Watershed Management

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Module No. # 07

Lecture No. # 29

Water Quality Modeling

Namaste and welcome back to the video course on watershed management.

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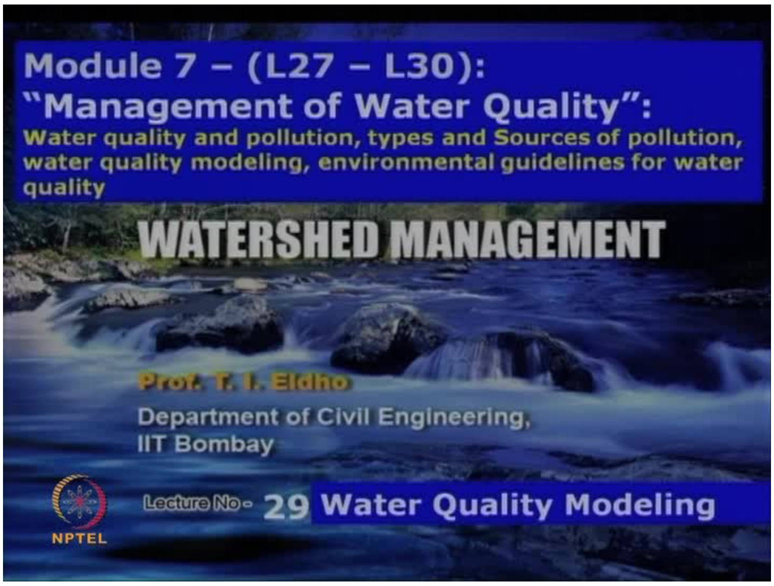

In today's lecture 29 and module number 7 on Management of Water Quality, we will discuss about Water Quality Modeling.

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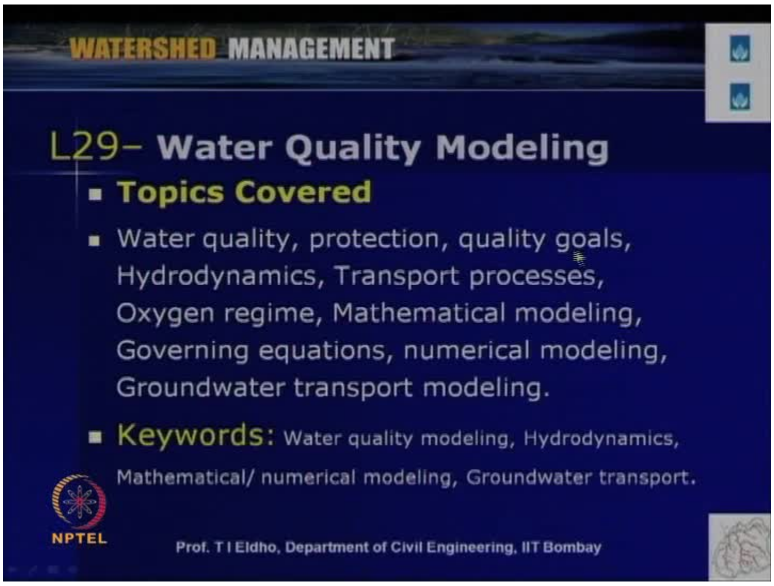

Some of the important topics covered in today's lecture includes water quality, protection, water quality, goals, hydrodynamics, transport processes, oxygen regime, mathematical modeling, governing equations, numerical modeling and groundwater transport modeling.

Some of the key words for today's lecture include water quality modeling, hydrodynamics mathematical or numerical modeling, and groundwater transport. As we were discussing earlier, water quality is a major issue when we deal with the water resource in a watershed. So, it is not only the quantity of water, which we have to get for various purposes, but also the quality for various purposes like drinking water, domestic usage or irrigation or industry. Certain specific qualities to be met or certain standards to be met like World Health Organization standards or Indian standards or British standards etc.

As we discussed in the previous lectures, we were discussing about the various sources of pollution for surface water, ground water. Various issues related to this have already been discussed in the last few lectures. When we deal with particular areas like watershed and as we have discussed, the pollution can be surface water or the ground water pollution.

We have to study in detail about what will be the present status, when we are looking into a particular aspect and what is the present status like which area is polluted like ground water or surface water, what are the types of pollution, where is the source of pollution and then what type of measures we can adopt to control this pollution and what kind of remediation can be done. So all those aspects were discussed in the last few lectures.

As we have seen, when we deal with surface water quality or groundwater quality, we have to always see the water quality within the perspective of what is the spread of the pollution or where it is moving further. In that way, water quality modeling is very important. Water quality modeling means through mathematical or various types of models, we are trying to say how within the system like in control volume or within a domain how the pollutant is or the contaminant plume is moving or how the behavior within the systems, so that is what we are trying to study when we say about water quality modeling. It can be either surface water quality modeling or ground quality modeling.

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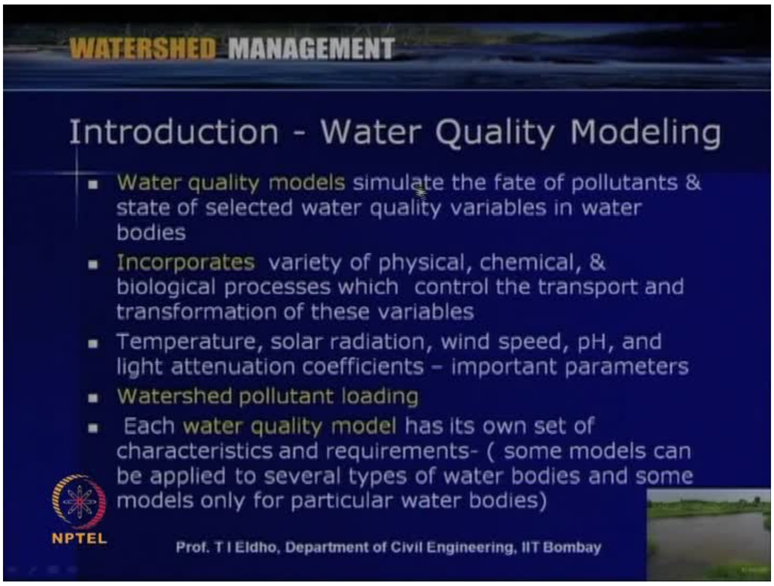

Let us look into the various aspects of this water quality modeling. Water quality models simulate the fate of pollutants and state of selected water quality variables in water bodies. It can be total dissolved solids, COD, BOD. So, what type of parameters we choose accordingly and develop the water quality model. So, this type of water quality models incorporates variety of physical, chemical and biological processes, which control the transport and transformation of these variables. When we consider watershed either in surface water or groundwater, the contaminant or the plume will be moving from one location to another location with the movement of the water. So, how this movement is taking place or how we can control the transport and transformations? That is what we are trying to do through water quality modeling.

Various parameters like temperature, solar radiation, wind speed, pH, light attenuation coefficients. Many parameters can control the type of the contaminant movement or pollutant movement within surface water or ground water within a watershed. In that way, we have to see the pollutant loading within the watershed. How much pollution is there and which direction it is moving within surface water or groundwater, so that way each water quality model has its own set of characteristics and requirements.

Depending upon what type of parameter we are trying to model, we have to develop a specific type of water quality modeling either for surface water or ground water. so depending upon what type of way we are trying to model the system. In that way, each water quality model has its own set of characteristics and requirements. So, some models can be applied to several types of water bodies and some models only for particular water bodies.

Model can be specific for particular cases or we can develop generalized models, so that can be applicable to most of the problems. It can be like nutrient models, the algae movement or the TDS within the surface water or groundwater. We can consider particular type of parameters, its behaviour, its transport or its movement within the aquatic environment either in surface water or the groundwater.

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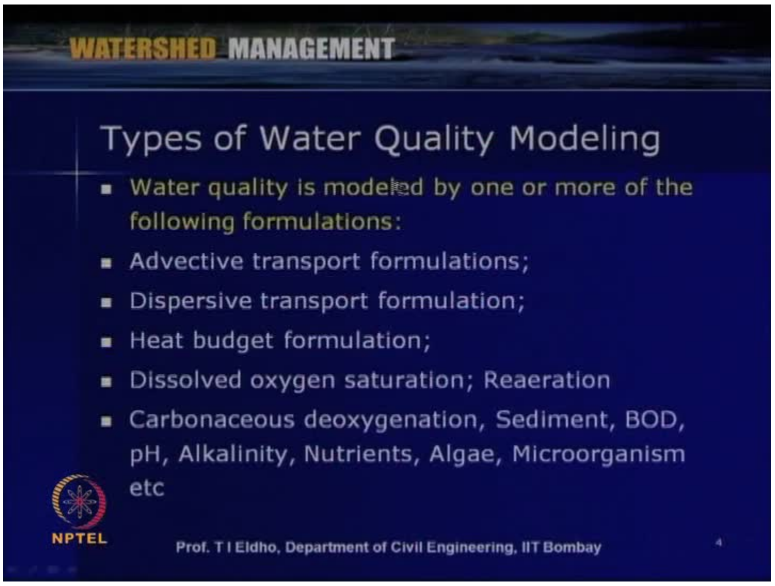

Within this perspective, when we say about the water quality modeling, we can have different types of water quality models. So, water quality is modeled by one or more of the following formulations. It depends upon what kind of pollutant or contaminant is there, what is the process of movement or how the behavior of that particular system within the particular control volume or particular domain is. We can have advective transport formulations, where mainly the advection or how the movement is taking place or the advective transport formulations is.

We can have dispersive transport formulations within the surface water or ground water. If heat is the main source of pollution like the hot water coming from thermal power plants to the lakes or to the ocean or to the rivers, we can see how the heat transport is taking place. In that way, we can have heat budget formulations. We can also study the issues related to water quality, related to dissolved oxygen content and then whether it is a decreasing or increasing.

