Course Name: Watershed Hydrology

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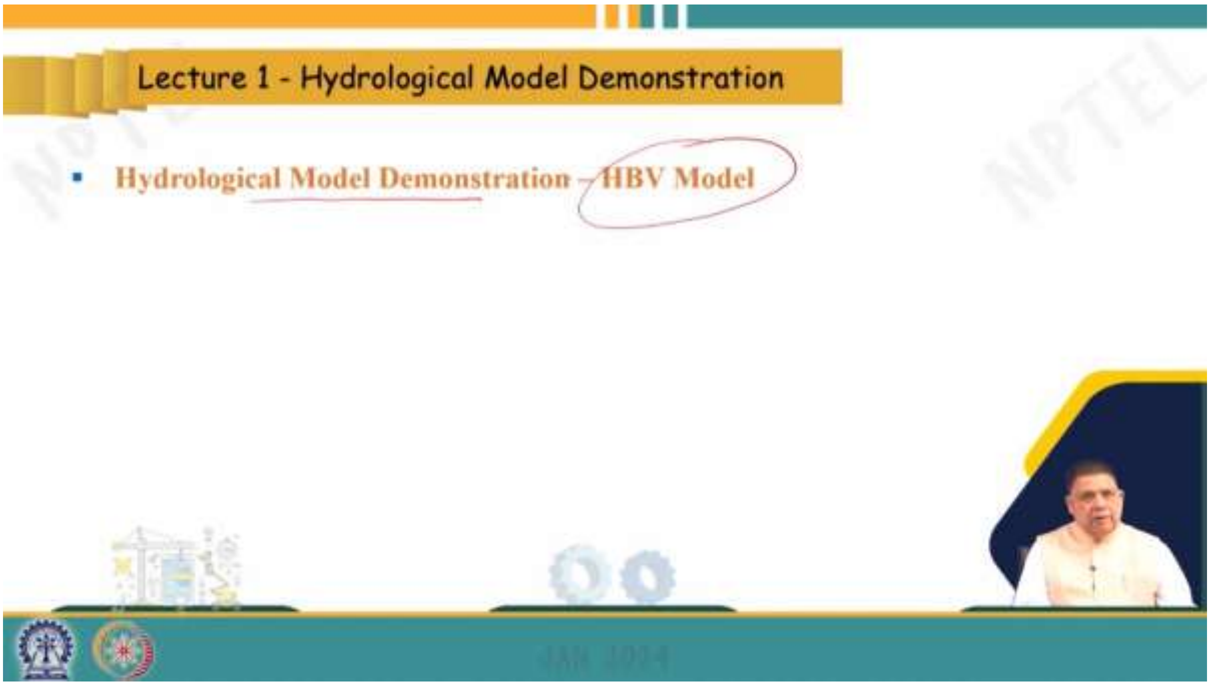
Week: 12

Lecture 56: Hydrological Model Demonstration

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 in Module 12, which is the final module of this course, and this is Lecture Number 1. The topic for today is Hydrological Model Demonstration.

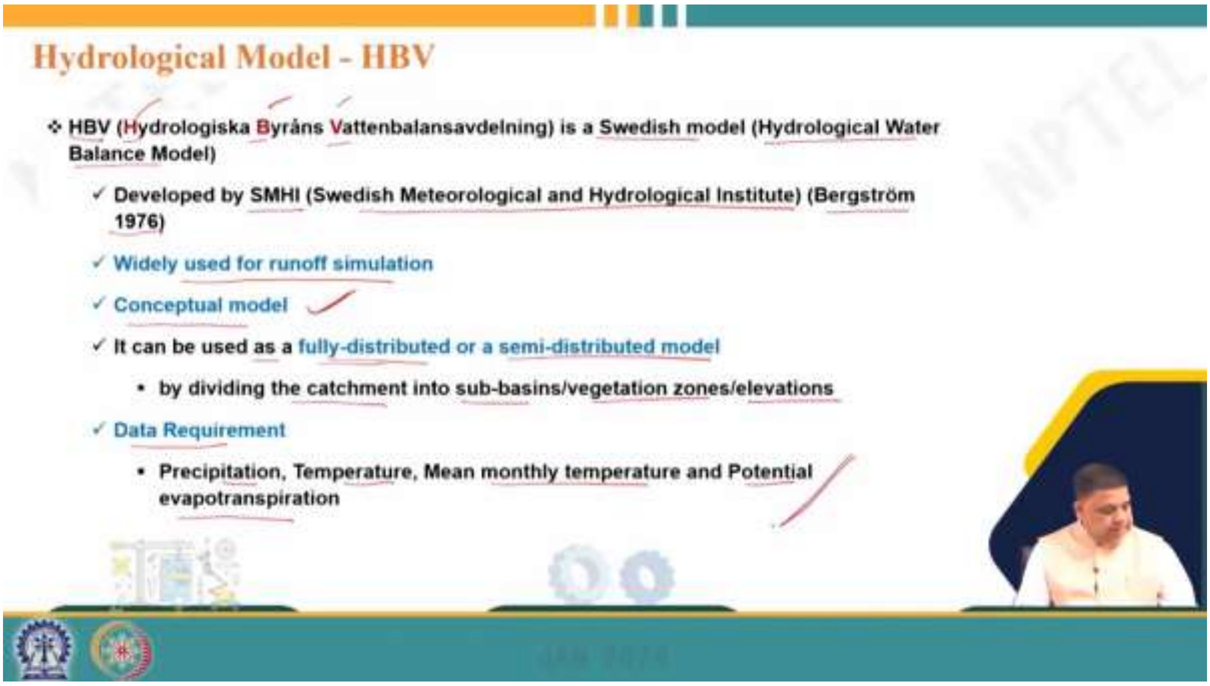
In this particular module, as promised in the beginning, we will have a miscellaneous focus. We will include a demonstration of hydrological models as a part of this module. Additionally, we will cover certain important topics that were not addressed in the earlier 11 modules. Finally, we will revise concepts through GATE multiple choice questions. We will address various multiple-choice questions that were asked in the GATE examination. Through them, we will attempt to revise the concepts, and we will also include a doubt-clearing lecture in this particular module.

So, today, we begin with the hydrological model demonstration, and we have chosen the HBV model for this purpose.

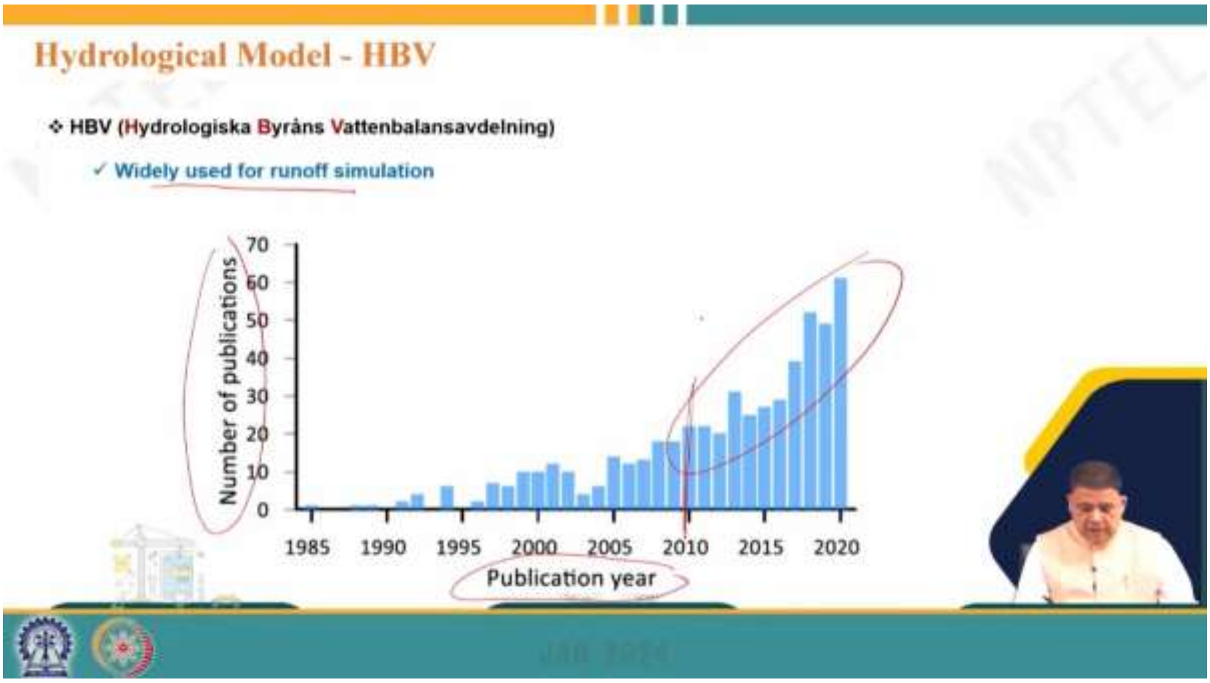


Now, the HBV model, which is basically a Swedish model, the H, B, and V come from the Swedish name Hydrologiska Byrans Vattenbalansavdeining . Of course, the pronunciation may not be correct, but HVV comes from there, and it means Hydrological Water Balance Model. It was developed by SMHI, the Swedish Meteorological and Hydrological Institute, in Stockholm.

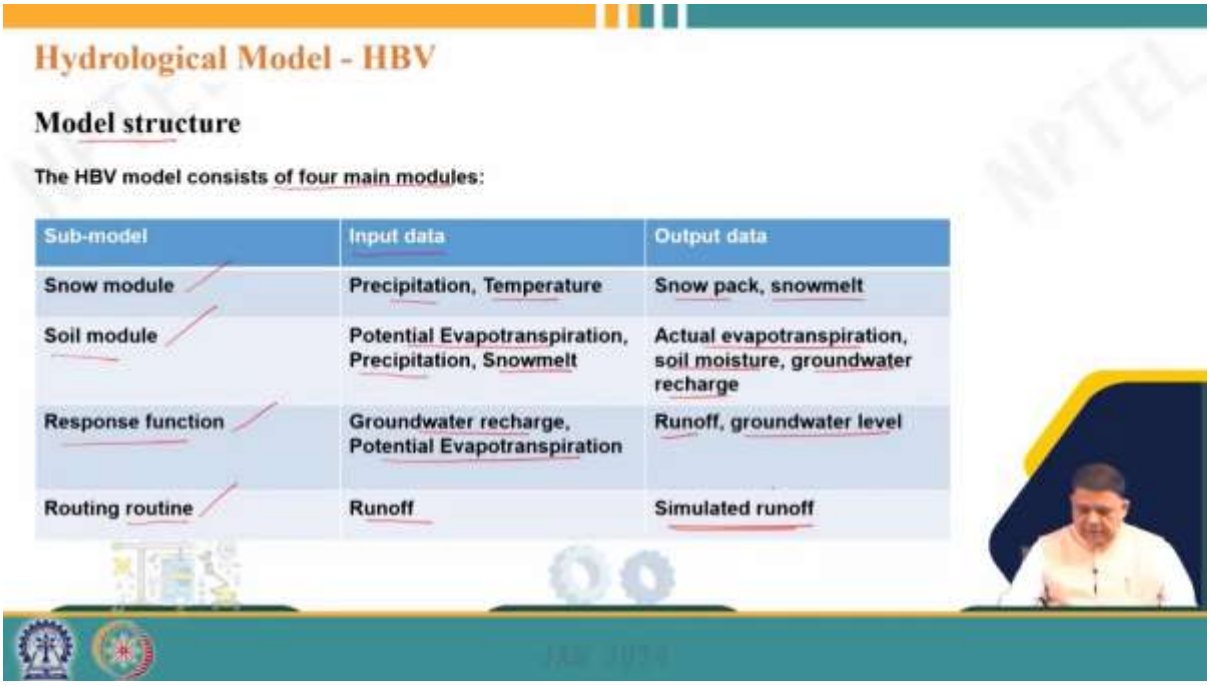
The first paper that was published was by Bergstrom in 1976. It is one of the widely used runoff simulation models and is basically a conceptual model. If you remember, we discussed while discussing modeling, we classified models based on process description. So, it falls into that category. This is a conceptual model and can be used as a fully distributed or semi-distributed model by dividing the catchment into sub-basins, vegetation zones, or elevations. This is important because, if you recall our discussion on modeling classification, we discussed that conceptual models are typically lumped, meaning they take a single unit for the entire basin. But here, this model provides this flexibility that you can have distributions based on various factors. Then, as for data requirements, this model requires precipitation, temperature, mean monthly temperature, and potential evapotranspiration as input data.



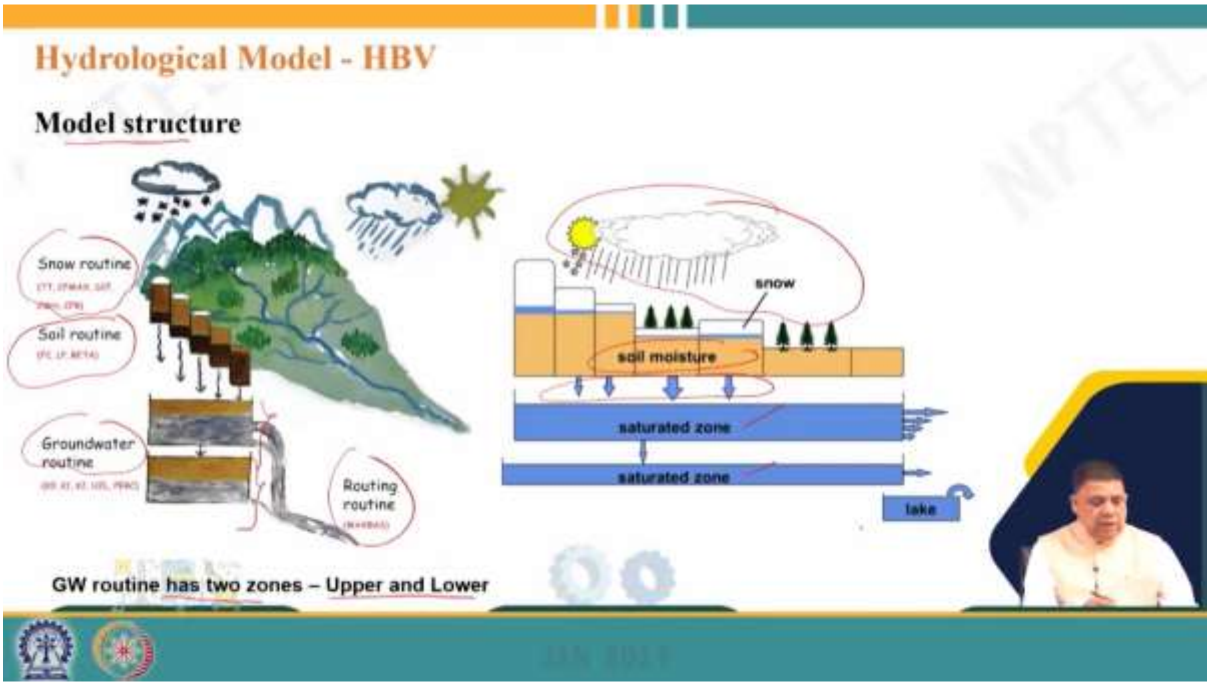
Now, I already mentioned that it is one of the widely used models for runoff simulation, and that could be seen from the number of publications that have come up since its inception. As you can see, in the last 10 years or so, there is a large number of papers on HVV model application, which shows the popularity of this particular model.



