Introduction to Civil Engineering Profession
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Lecture – 17
Hydrology and Water Security

I come from the environmental water resources division. My research is focused on you know water security, food security, climate change, impact on food production, stuff like that.

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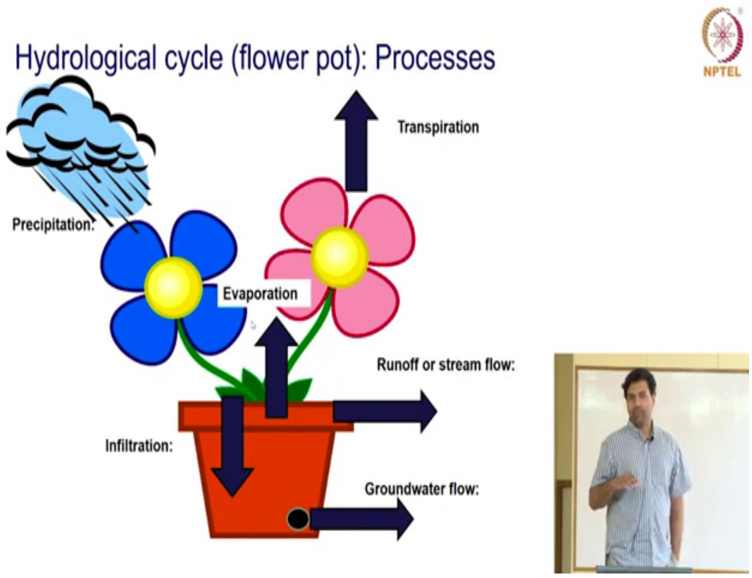

Before we go and talk about the global hydrological cycle, you know I wanted to give some feel for numbers for you know a small flower pot here, you know. Whatever processes happen at the flower pot, also happens at the hydrological cycle on a global scale. But its you know there are a few complications in terms of heterogeneity and you know, few other things. We will go step at a time, but let us say we have a flower pot and then you know we have some rain or we have some we water it ok. So, that is our precipitation which is the input to the system ok.

And then the water if you pour very fast or too much water, it will spill it will fill the pot it will spill over and it will overflow. So, that process is called runoff or stream flow. So, that is what happens in the earth also. When you have a lot of shower the earth cannot absorb it, it will start ponding and it will start flowing off runoff. So, that is your runoff.

Some water actually goes inside it infiltrates into the soil, and you have soil moisture and you have ground water. So, you have infiltration process where you can have saturated, unsaturated soil moisture.

Also, if you go further deep you have your groundwater which is saturated. And then ground water actually flows based on gradients. So, you can have some regions which are higher, some regions which are lower. And then if there is saturation saturated ground water, water flows from higher head to lower head.

So, you will have regional groundwater flow. In our flower pot we have leakage. So, we have all parts all planting parts have some hole in the bottom to let for drainage. So, we have leakage or drainage at the bottom. Now we also have evaporation from the surface. So, you have bad soil. Some portion of the flower part has plants some portion of it is has bad soil. So, you can have bad soil evaporation.

Based on your sunlight, temperature, humidity and things like that you will have different rates of evaporation. And finally, the basic reason we are pouring water for a flower pot is for the plants to uptake water. So, plants actually use water its not evaporation its called transpiration. So, the process by which water goes from the soil through the plant and then comes out of the leaf is called transpiration.

So, together there are two fluxes that go out into the air. So, one is evaporation directly from soil or you know water bodies escaping into the air. So, that is evaporation. The other is transpiration which is flowing through the plants. And then two which is liquid water you get runoff at the surface level or you got you get groundwater flow at the subsurface level. So, basically this kind of gives this cartoon kind of gives a feel for; what are some storages? What are some fluxes?

