Water Resources Systems

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Module No. # 01

Lecture No. # 02

Definitions and Types of Systems

Good morning, and welcome to this the lecture number 2, of the course, Water Resource Systems - Modeling Techniques and Analysis. If you recall in the last lecture, we just introduced various types of problems that we may come across in water resources, where the systems techniques will be useful, especially you know, we started with the definition of water resource system, where you have a single reservoir find by the rainfall in the catchment area, and then you control the flows in the reservoir, because you are spreading the water in the reservoir; there is a evaporation loss, there is also an infiltration loss that takes place in the reservoir.

And then, you control the flows through your gated operation or through the spillways. Spillway is the water that reaches the top of the dam will go over the spillway, and then join the downstream river. In the process, the system will also generate hydro power typically, and then you use the water for irrigation, and municipal and industrial water supply. Another major purpose of reservoir, as I mentioned in the last lecture, is that it serves also a flood control, the purpose of flood control. Where the reservoir is kept empty to certain extent to absorb the flood waters during the flood season, and then the store it for use in the non flood season.

Then, you have the components of ground water where you may have recharge due to irrigation, as well as recharge due to natural rainfall, and then the part of the ground water also subsequently adds to the stream as the base flow. So, you have all these components continuously interacting with each other. Then on the downstream of the reservoir, the flow that it left out from the reservoir as well as the flow that is generated in the downstream catchment, because of the rainfall.

You will have water quality control problems, because of the industrial and municipal effluents that are joining the stream, downstream of the reservoir as well as the non point source pollution that arises, because of the runoff that takes place in the agricultural fields typically which picks up pesticides and fertilizers, and then (( )) also the non point source pollution is caused by the sediments themselves. The water would be carrying the sediments and then it (( )) and that causes the non point source pollution. The non point source pollution in general is non controllable whereas, the point source pollution which is typically, because of industrial and municipal effluents can be control by providing treatments.

So, this whole integration of the components constitutes, one water resource system where different components are continuously interacting with each other, you take any action on one any one of the components, the other component get gets affected, because of this. And therefore, there is a need for us to look at water resources system you know holistic, synthetic, and integrated manner and modeled the water resources system to answer some very important questions related to the operation as well as management, as well as development of the water resource systems.

So, we covered several different examples in the last class. We will continue with that discussion now, and perhaps we will go to more specific in this lecture, defining what we mean by a system, and then what are different types of systems? And then we will go on to introduction to systems analysis techniques themselves in this class.

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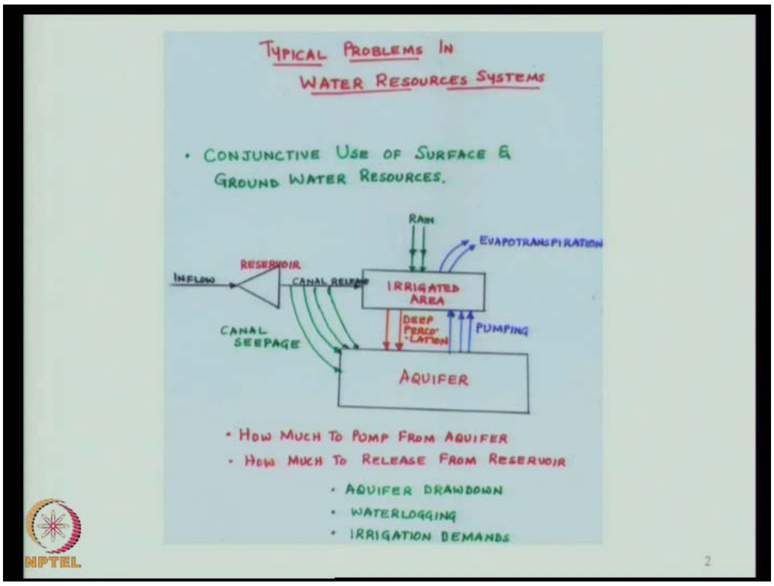

So, just taking off from where we left in the last class, you again consider the conjunctive system where you have, the inflow that is coming to the reservoir, this is the reservoir here. And this in flow is generated, because of the rainfall typically in the region that we are in this in flow is generated mainly, because of the rainfall that is occurring in the catchment area. There is a reservoir there, and then you are supplying the water through canal networks to an irrigated area. Now, this irrigated area may compress of several crops. So, this is just a conceptual representation of the irrigation irrigated area.

At the irrigated area the crops are also fed by rain water, and there is a evapo transpiration that takes places, this is actually the consumptive use of water. The crops and the vegetation actually consume the water, and that is through the that is the major through the evapo transpiration. Then at the irrigated area, there is also a deep percolation that takes place, because in the side layer the crops can extract water only from the so call effective (( )) to all of these conceptual cover as your progress along, but there is a effective root depth from which the crops absorb the water or crops can suck the water.

Typically the effective root depth is slightly larger than the actual root depth. And in this effective root depth when the soil moisture builds up, it can hold the soil moisture only up to fill capacity, over and above the fill capacity, it starts percolating down. And that is what we call us depercolation. So, this is the depercolation that takes places in the irrigated area. This depercolation may or may not directly join the ground water aquifer as recharge. So, the recharge that takes place to the agriculture the to the aquifer I am sorry, will come from rainfall falling on the irrigated area, and then through depercolation it can act to aquifer or whatever application that we have made from the canal to the irrigated area, the excess water can also come down as depercolation and can join as aquifer.

To the same irrigated area we may also be supplying ground water through pumping, so, there is a pumping that is involved in the on the aquifer, and then we pump and then supplie to the irrigated area. Similarly, as the water is flowing through the canal network, there is a significant amount of seepage that takes place, and part of this seepage will also join the aquifer, may also join the aquifer as canal recharge. So, you have recharge among on the one hand through rainfall, and the irrigation water application itself, and on the other hand through the canal seepage that takes place and then it may add to aquifer.

Now, this is simplistic representation as you go to smaller and smaller scales all of these processes may get quiet complicated, but we were looking out a large scale system where you want to plan for the conjunctive use of surface water, and ground water. Between which means essentially we are asking the question, how much of surface water we need to use - how much of ground water we need to use? And we have the understanding of the entire physical processes that takes place here, we using this knowledge we want to arrive at decisions on how much surface water, and how much ground water during the intra seasonal periods, let us say of every month and also during intra, inter annual periods. Let us say for first 5 years we do something, next 5 years to do some other thing etcetera.

