Watershed Management
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Module No. # 04
Lecture No. # 15
Watershed Modeling

Welcome to the video course on watershed management in module number 4, lecture number 15. Today, we will discuss about the watershed modeling approaches.

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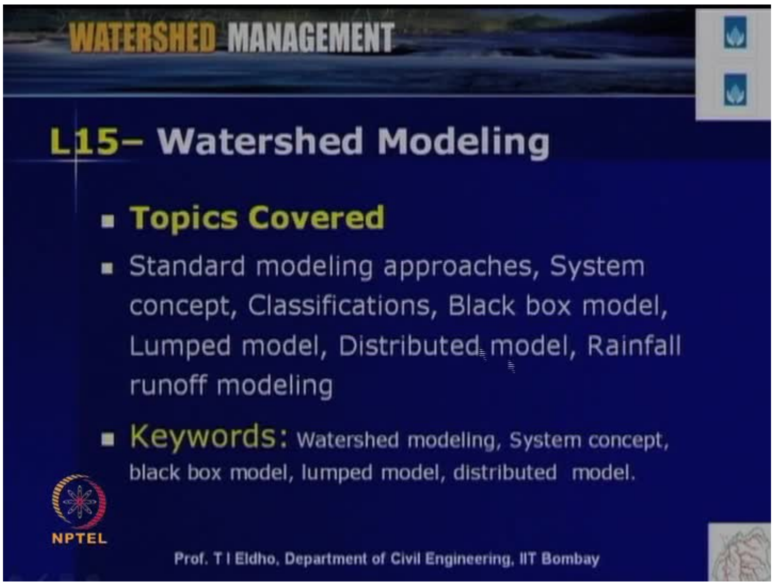

Some of the important topics covered today includes the standard modeling approaches, system concept, classifications, black box model, lumped model, distributed model, rainfall runoff modeling. Some of the important keywords for today's lecture include watershed modeling, system concept, black box model, lumped model and distributed model.

So, as we discussed earlier when we are going for watershed planning and management, we have to see the response of various resources in that system; say one of the most important resource is the water within the watershed. The water is concerned as a resource; water main source is from the rainfall. So, that means for the given precipitation conditions, we have to identify how much will be the runoff. So, runoff condition we have to simulate, for especially in this context we have to do modeling of the watershed.

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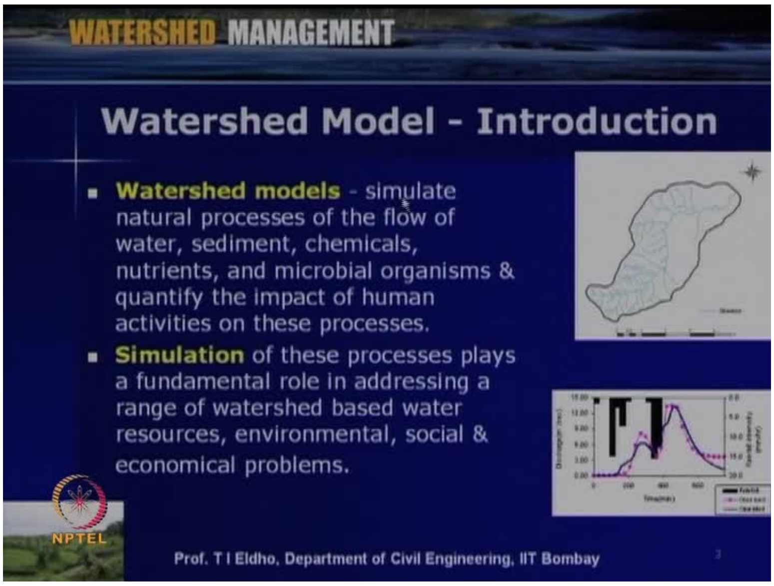

A watershed model means, in watershed models we simulate the natural processes of the flow of water, sediment, chemicals, nutrients and microbial organisms and quantify the impact of human activities on these processes. So, that means, in a watershed when we interfere in terms of various land use and various other activities, then there will be lot of changes will take place. We can identify what will be corresponding to the particular changes; what will be happening to various processes. That way a watershed model simulates the natural process of the flow of either water; it can be water or sediment or chemicals or nutrients like that. So, for the given type of activities or for the particular activities, how it is going to affect these processes? That is what we are going to simulate by using the watershed model.

In all these, we can see that the simulation is for these, the processes play as far as simulation is concerned. Simulation of these processes plays and here a fundamental role in addressing a range of watershed based water resource, environmental, social and economic problems.

When we are developing a particular watershed plan or a watershed management program, we have to see when we are interfering within the system. For example, when we are going to construct a check dam then how much water can be stored? What will be the,… how the system will be behaving? So, all those things we have to identify. We may be simulating for various problems like water related problems or environment related problems or social and economic related problems.

So, that way the watershed models are very useful. Actually, watershed models are essential while developing the watershed management plans.

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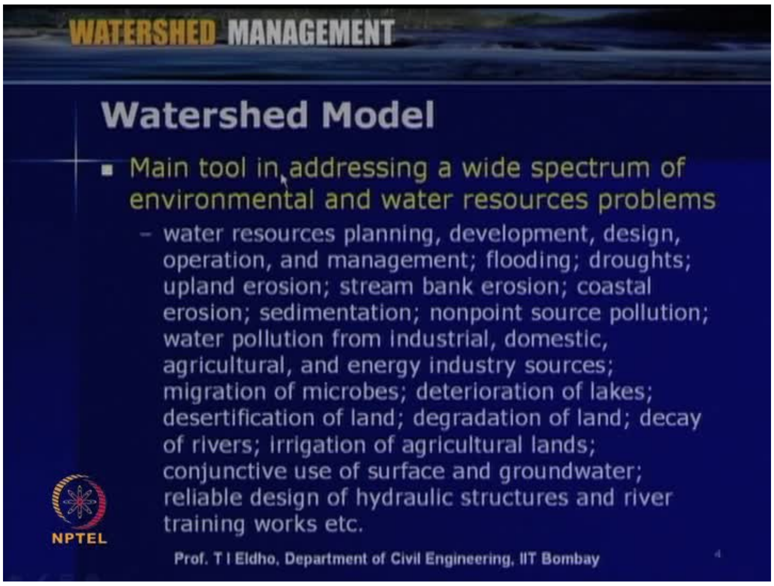

As far as watershed model is concerned, as I mentioned, this is one of the important tool to see that how the system is responding. That way we can say that watershed model is a tool which addresses a wide spectrum of environmental and water resources problems, for the given watershed or for the given river basin or catchment which we consider. When I say the wide spectrum, number of problems we can address through this watershed - various type of watershed models. So, the spectral problems that we can handle with watershed models include water resource planning, development, design, operation and management.

So, that means if you are going to develop a reservoir within the watershed, then how to plan it and how to develop it and then we can see how to manage it. Then we can also simulate like the flooding problems, then drought problems, then like erosion. So, problems like soil erosion, sedimentation, then stream bank erosion, coastal erosion, sedimentation, nonpoint source of pollution, water pollution from industrial, domestic agricultural and energy industry sources; migration of microbes, deterioration of lakes, decertification of land, then degradation of land, decay of rivers, irrigation of agricultural land, conjunctive use of surface and ground water, reliable design of hydraulic structures and river training works, etcetera.

As I mentioned we can develop watershed models for a wide spectral of problems. So that we can easily understand what will be the effect of various interventions within the watershed and what is going to happen within the watershed like, if you are going to construct a check dam.

What will be this as far as water management is concerned? How the system is going to behave? Or, when we go for say the soil consideration measures, how the soil erosion can be reduced? Or, when we are going for the environmental planning like reduction of the pollution sources, then how the system is going to behave? All these aspects we can address while simulating the particular type of watershed model.

Now, when we are discussing about the watershed models generally, we can go for a system approach. So, as we have already seen we will be considering the watershed as an area or as a particular domain. That particular area we can consider as a system and then within that system, what will be happening; most of the time we will be looking to the watershed simulation using a model by using a system approach.

In the system approach for example, if water related problems are concerned we can use various conservation principle like conservation of mass, conservation of momentum, conservation of energy, etcetera. So, if you consider conservation of mass, then we can see that inflow minus outflow is equal to rate of change of storage. So, like that we can develop particular system equation for the given watershed area by using a system approach.

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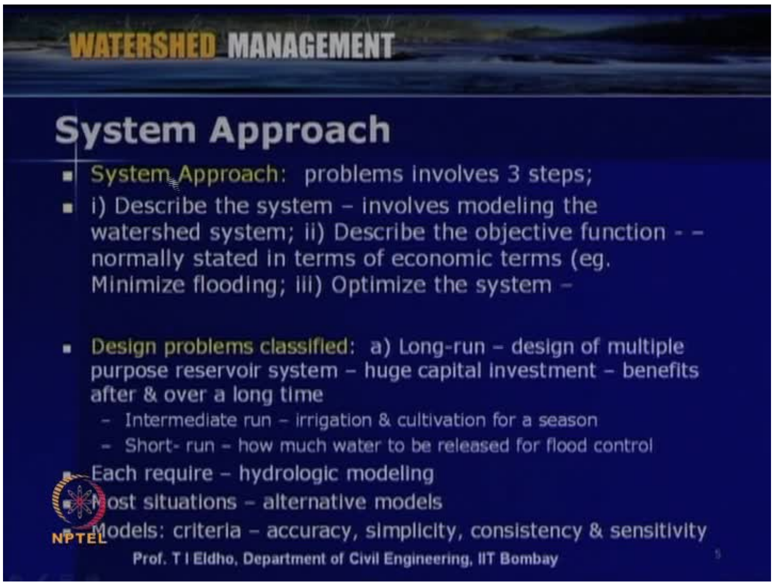

System approach we can generally,… We use for watershed modeling. System approach - the problems involves 3 steps. First one is where we can,… You have to describe the system. Describe the system means, we identify the boundaries of the system and then various other features within the system. So, this involves modeling the watershed system. We can identify the domain, then boundary conditions and other parameters as far as the system is concerned.

Then second problem can be described. The objective function say, generally the system whatever we are going to do, say the water as a resource; so whether we may be going for optimization; so like, minimize the cost and maximize the benefits; so like that. That way, we can describe an objective function generally stated in terms of economic terms like, minimize the flood hazards or maximize the water availability; so like that. So, second problem can be: we can describe an objective function and in terms of that then within by using say, certain constraints we can optimize the total system.

The third one: problem can be optimization of the system. So, in a systematic approach or system approach, say we describe the system and then we can go for a simulation of the system; then we can go for optimization of the system. As far as various watershed models are concerned, most of the time we are looking for design problems. Say, as far as what is happening with respect to the particular resource like water is concerned, we will be looking to the design problems. So, these design problems we can classify into three categories.

First one is long run type of problems. Long run means we look into say, once a system is developed we will be looking to what is happening for a long time like 1 year, 2 years or a number of years what will be the system. So, in long run for example, design of multipurpose reservoir systems, huge capital investment will be there. So, we have to see the benefits after say over a long period of time; so what will be the,… How the system will be behaving.

Then, second classification is intermediate run: so intermediate run for short period like may be it can be for few months or it can be few weeks like that. For example, irrigation and cultivation for a particular season; so far we know how much is the storage within the reservoir and then how we can plan as far as the water release is concerned. So, that is as far as the intermediate run is concerned.

Then, short run design problems means, say it is for a day or a few days or few hours; how we are going to manage the system.