If you go for aeration, how we can re-aerate and how saturation can be achieved? We can have different types of water quality models related to carbonaceous de-oxygenation or COD, sediment, movement and related modeling, biochemical oxygen demand, pH, alkalinity, nutrients, algae and microorganisms within the surface water or ground water. Depending upon what type of parameter we are trying to model or depending upon what kind of contaminant, we are trying to study within that watershed or within the particular area. In that way, we can have specific type of water quality model like advective transport model with respect to the processes or like sediment transport modeling or nutrient modeling.

As we discussed earlier, when we consider within the perspective of watershed, it is an area with specific boundaries in a hydrologic system. The main source of water is rainfall, surface run off, infiltration of groundwater and finally this river water will be moving to the ocean. When we deal with the water quality modeling, we have to see what kind of things are coming to the watershed or what kind of things will be going out of the watershed.

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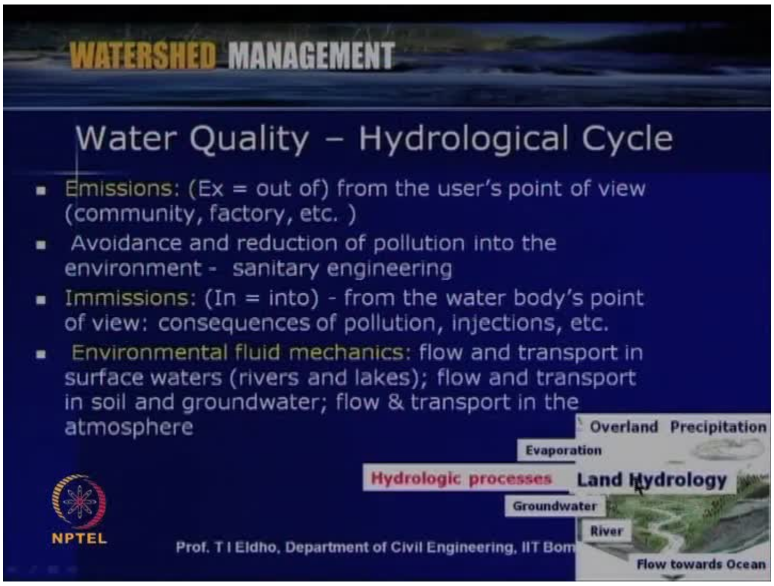

When we deal with water quality modeling within the perspective of hydraulic cycle or within the perspective of watershed, we have to deal with emissions that means what is coming out of like from the user's point of view like from the community, what is emitted or what is coming out like sewage or from the factory, what kind of affluent is coming.

Avoidance and reduction of pollution into the environment, so that is generally what we will be discussing in these related issues. In sanitary engineering or environmental engineering, another thing, which we have to generally deal within the watershed perspective is emissions that means it is into coming into the system. From the water body's point of view, what kind of pollutant water is coming to the system and then consequence of pollution then injection etc. Now, a new branch of fluid mechanics has been evolved in the last few years, so it is named as environmental fluid mechanics, where we are trying to study or we are trying to model the behavior of various pollutants and its behavior within the system like control volume or within that domain. The flow and transport in surface water like rivers and lakes flow, transport in soil and groundwater flow and transport in the atmosphere. So, like that a new branch of engineering or fluid mechanics has come, which is called a environmental fluid mechanics, where the various issues related to transport behavior within the water soil and air are discussed.

Within the perspective of water quality, we will be discussing what will be the behavior of particular contamination with in river or lake or pond like that. As far as surface water is concerned or within the ocean and groundwater is concerned, what happens within an aquifer environment? How pollutant is moving? All those issues will be discussed within the perspective of the hydrologic cycle.

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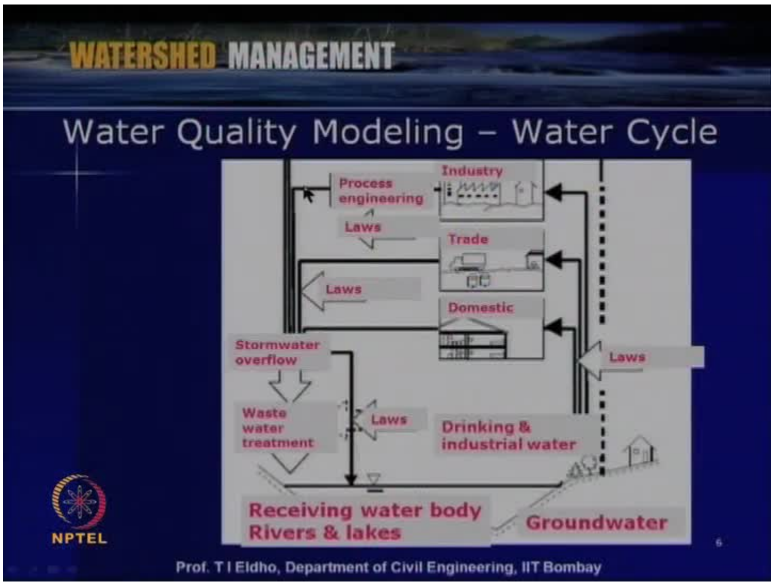

When we consider the water quality issues related to perspective water cycle, the water is supplied from surface water source or groundwater source. It will be taken for domestic purpose, industry purpose or trade purpose or various other purposes. This intake will be restricted through various laws and after this industrial trade or domestic processes, affluent will be there. Within the process engineering, whatever we can do, the treatment and all those things and finally the sewage water or storm water is coming as storm water overflow as waste water. Again, it is coming back to the systems like receiving water body like rivers, lakes or ocean and that also affect the groundwater system. We can say that the water quality issues are also related to water cycle. Since water is taken from surface water or ground water sources and after specific usage, it is coming back to the system either treated water or sometimes with affluence or with some contamination.

In that way, we can say that when we deal with the water quality modeling, these are the issues related to the water cycle. When we deal with water quality modeling, we have to see what kind of protection measures that we are looking for, what are the aims or what are the goals, which we have to set for the particular watershed or particular issues are concerned.

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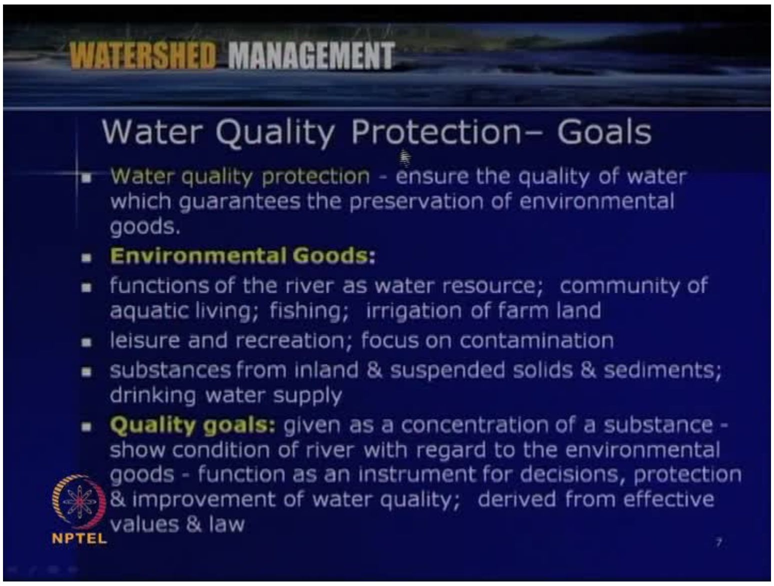

These are some of the important questions, which we may have to answer generally. As far as water quality protection is concerned, we are trying to ensure the quality of water, which guaranty the preservation of environmental goods. As we already discussed earlier, the water quality is in terms of surface water or groundwater within the perspective of environmental goods.

We can say that this is the standard, which we are looking for the waste and the treated water coming to the lake or to the river. Like that we have the water quality protection, since the existing water within the river has to be protected with respect to the outside water or the waste water or the treated water coming to the aquifer systems through the river systems or the aquifer systems, wherever the interaction will be taking place. When we look into the environmental goods, it is just like the functions of the river as water resource, then community of aquatic living, fishing, irrigation of farm land and then for leisure and recreation purpose.

As far as contamination is concerned, various standards are there and we have to set various goals. We have to see the substances from inland, suspended solids and sediments. Especially for drinking water, we have to see the overall best quality of what is required for drinking water purposes. In that way, we can set the environmental goals or environmental goods with respect to specific usage and with respect to the available sources can be set either for surface water or groundwater.

As we discussed, most of the time there will be interaction between the surface water and ground water. If the surface water is affected like rivers lakes or ponds and they may also automatically affect the groundwater system. When we look into the water quality goals; water quality goals are given as a concentration of a substance like TDA. It should be less than 500 PPM or the flow rate should be within the range of 2 PPM. So, like that we can set various quality goals. This water quality goals shows condition, for example, if you consider river with regards to the environmental goods, then function as an instrument for decisions protection and improvement of water quality. So, these are generally derived from effective values and laws.

As far as the water quality goals are concerned for various countries or various standards, various quality goals will be set and this depends upon the various environmental regulations, specific water usage and then the location of the area. Many parameters are there to set specific type of water quality goals or water quality protection measures. So, all that depends upon various parameters.