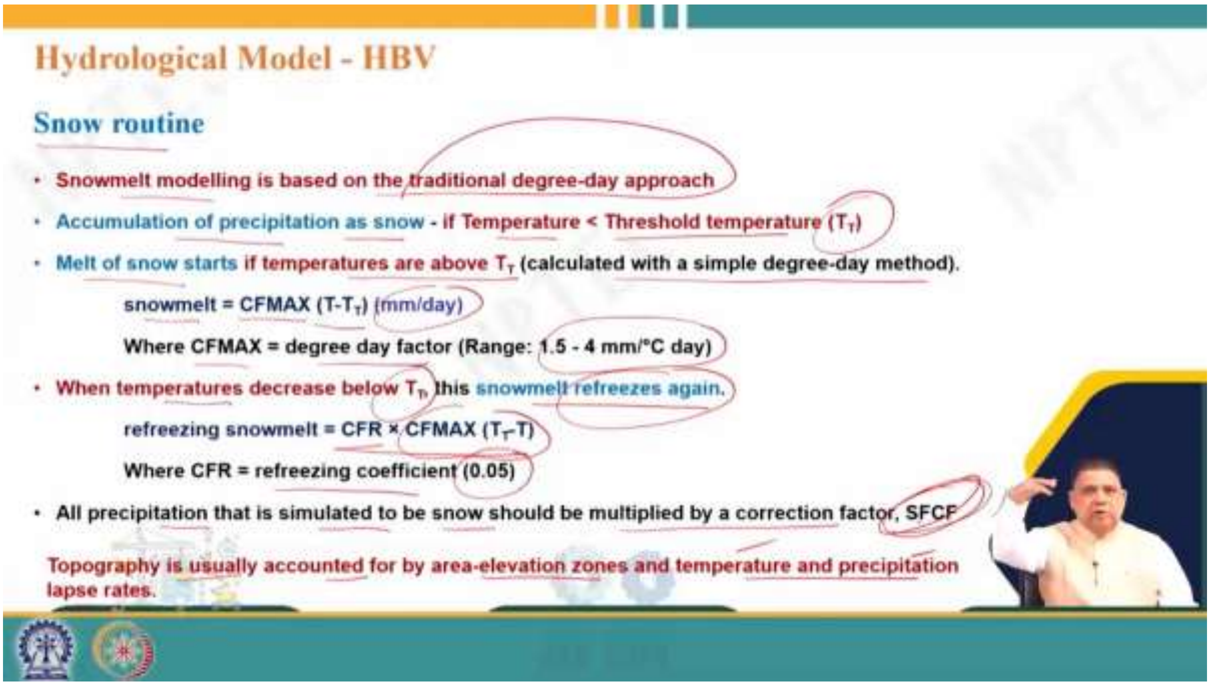
Now, coming to the model structure, it consists of four main modules: the snow module, soil module, response function (which basically deals with the groundwater module), and a routine module. The input data corresponding to these modules are as follows: the snow module requires precipitation and temperature, and the output is snowpack and snowmelt. As far as the soil module goes, input data includes potential evapotranspiration, precipitation, and snowmelt, and output data include evapotranspiration, soil moisture, and groundwater recharge. So, these are the outputs of the soil module. Then we have a groundwater reservoir response function, which is basically a groundwater model. Inputs include groundwater recharge, potential evapotranspiration, runoff, and groundwater levels. When we say "runoff," it basically refers to the groundwater runoff, which is the output data. As for the routine model, the input data is runoff, and the output data is simulated runoff at the outlet. So, whatever runoff is generated in the basin is routed to the outlet, and that is where simulated runoff is the output of this particular model.



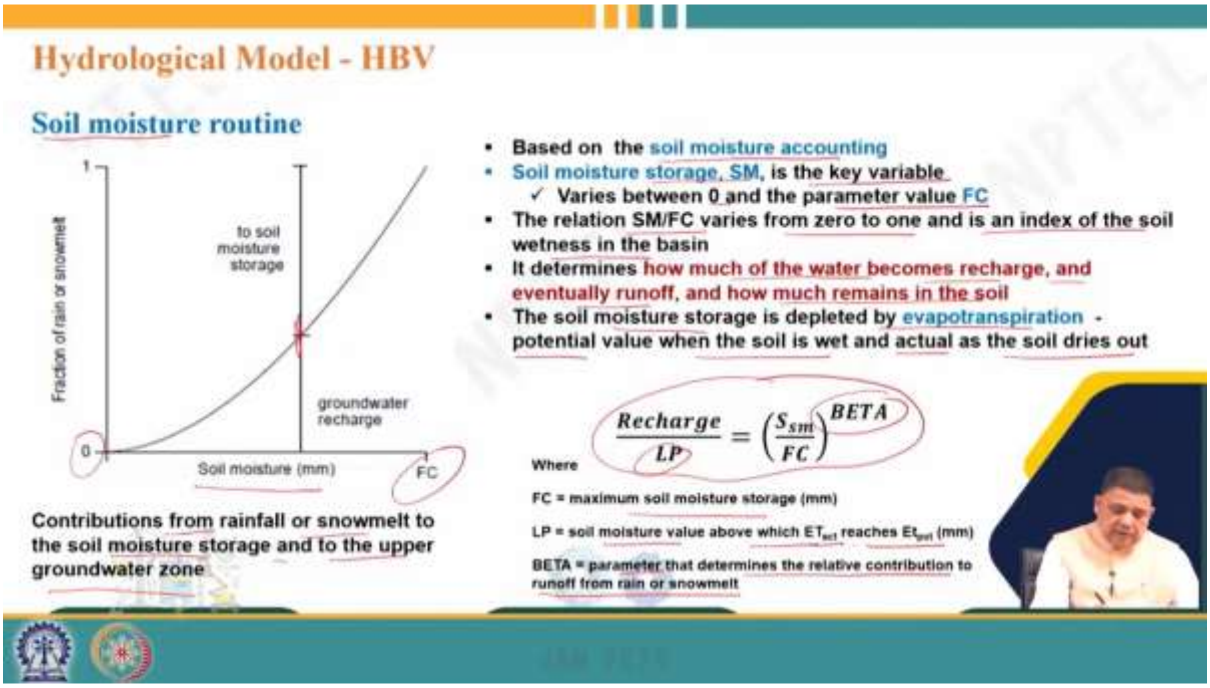
Now, sticking within the model structure, as you can see, this is the pictorial view of the model structure. The first routine is the snow routine, which basically takes care of the inflow to the catchment, either in the form of precipitation, which could be rainfall or snowfall, depending on the temperature. Then, of course, once rainfall or precipitation occurs, the water reaches the soil routine and finally, it enters the groundwater routine. The groundwater routine has two zones, as you can see, a two-bucket model, comprising the upper zone and the lower zone. When the runoff is generated from the groundwater routine, the routing routine takes it to the outlet. So, obviously, you have precipitation in the form of rainfall or snowfall, which fills up the soil moisture. From there, the water percolates to the groundwater zone, which is the saturated zone basically, and there are two zones. Finally, runoff takes place, which is taken to the outlet of the structure, that is, the outlet. So, this is how these four routings are placed, actually.



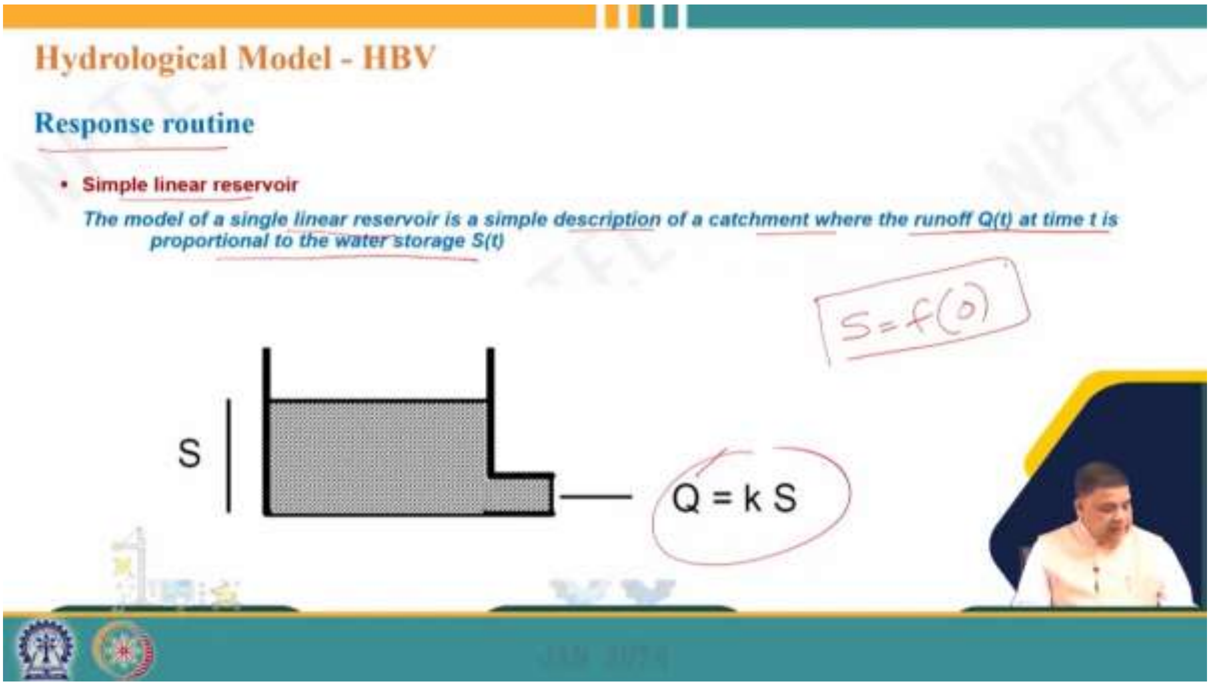
Now, let us start talking about the routines. The first one is the snow routine, and snowmelt modeling is based on the traditional degree-day approach. So, it uses the traditional degree-day approach for snowmelt modeling. Accumulation of precipitation as snow takes place if the temperature is less than a threshold temperature. So, if the ambient temperature is less than the threshold temperature, then precipitation gets converted into snowfall; even the water drops get converted into snowfall. Melting of snow starts if temperatures are above TT, which is calculated using a simple degree-day approach already mentioned, and snowmelt basically is a function given by CFMAX (T - TT) millimetre per day, where CFMAX is a degree-day factor which ranges between 1.4 and 4.5 millimetre per degree day. And when the temperature once again reduces or decreases below TT, then snowmelt refreezes again. So, of course, it is the temperature which governs; if it is below a certain threshold size, then all the precipitation will be in the form of snow. If the temperature goes above TT, then, of course, snowmelt occurs; and if again the temperature goes back to less than TT then, of course, the refreezing takes place, and this is like an equation. So, obviously, this is the melt we have seen, and CFR is the refreezing coefficient, which is typically 0.05. So, all precipitation that is simulated to be snow should be multiplied by a correction factor. So, of course, that correction factor also converts the snow quantity. Topography is usually accounted for by area elevation zones and temperature and precipitation lapse. So, you can have the distribution in the form of elevations, and, of course, there, the temperatures and precipitation will change according to elevation.



