Advanced Hydrology
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Lecture – 1

Good morning and welcome to this video course on Advanced Hydrology. My name is Ashu Jain, I am Associate Professor in the Department of Civil Engineering at IIT, Kanpur. If you would need to contact me for any reason for clarifying any doubts or you know asking any questions you can contact me through e-mail at this address. If you can remember my name Ashu Jain that is a s h u j a i n at IIT k dot a c dot in and you can also call me at this number.

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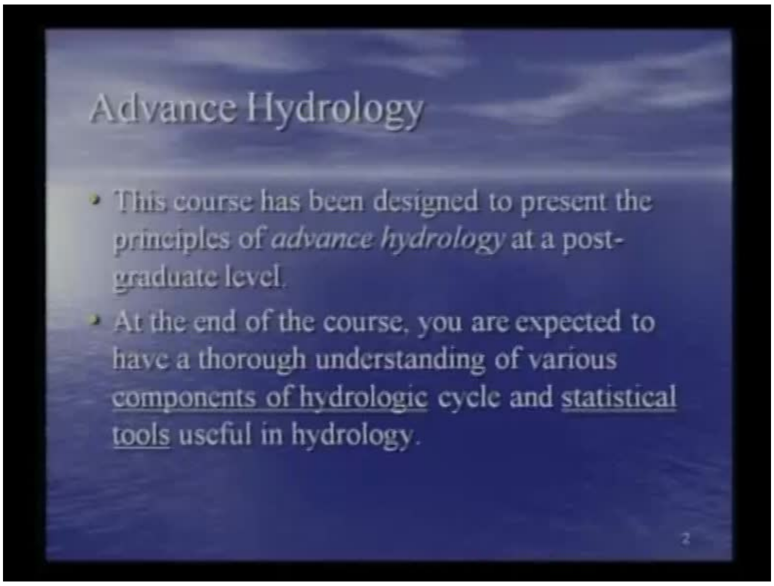

This course has been designed to present the principles of Advance Hydrology at a PG level or a Post Graduate level. The basic knowledge of hydrology would be desirable in this course; however, it would not be necessary. At the end of the course a serious student is expected to have a thorough understanding of various components of the hydrologic cycle and the statistical tools that are useful in hydrology.

I have underlined the components of hydrologic cycle and the statistical tools, which basically meets that there are two components of this course. In which one we would look at the components of the hydrologic cycle from the conceptual point of view and other is from the statistical point of view.

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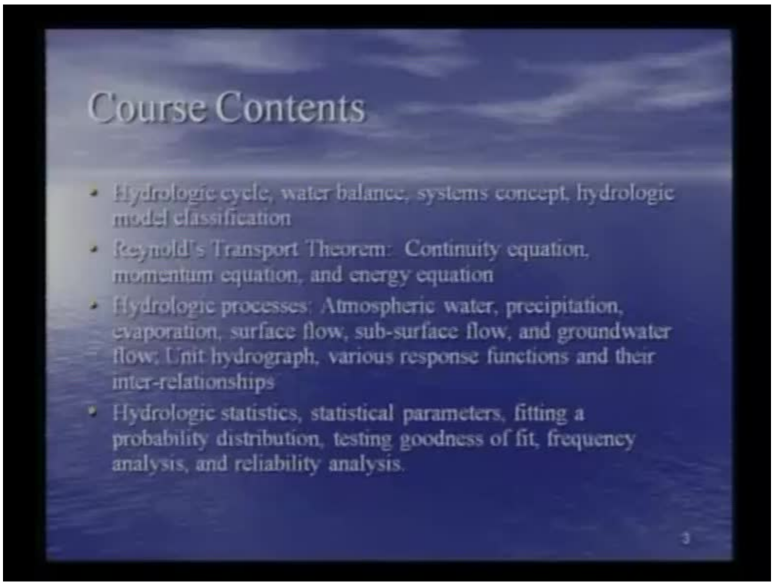

Coming to the contents of the course I would like to just give you a very brief background about the course initially, these are the contents. First we will look at the hydrologic cycle the water balance, systems concepts and hydrologic model classification. Then we would look at what is called a Reynolds transport theorem it is a basic equation which moderns the moments of fluid any kind of fluid and in our case it will be water. And all the three basic equations that is continuity equation, momentum equation and energy equation can be derived from this Reynolds transport theorem.

Then we would look at the hydrological processes, that is atmospheric water, precipitation, evaporations, surface flow, sub surface, flow and ground water flow. We would go into the hydrograph analysis that is unit hydrograph and various response functions and their inter relationships. Then we would be moving to hydrologic statistics in which we would look at the statistical parameters how effect a probability distribution to a given set of data, testing the goodness of fit frequency analysis and carrying out the reliability analysis.