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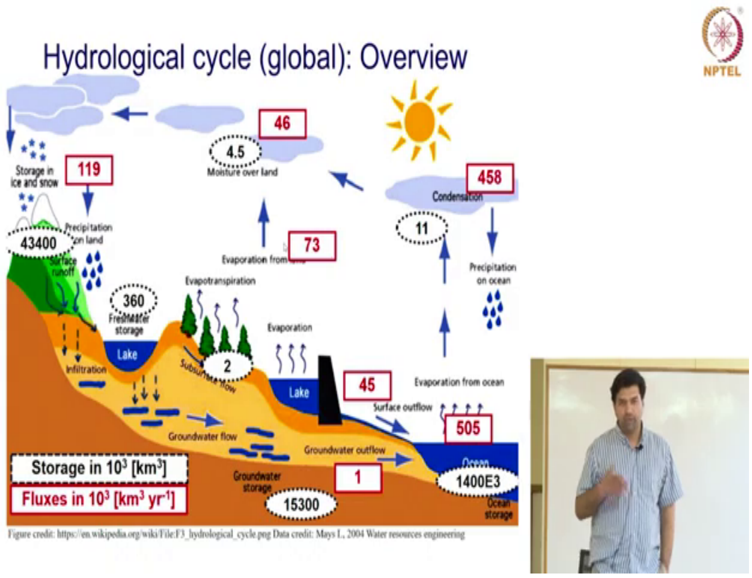

That we can expect at a small watershed or a flowerpot. So now, let us scale this up to the global level. So, we have now a global hydrological cycle, there is this spatial and temporal scales are much larger.

So, now we have evaporation; evaporation not only happens from the ocean. So, you can it also happens from the land masses there is lakes and rivers where evaporation, surface evaporation can happen. And there are plants and vegetation forests, grasslands, all kinds of ecosystems which transpire water. So, there is going to be large scale transpiration which is releasing water in the form of gaseous water vapor back into the atmosphere.

You have precipitation. So, we are used to having precipitation in the land, but we also have precipitation in the ocean. You know, water can precipitate in oceans also. In fact, more portion of water that falls as rain, falls in the ocean than in the land. So, that is your input. And you can not only have precipitation term in forms in terms of water, but you can also have precipitation in terms of snow, hail, sleet and different kinds of things.

Now then, what happens to the water that falls on the surface? So, once the water reaches the surface it can either pond, it can collect into lakes, it can flow in the rivers and have some surface water flow. So, these are your rivers and you know small streams and creeks that flow on the surface. So that is your surface outflow.

We also have water that is infiltrating deeper into the soil. And it being in terms becomes part of the groundwater. And now you have your regional groundwater flow and eventually all the water kind of goes into the ocean, right.

So, you have a cycle. The reason its called a cycle, because you have evaporation from the ocean and then precipitation back into the land. And then flow over the surface or under the surface. And then emptying it out into the ocean. You also have ever evaporation and transpiration that goes back into the atmosphere.

So, there is a big loop, there is a big cycle. Now the question is, at what timescales these are happening? Or what are the magnitudes of flows? And what are the magnitudes of storages? Can we put some numbers in this and see what happens?

So, let us see in terms of storages. If you want to, say, let us say this is a on an annual timescale; let us say we have steady state. Like, inter annual variability is low. So, on an average we want to see how much water is stored in different portions of the hydrological cycle.

So now, when we look at the ocean, the ocean has about 1.4 million cubic meter meters of water. So 1.4 million cubic meters of water is stored in the ocean, its a largest reservoir in terms of reservoir storage. So, then there is some amount of moisture that is stored in the atmosphere. So, this is your atmospheric water vapor.

So, when you talk about humidity and things like that there is water vapor stored in the atmosphere. And this it is the here we have split into two parts, the portion of water vapor that stored in the atmosphere on top of the land. And then the portion that is stored on top of the oceans. So obviously, you have more evaporation happening on the oceans. So, you are having a little bit larger proportion of moisture stored on top of the ocean atmosphere.

So then, we have a large amount of water about 43000 cubic kilometers stored as locked in ice caps. As snow and ice and things like that. And then you have a fairly small fraction of that as fresh water storage in lakes and surface waters. And an another significant portion of storage is in your ground water about 15000 cubic kilometers.

So, this whole flux on an average on an annual average scale is kind of you know there may be some variability between here and here, but overall these are the numbers that you can think about. So now, this is the storage now what about flux? So, there is always exchange of mass between one reservoir and another reservoir.