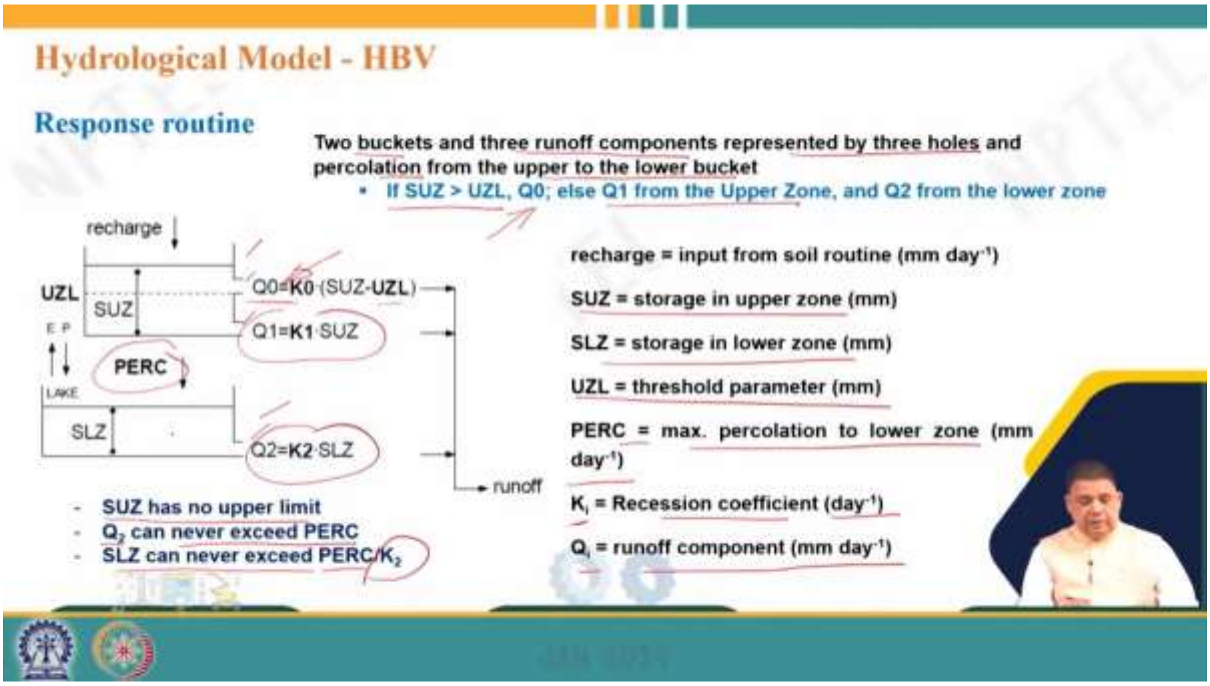
Then, the next routine is the soil moisture routine, which is based on soil moisture accounting, and soil moisture storage (SM) is the key variable. Soil moisture storage is the key variable, and it varies between 0 and parameter value FC , which amounts to field capacity. As you can see in this graph, it varies between 0 to FC . And the relation SM/FC varies from 0 to 1 and index of the soil wetness in the basin. So, of course, if SM is higher, that is, this ratio is closer to 1, that means soil moisture is very close to field capacity, and that means the soil is close to saturation. It determines how much of the water becomes recharge and eventually runoff and how much remains in the soil. So, of course, this ratio will govern that. The soil moisture storage is depleted by evapotranspiration at potential rate when the soil is wet and actual rate when the soil dries out. So, if enough soil is there, potential rate evaporation will take place when the soil moisture reduces; then, of course, the actual evapotranspiration rate will take place. And, of course, this is a relationship which governs how much water will be recharged. So, here LP is the soil moisture value above which actual evapotranspiration actually reaches potential value. And FC already, we have seen, is the maximum soil storage. SM is soil moisture storage, and BETA is a parameter that determines the relative contribution to runoff from rain or snowmelt. So, of course, the contribution from rain or snowmelt to the soil moisture storage and to the upper groundwater zone. So, of course, when soil moisture is above a particular threshold, then it gets recharged or it percolates into the groundwater. This is the soil moisture routine.



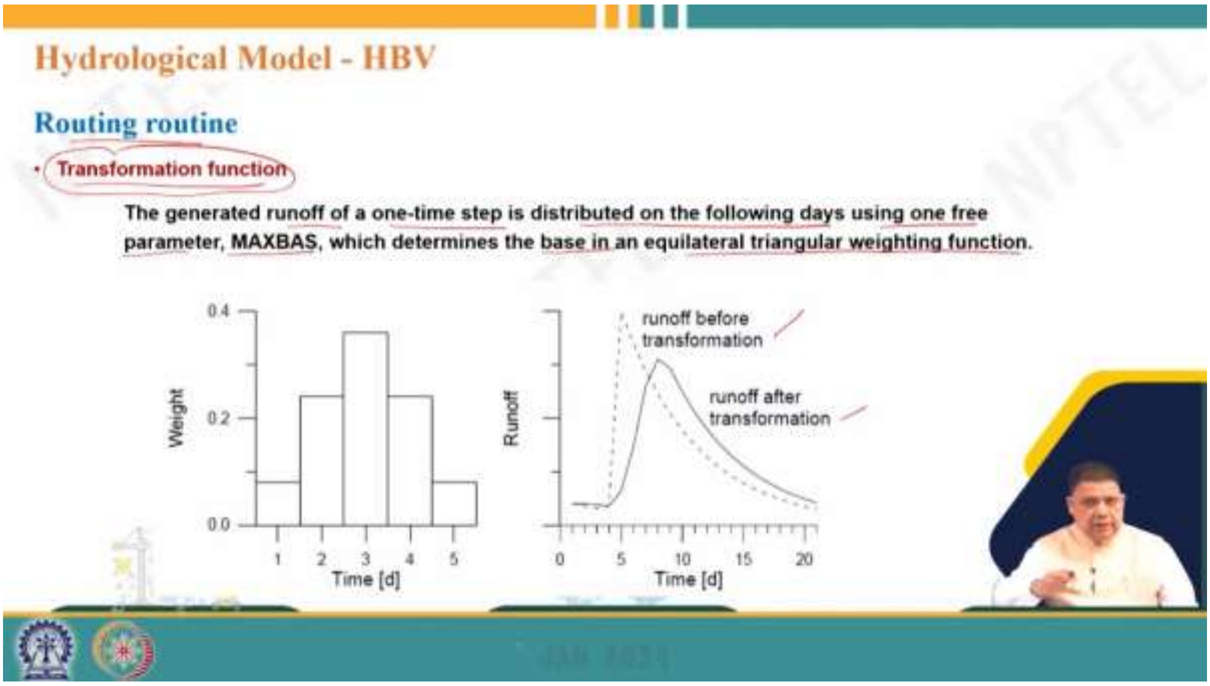
Then we have the response routine, which depends on a simple linear reservoir, that is, the model of a single linear reservoir is a simple description of a catchment where the runoff Q at time t is proportional to the storage. So, already, we have discussed in flooding that a linear reservoir means storage is a function of outflow only. So, that means storage and outflow are related. So, we can write it in this form also. So, Q is a function of storage basically. Or storage is a function of outflow; that is how we define a linear reservoir.



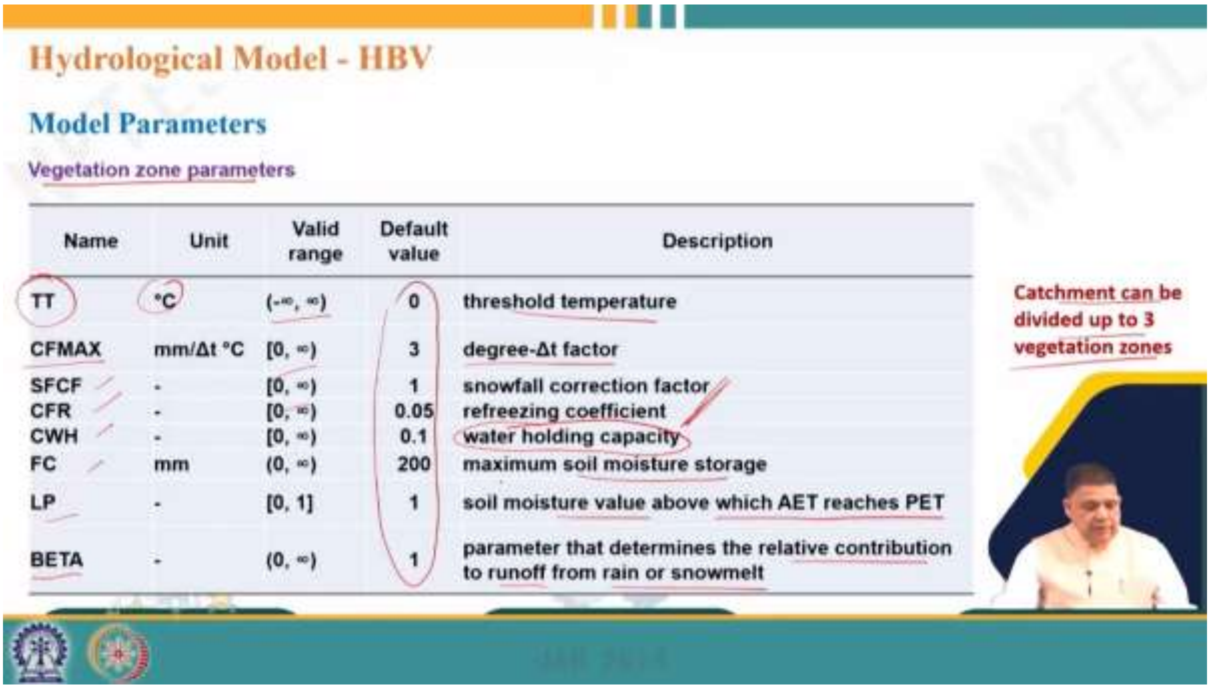
So, in this, there are 2 buckets and 3 runoff components represented by 3 holes and percolation from the upper to lower bucket. These are the various components. So, there are 2 buckets: the upper bucket and the lower bucket, and 3 runoff components, as you can see. There are 2 runoff components here, and there is one in the lower zone, which is represented by 3 holes through which runoff will go out. And of course, there is percolation which takes care of the water movement from the upper to the lower bucket. Now, within SUZ, if you consider the upper zone, then it has no upper limit, it has no moisture limit, but here there is a UZL, that is, our threshold parameter is defined here. Here, SUZ is the storage in the upper zone, SLZ is the storage in the lower zone. So, we are talking about the upper zone; it has no limit, and there is a threshold parameter. So, if SUZ is greater than UZL, if the soil moisture is more, then obviously, Q0 will also flow out from here in this form; else, Q1 from the upper zone. So, otherwise, if it is below this UZL, then only one. So, there are 3 holes, but the top one is conditional: if SUZ is greater than UZL, then only this Q0 will take place; otherwise, Q1 will take place, and percolation is the maximum percolation to the lower zone in millimetre per day, and this goes into the lower zone. And Q2 can never exceed percolation. So, this is the Q2 from this lower storage, but it can never exceed percolation. So, that is the limit fixed, and SLZ can never exceed percolation by K2 where K1, K0, K1, and K2 are the recession coefficients per day, and Q is the runoff coefficient in millimetre per day. So, Q0, Q1, Q2. There are 3 holes, 0, 1, and 2. They are represented 0 and 1 in the upper bucket and Q2 in the lower bucket. So, this is how the response routine works.



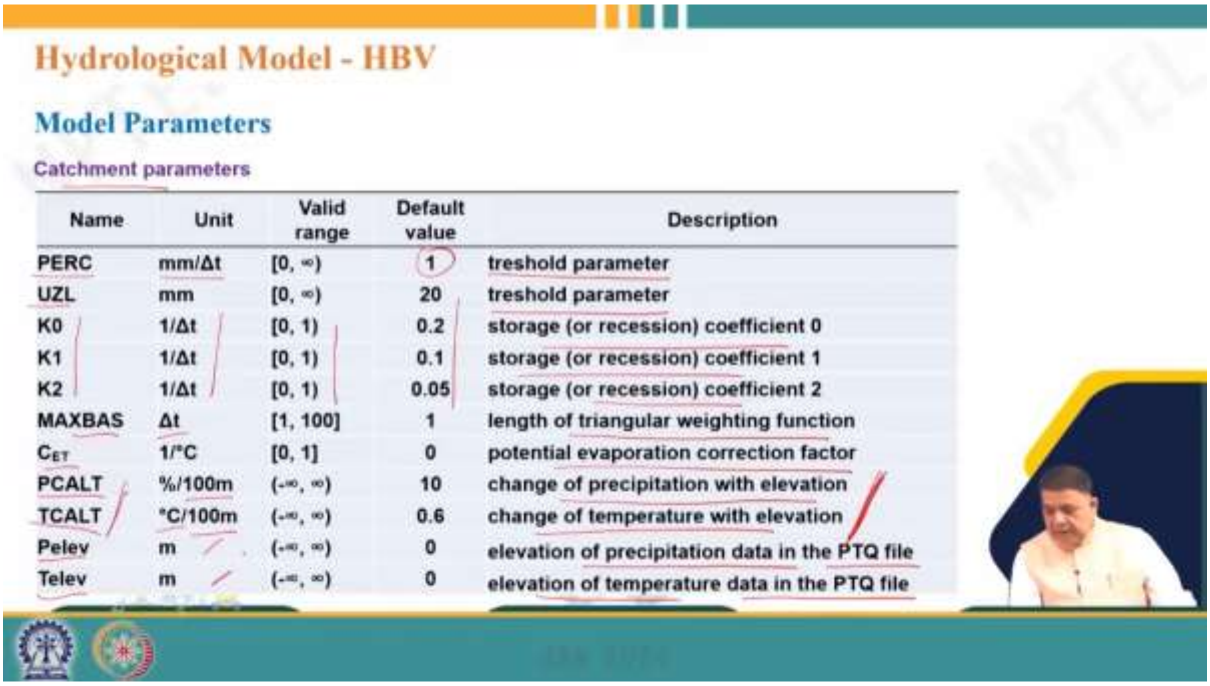
Lastly, we have the routing routine, which basically works on a transformation function. The generated runoff of a one-time step is distributed over the following days using one free parameter, max pass, which determines the base in an equilateral triangular weighing function. Basically, because runoff will be generated, but the time to the outlet could vary, and that is where this transformation function comes into the picture. So, it is assumed to be equilateral triangular, and the weighing fraction is accordingly decided. So, runoff before transformation impacts the base, causing the time over days where the water reaches the outlet to increase.



Now, we come to model parameters. There are two types of parameters here. One is related to vegetation zone parameters, which include Tt, as we already saw, which is the threshold temperature in degrees Celsius. CFMAX , as we have seen, is the degree delta T factor. Then there are SFCF, CFR , CWH, FC , which we have already discussed, and these are the CWH parameters. CWH is the water holding capacity of the soil, and these two are basically in the soil moisture routine. Fc is the maximum soil moisture storage, LP is the soil moisture value above which AET reaches PET, and beta, of course, determines the relative contribution to runoff from rain on slow made. So, their units and their range, the valid range, is assigned, and these are the default values which the model recommends, but users have the freedom to play with these values. Here, the catchment can be divided into up to 3 vegetation zones. Earlier, we discussed elevation-based vegetation zones as well.



Then the second set of parameters come are catchment parameters. These are like perk, as we already saw, it is in millimetre per degree T and per unit time, that is, a threshold parameter, and its default value is 1, but its valid range is from 0 to infinity. Then you have UZL, as we discussed earlier, again a threshold parameter above which Q0 will work. K0, K1, K2 are the storage or the source and coefficients 0, 1, 2, and their values, ranges, and units are given here. MAXBAS is the delta T length of triangular weighing factor, CEt is the potential evaporation correction factor, PCALT and TCALT are the change of precipitation with elevation. So, if you have more than one zone, then how temperature and precipitation will vary with the zone, that is, the percentage per 100 meters or degrees Celsius per 100 meters, and that is defined by these PCALT and TCALT . P elevation and T elevation are the elevations of precipitation data in the PTQ file and the elevation of temperature data in the PTQ file. So, these are in meters, specified in meters. These are the various kinds of parameters that are.



