Watershed Management

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Lecture No. # 25

Integrated Watershed Modeling Using Numerical Methods, GIS and Remote Sensing

Namaste and welcome back to the video course on Watershed management. In module number 6, in use of modern techniques in watershed management, lecture number 25, today we will discuss about integrated watershed modeling using numerical methods, GIS and remote sensing.

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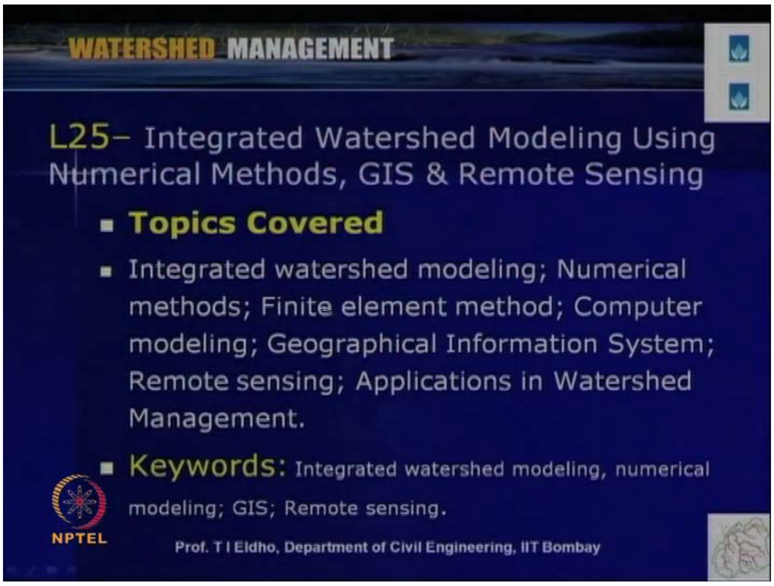

So, in the last few lectures, we have discussing about the geographical information system, remote sensing, decision support systems and its applications. So, in today's lecture of the topic is how we can utilize this geography information system, remote sensing and numerical methods, which we have discussed in some of the earlier lectures.

So, we can, how we can use in a integrated way, and then, what are the difficulties; what are the advantages; then, how we can apply for say specific case studies; so, like that, today's lecture is put.

So, some of the topics covered include - Integrated watershed modeling, Numerical methods, Finite element method, Computer modeling, Geographical information system, Remote sensing and applications in watershed management. Then for today's lecture the key words: Integrated watershed modeling, numerical modeling; geographical information system and remote sensing.

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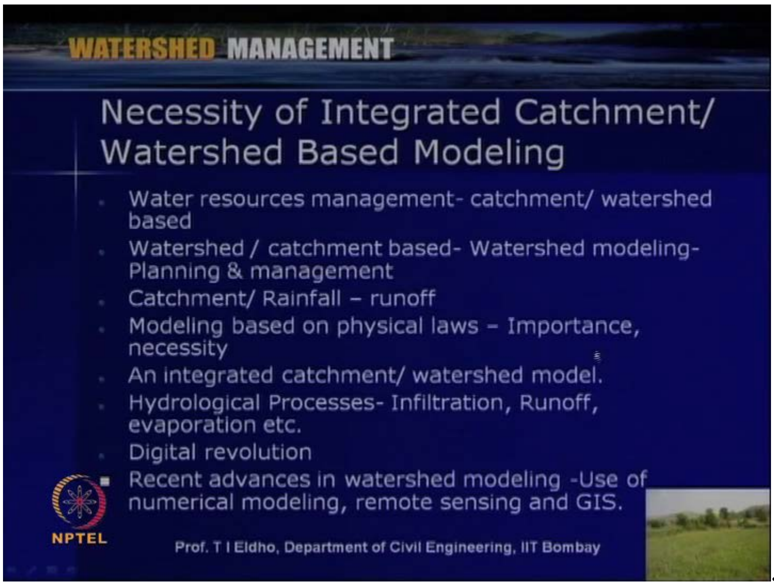

So, as we were discussing earlier, so, watershed management is a very complex process. We need to consider various systems related to land, water, then human being, then the flora and fauna within the area. So, that way, so, we have seen that, to study, to predict what will happen if some specific projects are implemented to study, what will happen. We have to go for modeling and then we have to understand the system in an effective way.

So, that way, say for example, when we are dealing with water, so, we will be discussing about rainfall to runoff modeling. So, that way, when we are going for rainfall runoff modeling; so, as we discussed in some of the previous lectures, we have to consider all the hydrological processes at various levels and then we have to model this processes, and then, in this way, we need a huge a quantity of data, say geographical data, topological data, topographical data, climatological data, like that.

So, when we have to use all these data, and then, we are going for modeling say in a prediction mode to simulates, say what will happen within the system. So, that way, if we can integrate say the computer models like a numerical models which is generally used for rainfall runoff or sediment yield or erosion type models, and then, we combine together these type of models - hydrological models or other kinds of models with geographical information systems and remote sensing, which gives a good data base when we can combine integrate together this modern tools. Then we have effective tool which can be used for watershed modeling or watershed management.

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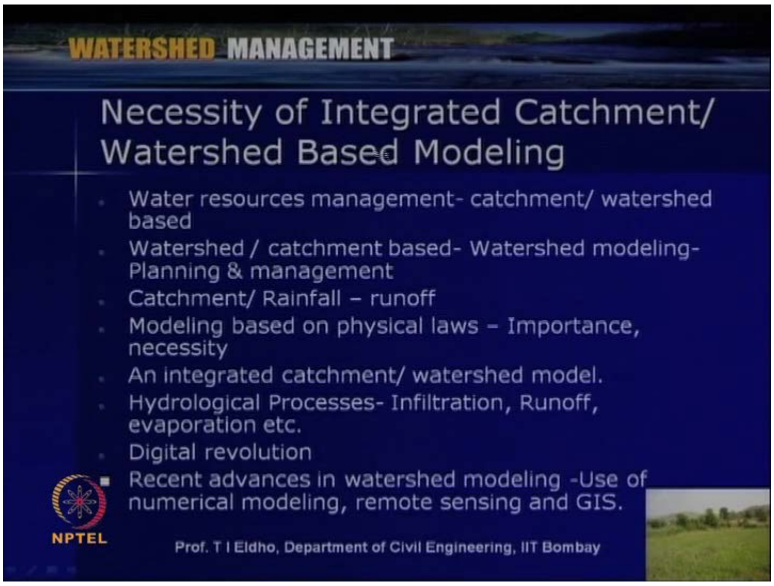

So, let us look some of the important points which we are discussed earlier also. So, here, in this slide, I have come to the necessity of integrated catchment or watershed based modeling. So, as I already mentioned, say water resource management, say generally we do catchment based or watershed based, and then, when we deal with watershed based or catchment based planning and management, we have to deal with huge amount of data, and then, we have to see the variation, spatial variation, temporal variation.

So, as we discussed, say rainfall runoff modeling, so, we need to assess how much will be the runoff within the watershed, say for the given rainfall conditions or for the possible rainfall conditions, or we may have to assess say what will happen, if any the effect, if we consider the effect of climate change, or what will happen if the soil loss or erosion problems is a exceeding certain limits. So, all those studies we need to have an integrated approach.

So, modeling say most of the time as we discussed earlier, modeling can be either simply black box based approach or empirical approach or lumped approach or distributed approach, but we can as we discussed earlier also, the distributed based modeling or a physically based models based upon the physical loss or conservation of mass, momentum and energy. These kinds of models are very essential to see what will really happening within the watershed or within the area for the given conditions. So, these kinds of physically based models only can predict; so, the variations with respect to spatial or with respect to temporal for the given condition.

So, that way, the models based on physical loss are very important and necessary in the case of watershed modeling. So, we need to go for integrated catchment of watershed based approach while dealing with various problem related to water or soil or land or the sustainable development of the system.

So, if we consider water or hydrological aspects, so, the hydrological processes we have to consider like infiltration, then evapotranspiration, runoff, then ground water component, etcetera. So, if you consider the last 50 years development in this area, so earlier say before 96 or 1950s, it was so difficult to do these kinds of studies in a comprehensive way. Since the area which we are considering is large, and then, we cannot develop physical models or laboratory based models or you have to go to the field and then take the measurements all these things were so difficult.

So, that way, when this due to the digital revolution which has taken place last 50 years, say huge changes have taken place in the area of this kinds of modeling. So, with the development of the computer techniques technologies, modern numerical techniques, like a finite different method, finite element method, etcetera, came to picture, and then, that way, the solution of various hydrological processes or hydrological modeling became much much easier, and much, much faster, and much, much more comprehensive.

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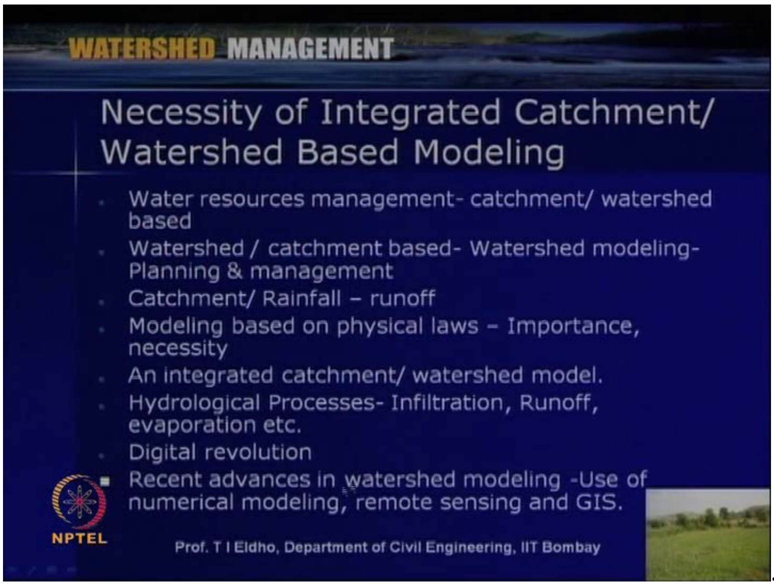

So, and then, as I mentioned when we deal with these kinds modeling, we have to deal with the huge data set. So, these data set which needed for these kinds modeling we can obtain from the geographical information systems or remote sensing which we have discussed in the last few lectures.

So, that way, the recent advances in watershed modeling is the use of combined or integrated approach of numerical modeling, remote sensing and GIS so that already the large development have been taken place in this area, and then, now, sophisticated models are available for the integrated watershed or integrated water resource management approach.