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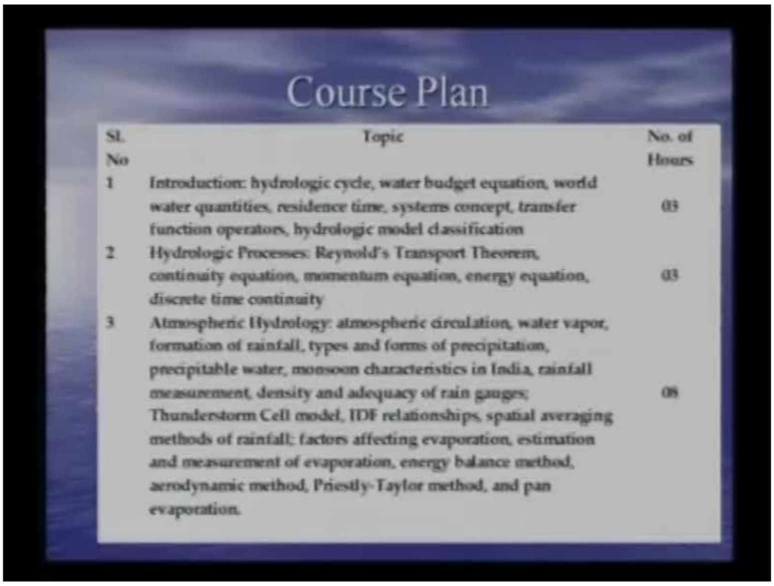

Now, coming to the course plan that is basically a some detailed topics and approximate number of lectures in each topic. Among the introduction we would look at the hydrologic cycle, the water budget equation, the revolve water quantities, residence time, systems concept, transfer function of waiters hydrologic model classification; all of this I expect to take about three lectures.

Then moving to the hydrological processes we would look at the derivation of the Reynolds transport theorem. Then derivation of continuity momentum and energy equation from the Reynolds transport theorem, and we will look at the discrete time continuity this is expected to take about three lectures. Each lecture would be about 1 hour then if the third module we move to the atmospheric water or atmospheric hydrology.

In which we would look at the atmospheric circulation, water vapor, formation of rainfall types and forms of precipitation, perceptible water, monsoon characteristic in India, the rainfall measurement density and adequacy of rain gages. Then we would look at what is called a thunder storm model out of which we will get the rainfall intensity we will derive an expression. Idea of relationship that is intensity duration, frequency, relationships, special averaging of rainfall, factors affecting evaporation.

Estimation and measurement of evaporation energy balance method aerodynamic method and Priestly-Taylor method and plan evaporation. All these things will take about eight lectures.

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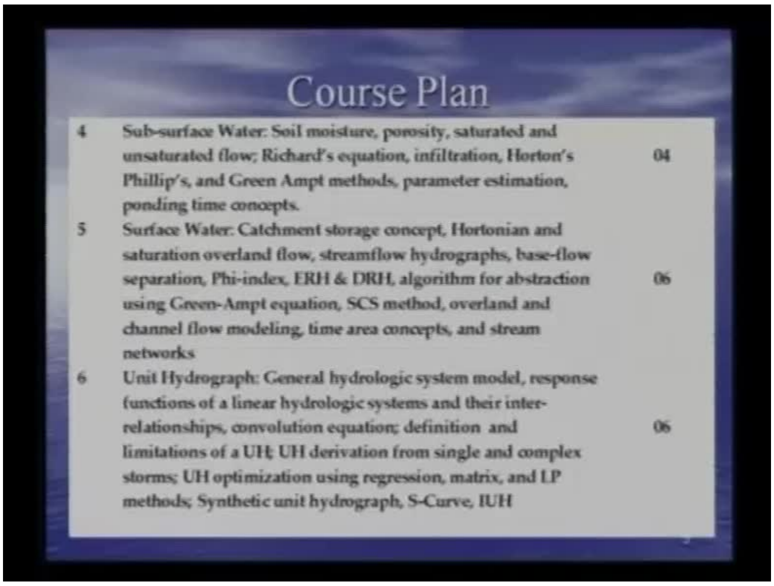

Continuing the 4th module will consist of subsurface hydrology in which we would look at the soil moisture, profile the porosity, saturated and unsaturated flow, Richards equation, infiltration, Horton’s equation and Philips equation, Green Ampts. And then parameter estimation and founding time concepts, all of thiswill take about 4 lectures in surface water we would look at the catchments storage concepts, the hortonian and saturation overlain flow concepts, stream flow hydrographs, base flow separation, pie index ERH and DRH concepts, algorithm for up section using Green Ampt equation SCS method overland flow and channel flow, modeling, time area concepts and the stream flow networks.

