ca to the power 0.3.

Now, another important aspect is the circulatory ratio. So, the circulatory ratio is the As far as basin shape is concerned, circulatory ratio means the ratio of basin area to the area of circle having equal perimeter as the perimeter of drainage basin. That means, circulatory ratio is defined as the ratio of the basin area A u divided by the area of a circle, which has equal perimeter as the perimeter of the drainage basin. So, generally, depending upon the watershed, the circulatory ratio can vary from 0.6 to 0.7.

Then as far as shape is concerned, another important parameter is so called elongation ratio. As I mentioned, with this shows whether what is the shape like say, narrow type or broad type watershed. So, the elongation ratio it is a ratio of the diameter of a circle, D c having same area as the basin to the maximum basin length.

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So, the elongation ratio R l is equal to D c by L bm, where D c is the diameter of a circle having same area and then L bm is the maximum basin length. As far as the basin shape is concerned, these four important factors or four important parameters like length of the center of area, then shape factor, circulatory ratio and the elongation ratio.

Now, again let us come back to some of the other important watershed characteristics or say cold watershed factors. As we can see, if you go to any of the watershed, we can see that when we go from one location of the watershed to another location, the various features or the various geographical or physiographical features are varying from one location to another location.

So, you can see that this is a watershed say, here you can see the relief is changing, the slope is changing, then say, the land use is changing. So, all the parameters are changing from one location to another location and then in the direction-wise also. That is why, we can say that any of the watershed is say as when we go for watershed modeling, watershed, we have to consider as highly heterogeneous and anisotropic. So, as far as any parameter is concerned, all these parameters will be varying from one location to another location in the lengthwise or any location-wise.

We have say other parameters like land cover. You can see that this watershed here grass is there, then other location say plants are there or some other location trees are there; so, the land cover is changing and land use is concerned say, some of the area may be covered by the agricultural land, some of the area may be forest land and according that land use will be varying and when especially when we go for watershed modeling, one of the important aspects in scientific modeling, what we have to consider is the roughness of the area.

When we are transforming the rainfall to runoff, various hydrological process, which we have to consider. So, when we go for physical modeling, the runoff depends upon the roughness of the watershed. So, this roughness can vary according to the various parameters like land cover, land use and the type of soil.

Then as far as soil is concerned, some of the important soil characteristics like texture of the soil, how is the texture, then what is a soil structure, then of course, as far as runoff is concerned, how is the soil moisture and then especially, when we go for various modeling, we can classify the various soil types within the watershed into various groups.

So, that kind of classification, we call it as hydrological soil groups. This aspect we will be discussing in some later lectures. So, hydrological soil groups accordingly we can identify various parameters like say, the initial soil moisture or the hydraulic conductivity as far as the soil is concerned. So, like that number of soil characteristics, which we have to deal as far as the watershed is concerned.

Now, again, coming back to the say watershed is concerned to the channels within the That means, the drainage or the channels within a watershed is very important in watershed modeling.

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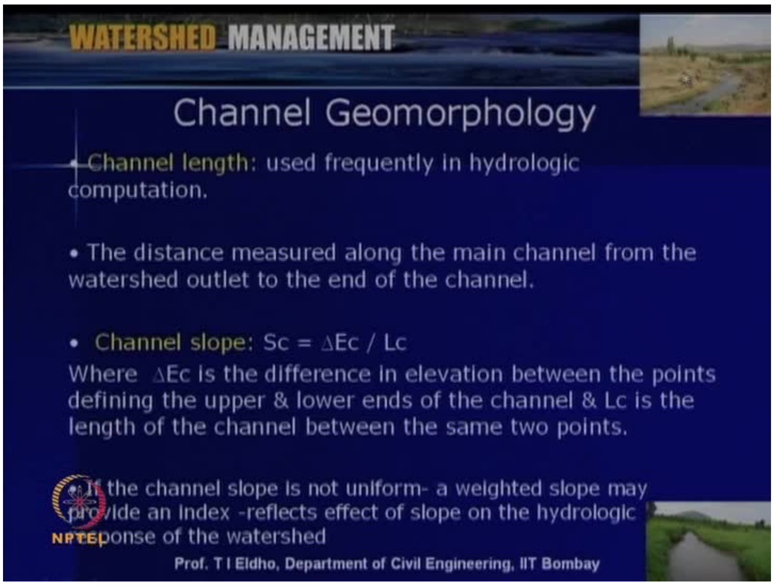


Channel geomorphology is one of the important aspect, which we have to consider. So, channel geomorphology is concerned, some of the important aspect, which we have to consider include channel length. So, this is as we already discussed earlier. This channel length is used frequently in hydrological computations. So, when we say we have to identify what will be the runoff available at the outlet of the watershed, we have to see what the channel length is. Accordingly, we will be routing the flow what is happening as far as the rainfall to runoff within the watershed.

Then the distance measured along the main channel from the watershed outlet to the end of the channel, that is, the channel length as we discussed. So, the channel length is the distance measured along the main channel from the watershed outlet to the end of the channel.

Channel slope: channel slope is equal to delta E c by L c, where delta E c is the difference in elevation between the points defining the upper and lower ends of the channel and L c is the length of the channel between the same 2 points. So, if this is a channel, from one end to the other end, what is the length and what is the elevation difference? From that, we can calculate the channel slope.

Most of the watershed due to the heterogeneity, channel slope will keep on changing. If the channel slope keeps on changing from one point to another point, then we can take somewhat an average of the channel slope. If the channel slope is not uniform, a weighted slope may provide an index; that reflects effect of slope on the hydrological response of the watershed.

As I mentioned it, when there is rainfall to runoff process taking place, we have to route the flow and then we have to also consider the channel slope. So, how much is the hydrological response that depends upon the channel slope.

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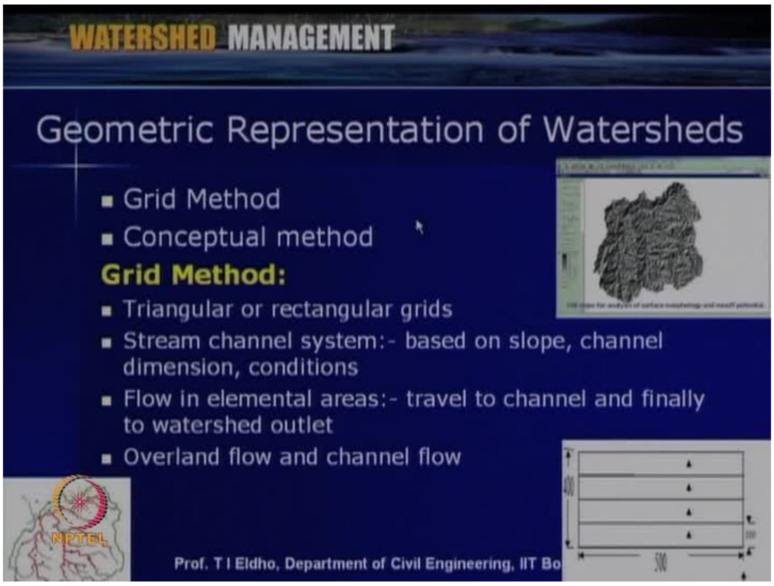


Now, when we deal with the watershed modeling, we have to represent the various features within the watershed by considering the length aspects or the areal aspects and then the elevation aspects like that.

So, the geometric representation of watershed is very important in watershed modeling. There are basically 2 concepts generally used as far as the geometric representation is concerned. First one is called a grid method and second one is called a conceptual method. So, both these methods, we will discuss in detail.

In the grid method, what we have to do, we generate As far as the watershed area is concerned, if we know the boundary of the watershed, what we can do, we can put the watershed boundary within a rectangular or triangular grids. So, in the grid method, we represent the grid just like a triangular grid or rectangular grid. So, the stream channel system As far as watershed modeling is concerned, we have to consider the overland type flow and the channel type flow.