So, this is a type of question that we would like to answer to the systems analysis. In posing this problem, we need to understand several physical conditions that we need to ensure. So, we are trying to pose this problem as a mathematical problem, and then we have to ensure that the physicals, physical conditions are all met in the mathematical problem. That is a main challenge of any systems analysis.

So, typically what are the decisions at we are looking for, we are looking for how much to pump from this aquifer, and how much to supply from the surface reservoir. So, there is one source of surface water, there is another source of ground water. So, we are simply asking the question how much of surface water, and how much of ground water we need to use. Such that it becomes sustainable in some sense, what do we mean by that, let us say that instead of surface water, you simply keep on using only the ground water; what happens? The ground water levels keep on depleting, and then it goes to such an extent that it becomes irrecoverable, no matter how much recharge are putting, because we are drawing more water than you are putting in the system becomes unsustainable and therefore, you would like to supplement this supply with the surface water.

So, the first condition we are putting is that the ground water level should not go below certain predefined level. The second condition is lets say that you do not touch ground water at all, but keep on using the surface water. What happens? Through the canal networks you are supplying the water in to the ground water through the canal seepage, and also through irrigation and rainfall, you are also recharge in ground utilizing the ground water. As the result of which the ground water levels keep on coming up, and they came the come up to such a level that they interim in to the root zone of the crops.

So, they come very close to the surface and surfaces - soil surface and therefore, they cause what are called as the water logging problems. So, this soil gets water log and therefore, the crops will start suffering. So, there is a lower limit of the ground water table, and there is a higher limit of the ground table. So, you would like to operate this system; such that the groundwater level is always within these limits. So, that is a first condition (( )). So, that is what to we mean by this condition.

So, we are making decisions on how much to pump from the aquifer and how much to release from the reservoir, during various time periods; let us say that you may talk of time periods as 10 days, 15 days, 1 month etcetera. So, we answer this question at various time periods during the year, we arrive at these decisions to be implemented at various time periods within the year.

While maintaining the condition of aquifer draw down; that means, you are using the ground water such that the ground water level is always within those to limits that I just mention that it does not cause a water logging, yet at the same time it does not go so down, that it becomes unsustainable for utilization. Then, at the same time what is your main purpose? Your main purpose is to make sure that all your agriculture demands are make to. So, you would like to use this water both surface as well as ground water, such that you are able to meet the irrigation demands, you are able to meet the municipal and industrial demands and so on.

So, whatever demands are there for this particular system you are able to meet them completely or with high reliability, and yet at the same time you are making sure that these conditions of ground water are maintained. So, this is the way we pose the conjunctive use problem. Now, how to convert this in to a mathematical statement etcetera will see, we will see in the subsequent classes. Right now, let us understand what type of problems types of problem that we address, typically in the systems analysis domain.

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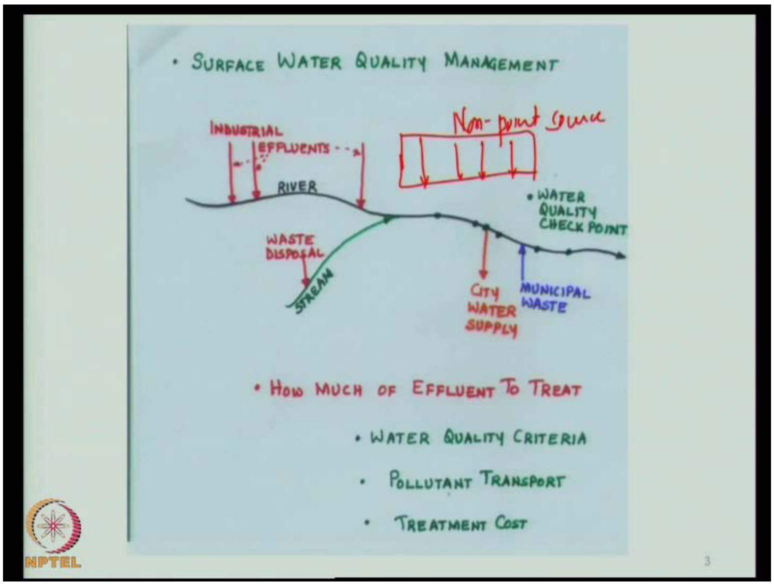

Let us look at just, for completeness will look at some other problem, as I was mentioning in the last class, as you go downstream of the reservoir where the river flows will be smaller, much smaller compared to the situation where there was no reservoir, if there was no reservoir the entire stream flow (( )) and then augmented the flow downstream, but the moment you put a reservoir, you are putting the block to that and therefore, the downstream flows will now only control flows. So, if you look at the river system like this, you may have several industrial effluents, you have another stream here. So, there may be effluents and then there may be a waste disposal, this may be waste and municipal disposals, and you would like to use the water from the stream for let us say city water supply.

So, you have a city to which you want to supply the water from this point, and this city also produces the waste and then puts it back into the stream with treatment or without treatment. And then you would like to maintain the water quality at several of these points called as water quality check points. So, what are the questions that you would like to pose, that you want to maintain this water quality at various points and therefore, you need to apply treatments at all these effluent points.

Now, in addition to these, there is also like I mentioned in the last class, there is also a non point source pollution that comes in like this, all through this river system there is a non point source pollution. So, we take (( )) this non point source pollution which cannot be controlled, but it affects the water quality, while it may not be controlled, it does affect the water quality at various locations. So, in addition to the point sources of pollution, you also are the non point source pollution and therefore, when you are asking the question of how much to treat at individual point source pollution. You need to look at the non point source pollution also.

Say for example, you want to maintain the water quality at this location where you are withdrawing the water for a certain purpose. Let us say municipal and industrial water supply. Although you may treat the water before supplying for the m and i that is municipal and industrial supply, even for drawing the water you would like to maintain certain water quality at this location. And therefore, you have to look at the stream points of this, and then see how much of treatment that is necessary at all of these points. So, the question that we pose is what is the minimum treatment level, that you want to provide at all of these locations, such that you are able to maintain water quality at specified points on the river system.

The pollutant transport from one point to another point in the river system is governed by the entire hydraulics of the system, it is also governed by the transport phenomena of the pollutants. Let us say that you are talking about the biochemical oxygen demand being put here. Then it respond in terms of lowering of the dissolved oxygen. So, we may be interested in maintaining the dissolved oxygen at certain level. And how the (( )) that is the biochemical oxygen demand, translates itself into d o at certain point; this process is fairly well understood, and we can put it in elegant mathematical form of if you have a particular d o level, we know what kind of d o level that exists at this location.

