Computational Hydraulics

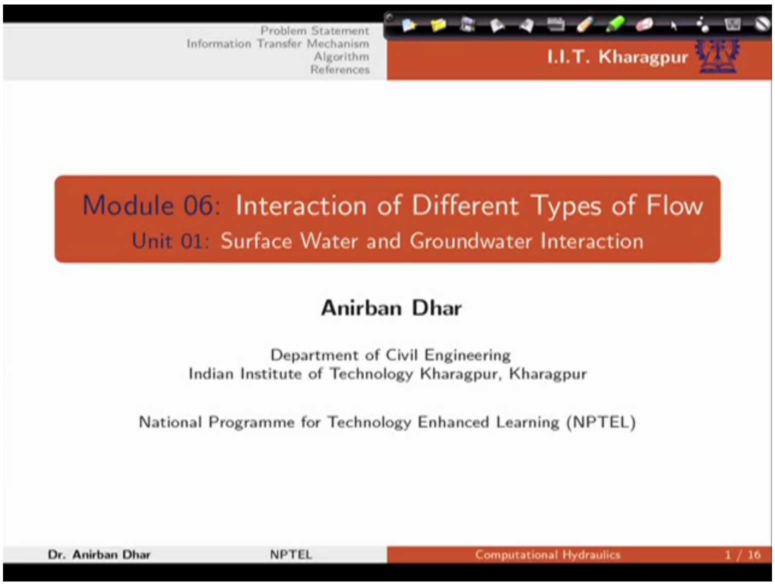
Professor Anirban Dhar
Department of Civil Engineering
Indian Institute of Technology Kharagpur

Lecture 50

Surface Water and Ground Water Interaction

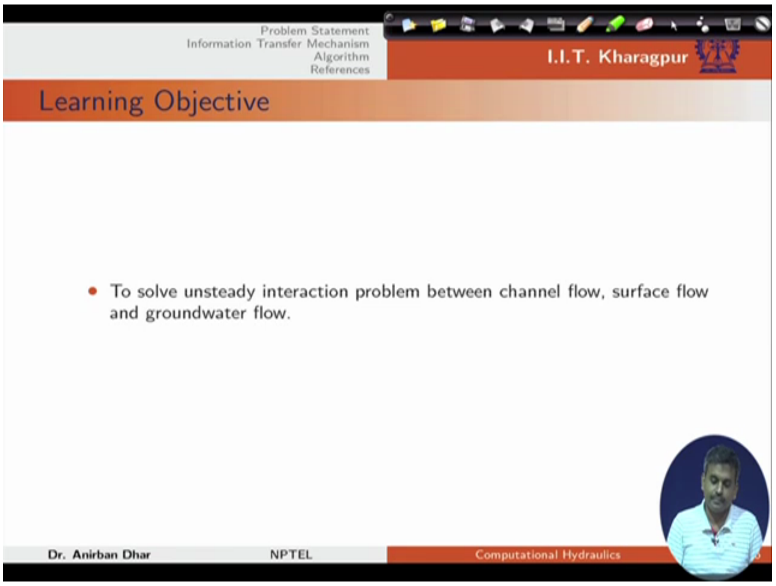
Welcome to this lecture of the course computational hydraulics. We are in module 6 interaction of different types of flow and this is unit number 1, surface water and ground water interaction.

(Refer Slide Time: 00:37)



In this particular module I will be talking about interaction of different kinds of flow and specifically this module has got only one unit and this is surface water and ground water interaction. But at the same time I will usually talk about the pipe flow during this interaction. Learning objective, at the end of this unit students will be able to solve unsteady interaction problem between channel flow, surface flow and groundwater flow.

(Refer Slide Time: 01:24)

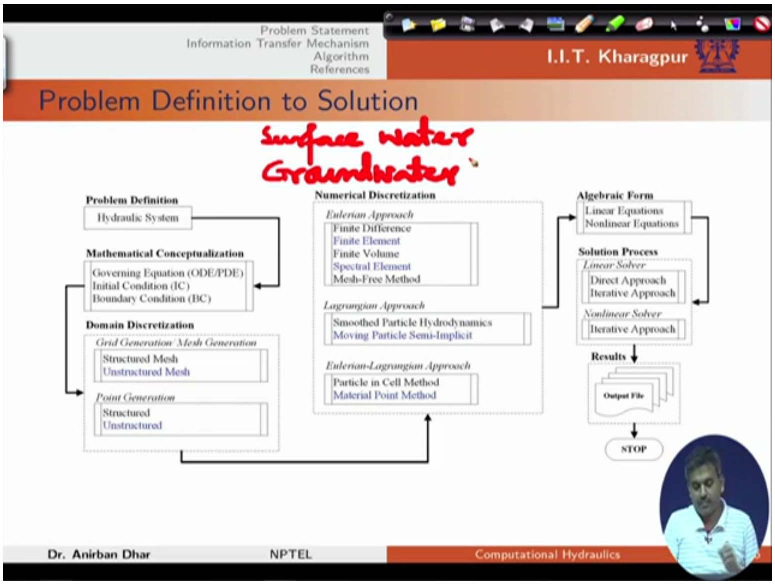


So this is our general structure of the course. For a particular problem we need to identify the problem definition which is for the hydraulic system then we need to mathematically conceptualize the problem in terms of governing equation, initial condition and boundary conditions. After that we need to discretize the domain either with structured unstructured grid or point method that is mesh free approach.

And finally we need to discretize the governing equations and we need the algebraic form of the governing equation. So governing equations or discretized form of the governing equation these maybe linear or nonlinear in nature. And depending on that we need to apply different solvers. For linear problems we have direct or iterative approaches and for nonlinear method we have only iterative approach available. But in this case for interaction we have three components one is surface water, next one is ground water.

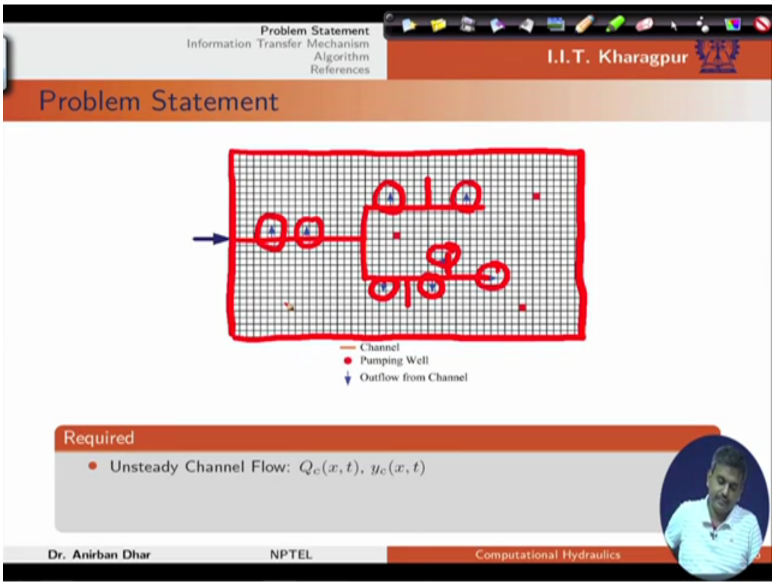
Now in the surface water and ground water can be conceptualized or mathematically conceptualized in terms of single governing equation. But whatever we have discussed in this course in that one we have talked about one dimensional channel flow, two dimensional surface flow and two dimensional ground water flow. So let us integrate this one dimensional channel flow, two dimensional surface flow and two dimensional ground water flow for this problem.

(Refer Slide Time: 04:09)



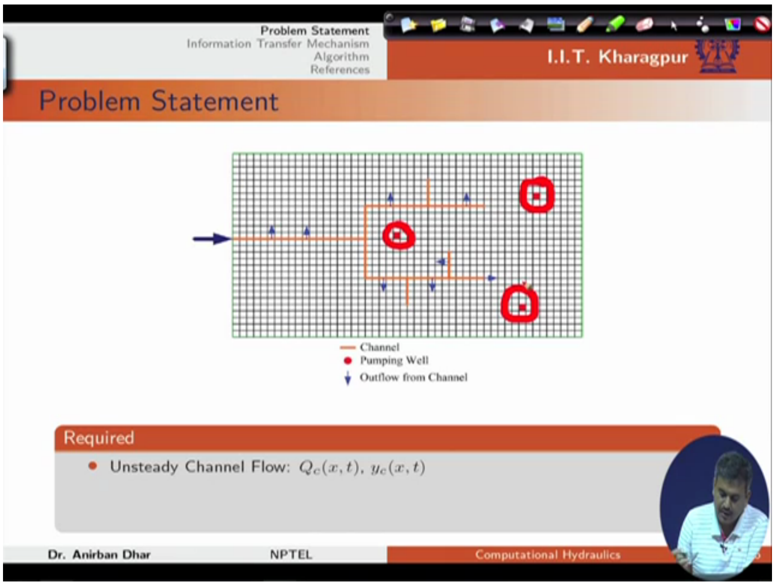
Now let us define the problem. What is the problem statement? Problem statement is let us say this is the area which is a particular command area or irrigation command area and we need to supply water for this irrigation command through 1D channel network. This is our channel network and within this channel network there are number of branches available. And we have this blue ones these are outlet points. Through these outlet points the water is supplied to the field.

(Refer Slide Time: 05:11)



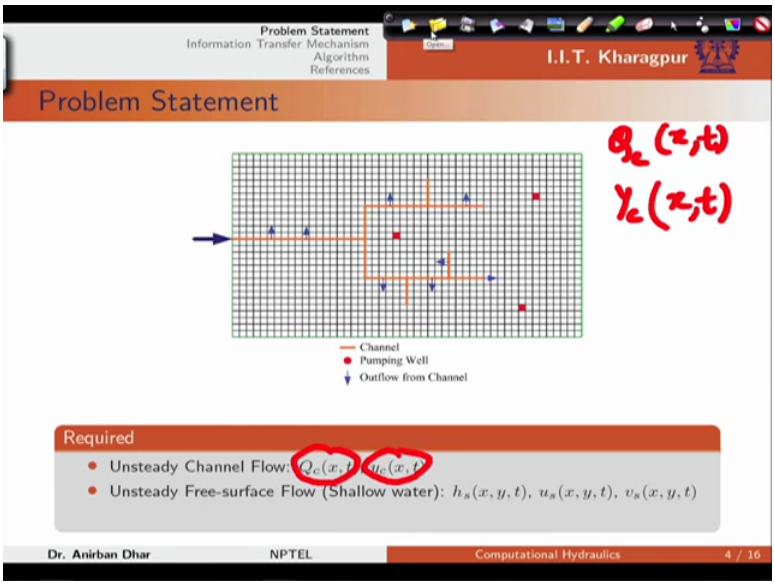
Now for a particular irrigation system water is applied at the head of the channel reach and this water may be sufficient or in some cases may not be sufficient for the irrigation command. Then we need to pump out water from the ground water system. So these three are pumping wells.

