Course Name: Watershed Hydrology

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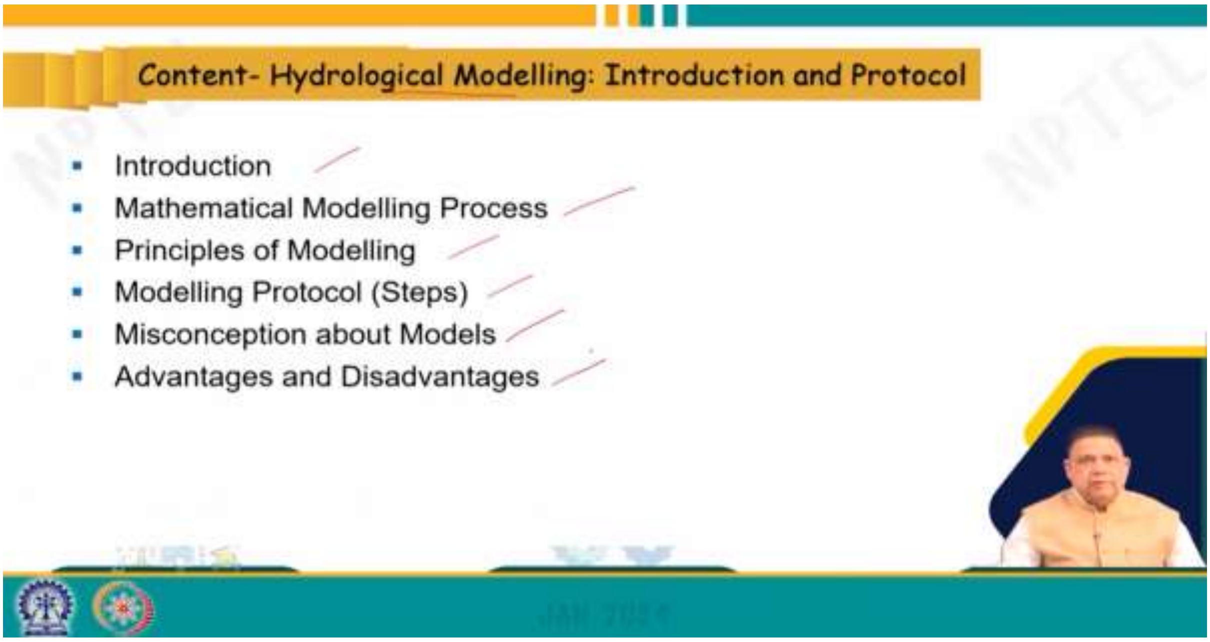
Institute Name: Indian Institute of Technology Kharagpur

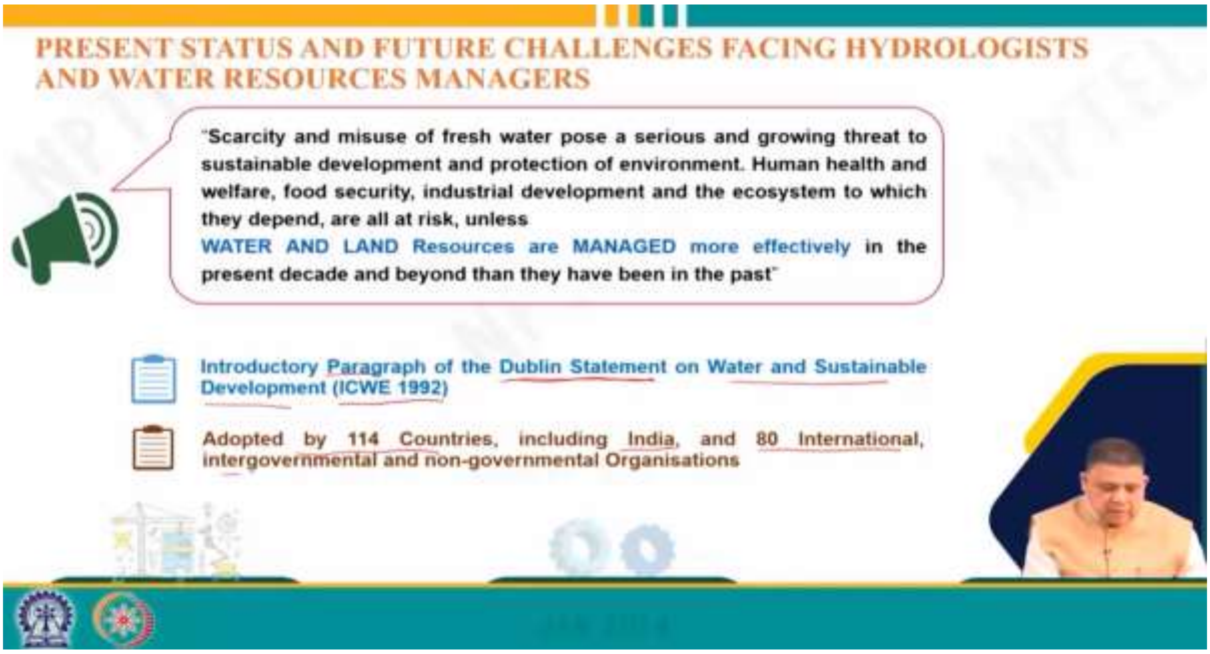
Week: 08

Lecture 36: Hydrological Modelling: Introduction and Protocol

Hello, friends. Welcome back to this online certification course on Watershed Hydrology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. We are beginning module 8 today. This is lecture number 1.

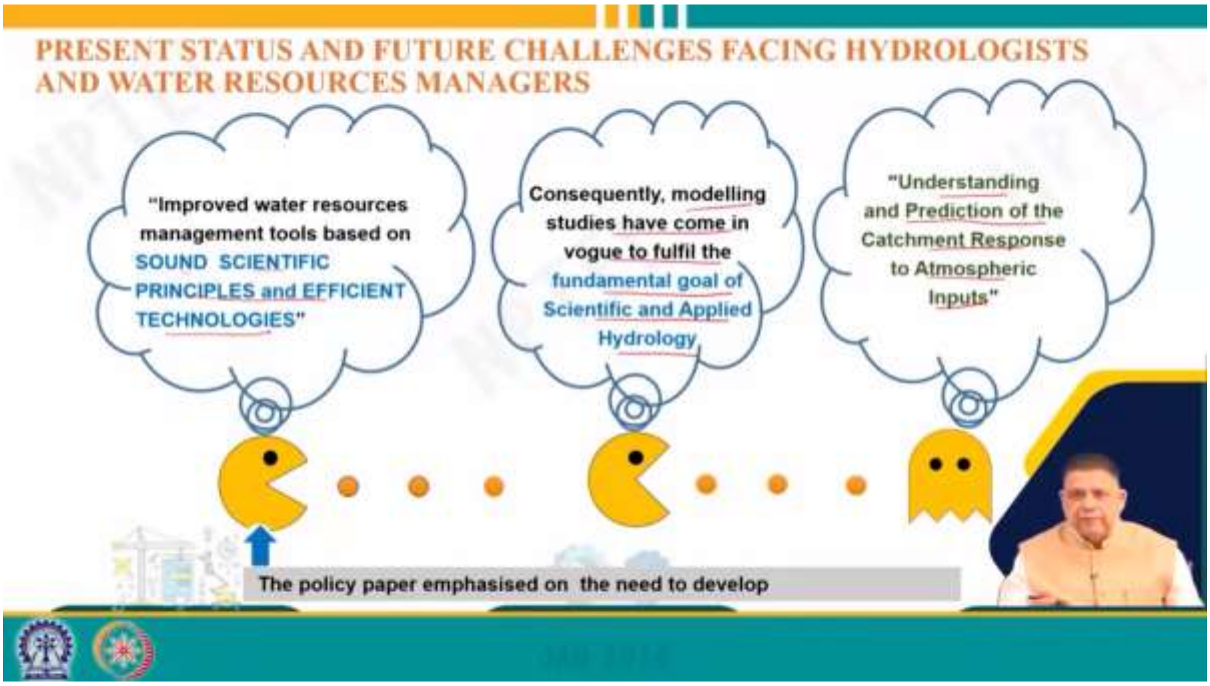


we will be introducing hydrological modelling and talking about modelling protocol in this lecture. The contents of this lecture are introduction, which means we will be introducing hydrological modelling. Then we will discuss the mathematically modelling process, talk about principles of modelling, discuss modelling steps or protocol, and also address misconceptions about models. Finally, we will delve into the advantages and disadvantages of hydrological modelling.