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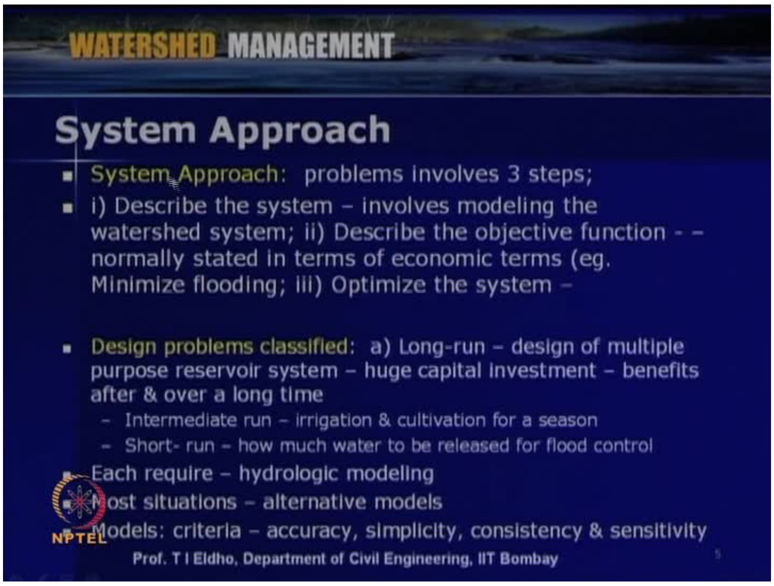

So, for example, how much water to be released for flood control? The rainfall is taking place continuously, so then we have to release the water from a reservoir. To control the flood - how to operate the system? That is a short run problem.

So, in all these either long run or intermediate or short run, we may require hydrological modeling and then we may have to identify various situations and then we have to go for alternate models. So, it is always say there will not be a unique solution; number of solutions will be there, and each solution will have its own advantages and disadvantages. We have to identify, we have to study each of these scenarios or situations using different types of models and then we have to choose particular models.

So, then as far as watershed models are concerned, we have to choose or we have to select particular model, using certain criteria depending upon what are our objectives what are the resources to do the simulation or the modeling. Then also, it depends upon the accuracy; how much accurate should be the results; what you are getting? Then we are always looking for complex natural system by using number of assumptions, we are simplifying the system. So, the simplicity of the model or modeling approach we have to see and then some aspects like consistency and sensitivity, with respect to various parameters. So, all these aspects we have to consider when we look for particular watershed model or particular modeling approaches by using a system approach. So now we have seen most of the time we are using system approach as far as the watershed modeling is concerned.

Most of the time for example, if water as a resource is concerned we have to see the various hydrological processes taking place from precipitation to runoff. As we discussed in the previous lectures, like various losses like interception, evaporation, infiltration, etcetera will be there. So, we have to consider all those aspects while going for a rainfall to runoff modeling. Then say for the last few decades, number of models have been developed by various researchers by considering various theories and various aspects and by using number of assumptions also. There are very simple models to very complicated models.

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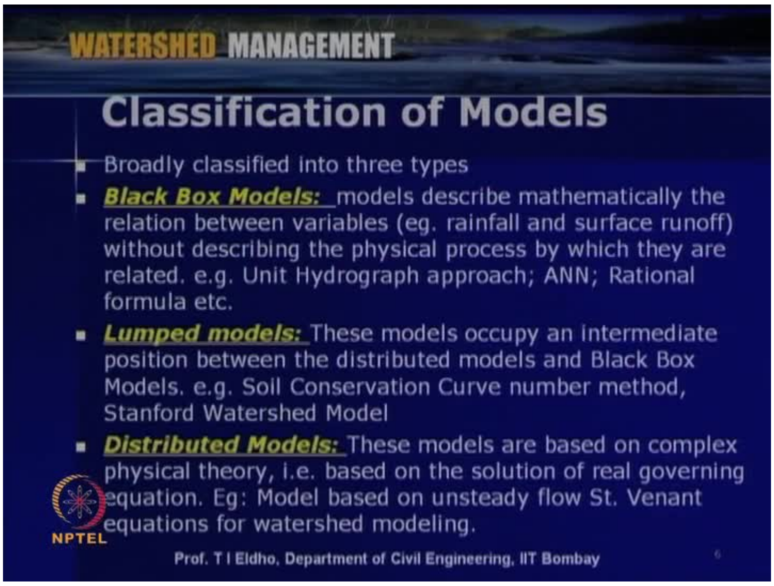

Accordingly, we can broadly classify the available watershed models into 3 types. The types are black box models, lumped models and distributed models. As far as a watershed model when we say black box models, these models describe mathematically the relation between variables for example, rainfall and surface runoff. So, without describing the physical process by which they are related, when we are using a black box model that means, say for example, important parameters are rainfall and runoff. Actually, as we discussed earlier number of processes will be there; physical processes will be taking place from rainfall to runoff. But, black box models we are not considering; all these physical process what is taking place within the watershed but, we are looking say we are developing simple relationship between the rainfall and runoff which may be particularly suitable for particular location or particular watershed, depending upon the various parameters.

Actually, this black box models are very simple models; very easy to use but then it may not be universally applicable and then it has got its own limitations since most of the physical process are not considered as far as this model is concerned - black box model is concerned. Some of the examples include like unit hydrograph approach, then artificial neural network for a particular rainfall runoff modeling for a particular location, then a rational formula etcetera.

These are all simplified forms which simply give a relationship between rainfall to runoff and then for example, in artificial network by collecting the data for a long duration may be for many years. How the runoff is taking place at a particular location or at the outlet of watershed? Then, we can say if you know the rainfall and runoff, so then we can identify a relationship for that particular location; valid for that particular location by considering the available rainfall and the runoff. So, that way then it is called simply a black box model, since we do not consider most of the important processes taking place within the watershed what is happening.

Then, second type of model is called lumped models. Lumped models occupy an intermediate position between the distributed model and black box models. So, here you can see that say some of the aspects of the physical process are taken care but, not all the important aspects of the physical systems. But, some system like conservation of mass is considered while considering the… when we are saying that simple model like inflow minus outflow is equal to change in storage.

That is actually, we are concerned the conservation of mass principle. So, that kind of model is a lumped model, but it is that kind of model say, we will not consider all the physical processes taking place within the watershed for example, our soil conservation curve number method which we will be discussing in today’s lecture.

So that is a lumped model and then Stanford watershed model is a lumped model, and then this mass balance type models are all lumped models, and then, the next type of model is called the distributed models. These distributed models - a number of different types of models are available. So, in the distributed models we consider all the physical processes taking place within the watershed, say for example, if we consider rainfall to runoff.

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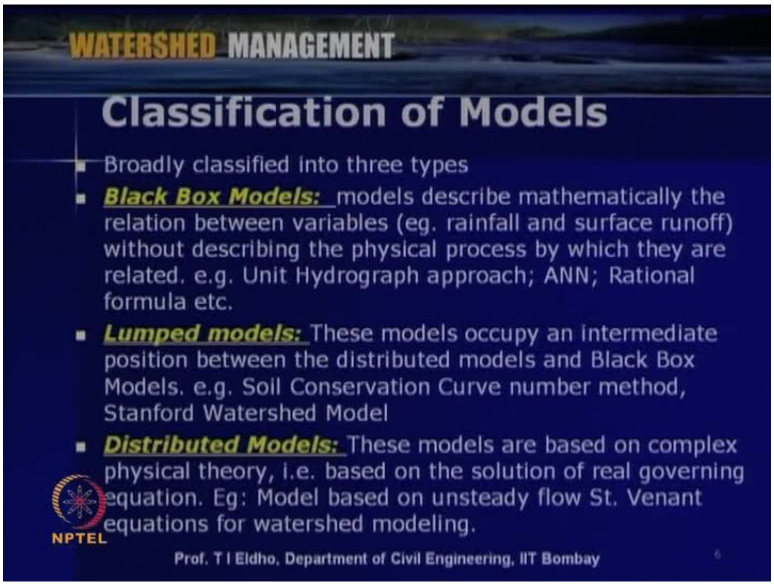

Then we will be solving the governing equations say for example, partial differential equations such as Saint Venant equations or Navier stocks equations which consider conservation of mass then conservation of momentum. Most of the important physical processes taking place the watershed we consider in that and then we develop a model.

So like when we solve the Saint Venant's equation for over land flow or channel flow using a numerical tool like a finite difference method or finite term method; so that kind of model is called a distributed model. Here, the distributed model construction of a distributed model is very very complex. We need a large number of parameters and then so much of efforts are required but, the advantage is that, that type of distributed model gives all the processes taking place. So, it shows the physics of the problem; that way when we consider the total processes taking place in a watershed, that is very important say, this distributed models are very important as far as the watershed modeling is concerned.

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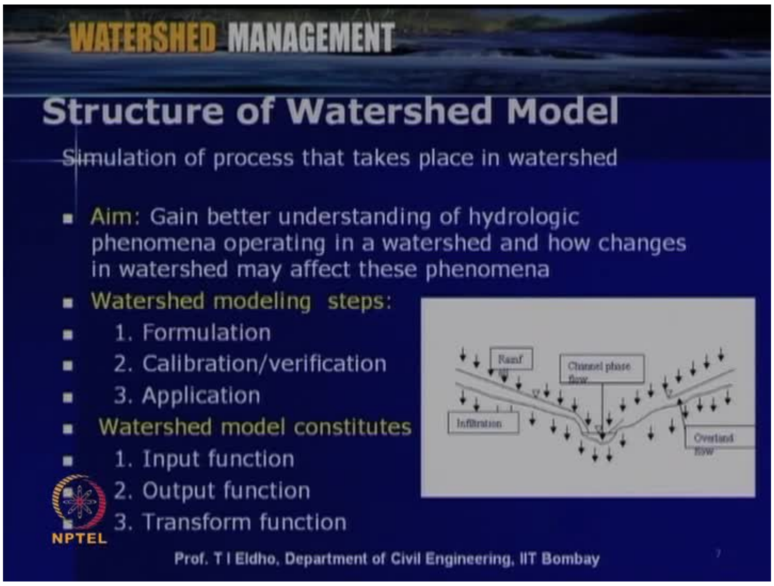

So, that way now, as we have seen we can classify the watershed models into black box model, then lumped models and the distributed models. As we have already seen earlier when we develop a watershed model, the structure of the watershed model what we are trying to see is the simulation of process that takes place within the watershed. Most of the time, the aim is to gain better understanding of hydrologic phenomena operating in a watershed and how changes in watershed may affect this phenomena.

As I mentioned, if say for a given rainfall condition, how the runoff will be taking place? Or, we say once we adopt various measures for example, for soil conservation measures or rain water harvesting measures, what will be this impact? So, that is what we are trying to understand through simulation models. As we discussed earlier any of the watershed models there are mainly 3 steps.

We have to formulate particular watershed model; so first we have to conceptualize the model and if you are going for physical modeling then, the particular governing equation we have to consider; boundary conditions we had to consider. Then we may develop the model or we can get the model from outside sources. So, that is the first step that is, the formulation then we have to calibrate and verify that particular model. The calibration process includes identifying various parameters which governs the various processes taking place within the watershed.

Then verification means we are trying to identify whether we are checking whether the model is giving the appropriate results so that is verification and then we apply the model for particular simulation for the given condition so that is the third one is the application. So, generally as we discussed earlier also any of the watershed model constitute there will be an input function and then there will be an output function and then there will be transfer function. So, as you can see that the input function can be the rainfall taking place within the watershed then output function can be the runoff taking place within the watershed and transform function is various processes taking place between the rainfall runoff like interception losses infiltration losses and various losses taking place within the watershed when this transformation from rainfall to runoff takes place. That way we will be modeling a watershed.