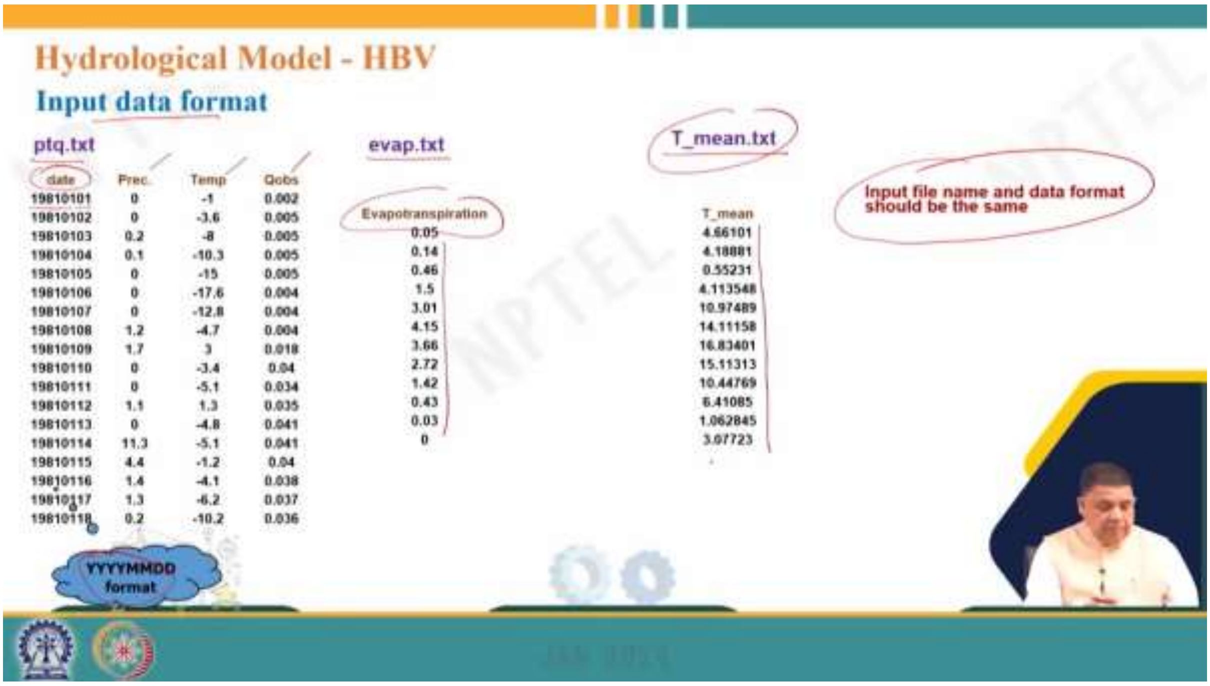
Hydrological Model - HBV

Model Parameters

Catchment parameters

Name	Unit	Valid range	Default value	Description
PERC	mm/Δt	[0, ∞)	1	treshold parameter
UZL	mm	[0, ∞)	20	treshold parameter
K0	1/Δt	[0, 1)	0.2	storage (or recession) coefficient 0
K1	1/Δt	[0, 1)	0.1	storage (or recession) coefficient 1
K2	1/Δt	[0, 1)	0.05	storage (or recession) coefficient 2
MAXBAS	Δt	[1, 100]	1	length of triangular weighting function
C_{ET}	1/°C	[0, 1]	0	potential evaporation correction factor
PCALT	%/100m	(-∞, ∞)	10	change of precipitation with elevation
TCALT	°C/100m	(-∞, ∞)	0.6	change of temperature with elevation
Pelev	m	(-∞, ∞)	0	elevation of precipitation data in the PTQ file
Telev	m	(-∞, ∞)	0	elevation of temperature data in the PTQ file

Now, if you talk about the input data format, then this is the kind of data we have to use. So, we have three files: ptq.txt, evap.txt, and T_mean.txt, and the input file name and data format should remain the same. You are not allowed to change this; you have to follow the same filename and also the same data format. So, the important thing is that if you look at the date format, it is given as yyyy-mm-dd, so that means, first the year comes, then the month comes, and then the day comes. This is the format you have to use to keep your data. Then there are three columns: one for precipitation, one for temperature, and the third one for Q observed in the ptq.txt file. The evap.txt file basically consists of evapotranspiration data on a daily basis, and T_mean.txt is the mean temperature data, where the date is specified.



ptq.txt

date	Prec.	Temp	Qobs
19810101	0	-1	0.002
19810102	0	-3.6	0.005
19810103	0.2	-8	0.005
19810104	0.1	-10.3	0.005
19810105	0	-15	0.005
19810106	0	-17.6	0.004
19810107	0	-12.8	0.004
19810108	1.2	-4.7	0.004
19810109	1.7	3	0.018
19810110	0	-3.4	0.04
19810111	0	-5.1	0.034
19810112	1.1	1.3	0.035
19810113	0	-4.8	0.041
19810114	11.3	-5.1	0.041
19810115	4.4	-1.2	0.04
19810116	1.4	-4.1	0.038
19810117	1.3	-6.2	0.037
19810118	0.2	-10.2	0.036

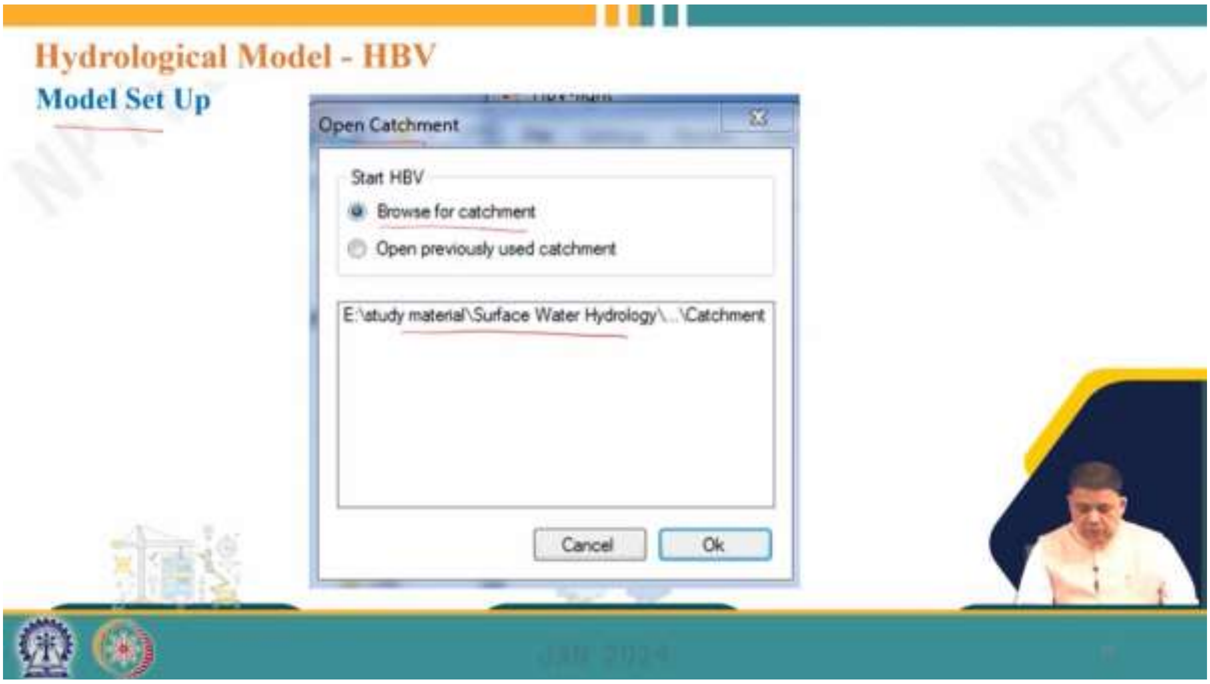
evap.txt

Evapotranspiration
0.05
0.14
0.46
1.5
3.01
4.15
3.66
2.72
1.42
0.43
0.03
0

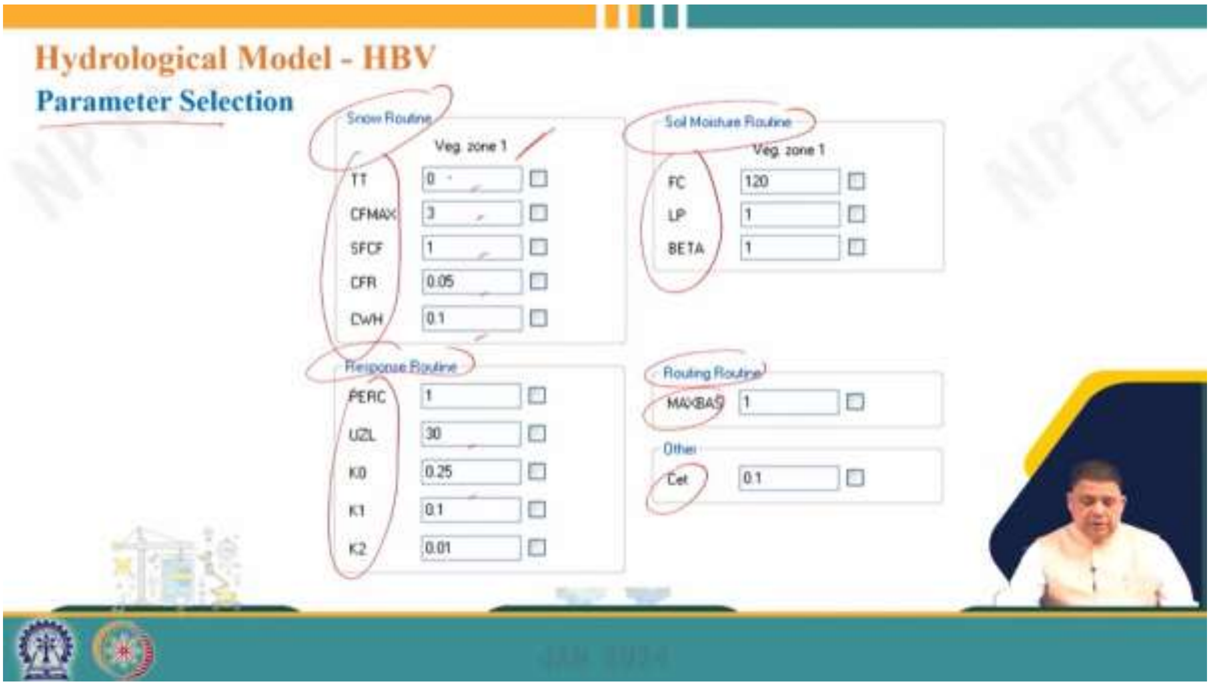
T_mean.txt

T_mean
4.66101
4.18881
0.55231
4.113548
10.97489
14.11158
16.83401
15.11313
10.44769
6.41085
1.062845
3.07723

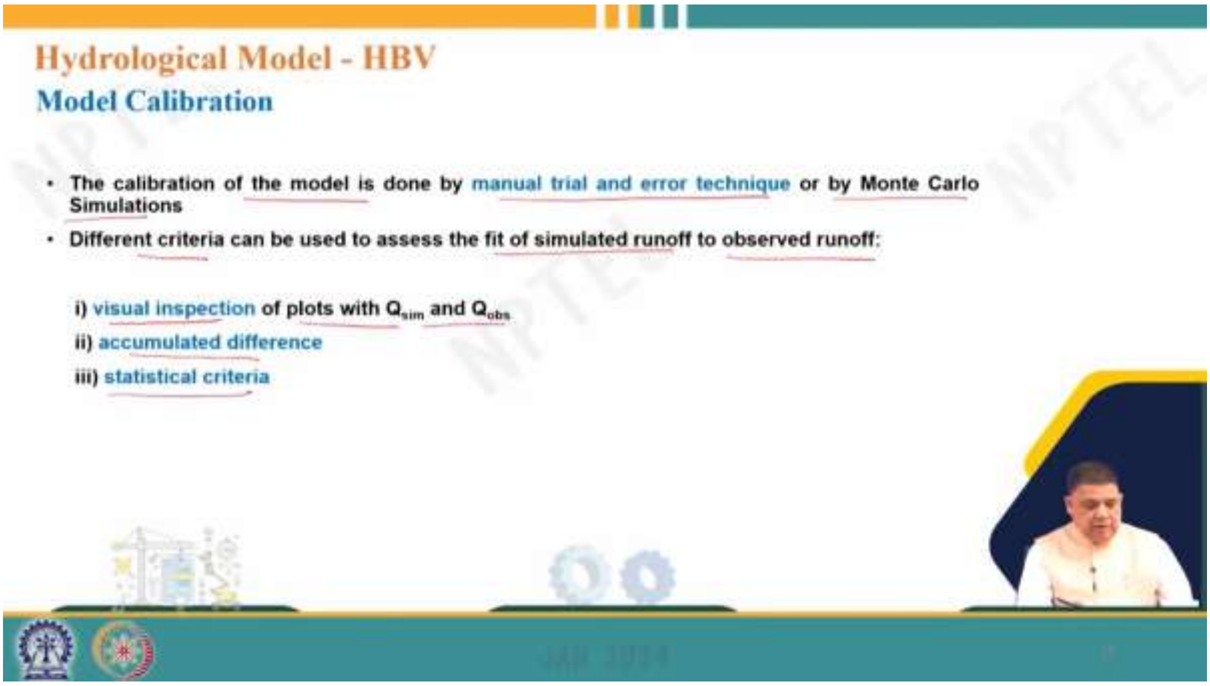
Now, coming to model setup, once we start the model setup, obviously, the first thing is that we have to open the catchment that we can browse for the catchment if you have already saved or we have to create a new one. So, of course, the directory will be shown, and you can select the directory.