The stream channel system is based upon the slope, channel dimensions and conditions, we have to deal. In the grid, we can use the triangular or rectangular grid and the flow in elemental areas like if this is the rectangular grid which we consider, the flow from one element to other element travel to channel and finally, to the watershed outlet. If this is the watershed outlet, which we consider, we can consider grid like represented here. As far as the flow is concerned, the flow travels say one grid to another grid, and finally, to an adjacent channel and finally, to the outlet of the watershed.

As I mentioned, watershed is concerned, we have to the see the overland flow and the channel flow. So, the overland flow and channel flow, mainly overland flow we can consider with respect to the rectangular grids or triangular grids and these grids will be connected to the channel. Generally, channel flow, we consider as one dimensional flow and overland flow, either we can consider as one dimensional strip type flow or two dimensional flow. So, this overland flow strips will be connected to the channel flow so that we can identify when the rainfall runoff process taking place. We can route the flow from say one overland strip to another strip and then that will be joining to a stream and through the stream, we can finally, route the flow to the outlet of the watershed.

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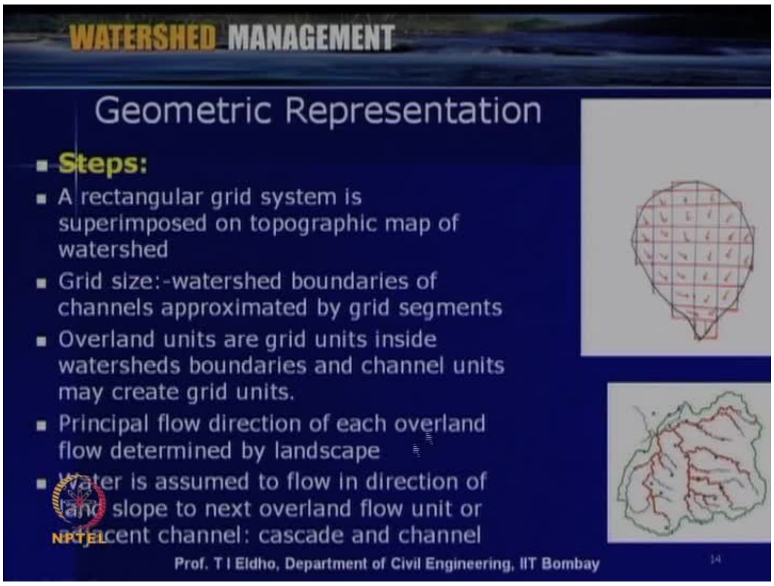

So the various steps which we have to consider as far as the geometric representation is concerned, the steps are listed here. We can consider rectangular grid system. You can see that if this is the outlet of the watershed, this is a rectangular system which we can consider. Rectangular grid system is superimposed on topographic map of the watershed.

We can get the topographic map of the watershed from which, we can identify the boundaries of the watershed. Then we can superimpose on a grid system like this and the grid size, the watershed boundaries of the channel approximated by grid segments. What is the grid segment accordingly, we can approximate the boundaries of the watershed. You can see that since when we consider especially rectangular grid system, we cannot exactly represent the variation of the boundary of the watershed so we can approximate it

But if you use triangular grid, then we can better way we can represent the regular boundaries as far as the watershed is concerned then say overland units are grid units inside watershed boundaries and channel units may create grid units. You can see that so this can be a channel unit which is going to the outlet or watershed.

These are all the overland units. That will be slowly merging to the coming to the channel segment is concerned. If this is the main channel, you can see that various small channels will be there and that will be coming under this grids and that will finally, join to the main channel.

So, the principal flow direction of each overland flow is determined by the landscape. So, you can see that the landscape what is the landscape like, what is the slope, what is the size of the watershed, what is the shape of the watershed and accordingly, principal flow direction will vary.

Water is used to flow in the direction of land slope to next overland flow unit or adjacent channel. So, we will be considering cascade type flow conditions so that these cascade of the overland flow will be joining to the channel. So that is the grid representation. We have already seen earlier grid method. In grid method, we can follow these steps as far as the geometric representation is concerned.

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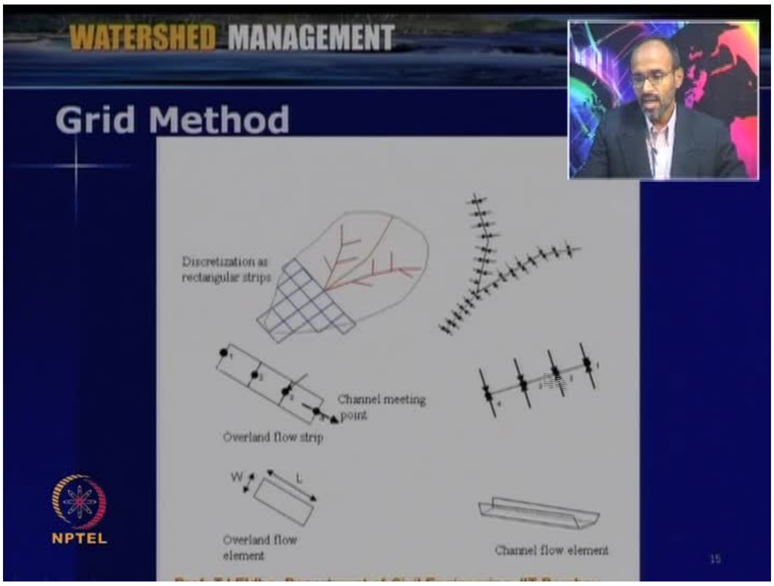


As I mentioned, if this is our watershed, so the overland flow is concerned, we consider the various grids say, one dimensional or two dimensional grids, as one dimensional strips and in two dimensional grids. These grids, you can see that it will be like this. It will keep on joining to the important channels.

So, channel is represented as one dimensional like this and then the overland flow is considered as an element like this, either in two dimension or one dimension and this will be joining. So, this is the way we do the representation, as far as the grid method is concerned

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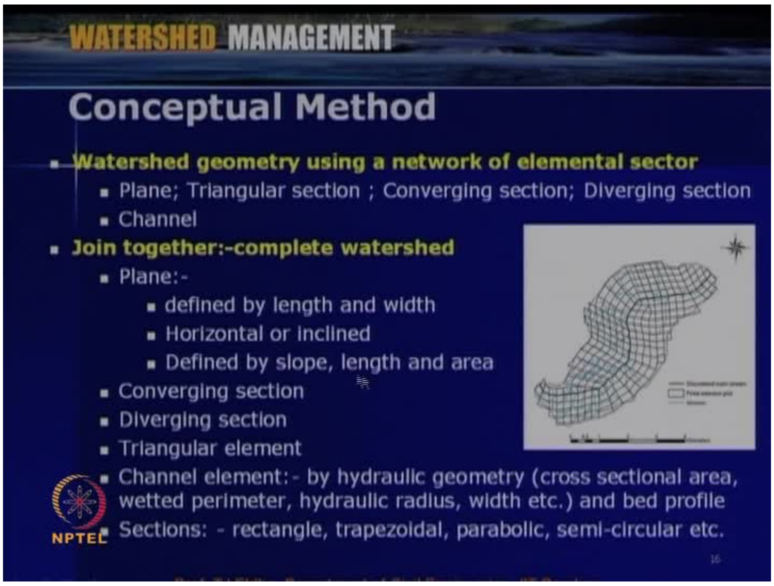


Now, the next one is the conceptual method. In the conceptual method, watershed geometry is defined using a network of various elemental sectors like a plane triangular section, converging section, diverging section and the of course, the channel

Say for example, if this is the watershed, then you can see that if this is the channel present, then we can consider various planes, then sometimes triangular shapes or the converging, this converging or diverging like that. When we join all this, say the sectors like a plane triangular or whatever sectors which we consider, then when we join together, we have the complete watershed.