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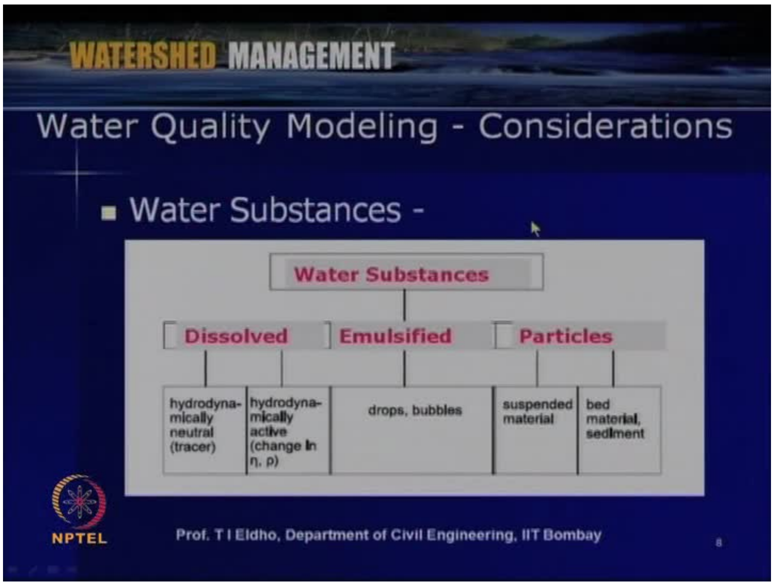

When we look into water quality modeling, various considerations have to be considered with respect to the various substances within the water that we discussed are due to the various source of pollution. As far as water is concerned, the substances within the water can be either dissolved substances or emulsified substances or particles within the water. As far as dissolved substances are concerned, it can either hydrodynamically neutral like a symbol tracer or hydrodynamically active like it can change its phase, density or viscosity and all those things. It can be like salt water within the fresh water or various chemical fluids within the water. So, water substance can be either dissolved or it can be emulsified like drops or bubbles like lather or other kinds of contaminations.

As far as particles are concerned, it can be suspended materials like your sediments coming from watershed or bed material and then other kinds of sediment things within flowing water like in river or within the watershed or overland flow or the channel flow. Wherever these particles will be loaded will be sometimes will within a suspended wave or it can settle with respect to the various environmental conditions or with respect to the velocity of the flow and other conditions. When we look into the water substances; we can divide it into dissolved, emulsified and particles.

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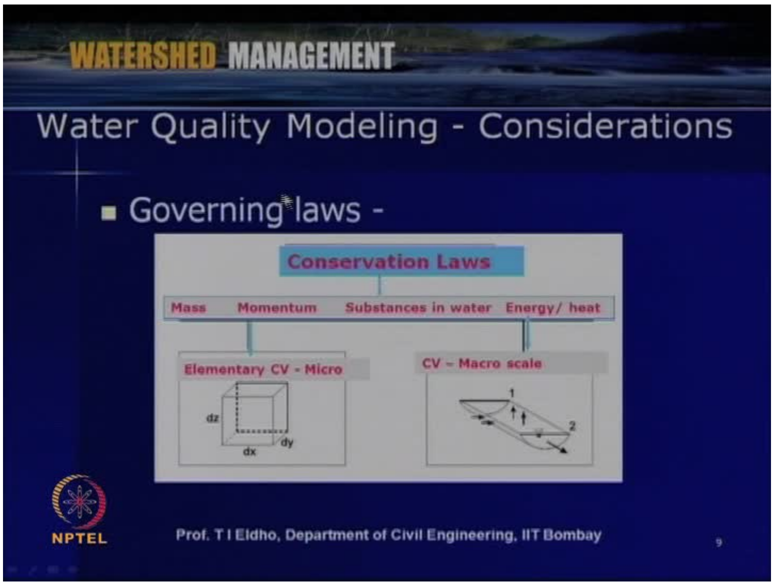

When we look into water quality modeling and as I mentioned, we are trying to depict various parameter, its behaviour or movement in terms of mathematical laws. Generally, we can use the governing laws as conservation laws. Most of the time we use the conservation laws like conservation of mass, conservation of momentum, the conservation of the energy or heat and then the substances in water. Like that the conservation laws and we can consider like conservation of mass momentum and energy.

When we are trying to develop the mathematical models, we can consider either micro scale or macro scale. Micro scale like elementary control volume - we can consider control volume like dx into dy into dz of size like this. It can be on macro scale like two sections between or within river or within pond or lake. So, it can be either control volume; it can be elementary size or it can be macro scale. Most of the time, as far as water quality modeling is concerned, we will be trying to develop mathematical models. That is the way we can try to quantify the contaminations or the pollutant movement within the aquatic environmental in surface water or groundwater.

Mathematical models – First, we are trying to set in terms of certain governing equations, boundary conditions and initial conditions. It can be the with respect to special variations like one dimension, two dimension or three dimension and it can be time dependent or time independent. So, it can be steady state or transient variations; otherwise, if you want to look in a holistic way as far as water quality is concerned with respect to the measurements at various location, it is a quite cumbersome and very expensive process.

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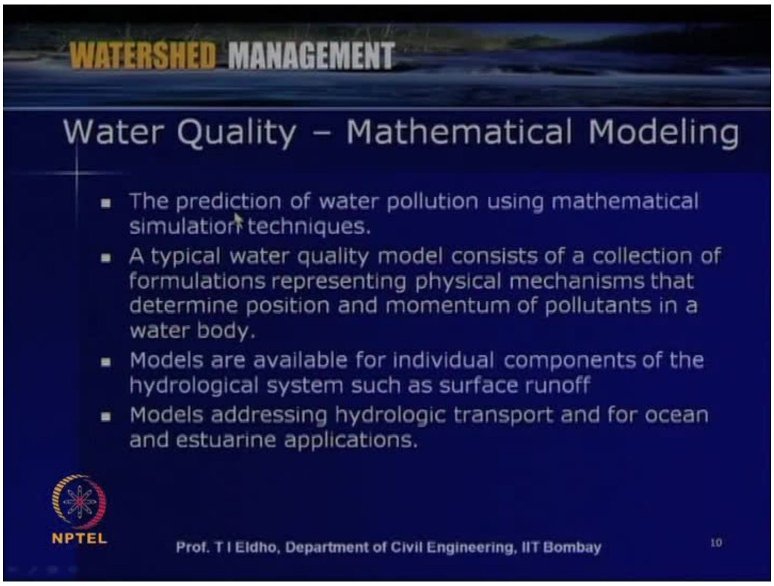

We are looking at mathematical modeling. As far as water quality is concerned, it tries to give the prediction of water pollution using mathematical simulation techniques. A typical water quality model consists of collection of formulations representing physical mechanisms that determine the position and momentum of pollutants within the water body. As we discussed, governing equations are generally coming from consideration of mass, momentum and energy. In that way, specific models are derived, mathematical models are derived.

These models are available for individual components of the hydrological systems such as surface runoff or groundwater systems or various specific type of reactive transport or specific components of the pollutant is concerned. So, these type of models are addressing the hydrologic transport for ocean and estuarine applications. Transport can be as far as within the surface water environment like lake, river, pond, ocean and also it can be within the ground water systems.

In that way also, it is possible as far as water quality modeling is concerned. We first try to represent the particular pollutants or contaminant within the environment in terms of mathematical description like governing equations and the boundary conditions. In this way, we are trying to develop the water quality models. Various processes like diffusion, dispersion, advective transport, reactive transport have been discussed in some of the earlier lectures.

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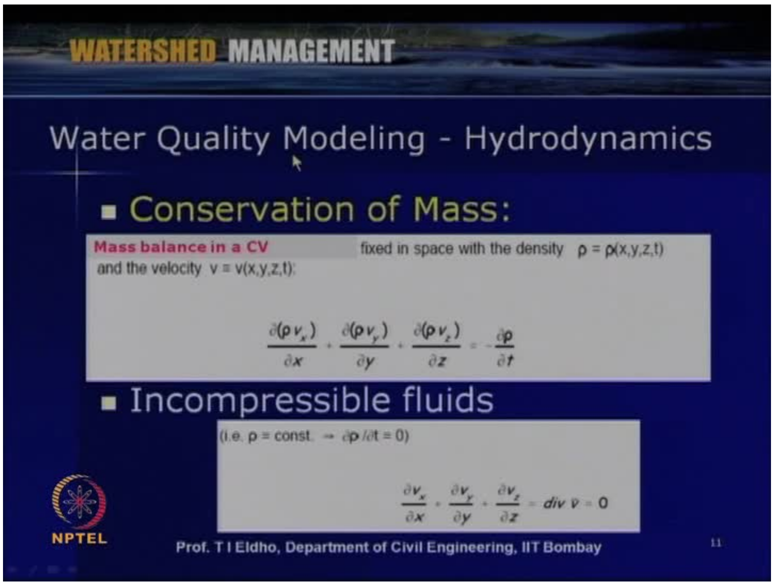

In that way, we have to understand the hydrodynamics that what is happening within the surface water or groundwater. How the flow is taking place, the depth variations with respect to space and time and then velocity variations, pressure variations etc. We have to first understand the hydrodynamics or the mechanism of flow within the domain or within the environment, which you are considering. We have to first do hydrodynamics modeling and then we will be going for the water quality modeling or transport modeling. Hydrodynamics is concerned; generally we can represent the governing equations in terms of conservation of mass and then conservation of momentum or conservation of energy.

Conservation of mass is called continuity equation. We can derive as shown in this equation. Here, v x, v y and v z are the velocity components in x, y, z directions, rho is the density and t is the time. We can derive this when we consider the time variation and density variation. If you are considering, for example, like water, we consider it as incompressible fluid. This equation converts to the continuity equation like this, where del v x by del x plus del v y by del y plus del v z by del z is equal to 0. We can derive the continuity equation based upon the conservation of mass.

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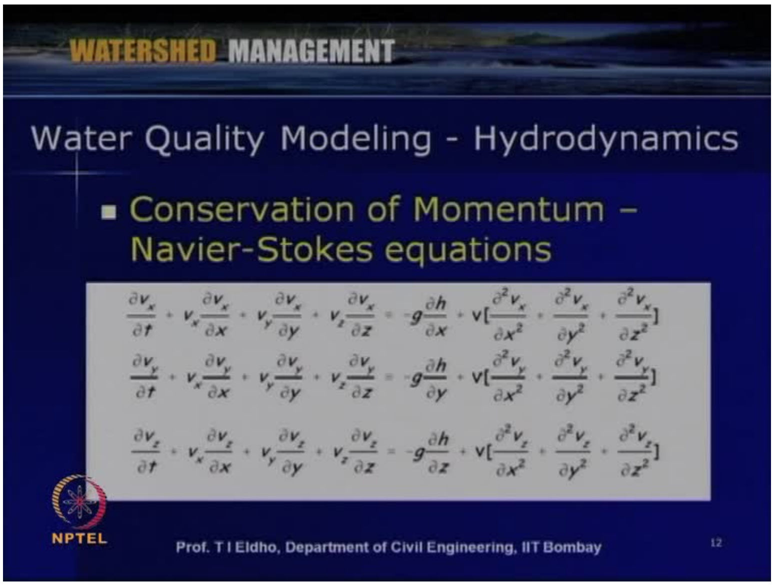

Other types of equation, which we have to generally solve is the equation based upon the conservation of momentum. Generally, these equations are called Navier-Stokes equations. So, in three dimension, we can have governing equations in x, y, z direction. For example, the velocity variations in x, y, z directions are represented as v x, v y and v z, g is acceleration due to gravity, h is the flow depth and mu is the kinematic viscosity. We can represent this equation, for example in x direction and del v x by del t plus v x into del v x by del x plus v y into del v x by del y plus v z into del v x by del z is equal to minus g del h by del x plus mu into del square v x by d x square plus del square v x by del y square plus del square v x by del z square.