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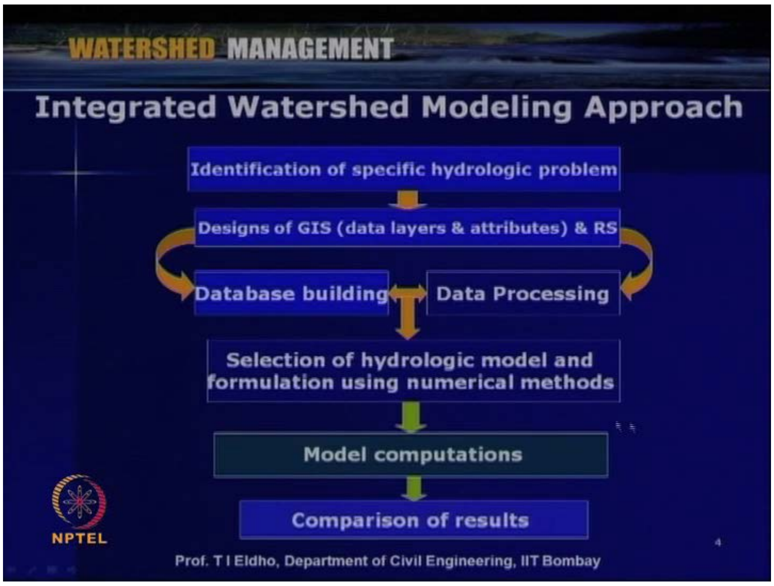

So, here, I have shown a flow chart where how we can do integrated watershed modeling approach. So, first step is we have to identify the specific problem; it can be hydrologic problem or it can be soil erosion problem or sediment yield problem or whatever problem which we are trying to do as far as the watershed is concerned so that we can identify, and then, for any of these kinds of studies, we need good amount of data.

So, we can send a geographical information systems based upon the available data, the topper sheets and other maps. So, next step is design of the geographical information systems like data layers and attributes, and then, of course, to identify the variation taking place for the watershed spatially or temporarily, we can use the remote sensing. So, the second step here as shown in this slides is the use of GIS and remote sensing in an integrated way so that we are having the database.

Based on using the GIS and remote sensing, we can develop the database. So, database building and then this data can be processed in different ways so that the way which we needed like a various maps like digital elevation models, land use map, slope map, land cover map, soil map, etcetera, we can make. So, this is the third step where database and data processing can be done within the environment of geographical information systems and remote sensing.

And then next step is either we can develop the hydrologic model or we can select the hydrological model, and then, say formulation using numerical methods. So, we can select the approach which we are doing through conceptualization, mathematical modeling, and then, either we can chose appropriate hydrologic model or we can develop our own model based upon the needs for that particular problem.

So then, say once the model is chosen and then or the model is developed, and then, as we discussed earlier, we have to calibrate and validate. So, all those things are needed. So then, we can go for the model computations; the next step is model computations. So, as shown in this case, the fifth step is model computations, and then, we can based upon this model computations or simulations, we can compare the results or we can generate various scenarios or various alternative plans and then study in detail.

So, that way, an integrated approach of geographical information system remote sensing and hydrological models or numerical methods a basic structure can be like this, and then, we can integrate together so that we will be having an effective tool for the particular problem which we consider whether it is a rainfall runoff modeling or hydrologic modeling or soil erosion modeling or what kind of studies which we are planning for the particular watershed, which we are considering.

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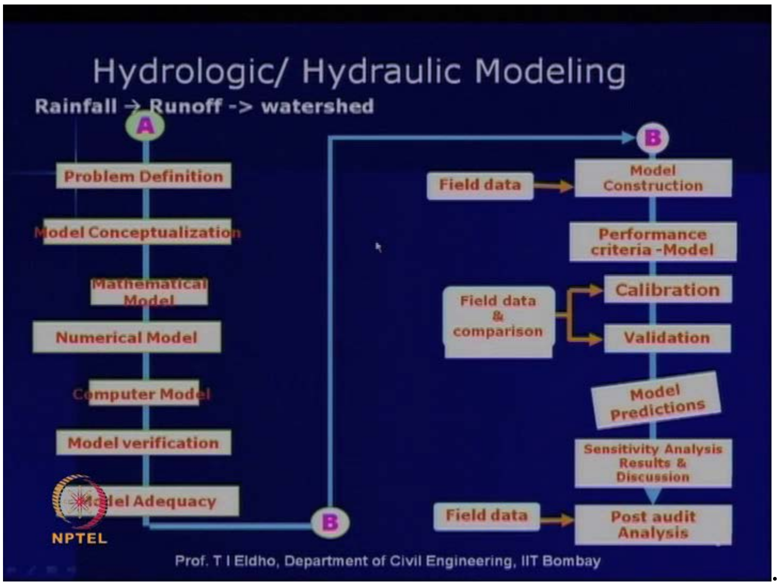

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So, now, when we are dealing with hydrologic and hydraulic modeling, so, here, I have put a slide which we have discussed earlier also. For example, rainfall to runoff, so, two aspects is there: first one is hydrologic modeling and then hydraulic routine or hydraulic modeling.

So, we have to start with the problem like to assess the runoff within the watershed. So, that is a problem definition for the given rainfall condition, and then, we have to conceptualize the model, like overland flow, channel flow, like that whether one dimension, two dimensions, and then, we can develop the mathematical model and then we can choose the numerical model, and then, based upon that numerical models, this numerical model can be like the tools like a finite difference method, finite element method, etcetera, and then, based upon that, we can have the computer model, and then, we have to go through a process of model calibration or verification and then we have to assess the model adequacy.

So, this is the first part, and then, second part - we have to collect the field data; then we have to compare the field data and assess the field data, and then, once the model is constructed, we have to go for the performance or criteria evaluation, then calibration validation, then model predictions, and then, sensitivity analysis results and discussions and then post audit analysis or and then further check cross checking with the field data. So, like that, we can do the hydrologic or hydraulic modeling.

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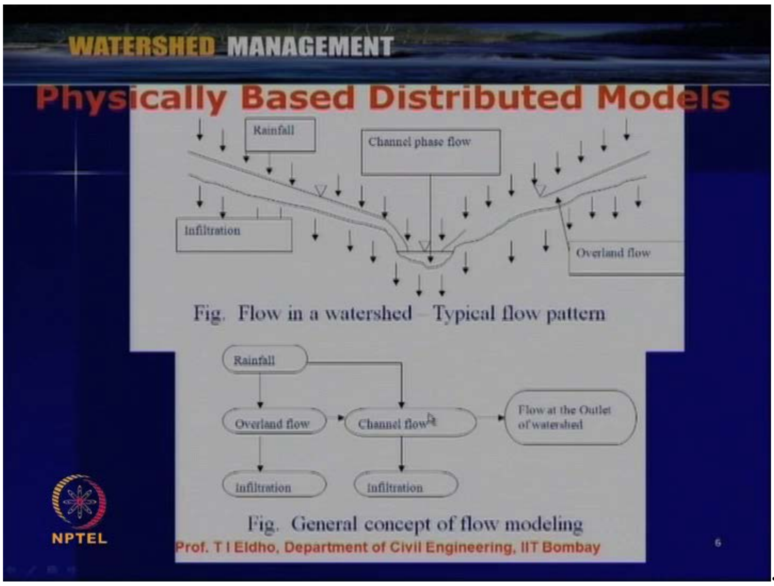

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So, here also as I mentioned, we can integrate these system like geographical information systems and then the remote sensing data for such kind of integrated modeling. So, as I mentioned earlier, most of the time we need to go for physically based modeling since that is very important, since that give show the system is behaving spatially and temporally, and then, we can study what is happening minute wise or hourly wise or the way which we want. So, that way, for example, when we are dealing with rainfall to runoff, so, here, this particular flow chart shows for event based rainfall runoff modeling. So, rainfall is taking place within an area watershed and this is the overland flow and then this is a channel flow. Then the flow development takes place or runoff starts, and then, infiltration also taking place.

So, depending upon the model which we consider, we can have various components including the evapo-transpiration, ground water component, etcetera. So, a general concept of flow modeling say for rainfall to runoff is shown here. So, we start with the rainfall. Then the overland flow component - we can simulate, and then, infiltration we can consider and then the channel flow basis and then flow at the outlet of the watershed or particular location where we are looking for.

So, that way, we can develop the model and then we can consider the physically based distributed model. So, physically based distributed model - it needs lot of data and the modeling efforts are very high, but even though the results may not be so good but it gives so much of physics of the problem so that we can easily understand what is the mechanism taking place within the watershed. Say for example, when rainfall to runoff process is taking place.

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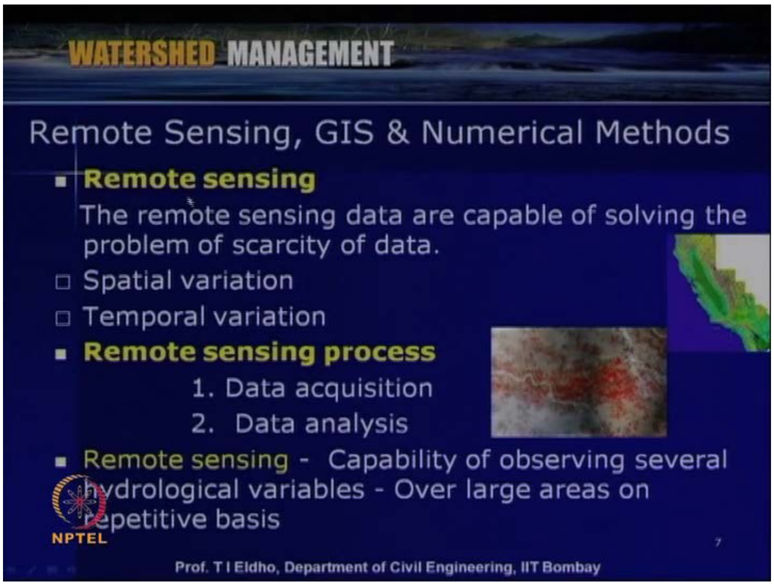

So, that way, physically based distributed modeling is very important, and now, we are discussing about the integrated approach of numerical methods, GIS and remote sensing. So, as we discussed in the another previous lecture, so, remote sensing is one of the important tool used in hydrological modeling. So, the remote sensing data are capable of solving the problem of scarcity of data. Since we need huge amount of data, we can get these data from the remote sensing. For example, this is the remote sensing picture which shows the various land use, land cover, the channel location, like that. So, the importance of remote sensing we have already discussed in one of the earlier lecture.