The plain is defined by the length and width and that can be either horizontal or inclined and then they said it is defined by the slope length and area, so like that. Then as far as converging section is considered, you can see that depending upon the variation of the shape of watershed and the slope, we may use converging section or diverging section.

Then many times it will better to use triangular element so that you can easily represent the regular shape of the watershed. As far as channel element is concerned, the hydraulic geometry like cross sectional area, wetted perimeter, hydraulic radius, width etcetera and we will be considering as far as the channel element is concerned.

So as far as this watershed is concerned, this is the channel. So, we will be considering what is the cross sectional area of this channel, what is the vector perimeter, hydraulic radius, width etcetera and the bed profile.

As far as the channel section is concerned, it can be either rectangular section as usual rectangular, or trapezoidal, parabolic or semicircular or triangular section. Like that various sections are possible, as far as the channel section is concerned.

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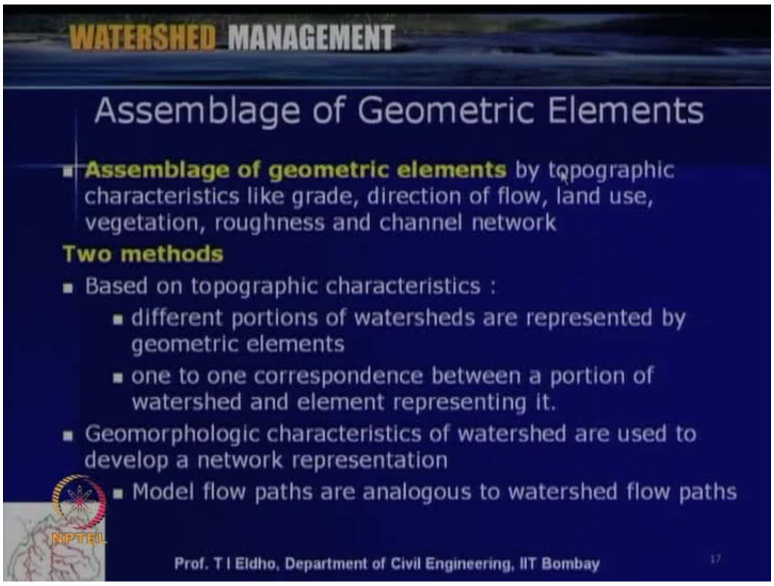


Now, the geometric approach: we can assemble all these elements together so that the entire watershed can be represented by one or another kind of the element. So, we assemble all these geometry elements by topography characteristics like grade, direction of flow, land use, vegetation roughness and the channel network. (Refer Slide Time: 38:51) So, that is very clear from this figure.

There are basically, two methods to do this assembly. So, first one is based on the topography characteristics like different portions of watershed are represented by the geometric elements and then one to one correspondence between a portion of watershed and the element representing it. So, we do this assemblage based upon the topography characteristics and a second one is we can consider geomorphic characteristics of the watershed. Here, we use this geomorphic characteristic to develop a network representation like this so that the model flow paths are analogous to the watershed flow paths. So, the assembly can be done either based upon the topography characteristics or the geomorphologic characteristics.

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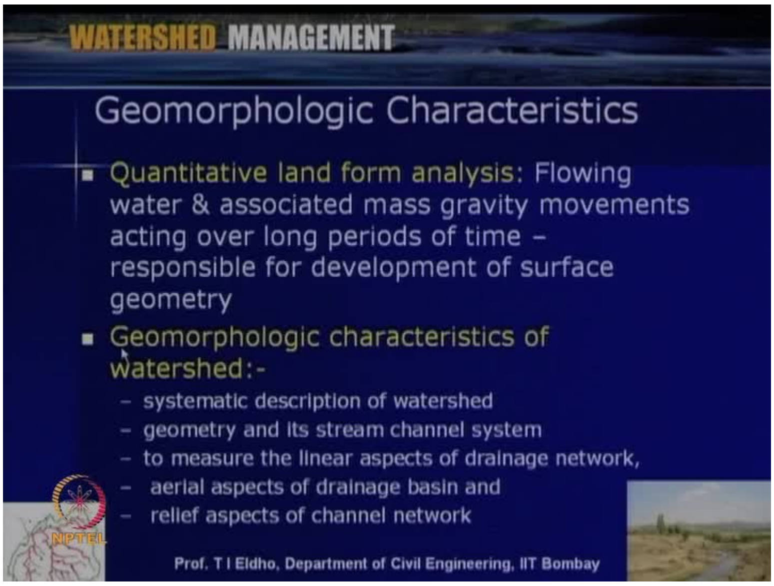


As far as geomorphologic characteristics are concerned, we have to deal with the competitive land form analysis like flowing water and associated mass gravity movements acting over long periods of time. How the flow is taking place and then associated mass gravity movements - all these we have to consider and this is responsible for development of surface geometry. So, a watershed can evolve according to the flow pattern what is happening within the watershed. So, we have to assess what kind of a variation is taking place within the watershed.

Then as far as geomorphologic characteristics of watershed is concerned, we have to systemically describe the watershed. So, a systemic description of watershed is required and geometry and its stream channel system, we have to identify. We have to measure the linear aspects of drainage network, how much is the length of the drainage system and then like aerial aspect of the drainage basin and then relief aspects or elevation aspects of the channel network within the watershed. So, these are some of the important characteristics as far as the geomorphological features of the watershed.

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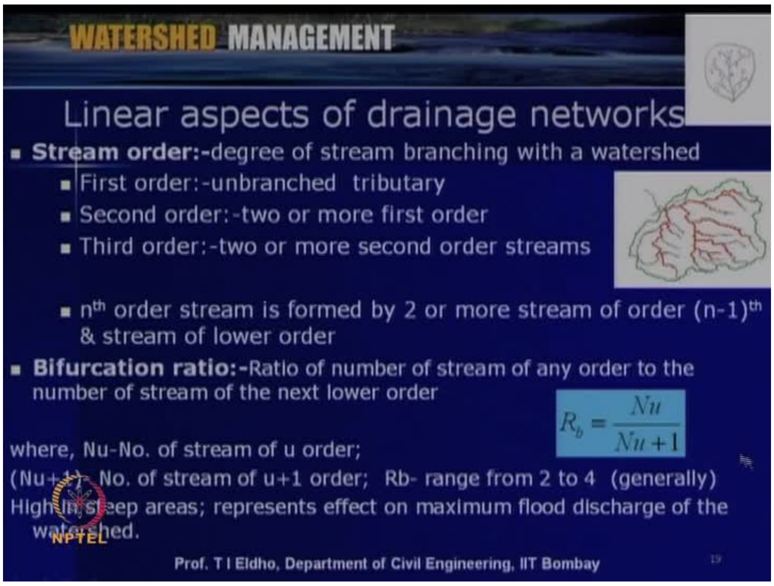


So, we have detailed discussion as far as the linear aerial and the relief aspects of the watershed is concerned. First, let us look into the linear aspects of drainage network. So, we can see that when we deal with a watershed, this is a watershed or this is a watershed which I have drawn. so the stream order means Stream order is the indicates the degree of stream branching within a watershed. So, you can see that this is the main stream and we can see that there will be a number of branching.

So, the first order means there will not be any branch - unbranched tributary. You can see that these are all first branch, where one is indicated; that is the first branch. So, this original watershed is considered, this blue line indicates the first branch, first order. Then second order: two or more first order so you can see that two or more first order keep on joining; so, this is called as second order. This one, whatever is indicated in blue is the second order. Then third order means two or more second order streams are coming together. So, this is the third order as far as the stream order is concerned. So, like that n th order stream is formed by 2 or more stream of order n minus 1 th and a stream of lower order; so, that is the n th order of the stream.