All of this would take about 6 lectures, then we come to the hydrograph analysis in which we would look at the concept of unit hydrograph the general hydrologic system model concept, the response functions of a linear hydrologic system and their inter relationships. The convolution equation the defilation and limitations of the UH and instantaneous unit hydrograph, the derivation of the unit hydrograph for a single and complex storm.

And optimization of a UH using the data and different techniques such as regression and linear programming methods. We would also look at this synthetic unit hydrograph towards the en, so all of this we will take about 6 lectures.

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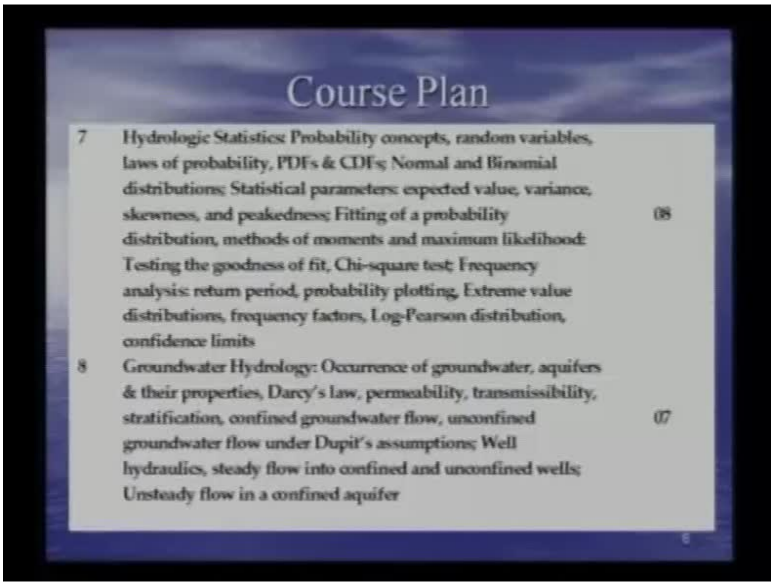

Then we move to the hydrologic statistics in which we would look at the probability concepts, random variables the laws of probability PDF's and CDF's, normal and binomial distributions, statistical parameters, the expected value variance skewness and wickedness, fitting a probability distribution methods of movements and maximum likelihood. Testing a goodness of fit using the chi square method and probability plotting method, extreme value distribution frequency factors, lock Pearson distribution, etcetera.

And this is expected to take about 8 lecture, towards the end of this course we will move to the ground water hydrology and we would spend about 7 hours in that. In which we would look at the occurrence of ground water aquifers and their properties Dancy's law permeability, transmissibility stratification and confined ground water flow, unconfined ground water flow, under dupe's assumptions. Well hydraulics, steady flow into the confined and unconfined wells and unsteady flow in the confined aquifers.

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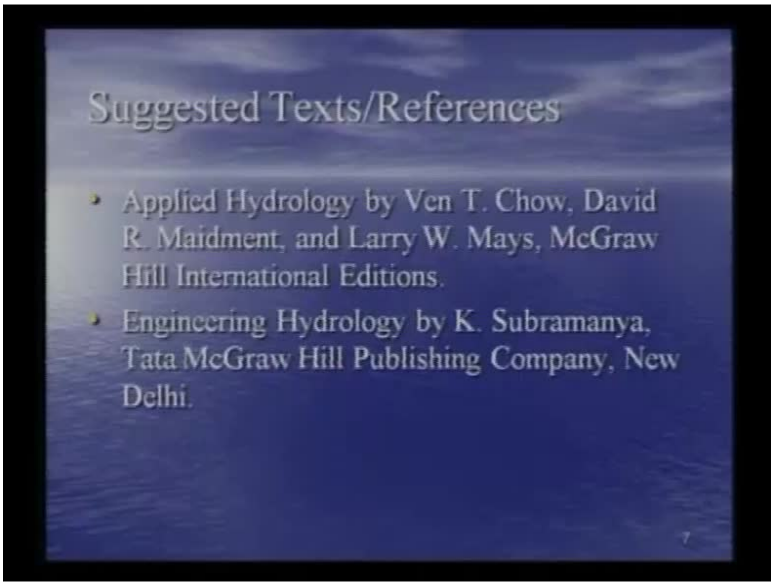

For this course I will be following these books mainly applied hydrology by a Ven T Chow, David R Maidment and Larry W Mays, which is published by the McGraw Hill publications. And the second book for the reference I would like to follow in the course is a engineering hydrology by K Subramanya it is published by Tata McGraw Hill publishing company in New Delhi.