(Refer Slide Time: 05:51)



And finally when we will be applying water to the field through these outlets obviously water will travel in the field and there will be surface water flow in the field itself. And that is two dimensional in nature as per our conceptualization. Now we have three components, one is unsteady channel flow. In unsteady channel flow we need to find out what is Qc and yc? Qc is a function of x and t. Yc is also function of x and t. What is Qc? Qc is the discharge in the channel and yc is the flow depth in the channel.

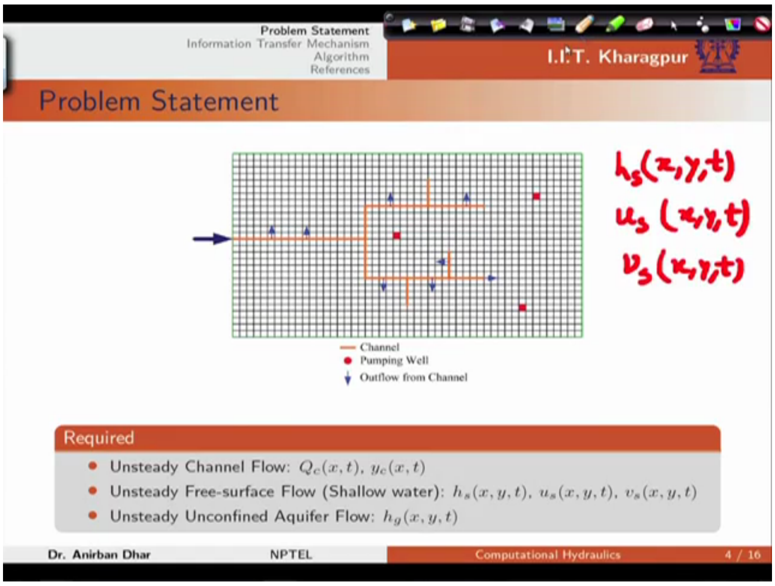
(Refer Slide Time: 07:00)



Now in this case after this outflow from the channel network water will travel to the field and there will be two dimensional surface flow. So if we want to model that surface flooding or surface flow components it should be modelled through this shallow water flow equation. In shallow water flow equation hS which is the function of x, y and t that is the total flow depth there in the field. Then we have us and vs. These are also functions of x, y and t.

Now third component which is required for the system is unsteady unconfined aquifer flow because your first layer or unconfined layer is connected directly with the surface through unsaturated zone. There will be one saturated zone and unsaturated zone in the system.

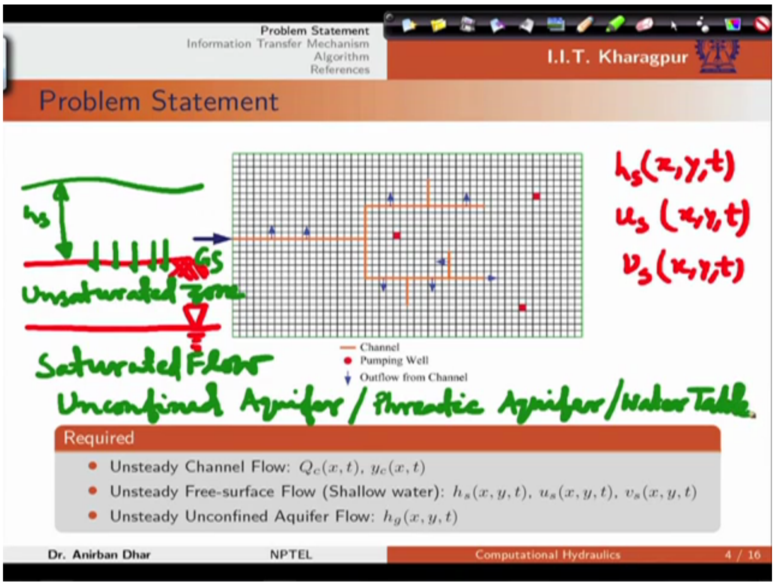
(Refer Slide Time: 08:36)



So if this is our ground surface and in the bottom we have water table at this level so for this system we will have surface water flow. In this case this is our hS. Now this hS is there and obviously they will be infiltration through this zone which is the ground surface or GS. And it will travel through this unsaturated zone and in the bottom we have saturated flow condition. This saturated flow condition is there for unconfined aquifer system.

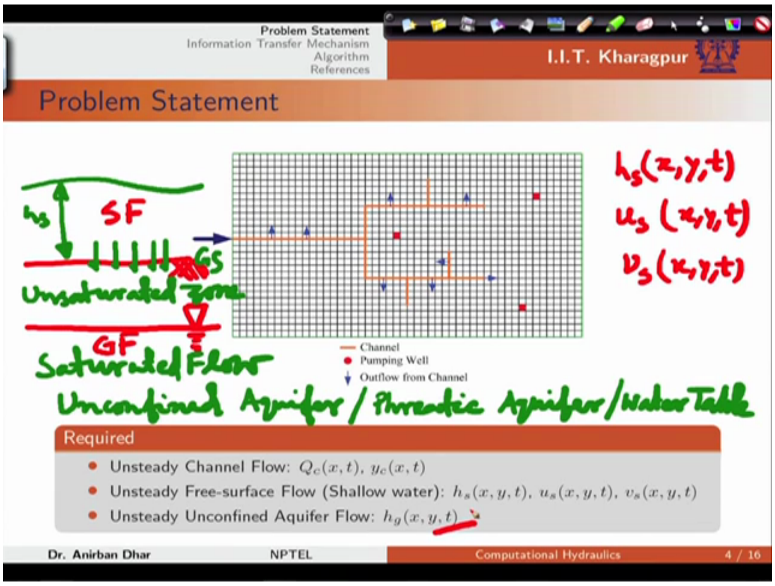
For unconfined aquifer system we do not have any confining layer on top so it is directly connected to atmosphere. And unconfined aquifer system is also called as phreatic aquifer or water table aquifer.

(Refer Slide Time: 10:40)



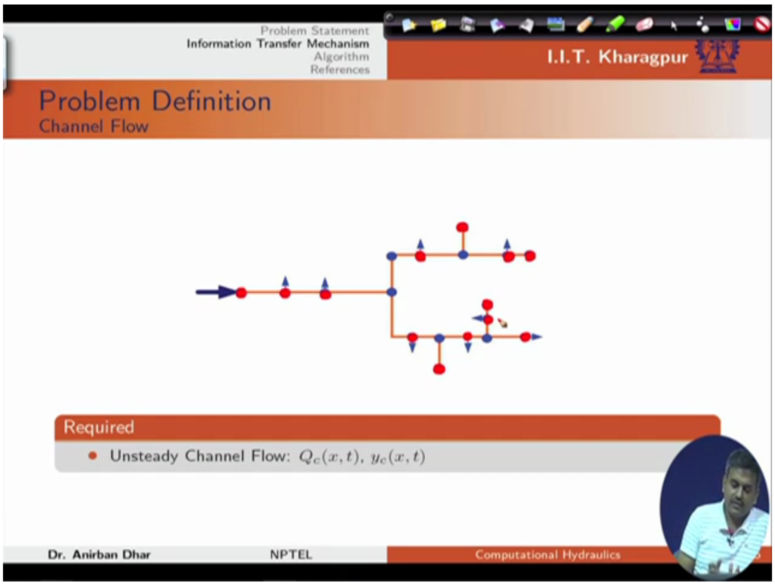
Now in this case we have surface flow which is or this is SF or surface flow and below this water table we have GF or ground water flow which is for unconfined aquifer system. Now there will be recharge through this unsaturated zone towards this ground water table and after getting this recharge obviously we can solve this ground water equation. So for ground water problem which is unsteady unconfined aquifer flow we need to find out hg or what is the hydraulic head with respect to datum?

(Refer Slide Time: 11:40)



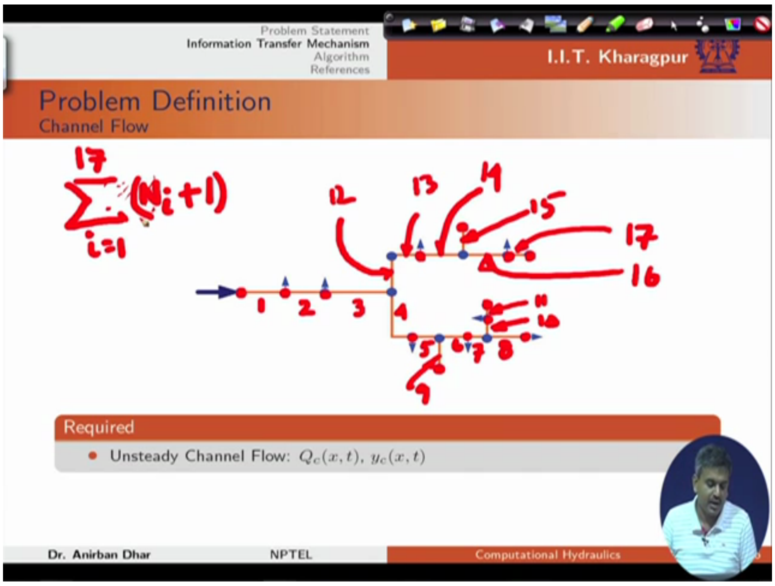
Now we can divide it into three components. First one is channel flow so we have these are external junction points, at the same time if we have these points, these are also outlet points or outflow points in between. And others are internal junction points. So we need a certain number of equations.

(Refer Slide Time: 12:31)



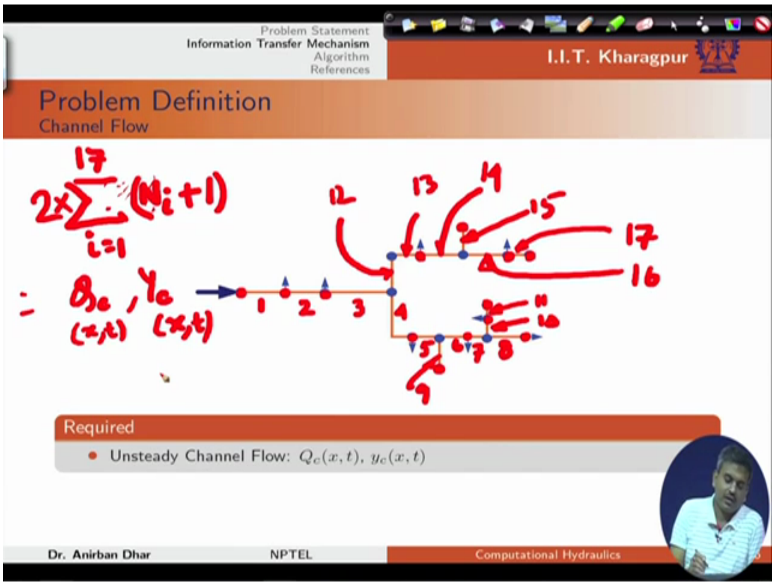
Let us say in this case we have 1, 2, 3, 4, 5, then 6, 7, 8, this is 9, this one is 10, on this side we have 11, let us say this is 12, this is 13 , this is 14, this is 15, 16 and 17 channel reaches in this case and we have one inflow condition. So for 17 channel reaches we have all total if we divide this one into number of reaches so for 17 if we have summation i equals to 1 to 17 N1 or Ni plus 1 this is the total number of sections for ith reach.