According to these, we can now have various definitions like a bifurcation ratio. Bifurcation ratio is the ratio number of stream of any order to the number of stream of the next lower order. So, if N u is the order of the watershed as far as the watershed is concerned, N u is the number of stream of u th order. Then the bifurcation ratio is N u divided by N u plus 1, where N u plus 1 is the number of stream of u plus 1 th order. So, we have already seen the stream order. So, a bifurcation ratio means N u divided by N u plus 1.

This indicates whether it is what is the way the watershed say the nature of the watershed, whether it is steep or whether it is mild steep. So, this represents the effect on maximum flood discharge of the watershed. So, bifurcation ratio based upon the stream order, is one of the important indicator as far as the maximum flood discharge to the outlet of the watershed is concerned.

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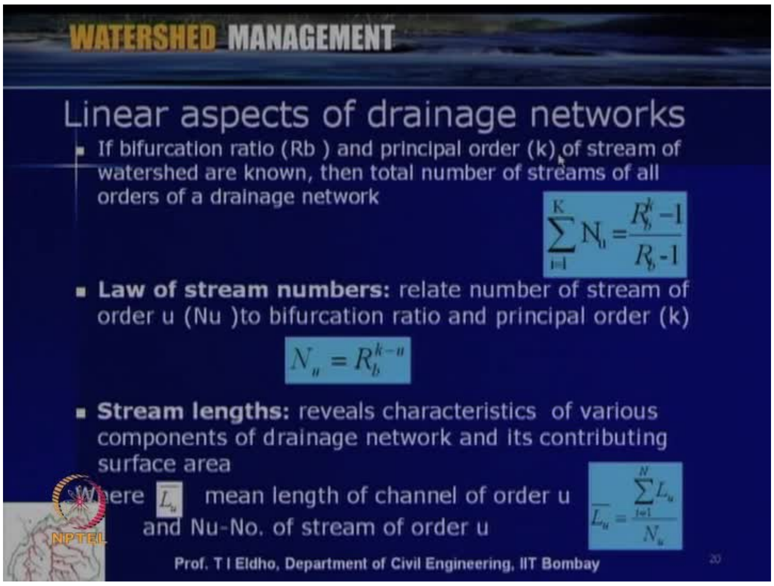


Then say, bifurcation ratio and a principal order k of stream of watershed are known, then total number of streams of all orders of a drainage network, we can identify as sigma is equal to one to k, N u is equal to R b k minus 1 divided by R b minus 1. So, this depends upon the bifurcation ratio and the stream order.

Then another important definition as far as the liner aspect is concerned, is the so called a law of stream number. This relates the number of stream of order u; that means N u to bifurcation ratio and the principal order k. So, N u is equal to R b to the power k minus u, where R b is bifurcation ratio and N u is the stream of order u. So, that is the so called a law of stream numbers. These are some of the definitions which indicates what is the linear nature as far as the drainage is concerned, drainage pattern is concerned, and how it is changing from one watershed to another watershed. We can quantify in terms of this definition as far as the watershed nature is concerned.

Then stream length, we can define, as it reveals the characteristics of various commands of drainage network and its contributing surface area. If L u is the mean length of the channel of order u, L u bar is equal to sigma is equal to 1 to N, L u divided by N u, where N u is the stream order of u; so, that is another definition stream length.

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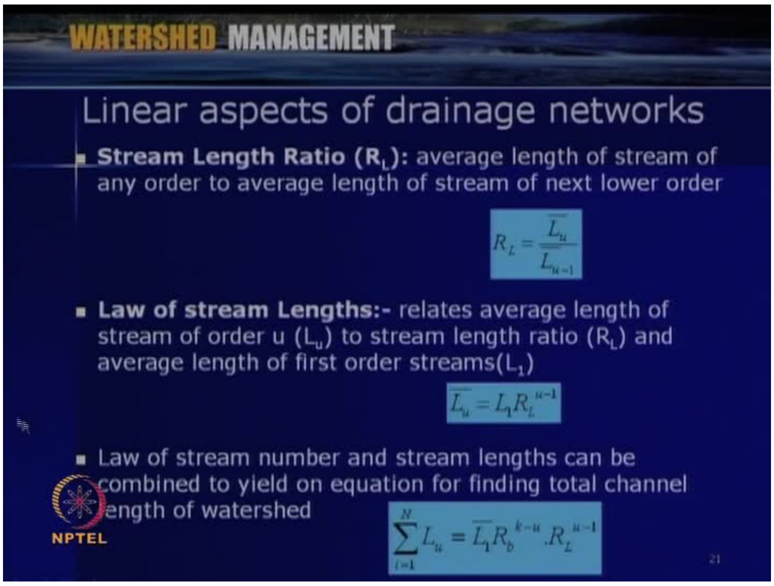


Then some other definitions like stream length ratio. So, that is the average length of stream of any order to average length of stream of next order - lower order. So, R L is equal to L u bar divided by L u minus 1 bar; so, that is called stream length ratio. Then law of stream lengths relates average length of stream order u to stream length of ratio R L and the average length of first order streams. So, L u bar is equal to L 1 into R L to the power u minus 1. Then another definition like lower stream number and stream lengths can be combined to yield on equation for finding the total channel length. So, the total channel length, we can identify based on the lower stream number and a stream lengths.

So, sigma i is equal to 1 to N, L u is equal to L 1 bar into R b to the power k minus u you know, R L to the power u minus 1. So, these are some of the important linear aspects. So, we can quantify the drainage pattern as far as the length of the drainage pattern or the variations within the watershed by using the linear aspects.

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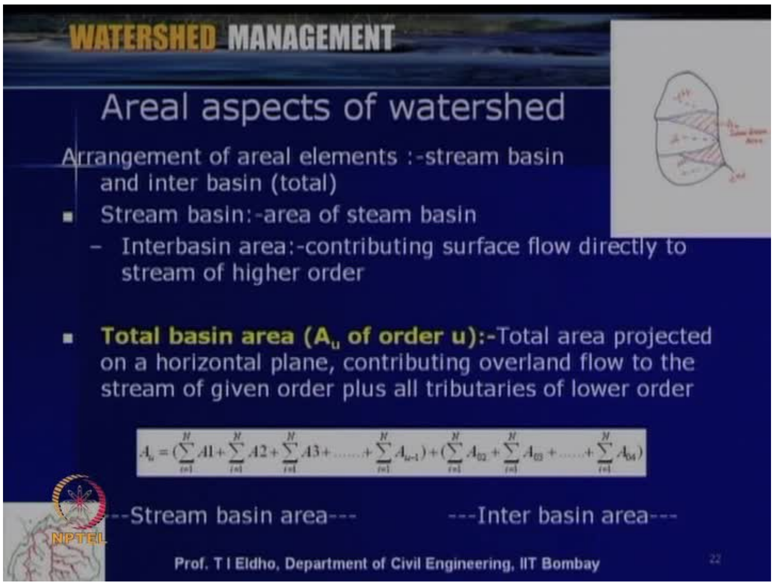


Now, let us look into areal aspects of the watershed. This indicates the arrangement of areal elements like a stream basin and inter basin. This is the stream basin and this so called inter basin. Stream basin means area of stream basin. This is the stream, then what is the corresponding area; so, that is the stream basin.

Then inter basin area is the contributing surface flow directly to the stream of higher order. That is the definition of inter basin area. So, the total basin area say, A u of order u, it is the total area projected on a horizontal plane contributing overland flow to the stream of given order plus all the tributaries of lower order. So, A u is equal to sigma is equal to 1 to N, A 1 plus sigma is equal to 1, A 2 plus like that plus sigma is equal 1, A 0 2 plus sigma is equal to 1, A 0 3 like that. So, this represents a stream basin area as I mentioned here and this represents, what is put in this red colour that represents the inner basin area. So, the total basin area, we can identify like this.