Now, using such mathematical forms, we pose the question of how much to treat at various locations such that we are able to maintain the water quality at pre specified levels. So, we meet the water quality criteria, and then we use a pollutant transport, and then we minimize the treatment cost; obviously, we cannot say you treat hundred percent, because the it is first of all not technically feasible and also it becomes economically unviable. And therefore, we look at those treatment levels which will those minimum treatment levels which will help us achieve the water quality at several location. So, this is one of the typical problems that we can address using the we need to address using the systems techniques.

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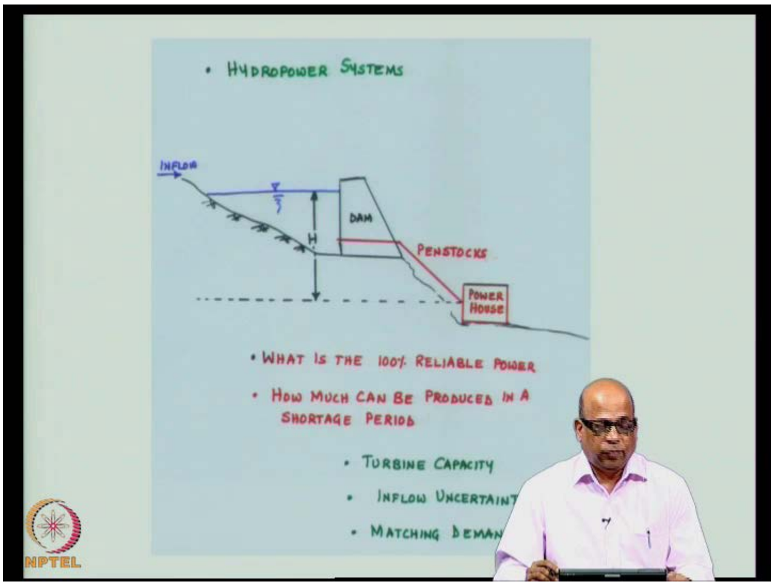

Then we look at the hydro power systems typically you have a dam constructed, and the upstream of the dam is the reservoir, and you have a drop natural drop that will be available, and you have a power house here. So, how do we produce the power from the dam, you release the water into the penstocks and then there will be a turbine here, because of the force created by this head, energy created by this head, the turbines are rotated and because of which you generate power. As you can see the power that is generated is directly a function of the head that is available, let us say this is a turbine level, and this is the reservoir level.

So, you have a head of h meters, and this will govern the energy that is generated at this power house. Not only the head, but also the discharge that you pass through the penstocks; so, there is a water flow that is taking place through the penstock and that also governs the power that is generated here, typically this is a non-linear multiplicative relationship, if we say that q is the discharge, h is the head then typically it will be a function of q into h. How much we can produce is the function of q into h.

Simple, simple as it seems; however, if you look at what is happening at this reservoir - the reservoir levels are governed by the inflows and then as you are releasing water into this, the reservoir level fluctuates, there is a inflows that is coming in and there is an outflows that is going out and therefore, the reservoir level is continuously fluctuating. As a result of it, the head h also start fluctuating. To produce a given amount of power here, for a given head, you need to pass in given discharge q, but because the head is dependent on the inflow head is also dependent on the discharge, the discharge is also dependent on the head, and so on, so there is a continuous interaction between all of these variables, we need to account for all these variables in a mathematical form before we can arrive at optimal decision are the best decision that are possible from such as system.

And what are the decision that will be looking for given the hydrology in terms of inflow, in terms of rainfall, in terms of the evaporation rites and the counter level certain are existing which govern the area capacity relationship at the reservoir, given all this features will not to maximize the hydro power. Maximize the an hydro power and that would be also govern by the plan capacity itself, you may have design the plan plan for a particular capacity of power production. So, no matter how much had you create, no matter how much discharge the pass through that particular that particular head, there is a maximum limit up to which you can produce the hydro power.

So, we put this conditions and ask what is the power that can be produce with hundred percent reliable or hundred percent dependence, what does that mean, that means that you want to produce the hydro power at that level hundred percent of the time. Given that the inflows or fluctuating still, you would like make use of a storage, and then produce the power that particular power hundred percent of the time. So, that question that we are asking is what is the hundred percent reliable power?

Then how much can be produce you know shortage period; let us say that the inflows are much smaller compare to the average inflows etcetera. Then, what is the minimum power that we can produce. So, this we need to address using the considering the variations in the inflow and the rainfall in the fragment area and so on. Then, you are doing this we need to look at the turbine capacity or (( )) we need to also look at the inflow on certainty, because this is govern by the rainfall and the rainfall is random in nature and therefore, the inflow becomes random. So, there is a uncertainty of the inflows, and then we also look at matching demands with the supply.

That means there may be a certain demands for power, and there is a supply of power which can be ensure to the hydro power considerations here. Then we need to match the demands and supply. So, this kinds of problems can also be posted as systems problems may be system optimization problems, system simulation problem and so on, and then arrive at the best possible basicalls.

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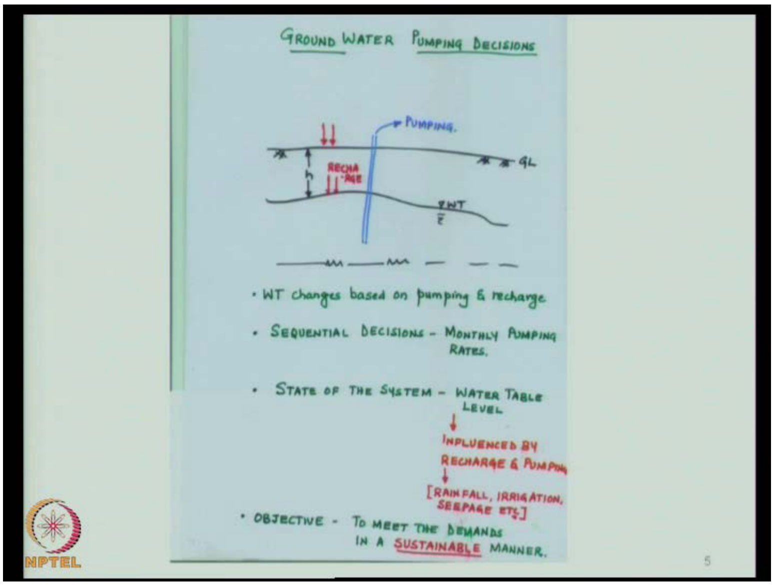

One more important aspect is on ground water pumping, let us say that there is no surface water source, and there is a ground water source that you want to use. Now, as you start pumping, let us say that there is a agricultural field here, we want to supply the water for agricultural field, and this is the water table of the x vapor, as a responds to the pumping, the head the pesometric head will be changing. So, the water table will respond to the pumping decisions as well as the recharge that is taking place.