In that way, we can represent the momentum equations. So, this is for x direction and similarly, we can write for y directions and z directions. We can solve to understand the hydrodynamics within the domain. We can solve the continuity equations and the moment equations, these three equations are for 3D problems and the continuity equations. From that we can obtain the velocity variation for the pressure, on depth variations within the domain or within the location or with in the area, which we are considering. The modeling can be three dimension or two dimension or one dimension depending upon the various consideration with which we are trying to model the system. This gives the solutions of this continuity and moment equations give the variations of the velocities and the depth or the pressure variations within the flow domain.

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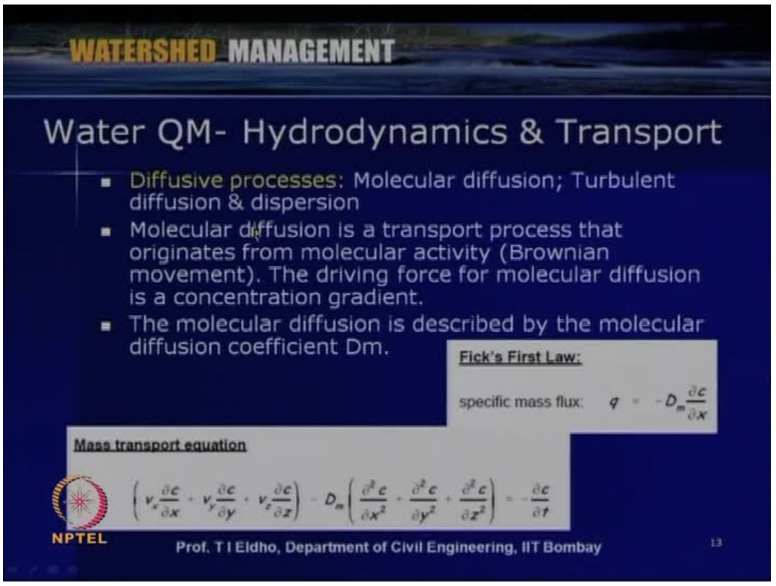

As far as transport is concerned, we have to consider various processes like diffusive process, molecular diffusion, turbulent diffusion and dispersions. If molecule diffusion is concerned, it is the transport process that originates from the molecular activities like your Brownian movement.

Driving force for molecule diffusion is the concentration gradient. Wherever the gradient is there and wherever the concentration is higher, then it will be moving towards low concentration gradient. It is based upon Fick's first law and so the molecule diffusion is generally described by the molecular diffusion coefficient as shown here. Fick's law is represented as q is equal to minus D m del c by del x, where c is the concentration, D m is the diffusion coefficient. Based upon this Fick's law, we can derive the mass transport equation for control volume by considering the advective transport.

This governing equation is generally written in x, y, z direction. Here, a specific equation for mass transport in x, y, z direction is specifically for the hydrodynamics and mass transport equation is only with respect to the variation in x, y, z direction as shown in this equation. It is v x into del c by del x plus v y into del c by del y plus v z into del c by del z minus D m into del square c by del x square plus del square c by del y square plus del square c by del z square is equal to minus del c by del t. This gives the mass transport equation, we can get v in x, y, z direction by solving this one equation. Of course, v x, v y, v z is obtained from the solution of conservation of mass or continuity and momentum equations as described in the previous slides.

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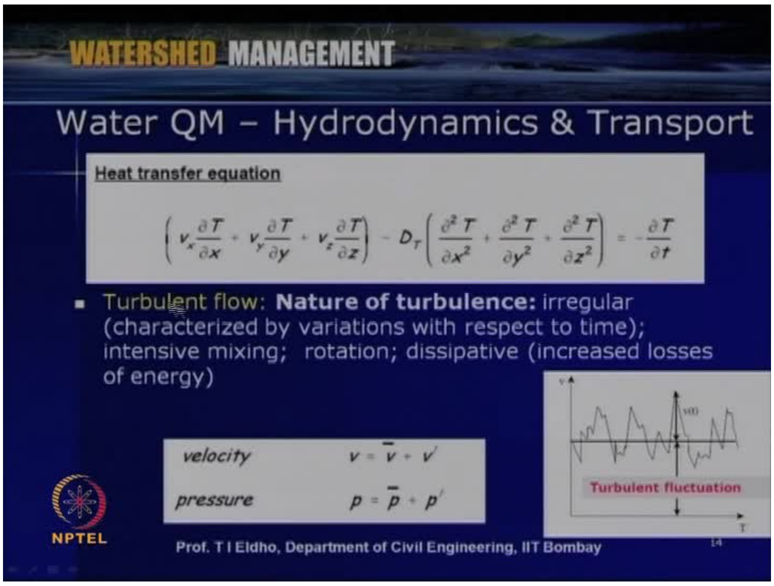

If you are trying to model the heat transfer problems related to the heat transport processes, which we have to consider. We can solve the governing equation can be obtained like this and d T stands for thermal diffusivity coefficient. T is the temperature and v x, v y is the velocity variation. So, we can solve this heat transfer equation.

Depending upon the flow conditions or the flow within the aquatic environment like in a lake or river or in a channel and the depending upon the velocity of the flow, it can be turbulent or the laminar. We can define it in terms of Reynolds number. Reynolds number variation is in terms of Reynolds number ratio, it is inertial force to viscous force. So, we have to first identify the turbulent flow or laminar flow and accordingly, if the flow is turbulent, we have to consider the turbulent nature of the flow.

Nature of turbulence like irregular is characterized by variations with respect to time. So, this is happening due to intensive mixing, rotation, dissipative movement. So, you can see that if it is laminar flow, then the velocity variation will be in layers or the flow will be in terms of layers. If it is turbulent flow, you can see that the velocity variation is the flow that is fluctuating or the velocity is varying. So that way, when the turbulent flow as far as the transport process is concerned, we have to consider variation with respect to mean variation. So, v is equal to v bar plus v dash, v is the velocity vector, v bar is the mean velocity and v dash is the fluctuating component. Similarly, the pressure variation or various other parameters can be considered as far as the turbulent flow is concerned.

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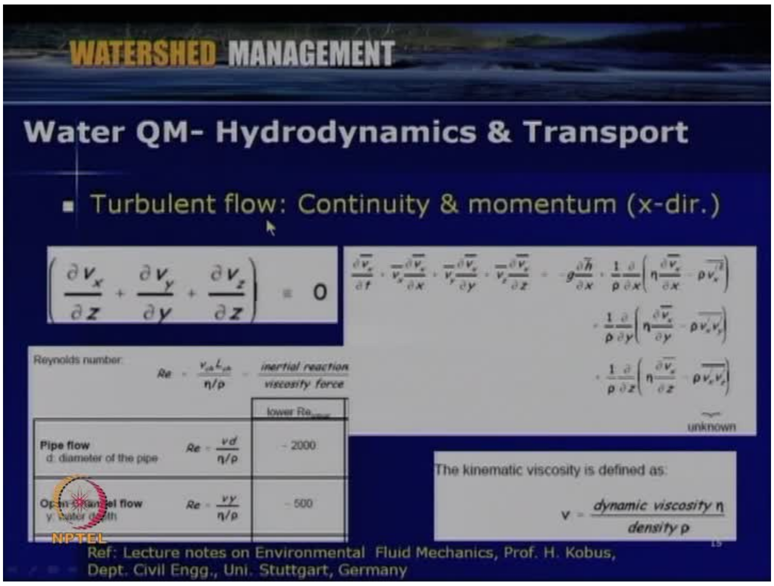

In a turbulent flow also, we have to solve the continuity equations and momentum equations. The continuity equation with respect to mean component is this equation and then the momentum terms from the Navier-Stokes equation. We can say transform with respect to this fluctuating components, mean component and then the final equation can be written in this.

We can see these equations in many of the standard fluid mechanics like fluid mechanics by Wylie and Streeter. As I mentioned, the main important parameter, which we govern is whether the flow is laminar turbulent. It is the Reynolds number, which is the ratio of inertial force to viscous force. For example, in pipe flow, flow will be laminar up to Reynolds number of 2000. From 2000 to 4000, we consider that variation or transformation is taking place to laminar to turbulent.

Above 4000, it will be completely turbulence, but upto 2000, we model it as laminar variation and laminar flow conditions is definitely above 2000. Above 4000, it is turbulent, but above 2000, the transformation is from laminar to turbulence as far as open general flow is concerned. Upto 500, we consider it as laminar and above that we consider as turbine flow conditions. We have to use the specific type of equations for laminar flow conditions or turbulent flow conditions.

The momentum equation, which is derived from the Navier-Stokes equation, which is generally called as Reynolds transport equation. It is described in terms of the fluctuating component of velocities like v x dash, v y dash and v z dash and it is variations. Here, this eta is the kinematic viscosity, which is defined as dynamic viscosity eta by rho. So, mu is equal to eta by rho, so in terms of that we can represent.