(Refer Slide Time: 14:24)



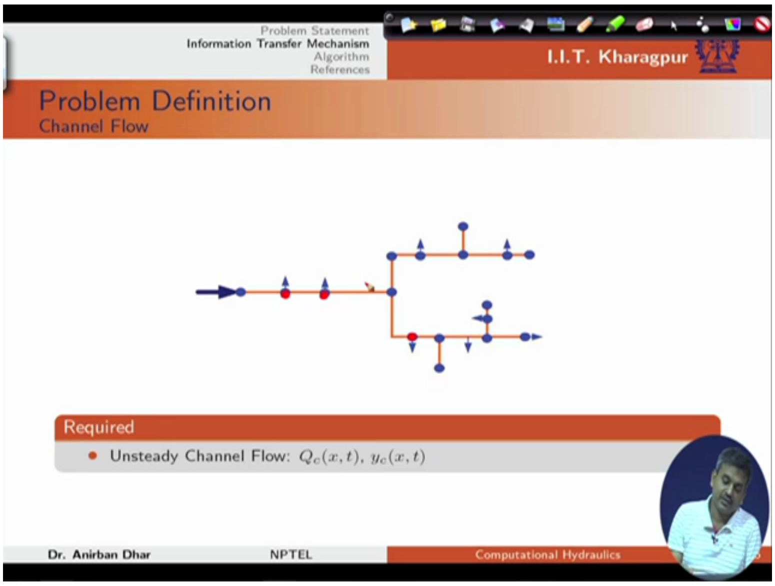
And if we sum it up obviously we will get the total number of sections. We should multiply it with 2. That will give us the total number of unknowns because at each section we need to find out what is Qc and yc for this system? And Qc and yc these two values are functions of x and t, this is also functions of x and t. Obviously this is one unsteady channel network problem.

(Refer Slide Time: 15:04)



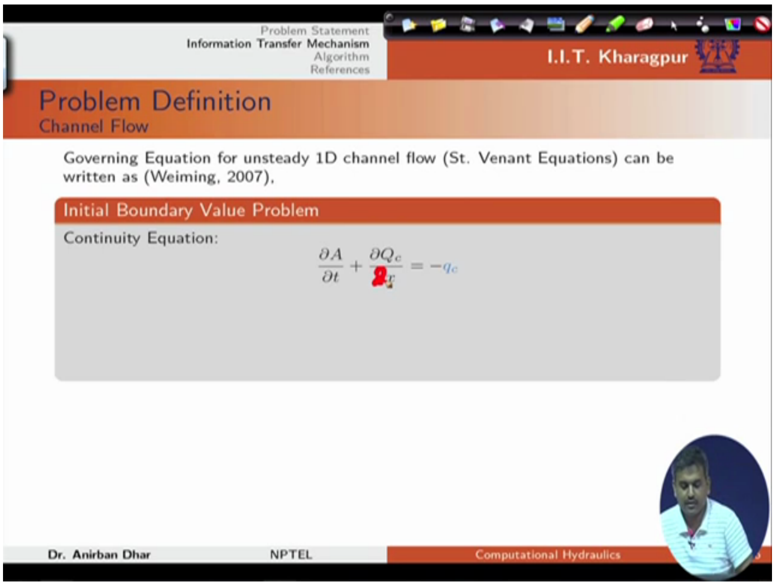
Depending on the upstream flow condition or upstream inflow condition there will be changes in the flow pattern and discharge within the channel network. Obviously these outlet points these points maybe through direct pipe flow or through some hydraulic structure. So we need to incorporate the effect of hydraulic structures within this system.

(Refer Slide Time: 15:41)



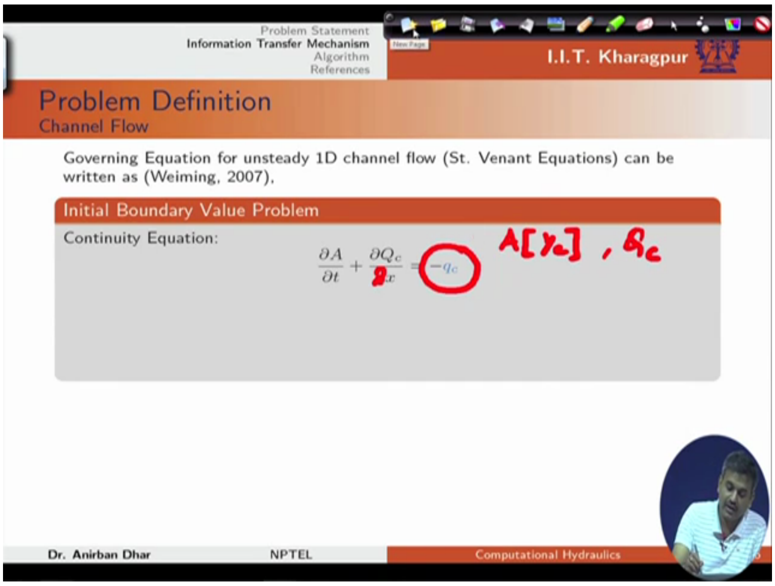
But obviously in simplified form we will get junction conditions in terms of discharge or flow depth that is energy condition and we can solve the problem using our channel network flow equation and we can utilise our generalized code with reverse flow situation for this one. And this is one unsteady problem. Now next one is our conceptualization in terms of governing equation. So in this case in continuity as per our previous consideration we have del A by del t and del c by del x. This is del c by del x.

(Refer Slide Time: 16:53)



So in this case one thing is important that is A is function of yc and Q is one variable here and this minus Qc this is important. Minus Qc means that I am allowing outflow from the channel network. That is there will be outflow from the channel network. So minus Qc is the outflow component.

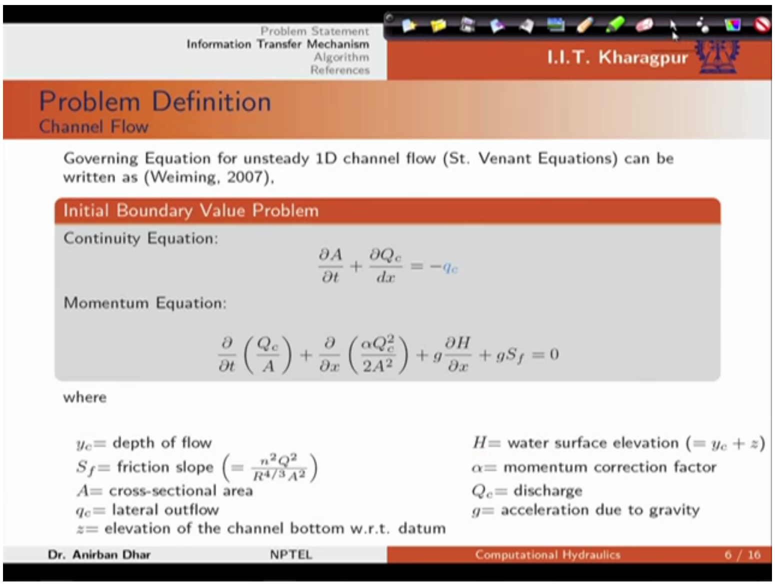
(Refer Slide Time: 17:23)



Next is momentum equation. This is the same equation that we have utilised for our unsteady channel network problem and these notations are standard ones. Yc is the depth of flow, SF is the friction slope, this is n square Q square R to the power 4 by 3 A square, A is again cross sectional area as I have told, this is function of Yc. Qc is the lateral outflow, our negative sign is there to consider the outflow condition and H is water surface elevation which is yc plus z for any section.

Alpha is the momentum correction factor, Qc is the discharge, g is the acceleration due to gravity and z is the elevation of the channel bottom with respect to datum.

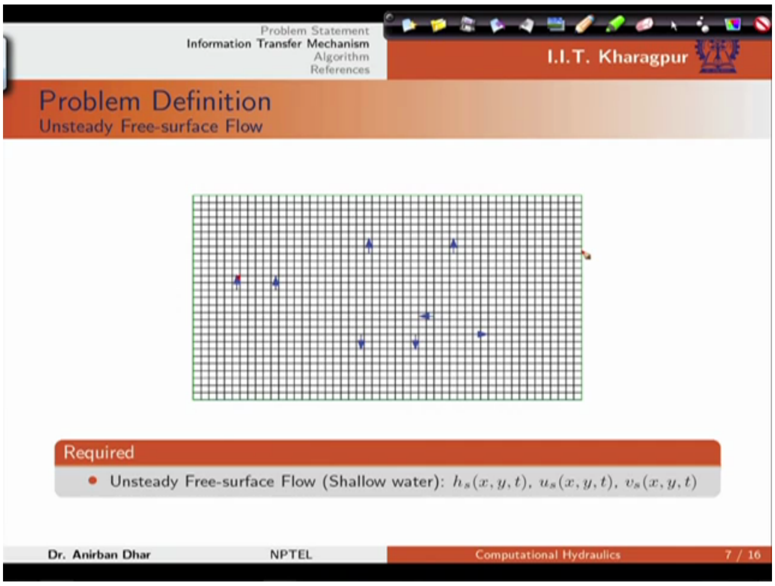
(Refer Slide Time: 18:41)



Now we need to consider this component and we need to link this component with the surface water because if there is lateral outflow from the channel obviously the contribution will be towards surface water flow situation which is two dimensional flow. Now in unsteady free surface flow condition which is shallow water flow condition these are inflow points or we have information about discharge values at these point or inflow values at these points for the surface water system.

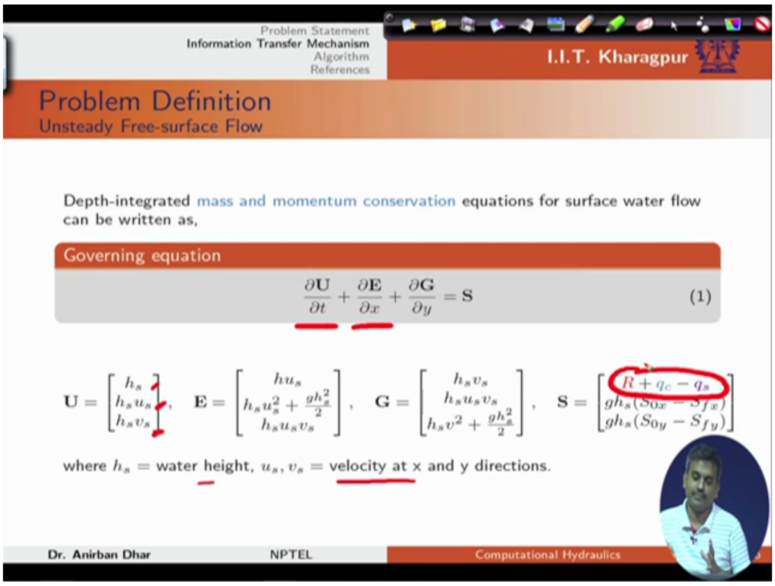
With this we can start our unsteady problem and we can solve it with definite boundary conditions. Obviously we need boundary condition for this command area because we have considered this rectangular system as irrigation command.