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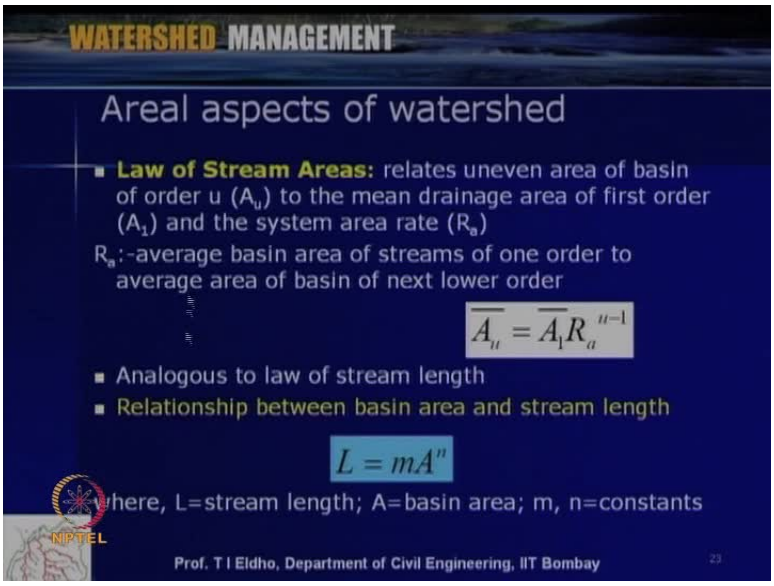


Then, very similar to the linear aspects, for areal aspects also, we can have low stream areas. So, that relates uneven area of basin of order u to the mean drainage area of first order A 1and the system area rate R a. So, A u bar is equal to A 1 bar into R a to the power u minus 1, where R a is the average basin area of stream of one order to average area of basin of next lower order.

This is analogous to the law of stream length as we have seen in the previous slide and then we can have a relationship between the basin area and the stream length. L is equal to m into A to the power n, where L is the stream length, A is the basin area and for the considered watershed m and n are some constants.

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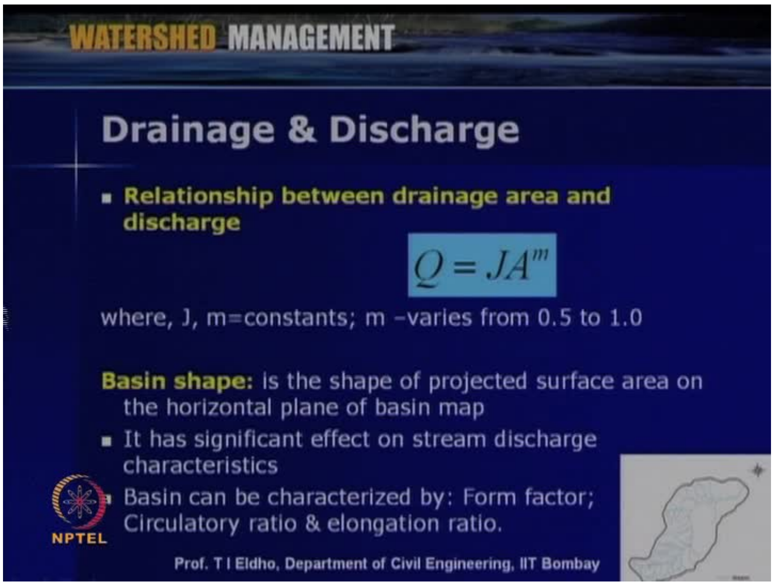


Then based upon this area and the drainage pattern, we can have some relationship as far as the drainage and discharge is concerned. So, the relationship between drainage and drainage area and the discharge we can be represent as Q is equal to J into A to the power m; J and m are some constants. This m can vary from, generally from 0.5 to 1. So, these are some of the as far as drainage and discharge is concerned and then basin shape is a shape of projected surface area on the horizontal plane of basin shape. It has significantly impact effect on stream discharge characteristics. are concerned. The basin can be characterized by some important factors like form factor, circulatory ratio and the elongation ratio.

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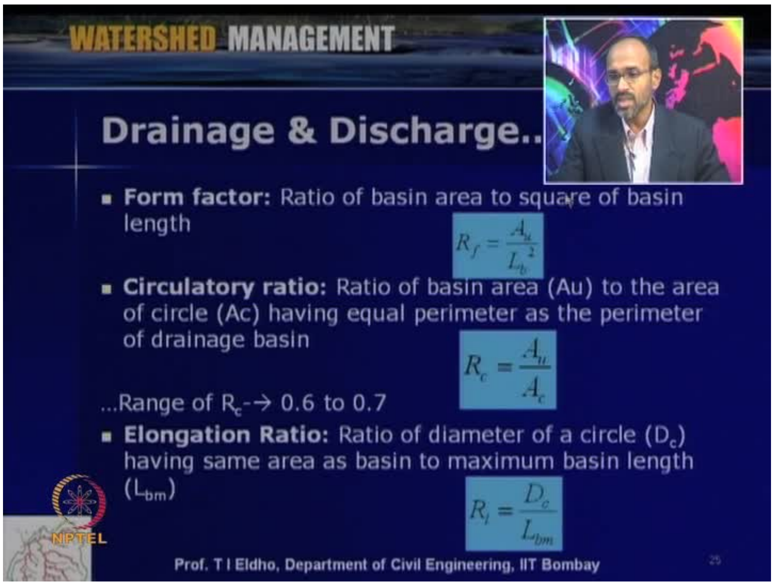


So, this definition we have already seen earlier, but within the context of basin shape, let us have a look again. The form factor means, it is a ratio of basin area to the square of basin length and then circulatory ratio is a ratio basin area to the area of circle having equal perimeter as the perimeter of drainage basin - A u by A c.

So, this can vary from 0.6 to 0.7, depending upon the watershed. Then elongation ratio is a ratio of diameter of a circle D c and same area as basin to the maximum basin length L bm. So, this is the elongation ratio. So, this defined the so called basin shape. This aspect also, we have seen earlier.

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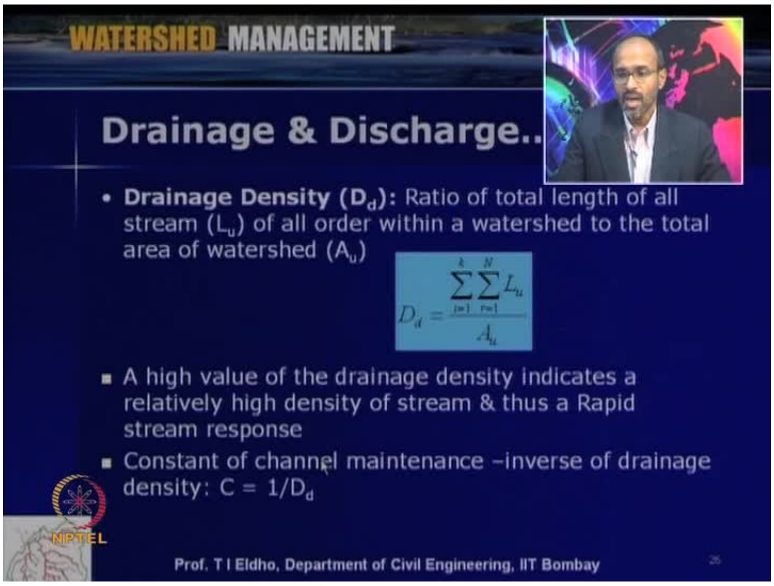


Now, another important aspect as far as the watershed is concerned is the so called drainage density. This indicates the ratio of total length of all stream of all order within a watershed to the total area of the watershed. So, drainage density can be defined as sigma is equal to 1 to k, sigma r is equal to 1 to N, L u divided by A u, where this gives what is the total, the ratio total length of all stream to what is the area of the watershed.