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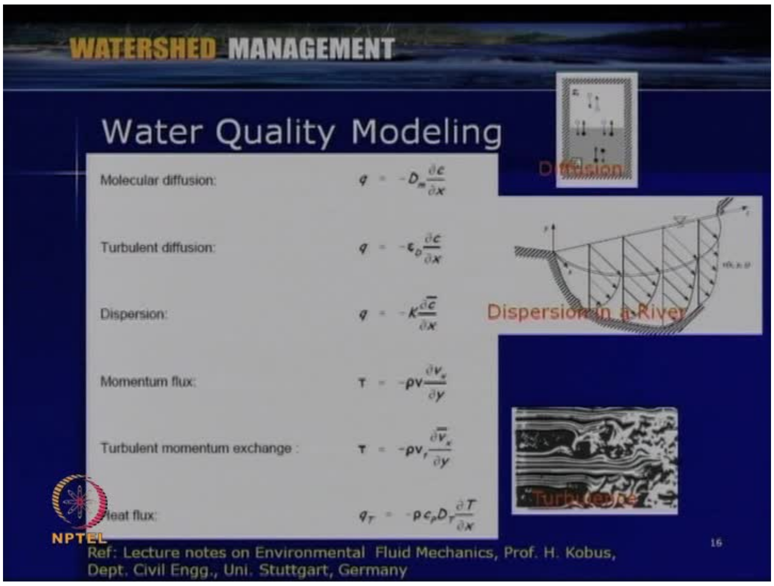

When we are looking for the water quality modeling, first we have to solve the hydrodynamics and then obtain various parameters like flow variations, pressure variations or the velocity variations either in laminar flow conditions or turbulent flow conditions. We have to solve the transport equation like advective transport equation, which we have mentioned. Solution of this transport equation is only possible, once we know the hydrodynamics or the flow variations. When we solve hydrodynamics equations or flow equations and transport equations together, we can get the wave flow variations and as well as the transport variation within the domain, which we consider.

As far as water quality modeling is concerned, we have discussed various important parameters that we have to consider are molecular diffusion, turbulent diffusion, dispersion, momentum flux, turbulent momentum exchange, heat flux etc. so, various terms are quantified as shown here. Like diffusion, what is happening in dispersion within a river or turbulence? We have to consider all this when we look into water quality modeling. Anyway, going into all details of this is not the purpose of this lecture, since we are discussing the water quality issues relevant to watershed modeling, so that way we are not going into all the details of these kinds of water quality modeling.

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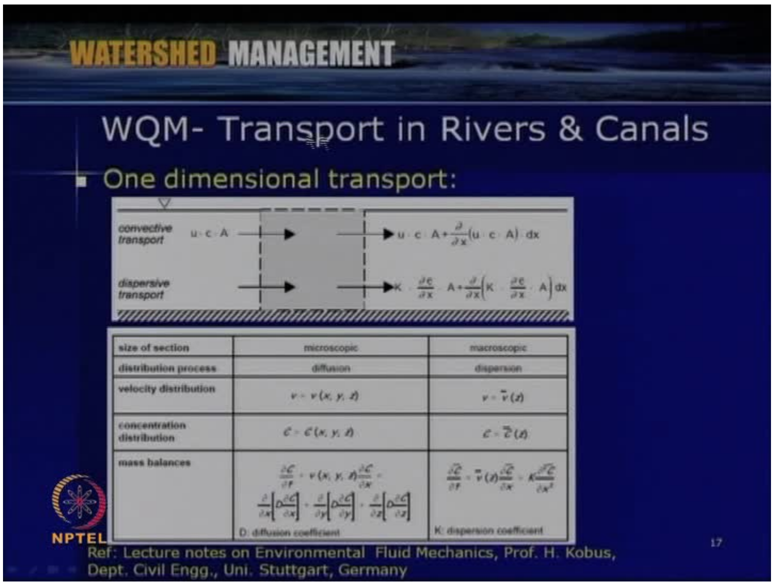

As far as water quality modeling, for example, transport in rivers and canals are concerned, it is one dimensional transport. If you consider the convective transport or dispersive transport, the governing equations, which we have to solve is shown here. Here, u is the velocity, c is the concentration, A is the area flow, K is the dispersion coefficient. We can consider a control volume like this and then we can do the water quality modeling like your size of section; microscopic or macroscopic.

These details are taken from the lecture notes of Professor Kobus, department of civil engineering university of Stuttgart, Germany. What are the course notes on environmental fluid mechanics? Like distribution process, diffusion, we have to consider like this, which is coming from the Fick’s law and then macroscopic dispersion. All those things will have to see the advective transport behavior within the system.

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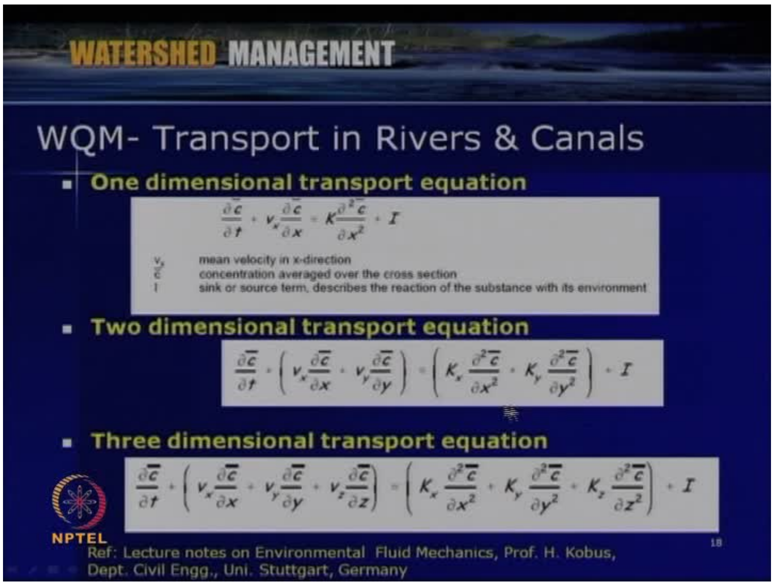

As modeling is concerned, for example, in the contaminant transport within a river channel, modeling can be in one dimensional modeling or two dimensional modeling or three dimensional modeling and accordingly, the governing equations are given. For example, one dimensional modeling is del c by del t plus v x into del c by del x is equal to K into del square c by del x square, where K is the dispersion coefficient, I is the sink or source term, like that we can represent.

Similarly, if you are considering two-dimensional transport water quality modeling, we have to solve the equation in x and y. so, this equation will be the governing equation. Three dimensional transport equation will be with respect to v x, v y, v z. We have to solve this system coupled with the flow equations or community equation and the momentum equations. We are depending upon what kind of water quality modeling you are intended to do like in the transport phenomena or the contaminant transport in river or in a lake or whatever system that we are considering. We can go for one dimensional modeling, for example, river quality modeling can be done in one dimensional modeling or two dimensional modeling or three dimensional modeling.

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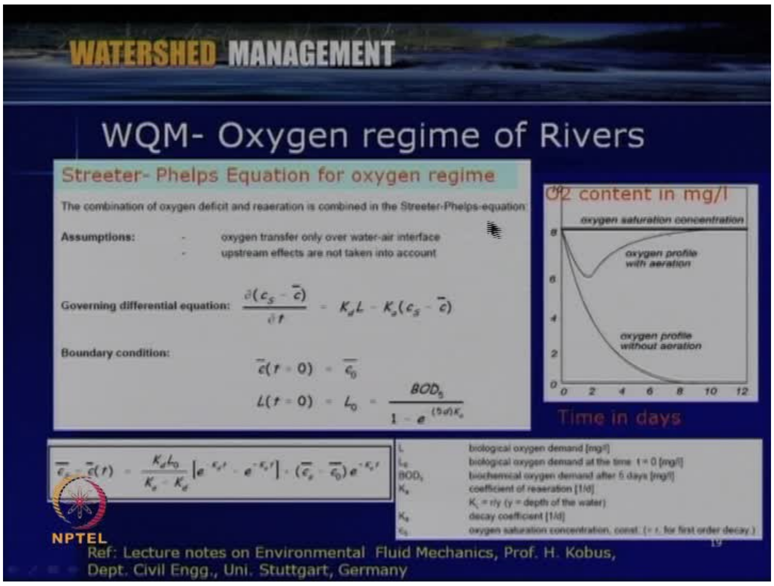

Another important aspect, which we will generally be looking, is the oxygen regime of rivers. When we are looking for the river quality modeling, we can represent this in terms of dissolved oxygen. The combination of oxygen deficit and re-aeration are in terms of an equation called Streeter-Phelps equation. Here, assumption is used in the derivation of this equation includes oxygen transfer only over water air interface, upstream effects are not taken into account.

The governing equation is del c s minus c bar by del t is equal to K d into L minus K a into c s minus c bar, where parameters like L is the biological oxygen demand, L 0 is the biological oxygen demand at time t equal to 0, k a is the coefficient of re-aeration, then K L is equal to r by y. K d is the decay coefficient c s is the oxygen saturation concentration. With respect to certain boundary conditions, with respect to this concentration of dissolved oxygen, BOD and with particular conditions, we can identify the oxygen regime within the river. So, you can see that if oxygen is with respect to time in days and if you consider particular location, oxygen saturation is this.

Depending upon the contaminant pollutant load within the river, if the oxygen profile has no aeration that is taking place, then it will be keep on decreasing like this. If there is aeration or aeration is taking place, then oxygen profile with aeration is shown. As shown in figure, it has been reproduced from the lecture notes of Professor Kobus. As far as Streeter-Phelps equation is concerned, we can even have an analytical solution as given here. When we are looking for the modeling of oxygen regime within river, we can even use this Streeter-Phelps equation. Correspondingly, we can identify how the oxygen content changes with particular section or within the longitudinal section of the river.