(Refer Slide Time: 19:53)



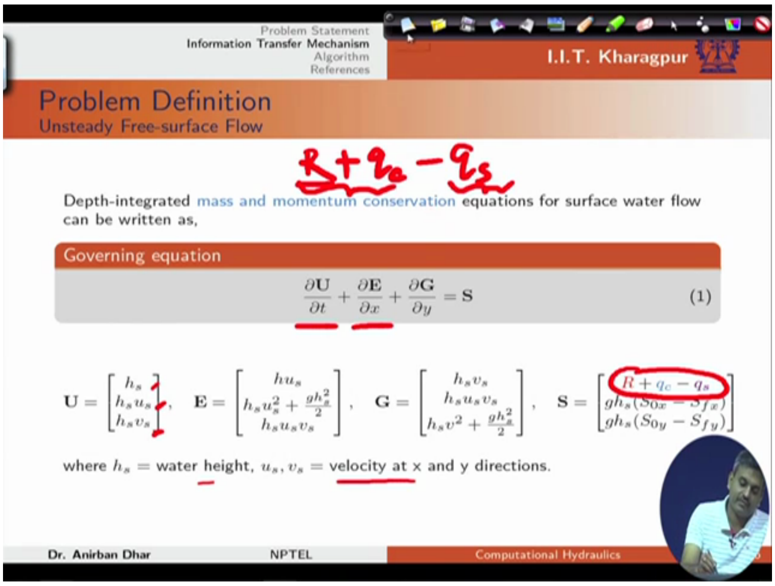
Now next problem is definition of the governing equation in vector form. We can write del U by del t, del E by del x, del G by del y equals to S. And this is hS, us, vs these are water height. This depth velocity at x and y directions and this component is important because we need to find out the linkage between channel flow and surface water flow.

(Refer Slide Time: 20:36)



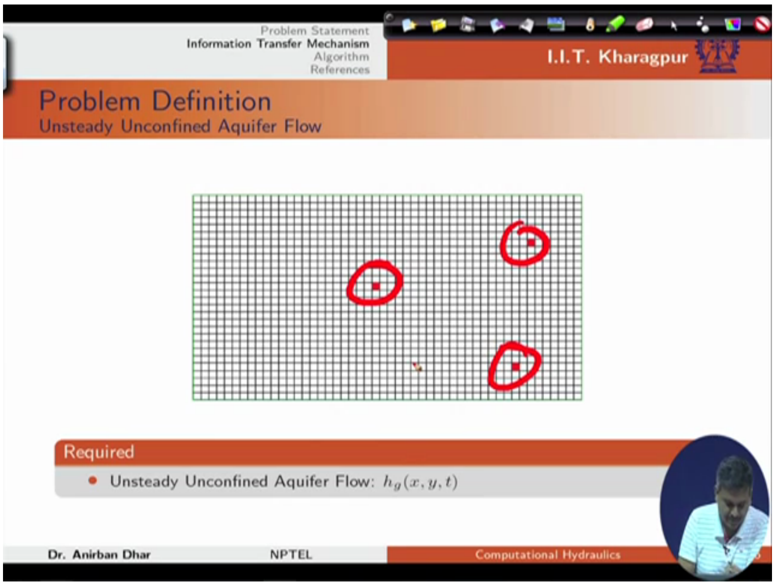
What is the linkage? Linkage is here, if I have rainfall component R is rainfall and plus qc which is qc is the channel outflow. So this contribution is coming from channel. R is rainfall which is occurring in the area. So R plus qc minus qs. What is this qs? Qs is the infiltration component. So we can deduct this amount to get the maximum or the total inflow to the system. This is inflow minus outflow. So effective inflow to the system is R plus qc minus qs.

(Refer Slide Time: 21:35)



Now we need to link these parameters. Out of these parameters rainfall we cannot directly link with groundwater flow system. We need another component because if there is rainfall in a particular area so total amount will not get recharged into the system. Partial or a fraction of that will be there for infiltration. So let us say that qs is that amount. Now we need to link this qs with our ground water equation. So this is our unconfined unsteady aquifer flow model where we have three pumping wells, 1, 2 and 3.

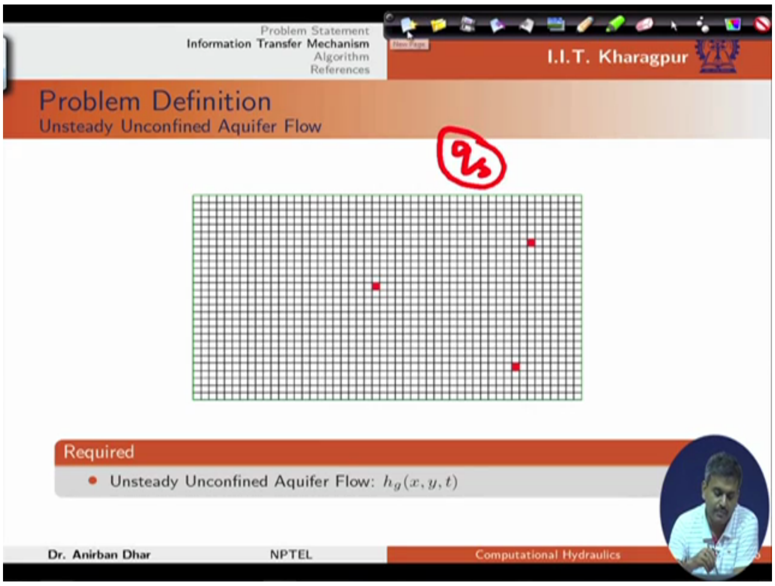
(Refer Slide Time: 22:40)



And in this case we need to find out what is hg which is again function of x, y and t. And we should remember that at every cell because I have discretized it into number of cells so at every cell we will have information about qs. Qs is the component which is coming from our or which is linking the surface water and ground water. So qs is the amount which is coming out from the surface water system and it is getting recharged into the saturated ground water flow as saturated ground water flow component.

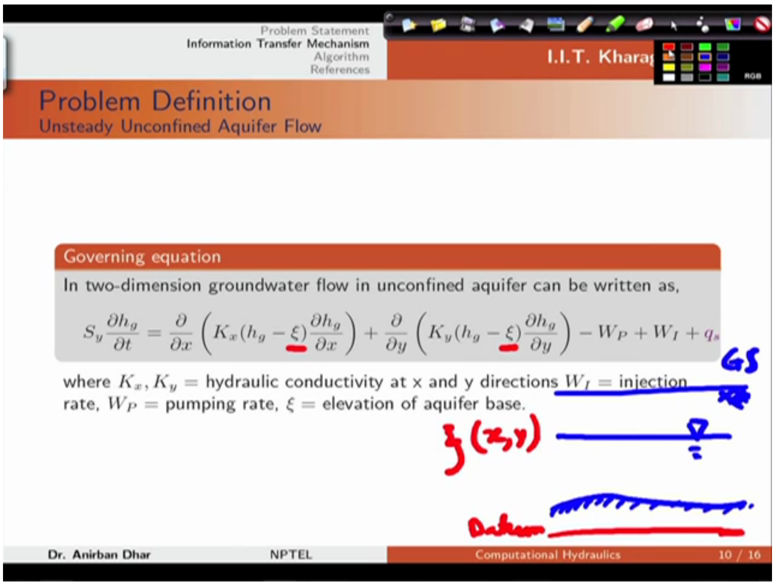
So obviously in this case we are considering that whatever amount is getting recharged into the system that is directly added to the ground water system. There is no loss in unsaturated zone.

(Refer Slide Time: 24:00)



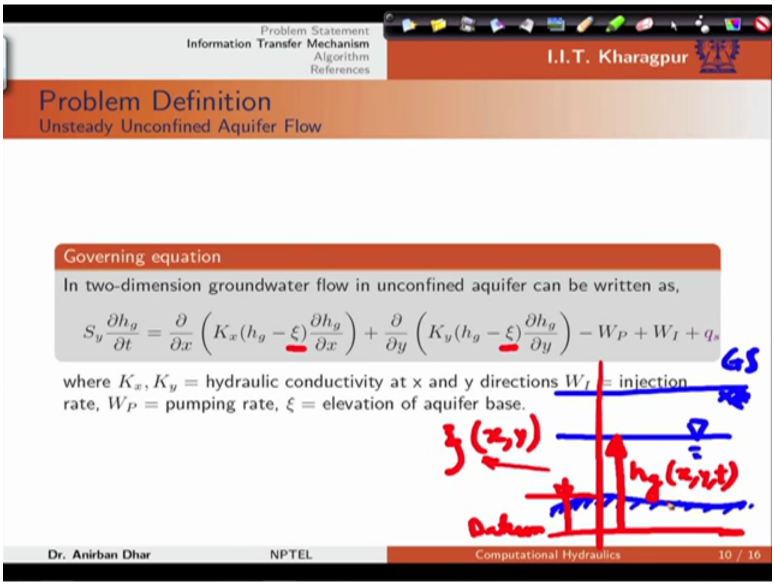
So in this case we can utilise our usual governing equation for solution. So what is that governing equation? Now I have modified this equation because we need to consider the bed elevation of the aquifer. This bed elevation component this is again function of x and y. So we are considering bed elevation with respect to a particular datum. So if I consider that this is my datum and this is the ground water table and this is my base of the aquifer then we have this is ground surface or GS.