A high value of the drainage density indicates a relative high density of streams and there is a rapid stream response will be there. For example, this watershed is concerned may be in rapid stream responds, then constant of channel maintenance, it is the inverse of drainage density. We can define another term called constant of channel maintenance. So, that is C equal to 1 by drainage density

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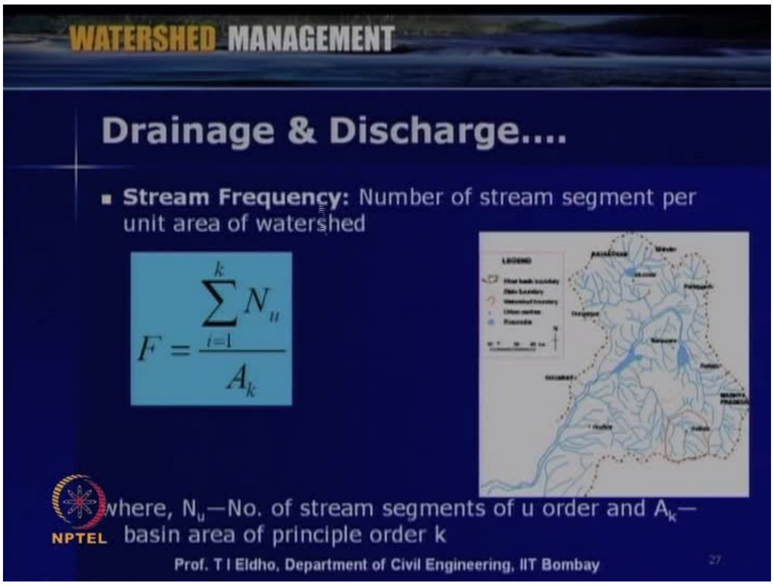


Also, another term as far as the drainage and discharge is concerned or drainage is concerned, we can define stream frequency as the number of stream segment per unit area of the watershed. So, F is equal to i is equal to 1 to k, N u divided by A k, where N u is a number of stream segments of u th order and A k is the basin area of the principal order k. This is as far as the stream frequency is concerned.

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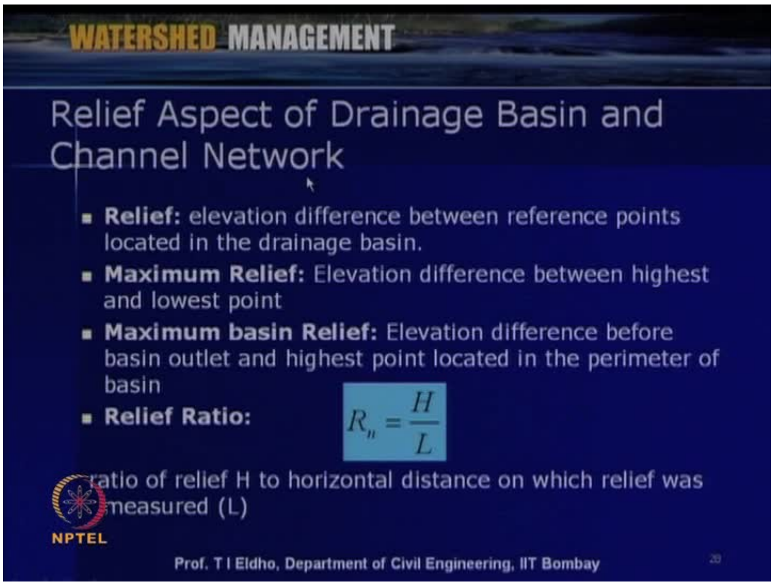


Now, the last aspect is the so called relief aspect that is based upon the elevation. Relief is the elevation difference between the reference points located in the drainage basin. So, maximum relief is the elevation difference between the highest and lowest point within the watershed. A maximum basin relief means elevation difference before basin outlet and highest point located in the perimeter of the basin; so that is the so called maximum basin relief and we also have a ratio called a relief ratio; that is the H by L, where H is the horizontal distance on which relief was measured L. This is the ratio of relief H to the horizontal distance L.

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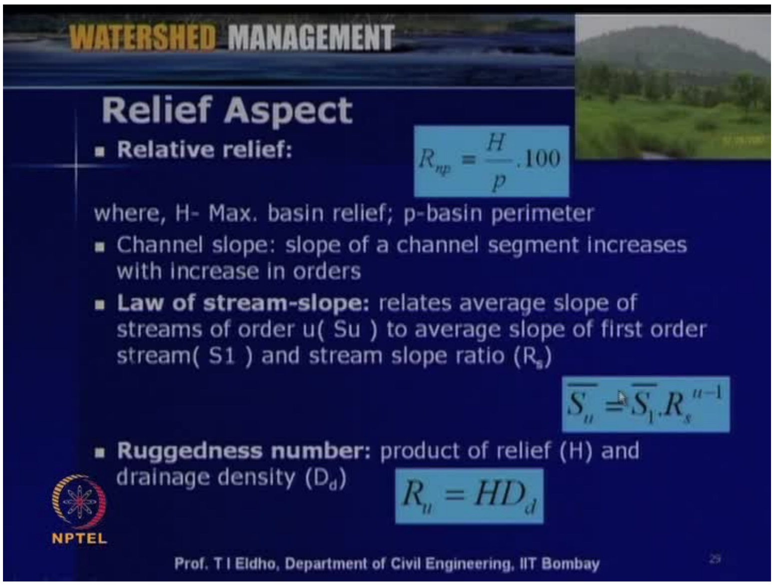


Then also as we defined earlier, we can have a relative relief and that is H by p into 100, where H is the maximum basin relief and p is the basin parameter and then according to the elevation, the channel slope also we have to consider. Slope of a channel segment increases with increase in orders.

We can combine the law of stream with respect to slope, like this. So, it reflects the average slope of stream of order u to average slope of first order stream and stream slope ratio is S u bar is equal to S 1 bar into R plus to the power u minus 1. Another important aspect which we can use is called ruggedness number as far as watershed is concerned. It is a product of relief H and the drainage density. So, this is one of the important parameter, which is used to characterize a watershed. R u is equal to the relief into drainage density H into D d.

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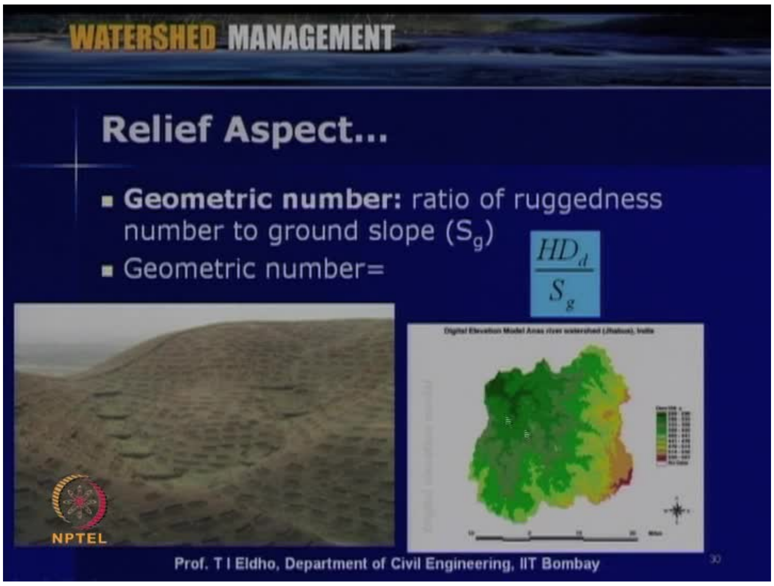


Then finally, another number called geometric number also we can use. That is H into D d. That means the ruggedness number divided by the so called geometry; it is called geometric number; that is a ratio H D d divided by the ground slope S g.