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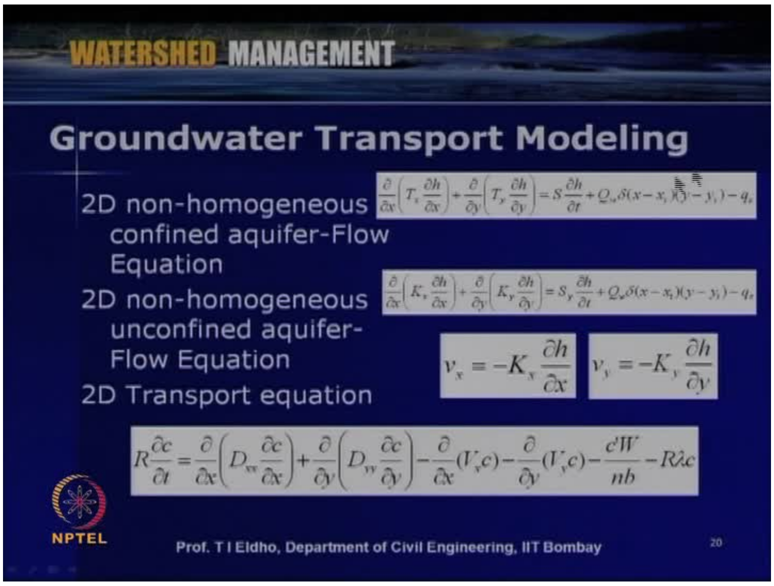

Another aspect that we discussed is the water quality. It can be either surface water or groundwater, so this groundwater transport has to be modeled with respect to the flow and transport phenomena. For example, when we consider two dimensional flow and transport modeling governing equation in a confined aquifer, we can write this del by del x of K x into del h by del x plus del by del y of K y and del h by del y is equal to S into del h by del t plus Q w delta into x minus x i into y minus y i minus q s.

Similarly, this T x, T y are the transivity or the aquifer system K x, K y have hydraulic conductivities. In similar way, the equation can be written for unconfined aquifer, Q w is the pumping at particular location and q s is the source of sink terms within the aquifer systems. Based upon these flow equations, we can solve these equations based up on the appropriate boundary conditions and initial conditions. We will be getting the head distribution within the aquifer systems. Using the Darcy's law, we can get the velocity variation v x and v y as shown here.

We can put this v x, v y in the transport equation, which is given here, where R is the retardation coefficient. Generally, we can consider that it is equal to 1, if there is no retardation effect to be considered. D x and D y are the dispersion coefficients, v x and v y are the velocity obtained and c is the concentration and lambda is the ready active decay coefficient. Depending upon what type of parameters we will be modeling as far as ground water is concerned, we can use the ground water transport modeling.

As far as water quality modeling is concerned, we can look into surface water quality modeling or groundwater quality modeling. For specific processes, we can have specific type of mathematical equations or models or specific component like TDS or BOD or COD or nutrients or algae or microorganisms and we can have specific set of equations. So, we will be solving these type or sets of equations and we will be trying to get a solution as far as the flow and transport process is concerned. While solving these types of equations, you can see all partial differential equations. We can specify few simple cases only and we can have the analytical solutions. For most of the field problems, we cannot have the analytical solutions.

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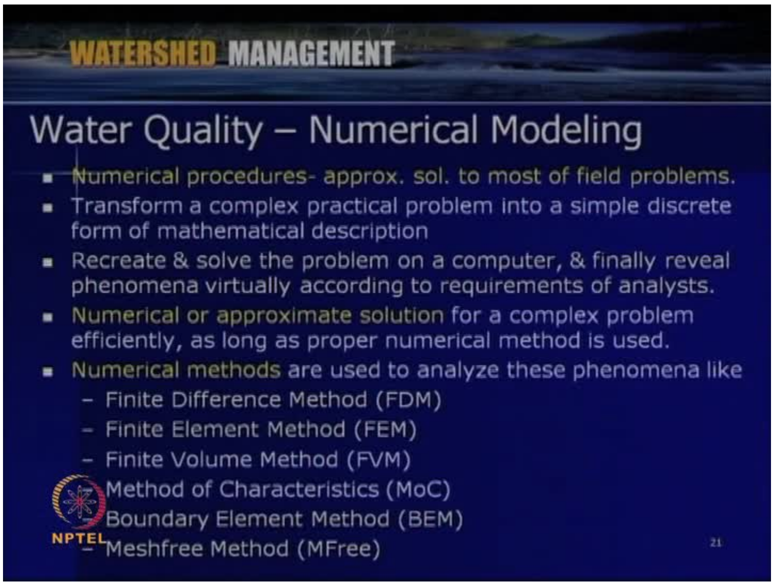

As we discussed earlier, we have to go for numerical modeling. Numerical procedures give the approximate solution to most of the field problems. This numerical model transforms a complex practical problem into a simple discrete form of mathematical description. These numerical models recreate and solve the problem on a computer and finally reveal the phenomena according to requirement of the user.

Numerical approximate solutions, for a complex problem efficiently, as long as proper numerical method is used. There are number of numerical methods available with respect to the last few decades and with the advancement in computer technology, number of numerical models like finite difference method, finite element method, finite volume method or characteristics boundary element method, mesh free methods and like that number of techniques have been developed.

Depending upon what type of process we are trying to model or what kind of contaminant we are trying to model within the aquatic environmental, either surface water or ground water, we can chose specified model and specified technology. Nowadays, large number of models is available in the market based up on various numerical techniques like finite element method or finite difference methods, which are the most commonly used numerical tools. So, we can choose them depending upon the user's familiarity and needs. We can choose particular models for surface water quality analysis or groundwater quality analysis.

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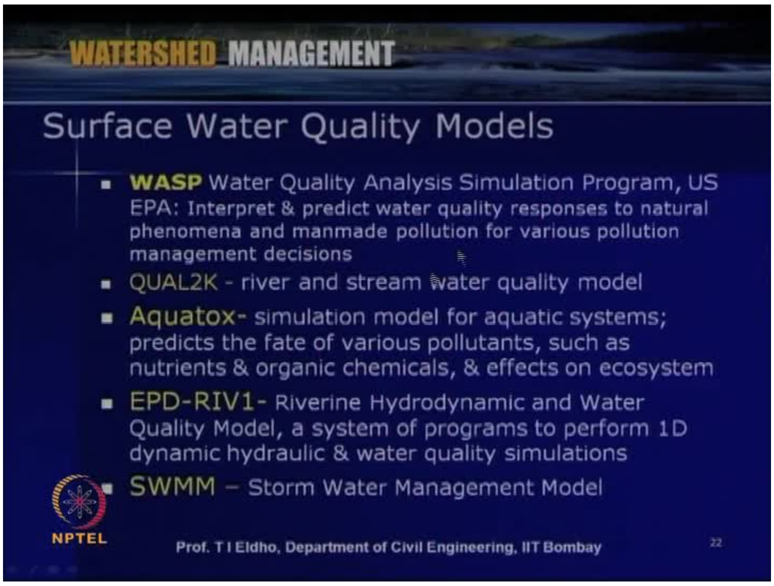

As far as surface water quality models are concerned, few of the most commonly used models have been listed here. First one is the WASP - Water Quality Analysis Simulation Program. It is by United State Environment Protection Agency. This WASP interprets and predicts water quality responses to natural phenomena and manmade pollution for various pollution management decisions.

Another model is called QUAL2K, quality 2k and this model is used for river and stream water quality models, either 1D or 2D. Another model is called Aquatox; this model is used for simulation of aquatic systems. It predicts the fate of various pollutants such as nutrients and organic chemicals or effects on ecosystem. Another model EPD-RIV1-Riverine Hydrodynamic and water quality model, it is a system of programs to perform 1D hydraulic water quality simulations.

The famous SWMM model, Storm Water Management Model, where the hydrodynamics and the transport within the open channels can be simulated, so that is the SWMM model. Large numbers of surface water quality models are available in literature and in the market. Depending upon what type of problem you are going to solve and what kind of contamination you have to address, we can choose a specific type of model.

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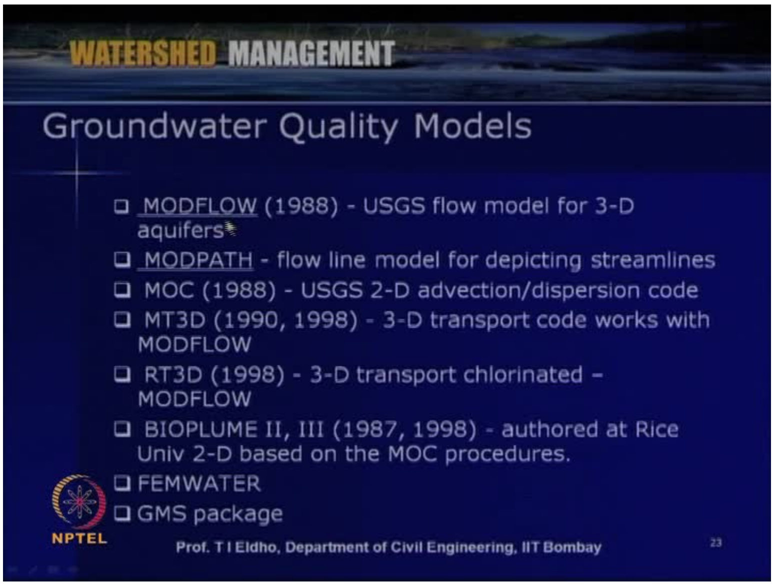

As far as groundwater quality models for flow modeling are concerned, we can use this standard model based up on final difference called a mudflow. It is given by United State Geological Survey, USGS. MODPATH flow line model for depicting streamlines. MOC has USGS 2-D advection dispersion code. MT3D is 3-D transport code, with which works in congestion with coupled with MODFLOW. RT3D is transport of reactive transport models and this also works with mudflow. BIOPLUME II and III are related to the bio remediation modeling. Finite Element Based Models like FEM water, then number of other packages like groundwater modeling systems.

As far as groundwater quality modeling is concerned, it is dependant upon the type of model, which you are looking for one dimension, two dimensions or three dimension and dependant upon the contaminant, which we have to address. So, we can choose specific type of models and then we can use for the groundwater quality modeling.