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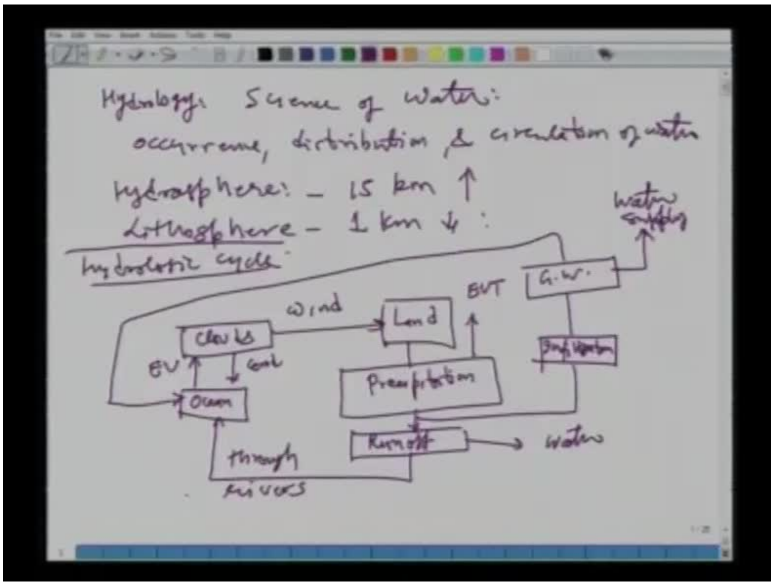

So, with this brief overview of the coursewe would like to get started. So first of all we would look at the name suggest the name of this course is advanced hydrology. So, the first question I would like to answer is, what is hydrology and how do we define hydrology. As a layman or for any person what is hydrology, first we will look at the definition of hydrology. For a layman what is hydrology is simply science of water; however, if you get little technical, what is hydrology? Is it is defined as the occurrence, distribution and circulation of water.

As we know the water is constantly moving in different parts of this earth in the atmosphere, on the land and in the ground. When we talk of the occurrence distribution and circulation of water, it may be either in the gasses phase or in the water vapor form or in the liquid phase. And when we talk of it is circulation it is in the hydrosphere, in the atmosphere that is about 15 kilometers above the earth all right. So, as a practical hydrologists we are interested in the movement of water about 15 kilometers from the ground into the atmosphere.

Into the ground we are focus more on the lithosphere which is about 1 kilometer below the ground. Whenever we talk about a hydrology any book you follow you will deal with what is called a hydrologic cycle, as we know that the water is constantly moving in different parts of the hydrologic cycle or different phases on the earth, it is a closed loop system in which the water starts evaporating from the ocean. So, what we will do is we will look at this hydrologic cycle, let us say starting from ocean.

And then we may also have condensation, due to the heat energy that is provided by the sun, the water starts evaporating from oceans in the form of clouds and due to the wind action, it moves over the land masses. And the onto the land it will precipitate in the form of precipitation and this precipitation can be in any form either a various forms of precipitation which we will at later in this course.

So, it could be either rain, it could be hell snow andmany other different forms, part of this precipitation again and become evaporation or from land it will become evapo transportation and part of it will become what is called run off, what happens to this run off. This run off finally, goes into the ocean through streams and rivers and part of this precipitation, which falls on the earth becomes infiltration. Infiltration is the part of the water or precipitation that goes into the ground, as we know and this done percolates deep and goes into a ground water.

This ground water also after a very long time in the form of base flow goes back to oceans through the rivers and streams are on the land, from the ground water, we do some manualinteraction and then we take the water out or water supply and from runoff also we take water manually for differentvarious purposes. So, we see that the water is moving in different parts of the earth in various phases in liquid as well as gases phase and all of these interactions is extremely complex and thorough understanding of the basic governing principles of movement of this water are necessary to model the hydrologic cycle.

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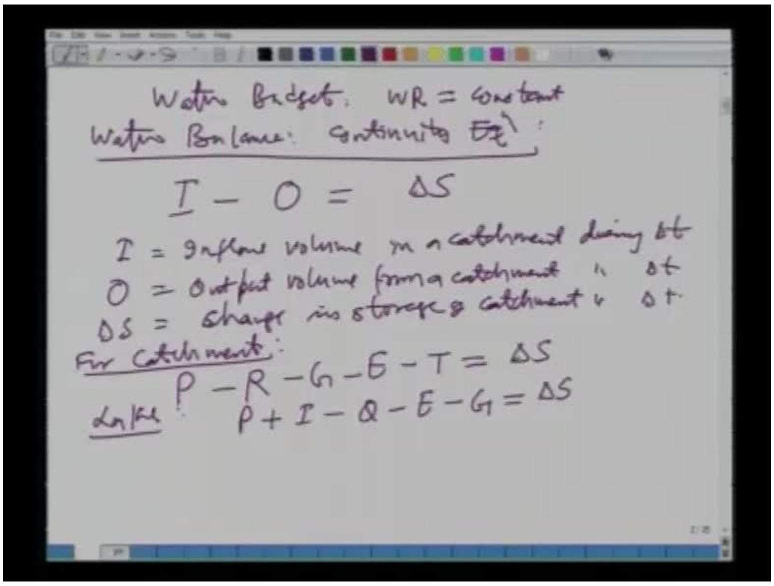

Before we move on we would like to look at the basic concept or one main fact about this hydrologic cycle is what is called the water budget. It says that the total amount of water or water resources are constant, when we say the total water resources are constant we mean that we are applying what is called the water balance equation or famously it is known as the continuity equation. The continuity equation which can be applied to any phase of the hydrologic cycle basically states that input minus output is the change in storage.