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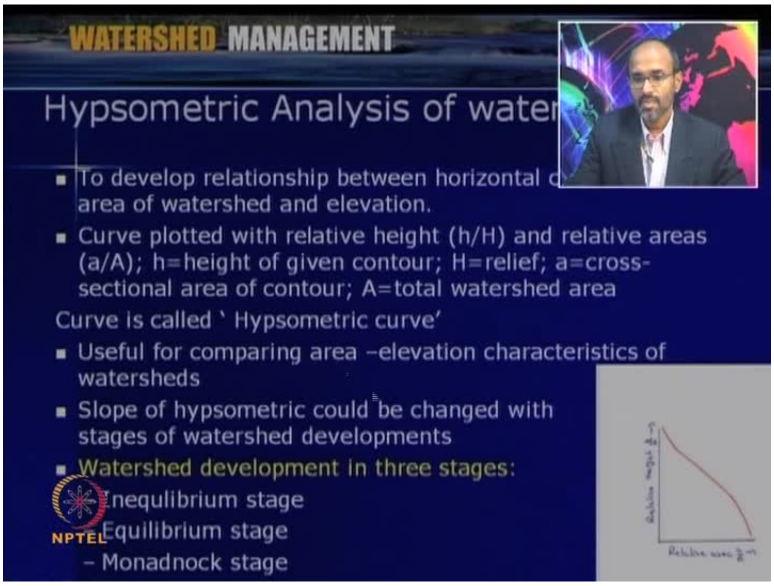


Well, before closing this lecture When we deal with since we have now seen the various aspects like linear aspects, areal aspects and then the relief aspects. Accordingly, as far as watershed variation is concerned, as far as the relief variation is concerned, we can have an analysis called hypsometric analysis.

So, this gives a relationship between the horizontal cross sectional area of watershed and its elevation. This is a curve plotted with relative height h by H so on the y axis and relative areas a by A, where h is the height of given contour, capital H is the relief, a is the cross sectional area of contour and capital A is the total watershed area.

This curve is the so called hypsometric curve. For the given watershed, we can develop this hypsometric curve. This is very useful to compare the elevation characteristics as far as the watershed is concerned. Accordingly, the slope can be identified and the runoff process, also we can identify.

So, slope of hypsometric could be changed with the stages of watershed developments. According to the developments taking place within a watershed, we can classify the watershed into three stages: one is so called Inequilibrium stage, second one is called equilibrium stage and third one is called a Monadnock stage.

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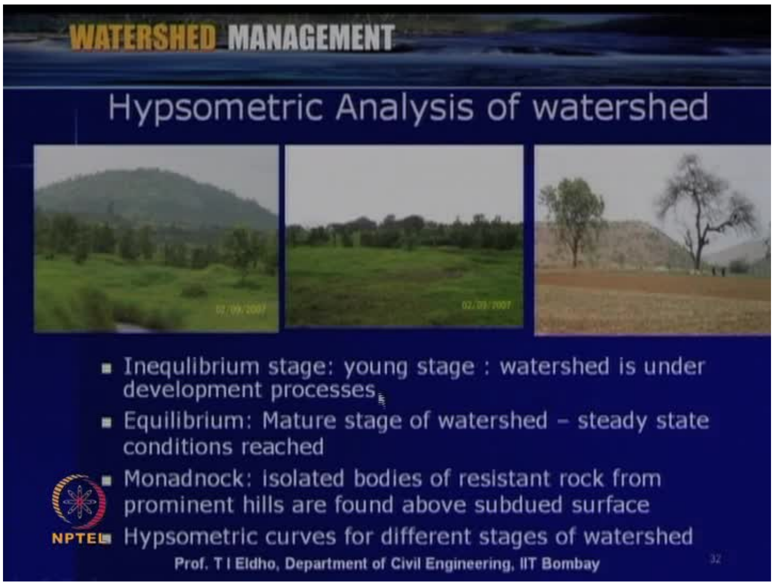


So, this inequilibrium stage is a young stage so that watershed is under development process. You can see that the watershed is still evolving, various things keep on happening; so, no equilibrium is reached. Second one is equilibrium stage; so, this is a matured stage of watershed, where steady state conditions are reached. All the parameters are concerned, there is not much change taking place.

Then third one is the so called Monadnock stage. So, this isolated bodies or resistant rocks, as we can see here from prominent hills are found above subdued surface. So, that is called as stage called an Monadnock stage. So, three important stages as far as the development of watershed: Inequilibrium, equilibrium and Monadnock.

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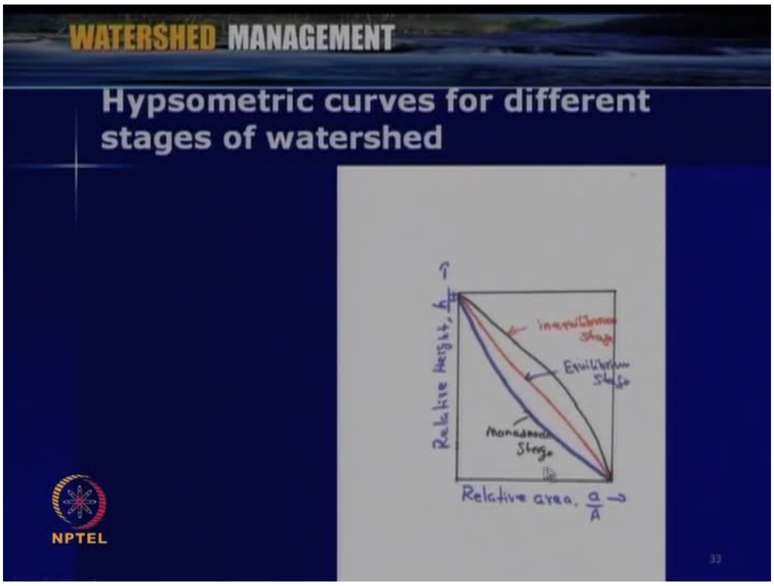


If you do a hypsometric analysis, we can identify how these stages will be varying. So, this figure shows, This is taken from the book of Ranveer singh. This is relative area a by A is plotted on x axis and relative height h by H. So, this top curve - black colour indicates Inequilibrium stage and middle one - red color indicates equilibrium stage and the last one called Monadnock stage. Accordingly, we can identify.

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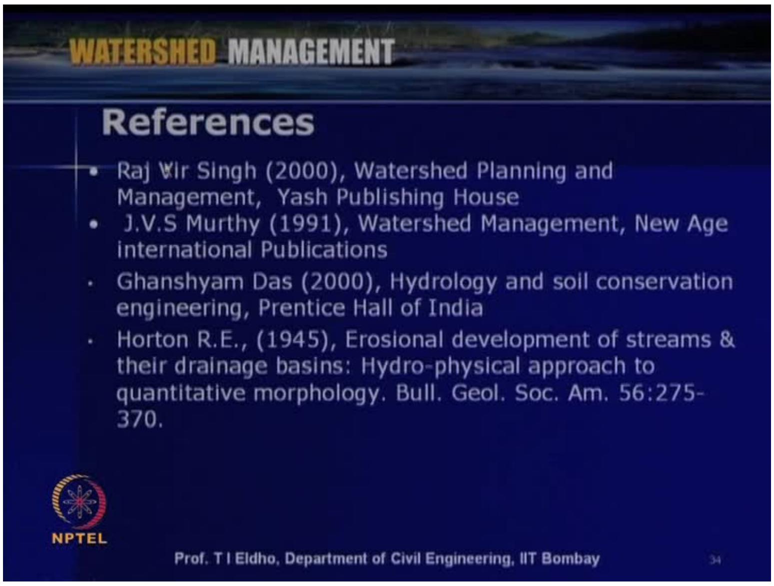


Some of the important references used for today's lecture watershed planning and management Raj Vir Singh and then some of the other references.