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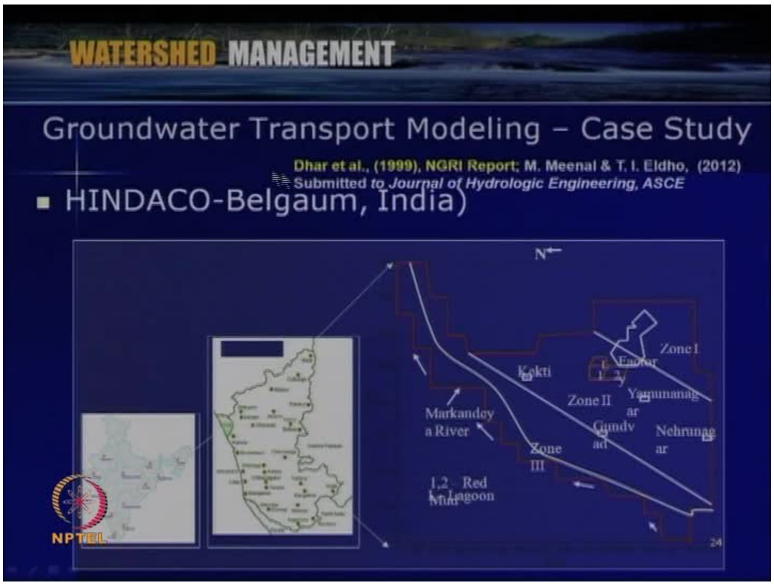

Now, before closing this lecture, we will briefly go through how specific type of groundwater quality model can be used to predict the transport phenomena; transport within an aquifer system. The case study is HINDACO in Belgaum area. This is the aquifer system, the domain area. One of my student, Meenal has modeled using the mesh free model, which she has developed. Details of this study area are given in Dhar et al in 1999. Meena and Eldho submitted it to the Journal of Hydrologic Engineering, ASCE.

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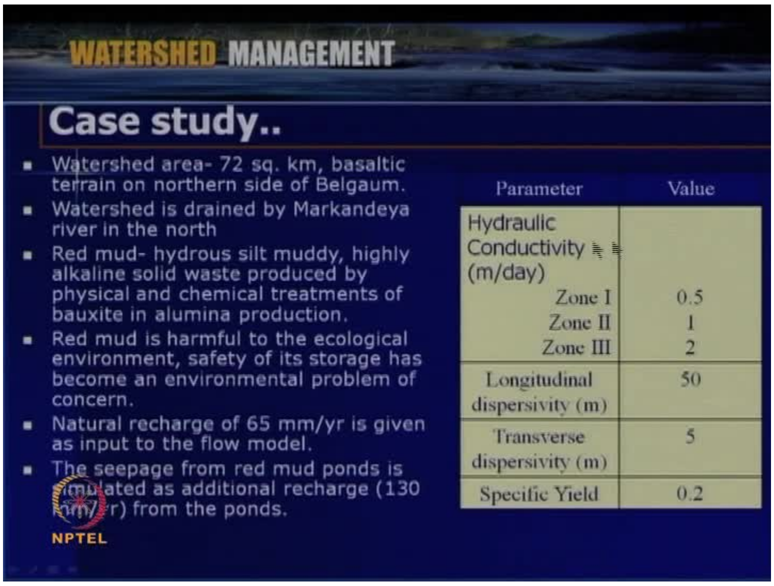

Some of the parameters considered in this study area: watershed area; the aquifer area is about 72 square kilometer. This is basaltic terrain on northern side of Belgaum. Watershed is drained by a river called Markandeya river in this north. Here, the main source of pollution is red mud hydrous silt muddy, highly alkaline solid and waste produced by physical and chemical treatments of bauxite industry in this particular location.

Main source of pollution is TDS coming from red mud. It is harmful to the ecological environment safety of its storage and it has become an environmental problem. The natural recharge in this area is 65 millimeter per year as estimated by National Geographical Research Institute, NGRI. The seepage from red mud pond is above and simulated as additional recharge about 130 mm per year. As far as the aquifer system is concerned in the model for modeling purpose, we consider three zones. They are zone I, zone II and zone III as shown here. This one is zone III; this is zone II; then zone I.

This is the Markandeya river on this side. Here, the longitudinal dispersivity is considered as 50, transverse dispersivity as 5 and specific yield of the aquifer is considered as 0.2. For zone I, the hydraulic conductivity is 0.5 meter per day. Zone II is 1 meter per day and zone III is 2 meter per day.

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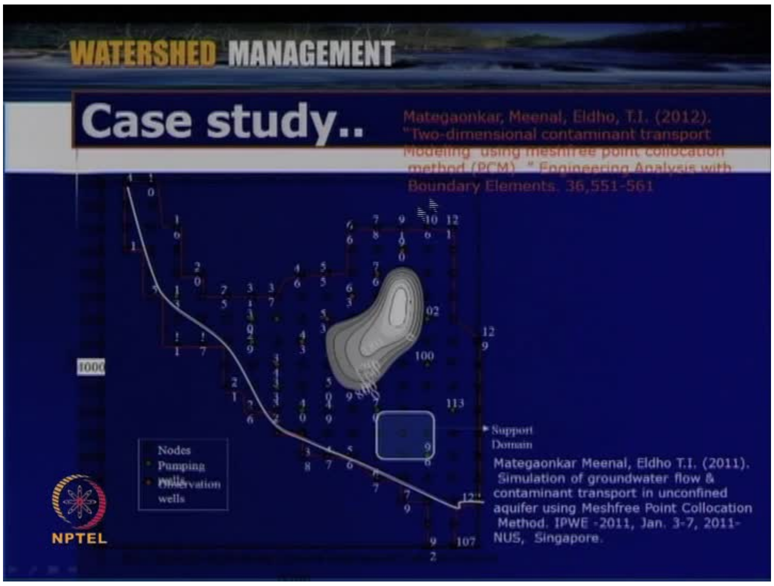

As I mentioned, my student Meenal has developed a mesh free model. The details are given in this conference paper and as well as in this submitted general paper. This is the domain, which we are considering that is the mesh free model; contaminant or existing plume. Our aim was after 10 years, how much the contamination will be spreading? Here, we developed a flow model and the transport model based upon the mesh free technique.

Here, we simply use notes, so details of this mesh free technique can be looked into this paper in the general engineering analysis with the boundary elements published in 2012. Two dimensional contaminant transport modeling using mesh free point location method. Here, this is the aquifer domain, these are some of the notes used for the modeling and this is the existing plume. So, using flow and transport in 2D, we considered a 2D model.

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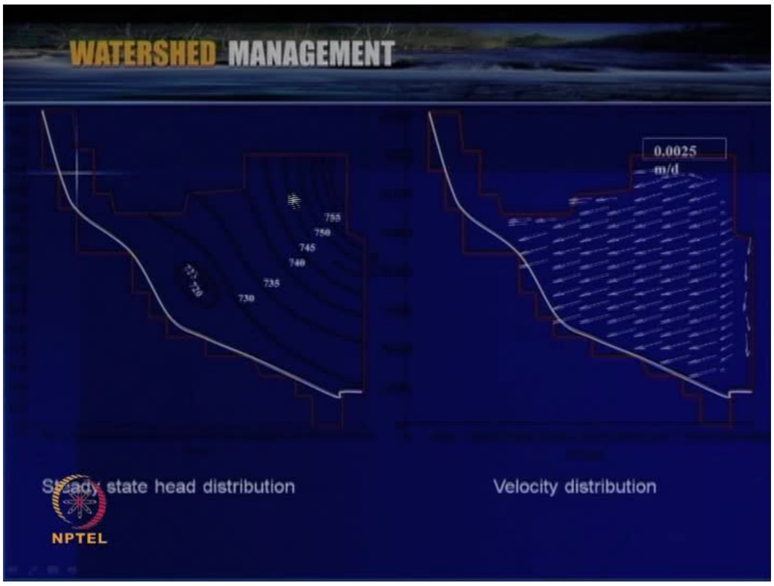

This is the head study state head distribution within the aquifer system varying from 755 meter to 720 meter. Here, the river flow and this head variation is based upon this velocity distribution. It has been determined by running the model, the coupled flow and transport model.

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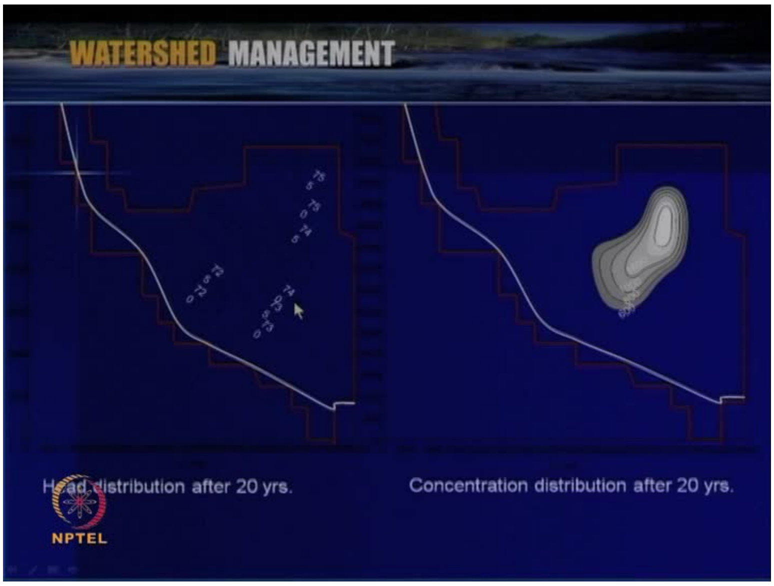

Head distribution after 20 years - this model has been done for 20 years and then you can see the various head variation within the aquifer system after the simulation for 20 years. This is 755, 750, 745, 740, 735, 730, 725, 720 and like that we identified them with respect to some of the abstraction taking place within the domain with respect to certain pumping wells existing in the aquifer system. Next, after 20 years of the simulation, how the contamination is spreading? You can see that this is the existing contamination with respect to the 1999 data. After 20 years, how the contamination is spreading? You can see that here small movement; the hydraulic conductivity is very low in this area. So, the contamination spreading is very small.