Now, this equation as we see it should be dimensionally homogeneous, so we define our I is the inflow volume in a catchment duringtime delta t. So, we are writing this equation atsome particular time duration delta t, which could a day, which could a week, a month or even and year. Similarly, O is the output or outflow volume from a catchment during the same time delta t and the delta S is the change in storage of the catchment during the same time delta t.

Now, this equation can be applied to any small component of hydrologic cycle for example, we can apply this to the whole catchment or we can apply this to a small reservoir or dam or we can apply this to under ground water or any different parts of the hydrologic cycle. So, for catchment we write difference inputs and outputs which are physically existing in the catchment.

So, the main input is the precipitation there could be runoff out of it, the ground water flow component, the evaporation, there may be some transpiration and all of that should some equal to the change in storage in the particular catchment. We can apply this to the lake in which we will have precipitation in a lake plus there may be some upstream inflow all right, water coming as the surface runoff into the lake minus there may be some surface outlook from the lake.

There will be some evaporation, there may be some seepage loses and all of that should be equal to the change in. And this is a very useful equation continuity equation or the water balance equation to, which we can manage our resources for a lake or for a dam or any catchment.

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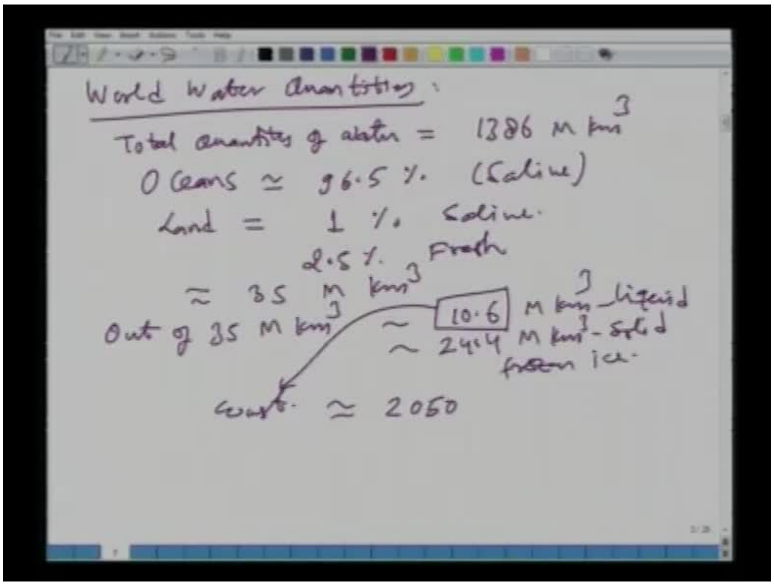

Moving on the next thing I would like to look at is the importance of hydrology in the form of what is called world water quantities. The total quantity of water that is available on earth is approximately 1386 million kilometer cube this includes all the water that is available on the earth. We know most of it contains in oceans, which is approximately 96.5 percent and as you know that the sea water is saline, and it is not useful for human consumption or for any useful purpose for that matter.

So, the remaining water which is on the land out of that 1 percent is saline. So, we have about 3.5 percent of water on land, which is saline and not useful again, that leaves us about 2.5 percent of the total water which is fresh water on land, which will be useful. And this comes out to be approximately 35 million kilometer cubed of water, which is fresh on the land.

However, out of this 35 million kilometer cubed of water approximately 10.6 million kilometer cube is liquid and the remaining about 24.4 million kilometer cubed of water is solid. And the solid water is is in the form of frozen ice and it is contained on the or exists on the mountain tops in the form of fleshers and frozen ice in the polar region.

So, this is all the water we have that is available for us or any kind of water management on the earth this water has remained constant over the years. And certain united nations approximations or estimations suggest that this will be sufficient up to 2050 why because the because of the industrial growth and economic you know expansion and. So, on the consumption of water is increasing everyday population is also increasing, so we do have sufficient water today, but the demand will exceed the water supply by about 2050.

So, we need to utilize our water resources we need to understand the various forms of water how it is occurring. So, that we take care of it very carefully and we use it optimally using engineering methods.