So, given the dynamics of ground water levels, we need to look at what is a optimum level at which you can pump, such that the system is sustainable in some such. And you need to make these decision sequential, what I mean by that is that you make up decision you start pumping it as the response to that the ground water level changes, and then base of the change it level of ground water you again update are decision, and then there is also a recharge that is taking place there is an entire dynamics that is involved here, through recharge, pumping, the ground water response and then based on that you make the optimal decision.

So, as you progress entire from time period to time period to time period, you update the state of the system in terms of the water level and then make decisions. So, this becomes a sequential decision. So, these are the in a kinds of features of such a problem. So, the water table changes based on pumping and recharge which is obvious and this can be accurately, fairly accurately model. Then you need to make a sequential decision, let us say that monthly rate, pumping rates or may be seasonal pumping rates, how much you want to pump during (( )) season, how much you want to pump during double season and so on. So, there is a sequential decision that need to take.

Then we define the state of system, let say by water table level - the water table level itself changes and this are the influence by the water table level or influence by the recharge and pumping. And recharge itself is influence by the rainfall irrigation, seepage and so on, with all of these physical features has the problem, we want to meet the demand in a sustainable manner. Again the sustainable I mean, you should not allow the ground water to deplete beyond the point, and you should not allow the ground water to come in to the roots in causing water logging.

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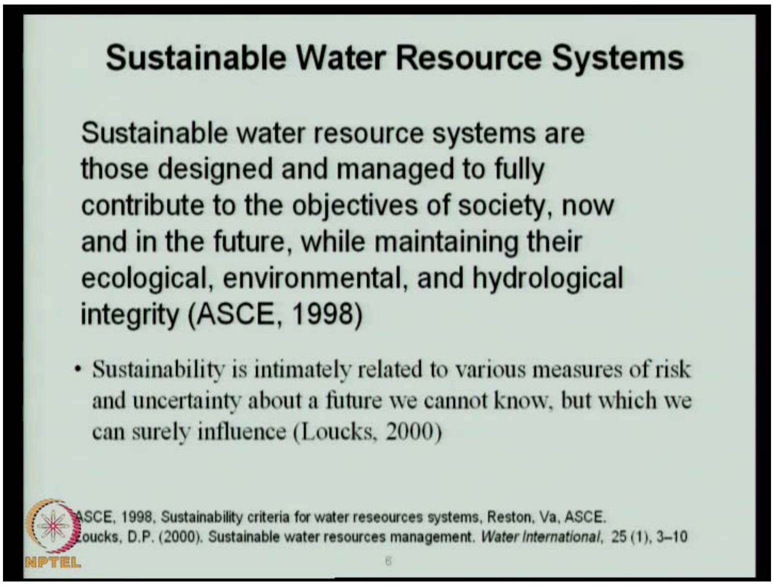

So, with that learn there are several problems at we discuss recharge on applicable, it can all be handled with system techniques. So, we just go one step ahead now, and when you are trying to model this systems, we should keep in mind with what purpose you want to model this system with what purpose, you want to operate and develop the particular system. Like I should in the previous class, you have a large river basin and you want to use the water of the river basin for the area of purposes, let say for hydro power for flood control, for irrigation purposes, for municipal and industrial demands and so on.

So, you want to use the waters from various purposes. When you are planning for the usage of water, you have to look ahead, and see how sustainable are your decisions. And what do we mean by sustainability in the broad sense like as said in the previous class, in the broad sense you would like to meet the demands today, tomorrow, and for the years to come, for the generation to come with the water that is available, yet at the same time ensuring that the integrity of a system, reverse system is not lost.

What do I mean by that you have the ecological aspects, you have the environmental aspects, you have the economic aspects, you have the social aspects etcetera. So, there is there is a certain amount of stability that reverse system has reach, you do not part of the stability too much. And that means, has to how we define the sustainability of water resource systems. So, only definition which is the useful definitions that will be generally using is, the sustainable water resource systems are those designed, and managed to fully contribute to the objectives of society; now, and in the future, while maintaining their ecological, environmental and hydrological integrity.

So, we are saving that you want to use the waters for the years to come, for the generation to come, but making sure, but we do not disturb the integrity of a system (( )) of ecological, environmental as well as hydrological, we are talking about hydrological integrity. Now, because we are looking at the future the sustainability is closely related to various majors of risk, and uncertainty. About the future, we cannot know which certainty, but which we can surely influence by backing decision today, we are going to influence, the decisions in the generations to come.

And therefore, we need to keep track of the the implications of the decisions that you are making today. In all water resource systems, when you are looking at optimal solutions, when you are looking at best compromise solutions etcetera, we must keep in mind the sustainability issues.

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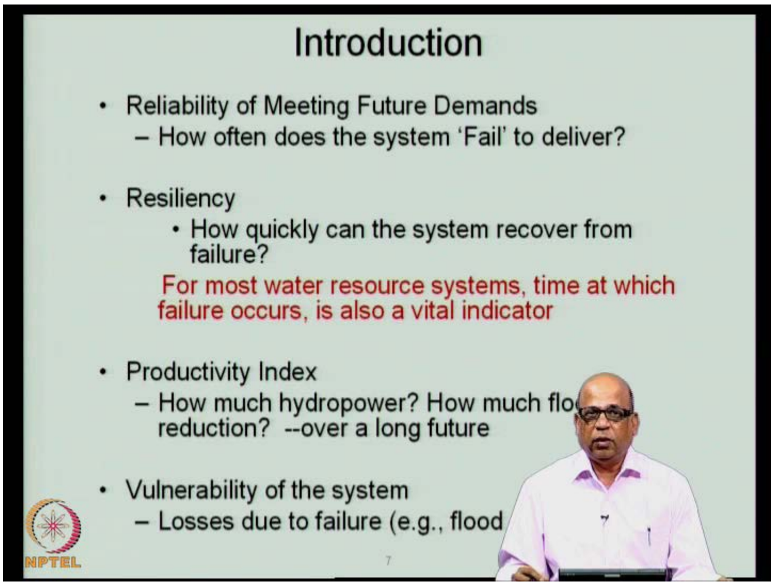

So, then when we are talking about sustainability, what kinds of conjugative images at we can think off. First has a said, we should able to meet the demands and therefore, we talk about reliability of meeting the demands. So, we make certain development replace, certain decision, certain operation plan and so on, such that the reliability of meeting the demands today, tomorrow and for the years to come is quiet high; which means we are asking the question, how reliable is the system?