So, the advantage is that when the satellite is passing over particular watershed or particular area, we can identify; we can get the spatial variation at a stretch for the particular watershed, and then, when again that satellite is coming back, we can consider weekly basis or monthly basis or seasonal wise or annual wise how the variation is taking place within the watershed. For, say, if you implement a project, what will be happening, or if the existing projects, what will be the situation taking place.

So, like that, the temporal variation we can easily understand with reference to remote sensing. So, that way, remote sensing is very important in these kinds of modeling. So, as we have seen, earlier remote sensing mainly two parts - first one is the data acquisition. So, data acquisition is done through satellites or other say media like aeroplane or other systems.

And then, this data is obtained in the (( )) for example, in Indian national remote sensing center located at Hyderabad is having all these data, and then, once this data which is needed for the particular area, we can obtain through from that agency and then we have to analyze the data so that, the wave, the area which we needed, we can get the complete details, say as a file which we can see in the computer and then analyze.

So, that way, remote sensing - it has the capability for observing several hydrologic variables over large areas on repetitive basis. So, that is the advantage of remote sensing. So, the capability of observing several hydrological variables over large areas on repetitive basis. So, that is the major advantage of remote sensing.

So then, the other tool like geographic information system, this about this GIS also we had a discussion earlier in one of our earlier lecture. So, here, what we do? We give the input like the topological data or the available data in terms of digital form or other scanned form, and then, this data is manipulated or transformed by various techniques within the GIS software, and then, we get the output, say output can be in various forms like maps, land use map, land cover map, soil map or digital elevation model, slope map, like that.

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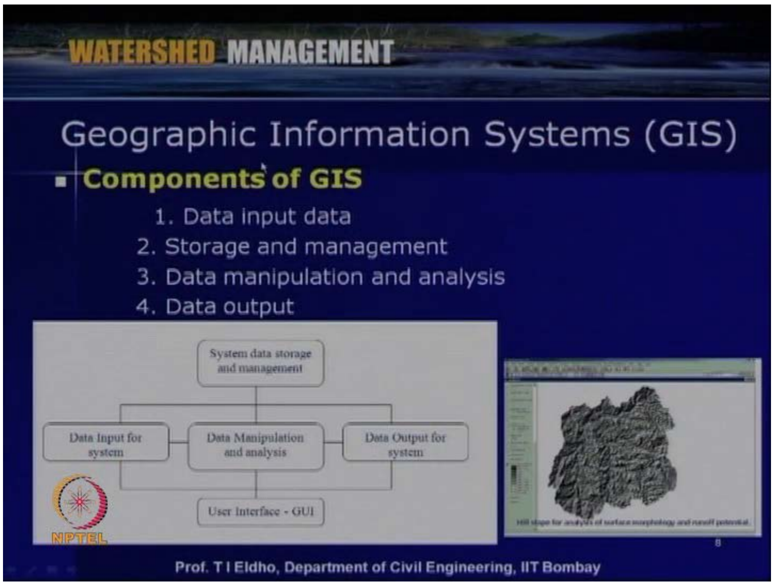

So, that way, the important components of GIS have the data input, then storage and management data manipulation and analysis and the data output. So, this shows a typical flow chart as far as the GIS is concerned. So, here data input of photo system. Then system data storage and management; then data manipulation and analysis, and data output for the system, and then everything is visible through a user interface so called a graphical user interface.

So, that way, as we have seen in the earlier lecture on GIS, so, we can effectively utilize the system and then generate various maps, say like we can delineate the watershed and then also obtain the digital elevation model or slope map like that. So, that way, GIS saves the major contribution as far as the hydrological watershed modeling is concerned.

And then next tool is the numerical methods or computer models. So, as we have already discussed earlier, to simulate, what will be happening within the system within a watershed for the given conditions, say like given rainfall conditions or when we are constructing a dam or a check dam or various when or we are going for various rain water harvesting measures, then what will happen as far as hydrologic process are concerned within the watershed.

So, this, we can do only through simulation or modeling. So, the system is so complex. So, that way, there is no easy solution or even exact solutions, analytical solutions are not available. So, we have to go for modeling. So, modeling can be like as we discussed, this can be simple black box or empirical models or lumped models or the distributed models. Especially when we are discussing with physically based distributed models, we have to solve very complicated partial differential equations like Saint Venant's equations. As we discussed earlier also, that models say we have to run through in computer and then we have to get for particular conditions, we have to run the model and get the results.

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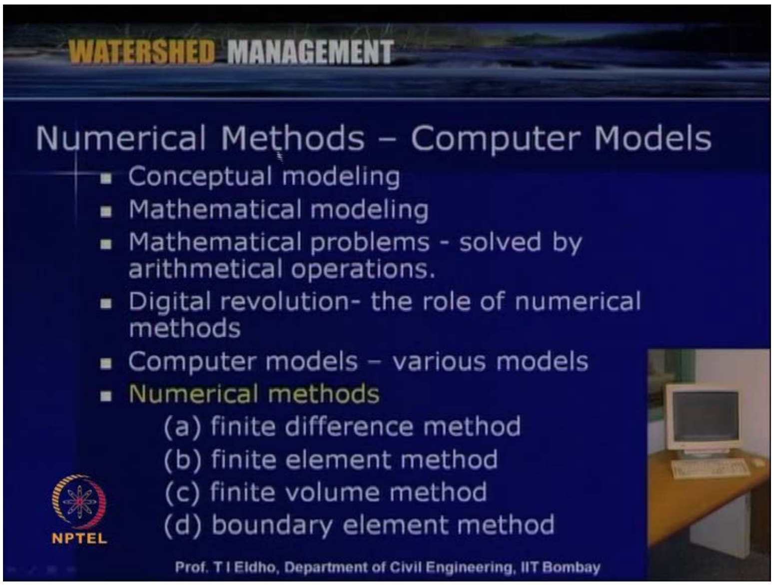

So, that way, numerical methods as we discussed earlier, the steps are conceptual modeling. So, based upon the requirement or the objectives, we can develop the conceptual model. Then mathematical modeling – so, we can obtain the governing equations, initial condition and boundary conditions depending upon the problem, and then mathematical problems - we solved and the models we solved by arithmetical operations or in computer.

So, as I mentioned, due to the digital revolution, now the numerical methods we generally use for these kinds of problems. So, like a finite difference method or finite element method which we have discussed earlier. So, computer models as we discussed number of models are available depending upon the requirement, depending upon the necessity or the data availability or the computer facility, we can choose particular models either in one dimensions, two dimension or three dimensions and then we can go for depending upon our objectives say particular modeling.

So, numerical methods - as I mentioned like a finite difference method, finite element method, finite volume method or boundary element method. So, like that, numbers of methods are available as far as numerical methods are concerned.

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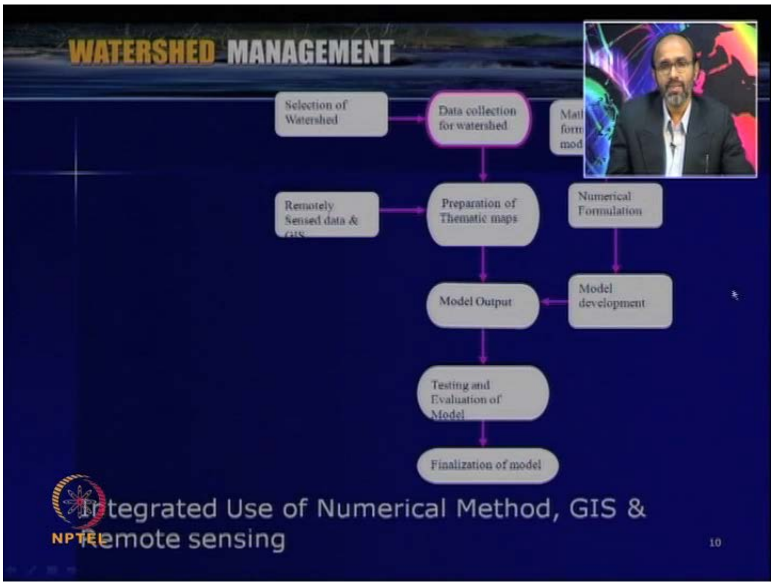

So, that way, now when we go for integrated watershed modeling using the numerical methods, GIS and remote sensing, so, this shows a typical flow chart. So, for the, first step is selection of the watershed or for the given watershed which is the watershed and then get the necessary data available data, and then, simultaneously, we can obtain the remote sensed data through satellites and then develop a GIS data base. So then, the data collection for watershed, so, physical data collection for the particular area, what kind of available data or from the field, we can collect various data, and then, we can delineate the watershed and then prepare various thematic maps based upon the remote sensing data and the available data. Simultaneously, we can go for the mathematical formulation.

So, we can decide depending upon the objectives whether we are going for a one-dimensional model or two-dimensional models or whether we are going for the physical models or lumped models or black box models. So, like that, we can decide.

So, if you are going, say for example, physical models, then we have to solve partial differential equations in one dimension or two dimensions generally. So then, we can do the numerical formulations and then we can develop the model. If you are going to build in your own model, then we model development. Otherwise, depending upon your requirement, you can purchase the particular software or we can download if it is freely available from the internet.

So then, by getting this model is developed for the particular area, and then, using these data, the available, the prepared data set we can say develop the model and then run the model. So, that way, the next step is model output.

So, once the model output is obtained, so, as I mentioned this is obtained through various process like calibration, validation. Since many parameters, we have to determine through this process, and the next step is testing and evaluation of the model, and then, for the particular conditions, particular watershed or particular area depending upon the requirement, we can finalize the model.

So, this way, this flow chart shows a typical model. So, here, as shown here, say various steps are shown here effectively. So, how we prepare a particular model as far as the watershed integrated watershed modeling is concerned? So, this flow chart shows the way which we develop the model.

So, now, for example, as I mentioned if you are going for the watershed based or if watershed modeling for rainfall to runoff say, if you are going to use the physically based model event based modeling, so then, we have to consider various hydrologic processes. So, here, in this slide, so, you can see the various steps which we can follow.