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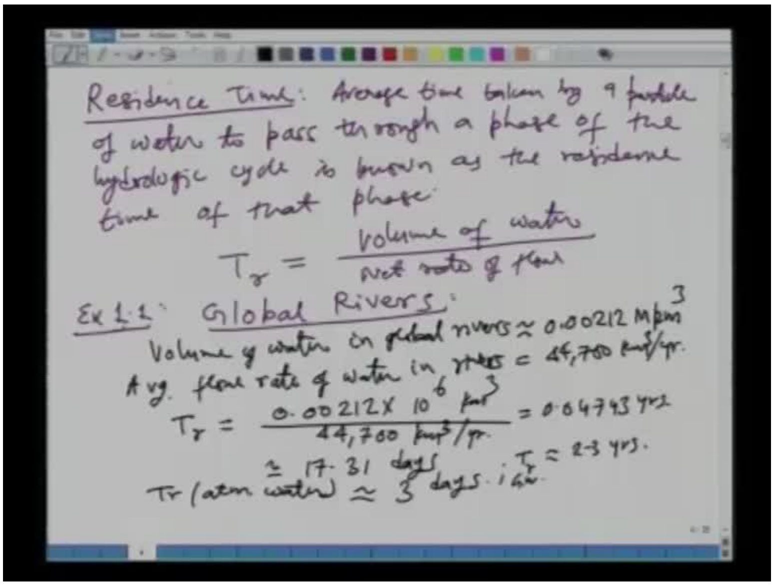

Moving on the next I would like to look that if very important concept of what is called a residence time as we have seen in the hydrologic cycle that the water occurs in the atmosphere, in the rivers, underground, in the oceans and various places on the earth. However, it will spend different amount of time in each phase of the earth and residence time will help us in understanding and modeling that particular phase. First of all looking at the definition it is the average time taken by a particle of water to pass through a phase of the hydrologic cycle is known as or is called the residence time of that particular phase. How can we calculate it, this is nothing but the volume of water in that phase divided by the net rate of flow in that particular phase.

So, what we will do next is I would like to look at an example of how we calculate the residence time and we will look at the example of the global rivers. If we look at the residence time of global rivers we can find the volume of water in global riversapproximately as 0.0021 million kilometer cube. And these numbers I am taking are from united nations approximations and we will look at them little later. The average flow rate which has been estimated of water in the global rivers is approximately 44,700 kilometer cube per year, as we see that the time duration here is annual or 1 year.

So, we are approximately, we are approximating the total amount of water that runs off or the runoff or total volume in in all the rivers of the world taken together if we sum that all of it will be approximately 0.00212 million kilometer cube. So, using these two numbers we can find out the residence timeor global rivers as 0.00212 time 10 to the powers 6 that is kilometer cube divided by 44,700 kilometer cube per year and that will come out to be about 0.04743 years and approximately 7.31 days.

So, this way we can find out or we know that on an average approximately when the water enters any of the rivers, it spends about 17 days in that river and this number is as I said global average in different parts of the world this number may vary. So, rivers which are very steep it may be less time and very flat long rivers it may be slightly more but on an average that is (( )) how this number is useful. We can compare the residence time for example, for atmospheric water if we find it out using the united nations approximations of total volume of water in the atmosphere. And the average flow rate that is precipitation or condensation it comes out approximately about three days.

So, in the atmosphere the water spends about a 3 days and the rivers it spends about 17 days. So, it tells us about the accuracy of the hydrological modeling for example, the atmospheric water system is highly dynamic all right, it the atmospheric conditions or the climatic conditions can change dramatically within a matter of hours, in fact all right. So, that kind of system will be difficult to model as compared to the other system which is or in which the residence time is more or water spends more time. Similarly, if we find out the residence time these are just approximate numbers I am writing for ground water it is approximately of the order of 2 to 3 years. What does that mean is once the water enters into the ground it takes about 2 to 3 years to come out of it all right. So, it spends a lot of time all right, so it is easy to track it is movements and carry out the modeling process.

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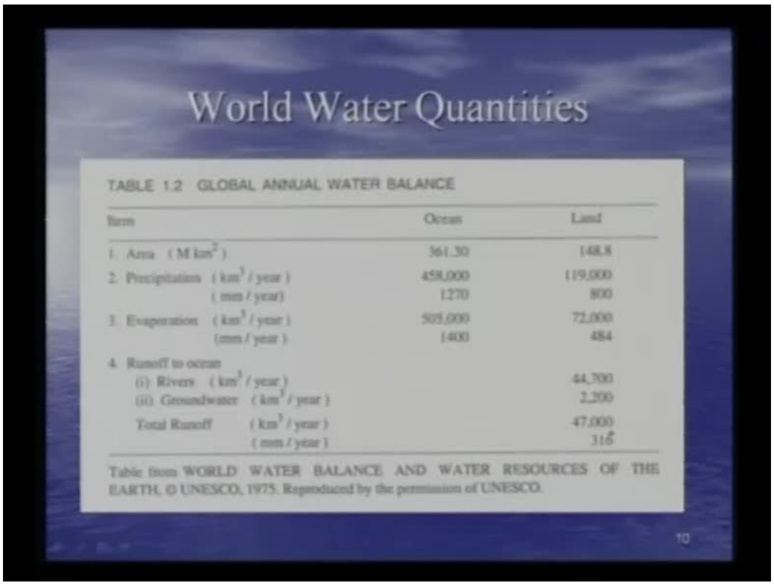