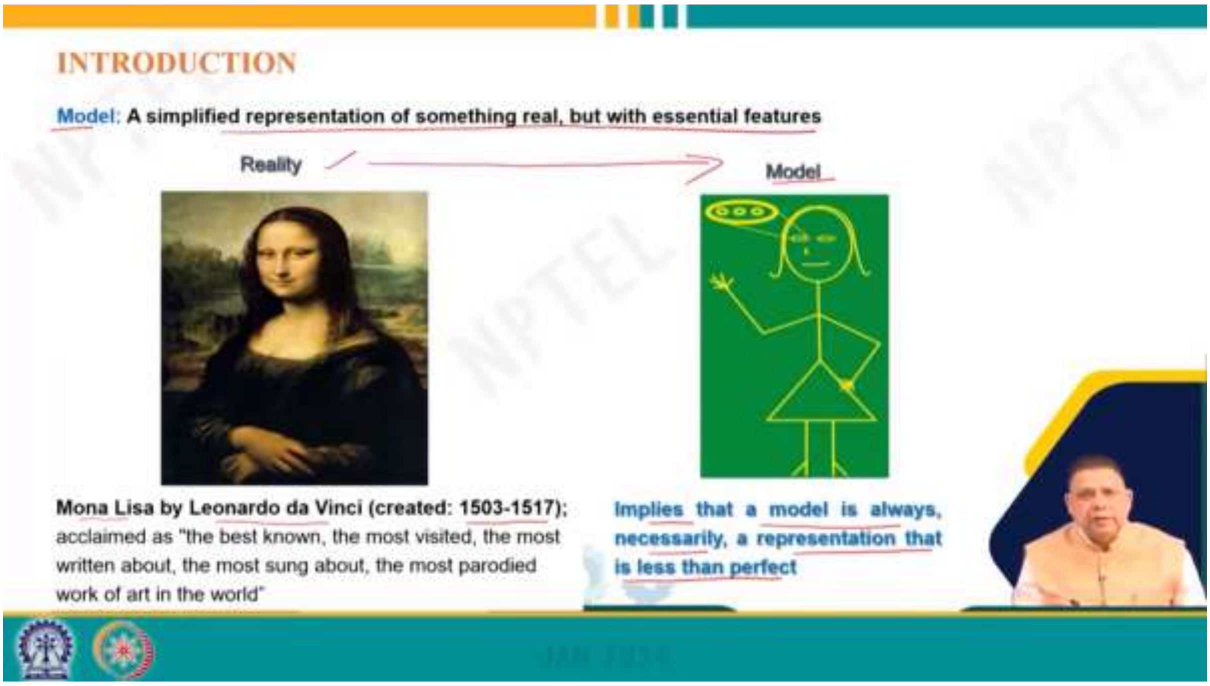


Now, coming to the present stages and future challenges facing hydrologists and water resources managers, I quote: "Scarcity and misuse of fresh water pose a serious and growing threat to the sustainable development and protection of the environment. Human health and welfare, food security, industrial development, and the ecosystems to which they depend are all at risk unless water and land resources are managed more effectively in the present decade and beyond than they have been in the past." So, this particular statement just read is the introductory paragraph of what is referred to as WED statement on water and sustainable development. WED stands for World Environment Day statement on water and sustainable development ICWE 1992.

So, ICWE stands for International Conference on Water and Environment, which occurred in 1992 and which is popularly known as the Earth Summit. Though it occurred in Rio de Janeiro, Brazil, the statement that was prepared and that is called the Dublin statement on water sustainable in development, that is what this introductory paragraph said. And this statement was adopted by 114 countries, including India, and 80 international intergovernmental and nongovernmental organizations. So, it was a very important paper.



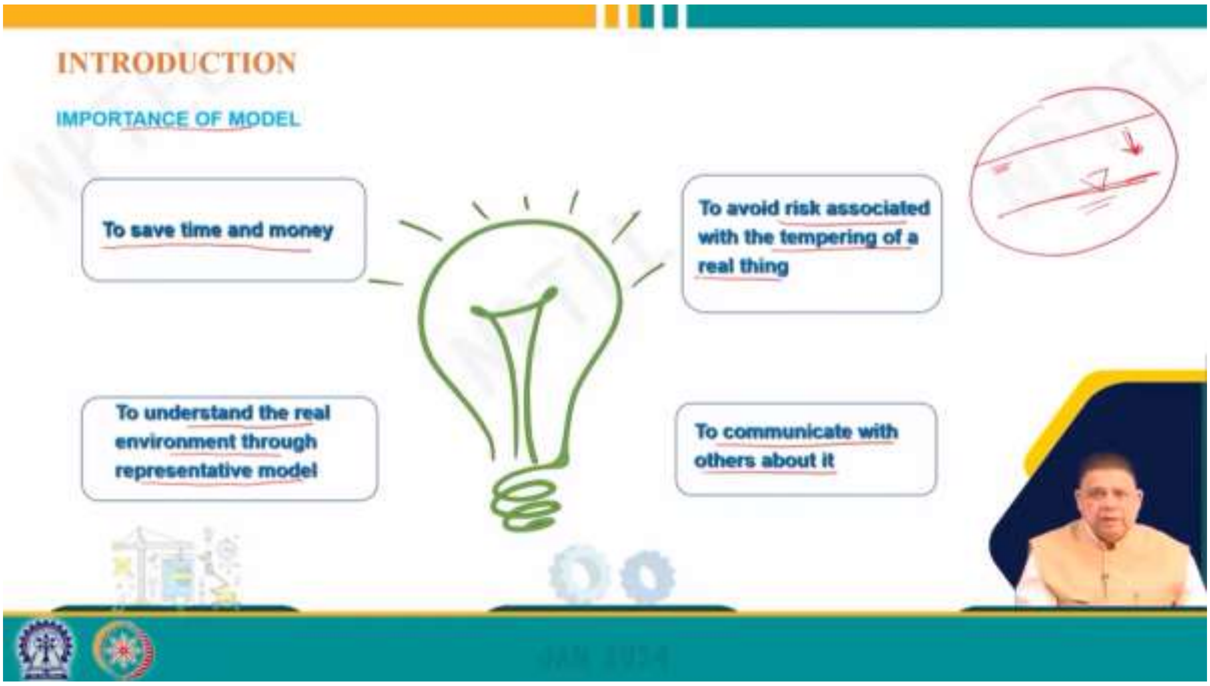
The policy paper emphasized the need to develop improved water resources management tools based on sound scientific principles and efficient technology. Consequently, modelling studies have come in vogue to fulfil the fundamental goal of scientific and applied hydrology. So, that gave impetus; this particular Earth Summit gave impetus to the development of modelling studies. Following that, although there were some hydrological models, but following the Earth Summit, a series of hydrological models have been developed, and modelling studies came in a big way to tackle the fundamental goal of scientific and applied hydrology, which we have discussed many times, that is understanding and prediction of the catchment response to atmospheric inputs. That is why earlier we discussed, we talked in terms of the rainfall-runoff transformation process. So, basically understanding and predicting rainfall runoff transformation process, that's what occurs if rainfall occurs, that is basically the fundamental goal, and that is where hydrological modelling has started playing a major role since 1992.



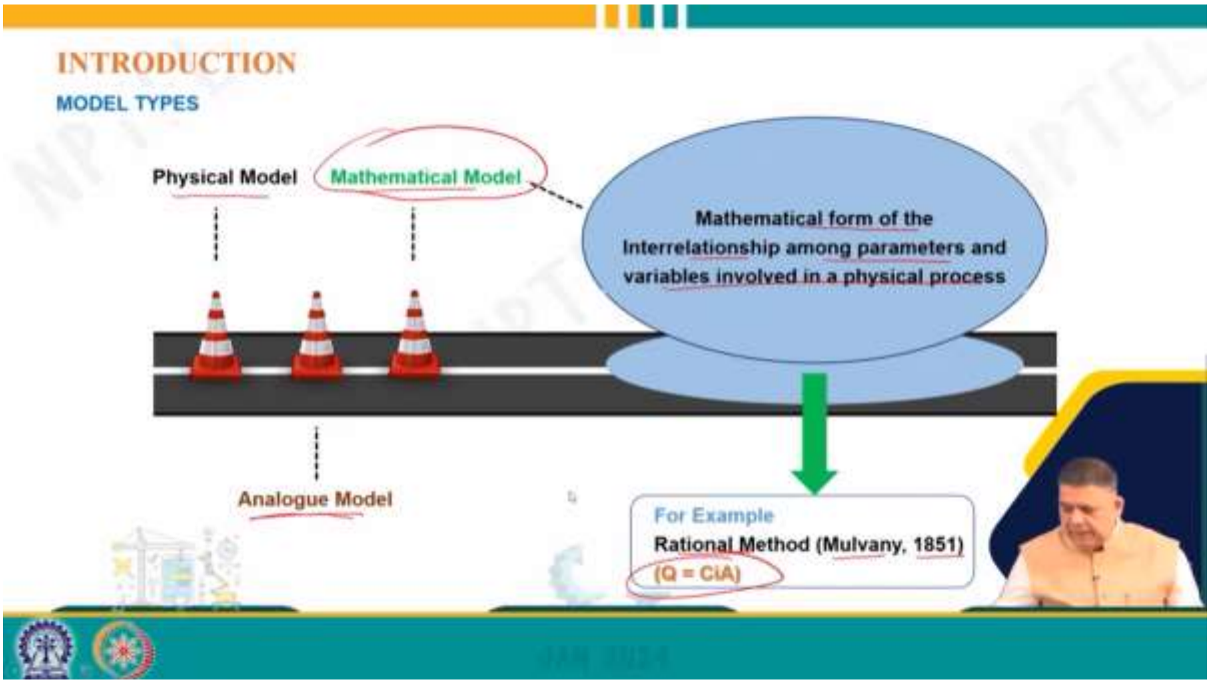
Now, coming to defining a model, a model is a simplified representation of something real, but with essential features. So, something real which is simplified is represented simply in a model, and essential features of that real thing will obviously be there. For example, if we look at reality, this picture, I hope everybody knows, it is the Mona Lisa by Leonardo da Vinci, which was created during 1500 to 1517, and this particular art piece is acclaimed as the best-known, the most-visited, the most-written-about, the most-sung-about, and the most-parodied work of art in the world.

So, that is so famous, an art. Now, if this reality is given to a modeler and asked to develop a model, then he may come up with something like this. So, this model reality to model, this is how it could be. So, it says that it is some simplified representation of something real. So, it is a simplified representation, but with essential features.

So, essential features are all preserved; like there, you can see two eyes, two eyes here, a hand is there, hair is there, lips are there, nose there. So, all those features are there, but obviously, it is not as beautiful as the reality. So, in a nutshell, this implies that a model is always necessarily a representation that is less than perfect. So, whenever you talk about the model or you work with the model, you should always remember that a model is a simplified representation, and it will always have some imperfections that we have to accept and move forward, that is very important.