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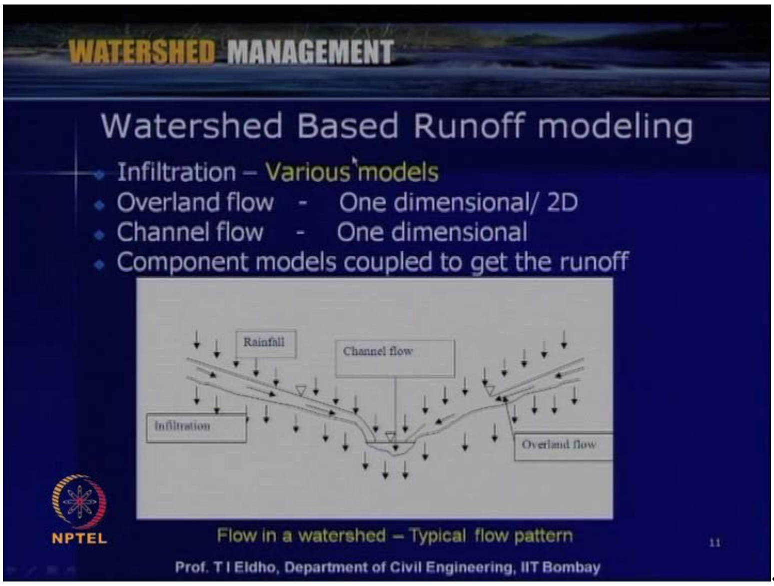

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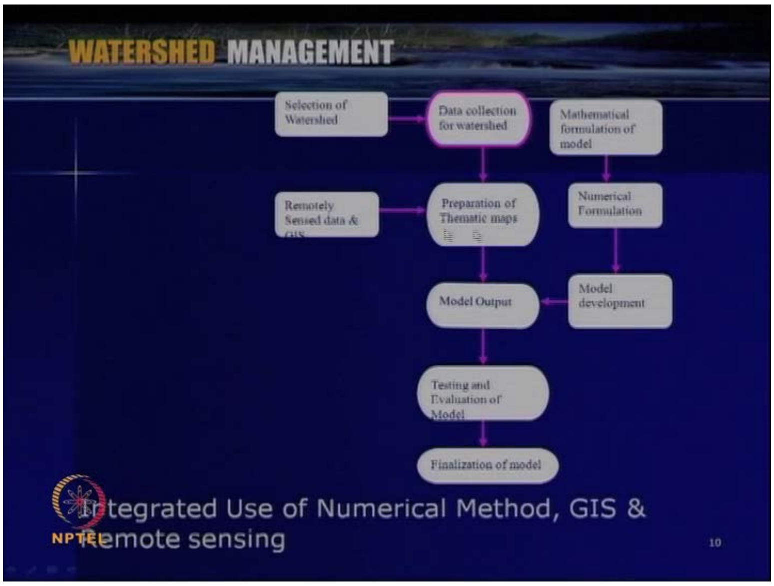

So, here, depending upon the requirement, so, these are the steps the flow chart which I mentioned. So, here, starting with the various database development, model development, and then evaluation and finalization of the model, and then, if you are going for rainfall runoff modeling, we can decide the infiltration models which we are going to use various models are available as we discussed earlier.

So, like a Philips model, Venant model, c a c n based model, like that we can decide the infiltration model, and then, overland flow is concerned, since this we can have either one-dimensional based model or two-dimensional based model, depending upon the data availability and requirement, and generally, the channel flow when we are going for rainfall runoff modeling in watershed, we can go for one-dimensional modeling. Then we couple all these processes like infiltration, overland and channel flow so that we can get the runoff at particular location. So, in these kinds of event based model, most of the time, we can neglect the evapo-transpiration since it is done for few hours depending upon the rainfall condition, but if sufficient data is available, we can consider other process also like interception inter flow, then evapo-transpiration, etcetera for the particular watershed. So, that way, we can go for the modeling.

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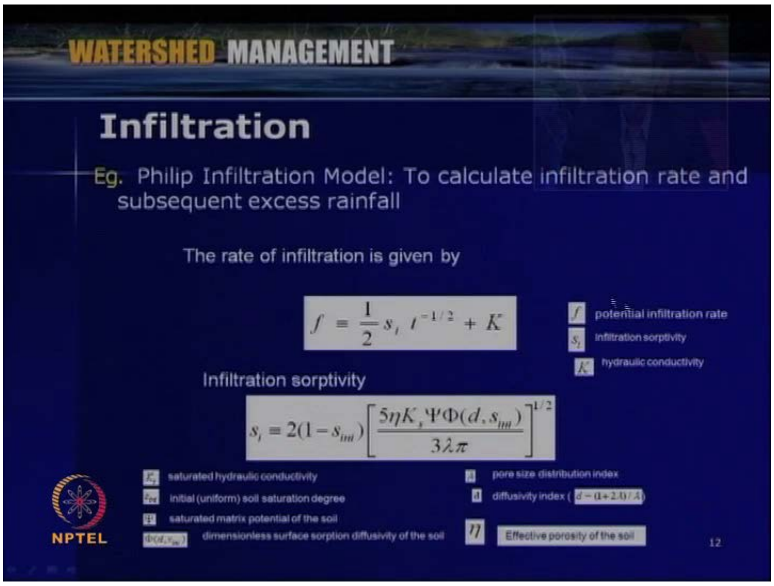

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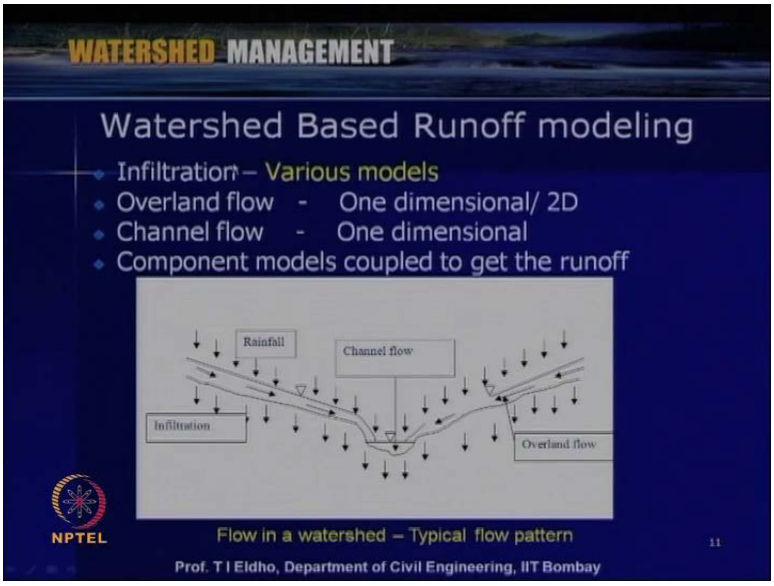

So then, as I mentioned say at IIT Bombay, we developed a model physically based model for rainfall runoff modeling for watersheds. So, the details we are going to discuss in the coming few slides. So, here, we developed the one-dimensional models, steep based model for overland, and then, channel flows, one-dimensional diffusion wave based and overland flow as kinematic wave based model.

So, there various details we discuss in these few slides. So, infiltration has been modeled using Philip infiltration model. So, to, here, the purpose is to calculate infiltration rate and subsequent excess rainfall. So, that is what we are trying to do. So, the rate of infiltration is given by in the Philip model by this equation, and here, f is the potential infiltration rate, and S i is the infiltration sorptivity; K is the hydraulic saturated hydraulic conductivity, and this infiltration sorptivity is given by this equation.

So, here, K is hydraulic conductivity, and then, in this equation, here you can see that K s is the saturated hydraulic conductivity; (( )) is the initial soil saturation degree and psi is the saturated matrix potential of the soil; then lambda is the pore size distribution, like that.

So, that way, this Philip infiltration model one of the commonly used model. So, the details are available in most of the text books or the web, and then, as far as overland flow is concerned, as I mentioned we can go for two-dimensional models or one-dimensional model.

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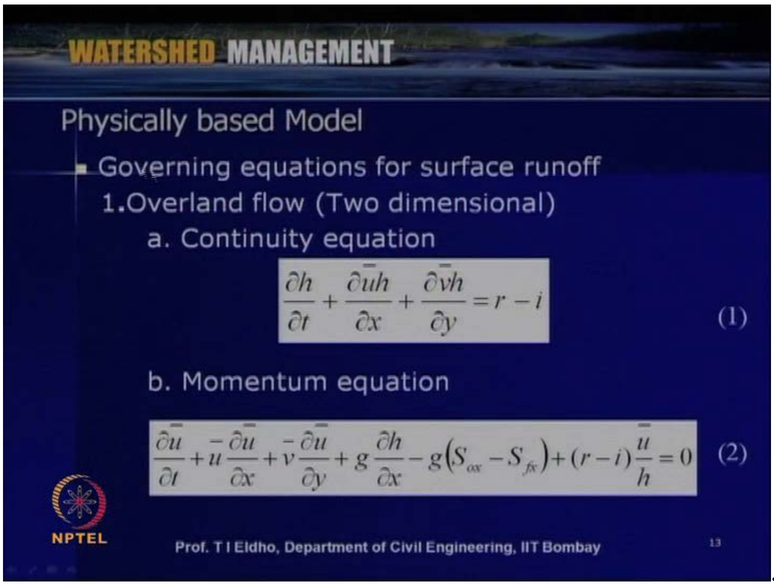

So, the governing equations here, in this slide, I have kept. So, here, overland flow if we are doing two-dimensional modeling, the continuity equation is given by this equation - del h by del t plus del u bar h by del x plus del v bar h by del y is equal to r minus i - where h is the depth of flow and u bar is the velocity and v bar is the velocity u in x and y directions, and then, r is the rainfall intensity and i is the infiltration rate.

And then we have to solve simultaneous momentum equation x direction. This equation gives the momentum equation x direction. So, here, S ox is the channel or the overland slope and S fx is the energy slope and then this is in x direction, and similarly, we have to solve the equation y direction, so, where the equation is given here.

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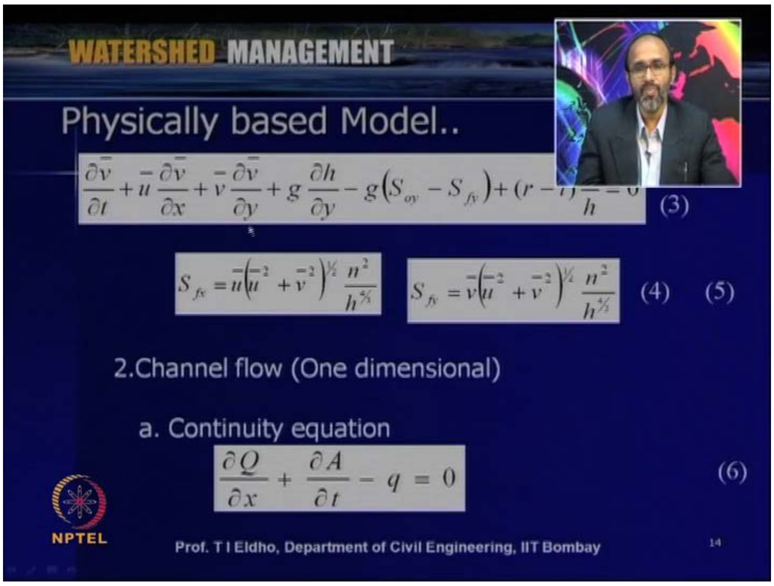

And this energy slope – here, we can use the Manning's equation as given in this equation number 4 and 5. So, that way, say these equations if we are going for two-dimensional modeling, we can directly solve these equations and then we can get the output will be the depth of flow at particular location and the velocity is in x and y direction at the at particular time step or particular location, and then, channel flow is concerned, as I mentioned generally we can go for one-dimensional modeling.