So for example, what I mean, what do I mean by the reservoir? So, there is a reservoir of moisture in the air in the atmosphere. There is a reservoir of moisture in the ocean. There is a reservoir of moisture let us say, in lakes. So, there are they are constantly interacting and they are exchanging mass.

So for example, a surface water or subsurface water which was in liquid form is now being transpired through the plants or evaporated. And put back into the atmosphere as soil moisture. So how does, how do these things interact? What are the rates of change of you know interaction of mass flux between these storages?

So, here are the storage was storages storage fluxes in sorry mass fluxes in terms of kilometer cube per year and they are highlighted in red. So let us see, from the ocean we have about 505 cubic kilometers per year of moisture. That escapes from the ocean as evaporation and puts gets back put back into the atmosphere. And of that about 458 kilometer cube per year falls back into the ocean as precipitation.

So, significant amount of ocean water that evaporates actually comes back as precipitation into the ocean. Some of it gets carried about 46 cubic kilometeres get carried back in inland, as moisture. And this 46 comes back into the ocean. So, you see 45 as surface and 1 as groundwater flow comes back into the ocean. So, between land surface and ocean you have 46 cubic kilometers per year that goes from ocean to the land as water vapor and about 46 that comes back as water.

So, then once you get into the atmospheric sorry land atmosphere; so you have evaporation and transpiration coming from plants. So, about 73 cubic kilometer per year. Combine that with the ocean contribution. So, we will have about 119 that precipitates back into the land. And so, some of it infiltrates and then you have surface runoff and you have groundwater flow.

So, among these you can see your groundwater flow flux is fairly slow. Whereas, your fluxes in the atmosphere are fairly fast. This is in terms of fluxes. But if you look at in terms of storages, your storages in atmosphere are very small, right? You have about 15 cubic kilometers, your storage is very small. Whereas, your storage in groundwater is 15000 cubic kilometers.

So, there is a huge discrepancy between the magnitude of flux that you see as storage and the magnitude of flux that you see as sorry magnitude of volume of water that you see as storage and then the magnitude of flux that you see, exchange between these reservoirs. So, as a result what do we get?

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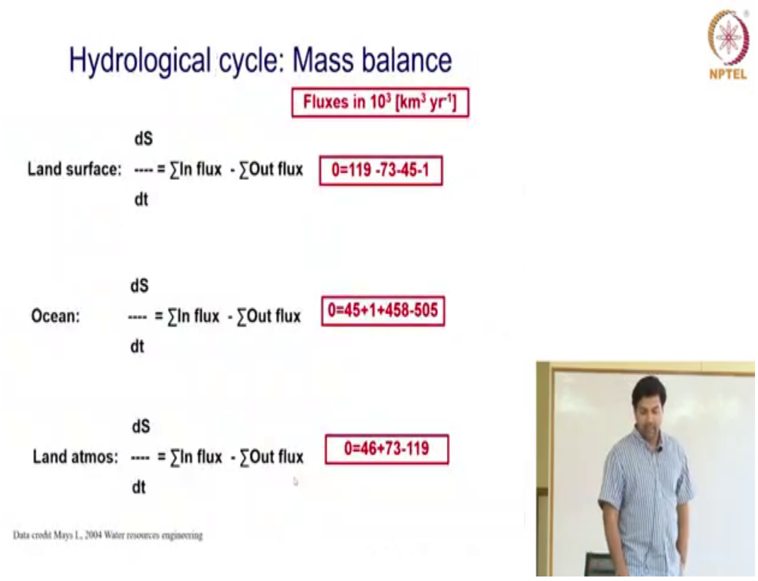

So, let us do some mass balance ok. So, in terms of land surface flux. So, this is just recap on what I said earlier. So, if you just take land surface, the rate of change of storage of soil moisture in the land surface is equal to sum of influx minus sum of out flux. So I say, on an annual scale things are balanced. So, flux is 0, rate of change of storage is 0. So, your net flux is also 0. So, there are inputs and outputs. So, here I have put 119 as input and 3 outputs 73, 45 and 1.