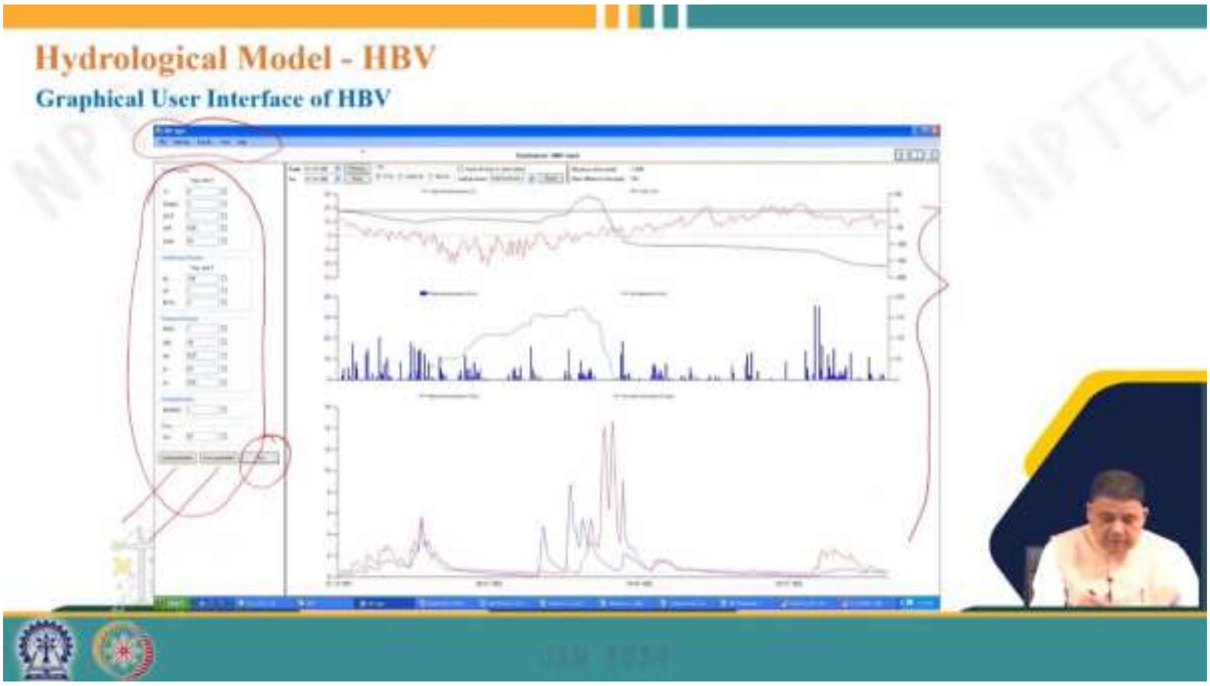
Then, of course, it will show you parameter selection. These are the various parameters. The snow routine has these five parameters, the soil moisture routine has three parameters, the response routine has these five parameters, and the routing routine has one parameter, and there is one more parameter, CET. So, these are the parameters, and so these are default values already shown here, but one can always go and change these values, and this is only zone 1, but if you have zone 2 or zone 3, then, of course, you will have multiple data for different zones. So, these are default values, but users can change these values.



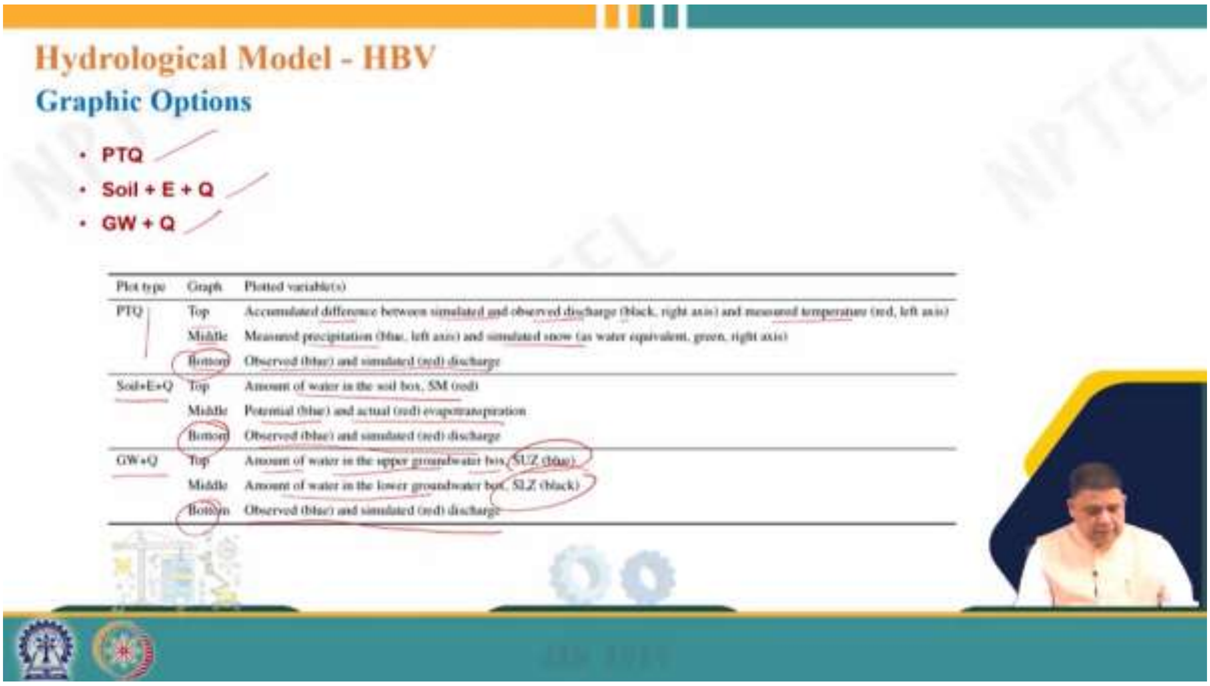
Then we come to model calibration. Model calibration and the calibration of the model is done by manual trial and error technique or by Monte Carlo simulation. So, there are two possibilities: one is to go by manual. Earlier, we discussed calibration while talking about hydrological models, that you can either have manual calibration or automatic calibration. So, it has both possibilities that you can go for manual calibration or you can use Monte Carlo simulations for automatic calibration, and different criteria can be used to assess the fit of simulated runoff or observed runoff, like you can have visual inspection of plots with Q simulated and Q observed. You can have an accumulated difference between Q simulated and Q observed, and of course, you can have statistical criteria based on which you can judge your calibration accuracy.



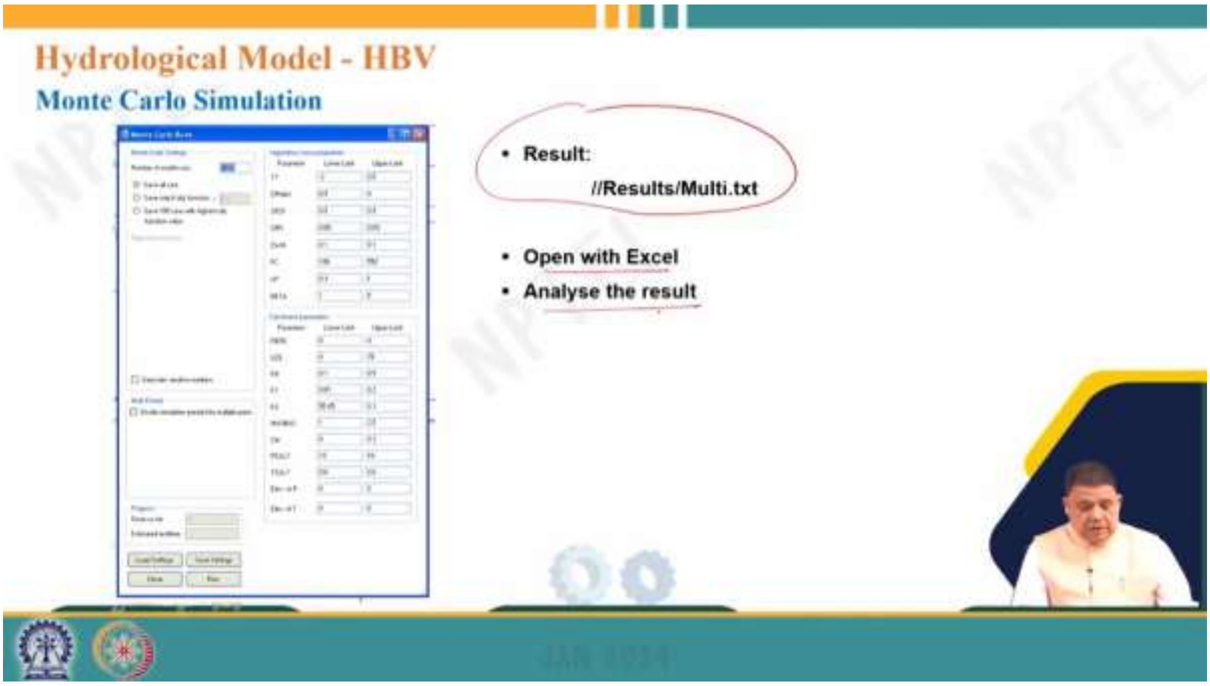
And this shows the graphical user interface of the HVV. So, all the tabs are shown here, and the parameters will be shown here, basically, and then, I mean, load parameter shape parameter. So, you can change the parameter and shape parameter, and of course, the model run is also done from here, and this is the graphical picture. We have three different, that is, this is the simulation period, and these are the options given here.



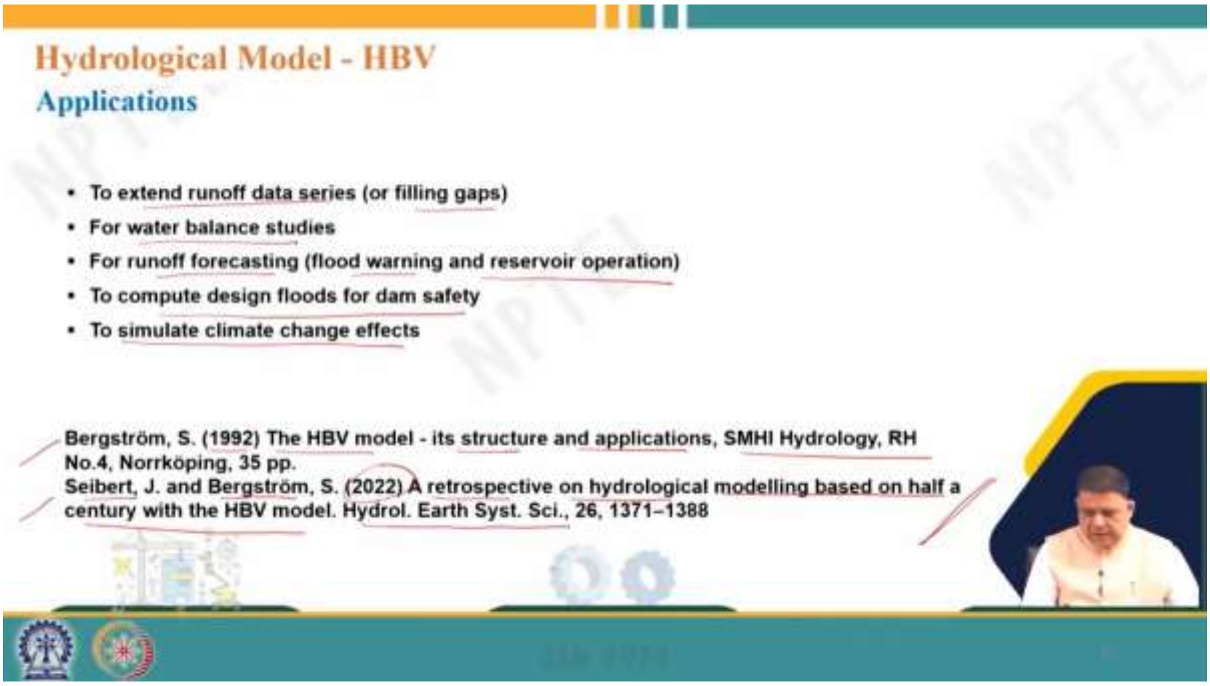
So, basically, graphic options, you can see that there are three graphs here. So, three different graphic options are available: PTQ soil plus E plus Q groundwater plus Q. So, PTQ means accumulated difference between simulated and observed discharge, and measured temperature will be shown on the top panel. So, the top panel will have these two values, then a middle panel has measured precipitation and simulated snow, and the bottom panel will have observed and simulated discharge. So, this bottom panel in all three will remain the same, say observed and simulated discharge because most of your statistics are calculated based on using this data, but other plots could vary like, for example, soil + E + Q. So, Q does not change, but the first one is the amount of water in the soil box, that is, my soil moisture, and the middle has potential and natural evapotranspiration. So, here focus is more on soil and evaporation and of course, discharge. Then the third one is groundwater + Q, the third one, as I said, the bottom panel remains the same, the top panel will show the amount of water in the upper groundwater box SUZ and the amount of water in the lower SLZ. So, it will show you groundwater values in the two boxes which we have or two buckets which we have discussed earlier.