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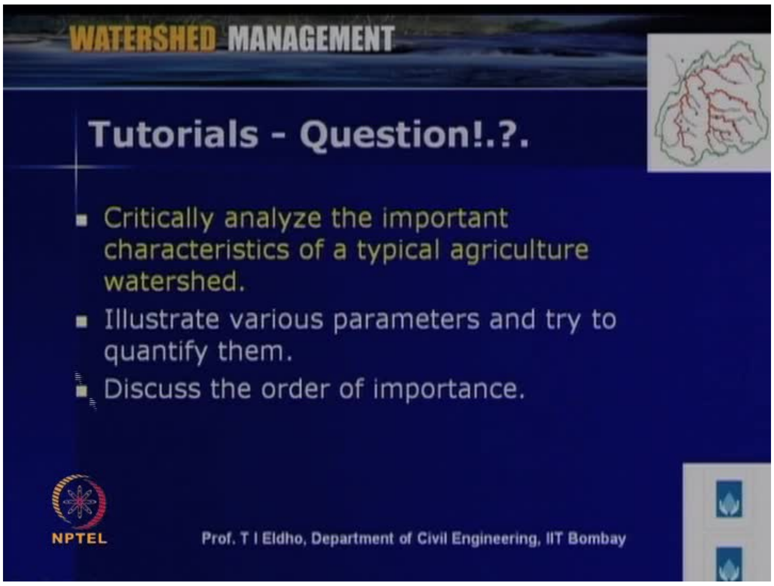


As usual before closing the lecture, say one tutorial question, which we can attempt. Critically analyze the important characteristics of a typical agricultural watershed. Illustrate various parameters and try to quantify them and discuss the order of importance as far as the agriculture watershed is concerned

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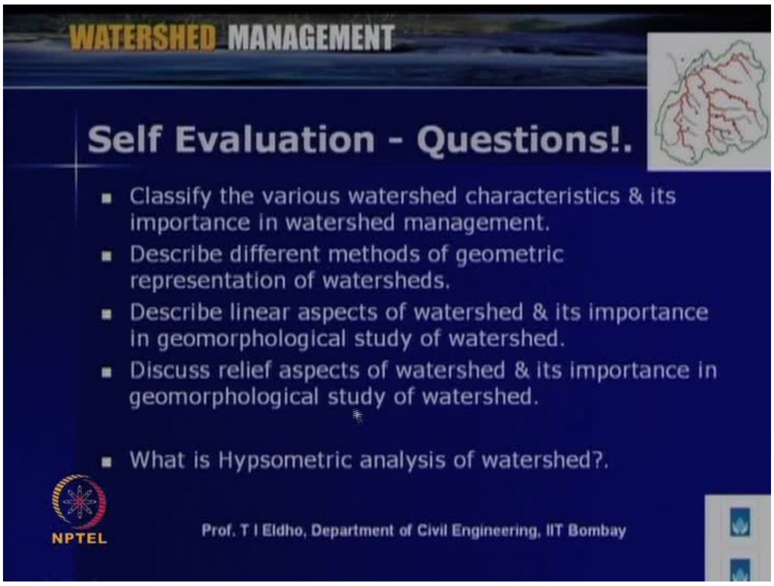


Few self-evaluation questions like classify the various watershed characteristics and its importance in watershed management. Describe different methods of geometric representation of watersheds. Then describe linear aspects of watershed and its importance in a geomorphological study of watershed. Then discuss relief aspects of watershed and its importance in geomorphological study and what is hypsometric analysis of watershed? So, all these questions, if you go through the lecture, all these things we have discussed.

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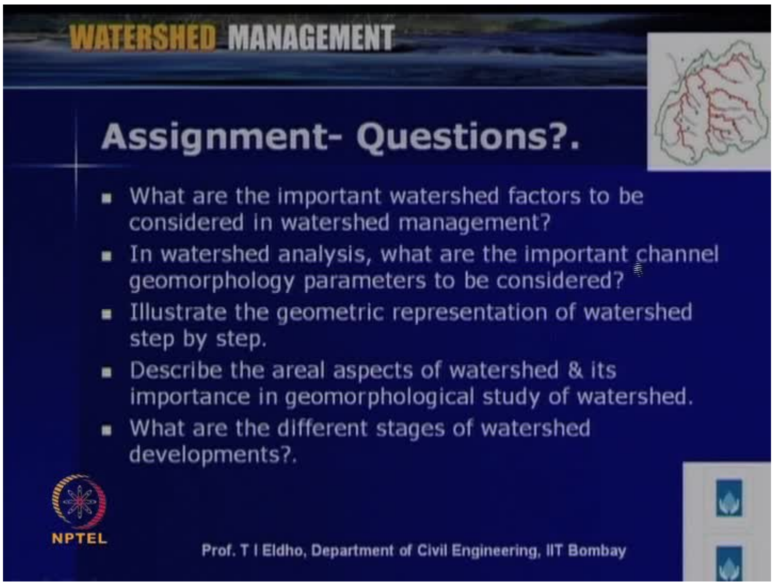

Some assignment questions like what are the important watershed factors to be considered in watershed management. In watershed analysis, what are the important channel geomorphology and parameters to be considered? Illustrate the geometric representation of watershed step by step. Then describe the areal aspects of watershed and its importance in geomorphological study and what are the different stages of watershed developments? So, all these questions you can get answer, when you go through this today's lecture.

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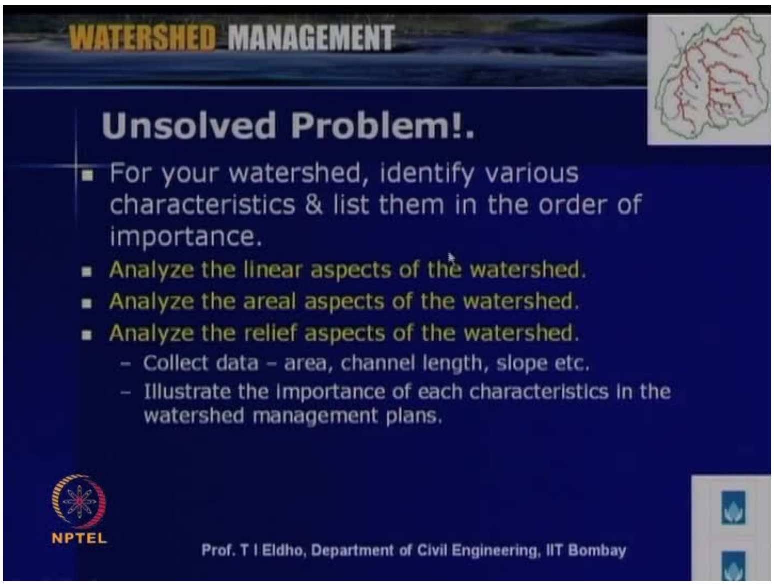


Then finally, one unsolved problem. For your watershed, where you are living, you can identify the various characteristics and then list them in order of importance. Then analyze the linear aspects of the watershed, analyze the areal aspects and relief aspects. So, you can collect various data related to elevation, area, channel length, slope etcetera. Then you can make a matrix, which illustrate the importance of each characteristics in the watershed management plans.

So, in today's lecture, we were discussing about the various important watershed characteristics. In the next lecture, we will be discussing the watershed delineation and various methodologies. So, this is the module on watershed modeling. Thank you.