Now, as I was taking about how we get this number is using the world water quantities or this data from the united nations approximations. This table shows the global annual water balance in different parts of the earth for example, runoff to ocean you see rivers kilometer cube per year, which we just took in this example is 44,700 in ground water it is 2,200 that is the approximate rate of ground water flow towards the ocean, total runoff is that much and in millimeters per year is that much.

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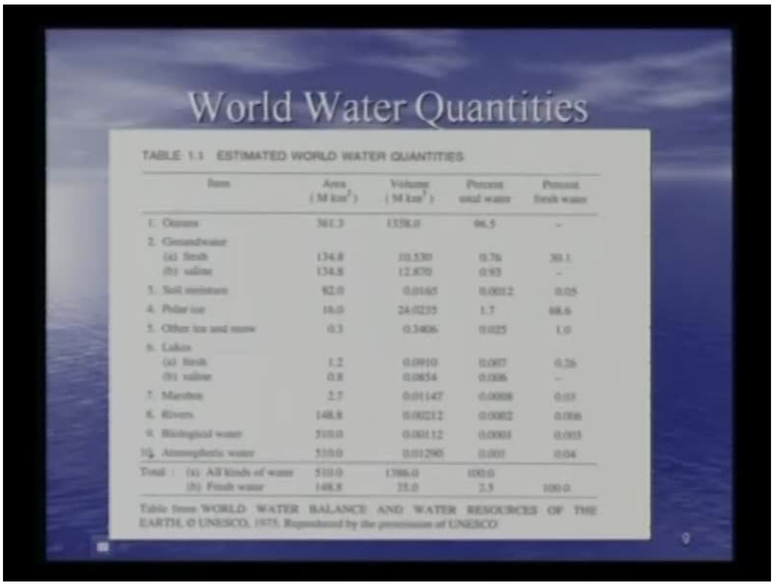

So, we see that these are the world water quantities which united nations has approximated which are very Hendy in making certain calculation. The other table which is estimated world water quantities, it talks about the total volume of ocean water is 1338 million kilometer cube and it is the percentage of total. Similarly, the ground water we see the fresh water is about 10.53 million kilometer cube which forms about 0.76percent and so on.

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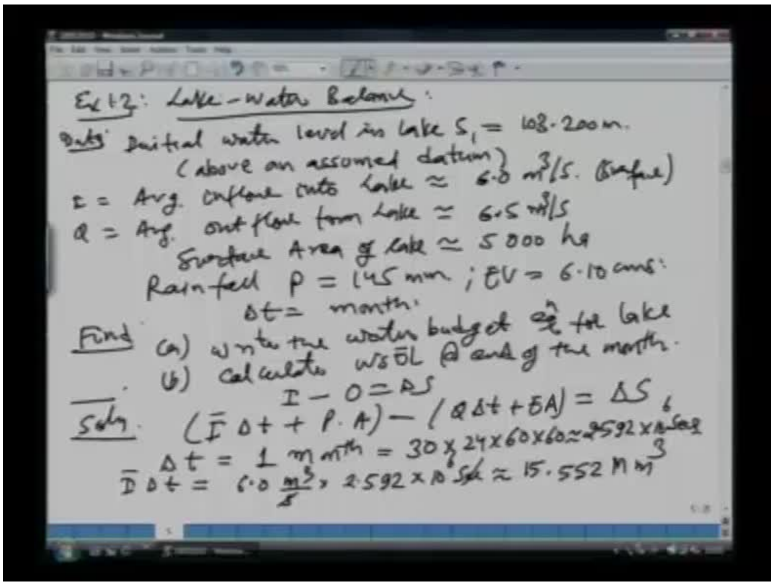

So, moving on now we will look at an example of lake water balance we looked at the water budget equation for the catchment, we will look at the lake water balance. How the continuity equation can be extremely useful in finding out different components or estimatingsome of the things, which will help us in managing the water resources. The initial water level in the lake is given to us let us say it is S 1 is 103.2 meters and all these numbers are above and assumed datum. The average inflow these are the data which are given to us into the lake is about 6.0 meter cube per second and it is from surface sources.