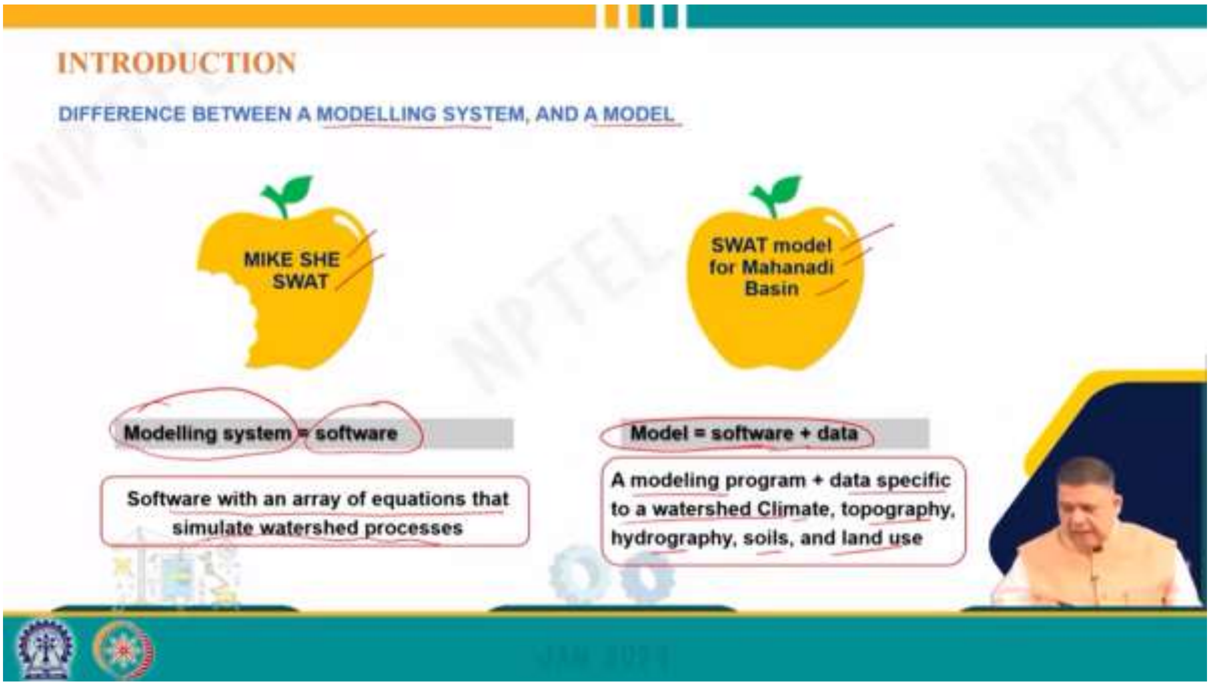


Now, coming to why modelling and what is the importance, why models are so much talked about. The importance of models could be that they result in the saving of time and money. Now, if you have to do some kind of data generation or make somebody understand infiltration, then obviously, you have to carry out an infiltration experiment, and you have to get the data, you have to analyse the data. So, that means, it always involves a lot of time to carry out experiments and also money in order to plan the experiments, to carry out the experiments, and so on. So, obviously, any experimentation which we do involves resources, but using the model we can save that time and money. Also, modelling is required to understand the real environment through a representative model. So, again, if you have to explain somebody what happens below the ground surface or below water, say we have a surface water here, soil surface here, then you have a water table here, then you want to explain somebody what happens to water here, I mean you cannot, because in field conditions you cannot. But if you have a representative model, then you can really show that water, when water moves, it passes through like pictures we have seen, it passes through the soil pores because of gravity, meniscus is formed. So, all those processes you can really make one visualize through models. Thirdly, it's to avoid risk associated with tampering of a real thing if the real thing is very expensive. So, if, for example, an aircraft or a rocket, and you have to do some experimentation there or some changes there, you cannot really work on the real thing because it is very expensive and during the process you may tamper the real thing. So, there is always a risk, and that is why we take the help of a simulator, which is also a model. So, that is why we take the help of a model, and of course, to communicate with others about it. For example, if you have to, let's say this is a particular experiment, only if you have to talk to somebody, that person has to come here, you have to explain. But you can always have a representative model which you can carry with you on a laptop or a system, and then you can explain what you are trying to do, why you are trying to do, and so on, so forth. So, you can communicate about the thing with the help of a model more effectively. So, these are the reasons why models are properly used.



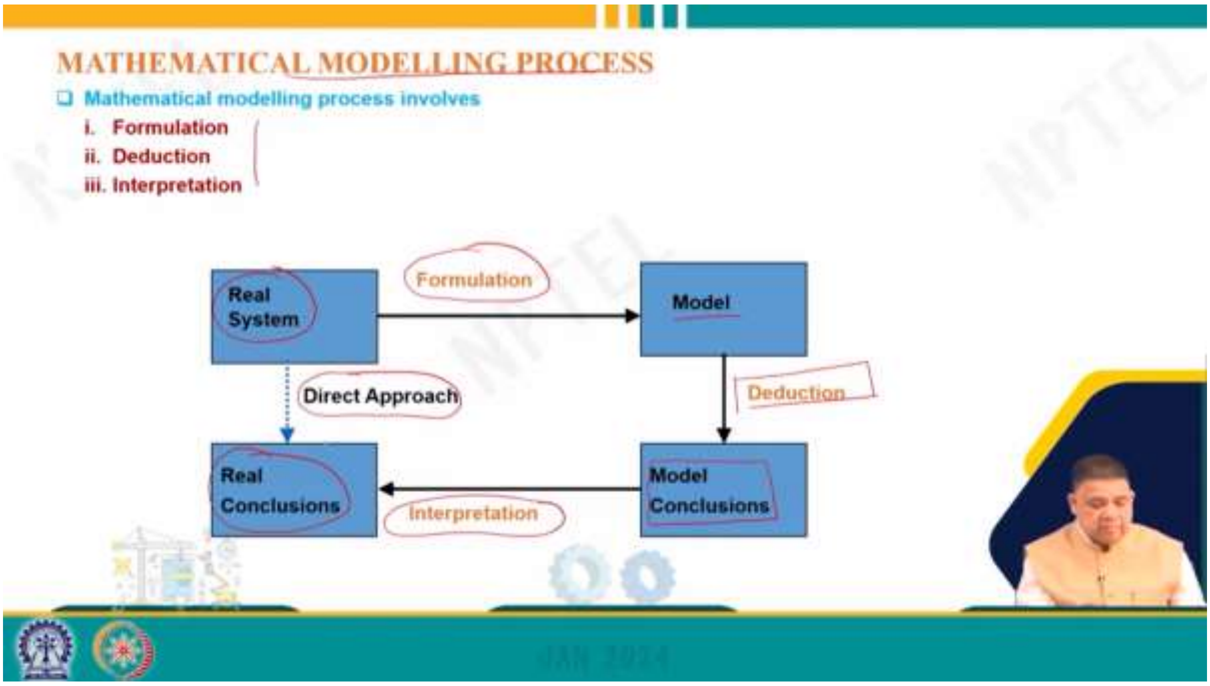
Now, coming to model types, a model could be of three different types: a physical model, an analogy model, and a mathematical model. Now, when we say physical model, this is nothing but a replica of something. For example, you have in our drawing rooms, we have Taj Mal placed or an airplane placed. So, that is basically a physical model where you would, of course, with physical models, you also do a lot of simulation and experiment, but typically that is a physical model. Then you have an analogy model, which basically functions based on analogy, analogy in characteristics. So, for example, when you have a water source and you pump the water, then obviously, if you have a pipe system, that water will flow in that. So, you can have that kind of system, and analogy could be that you have an electrical circuit, you switch the switch on, and then obviously, the electrical current will flow. So, it is very similar. So, through analogy, you can explain the working.

So, that is a kind of analogy model, and the third one is the mathematical model, and in our discussion further, we will be talking about mathematical models only. So, it is a mathematical form of the interrelationship among parameters and variables involved in the physical process. So, mathematical models represent or they are the mathematical form of interrelationship and parameters variables involved in a physical process. That is why if you understand the essential working of the system and express that in mathematical form, then nothing, but it is a mathematical model. For example, the rational method given by Mulvaney 1851 q equals to c i a, that is a model, that is a mathematical model. So, obviously, a model could be very simple, and it could be pretty complicated depending upon what kind of process we are trying to model.