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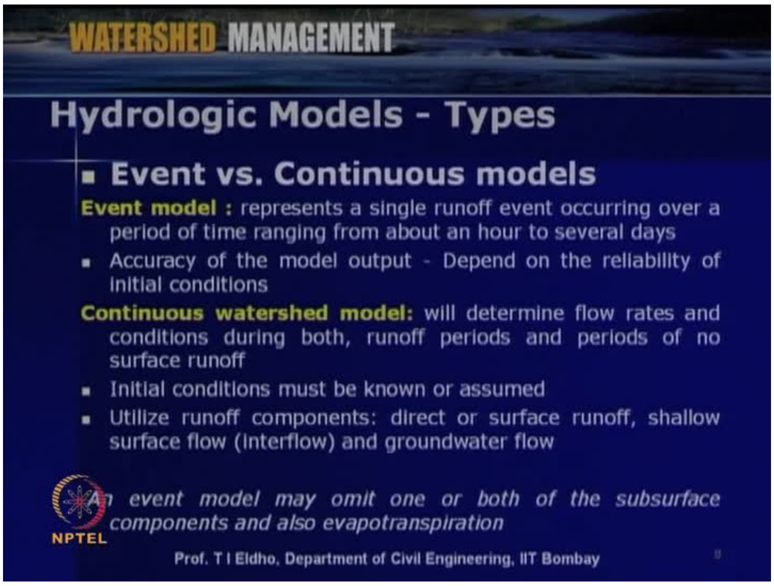

Now, we will be discussing various types of hydrological models. So, we can see that in literature considering the types of models which are developed or various methodologies adopted or what kind of phenomena are model. Accordingly, we can see different types of models now we will discuss the hydrologic models. So, first classification is the hydrologic model can be either event wise or continuous wise so event verses continuous models. Event model means it represent the model represents a single runoff event occurring over a period of time ranging from about an hour to several days.

So, this event modeling is very important when we are looking for the flood simulation of a watershed. Since flooding most of the time taking place say for a heavy rainfall for few hours and then with respect to that, how much is the runoff is coming and then accordingly we may have to identify how is the process taking place. So, we have to identify event wise say, we know these minute-wise or at least hour-wise we had to identify the rainfall process and then the runoff process. By considering all the hydrological process taking place, we need a lot of data; so the accuracy of the model input, output depends upon the reliability of initial conditions. So, event model can be like a flood simulation model for a watershed or an urban watershed.

Then second variety of here is continuous models. Continuous watershed model will determine flow rates and conditions during both runoff periods and periods of no surface runoff. So, this is for long time simulation; it is not simply during the event but after the events also what will be happening. So, may be it can be for weeks or for months or may be for a year, so like that or few years. We are simulating the various processes continuously. So, we may have to give the initial conditions and then we utilize the runoff components like direct or surface runoff, then shallow surface flow, interflow and ground water flow. All these components we may have to consider the continuous watershed simulation. Here, say for example, when we are developing a dam or a check dam at the outlet of a watershed, we may have to do a continuous simulation. Continuous watershed models so that, we can identify say once the rainfall is taking place then water is stored and then, for how many months or how many seasons we can utilize that water?

So, there we have various losses also. So an event model may omit one or both of the subsurface components and also evapotranspiration depending upon the modeling accuracy we are looking for. But, continuous watershed model we have to consider this evapotranspiration losses and also the various subsurface components.

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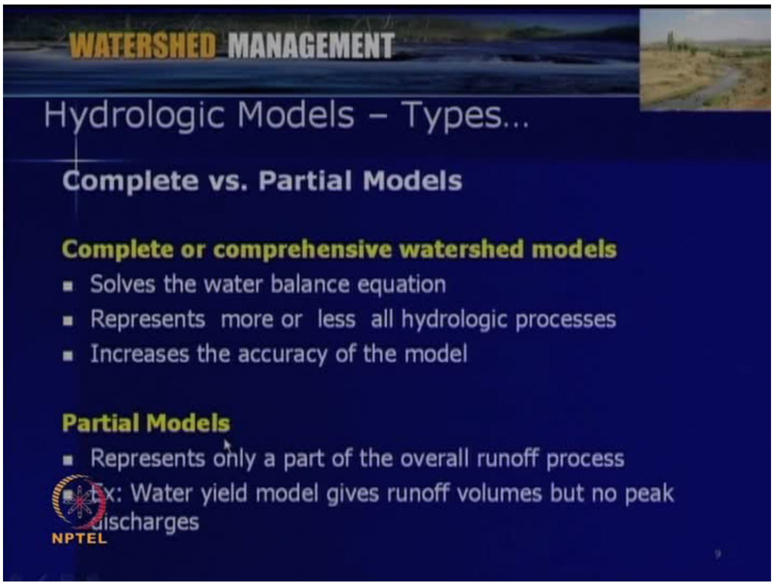

Then second type of model is called a complete verses partial models - complete models or comprehensive watershed models. Here, we consider most of the hydrologic processes taking place. So this here, we solve the water balance equation then it represents more or less all hydrologic processes then it increase the accuracy of the model. Since all the aspects are considered in the simulation process for example, rainfall runoff and the particular location of the watershed outlet.

We have to identify how is the flow pattern taking place; so, that way a comprehensive or complete watershed model consider most of the important hydraulic process. Then, partial models means, represent only a part of the overall runoff process. We may not consider for example evapotranspiration or infiltration or various other processes. So, for example, water yield models gives runoff volumes but, no peak discharges; so, it will not give a holistic picture of what is happening if you say partial model.

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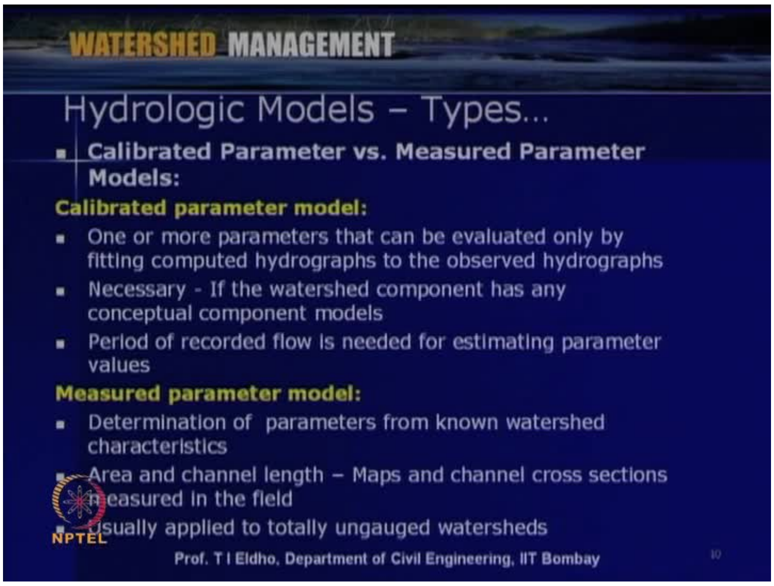

Another classification is with respect to the calibrated parameter verses measured parameter models. So, calibrated parameter model means one or more parameters that can be evaluated only by fitting computed hydrographs to the observed hydrographs. Here, we can calibrate various parameters based upon the observed. We will try to fit with the computed hydrographs; so, this is necessary; the watershed components are so only conceptual component models. So the period of record flow is needed for estimating the parameter values and the second category here is measured parameter model. Here, we are trying to determine the parameters from known watershed characteristics; so watershed characteristics are already known. From that we can identify the parameters so area and channel length like this type of parameters maps and channel cross section measured in the field; so these are all known parameters.

Usually, we use these kinds of models for to totally for ungauged watershed. The important measured parameters we directly put but some of the other parameters which are difficult to measure we use the standard values.

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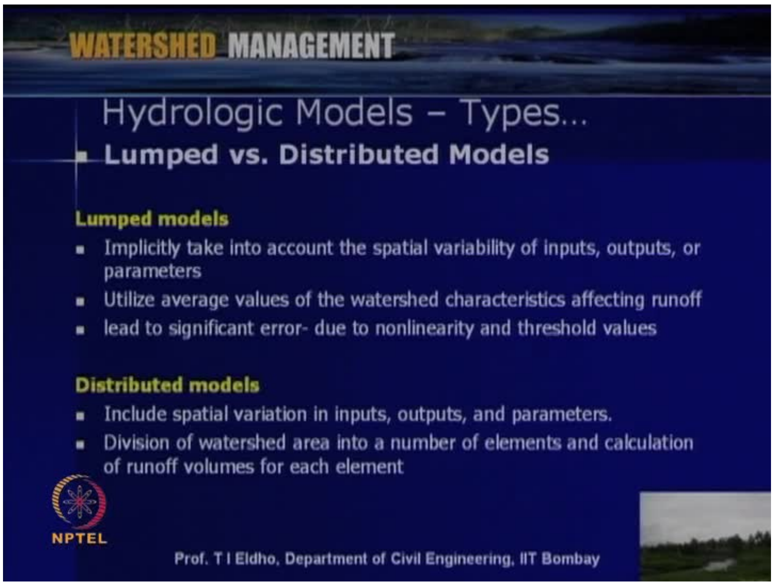

So, then under classification is as far as models are concerned; as we discussed earlier also, this is 2 important types of modeling concept which we used in hydrological modeling. So, that is lumped verses distributed models - as we discussed. Lumped models means we implicitly take into account the spatial variability of inputs outputs or parameters. We lump the systems for the given watershed or given zone of the watershed since we do not know the exact behavior in a distributed way. So, then we utilize the average values of the watershed characteristics affecting the runoff. This may lead to significant error due to non-linearity and threshold values. As we have seen earlier say, watershed is concerned various parameters are changing from one location to another location. So what we do? We consider for either for the total watershed or for the particular zones. We consider for the watershed, we lump various parameter by taking an average value and then we run the model; so that is called a lumped model.

Second category here is so-called distributed model so distributed model; include spatial variation in inputs outputs and parameters so here most of the important characteristics of the watershed are considered. Then we look say how the variation is taking place? Division of watershed area into a number of elements and calculation of runoff volumes for each element; so anyway, in any kind of model we cannot represent all the aspects as far as the variations are concerned. So, a total distributed model by considering all the variations of various parameters are an impossible task in watershed modeling.

So, what we do? we can consider small small zones or small small elements or grid and then we can average various parameters like Manning's reference coefficient or the hydraulic conductivity or porosity or like that; various parameters and then we consider as much as possible that these parameters variations so when we consider modeling like that, that type of models are called as distributed models.

So, then now finally, we have seen the various classifications as far as the models are concerned. Again, by considering what we had discussed so far, so as far as hydrological models are concerned, now this hydrological models are also part of watershed models, so hydrologic models mainly deal with the rainfall to runoff process.