In terms of its ability to meet the demands, as the first question that we ask. Then, in periods where the system fails, in terms of its ability to meet the demands; so, in there are certain periods in reach the system is unable to meet the demands. And these are the failure states, once the system enters into the failure state, how to click and in it re bounce back, recover from the failure. Now, that is the major of resiliency. So, we say how resiliency the system - how reliable is a system, in terms of stability to meet the demand; how resilient is the system in terms of its ability to bounce back from failure once a failure occurs.

In fact, in water resource systems, it is not just a amount of failure that is important as you can very easily see, it is also the time of failure, that is also important. For example, if you are looking at agricultural water supply, if the same amount of failure in in terms of the deficit of water supply occurs during different time periods, the crop response to be different during, the different time periods. And therefore, it is also important for you to understand, but it is not just the quantum of failure, but it is also the timing of failure that is important and resiliency of the system has to be building, has to be major both with respect to the quantum of failure as well as with respect to the timing of the failure.

Then, we will also have productivity index, let us say you have talking about agricultural productivity - you are talking about productivity in terms of hydro power (( )), you have talking about productivity in terms of the flood control that you have been able to achieve etcetera. So, the productivity is actually what is the return that you get out of certain distance to make; then he also have vulnerability our system. That means, that is a failure that occurs. And because of these failures, there are huge losses that take place.

Let us say that, you beat a system had flood control, but they floods did occur and then your system fail to control bus, the types of floods and because of which huge economic as well as likelihood losses takes place, and therefore the vulnerability of the system is directly related to the consequences after year. So, these are some of the major at we use, as the majors of sustainability. So, when when we are planning for water resources system operations planning, development and so on. We need to keep into keep in mind these particular majors, and there are several other majors as we discussed case studies, we will understand in the appreciate developments.

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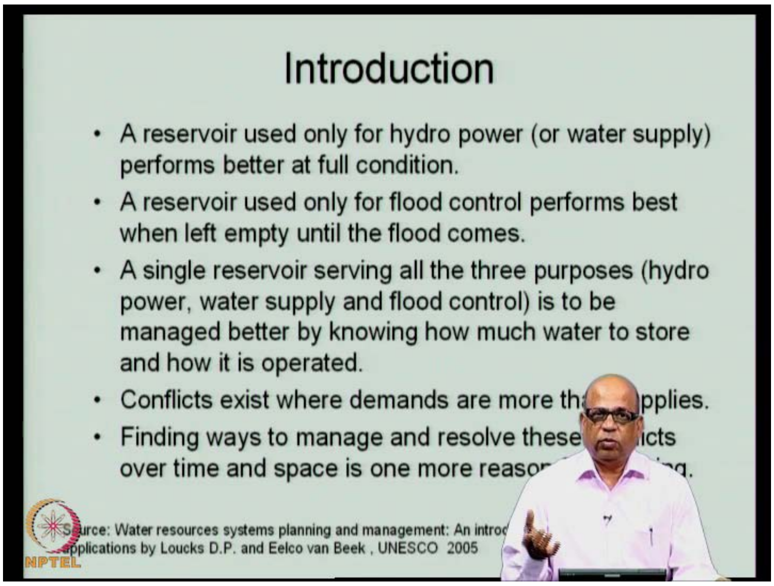

Now, typically whenever you are talking about water resource systems, as I mention in the previous class. We are talking about certain amount of storage, because you have create a storage, there are reservoir. Let us say that you may have one reservoir, two reservoir, multiple number of reservoir and so on in the river basin. Now, the reservoir typically some various purposes. And these purposes are often conflicting with each other. Let us say that, you have a reservoir which is main to serve the purpose of irrigation or agricultural or to meet the agricultural demand, compare this with what happens if the irrigation, if a reservoir is beat for flood control.

Let us say there are only two separate purposes - one is flood control, one is water supply for agricultural purpose. Now, the water supply purpose, we require that you store the water as much as you want as much as you can. So, that you can use the water during the periods of (( )) or the periods of meet, to meet the demands. Whereas for flood control the necessity is that you keep the reservoir levels at low as possible. So, that you can observe the flood waters from the flooding impact occurs. So, the flood control meets wants you to make the reservoir levels as low as possible, where as the irrigation makes wants you to make the reservoir level as high as possible.

So, these two are conflicting objectives. Similarly you consider hydro power. In hydro power you would like to maintain a high head, and therefore, high reservoir level. Whereas, the flood control again requires, the reservoir level is to be lower. And therefore, you need to address conflicting objectives of various purposes for which (( )) reservoir. So, that thing you just go throw it. So, reservoir that is used only for hydro power or water supply, performs better at full condition. As as you maintain your water levels high, it performs better and better.

The reservoir used only for flood control performs best when left empty empty and other flood conditions, because there is flood that is coming in, and you have created a buffer storage, the reservoir actually actually acts as the shock absorb in that case, where the entire flood waters can be observed as a storage. So, that the downstream areas is protected from floods. So, it performs the best when you have lower water levels or that is the storage available.

A single reservoir serving all the three purposes for example, hydro power, water supply and flood control is to be managed better by knowing how much water to store, and how it is operated. So, may be during the flooding season, you may operate it in a different way by which by through which you maintain, large amount of buffer storage and during the non flooding season when the water is actually needed, you maintain higher levels of storage.

So, this is a this is a conflict that system models. So, the conflicts exist where demands are more than supplies, you will say that there is a certain pattern of inflow, and then this pattern of inflow, we want to use it for a meeting the demands, irrigation, hydro power, municipal and area, industrial as well as the downstream water conflicts control, your demands because of these, you want to maintain that and if you are inflows or supplies much smaller than the total demands. Then there is a competition for water, among various users and these competitions can be built in to system owner.