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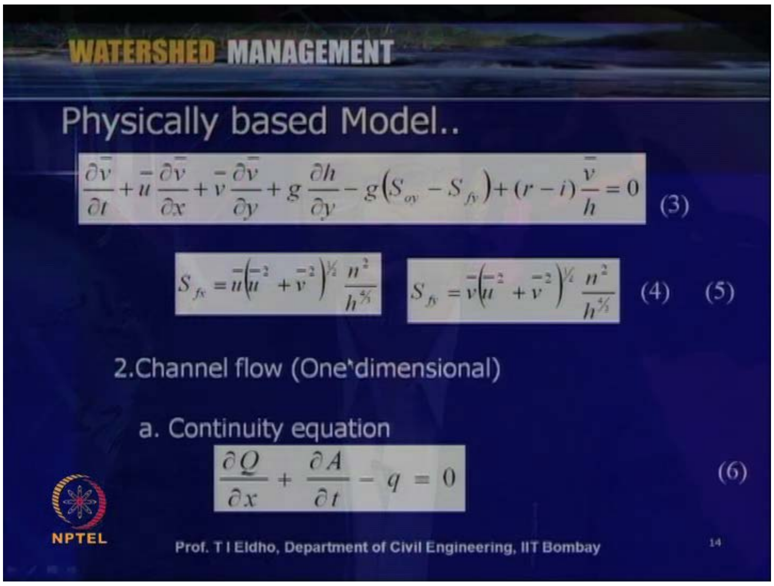

So, for one-dimensional channel flow modeling, we have to solve the continuity equation and the momentum equation. So, continuity equation is given by del Q by del x plus del A by del t minus q is equal to 0 - where Q is the discharge; t is the time; A is the flow cross section area small; q is the overland flow component coming to the channel and that we have to route, and the momentum equation one dimension is shown by this equation number 7.

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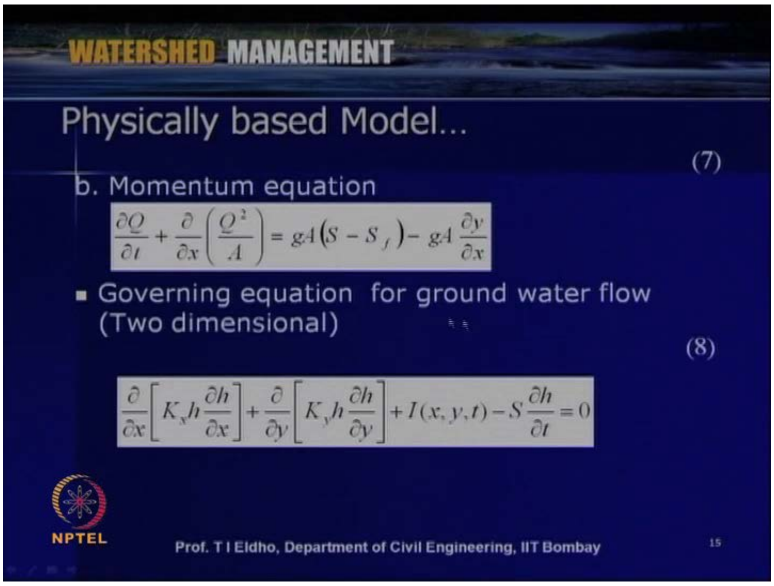

So, which is del Q by del t plus del by del x of Q square by A is equal to g into A into S minus S f minus gA into del y by del x - where S f is the energy slope; S is the channel slope and g is the acceleration due to gravity, and then, sometimes depending upon the requirement, we can also combine this overland flow and channel flow model with a ground water flow model. If there is interaction is expected between the components or if you want to go for further complex comprehensive modeling.

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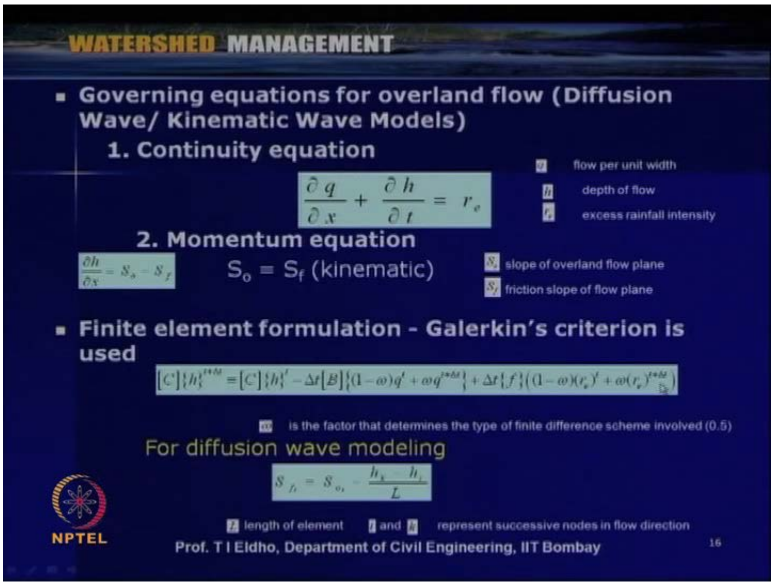

So governing equation for ground water flow in two dimension is given by this equation number 8 - del by del x of k x h in del h by del x plus del by del y of k y h del h by del y plus i x y t minus s del h by del t - where h is the hydraulic head; k x and k y are hydraulic conductivity in x y direction; i is this the infiltration or the inflow coming to the system; S is the specific yield or storage coefficient depending upon the system.

So, as I mentioned at IIT Bombay, we developed a one-dimensional model for overland flow in one-dimensional. That was kinematic wave based, and then, channel flow using diffusion wave based model. So, the details are given here in this slide. So, here, we use the finite element method to solve these governing equations for continuity and momentum equation.

So, here, say the kinematic wave or diffusion wave, the continuity equation is given by this equation. So, earlier equations what we considered is the continuity equation and the momentum equation are the full form of the Saint Venant’s equations, but here, the diffusion wave or kinematic wave are simplified forms of dynamic wave or the Saint

Venant's equation. So, the momentum equation - when we consider the bed slope is equal to energy slope, that form is called kinematic wave form.

So, this equation and we consider the continuity equation, and then, when we consider del h by del x is equal to S 0 minus S f that equation plus this continuity equation, when we solve, then that is the diffusion wave form of the Saint Venant's equation. So, in the model, we solve this equations using the finite element method using the Galerkin criterions, which we discussed earlier also in one of the previous lecture.

So, we approximated this equation by using this condition also using the shape functions linearly line elements, and then, one-dimensional model has been developed. So, this shows the final finite element system equation, and the diffusion wave - if you want to use, this can be approximated like this and then keep it in the model.

So, we can have the either kinematic wave model or the diffusion wave model for the overland flow component, and then, this overland flow will be joining the channel. So, the channel flow is also modeled as one-dimensional flow. So, here, we have to solve the continuity equation given by this equation.

And the kinematic wave form for the channel flow again we substitute bed slope is equal to energy slope as given in this equation, and the diffusion wave form will be del h by del x is equal to S 0 S minus S f c - where S is the bed slope; S f is the energy slope. So, here, we use the Manning's equation to get the energy slope and corresponding, the, give the discharge.

So, here again, we use the Galerkin finite element method for the solution of this system equation for the channel flow for the routing purpose, and then, this is the system of equations. So this, we discussed earlier also, and the diffusion wave form, we can approximate like this, or in the kinematic wave form, we can simply put S 0 equal to S f.

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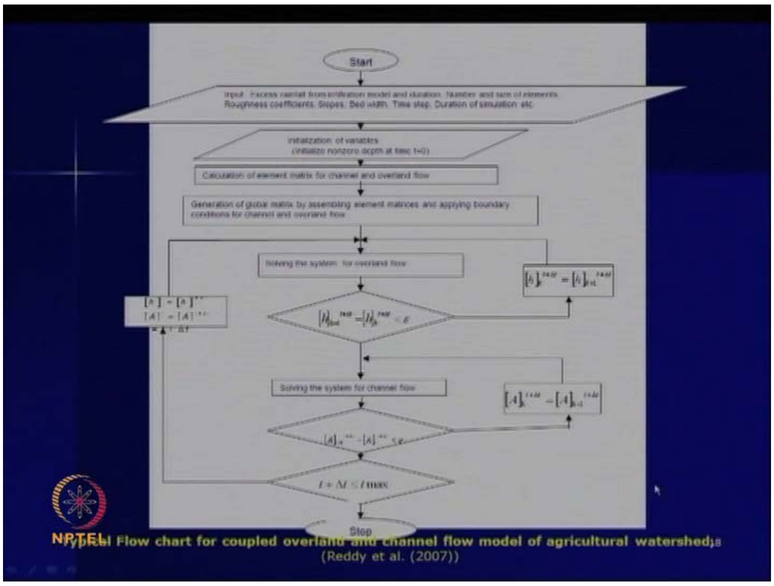

So, that way, we develop the channel flow and then we combined the overland flow component with the channel flow component so that we can get the coupled model as far as the overland flow and channel flow is concerned. So, this is a physically based model of course one dimensional in nature. So, that gives the, for the given rainfall condition, how the runoff is generated, and then, the details we can get at as either depth of flow or the discharge at particular location at any given time.

So, that way, we developed a coupled model by considering the overland flow and channel flow solved by finite element method. So, we consider the kinematic wave approach or the diffusion wave approach for the overland flow and also diffusion wave approach has been used for the channel flow.