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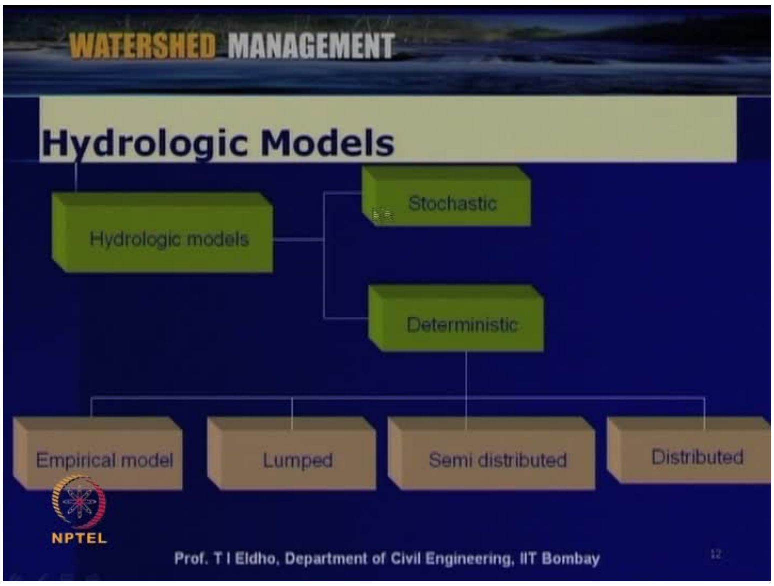

So that way hydrologic models we can classify into two categories: one is deterministic type of hydrological models and second one is stochastic hydrological models.

A deterministic hydrological model means it is deterministic; many of the parameters are deterministic. So, we are not considering any probability or the stocasticity as far as the system is concerned. Here, we use a typical type of equations; we solve a typical type of governing equations in a deterministic way with the various parameters we assume are known and then we are trying to find for example, rainfall to runoff for various hydrologic process are concerned.

Then the stochastic models we consider the stochasticity or the probability condition say, like the rainfall is a probable parameter. So, its variation we consider with respect to probability probabilistic distribution or stochastic. Then like various watershed parameters like hydraulic conductivity or the parameters which drastically varies we consider its probability distribution and then how it is varying. So, that way when we call model that kind of hydrologic models are called as stochastic hydrological models. As far as deterministic hydrological models are concerned, we can again classify like empirical models. So, there we can, we are using typical type of equations; just like rational formula or some of the black box models - that is so-called empirical model.

Then we are having the lumped models: lumped models means say some of the aspects like conservation of mass or that kind of system is considered. That is so-called lumped models.

SES curve number method is a lumped model; then semi distributed model semi distributed model means, all the variations are not considered or it is not fully distributed models. Some aspects we lump with respect to various parameters but some aspects we considered the distributed. So, then we call it as a semi distributed model; then the other type of model is the last one is so-called distributed model.

So, various parameters distribution we consider and then we consider the real physics of the problem. We solve the governing equations; partial differential equations which govern the hydrologic process and that type of models are called a distributed models.

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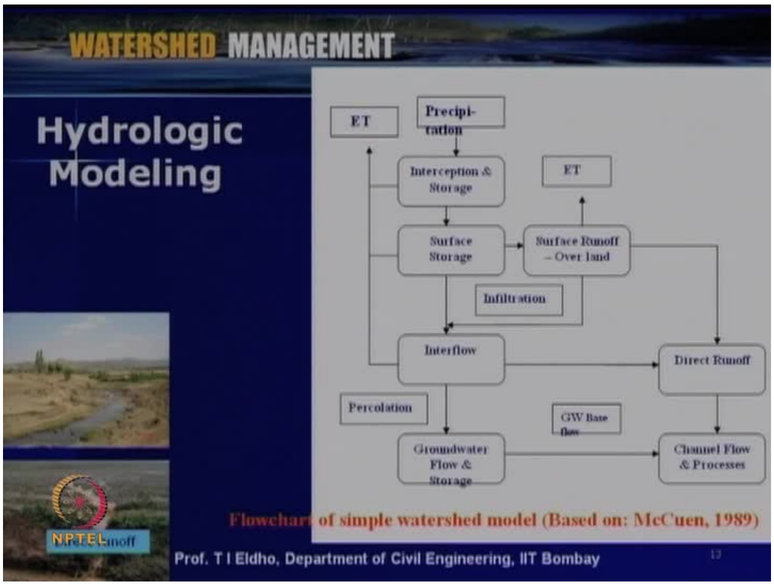

Now, when we discuss hydrologic modeling, in the last few lectures we had discussed various hydrologic parameters which govern for example rainfall to runoff. This we have already seen; so when we consider hydrologic modeling for example, for the given rainfall condition, how much is the runoff or, at the outlet of watershed how is the flow pattern will be varying?

So, then we have to consider the various hydrologic processes taking place within the watershed. This we start with the precipitation or the rainfall; then, as we have seen various losses like interception and then the depression storages, that we have to consider. Then, like evapotranspiration will be taking place; so that we have to consider; then, there may be some surface storage as far as the area is concerned then once the surface storage has full, the runoff starts so the surface runoff, so-called overland flow.

Then infiltration also simultaneously taking place from the watershed; so that infiltration will be going to the soil and then it may reach to the aquifer system. So, then there can be also coming back flow called interflow. In all these there will be evapotranspiration and finally, all these interflow coming together with surface runoff is called a direct runoff and that will be joining the channels. That is so-called channel flow and its corresponding processes. Then with respect to infiltration and then ground water flow condition, there will be interaction between the groundwater and the surface water. That is the groundwater base flow taking place; that will be joining the channel flow and of course, rivers also. So, this shows a typical hydrologic modeling from precipitation to runoff say, by considering a particular watershed.

Depending upon the type of model which we can develop, we may consider some of the important processes in this. Like of course, precipitation and runoff you have to consider but now like interception we may not consider or the interflow component we may not consider. But of course infiltration is one of the important parameter which we have to consider and then evapotranspiration also. So that way the hydrologic model we can developed say which can be either simplified model or complex model or a semi complex model depending upon what type of hydrologic processes will be consider as far as the model which we develop.

Now, say when we are going to select a particular watershed model so we have to see certain criteria we are meeting.

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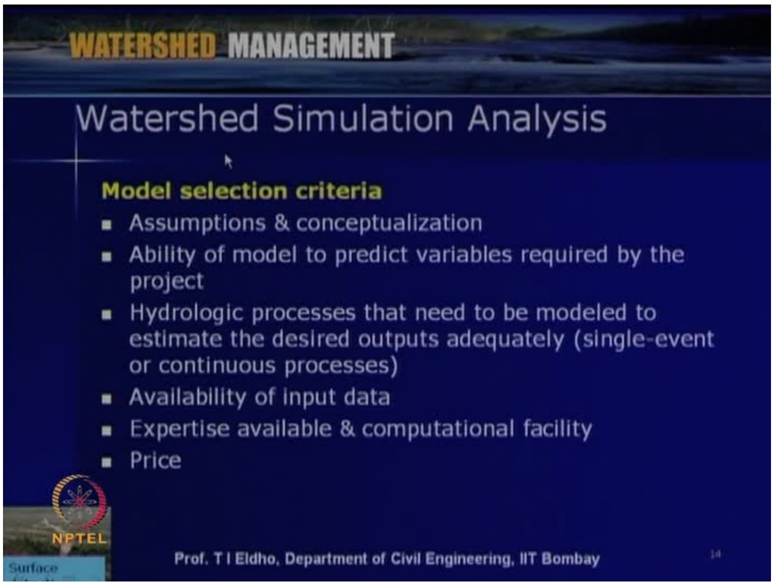

What are the important criteria? The important criteria I have listed here; so, we may have to look into various assumptions which we are using. First we delineate the watershed and then we are looking whether of course, the flow for example, the when we are going for flow simulation flow is taking place in 3 dimension but we may consider the flow variations as 2 dimension or 1 dimension. So, that kind of assumptions we can put and then we can conceptualize a model. So that is assumptions and conceptualization step. Then the ability of model to predict variables required by the project or required by the objectives. Already if the objectives, what we are trying to do, so according to the objectives, the selected model or the model which we are going to choose. So, whether that we have the ability to give those particular values or particular results; so that is the ability of model to predict the variables.

Then hydrologic process - that need to be modeled to estimate the desired output adequately; so like either single event model or continuous process, that is another selection criteria. Then, of course, most important aspect is whether we have sufficient input data. So if sufficient and accurate input data is there then only we can go for very complex models which can give that result. But, if sufficient data by considering various aspects are not there then we have to go for simplified models. Then of course, we have to see a good modeler is available; like an expert is available and then if you are going for computational models and computational facility we have to see. Then what is the cost which we can pay for that particular modeling? Or, so like what is the price of, if you are going to choose software? Or, if you are going to hire an expert then what is the price which we may have to pay? So, these are some of the important selection criteria ,as far as, when we look for a watershed model in the case of watershed simulation considered.

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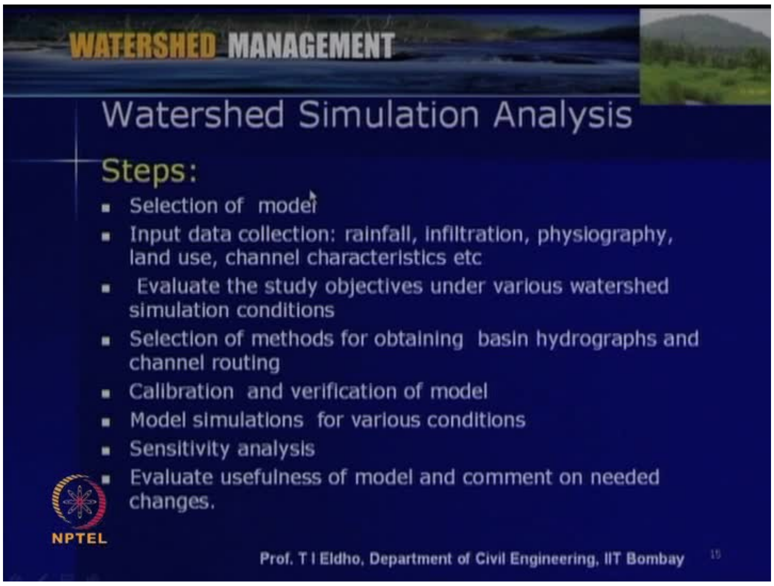

Now, here I have listed some of the important steps which we systematically follow as far as watershed simulation or analysis concerned by using models. So, first one is once the watershed is conceptualized and then various aspects we know and then our objectives are set. Then, we can go for particular models; so first step is we select the model or selection of models. This depends upon the various assumptions, what type of objectives we are setting. Then, next step is input data collection; so data collection, like rainfall, infiltration, physiography, land use, channel characteristics etcetera we have to get the input data.

Then, evaluate the study objectives; under various watershed simulation conditions; then, a selection of methods for obtaining say like basin hydrographs and channel routing. So, this is what kind of methodology we are choosing; then calibration and verification of the model. then we go for model simulation for various conditions. Then, as we discussed earlier we may have to go for sensitivity analysis of various parameters; then we may evaluate the usefulness of model, and then, we may have to do we to comment on various aspects. As far as the simulations are concerned, these are some of the important steps which we consider as far as the watershed models are concerned.

So, now in the next few slides we concentrate upon the rainfall runoff models which we commonly use. First we will discuss some of the black box models or some of the empirical equations and then we will discuss lumped model so-called soil conservation service curve number model.