The average outflow from the lake that is given to us is 6.5 meter cube per second. So, this is your let say I and this is your Q the surface area of the lake is given to us about 5000 hectors the average rate of rainfall in the month on the lake, P is about 145 millimeters. And the rate of evaporation is about 6.10 centimeter and the time period we are looking at is a month all these numbers are during a month.

So, these are the data or what is given to us and what we have to find is a write the water budget equation for the lake and b calculate the water surface elevation at the end of the month. To solve this problem we just need to write continuity equation that is inflow minus outflow is equal to change in storage. And inflow components are given to us and there are two inflow components in this case one is the surface inflow and another is the precipitation.

And as far as the outflows are concerned there is surface outflow q and also the evaporation. So, if we write the water budget equation this is the general continuity equation or we can write I bar delta t plus P times a this is I where I bar is the average rate of inflow into the lake and we multiplied this by the delta t because the equation has to be dimensionally homogenous. So, it is in volumetric units and then precipitation is in the length units. So, we need to multiplied this by the area of the other surface area of the lake, minus Q delta t plus evaporation these are the outflows from the lake and all of that has to be equal to the changes storage. So, this is your equation or answer to the part a of this equation.

Now, delta t we know is 1 month, we can convert it into seconds, so it will be assuming 30 days 24 hours 60 minutes 60 seconds it will be approximately 2.592 times 10 to the power 6 seconds. So, I delta t will be equal to 6.0 meter cube per second times 2.592 times 10 to the power 6 seconds, seconds cancelled out. So, it will be approximately 15.552 million meter cube, so this is the total volume of water that enters into the lake in the whole month.

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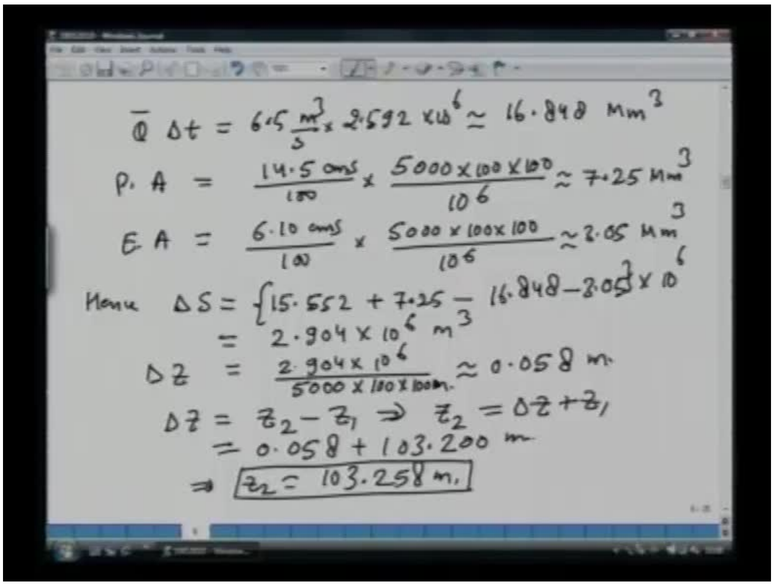

Now, similarly, calculating the average outflow from the lake is would be 6.5 which is meter cube per second again and we multiply this by the time and it will be approximately 16.848 million meter cube the other components are P times a which would be 14.5 centimeters over 100 in the meter. So, this is the amount of precipitation and that falls on the lake during the month in meters and this we multiply by the surface area which is 5000 hectors which is a plot of 100 meters by 100 meters. And if I divide by 10 to the power 6 the answer would be in million meter cube, so that we have all the quantities in the same units.

Similarly, we find out the evaporation losses from the lake it will be 6.10 centimeters divided by 100. So, this will be in meters multiplied by same thing and this also will be in million meter cube. Now, what we can do is we have calculated all the four quantities we can put this in the water budget equation therefore, we will have delta S is equal to 15.552 that was the inflow plus 7.25 is the precipitation minus 16.8458 is the outflow surface outflow.

And minus 3.05 is your evaporation losses and all these numbers are multiplied by 10 to the power 6, so that this is in meter cube. You simplify that it will be 2.904, 10 to the power 6 meter cube and which will be equal to 2.904 times 10 to the power 6 we want to convert into this length units. So, we multiply this by the area or the surface area of the lake which is 5000 hectors multiplied by 100 meters and 100 meters.

So, it will be about 0.058 meters. So, this is the change in storage or actually I should write this as delta z and this delta z 10 is nothing but z 2 minus z 1 from here you can find that the lake elevation at the end of the month will be equal to delta z plus z 1 right. So, it will be equal to 0.058 plus the initial level was 103.200 meters that would mean your z 2 is 103.258 meter. So, this way we see that we can find out the lake elevation at the end of the that particular month. So, we see that we use the continuity equation to solve a problem of the lake, water balance. So, with that we come to the conclusion of today's lecture and tomorrow we will start with the systems concept.