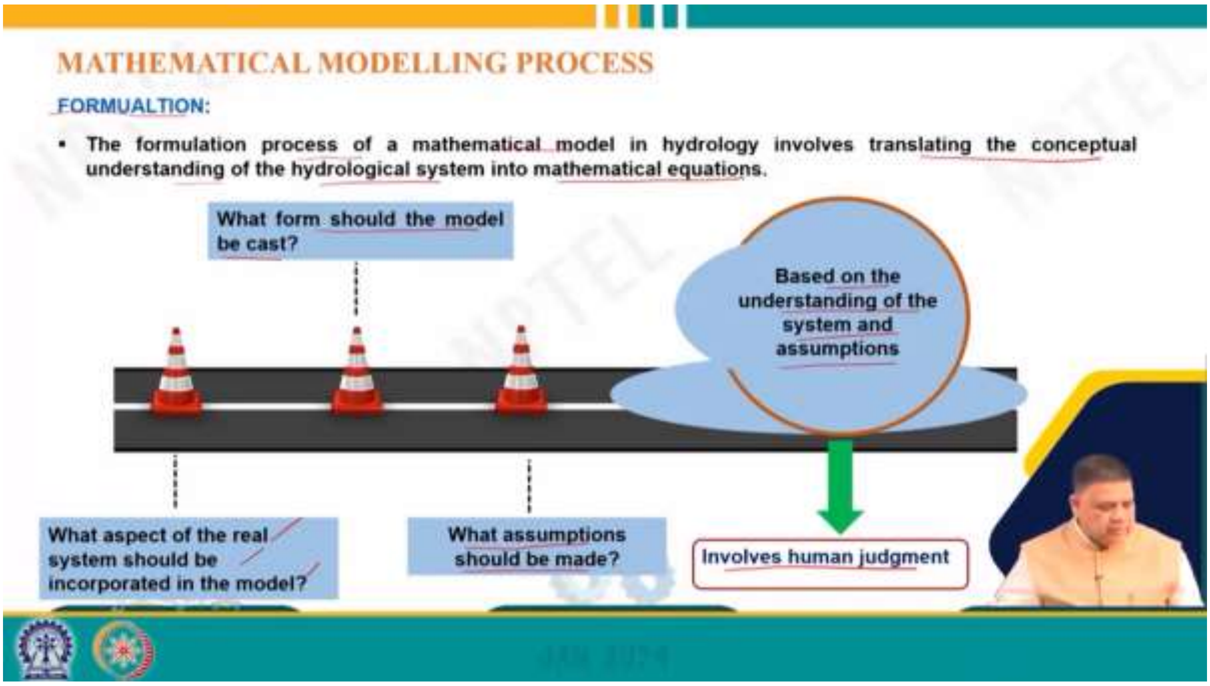
Now, there are two terms which are commonly used and misused, like modelling system and a model. So, we should be clear about when we what when we should say modelling system or when we refer to model because there is a confusion or there is a slight change, difference between these two. So, when we talk, when you say modelling system, then we basically refer to the software, the software with an array of equations that simulate watershed processes or hydrological processes. So, that when we only have the software with us, we say that say modelling system, like C modelling system.

But when we include software has data pertaining to a particular watershed study area, that is a modelling system plus data specific to a watershed climate, topography, hydrology, soil, and land use. That means, all the data required to set up the model for a particular study area, then we call it a model. So, we say SWAT model for Mahanadi basin. So, when we say SWAT model for Mahanadi basin, it means that the software we are using is SWAT and the data which has been used to set up the model belong to Manadi basin. So, it is a SWAT model for Mahanadi basin; otherwise, it will only be called a SWAT modelling system. So, this is there is a thin line and people interchangeably use these terms, but there is a thin dividing line and we should try to remember that.



Then coming to mathematical modelling process. So, mathematical modelling process involved three major steps: formulation, deduction, and interpretation. So, we can have a pictorial view like this. So, you have the real system, and obviously, you want to reach the real conclusion. So, the direct approach would be that you conduct experiments or whatever way you directly get the real system, you can conduct experiments and you get real conclusions, but if you want to take the mathematical modelling route, then you have to detour like this. So, the first step is formulation, that is, the essential working of the real system you express that in mathematical terms, that is the model. And once you have a model, then obviously, you go into enter the deduction phase. Deduction phase means you do whatever you need to do in order to solve the mathematical problem at hand, and then obviously, the solution will give you model conclusions, that is, the solution of the model is a model conclusion, of course, but we are interested in a real conclusion. So, obviously, then we need to translate these model conclusions into real conclusions, and that is where we need to adopt the interpretation process.

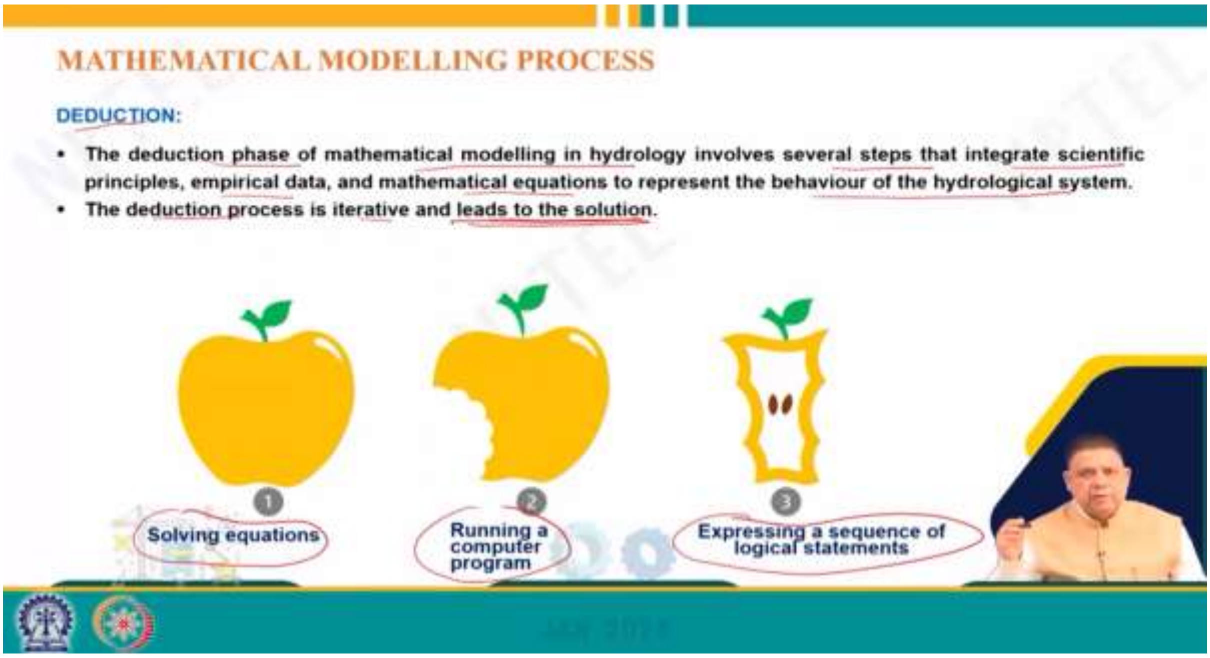
So, there are three different steps: formulation, deduction, and interpretation, and from the real system, we first formulate the model, then you deduce to reach the model conclusion, then you interpret to get to the real conclusion, that is the modelling process route, otherwise, you can always have the direct approach and you can do experiments and reach the real conclusions.



Now, let us take these steps one by one, say let us talk about formulation first. So, the formulation process of a mathematical model in hydrology involves translating the conceptual understanding of the hydrological system into mathematical equations. So, basically, the essential working of the system you try to express in mathematical terms, and obviously, this process involves certain questions to be answered like what aspect of the real system should be incorporated in the model. So, obviously, we have seen the hydrological cycle, we know we have evaporation, you have transpiration, we have condensation, and you have precipitation, you have infiltration, you have percolation, you have subsurface flows, surface flow, overland flow, and so many things, so many processes are occurring.

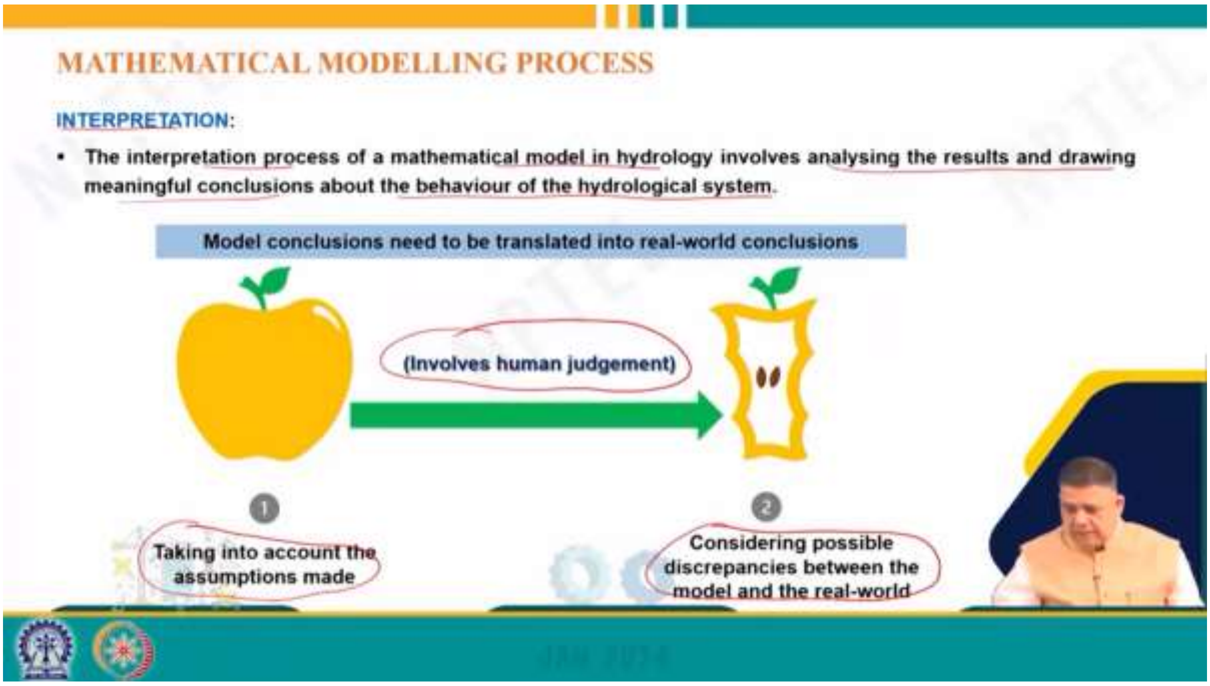
So, not necessarily you will include all in your model ultimately rainfall runoff transformation process is our goal. So, we may not include all the processes. So, basically, what aspect of the real system should be incorporated in the model that is a decision the modeler has to make. So, you may say that ok I will neglect interception in my model I will not consider interception, I will not consider percolation or I will not put groundwater component in my model. So, whatever way you can make that decision.