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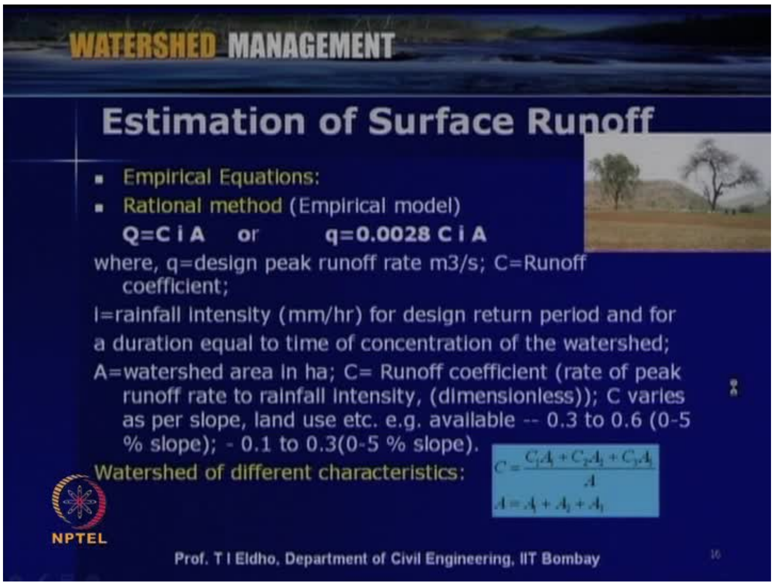

Now, we will discuss the surface runoff estimation; some of the important empirical equation one of the most commonly used empirical equation is so-called a rational method. By using the rational method this is the relationship giving the discharge or flow verses the rainfall for a given rainfall intensities.

So, Q is equal to C into i into A, where Q is the discharge or the flow C is the so-called runoff coefficient, i is the rainfall intensity and A is the area of the watershed which we consider. This we can write as small q is equal to 0.0028 C i A where small q is the design peak runoff rate in meter cube per second and C is the runoff coefficient and i is the rainfall intensity in millimeter per hour for design return period and for a duration equal to time of concentration of the watershed. So, this time of concentration is the maximum time which may take from stake for the water particular from the farthest point of the watershed; so this we will be discussing in the coming slide.

A is the watershed area in hectares; C is the runoff coefficient as I mentioned which shows the rate of peak runoff rate to rainfall intensity; so, these are dimensionless parameters. C varies as per slope land use, etcetera; for example, values can vary from 0.3 to 0.6, if the slope is varying from 0 to 5 percent then 0.1 to 0.3, so like that. That depends upon the land use of the particular watershed area. So, for a given watershed if the land use is varying from one location to another location, we can put different stones say like area can be divided into A 1, A 2, A 3, etcetera. Then, for each land use we can identify the runoff coefficient and then for the total watershed we can identify an average runoff coefficient which is C is equal to C 1 A 1 plus C 2 A 2 plus C 3 A 3.

For example, 3 land use and 3 areas; so then divide by total area A is equal to A 1 plus A 2 A 3. So, that way we can use this rational method for the given watershed. You can see that here the various watershed, this watershed is concerned; the land use is changing; so that way we can make an average runoff coefficient. Here, this is one simple formula which is very commonly used and then it is based upon number of assumptions. So, it be it is not an accurate method to get the runoff for a given rainfall condition but, it is an average method which shows a tendency of the flow condition.

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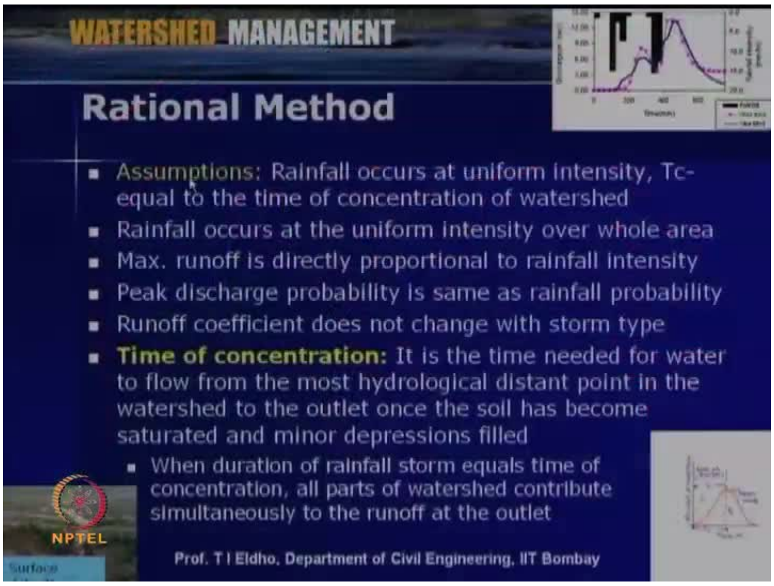

This rational method is based upon number of assumptions like rainfall occurs at uniform intensity and with Tc equal to the time of concentration of watershed. Then, second assumption is rainfall occurs at the uniform intensity over the whole area. Then maximum runoff is directly proportional to rainfall intensity; then peak discharge probability is same as rainfall probability; then runoff coefficient does not change with storm type. So, these are some of the important assumptions which we utilize in the this rational method, and then, as I mentioned, this time of concentration is very important in this method.

The time of concentration is the time needed for water to flow from the most hydrological distant point in the watershed to the outlet, once the soil has become saturated and minor depressions are filled. For example, if this is our watershed and this is the farthest point of the watershed; so this is the outlet; how much is the time taken for the water to flow from distance point to the outlet? So, when duration of rainfall term equals time of concentration, all parts of the watershed contribute simultaneously to the runoff at the outlet.

Once that time concentrations reached now, all parts to the outlet, the runoff will be taking place. Here this figure shows the time of concentration; here this is the time of concentration; so this is the hydrograph time verses the runoff; this time of concentration is one of the important parameter which we have to consider and this rational method is one simplified method; which give an overall range.

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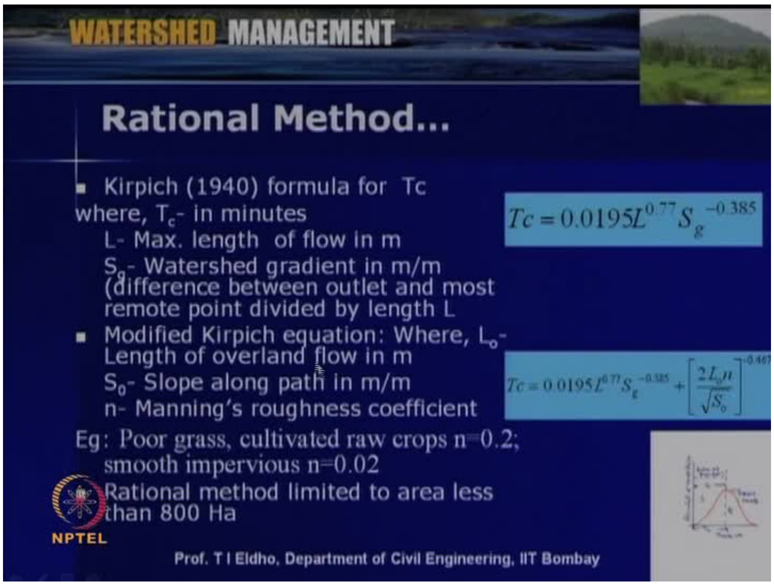

As far as time of concentration is we have to identify number of equations, are available based upon various observations by various researchers. One of the commonly used equation is so-called a Kirpich formula which was proposed in 1940. So, that is Tc time of concentration is equal to 0.0195 L to the power 0.77 into S g to the power minus 0.385 where Tc in minutes the time of concentration in minutes L is the maximal length of flow in meter, S g is the watershed gradient in meter per meter; so this is the difference between outlet and most remote point divided by length L.

This is generally used to identify what will be the time of concentration and now nowadays we can also use a modified Kirpich equation that is given by Tc is equal to 0.0195 L to the power 0.77 S g to the power minus 0.385 plus 2 L c rho n divided by square root of S 0 to the power of minus 0.467, where say L 0 is the length of overland flow in meter, S 0 is slope along path in meter by meter, n is the Manning's reference coefficient; so here we can see how this how this Tc is considered. So, say n is, we can identify from the literature like a, for a poor grass cultivated raw crops; n is equal to 0.2 and smooth impervious we can write n is equal to 0.02 like that.

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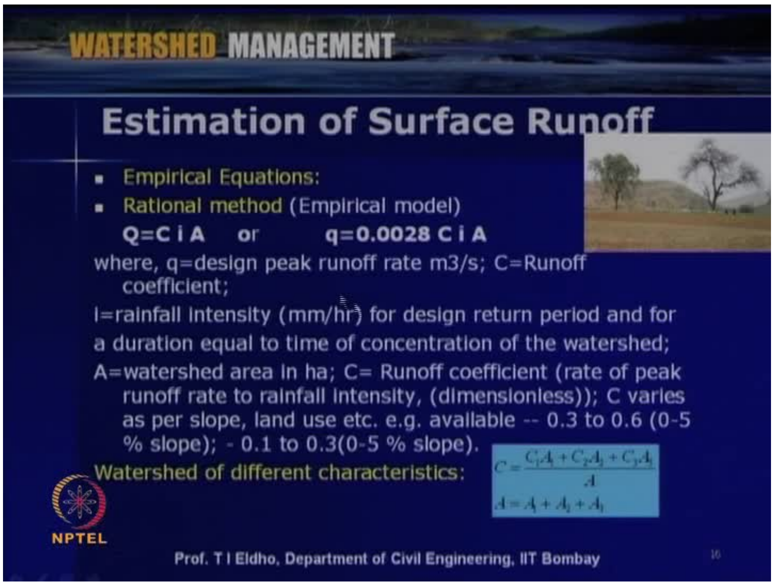

So we can identify for the given watershed conditions what will be the time of concentration, and then we can use this rational method to get the design peak runoff for the given condition.

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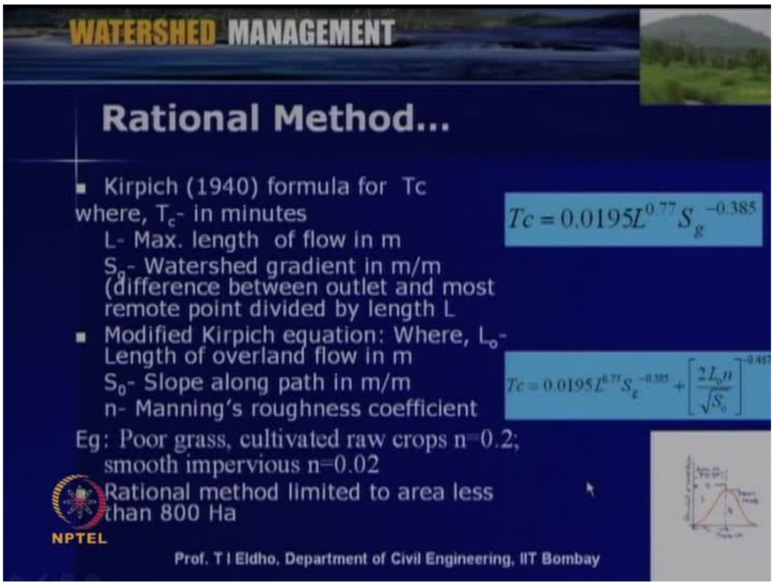

Generally, this rational method even though it is used for larger areas but, it is generally it is limited to area less than 800 hectares. But, some of the practitioners use for over large area also.