So, let us go back to the previous slide and see what we do. So, we have for. So basically, I am trying to do a mass balance for this surface. So, this is the land surface. So, 119 is the input that is this precipitation. And you have 73 as output here, 45 as the output here as surface runoff and 1 as groundwater.

So, you can also similarly do your ocean mass balance. So, quickly let us go back to the previous slide. So, before we go there. So, rate of change of storage ocean. So, basically ocean you know do not talk about sea level rise here. But you know, on an average let us say ocean fluxes are kind of storages are pretty much stable. So, you have 3 things that are going in 45, 1 and 458 and one thing that is going out 505.

So, let us see what are these fluxes? So, 505 is the evaporation from the ocean, that is going up. 458 is precipitation whatever water that evaporated is precipitating back into the ocean. So, that is about 458. 45 is surface water flow and 1 is ground water flow. So, on an average things are things seemed to be balanced.

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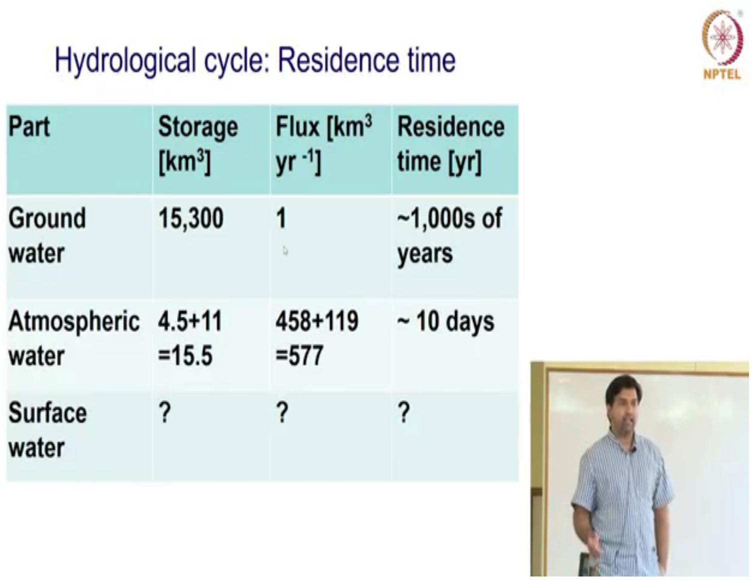

Part	Storage [km³]	Flux [km³ yr⁻¹]	Residence time [yr]
Ground water	15,300	1	~1,000s of years
Atmospheric water	4.5+11 =15.5	458+119 =577	~ 10 days
Surface water	?	?	?

Now so I was earlier mentioning about the consequence of different difference in magnitude between your storage and fluxes. So, let us look at ground water. Your ground water storage is about 15000 cubic kilometers. Whereas, your flux is only 1 cubic kilometer per year. So, we can compute some kind of a residence time or detention time.

So, you divide your storage over your flux. So, you will get an average estimate for how long? A water molecule kind of stays inside the groundwater. So, that comes out to be about you know several 1000 years. So, that is typical. You know, if you look at groundwater velocities you know, if you do not have any severe pumping and you know some man-made artifacts.

In naturally, water flows fairly gently because there is a lot of resistance you have to move through the soil, you have to move through the porous media and gradients are fairly less, not very steep. So, your moisture move your water moves are about few meters per year a few 10s of meters per year.

So, considering the global scale we have what takes about 1000 years for water to on an average 1000s of years for the water to move through the groundwater system. Whereas, if you flip it and look at the atmospheric storage.

So, let us go back to the atmospheric figure. So you have fluxes, your storages are fairly small. So, you have 4.5 and then you have 11. But your fluxes are very high 119, 46 and 73. So in this example, I have looked at 45 plus 11 as a total atmospheric storage.

Your fluxes are total incomings 458 and 73. So, this is a huge amount of flux that goes that puts water back into the atmosphere for a very little storage. As a result your retention time or a residence time is fairly low. And that is kind of you know few days so, about a fortnight. So, they say you know weather systems kind of last about 2 weeks, 1 to 2 weeks. So, this is where it comes from.

So, the time that water stays in the atmosphere is fairly is. Orders of magnitude is smaller then, how long it stays? Let us say for example, in the ground water. So, I will leave this as an exercise for you guys. You know why do not you do a quick calculation for what the surface water storage will be? And what the surface water flux will be? And so how much will the residence tank be?