(Refer Slide Time: 25:24)



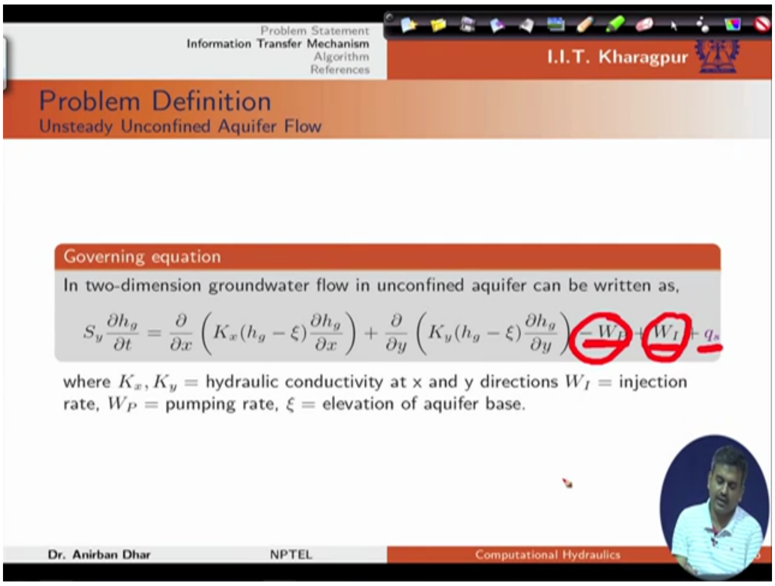
So for this problem we have a particular section. Let us consider this section there. At this section we have this theta at this point or psi in this case. This is the elevation of the aquifer with respect to datum and this is the total height of ground water. This is x, y and t.

(Refer Slide Time: 26:11)



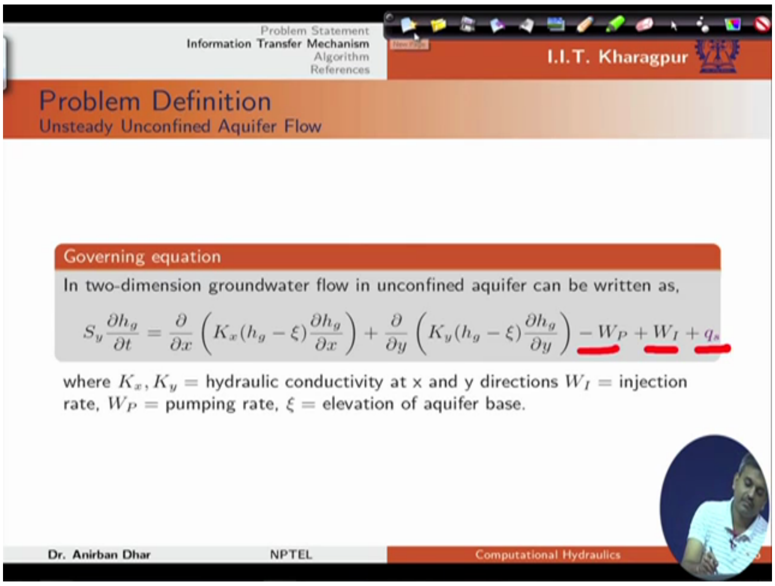
So in this case we need to deduct this amount for consideration of flow and other three components we have minus P, plus I and plus qs. Plus qs is the infiltration component which is coming from the surface water system. This component can be calculated using our standard one dimensional conceptual models or analytical models like (26:56) models. And it is minus WP is the pumping rate because we have three pumping wells in the system so we need to consider this component. And there can be injection wells in the system where we can inject water into the aquifer.

(Refer Slide Time: 27:21)



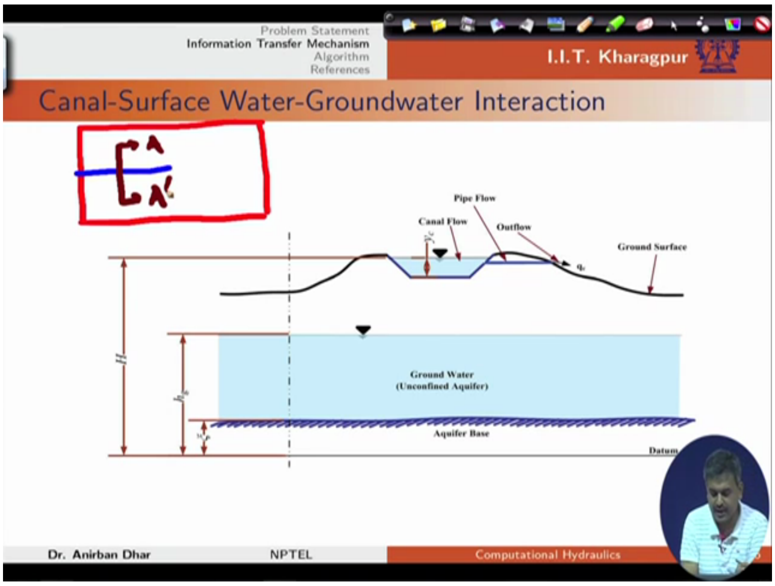
So considering these three components minus pumping, plus injection and plus qs, qs is the infiltrated water from our surface water system. That is getting added to the unconfined aquifer system.

(Refer Slide Time: 27:42)



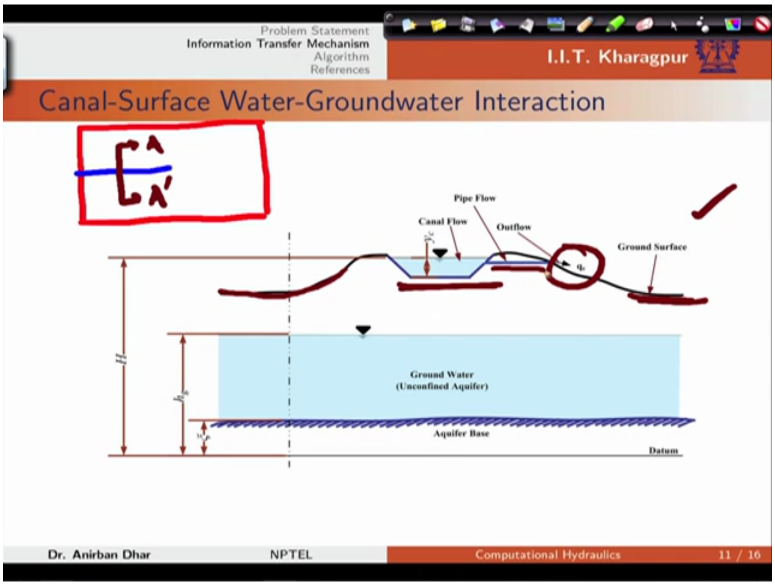
So obviously in this case we are considering these three components channel flow, surface flow and ground water flow. Let us see how these components are interacting with each other? Now this is canal surface water ground water interaction case. Now we have channel network let us say this is our one particular section. This was our rectangular domain for the command area and within that let us say this is our channel system. And if I take one section there let us say this is my section A, A prime.

(Refer Slide Time: 28:50)



If I take that section I should get this view and in that section I have this canal flow on top because canal is always at a higher elevation compared to usual ground surface. This is our ground surface on both sides and we have outflow component which is coming out from the canal system which is qc and this outflow is through pipe.

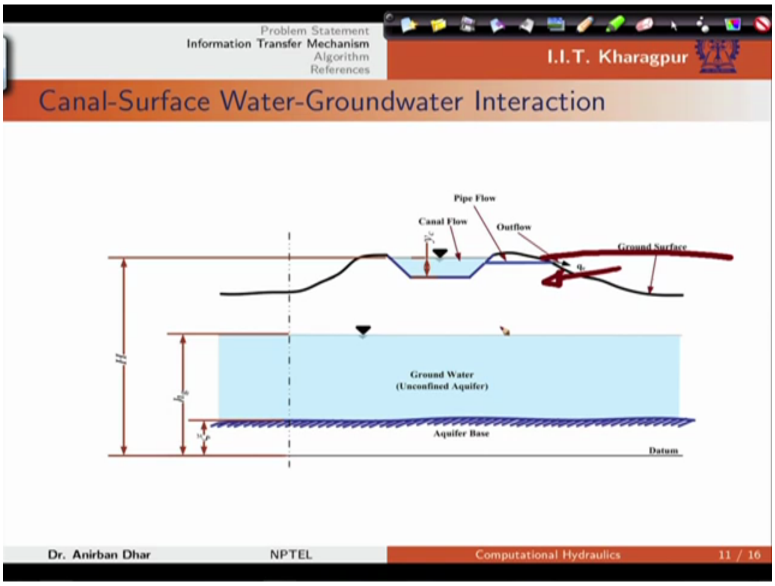
(Refer Slide Time: 29:30)



So we have linked canal flow with pipe flow Now if the water level is above this pipe inlet obviously there will be flow from left to right. If this water level is below the lower elevation of the outlet pipe then there will be no flow from left to right. That is qc. Then qc will be zero. Now in this case we are considering this canal flow through this outlet.

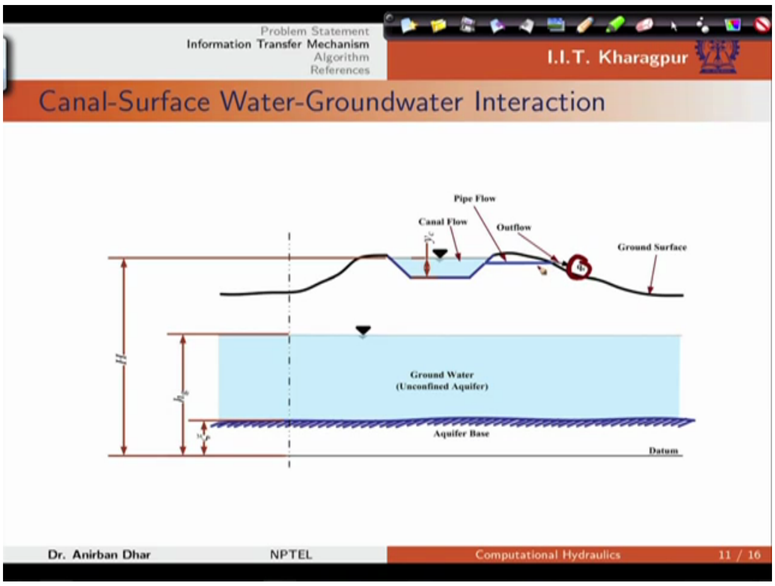
There may be situations where we have a flood situation in the right hand side then if we have surface flooding which is above this outlet but it is below this (30:50) height obviously there will be flow from right to left wards if there is difference in elevation.

(Refer Slide Time: 31:00)



So we can see that this qc is not fixed amount. It will vary depending on the condition in the 2D system or 2D surface flooding system and 1D canal flow system. Obviously in this case we are considering that canal is line 1. So there is no outflow or infiltration from the channel bottom or canal system. Only through outflow we have this component, qc is coming out from the system.