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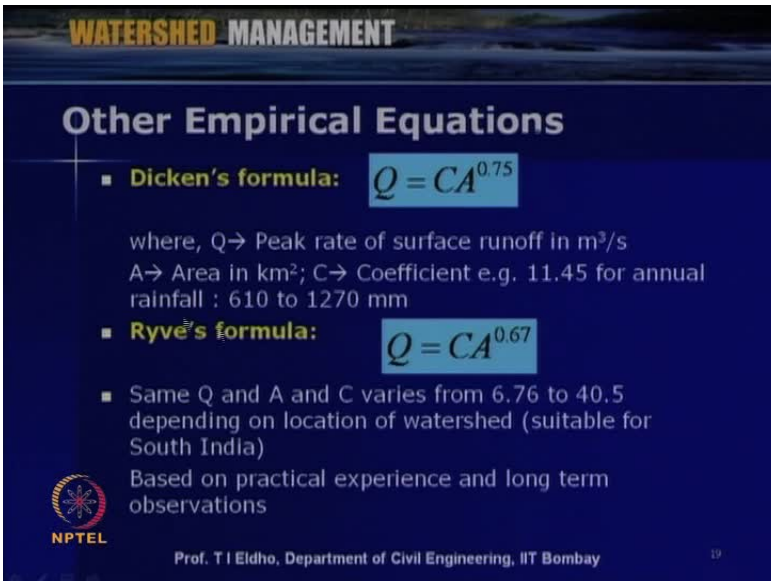

Then some other empirical equations are available based upon real field observations. Actually, that type of equations are valid only for that particular locations, particular situations. So, here I have listed some of the equations which are commonly used in Indian conditions; so first one is so-called the Dicken's formula.

So here, Q peak rate of surface runoff in meter cube per second is equal to C into A to the power 0.75; A is the area in square kilometer, C is the coefficient. So, this can vary from 11.45 for annual rainfall of 610 to 1270 mm. Then another commonly used equation is formula is called Ryve's formula. That is also very similar to Dicken's formula Q is equal to C into A to the power 0.67. So same Q A and C but here C varies from 6.76 to 40.5 depending upon location of watershed and this is generally developed for South India.

So these type of equations are based on practical experience and long term observations but, this we cannot apply anywhere but wherever it is developed by considering the rainfall, considering the runoff conditions, conditions these equations are developed and for that particular area we can utilize it.

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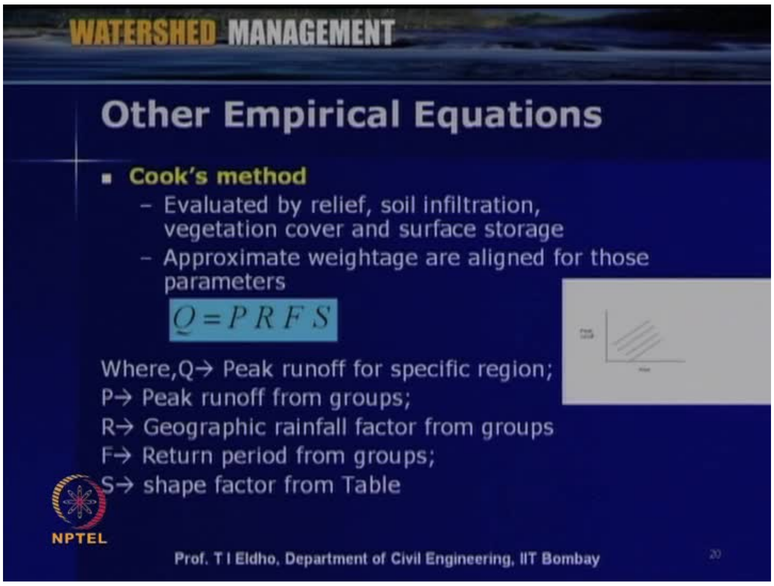

Then another equation is so-called Empirical equation - is called Cook's method. This method is based upon relief, soil infiltration, vegetation cover and surface storage. The question is Q is equal to P into R into F into S; so here. approximate weightage are aligned for these parameters.

So at Q is the peak runoff for specific region, P is the peak runoff from groups and R is the geographical rainfall from factor from groups; then, F is the return period from groups S is the shape factor from a table.

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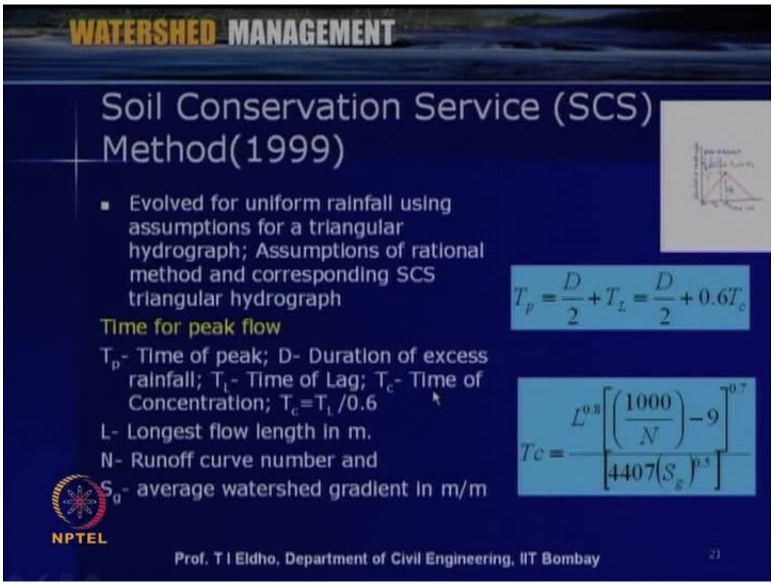

Here, this shows the area verses peak runoff variations; so these equations are developed based upon the observation for a particular area. Then, there is so-called soil conservation service method; here also this is evolved for uniform rainfall using assumptions for a triangular hydrograph like this (Refer Slide Time: 48:52). So, assumptions of rational method and corresponding SCS triangular hydrograph, is valid here also. Here, a T p the time of 2 peak is given by D by 2 plus T L; that means, equal to D by 2 plus 0.6 T c. So, D is the duration of excess rainfall T L is the time of lag and T c is the time of concentration T c is equal to T L b y 0.6. Then, T c also be approximated using this equation. So, here L is the longest flow length in meter N is the runoff curve number and S g is the average watershed gradient.

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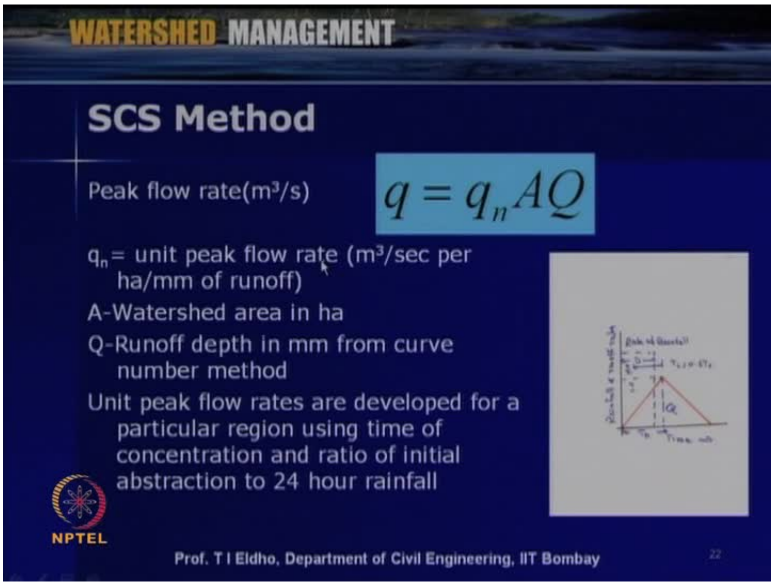

This is so-called soil conservation service method and then the peak flow rate we can identify q is equal to q n into A into q, where q n is the unit peak flow rate then A is the watershed area in hectares and capital Q is the runoff depth in millimeter from curve number method. Then unit peak flow rates are developed for a particular region using the time of concentration and ratio of initial abstraction to 24 hour rainfall. So, that is so-called SCS method.

Now, another important method which is a lumped model is so-called CS soil conservation service curve number method. This method is very commonly used in many countries and it is one of the accurate methods used for identification. How much is the runoff is possible for the given rainfall condition?.

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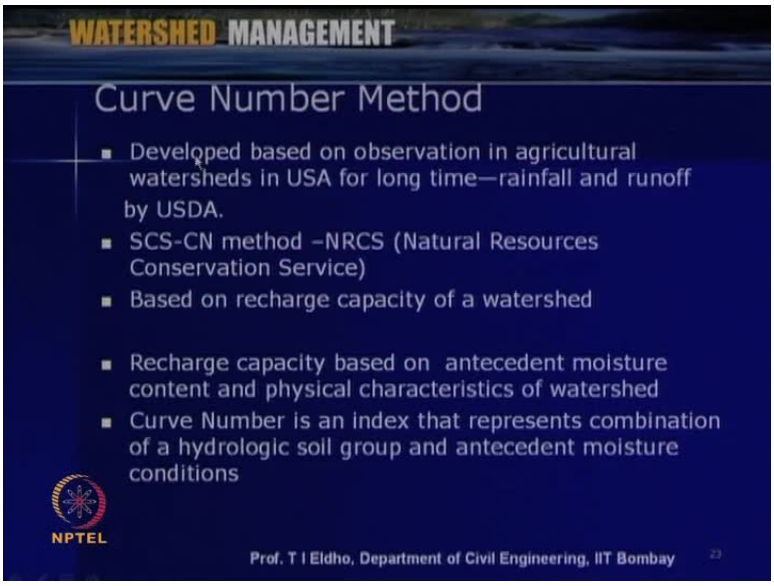

SCS curve number method is developed based on observations in agricultural watersheds in America for long time - rainfall and runoff by United States Department of Agriculture in number of watersheds in USA, for a long period say, in 1940s and 50s. So, SCS curve number or soil conservation service curve number method, nowadays called as NRCS curve number method - natural resource conservation service method So, this is based upon recharge capacity of a watershed and recharge capacity is based on antecedent moisture content and physical characteristics of the watershed. The curve number is an index that represents the combination of a hydrologic soil group and the antecedent moisture conditions.

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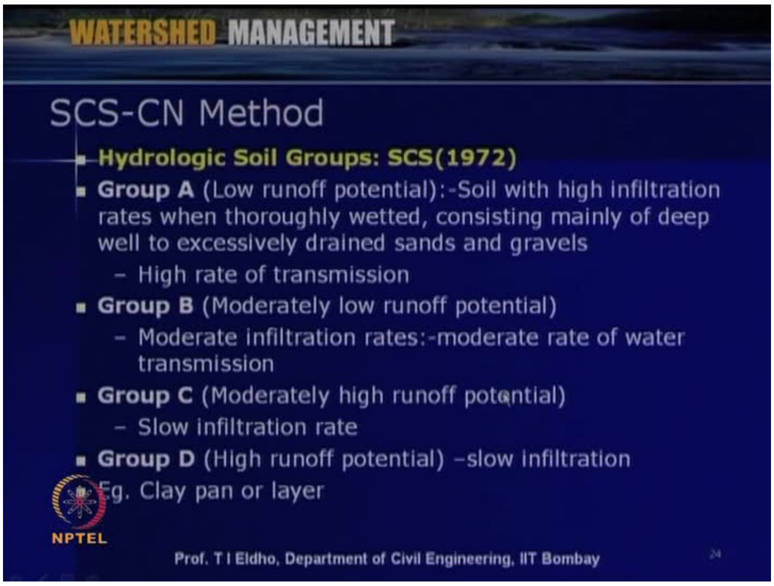

We, as far as the SCS-CN, various hydrological soil groups have been classified into 4 categories: group A, group B, group C and group D. Group A: its soil type is low runoff potential; soil with high infiltration rates; when thoroughly wetted consisting mainly of deep well to excessively drained sands and gravels. High rate of transmission and group B is moderately low runoff potential. So, here moderate infiltration rates, moderate rate of water transmission and group C is moderately high runoff potential and slow infiltration rate and group D is high runoff potential and slow infiltration rate like a clay pan or clay layer.