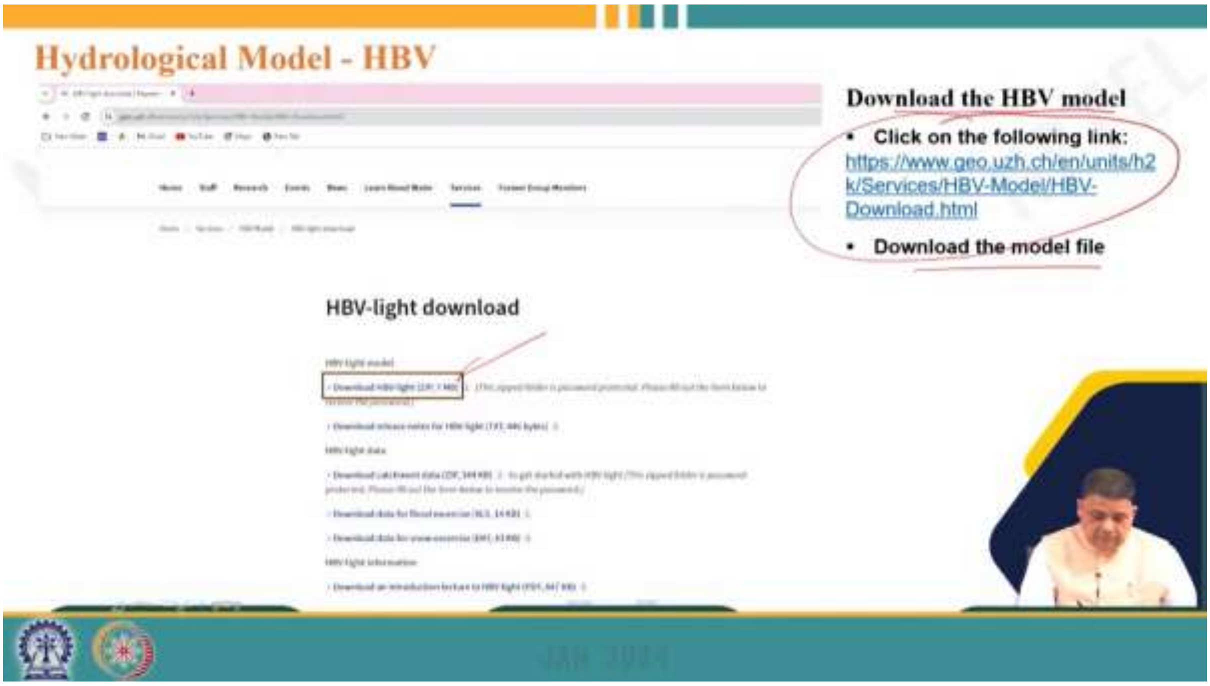
Then comes the results. Results can be saved in the typical file, and file name, and it can be opened with Excel, and results can be analysed, and you can also, as I mentioned, run multi-column simulations for the model.



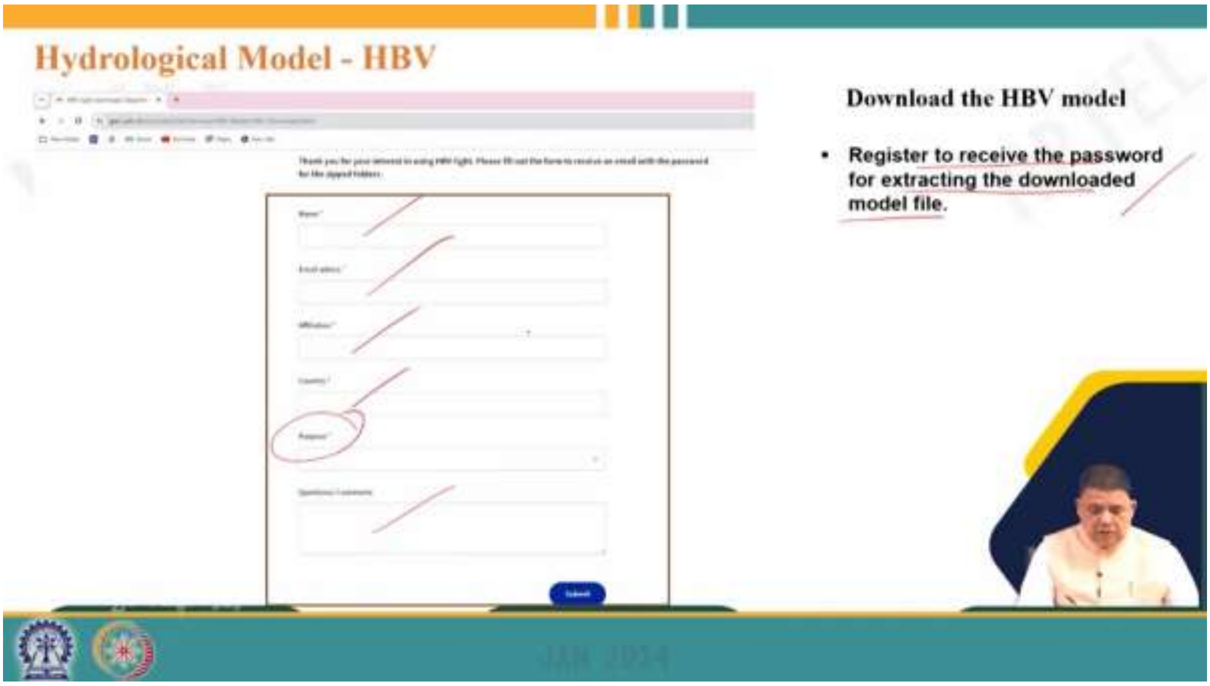
Now, coming to applications of the model, there are typical applications like extending runoff data series or filling gaps for water balance studies, for runoff forecasting or flood warning, and reservoir operation to compute design floods for dam safety and to simulate climate change effects. So, all those typical applications of hydrological models, HVV also does them, and these are the two defining papers on this particular model. The first one is the base paper published by Bergstrom in 1992, that is, the HBV model structure and applications, and it is a report of the institute just now earlier we mentioned where it has been developed. The second paper by Seibert and Bergstrom published in 2022, a retrospective on hydrological modeling based on half a century which HBV model. So, over half a century, what are the various applications that have been discussed, what changes have taken place in the model or in what changes have been introduced in the model and why those things have been discussed in this paper which is published in hydrological earth system sciences in 2022.



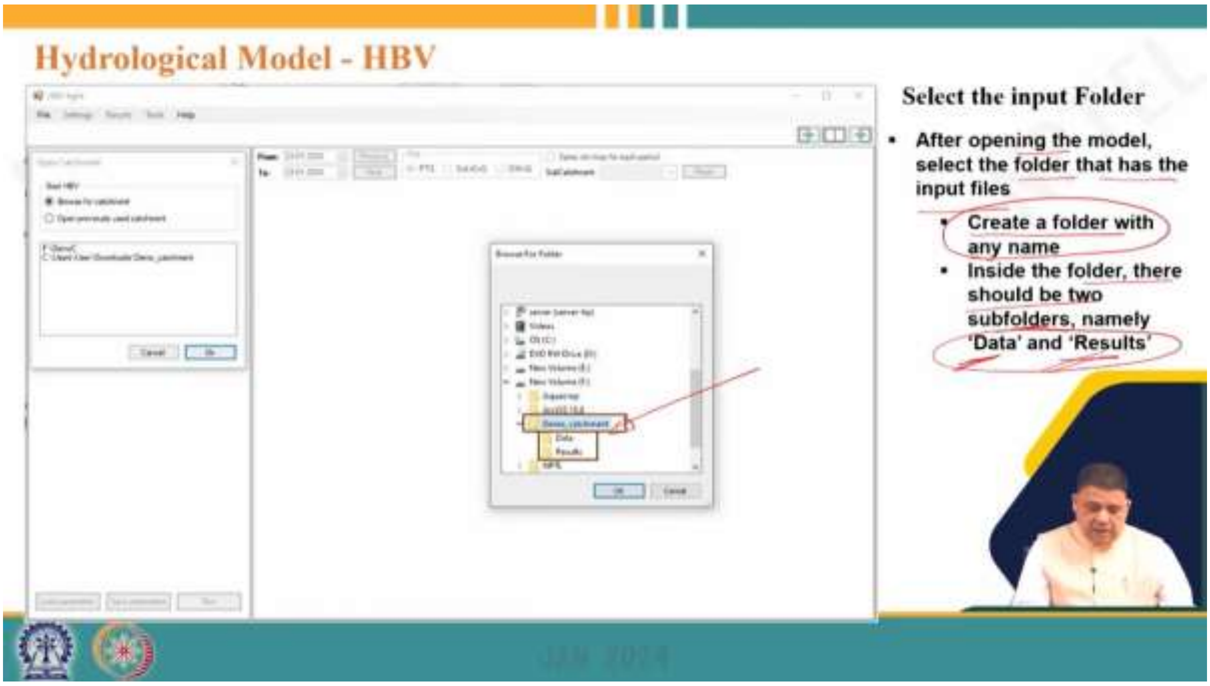
Now, we come to the real model, so obviously, this model is freeware and thus you can download the HBV model by clicking on the link provided here. So, you can click on this link and download the model, or you can copy this in your browser and then download this model. So, obviously, it will give you the option of downloading the file; it is around a 7 MB zip file which you have to download.



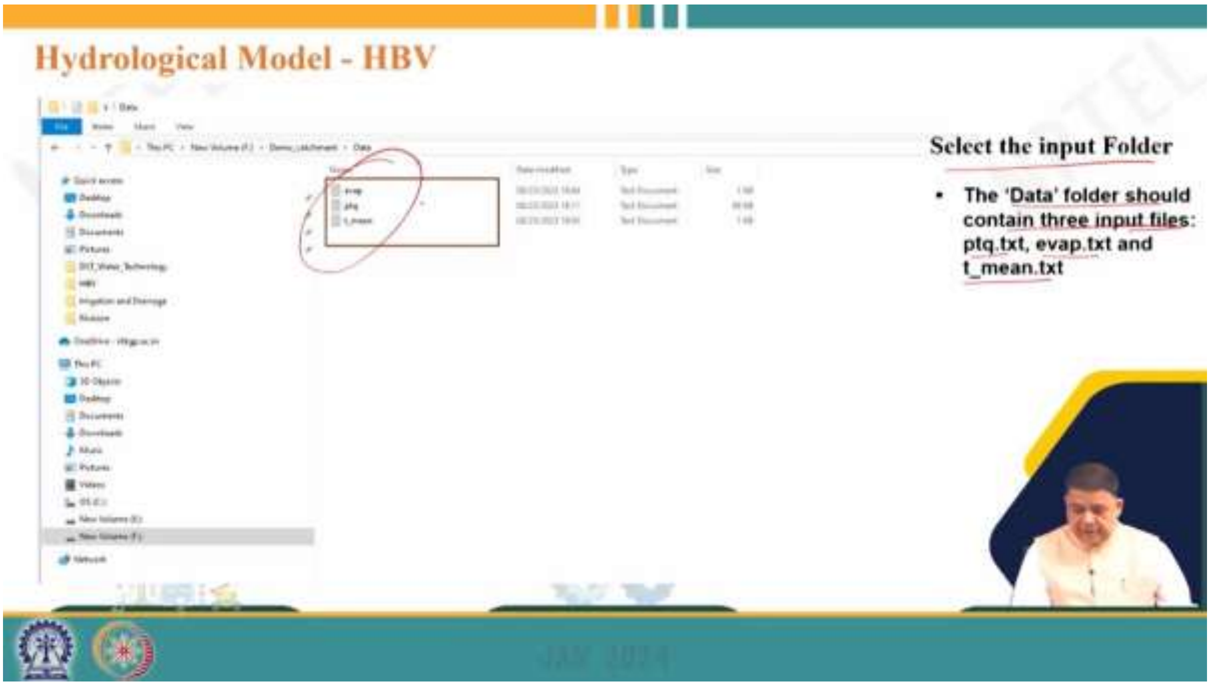
Then once you have downloaded it, you have to register to receive the password for extracting the downloaded model file. So, you can download, but you need a password to extract the files. So, for that, of course, you have to put all the information like your name, email address, affiliation, country, purpose for which whether it is academic or some other purpose, and if you have any questions or comments, so you can submit this and then they will send you the password.



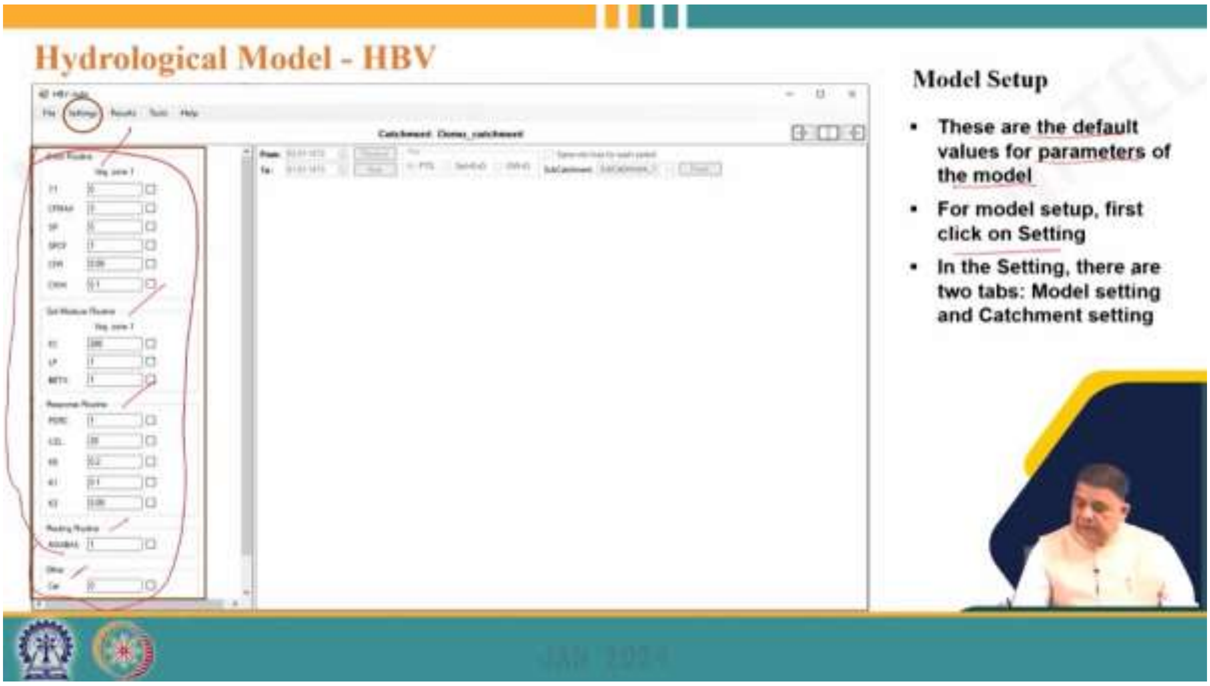
Now, once you are able to extract the model, then of course, you have to select the input folder, that is, you have to install the model and open the model for the purpose, and okay, if you press, then of course, it will give you a after opening the model you have to select the folder that has the input files. For example, it could be demo catchment or you can create a folder with any name; the folder name is free, but inside the folder, there should be two subfolders, namely data and results. So, these data and results should have the same name, but the folder name you can put the name of your particular model, particular study area or the town or basin or whatever, but these two subfolders are data and results that have to be have the same name.