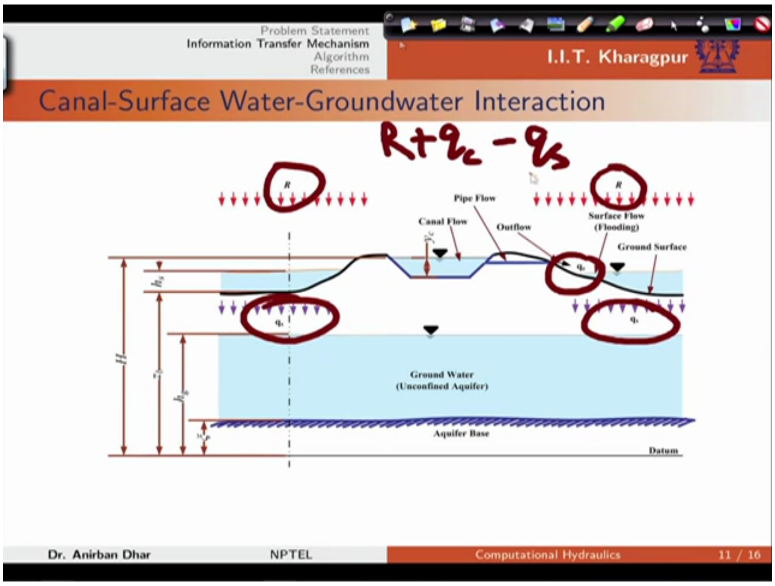
(Refer Slide Time: 32:01)



Now after I have got this qc amount from our channel network we can find out what will be the surface flooding situation in the two dimensional system. So this will be the surface flooding situation. Obviously as we are considering canal flow is one dimensional or channel flow as one dimensional. We are not considering any rainfall recharge on top of the canal. Only we will be considering this rainfall in the 2D surface flooding (sys) system.

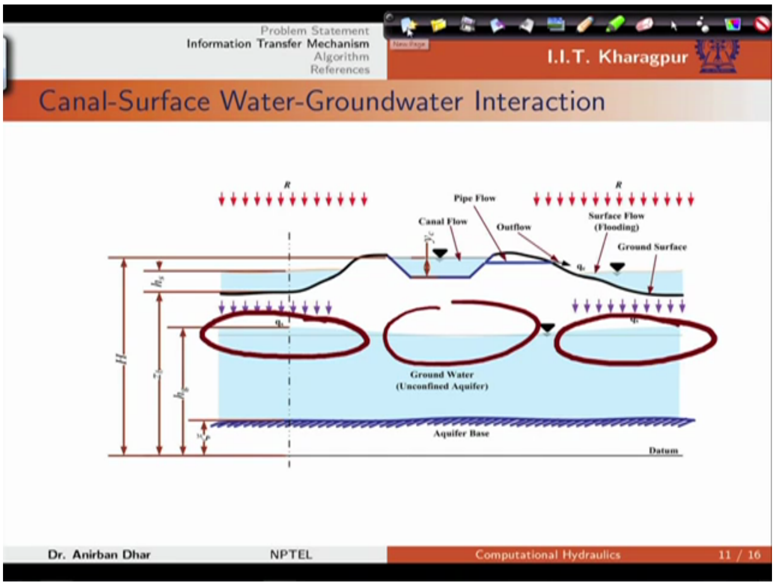
So obviously if there is outflow from the canal there will be rise in the water table or surface in the surface flooding situation. So this is the free surface there. So we have recharge component or rainfall here and qs is the infiltration component and qc is inflow. So that is why R plus qc minus qs is the net inflow to the system.

(Refer Slide Time: 33:40)



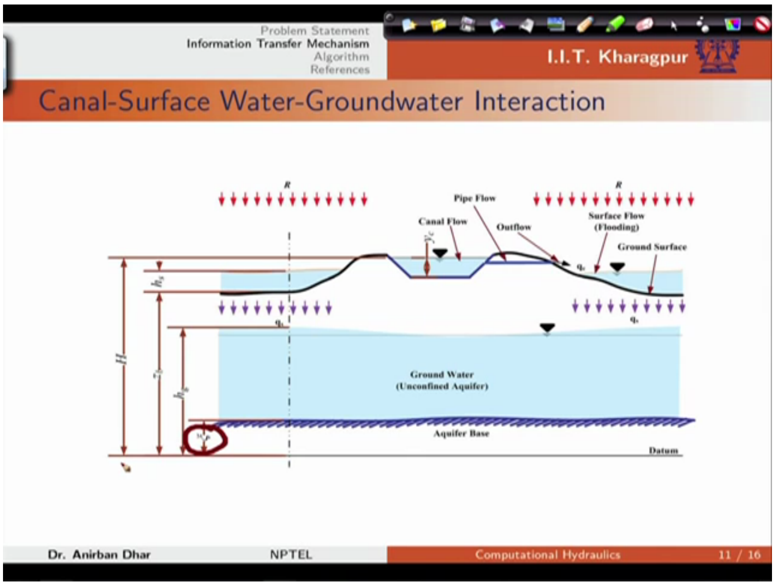
Now in this case we are considering this surface water system and when we have considered our canal flow still there will be ground water flow but without recharge from the surface water system. But when we have this recharge component available qs so we need to add this to our ground water system or which is the unconfined aquifer. In that case there will be a rise in the water table due to this recharge. Below this canal I have not considered this recharge because this is line 1 that is by conceptualization of this problem.

(Refer Slide Time: 34:47)



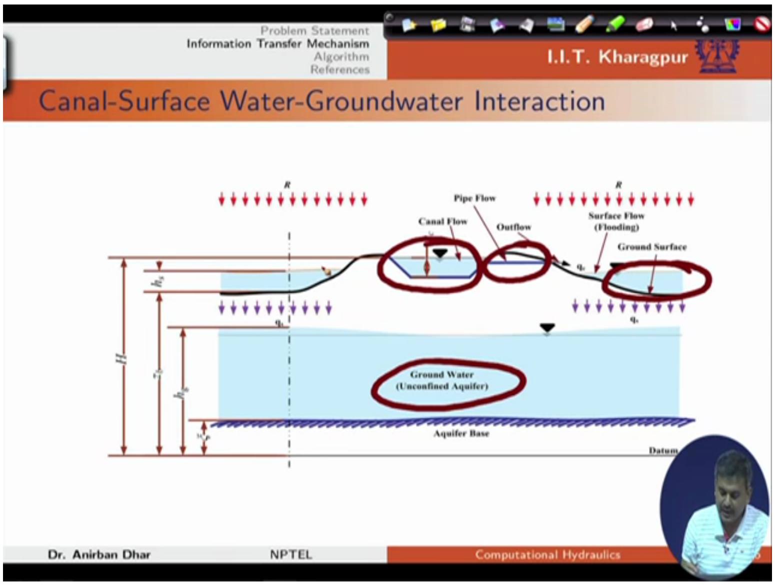
So in this case we need to define our values. So what are the values for our canal flow H which is water surface irrigation. H is nothing but yc plus z. So I have not shown this z but I have shown this yc and H. Obviously z will be H minus yc in this case. This hS is the surface water flow depth, zD is the water elevation of the ground surface, hg is the elevation of the ground water surface or (35:50) water table and in this case this is the elevation of the aquifer bottom.

(Refer Slide Time: 36:00)



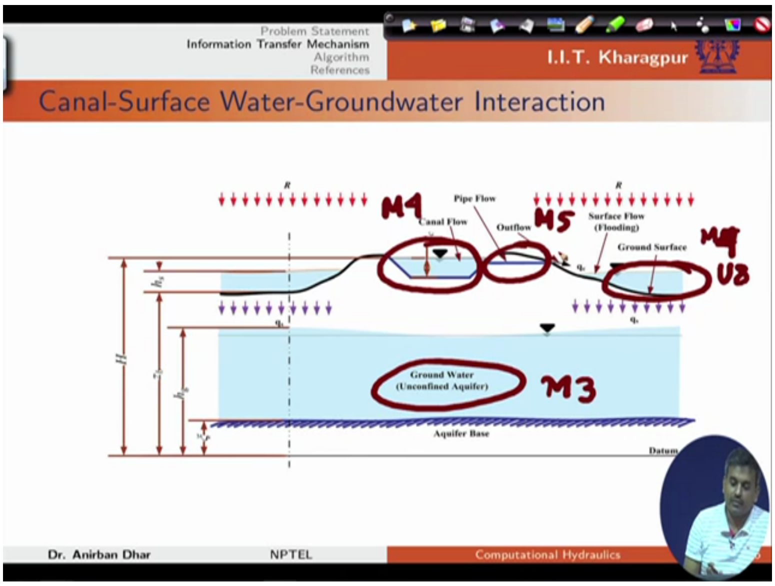
So these are the different components that we need to consider in the integrated system. Obviously in this case we have linked few things or few components. One is groundwater flow from the backward direction groundwater flow then we have surface water flow, we have pipe flow, we have channel.

(Refer Slide Time: 36:34)



In our module 3 we have discussed our discretization of the ground water flow equations. In module 4 I have discussed this canal flow or channel network flow problem, this one is module 3, module 4, module 5 is our ground surface or this also comes under module 4. This is last unit or unit 8 and this module 5 is our pipe network flow.

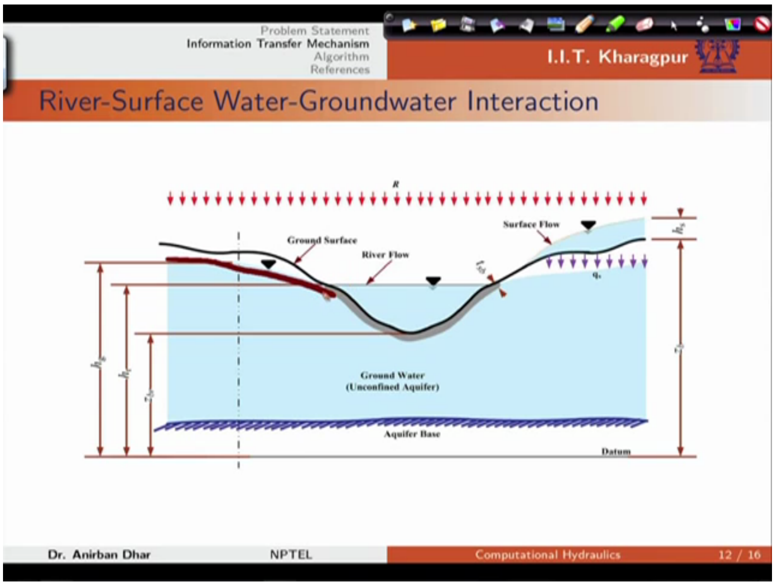
(Refer Slide Time: 37:30)



So we can integrate the discretization of different components from different modules and we can solve one integrated problem using our available governing equations. Now in this case we have linked this problem of 1D channel flow, pipe flow, our surface flooding and ground water flow components using recharge or discharge value. That is infiltration or outflow from the system or infiltration to the system.