Then what form should the model be caused? So, models could be of various types within the hydrological models which we will discuss little later. So, its formulation is state that modeler also has to decide what kind of model he is trying to develop he will develop in order to solve the problem at hand. Then obviously, during this entire process you would definitely need to make certain assumptions. So, all the assumptions should be made in order while translating the real working system into mathematical forms that all those decisions have to be made. And that obviously, all these decisions will be based on understanding of the system and the assumptions behind and what it goes behind that and that simply means it involves human judgment.

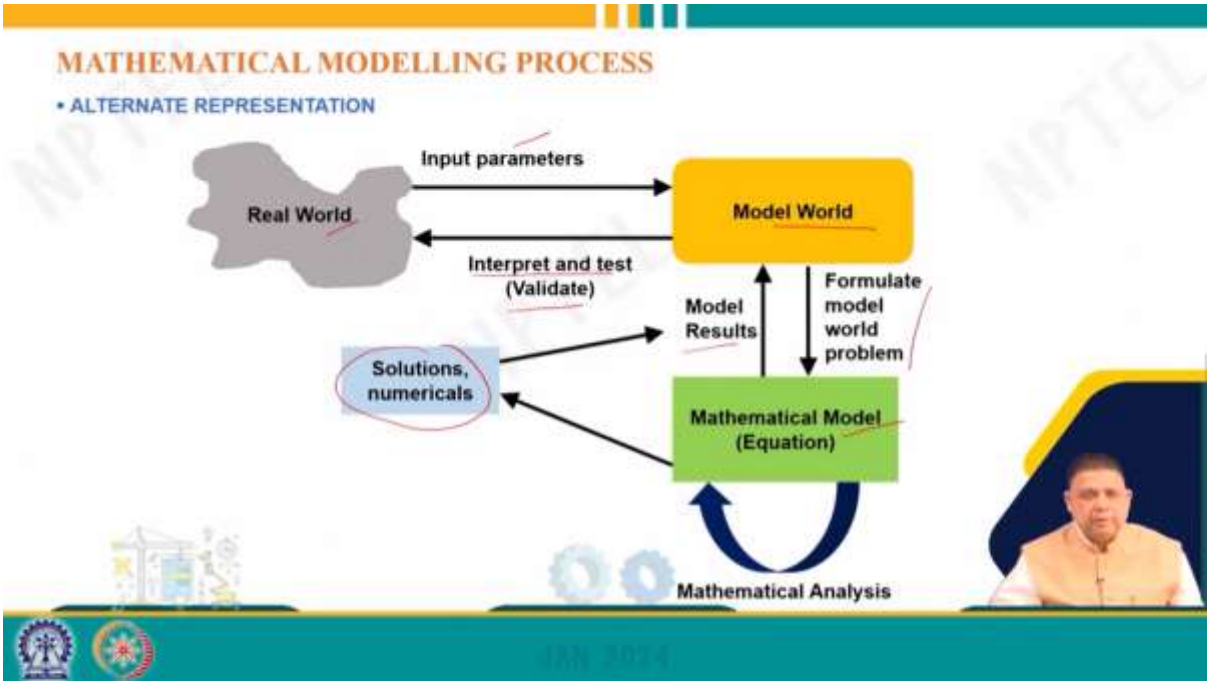


So, formulation involves human judgment because you have to make decisions like what aspect of model should be incorporated, what form should the model with, what assumption should be made and of course, your own understanding of the working essential working of the system. So, that is why human judgment is involved and that is why for a single process like rainfall runoff transformation you have hundreds of models available very similar looking, but certain things will be different certain assumptions will be different and that is why we have hundreds and thousands of models around us available for in hydrology also. So, that is important this state. Then comes deduction that is the deduction phase of the mathematical modelling in hydrology involves several steps that integrate scientific principles, empirical data, mathematical equations to represent the behaviour of the hydrological system. So, basically the deduction process or phase is iterative and leads to solution.

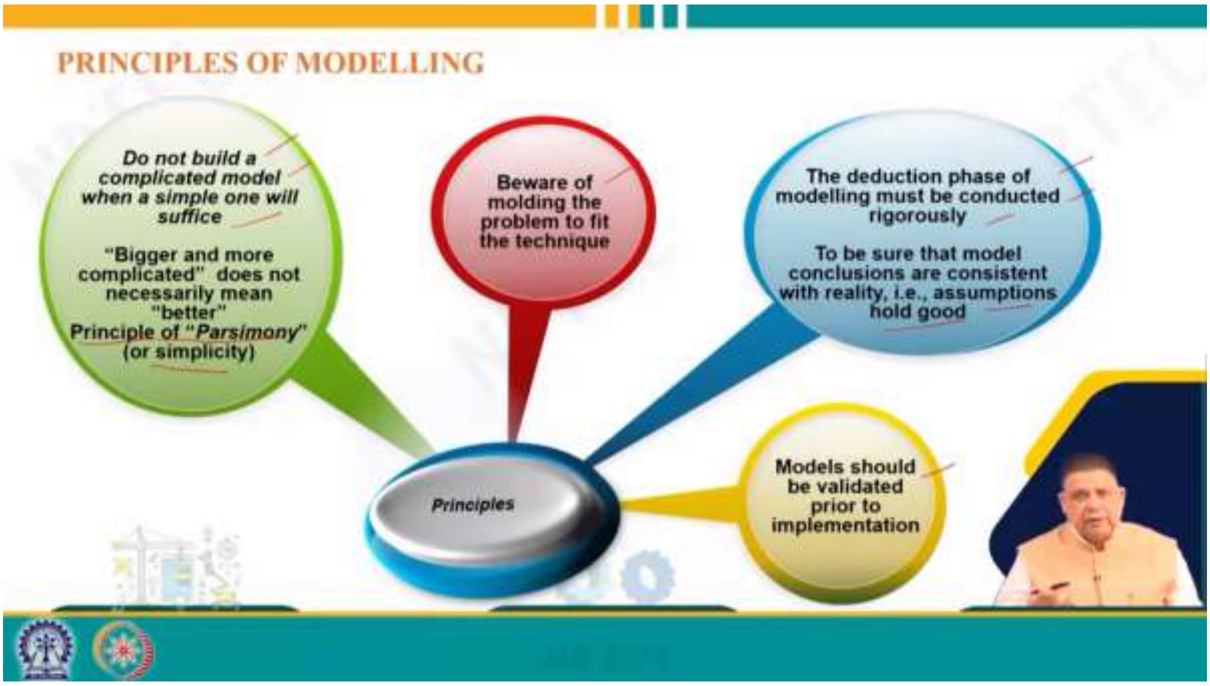
So, basically in this phase it basically involves solving equation, running a computer program or expressing a sequence of logical statement. So, that means, deduction phase includes any and every step that leads us to solution. So, basically this is nothing, but we are trying to solve the problem which we have formulated that is what deduction phase means and as the picture you remember from the model through deduction, we reach the model conclusions. And lastly, we have the third step that is interpretation that is interpretation process of a mathematical model in hydrology involves analysing the results and drawing meaningful conclusions about the behaviour of the hydrological system.



So, obviously, in this process if you remember the picture the model conclusions need to be translated into real world conclusion that is why we interpret the model conclusions. So, that we get to the real-world conclusions and obviously, in this case we have to take into account the assumptions that have been made while formulating the model because while translating the information you have to keep in mind that these were the assumptions. Then of course, considering the possible discrepancies between the model and the real world like some of the parameters in practice maybe I mean may have certain limitations, but while modelling you might not have considered that your or your model conclusions might not have considered that. So, that also has to be taken into account while translating the model conclusion into real conclusions and that simply means that this also involves human judgment. So, obviously, as you can see that in the entire plot of modelling process human judgment is involved right in the beginning that is formulation then while interpreting results. So, human judgment or the modeler role of modeler becomes very crucial in the entire mathematical modelling process.

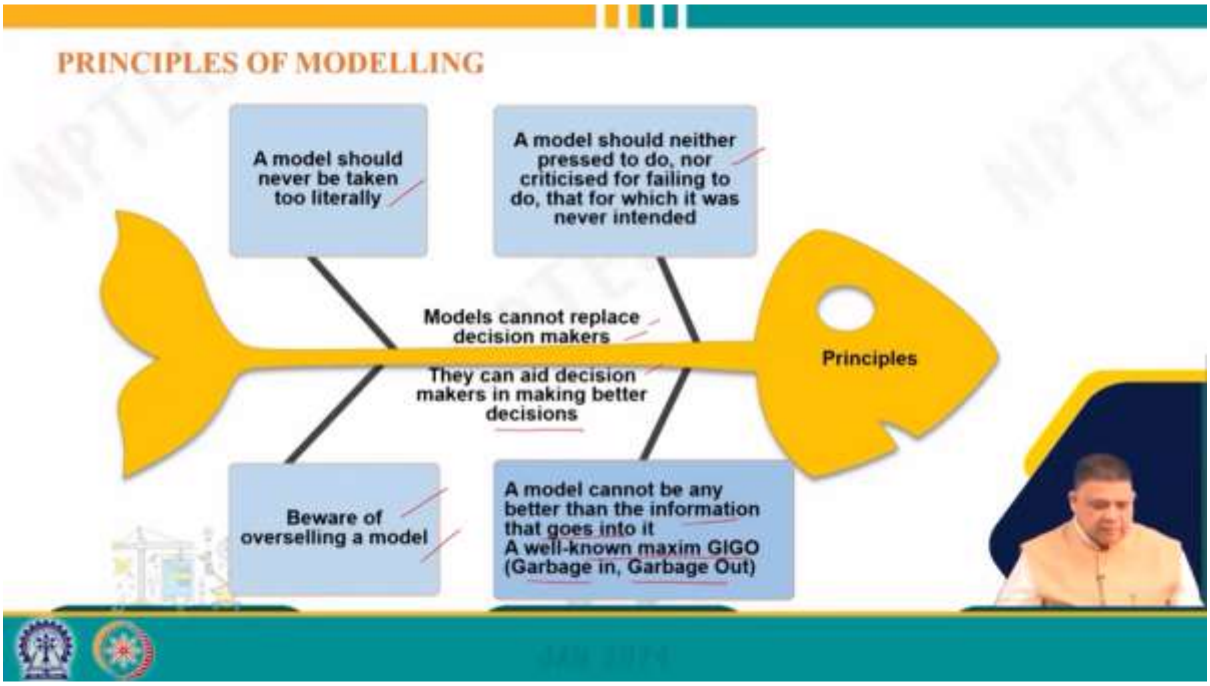


Then of course, this is the alternate representation of the mathematical modelling process similar thing that is you have real world you put real parameters you reach the model world you formulate model world problem you have mathematical modeler equations and then you through solutions or numerical you get to model results reach the word model world once again and then you interpret and test and validate to get them to the real world. So, same all the processes with earlier picture should this is shown in an alternative way. So, this is the entire modelling process.