The main purpose of presenting this case study is to show how these types of models can be developed as far as the flow and transport either in the aquifer, the groundwater system or the surface water system and also we can develop such models. Generally, we have to solve the flow and transport models together. Flow models give the variation of velocities and depth variation or the hydraulic potential within the aquifer systems as far as groundwater is concerned. Based upon that we can identify how the velocity variation is taking place.

We solve the transport equation either in 2D or 3D or whichever way we are modeling and that gives the variation of that particular constituents like TDS or that concentration. How it is moving, especially as well as temporarily, so that is the way we do the water quality modeling either for surface water or groundwater. The contamination spreading is very small and as you can see here, the main purpose of the presenting this case study is to show how these type of models can be developed as far as the flow and transport either in the aquifer, the groundwater systems or the surface water systems can also be developed.

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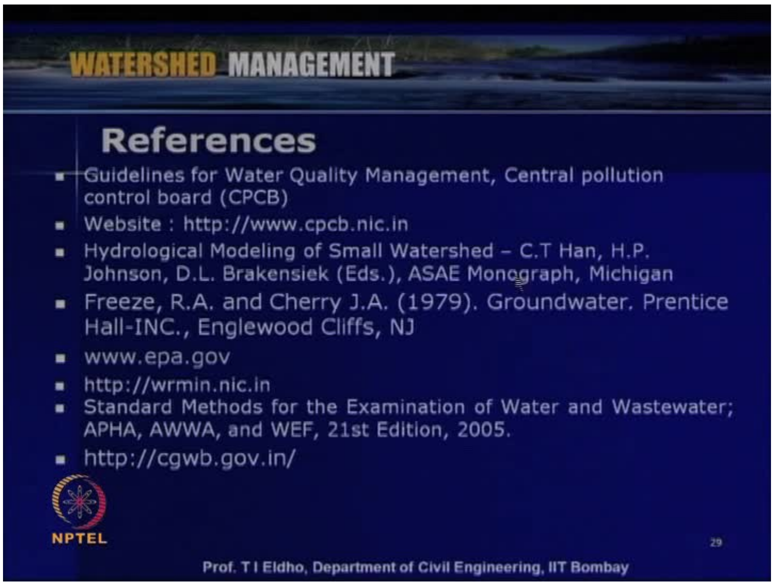

Some of the important references used for today’s lecture, especially the website triple w epa dot gov; it is an environment protection agency website and some of the other literature used for today’s lecture.

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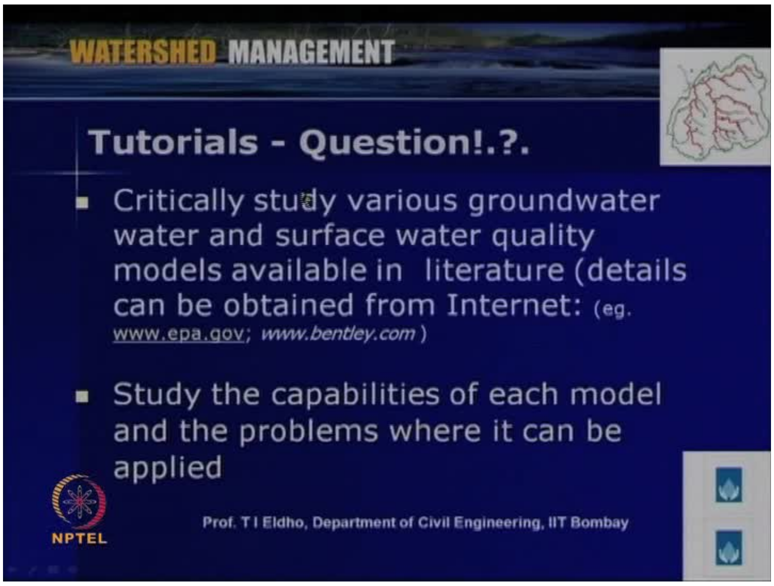

Before closing, some of the tutorial questions: critically study various groundwater and surface water quality models available in literature. We can see the various models available like in epa website or bentely website. Study the capabilities of each model and the problems, where it can be applied. Some of the models have already been discussed. Other models in detail can be got from the internet sources.

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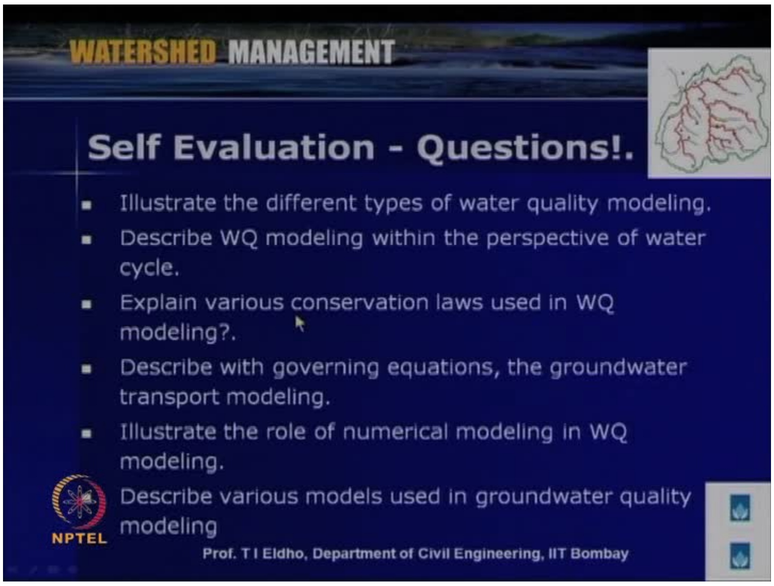

Some self-evaluation questions: evaluate the different types of water quality modeling. Describe water quality modeling within the perspective of water cycle. Explain various conservation laws used in water quality modeling. Describe with governing equations, the groundwater transport modeling. Illustrate the role of numerical modeling in water quality modeling. Describe various models used in water quality modeling. All these questions can be answered based upon today’s lecture.

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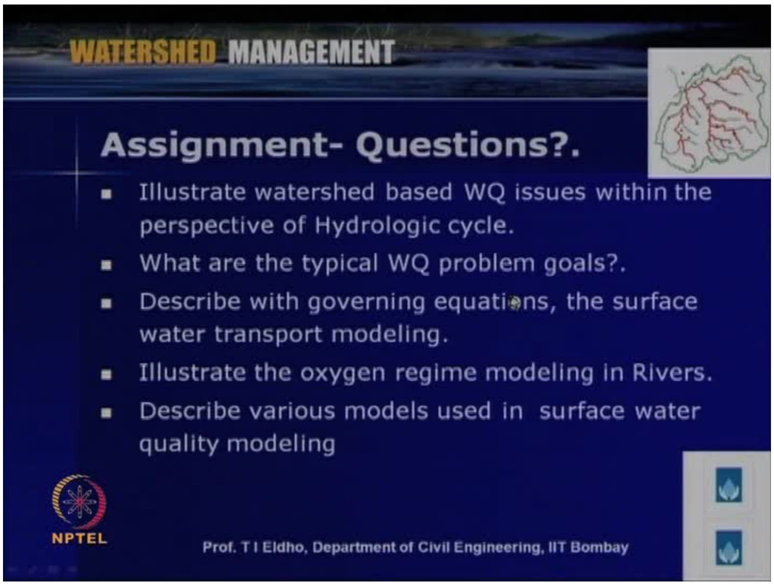

Few assignment questions like illustrate watershed based water quality issues within the perspective water hydrologic cycle. What are the typical water quality problems goals? Describe with governing equations, the surface water transport modeling. Illustrate the oxygen regime modeling in rivers or channels. Describe various models used in surface water quality modeling. All these questions can also be answered based upon today's lecture.

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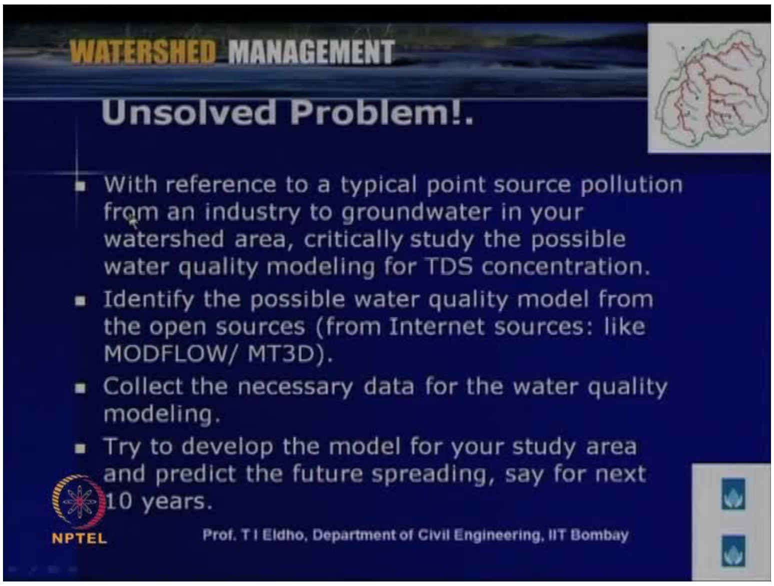

An unsolved problem with reference to typical point source pollution from an industry to groundwater in your watershed area, critically study the possible water quality modeling for TDS concentration. Identify the possible water quality model from the open sources like MODFLOW or MT3D, collect the necessary data for the water quality modeling and try to develop the model for your study area.

Predict the future spreading for next 10 years or 20 years. How the transport is taking place; contaminant transport or plume moment is taking place within the groundwater systems? So, what we discussed today is mainly on water quality modeling. So, we discussed about the surface water quality as well as groundwater quality. We discussed the mathematical governing equations and how we can model typical systems either in one dimension, two dimension or three dimension. We will be further discussing one more lecture on the water quality modeling related to environmental guidelines as far as the water quality issues are concerned in the next lecture. Thank you.