Then of course, within the folder, the data folder should contain three input files, that is, we said that we have two data and results. So, of course, the data is the most important one. It has three input files as we've seen: ptq.text, evap.text, and T_mean.text. So, these names you have to keep the same, and the format and name, as mentioned earlier, will remain intact; you cannot change them.

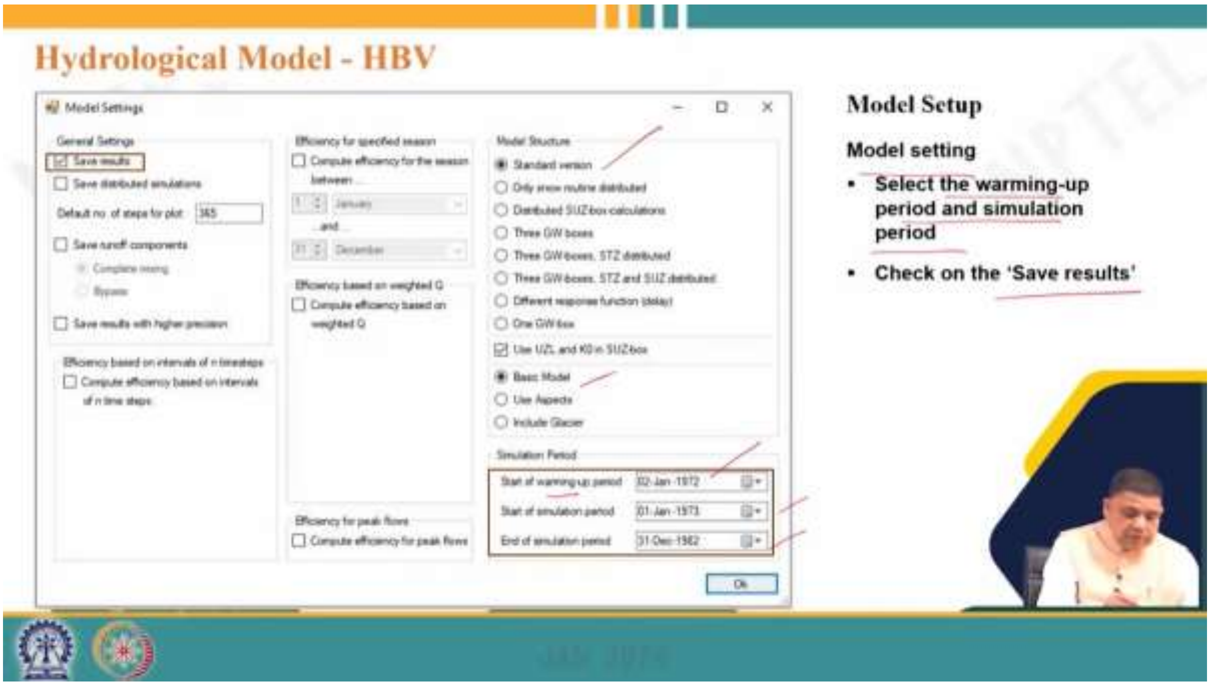


Then, coming to model setup, these are the parameters, as we said, that in the user interface on the left-hand panel, you will be able to see various parameters, as you can see here. So, for the snow routine, for the soil moisture routine, for the response routine, and for the routing routine, and there is an additional parameter. The model will show the default values, but you can always go and change the value. So, of course, we have to click on this setting; there are two tabs: model setting and catchment setting, and we have to then do this setting.

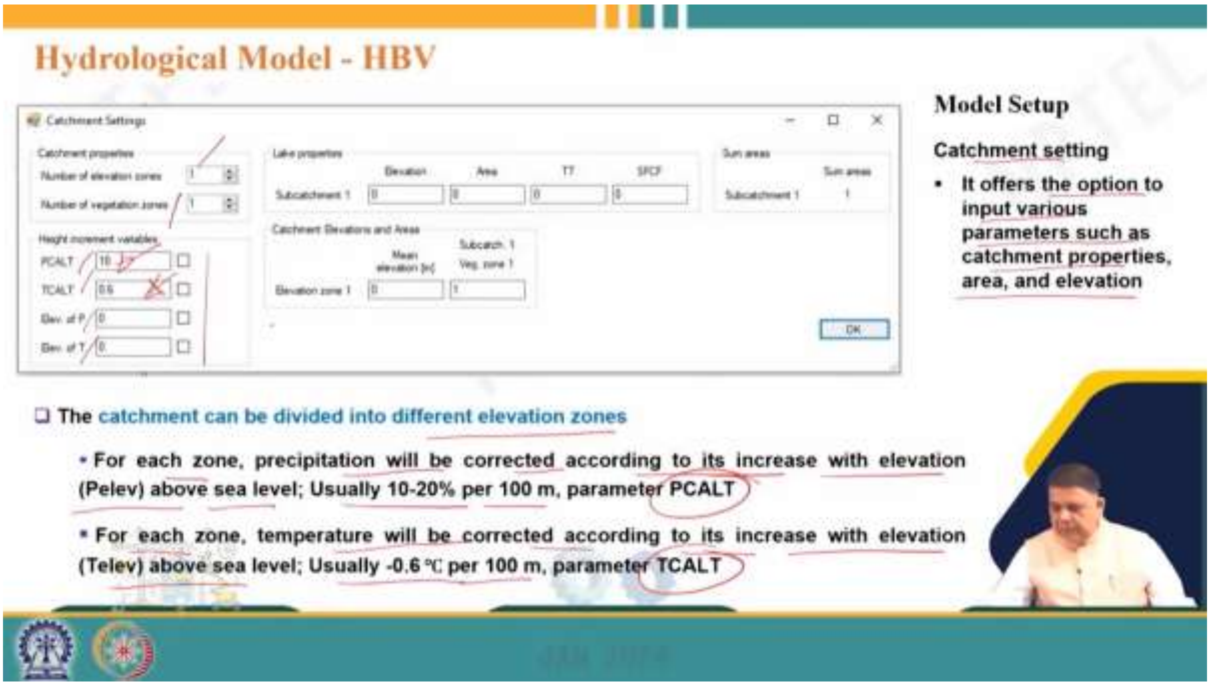


So, in the model setting, basically, this is the menu we will get. So, obviously, the important thing is selecting the warm-up period and simulation period. So, of course, we talked about the warm-up period; we talked about the simulation period and the length of data based on that you will make a decision, and obviously, you have to have calibration and validation sets separately.

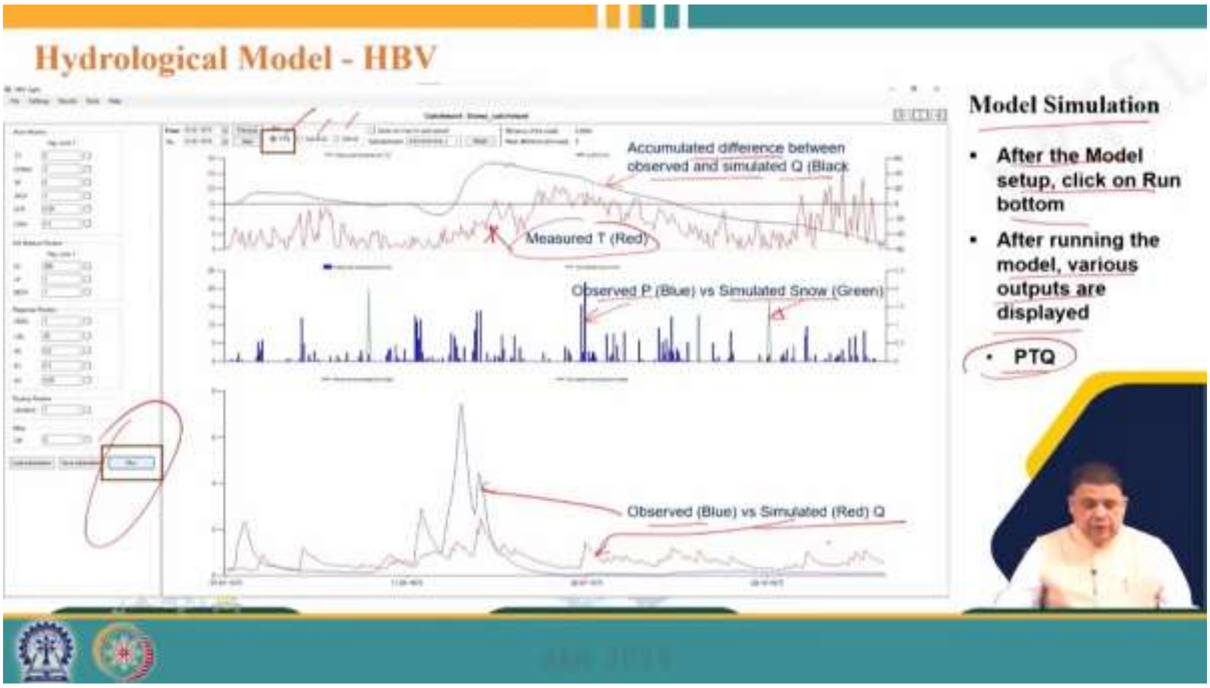
So, this is we are talking in terms of calibration. So, of course, the standard version you can have different possibilities; various versions are also available, and you can have the basic model, which to begin with, will be good enough. And so, you have to specify the warm-up period start and simulation period and end simulation, and when, of course, we have to check here to save results, so that results are saved, so you can analyse them.



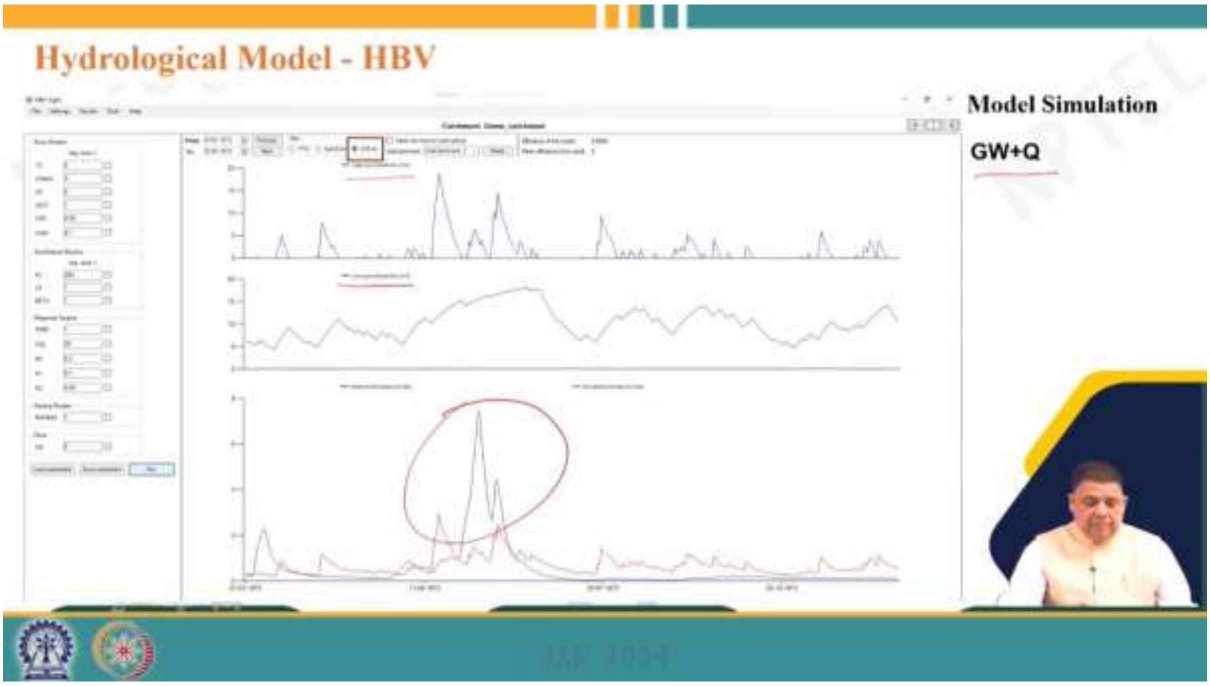
And then in the catchment setting, it offers the option of inputting various parameters such as catchment properties, area, and elevation. So, here, the number of zones, number of vegetation zones, and related parameters, here PCALT, TCALT, P elevation, T elevation, these values you can assign. And of course, as we discussed, it is possible that different elevations and those up to three elevation zones can be used. For each zone, precipitation will be corrected according to its increase with elevation, P elevation above sea level, usually 10 to 20 percent per 100 meters, and this is defined by PCALT. So, PCALT 10 percent shows here that there will be an increase of 10 percent per 100 meters in the precipitation value. And for each zone, temperature will be corrected according to its increase with elevation above sea level, usually minus 6 degrees Celsius per 100 meters. So, it is here, of course, it is in minus, of course, because temperature will go down as you go up. So, that is why it is minus here, and this TCALT parameter will take care of that. So, of course, all these, of course, one earlier also we discussed that before applying a model it is good that you have a theoretical background, which we have already seen, but if you understand the meaning of each and every parameter and variable then only you will be able to make a good judgment about the values you put or things like that. So, obviously, you have to be careful about the values you use.