Then comes the principles of modelling and principles of modelling there are several principles which we must follow for example, the first one is that do not build a complicated model when a simple one will suffice because bigger and more complicated does not necessarily mean better and so this is referred to as principle of parsimony or principle of simplicity. So, basically, when a simple model can do a process, we should not go for creating a complicated model because bigger and a bit more complicated does not necessarily mean better, but what happens the human beings have a tendency to show off. So, just to show off our knowledge we try to complicate things. So, that should be the first principle that by developing a hydrological model you should keep it as simple as possible and that simply means also that the number of parameters in the model will be less and that is where the principle of parsimony comes into the picture. Then beware of moulding the problem to fit the technique sometimes we get we get accustomed to using a particular technique say finite difference method or finite element method. So, obviously, whatever problem comes to the person he will try to use the technique he knows rather than trying to find out whether this technique is good enough or not. So, obviously, that is why this principle is that beware of modelling the problem to fit the technique.

So, first you should understand the problem and then choose the technique rather than change the problem to suit the technique you are aware of. The deduction phase of modelling must be conducted rigorously to be sure that model conclusions are consistent with reality and assumptions hold good. So, obviously, deduction phase has to be done more rigorously and of course, there are some techniques which we use for calibrating and validating or testing the model which we will discuss in coming lectures. Then the model should be validated prior to implementation. So, obviously, you cannot take the model results literally. So, you have to really calibrate and validate your model you should be very confident then only you can translate the model calculations to the real world.

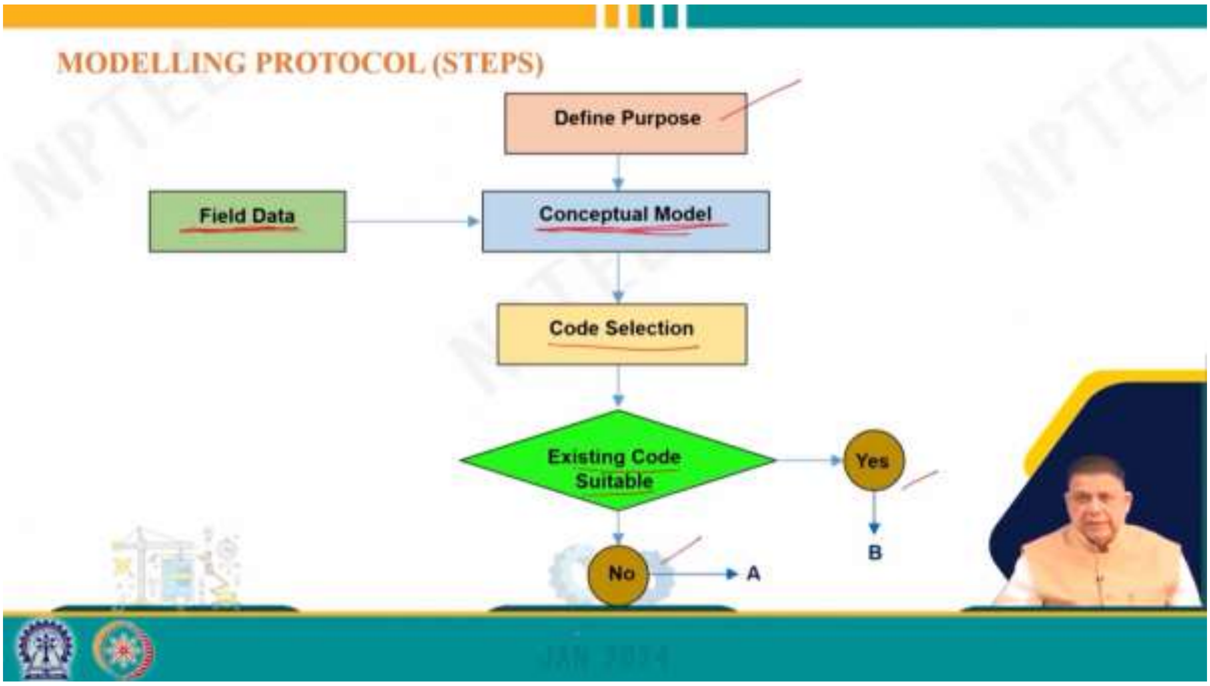


Then a model should never be taken too literally. So, obviously, we know that we have to again go back to the first that model is a simplified representation that is less than perfect. So, it is not perfect. So, obviously, you cannot take the results literally there are always I mean.

So, you have to again go into the models' basics. So, in order to know what assumptions have been made and so on so forth. A model should neither place to do nor criticize for failing to do that for which it was never intended. So, I have got obviously, every modelling or modelling system has a particular objective and under certain circumstances only certain assumptions only it works. So, obviously, we should never use a model for the purpose it was not intended to otherwise it will fail and then you will criticize the model, but that is why it is very important to understand the fundamentals behind a model before implementing them.

Be aware of overselling a model this again refers to the same thing there is nothing like a perfect model. So, you do not try to oversell a model you get acquainted to or get accustomed to. Then a model cannot be any better than information that goes into it a well-known maxim GIGO that is garbage in garbage out because it is a mathematical solution. So, your inputs are garbage the outputs will also be garbage. So, obviously, this tries to emphasize on the quality of data quality and quantity of data that is needed in order to get to model solutions.

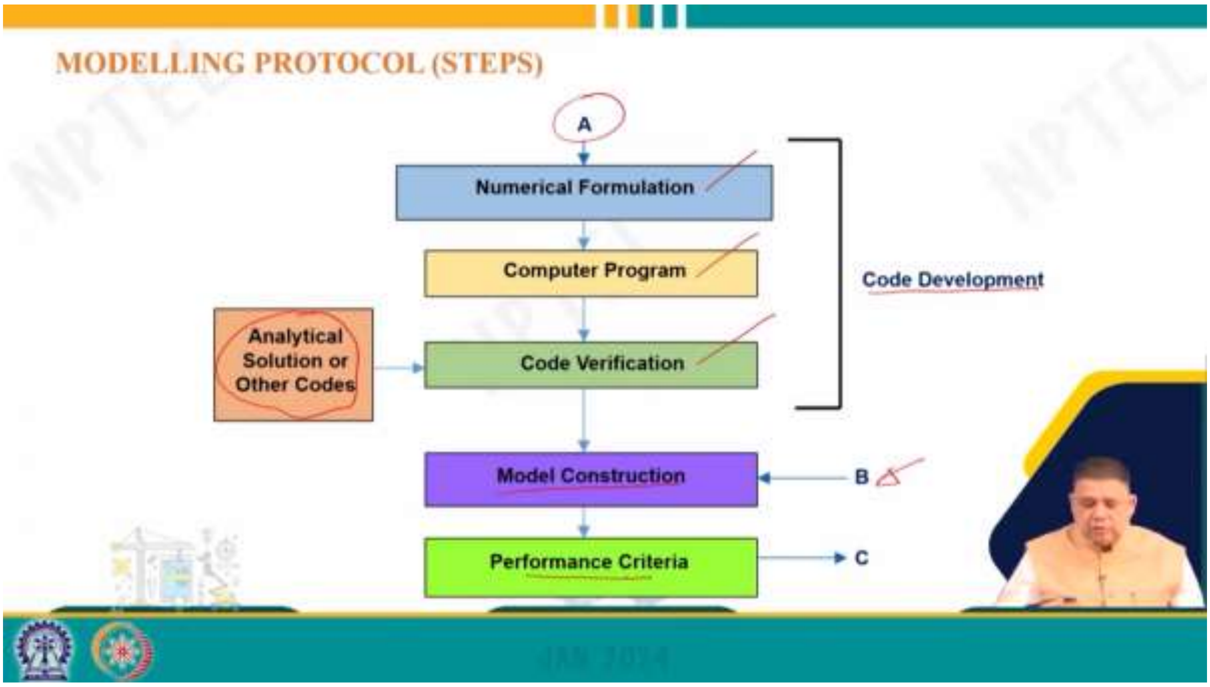
And models cannot replace decision-makers; they can aid decision-makers in making better decisions. This is one of the misconceptions that if you have a model, you do not need human beings, but modelers the role of modelers is very important. So, decision-making will be all done by the modeler, and a model can help in making better decisions. So, these are some of the principles of models we should always try to remember.