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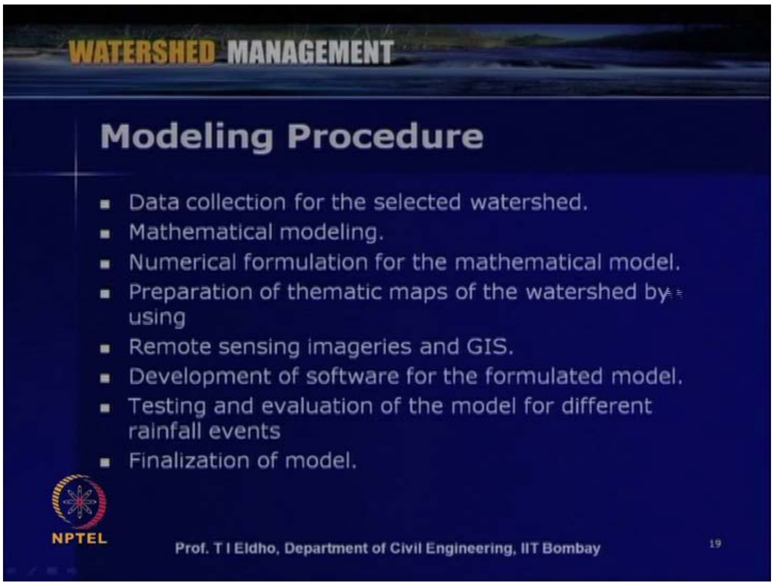

So, we combined or we coupled both models both are developed using the finite element methods in one dimensions, and when we solve this, we get the flow variation with respect to the depth variation or the discharge variation for the given rainfall conditions. So, how the runoff is taking place? So, the same flow chart here. I have shown as the various steps how we developed a model.

So, first of all either we collect the data, so, data collection for the selected watershed. Then as I mentioned, we have to go for the mathematical modeling. So, we identify the watershed area, delineate the watershed area. Then we will be identifying the governing equations whether full form of Saint Venant's equations or the diffusion wave form or the kinematic wave form. So, that gives the mathematical modeling. So, there also we have to prescribe the boundary conditions and the initial conditions.

Then the next step is the numerical formulation for the mathematical model. So, as I mentioned, we have to solve this partial differential equations; so, we have to go for numerical modeling. So, either finite difference method or finite element method can be used. So, the method which I mentioned in the previous slides used finite element methods, and then, next step is preparation of thematic maps of the watershed. So, by using the remote sensing imageries and GIS, so, that is the database for running the model, and then, development of software for the formulated model. So, here as I mentioned, we developed a model in one dimension using the finite element method.

Then we have to, depending upon the available data, we have to go for calibration of various parameters and then validation with respect to the available data. So, that way, testing and evaluation of the model for different rainfall events. So, that is the next step, and then, we can finalize the model.

So, once we finalize the model, say if it is for the particular watershed, so, once all these details are finalized for the given, say if you know the rainfall condition or the your prediction is done for particular the intensity of rainfall or particular rainfall pattern, then we can run this model and then identify how much will be the discharge taking place at the outlet of the watershed or at any particular location of the watershed, and then, we can see whether any flooding can takes place or how much water can be stored if there is a particular reservoir. So, like that, various uses are there for this type of event based or physically based modeling.

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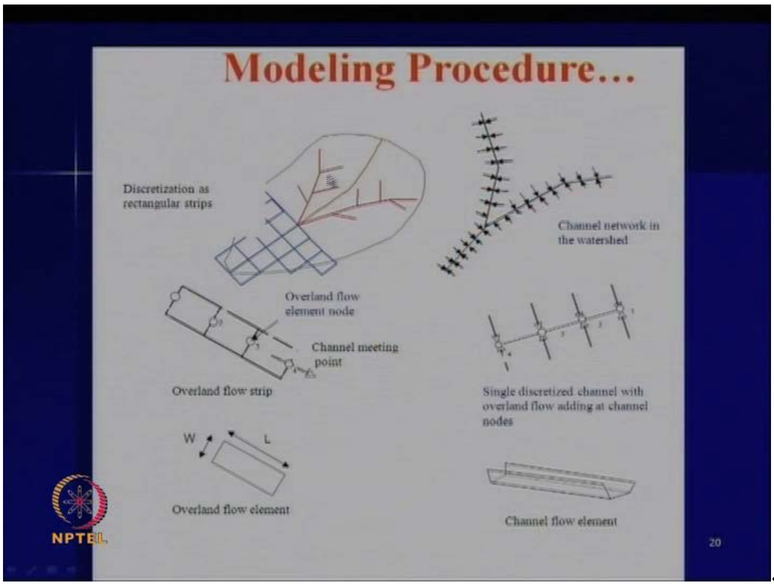

So, the modeling procedure again I will describe by using a figure. So, here, you can see that if this is our watershed which we consider, so, this is first we delineated the watershed and this is the area which we consider. So, this is the major stream and then minor channels or the streams coming to the major streams.

So, we have modeled the watershed using one-dimensional approach. So, we consider strips like that. So, depending upon the slope and the land use, we consider the strips like this. So, these are strips as shown here, and with respect to the rainfall, say the rainfall will be routed through this various elements and then it will be coming to the channel.

So, you can see that at various locations, the overland flow will be joining the channel like this, and then, that will be routed through the channel. So, this is the channel meeting point, and then, from one location to another location, it is routed. So, here, from the overland flow, strip is like this, and then, this is the single discretized channel with overland flow adding at channel nodes. So, overland flow is adding here at channel locations. So, this is a typical overland flow element, so, with length and width as shown here and this is the typical channel flow element in one dimension.

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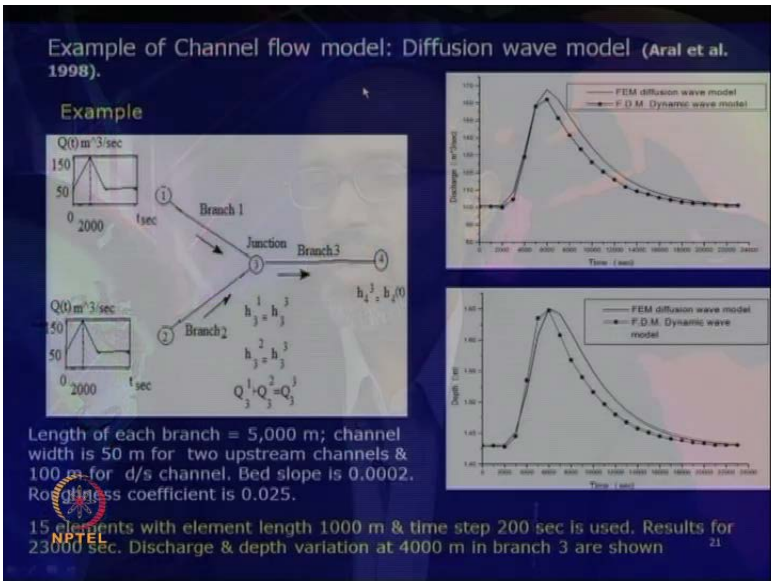

So, that way, we developed this model and we develop the code and then we verified with available analytical solutions and other available models. So, here, in this slide, as I mentioned this model has been verified with other available models and analytical solutions simple analytical solutions. So, here, I have shown the verification with respect to another model, finite difference model by Aral et al in 1998.

So, the problem is here three channels are there and here there is inflows at these location 1 and 2 inflows are there. The length of each branch is 5000 meter; channel width is 50 meter for 2 upstream channels, and then, 100 meter for downstream channel; then bed slope is 0.0002 roughness coefficient is considered as 0.025. So, that way, now, we have developed this; we have modeled this particular problem given by Aral et al.

So, here, 15 elements with element length of 1000 meter is used here. So, these channels are discretized. So, here we do not consider the overland flow separately, but we are assuming that at this location for this both channels, the flow is coming as given in this hydrograph here and that we are routing through the channels, and then, we want to identify at particular relocation. In branch 3, how the flow behavior is taking place and then compare with the model research given by Aral et al. So, our purpose here was to identify how effectively our model is working. So, this is only for the channel flow conditions.

So, 15 elements with element length 1000 meter and time step of 200 second has been used in this study. So, results for 23000 second is found and discharge and depth variation at 4000 meter in branch 3. So, here, at this location, we have routed the flow and then got the simulation in terms of discharge and depth. So, this figures shows the time is various versus discharge. So, here, for up to 23000 seconds in the model is run, and then, corresponding discharge variation at 4000 meter in branch 3 is shown here.

So, we can see that this is the comparison between finite element based diffusion wave model which we have developed, and then, the finite difference based dynamic wave model developed by Aral. So, you can see that good comparison you can observe. So, even though we have use the diffusion wave approach, so, here good comparison is there, and then, as the second graph shows the time versus depth. So, here, the depth in the channel is shown here and this is with respect to time.

So, that way, when we develop the model, we have to verify the model whether it is giving the results in an appropriate way with respect to the available models or analytical models or analytical solutions available. So, that way, we have verified this finite element based model for watersheds. The overland flow model has been actually verified for another analytical solution which has been shown one of the earlier lecture. So, this is for the channel flow.

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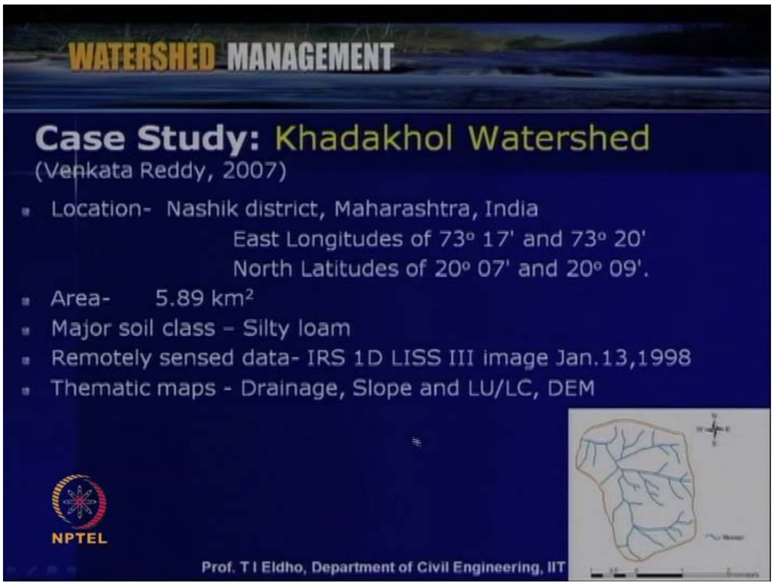

So, now, before closing this lecture, let us discuss one of the case study. So, today's case study is the integrated approach of the remote sensing, GIS and the computer models or hydrological modelfor a watershed called Khadakhol watershed. So, this integrated model which we discussed in the previous slides.