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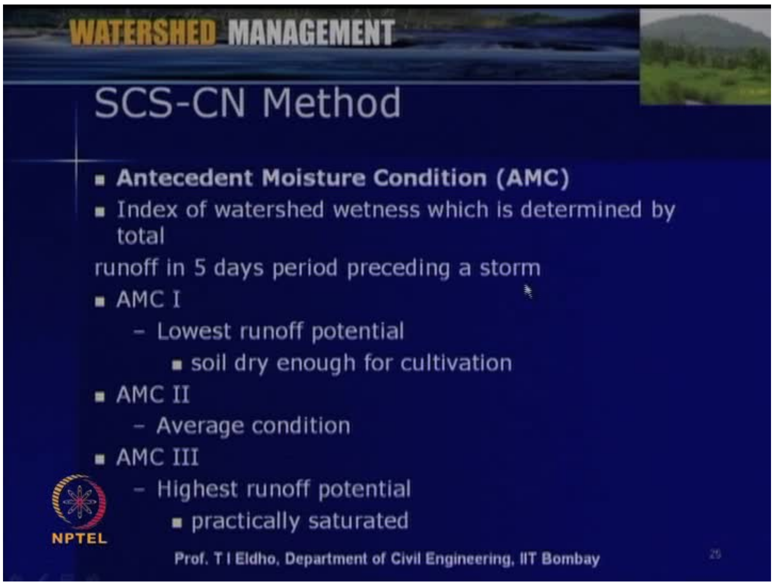

These are generally used for high soil groups and then this also method is based upon antecedent moisture conditions - so-called AMC conditions which is an index of watershed wetness which is determined by total say, by considering total runoff in 5 days period preceding a storm. So, there are 3 conditions: AMC 1 which shows the lowest runoff potential soil is dry enough for cultivation; and AMC 2 means average condition and AMC 3 means, highest runoff potential. So, practically the soil is saturated so that, immediately the runoff starts.

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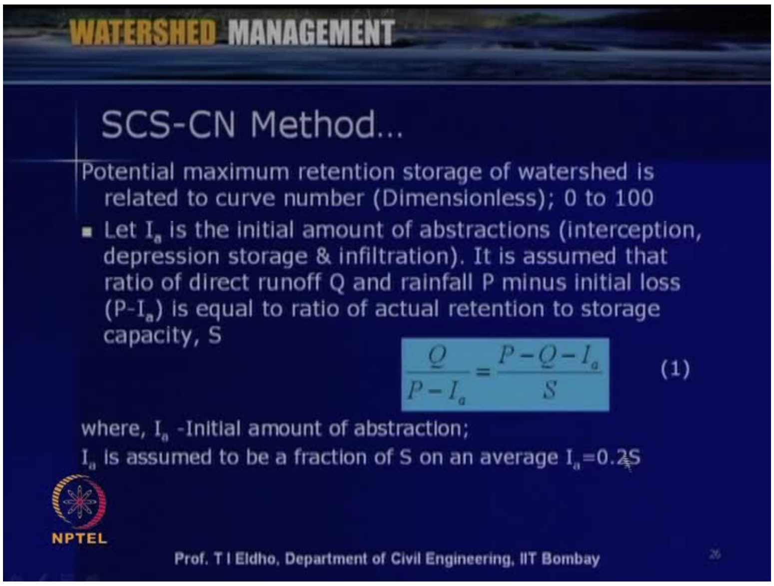

So, then in this method the potential maximum retention storage of watershed is related to curve number which is a dimensionless number - varies from 0 to 100. Here, if I a is the initial amount of abstractions like interception, depression storage and infiltration then, it is assumed that the ratio of direct runoff Q and rainfall P minus initial loss P minus I a is equal to ratio of actual retention to storage capacity. So, we can write Q by P minus I a is equal to P minus Q minus I a divided by S so where I a is the initial amount of abstraction. Generally, I a is assumed to be a fraction of this storage S and generally taken as I a is equal to 0.2S.

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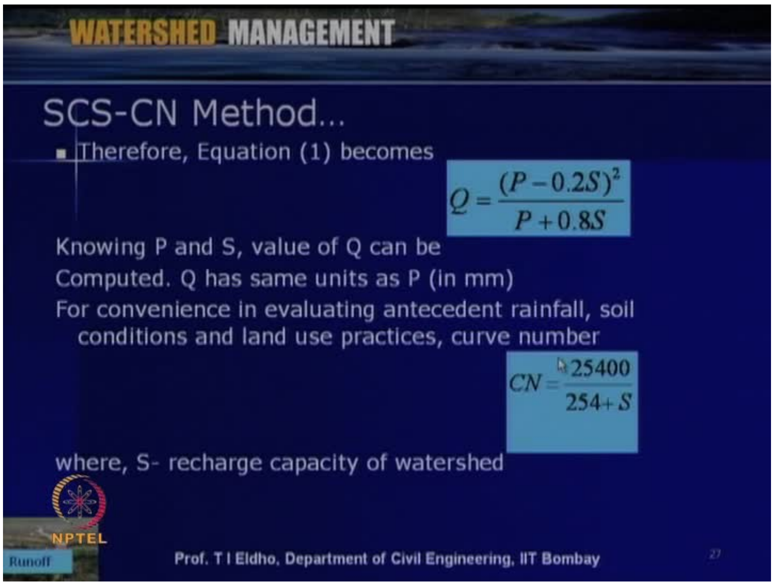

Now, from this equation number 1 we can write the Q which is we want to identify Q is the direct runoff; so that Q is equal to P minus 0.2S whole square divided by P plus 0.8S. So, knowing here in this equation which is a one parameter model; so, knowing P and S the rainfall and the S that means the storage then we can get the runoff. So, Q has same unit as P in millimeter. For convenience we can generate a number called curved numbers; so CN is equal to 25400 divided by 254 plus S, where S is the recharge capacity of watershed. So we identify curve number based upon this and that is varying from 0 to 100.

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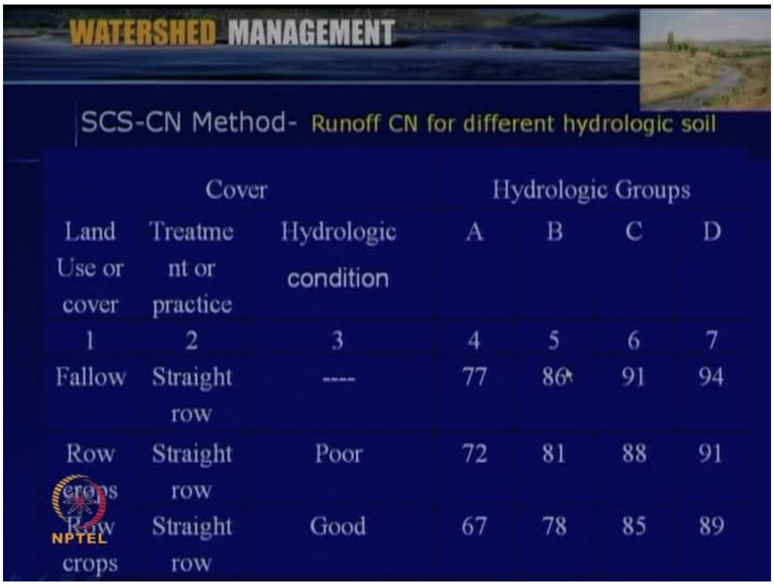

For the given hydrologic groups of soils and then antecedent moisture conditions, SCS curve number manual gives the various curve numbers for various land use or land cover and treatment type of practice then hydrologic conditions. So, various numbers varying from 0 to 100 are assigned. So, you can see this table, these tables are given in most of the hydrologic text book.

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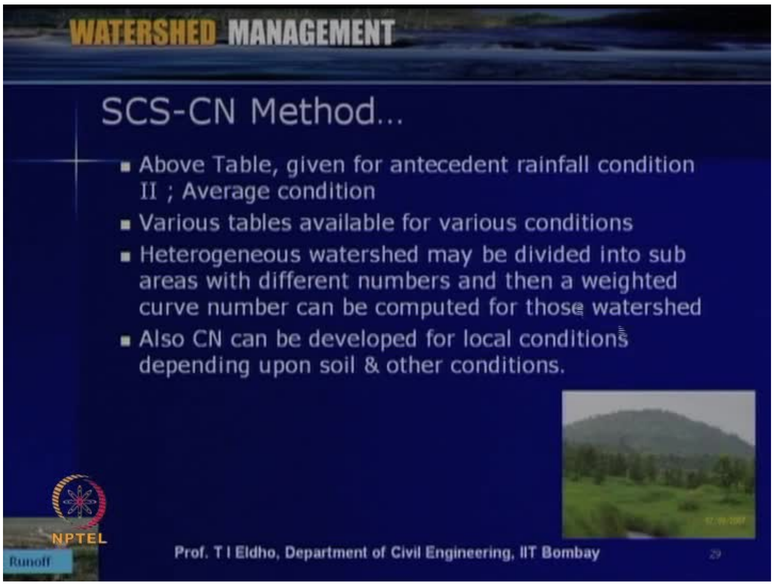

Say, above table given for a antecedent rainfall condition 2 and average condition; so, various tables available for various conditions we can obtain from, based upon that and these are available in standard text books.

Heterogeneous watershed may be divided into sub areas with different numbers and then we can get a weighted curve number and then we can get the curve number for the local condition depending upon the soil and other conditions.

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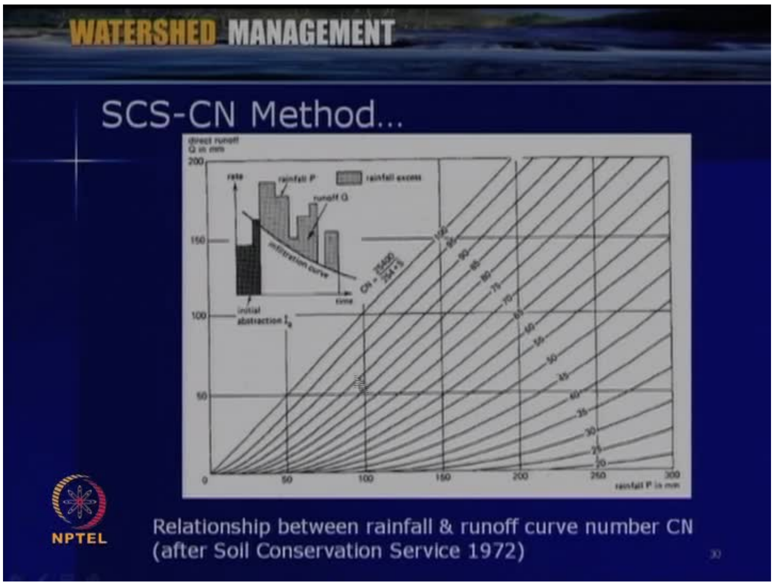

So, this here we can see that rainfall in x axis; rainfall in millimeter and the direct runoff Q. Here, infiltration curve is also drawn and then the curve number is obtained from this and curve number we can easily identify from this - the charts which is available in most of the hydrologic text book which is developed by soil conservation service manual 1972.