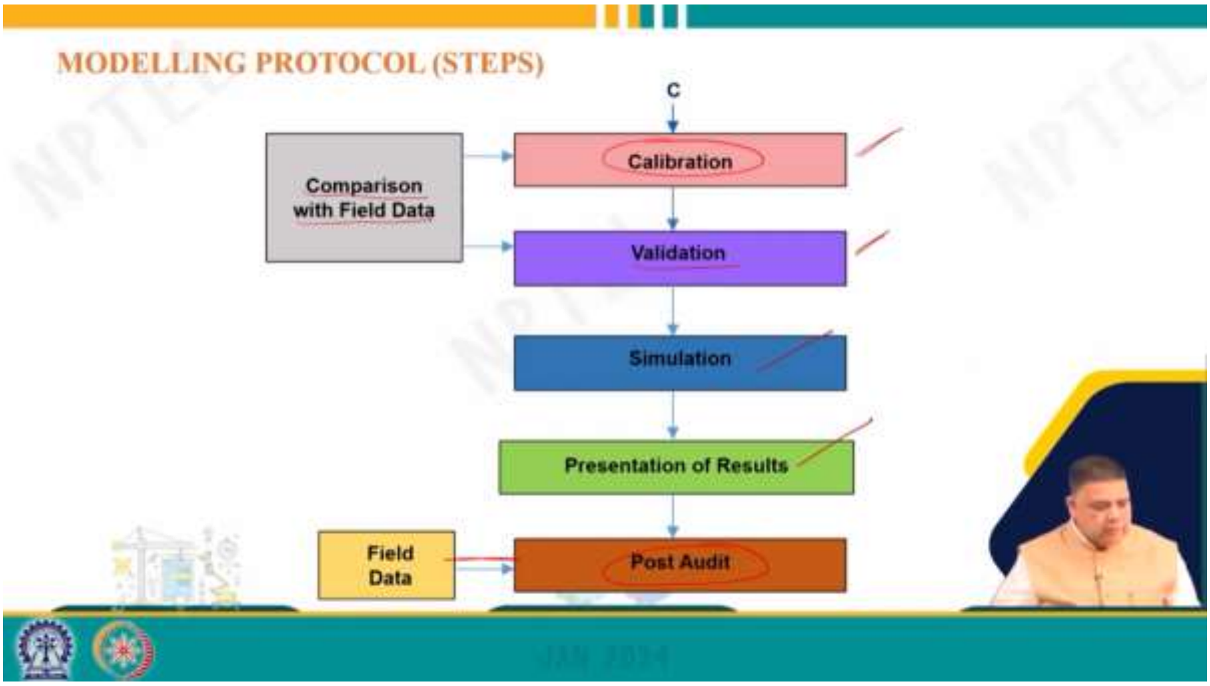
Then comes the modelling steps or modelling protocol, and obviously, the first step is, of course, to define the purpose for what you are trying to model, what you are trying to model, rainfall runoff or whatever.

And then, of course, you have to conceptualize the model. So, conceptualization, at this stage, you try to decide what components I am going to make, , this is what components I am going to include in my model. So, I may say that I will not consider interception; I will not consider evapotranspiration in my model while translating rainfall into runoff or transforming rainfall into runoff. So, that is kind of conceptualizing the model. And of course, at this stage, we should also have a fair idea of the field data which will be required to get to the real solutions.

Because if you can conceptualize a model and you put interception into your modelling system, but you do not have field data corresponding to interception, then obviously, how will you calibrate your model. So, obviously, this conceptualization state you have to always have a fair idea of what field data available. So, once you have conceptualized the model, then comes the code selection because today's world codes are available; there are libraries where codes are available to numerical solve anything. So, obviously, at this stage, you can always go into look for the codes and then you have to make a decision whether the existing code is suitable, yes, or there could be no, both possibilities are there.



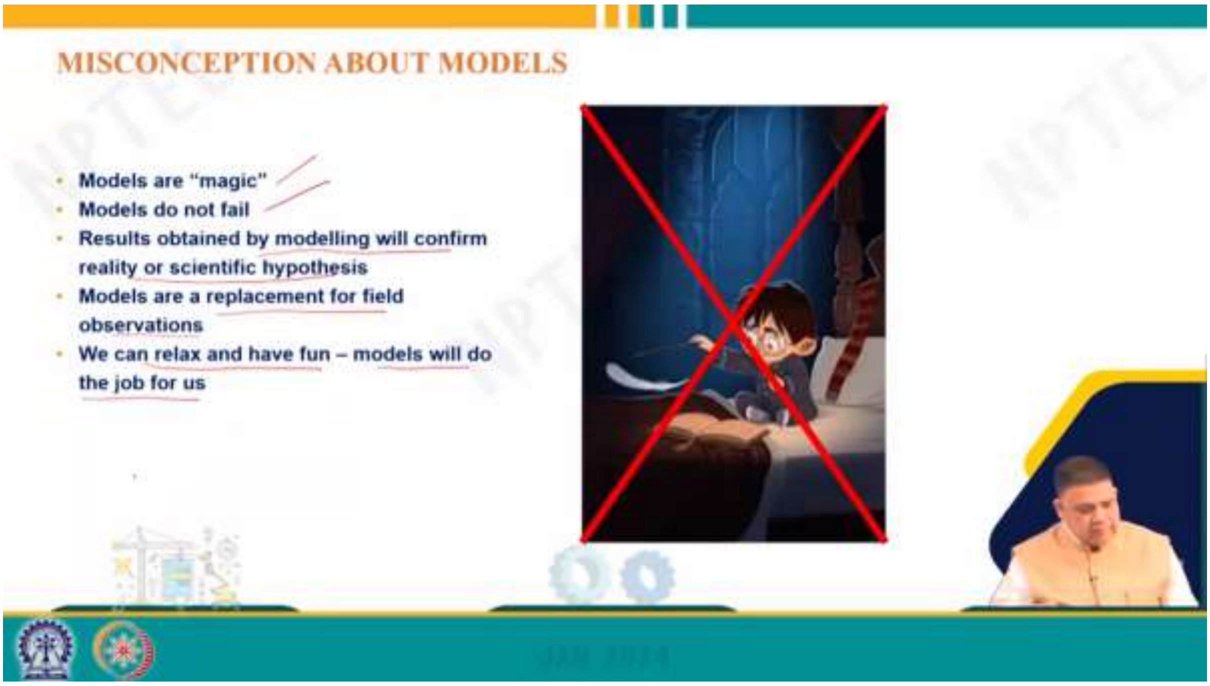
Now if the answer is no, then obviously, you have to go for code development. So, when the answer is no, that means, a route we have to go for code development, that means, you have to numerically formulate your problem; you have to write a computer program, and of course, you when your computer graph gives a solution you have to have code verification, which we can always do either using an analytical solution or any other code that is available. So, obviously, this is code development. So, once you have code already then existing codes suitable or when you have developed the code you reach this stage B that is the model construction. So, that means, this model construction means that you will be setting up the model, that is, you will include the data pertaining to your model, and then of course, there will be performance criteria based on which you will judge the performance of the model.



And here there are two important steps which use calibration and validation which we will discuss in great detail, in, in coming lecture we will spend a lot of time on this, but during calibration and validation both we compare the model results with the field data.

So, if you are modelling runoff, for example, then obviously, we will try to match the simulated runoff data with the field data and then make a decision whether my model is doing well or not. The difference between calibration and validation is that during the calibration process, we tune the model parameters until we are satisfied, that means, until we are satisfied with the performance criteria we have chosen. But when it comes to the validation phase, we take a different set of data and here we do not play with them, we do not play. So, whatever model parameters that are calibrated, we are allowed to use only those parameters.

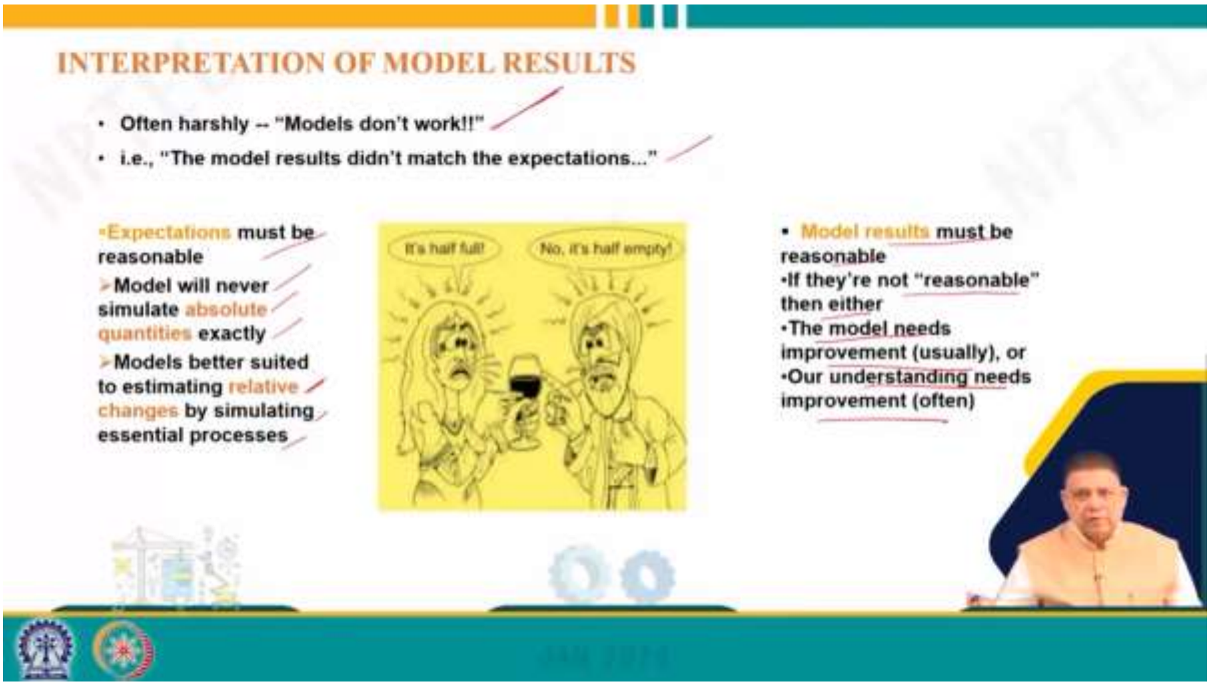
So, that is the validation. So, validation means that it is more general generality because you are testing the model performance with a fresh set of data without making any changes to the model. So, that is validation. And of course, once the model is calibrated and validated, then you simulate, you present the result and of course, a new step has been included recently, that is post-audit. That is again after a few years down the line, you go and again calibrate and validate your model with the field data in order to test whether your model is still performing or not because we know that because of climate change, because of land use changes, the conditions may change. So, just to be sure that your model's performance is as good as it was doing a few years back, you go and do the post-audit. So, these are the modelling steps typically we follow.