Here we have applied for a watershed of area 5.89 square kilometer and this watershed is located in Nasik district in Maharashtra, India, and longitudes and latitudes are given here. So, here, in this watershed, the major soil class is silty loam, and as far as remote sensing is concerned, we got the Indian remote sensing satellite data of 1D LISS 3 image of 13 January, 1998.

So, using the available topo-sheets, and then, with respect to the field conditions, the first step was the delineation of the watershed. So, we use the topo-sheet available and then remote sensing data to delineate the watershed.

So, the delineated watershed is shown in this figure. So, you can see that this is the boundary of the watershed, and then, so, here there is a major channel and then other streams are joining this channel. So, that way, the first step in any kind of watershed modeling is first based upon the topo-sheet and other data including the satellite data we can delineate the watershed.

And then we collected various data related to soil. Then of course, topo-sheet and related data, and then, the land use land cover data, we obtained through from the remote sensed data. So, this shows the delineated watershed. So, here, this is the main channel which we consider and these are all some of the minor streams coming to the main channel, and based upon the topo-sheet and then other the remote sensing data, we developed various thematic maps using the arc info software.

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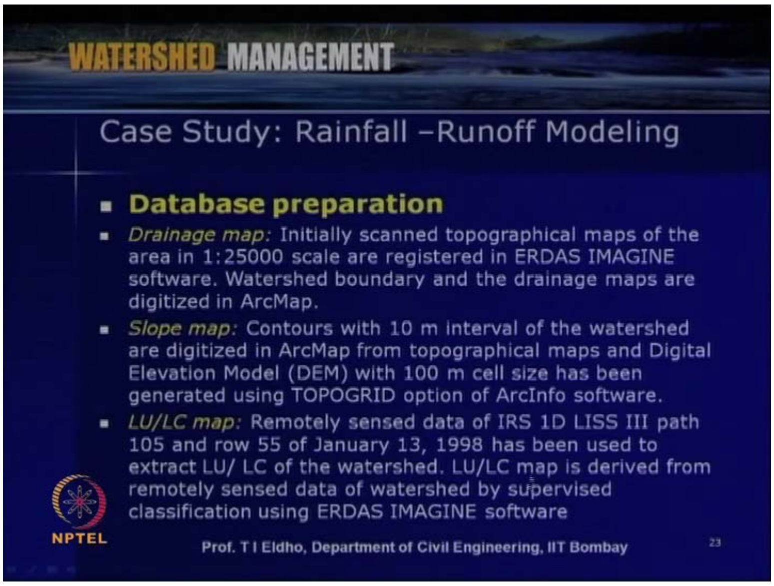

So, including the drainage slope map, land use land cover map, and the digital elevation model, so, this shows the drainage map for the Khadakhol watershed So, the drainage map as far as data-based preparation, the various steps here I have mentioned. So, the drainage map initially we scanned the topographical maps of the area which is in 1 is to 25000 scale.

And these are then registered in ERDAS imagine software and watershed boundary and the drainage maps are digitized in arc map. So, this, that way, we got the drainage map. Then we generated the slope map using the contours with 10 meter interval of the watershed which are digitized in arc map from topographical maps, and then, digital elevation model with 100 meter cell size has been generated using the topogrid option of the arc info software.

So, that is what has done for the digital elevation model development - DEM development - and a slope map development. So, once the DEM is generated using the topographic maps and the remote sensing data, so, we can get the slope map from the digital elevation model.

Then the land use land cover map say that we obtained from the remotely sensed data of IRS 1D LISS 3 path 105 and row 55 of January 13 1998. So, here, we extracted the land use land cover of the watershed and LU LC map is derived from the remotely sensed data of watershed by supervised classification using the ERDAS imagine software.

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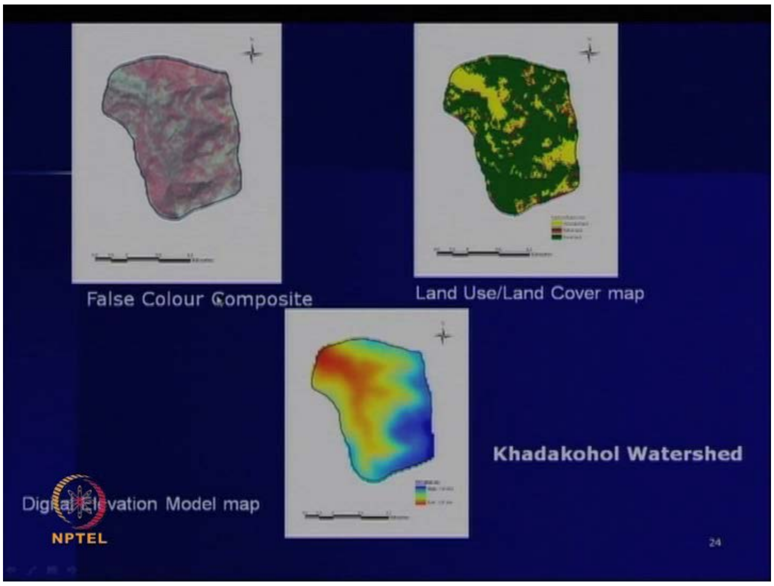

So, this, here, in these slides, first we did the supervised classification. So, that way, first we generated a false color composites, and then, using the various options available in the ada software, we obtain the land use and land cover map. So, as you can see, here this green indicates the forest land and yellow indicate the agricultural land and this is the fallow land. So, this is the land use land cover map for, the, this Khadakohol watershed, and this shows the digital elevation model for the watershed.

So, here, you can see that this is the levels are high and then recovers a channel. So, that way, the flow is taking place in this direction. So, as I mentioned earlier, so, here we use the one-dimensional the kinematic wave model for overland flow and then one-dimensional diffusion wave model for channel flow, and then, we use the Philips infiltration model. So, we have to do this finite element modeling in one dimension; we have to do a gridding.

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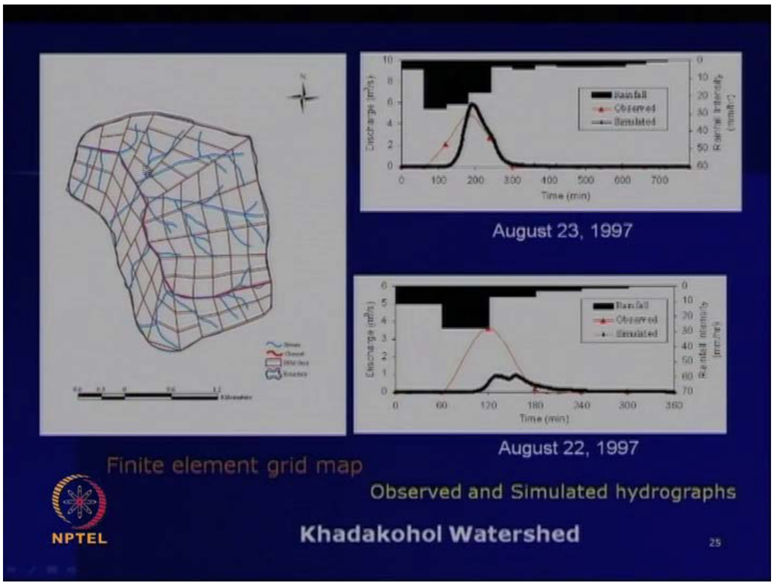

So, here, you can see in this slide, the gridding is shown here. So, this is the major channel within the watershed. So, accordingly, according to the slope of the, say within the watershed, so, we have made a strip. So, you can see that various strips coming say joining to a channel. So, these are the strips.

So, here, for these minor streams, we consider only a major stream major river or major stream like this. For all the other minor streams, we considered the as part of the overland flow only. So, that way, if you are considering, for example, one overland strip like this, so, the flow is suppose the given rainfall condition, we route the flow through this from one say cell to another cell. So, that it is a one-dimensional strip flow is taking place.

So, like that we discretized the system like this. So, this strip will be joining here; this strip will be joining here like this depending upon the slope, and then, land use land cover of the area. So then, we routed the flow through the channel. So, as I mentioned here for the Philip infiltration model, we have to consider various parameters like the hydraulic conductivity, saturated hydraulic conductivity, initial soil moisture, sorptivity, etcetera.

So, this parameters, it is a very difficult to determine from the field. So, we used some standard values available in literature and then from some of the field measurements with respect to soil data available. So, we obtain this data and then say these data we have calibrated for the given conditions.

So, for some of the rainfall events, measure data were available. Actually, as part of Indo-German watershed, guy Honore and his team had measured. The forgiven rainfall conditions, the runoff taking place at the outlet of the watershed. So, few number of events and the rainfall conditions and then corresponding runoff conditions were given. So, we used this data for the calibration of various parameters. So then, once the best fit like the hydrograph best fit discharge versus time, we plotted and then we went for the best fit.

So, we changed various parameters within the range. So, that process is called calibration and then we obtain the best parameters for the watershed like a saturated hydraulic conductivity, initial soil moisture, sorptivity, etcetera, and then, Manning’s roughness coefficients were obtained based upon the land use land cover for the overland flow, and then, as far as channel flow is concerned, at various sections with a field visit we identified how the pattern is there. Based upon that, we obtain the Manning’s roughness for the channel.

So then, as I mentioned, here we use the GIS for the purpose of development of this database. Then remote sensing - we use the purpose of tosses the land use land cover, and then, the hydrologic model finite element based hydrologic model rainfall runoff modeling we used. So, we used an integrated approach of computer modeling or numerical methods, GIS and remote sensing for this watershed modeling or Khadakohol watershed modeling with the objective of to identify how much is the runoff is taking place.

So, as I mentioned, we develop the model using the finite element approach and then the database were created and then we calibrated the model for various parameters using the available data and then we validated the model. So, here, in this slide, you can see few of the events observed and simulated hydrographs for the validated events.

So, here, twenty third August, 1997 for the given rainfall condition, here in this is the rainfall and this is the observed data and simulated data. So, good agreement we can see and this is for 22nd August, 1997. So, sometimes we get good response and sometimes there is not good fit. So, this depends upon some of the important parameters like initial soil moisture, then the saturated hydraulic conductivity, etcetera, how better we can say calibrate.