So, finding ways to manage and resolve these conflicts over time and space is one more reason for planning. So, we do the systems planning mainly to make sure that the systems become sustainable, as well as the conflicts are result to the best (( )) possible. So, these are some of the features

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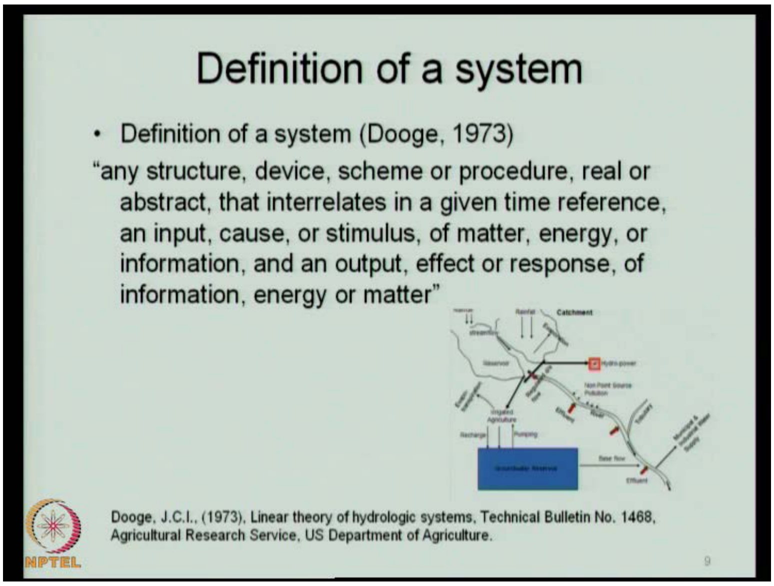

Now, we will go to more specifics. We are going to the second topic of the syllabus know, the first topic of introduction which I covered so far. Now, we will see, we will going to more specifics and start understanding what we mean by a system? A classical definition that we use in water resource systems and analysis is given by dooge, and this is the most accepted definition of system. So, let us go throw this. We will read this now, definition of a system as given by dooge, and this a reference linear theory of hydrologic systems taking Bulletin US department of agriculture. It says any structure device schema or procedure, real or abstract that interrelates in a given time reference an input cause or stimulus of matter energy or information, and an output, effect or response of information energy or matter. Very comprehensive definition that includes everything about a system; so, we are saying that you may have a structure, a device, scheme or simply a procedure.

It may be a real system or it may be a real situation or it may be an abstract situation. That interrelates in a given time reference an input cause or stimulus of matter energy or information, and an output effect or response of information energy or matter. So, in that sense let us look at the water resource system, example that we look later here. Now, we call this as a system. Let say that it has a structure. So, it has one structure here and it has a conceptual aquifer boundaries, which is also which also can be treated as a structure.

Then there are all functional components which are schemes for example, you may have a effluent discharge coming here, and non point source pollution coming here etcetera, so there all schemes. Then the resource structure for hydro power, and they there also fed by rainfall and stream flow, and that is a evaporation that is taking place here and so on. And then that is a municipal and industrial water supply that is taking place. So, there is a input here, and there is a cause for pollution here, and there is a stimulus in terms of the recharge that you are outputting here.

So, all of these components are interrupting with each other, and then you are producing an output in terms of the hydro power that is generated, in terms of the agriculture produce that you that you (( )) out of this and so on. So, in in the sense of this broad days to definition, the system that will just covered in the previous class, fix in well in terms of several of these components of these definition. So, that is a stimulus there, there is an input there in terms of reservoir in flow, there is also an output in terms of hydro power that is generated contributive output, there is also a response in terms of water quality and there is also a flow of energy as well as matter.

So, there is a flow of energy here, there is a flow of matter here. So, in that sense a typical water resource system, perfectly meet the definition of the system as given here. So, this is a bad level first cut definition of a system, depending on different situations, we may have several types of systems. So, let us see what are the types of systems at be typically considering in water resource systems. You may have, simple and complex systems. The simple systems are simple direct relation between input and output. Let us say I talking about, in flow to a reservoir generated by the rainfall. So, there is one input and there is one output. And there is a direct relationship, let us say we are able to build a direct regulation relationship between rainfall and runoff. So, that becomes a simple system. In the complex systems for example, we look at the system that you have here, this is a fairly complex system, if you are looking at the water quality at this location, you cannot directly related with only the flow that is coming here.

There may not be a direct relationship between the flow that is coming here, and the water quality here, because there are several other process that takes place which make the output at this location much more complex that is a simple direct relationship. What are this processes? There is a ground water flows that is coming here, there is a pollutant transport that is taking place between this point to this point, there are other pollutants there is a non point source pollution and so on , and so for. So, the a large number of possess will determinant the water quality at this location and therefore, this is not a simple system.

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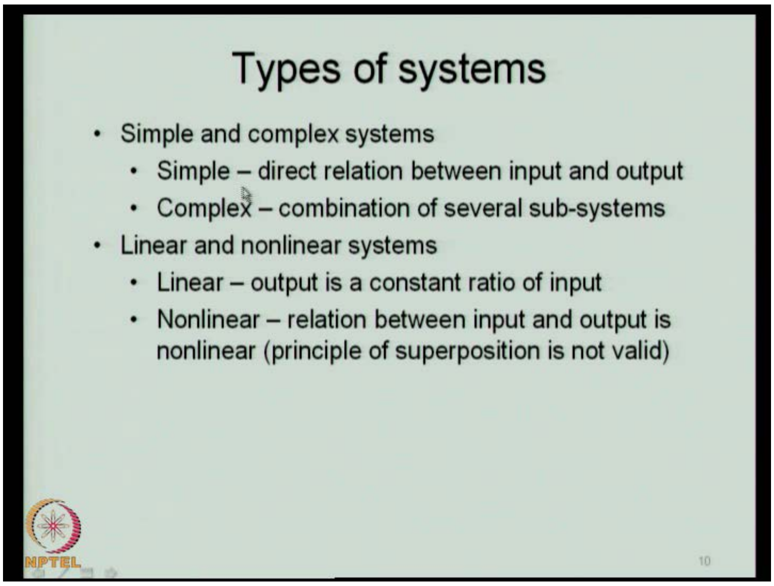

So, that defines simple and complex systems. Then you may have a linear and non-linear systems, the linear system is typically a linear function of the input that is output is a linear function of the input. It is a constant ratio for example, if you are looking at runoff as a linear function of rainfall. So, it becomes a linear system. In linear systems, the super pollution, principal of super pollution is valid, those who are go through the hydrological courses will know that the unit hydrograph theory is in fact a a unit (( )) in fact on linear system. Where the principal of super position will be valid. In non-linear systems the relationship between input and output it becomes non-linear.