Then there are certain misconceptions about the model, that is, the models are magic, that is, those at least people who have not worked with the model, they always feel that the model is magic, you just give some input, it will give you output, but those who really try to develop the model or those who try to work with the model, they would really probably able to tell that it is really a difficult task actually to set a model, to develop a model, to run a model.

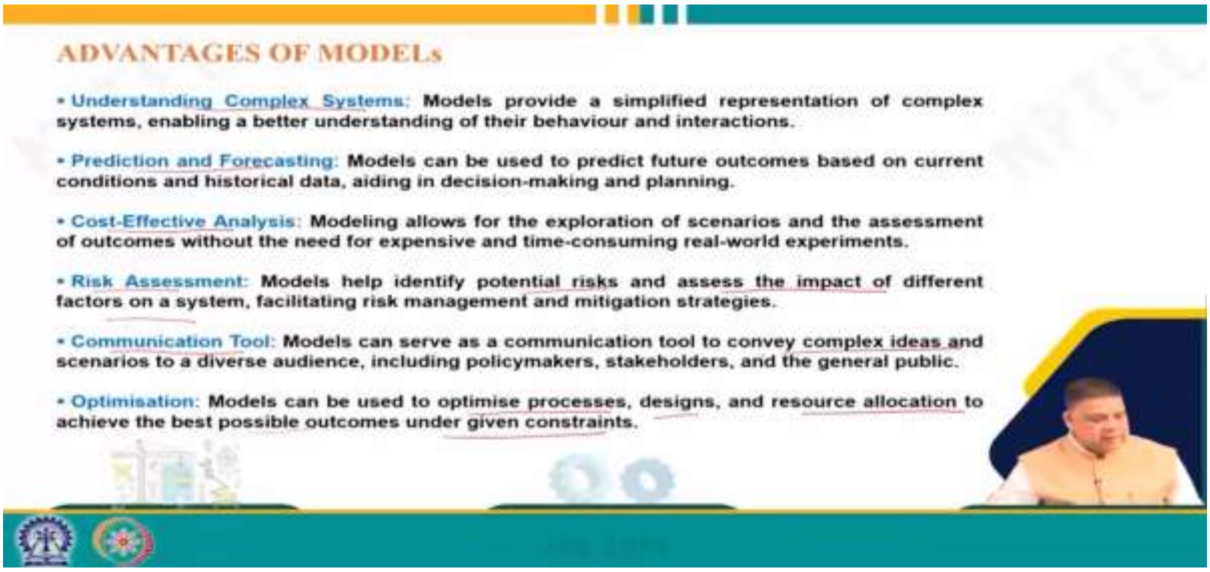
Then the next misconception is models do not fail, that is a misconception because as we already know that there is nothing like a perfect model. So, failure is always a possibility. Results obtained by modelling will confirm reality or scientific hypothesis again that is a misconception because we started with the statement that there is nothing like a perfect model, a representation which is less than perfect. So, obviously, an imperfect thing cannot really give you accurate results.

So, that some scientific reality or hypothesis could be tested. Then models are a replacement for field observations. We already saw GIGO, that is garbage in, garbage out. So, if your information is not correct, your results will not be correct. So, models cannot replace field observations, and then we can relax and have fun, models will do the job for us, and that is really not true. It is a difficult task actually for doing the model, working with the model.



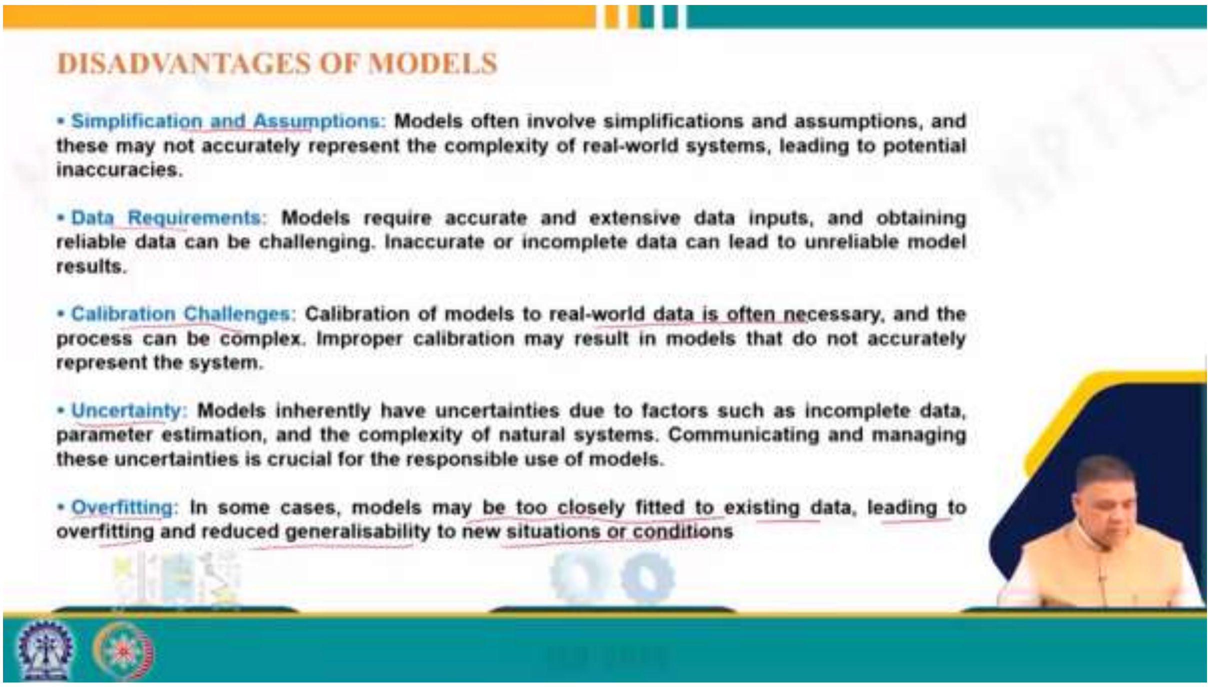
Then comes the interpretation of the results, how model results are interpreted. Often, harshly, you will hear that models do not work, and that is because the model results did not match the expectation. If that happens, then obviously, there are two possibilities. One is that our expectations were not correct. So, our expectations must be reasonable because models will never simulate absolute quantities exactly, and they are better suited to estimate relative changes by simulating essential processes.

So, obviously, when you are trying to use a model, the first thing is that you should be sure of the purpose for which the model has been developed, whether using it for the right purpose or not. And then you should always keep your expectations reasonable because models will not give you absolute values, but they will always give you a trend, that this is how things have changed or this is how with time things have changed. And of course, on the southern side, the model results must be reasonable, that is, under the circumstances if a model is being used for the purpose it was developed for, by giving it the right kind of data, then it should also give reasonable results. And if they are not reasonable, then either the model needs improvement, that there is something wrong with the model, so we need to improve the model, or our understanding needs improvement, that means, our testing of the mathematical essential working of the system itself has some flaw, and so it has not been translated well into the model. So, I mean, this is important that we understand this.



Then there are certain advantages of the model, that is, obviously, models can help us understand complex systems, which if you want to do experiments, probably it will be very complex, but with modelling, it is easier to understand complex systems.

Then, some of the things like prediction forecasting, that is, what is going to happen, we cannot really do experiments on that. So, only the models can help us predict in prediction and forecasting. Models result in cost-effective analysis, as we have always seen that they save time and money. So, obviously, they always result in cost-effective analysis. Models help in risk assessment, that is, identify potential risks and assess the impact of different factors on a system. Then, they can be used as effective communication tools. So, any complex idea you have or a system you are trying to model, then you can convey about that particular system in a better way using a model. Now, of course, the optimization the model can use to optimize processes, designs, resource allocation to achieve the best possible outcomes under given constraints.



By the same time, models also have certain disadvantages, like simplification and assumptions, they are the basic disadvantages of models. Data requirements, depending on the nature of the model, you require data. So, your model should have data requirements used that could be a big disadvantage of the model. Calibration is a challenging phase. We just discussed one of the steps was calibration. So, that is a challenging phase because you require real-world data and you have to have experience with the model parameters with the processor you understand the process as well, then only you can calibrate.

And of course, there is a challenge of uncertainty. Model results are always uncertain because of input data, because of the model structure, because of the process you are doing. So, uncertainty is always an issue. Also, there is a mathematical issue of overfitting. In some cases, a model may be too closely fitted to existing data leading to overfitting and reducing general ability to new solutions or conditions. So, if you mathematically overfit a model, probably that is also not a good thing to happen. So, these are some of the things one has to be aware of or be careful.

So, with this, we close this lecture. Thank you very much. So, we have introduced the hydrological modelling and the steps and some of the misconceptions about the models, and please give your feedback and raise your doubts or questions. I will be happy to answer on the forum. Thank you very much.