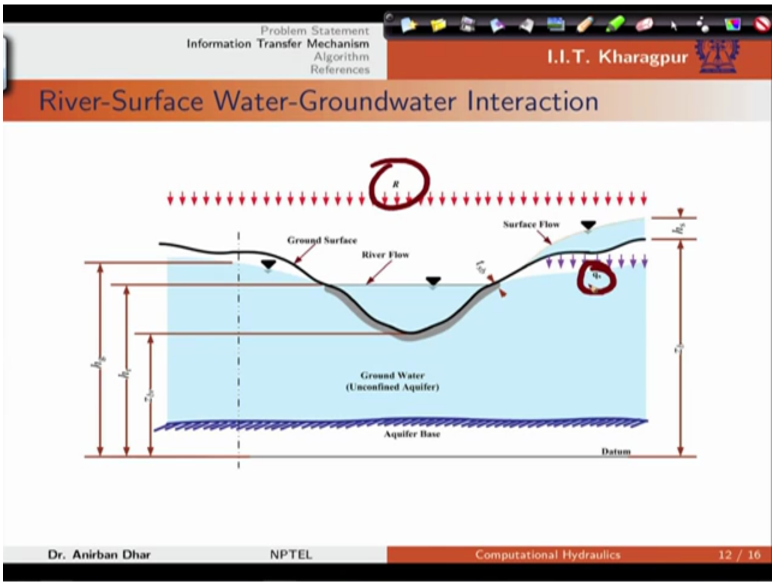
But there is another way of linking this surface water and ground water flow. In this case canal is at a higher elevation but if we consider river flow situation in that case river will be at a lower elevation, river bed. Now this is our regional ground water level.

(Refer Slide Time: 39:05)



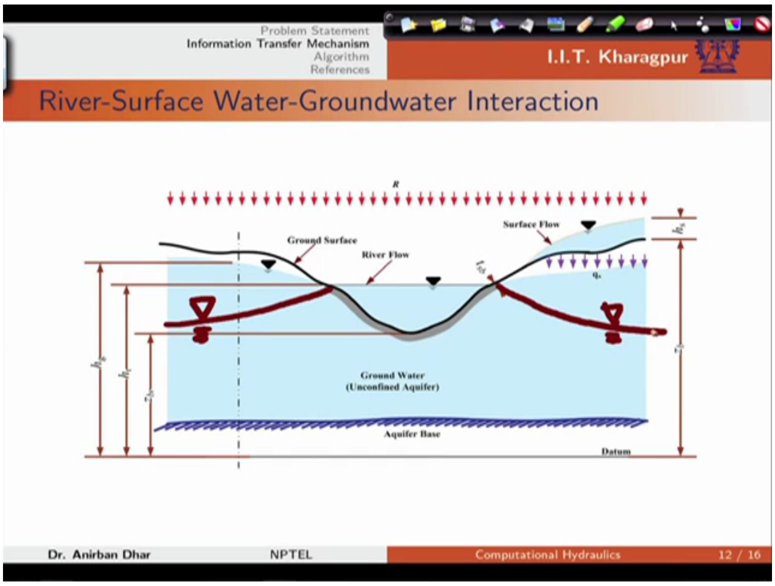
In that case this unconfined ground water table elevation should coincide with the water level or stage in the river. So we can solve this integrated surface ground water and river flow situation using our governing equations. But still in this case there can be surface flow. This surface flow may be due to rainfall. This surface flow may be due to rainfall, this qs is the infiltration which is coming out from the surface water system.

(Refer Slide Time: 40:00)



Obviously if we have water level at higher elevation at the ground water system then there will be flow of water from ground water system towards the river. The situation is called as gaining stream situation. And if we have a losing stream situation where our water level is like this. So this is the water surface elevation.

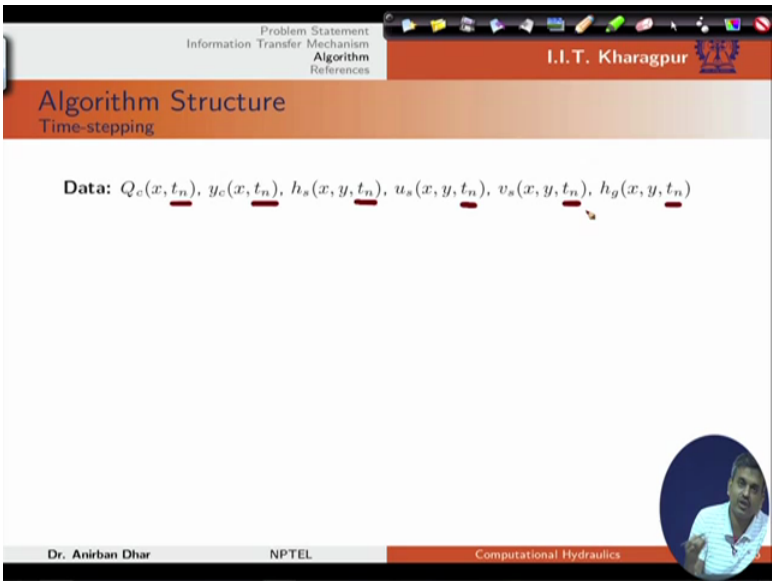
(Refer Slide Time: 40:53)



For our ground water system obviously there will be flow from our river system towards the ground water. So this is the losing stream situation. So we can model the interaction between ground water and surface water. In previous case in the canal flow situation there will be interaction between the surface flooding situation and canal flow. Still if we have water logging situation in the system then also there will be interaction between ground water and surface water.

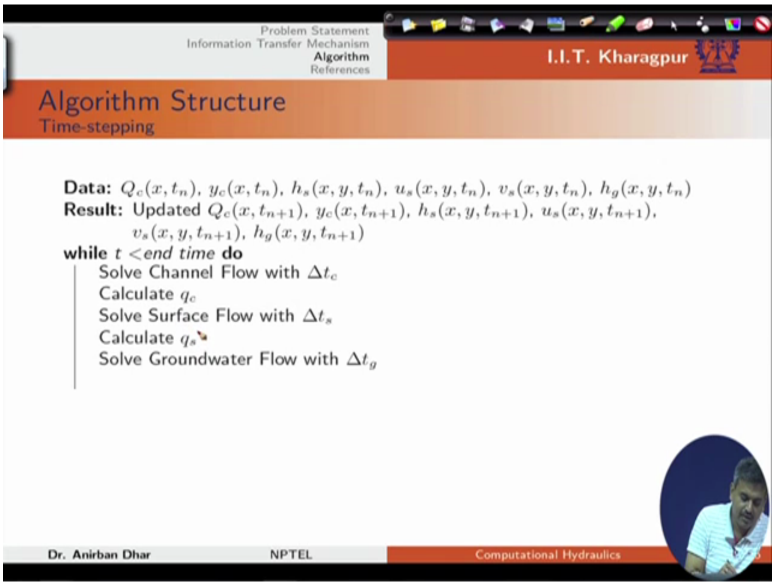
But in this case this ground water system is directly linked with the river flow situation. And surface water is linked through this qs. Obviously if there is a rise in the water table up to ground surface there will be interaction between surface flow and ground water flow. So what is algorithm structure? Data, let us say this is the information available at nth time level. So these are the values which are available at the nth time level.

(Refer Slide Time: 42:42)



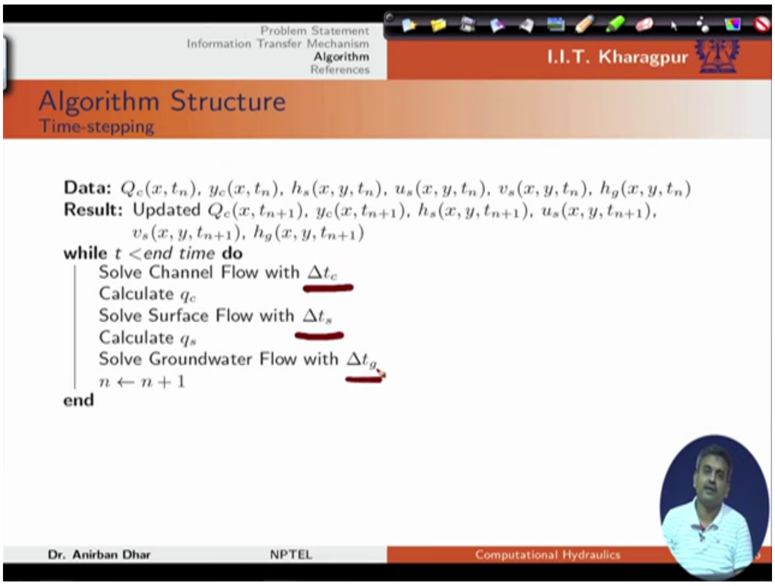
And what is our objective? Objective is to find out the value for updated Qc or x tn plus 1. That means at future time level what will be the value? Now what should be the structure? Structure is forward structure for the problem solve channel flow with delta tc then calculate Qc then solve surface water flow with delta ts then calculate qs because we need to use this qs for both surface flow and ground water flow. So this solve ground water flow system with delta tg.

(Refer Slide Time: 43:43)



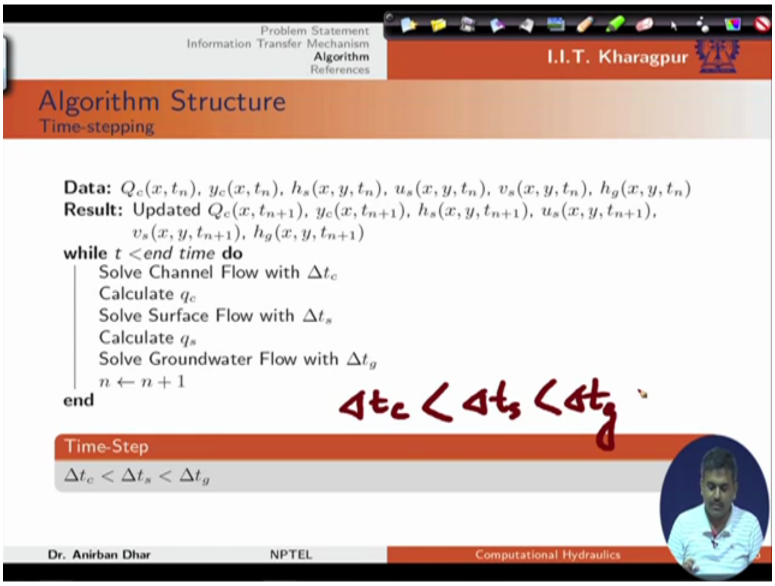
So in this case q is required for both so we need to calculate first here and then we need to solve surface water flow and ground water flow system. So finally we need to solve this ground water system with delta tg and n we should update to get the old time level value because now future time level value is old time level value or available value for the next time step. Now in this case these three things are important, delta tc, delta ts, delta tg.