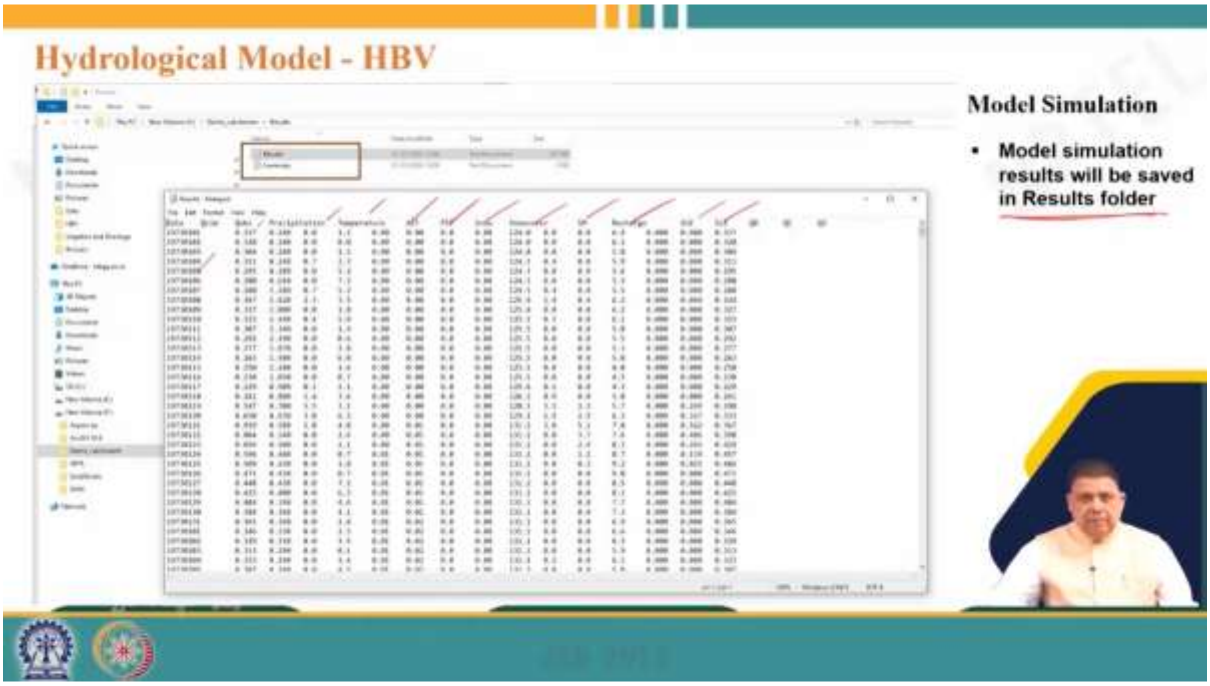
Then, of course, comes the model simulation. So, obviously, once you simply after the model setup click on the run button here, which we saw earlier, and once you do that after running the model various outputs will be displayed. You have various outputs displayed; this is a PTQ clicked here. So, this is PTQ option; you can also go for soil EQ or GW + EQ, which we discussed earlier, and of course, the PTQ option is chosen. So, it is showing you the accumulated difference between observed and simulated Q in black colour; this one, this one, then of course, this is major temperature is being shown here, and observed P in blue, and simulated snow in green. So, you can see here, this is simulated snow, this is observed P, and observed and simulated Q. So, the blue one is observed, and the simulated one is the red one. So, these are the various graphs you are able to see on the screen, right? So, this is in the PTQ option. Similarly, if you choose soil plus EQ and GW plus Q, then the top two panels will change, but the bottom panel will remain the same, and then of course, we can analyse the data the way we want.



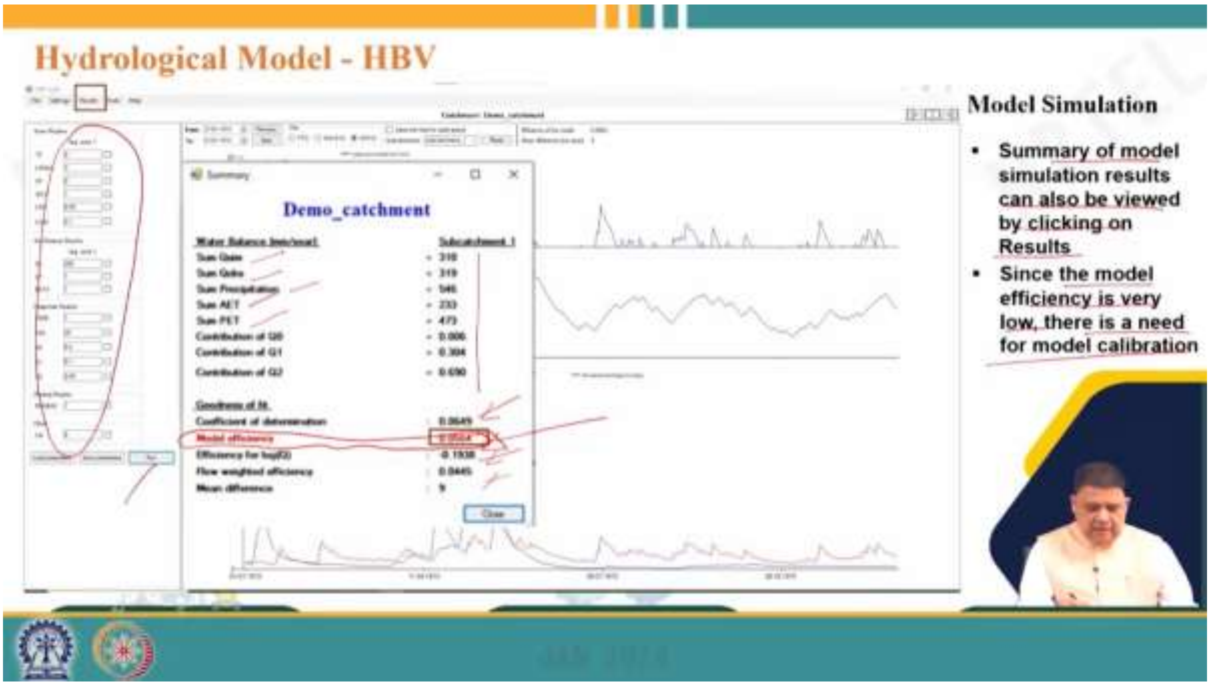
Then, of course, this is your soil plus GW option, which is being shown here. Here, you see potential above transpiration, observed and simulated runoff change, and the amount of water in the soil. So, that is what soil moisture is showing here, and this is soil plus EQ. Then, of course, we can have GW + Q. So, I said that the last panel does not change, but here you have lower groundwater and the upper. So, these two boxes, how the water is changing, that is being shown here in these two figures. So, depending on what you want to see, what output you want to see, you can see here on your screen.



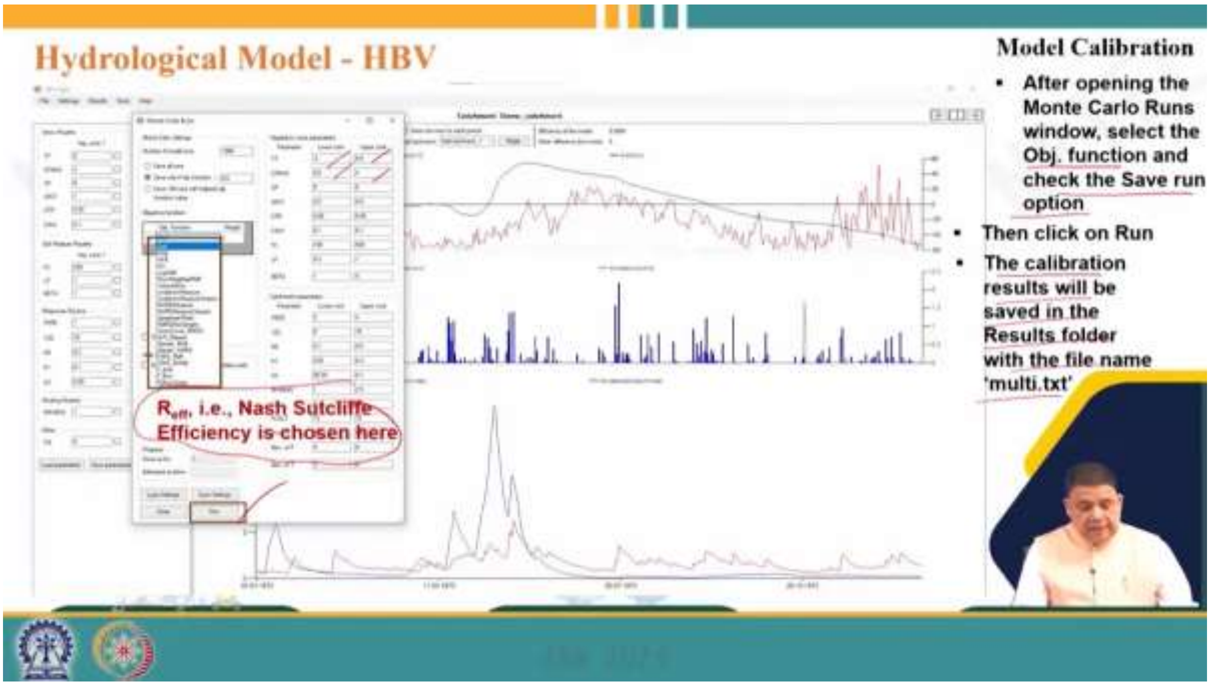
And of course, you can also get the model simulation results using the result file because it will be saved in the result folder. So, you can see, actually, you can see for different dates, Q simulated, Q observed, precipitation, temperature, ET, PT, snow, snow cover, SM recharge, SUZ, SLZ, all the values will be available here. So, you can take that into Excel, and you can plot on your own and do whatever analysis you wish to do.



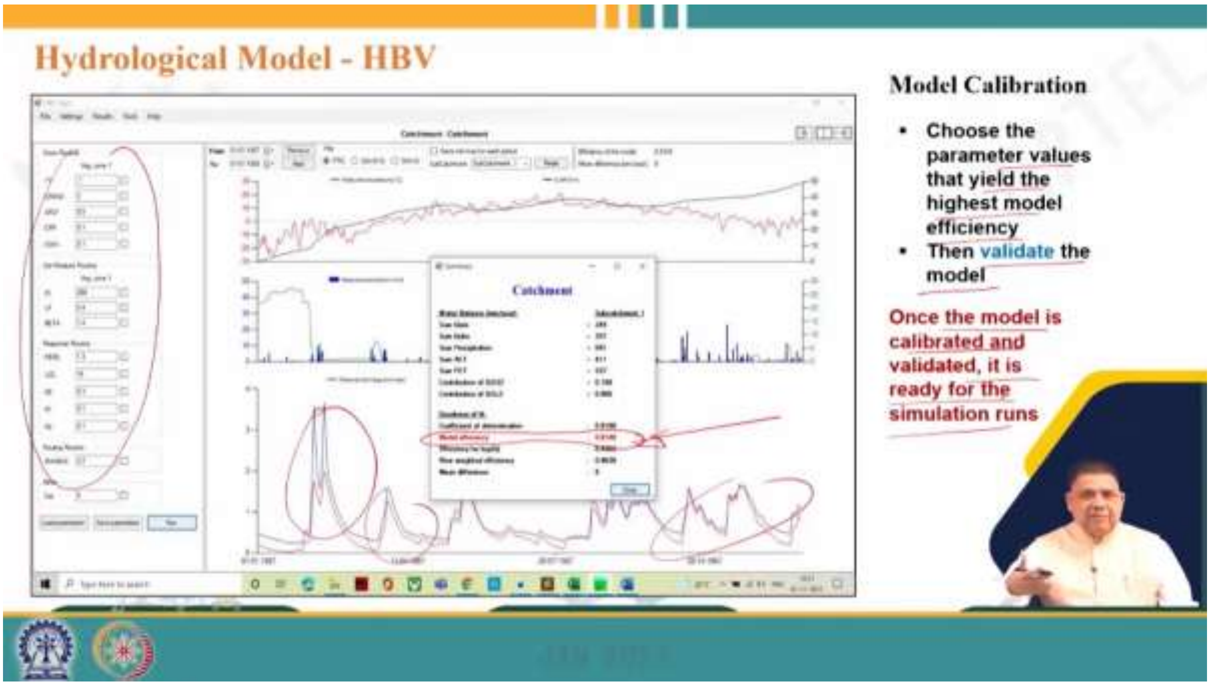
And beside that, a summary of model simulation results can also be viewed by clicking on the results here, and this is for your demo catchment, these are the results here. So, the same values are being shown here, that is, some ET, some PT, some precipitation, some Q simulation, some Q observed, you saw graphically why it is varying, but summation values are also given here. But at the same time, you can also see the statistical information like model efficiency or NOS frequency, coefficient of determination, log Q efficiency, and flow-weighted efficiency, various kinds of efficiency. But as you can see here that model efficiency, we discussed about this NOS, typically it ranges between minus infinity and 1; the ideal value is 1 and closer to 1 is what we look for. And because the model efficiency is very low because we use the default parameters probably then there is a need for model calibration. So, we need to go for model calibration, and we discussed earlier that we have 2 options; one is the manual calibration. So, that means, you can change these parameters manually one by one or together by keeping an eye, and then you run the model and keep on looking at your results, plotting your results, and keeping an eye on how your model statistics are changing.



Or you can use the inbuilt tool within the model, that is, Monte Carlo technique. So, obviously, we need to click on the tools tab here and then click on the Monte Carlo run. So, there are Monte Carlo runs, there are other options also, there is a gap optimization also, but we will only focus on the Monte Carlo run at the moment. So, Monte Carlo runs you can choose. And of course, in Monte Carlo runs after opening the Monte Carlo runs, we have to select the objective function and of course, check the save run option. So, obviously, various objective functions are there. So, let us say we have picked here RF, or natural efficiency, as our parameter for optimization. And then, of course, we can save the information, and parameter ranges are important here. So, a lower limit and upper limit because you know in automatic calibration we mentioned that the model itself or the algorithm will change the parameter values and fit it to the best level while maximizing the natural efficiency.



So, then obviously, we will click on the run button, and the calibration results will be saved in the result folder within the file name multi.txt, same thing. And of course, as you can see, this is the optimized value of model efficiency that has come, now 0.814 from 0.045 it was. So, obviously, you see that there is a significant change, and that is why you say there is a much better matching of observed and simulated discharges, and these are your best parameters. So, you can choose the parameter builder that yields the highest model efficiency. So, obviously, your model is calibrated now. The next step, as we know, is that we have to validate the model, that means, with these parameters, we will run the model for the next set of data and then see how our model is performing, and once the model is calibrated and validated, it is ready for the simulation runs. So, this is how you can download and run the HBB model and see the impact of calibration and validation. All those steps we discussed in the modeling, you will be able to realize for yourself. So, I think it will be a very interesting exercise if you do it, and I urge you to download the model and try to run it.



So, with this, we come to the end of this lecture where we talked about the HBB model and as I ask, please download the model, run the model, see for yourself hands-on training how the modeling really is done. Thank you very much. Please give your feedback and also raise your questions or doubts. We shall be happy to answer on the forum. Thank you.