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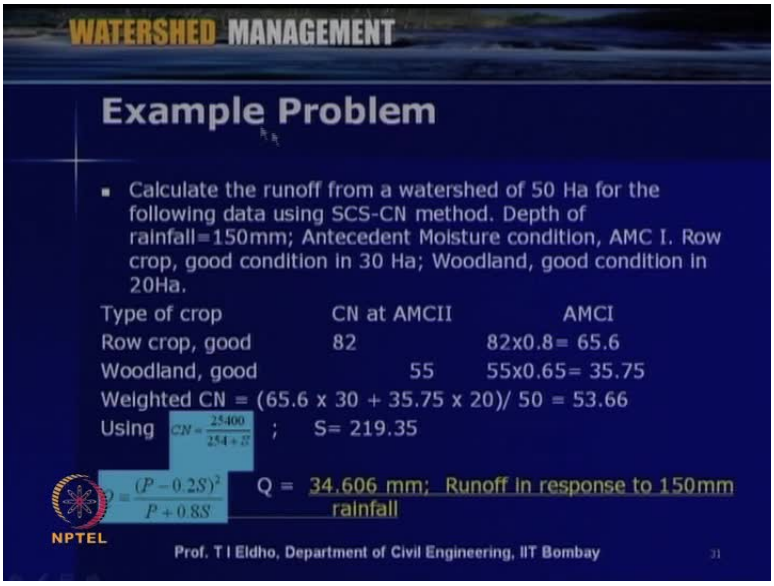

Now say, before closing this lecture, so one example problem: calculate the runoff from a watershed of 50 hectare for the following data using; SCS-CN method. So, depth of a rainfall is 150 mm, antecedent moisture condition is AMC 1, a Row crop good condition, 30 hectare and woodland good condition 20 hectare. So, here type of crop, then curve number, is given; so we can find corresponding AMC 1 conditions. From this you can see that weighted curve number; we can identify based upon this as 53.66. Then we can identify what is the curve number using this equation, and then, we can obtain this S value which is the storage, is equal to 219.35.

For this problem and then directly, we can obtain the runoff Q is equal to P minus 0.2S whole square divided by P plus 0.8S. So, Q - we can obtain this for this problem 34.606 millimeter. So, here the rainfall is 150 mm; the corresponding runoff for the watershed will be for the area will be 34.606 millimeter.

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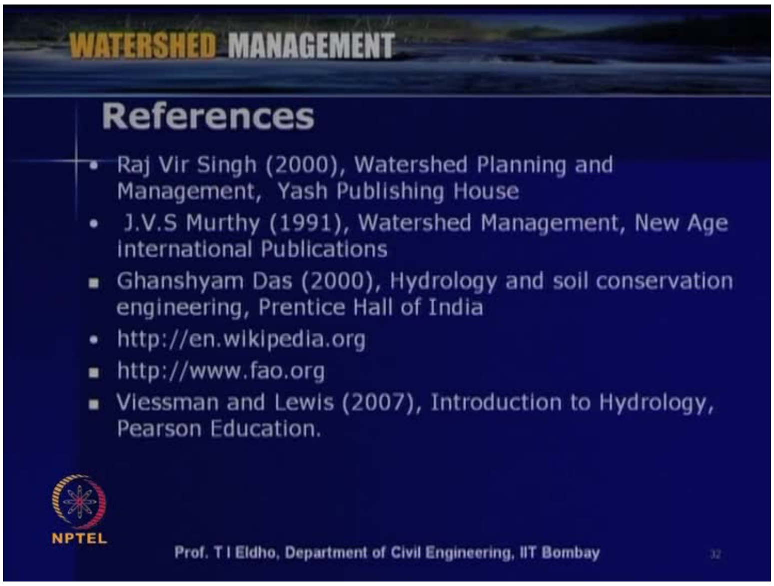

So, like this we can solve these various type of problems; even though say, this model is developed say CACA method, is developed for American watershed, we can use this for various conditions and now we apply this method for various countries at various locations and we can modify the curve number also by considering the various aspects of the watershed or area which we consider.

Nowadays, before the given conditions say for example, India is concerned we can develop the curve number for our local conditions.

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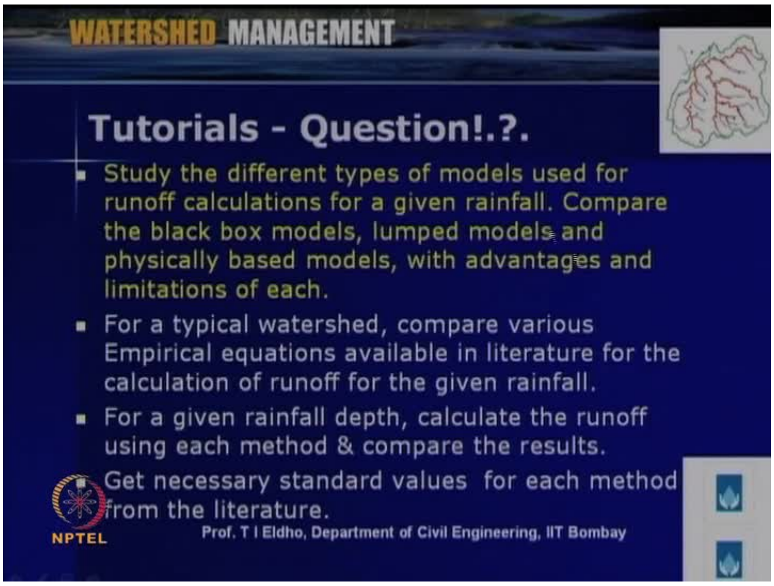

So, for today's lecture, these are some other references used and before closing the lecture one tutorial question. Study the different types of models used for runoff calculations for a given rainfall. Compare the black box models, lumped models and physically based model with advantages and limitations of each. For a typical watershed compare various empirical equations available in literature for the calculation of runoff. And, for a given rainfall depth, calculate the runoff using each method and compare the results; get necessary standard value for from the literature.

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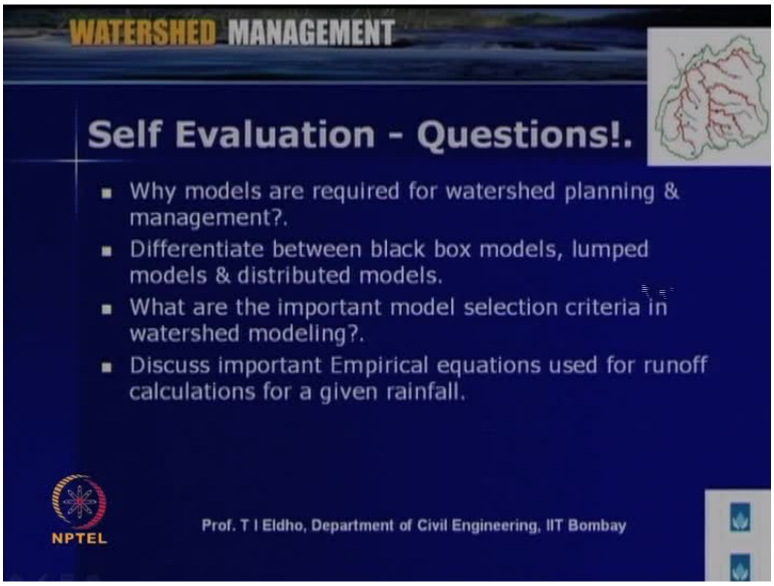

This tutorial can do based upon today,… in this lecture and some of the references given and a few self evaluation questions. Why models are required for watershed planning and management? Differentiate between black box models, lumped models and distributed models. And, what are the important model selection criteria in watershed modeling? Then, discuss important empirical equations used for runoff calculations for a given rainfall.

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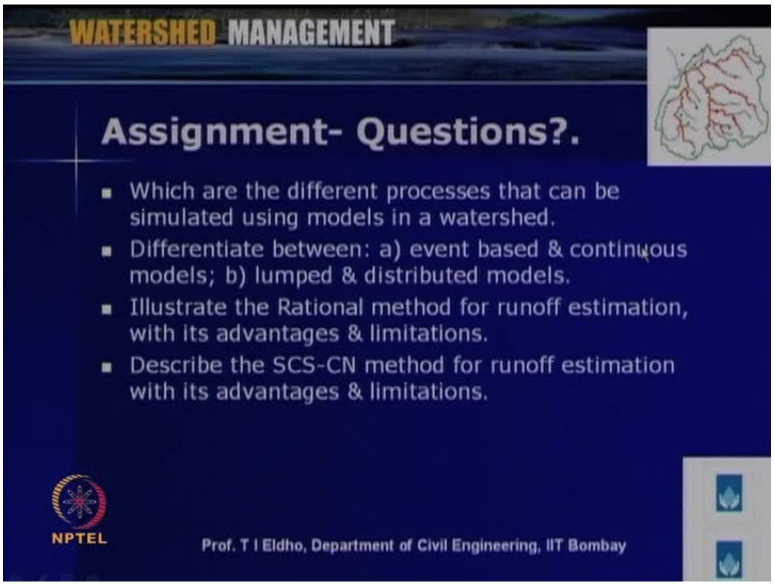

All this you can answer based upon today's lecture. Then, few assignment questions like, which are the different processes that can be simulated using models in a watershed? Then, differentiate between event based, continuous, lumped and distributed models. Then, illustrate the rational method for runoff estimation with its advantages and limitations. Describe the SCS-CN method for runoff estimation with its advantages and limitations.

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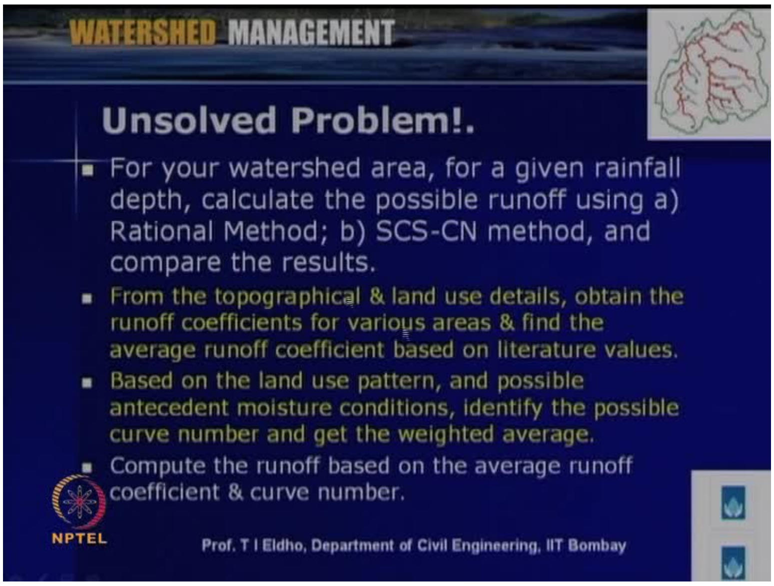

So all these questions you can easily answer through by going through today's lecture.

Well, one unsolved problem for your watershed area: for a given rainfall depth, calculate the possible runoff using rational method, SCS-CN method and compare the results.

From the topographical and land use details, obtain the runoff coefficients for various areas; find the average runoff coefficient based on literature values. Based on the land use pattern and possible antecedent moisture condition, identify the possible curve number and get the weighted average. Then, compute the runoff based on the average runoff coefficient and curve numbers; so this you can easily do for your area.

So, now today what we discussed is various hydraulic modeling approaches. We have discussed in detail about the empirical equation of black box models and the lumped models. In next lecture, we will be discussing the distributed models by considering the governing equation and other aspects. We will be discussing the physical models in the next lecture. Thank you very much.