(Refer Slide Time: 44:30)



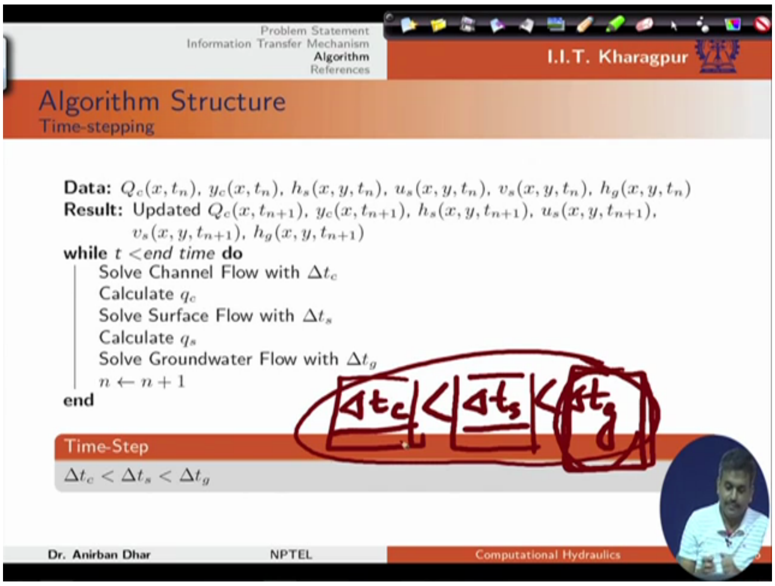
Let us say that we are utilising explicit formulation for our problem. Obviously depending on the requirement for different condition like CFL condition or other condition we need to restrict the delta t value. Obviously for surface water ground water interaction problem we have this usual condition. That means delta tc should be less than delta ts less than delta tg. So why this is happening? Because the groundwater flow is the slow process and it is a slow system.

(Refer Slide Time: 45:27)



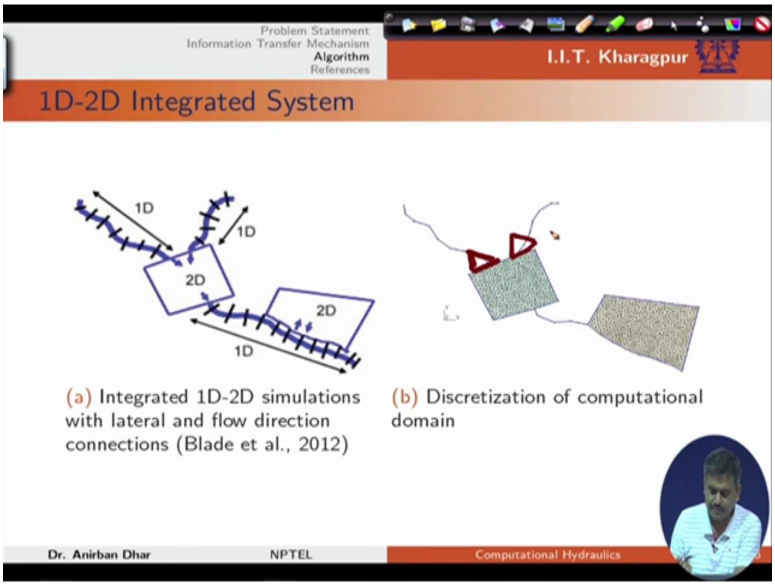
Then comes this delta ts or 2D surface flooding situation and finally 1D channel flow. Obviously this channel flow is much faster compared to our surface flooding situation. So this condition will be there. So for a particular time step this tg is more and tc is less. Obviously for a particular time period or del tg we need to iterate our surface flow situation number of times. Again for a particular delta s or surface flow situation we need to iterate this del tc number of times so that we can match the values or transfer the values at the end of any time period.

(Refer Slide Time: 46:35)



So this is the overall structure of the algorithm. We can utilise this information from different modules and we can integrate this discretization to solve one integrated problem. Now this is one example which is much more generalized one. Let us say that we have a reservoir inflow system. This is one reservoir there, this is another reservoir system on this side.

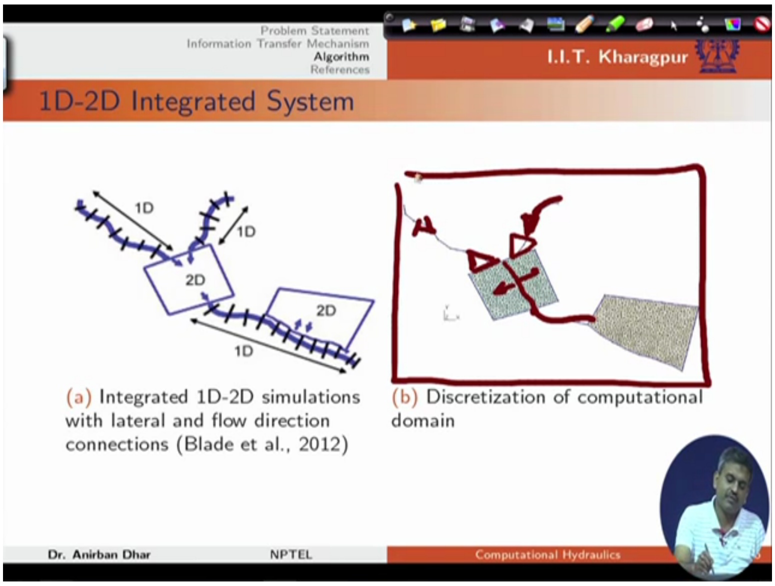
(Refer Slide Time: 47:23)



And we have this command area system available here. So flow is coming from there. This is 1D flow to the system. Again when water will be transferred to the command area so this is 2D flow. Again at this point it is 1D and it is coming to the downstream 2D flooding area or area of our concern because if we discretize the total domain the computational effort will be much more.

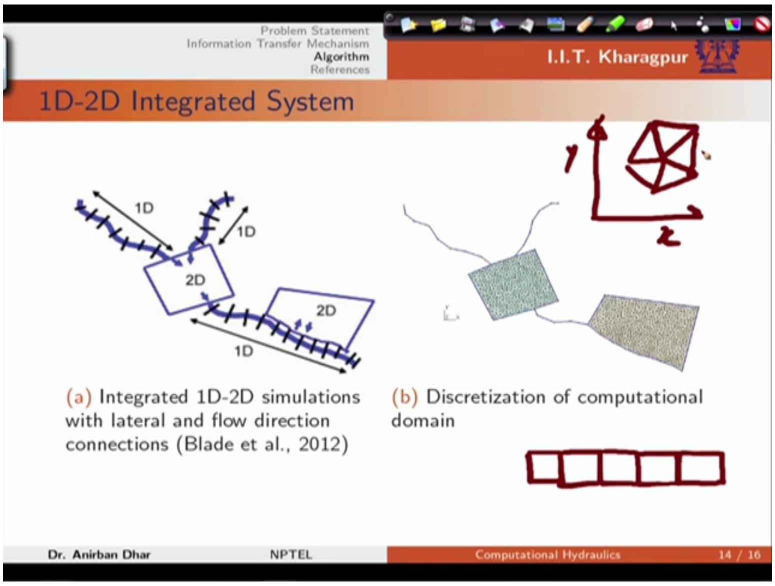
So we can conceptualize different components of the system in terms of 1D and 2D systems and we can integrate those systems to solve a particular integrated problem.

(Refer Slide Time: 48:22)



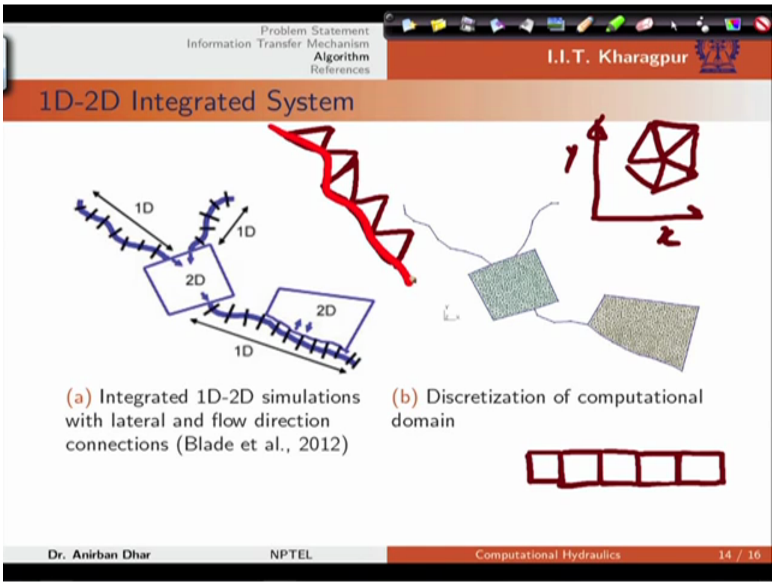
And this is discretization of the computational domain. Obviously we have only talked about the discretization in terms of rectangular gridding system which is according to the (48:47) coordinate system. But still with the (48:51) coordinate system itself we can use triangular mesh on quadrilateral mesh to divide the same domain into number of elements.

(Refer Slide Time: 49:06)



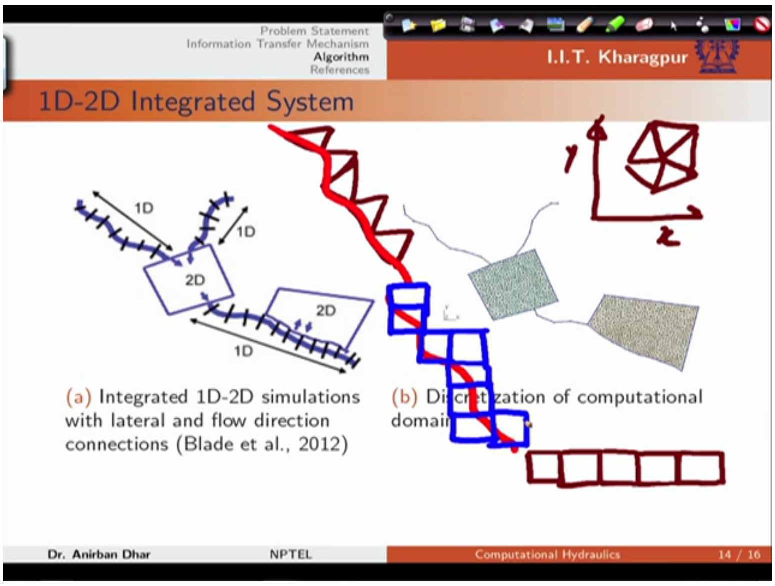
So what is the advantage of that? Advantage is that we can easily track the irregular boundaries. Near irregular boundaries this discretization is much better compared to our conventional rectangular gridding system. If this is our boundary let us say this is our boundary.

(Refer Slide Time: 49:40)



For same boundary if I want to utilise a rectangular gridding system then I need to include certain number of cells and I need to omit certain number of cells. So we cannot exactly track the boundary using or irregular boundary using our usual rectangular gridding system.

(Refer Slide Time: 50:26)



Obviously in that case we need to use this triangle meshes. So this is our overall idea about the integrated solution of the problem considering different components, it can be channel flow, it can be surface water flow, it can be ground water flow. Now we can integrate all components and we can solve this system using this integrated approach. Thank you.