So, very simple definition, let say you again you look at water quality at particular point. The b o d, d o d relationships here are all non-linear. So, you put a load here and you want a major, the output in terms of the water quality at this location that relationship is a non-linear relationship. And in the non-linear systems the principle of superposition is not valid. There is a whole theory for linear systems you will not at this point worry too much of about that, and those who have gone through the applied hydrologic course would know more about the linear systems.

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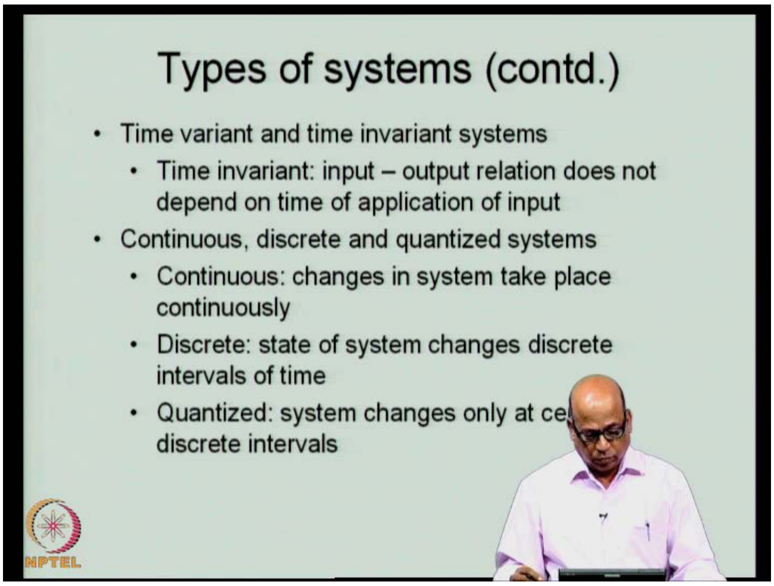

Then we have at time variant, and time invariant systems. In the time invariant systems with respect to time, the system parameter system behavior is change it. And typically all water resource systems are time in time invariant systems. Let me repeat that, in the time invariant system, the system behavior does not change with respect to time. Time variants system it varies with respect to time. In many situation you may have in fact, time variants system where you need to account for different types of behavior during different time periods; however, there are situations where we would like to approximate this as a time invariant systems, because of the simplicity with which you can handle the time invariants systems.

Then you have continuous, discrete and quantized system. In a continues system, the changes in system take place continuously. Typically you look at the inflow relationship - inflow cause by rainfall. As the rainfall occurs the inflow with responding continuously in in a continues stand manner. There was in the discrete systems, the responses of the system will be only occurring at discrete time periods. Let us say that you are talking about monthly operations of a reservoir. So, every month although you are operating it continuously, you are recoming change in the system in a discrete time intervals.

So, every month you will major the water level, and then say that this much amount of water has gone during this particular month, and the reservoir level has change from this state to this state. So, although the change would have in fact occurs continuously, you will (( )) the changes only at discrete time intervals. Then there are quantized systems where system changes only at certain discrete intervals. Typically in monsoon climates let say that you say the seasonal change in the ground water level - seasonal change in the reservoir level, because throughout this season something as happen and therefore, there is a condom change in the system at the end of the season. So, in quantized systems we take only discrete intervals, and then there is a quantum jump or quantum change in the state of the system.

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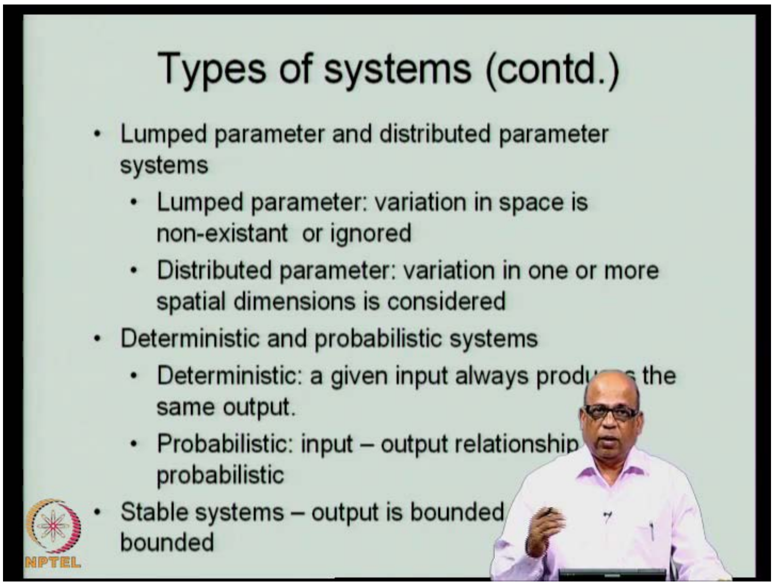

Then you have lumped parameter system, and distributed parameter system. As the name indicates, the lumped parameter you do not consider the variation in space, let us that you have a large river basin, and you have a several rain gauges there with all indicate that there is a spatial variations in the rainfall pattern in the river basin. However, you do not account for the spatial variations, you take only an average rainfall over the entire basin and then say that this is rainfall during the particular time periods. The spatial variations of the the of the various possess that or of interest or ignore. So, that is called as a lumped parameter system.

In the distributed parameter system, you may account for certain parameters or certain variables, the variations, spatial variations of these certain variables, and the parameters across space. For example, you have talking about distributed hydrologic model where from one sub basin to another sub basin, the parameters are changing, parameters in terms of storage coefficient, transitivity in terms of your runoff coefficient and so on. So, these may be changing from one point to another point and you would like to account for the spatial variability of these parameters and variables then you becomes the distributed parameter system.

Now, when we say distributed parameter system, it does not necessarily mean that all the parameters, all the variables are accounted for as distributed parameter or variable. We may choose some important parameters and variables and then account for the spatial variability of those particular parameters or variables. Then, we have the deterministic and probabilistic systems. The deterministic systems will always provide the same output for a given input; that means, like say that you look at to the (( )) type of models, x is equal to u t plus half a t square, you give a particular u which is a initial velocity the time and an exaltation a no matter when you applied, no matter where you applied, you always get the same yes.