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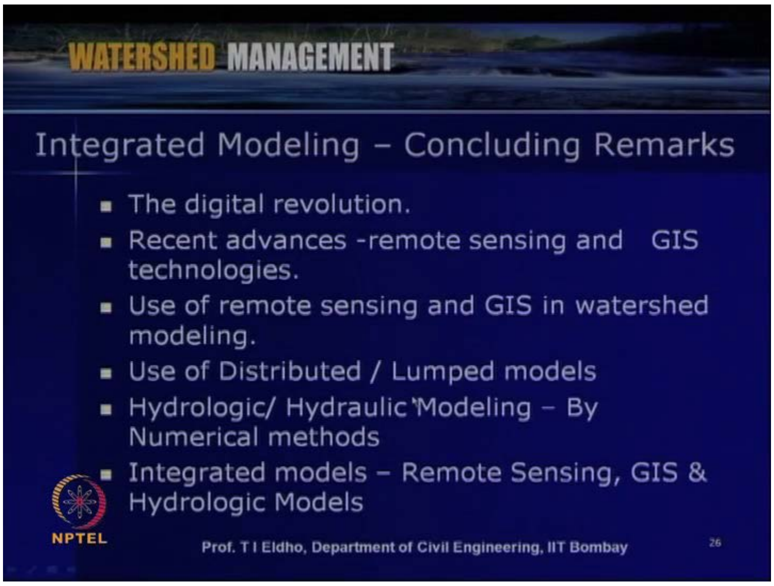

So, now, finally, what we are trying to discuss in today's lecture is, we can, an integrated approach using the GIS, remote sensing and the computer models are very useful say for watershed modeling like rainfall runoff modeling.

So, digital revolutions of computer development and numerical methods have contributed very much in this area. So, recent advances remote sensing and GIS technologies also very useful in this kinds of integrated modelinguse of remote sensing and GIS in watershed, we have demonstrated today.

And use of distributed model or lumped models depending upon the requirement, depending upon the data availability we can go for hydrologic hydraulic modeling by numerical methods. Then, when we go for integrated approach using remote sensing, GIS and hydrologic modeling, we are having a very good tool for the modeling, say for example, rainfall runoff modeling for the watershed.

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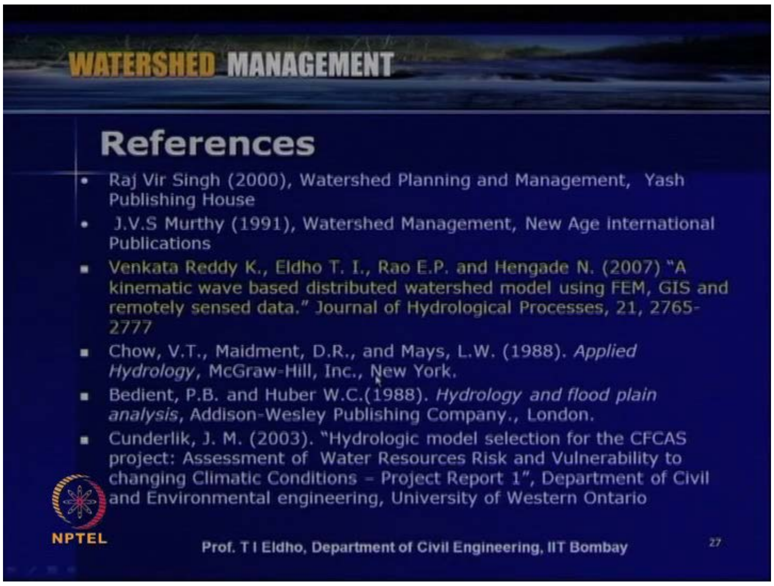

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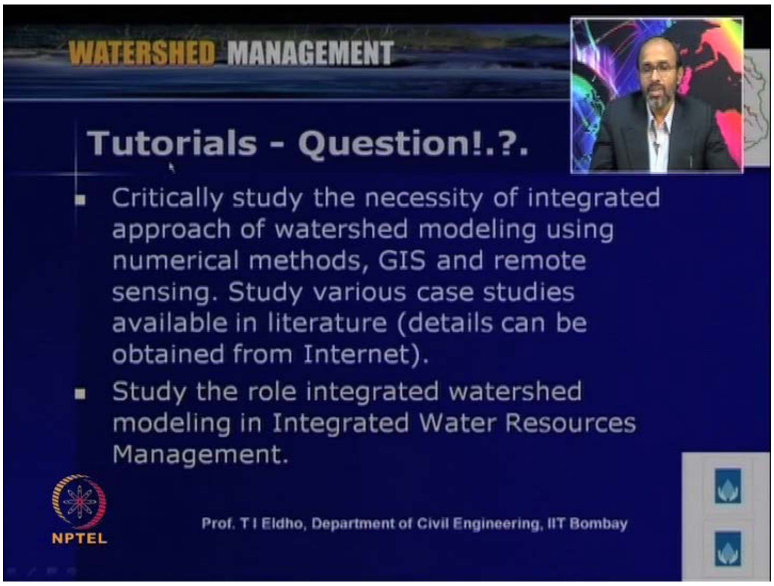

So, these are some of the important references which used for today's lecture, and before closing say few questions, tutorial questions – like, critically study the necessity of integrated approach of watershed modeling using numerical methods GIS and remote sensing. Study various case studies available in literature. So, these details, we can get from internet. Study the role of integrated watershed modeling in integrated water resource management.

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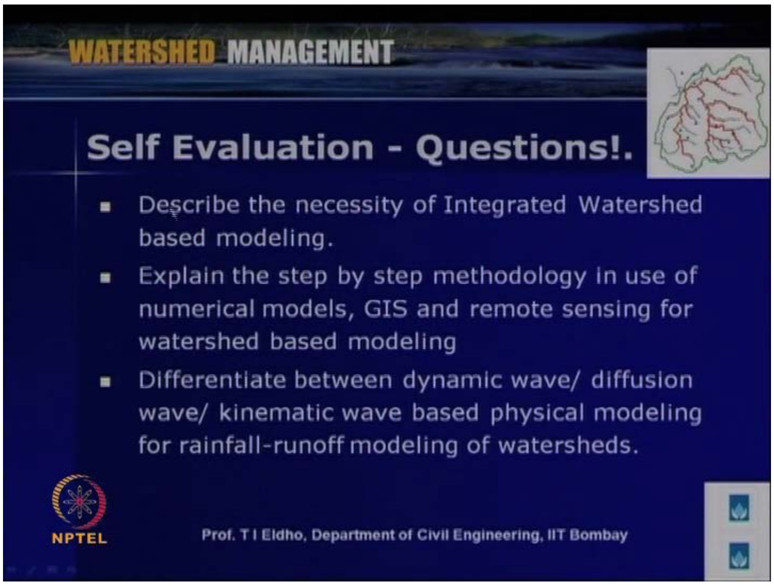

Then few self evaluation and the assignment questions - describe the necessity of integrated watershed based modeling. Explain the step by step methodology in use of numerical models, GIS and remote sensing for watershed based modeling. Differentiate between dynamic wave diffusion wave kinematic wave based physical modeling for rainfall runoff modeling of watershed. These details, we have discussed in some of the previous lectures.

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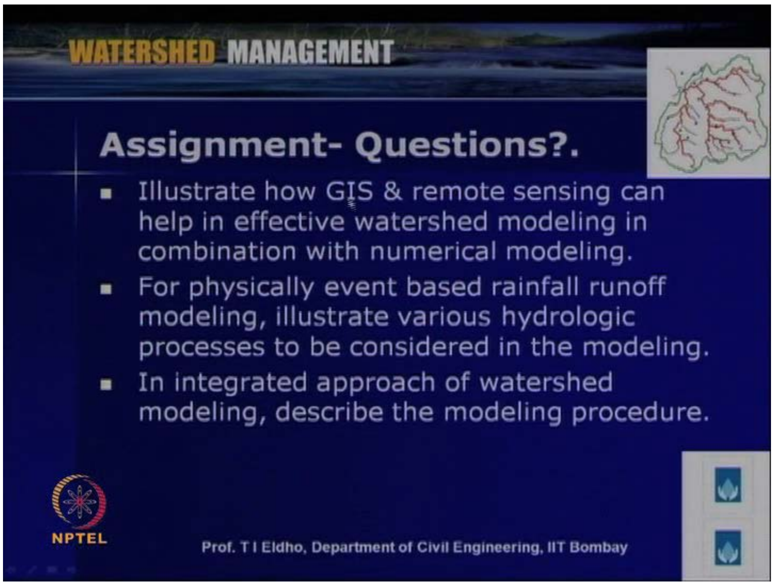

And then, few assignment questions - illustrate how GIS and remote sensing can help ineffective watershed modeling in combination with numerical modeling. For physically based event based rainfall runoff modeling, illustrate various hydrologic processes to be considered in the modeling. In integrated approach of watershed modeling, describe the modeling procedure. So, this questions you can easily answer by going through today's lectures.

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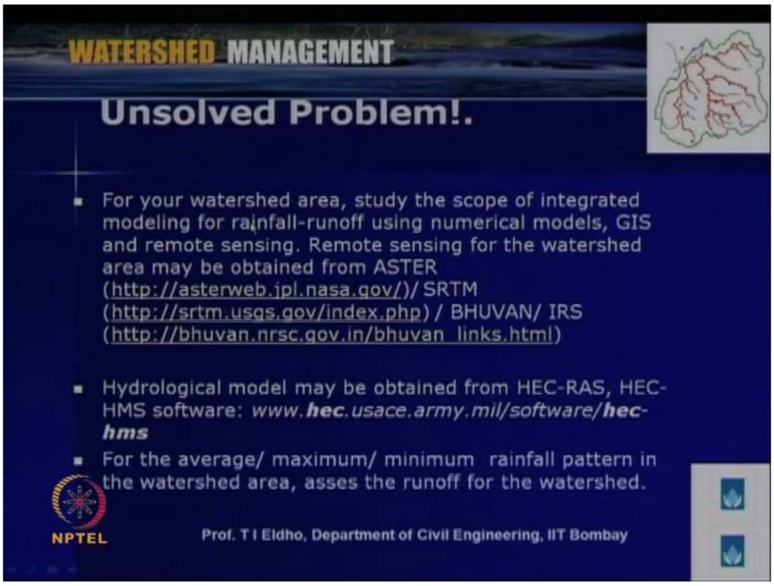

Then unsolved problem - for your watershed area, the scope of integrated modeling for rainfall runoff using numerical models, GIS and remote sensing explored. Remote sensing for the watershed area may be obtained from ASTER or SRTM or Bhuvan as I mentioned earlier. Then hydrologic modeling - we can use hec hms or hec ras model which is available in this website.

So, for the average maximum minimum rainfall patternin, the watershed area asses the runoff or the watershed so that we can have better, say rainfall runoff models, and then, we can go for rain water harvesting or other watershed based plans.

So, today, what we discussed is - integrated approach of modeling using the computer models or numerical methods, GIS and remote sensing. So, what we have found is - it is very effective in watershed modeling for rainfall runoff or other processes. Thank you.