So, these are called as the deterministic systems whereas, you look at any typical natural systems, in a typical water resource system, you provide the same input today, and tomorrow, the output that you get today will be different from the output that you get tomorrow. Or in terms of let say rainfall and runoff. You pay the same rainfall, you get different runoff during different time periods. So, they become uncertain or probabilistic systems; there are ways of handling, the probabilistic systems will cover this during this particular course. Then the you have the concert of stable systems, like the intitude understanding of the stability that you pattern the system, the system does not get, getting to an instable or unstable condition is still becomes is still is stable, which means that, if your input is bounded that you provide the input in certain range, the output is also bounded, output does not become unbounded.

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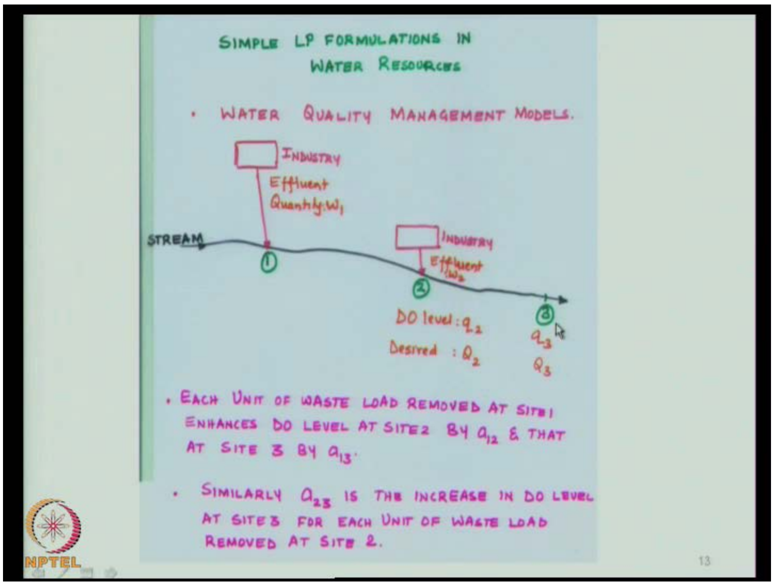

So, that becomes that defines the stability of the system. With that now, you have understood what we mean by a system, what are the characteristic of water resource system - what are the different types of system at will come across - how we classify them and so on. Let us start going into slightly more detail, more specifics of how we formulate this problems. I need not over emphasize the importants of correct formulations of the problems, you have a good physical understanding as the problem, that when you want to put it in to systems model, the correct formulation of the problem is extremely important.

We will start with a simple the problem, and see how this can be posed as a mathematical problem. We will again the revisit are water quality management problem, there you have extreme and let say there are only two industries here. Industry number one and industry number two. The industry number one puts an effluent quantity as w 1. So, there is a volume or weight of the effluent that is coming here. Similarly, industry number two is producing another effluent waste w 2 and it is putting at location number two. You would like to maintain the water quality at location number three, which means that you would like to use the water at location number three for some purpose.

Let say thus this simple problem, we will use the desired oxygen has one of the indicator of the water quality indicator. Because input a, effluent quality quantity w 1, there is a d o level or the desired oxygen level of q 2 are just location, and q 3 as just locations small q 2 and small q 3; you put a quantity of w 1 here, w 2 here as a result of (( )), you get a d o level of q 2 here, q 3 here which would be a function of several physical variables for example, the entire hydraulics of this relative (( )), the winds speed temperature and so on.

So, there are large number of variables at are affecting this level q 2 and q 3. But let us assume that we know what is a q 2 and what is a q 3 for the existing loads for w 1 and w 2. But you would like to make the desired oxygen level higher than what you have what here q 2 and q 3; so, you have a desired desired oxygen level of capital Q 2 here, and capital Q 3 here which means that you want to may improve the water quality from the small q 2 to capital q 2 here, and small them from small q 3 to capital q 3 here. How can we improve this water quality by applying treatment levels at this location which means that instead of saying I put w 1 here, I am a put w 1 into one minus x 5 which means I treat w 1 into x 1 amount of water, amount of effluent I am sorry, and then leave out only w 1 in to 1 minus x 1.

Let say I treat twenty five percent of it, I am leaving out seventy five percent. And similarly at w 2, I will treat certain fraction of that and then leave out the remaining part. So, that the water quality improves at this location. So, this is the problem. And then you ask the question how much should be x 1 here, and how much should be x 2 here; that means, what is the level to which I should treat at industry number 1, and what is the level to which I treat at x industry level industry number two, such that the minimum water quality that I get at this location is capital q two, the minimum water quality that I get at this location is capital q 3.

And then we would like to maintain the treatment levels at really the base minimum which means that you would like to minimize the cost of treatment. So, we pose the question as what are those minimum treatment levels at industry 1 and industry 2 which will make our water quality at desired level q 2 here, and desired level q 3 yet at the same time they are the minimum cost solutions.

Now, this is a problem and we will see how to formulate this simple problem as a systems problem, and typically I demonstrate this as an optimization problem where this we will do in the next class. So, this is just an understanding of how how we first understand the physical nature of the problem is, and how we clearly define in linguistic terms, what is that that you are interested in. And then once we are clear and what is that there were interested in, we convert these statements in to mathematical statements, put conditions, and put certain functions functional forms which can be optimized.

So, in summary then in today's class, you have seen now again continuation of the previous lecture, we have seen different types of problems that we come across in water resource systems. Typically starting with conjunctive use of surface, and ground water where you would like to maintain the ground water level within certain range and yet at the same time you would like to meet by irrigation demands municipal, and industrial demands and so on. Similarly ground water pumping, similarly we have seen problems of water quality maintenance, water quality maintenance at various locations in the river system.

And then we introduce the important concept of sustainability of water resource systems where we say that you manage, operate and develop a water resource system such that you are able to meet the demands today, tomorrow and for the years to come without sacrificing, the ecological, environmental and hydrological integrity of the system. In fact, the socio economics integrity also comes in today. And then we introduce the concepts of reliability, resistancy, vulnerability and other major of sustainability, and towards the end I just introduce the different types of systems, how we define a system and how what different types of systems that we come across generally; these will include linear systems, non-linear systems, deterministic probabilistic systems, simple systems, complex systems and so on.

Now, all of these concepts will become clearer and clearer as we start analyzing specific water resource systems. So, towards the end of the lecture, I just introduced the simple problem where we are interested in minimizing the treatment cost, while maintaining the water quality for just as simple system consisting only of two discharges and therefore, two decisions only is what were interested in. For this simple system, we will see in the next class, how we formulate the physically stated problem into a mathematical problem. Thank you for your attention.