So, maybe you can do a quick math. So, your fluxes and storages. Storages are in the black and fluxes are in red. Now can someone tell me what numbers will we get? So you want to do a mass balance. So, mass balance is we know that the mass balance is satisfied. So, there is no rate of change of storage.

So, you are trying to get storage over flux. So, without doing calculation what is a typical residence time that you would expect on the surface? Will it be a order of 1000s of years? Or will it be a order of 1 or 2 days? Or will it be kind of in between?

Student: In between.

In between. So, what is your estimate?

Student: About 100.

About 100 days good. Who else? So, what is your name?

Student: Anirudh.

Anirudh. So, who else agrees with Anirudh? About 100 days it sounds about right. So, we have quite a few people. Anybody has some other estimates? So, we have its not way-off. So, you can do the math, its several 100s of days. So, around 100 days is not a bad number.

So, when you think about you know storing water you know, if you want to store water in your surface versus if you want to store water in the ground. You think about what water is more accessible or you know more easily retrievable.

So, its probably your you know if you store it in the ground, its not moving very far very far away. And its there for a long time, not occupying space and additional space in terms of surface. You are preventing evaporation. And water moves fairly slowly in the subsurface. So, there are advantages to recharge groundwater.

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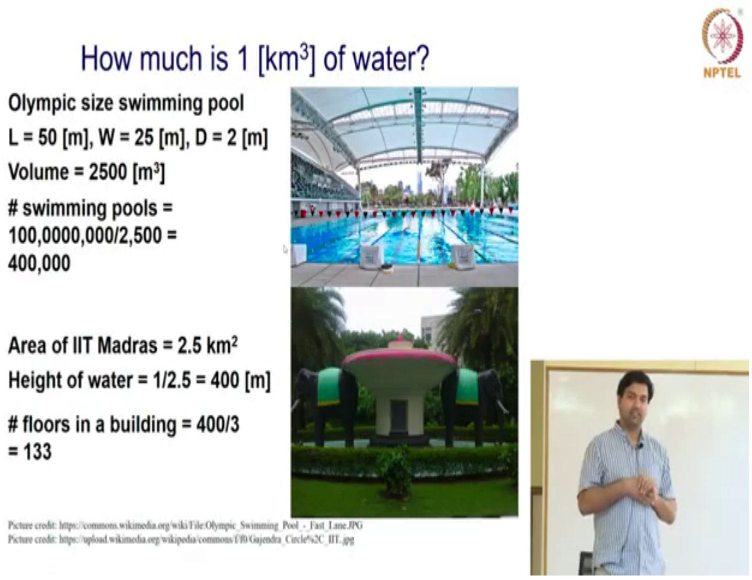

So, we talked about these numbers. So, 1 cubic kilometer, I mean that is, what is this one cubic kilometer? So, its some number. I mean, how big is it? How small is it? We have, I mean, we are talking about global scales and we are trying to move water. I wanted to get some, I want you guys to get some feel for some numbers here.

So, what is 1 cubic kilometer of water? How much is it? So, let us say I mean typically I want to think in terms of swimming pools. Like let us say our olympic size swimming pool has about 2500 meter cubed of water. So, 1 cubic kilometer is like 400,000 swimming pools.

So, that does not really help. Like how can I visualize 400 cubic 400,000 swimming pools like not able to get feel for the number. So, can we come up with some other estimate? So, let us say we take IIT campus, its about 2.5 kilometer squared. Now I want to put 1 cubic kilometer of water on top of this IIT campus. So, which means you will have about 400 meters of water all over the campus. And that will constitute about 1 cubic kilometer of water.

So, what is this 400 meters of water; 400 meters of water? How tall is it? So, its about you know 130 floors. Like, if you have a building its about 130 floors. So, that amount of water is 1 cubic kilometer all over campus. So, this whole 2.5 kilometer square area. You fill it up for 130 floors of water. So, that is 1 cubic kilometer. I mean, you get a feel for the numbers, its really high, its huge, really huge number, right?

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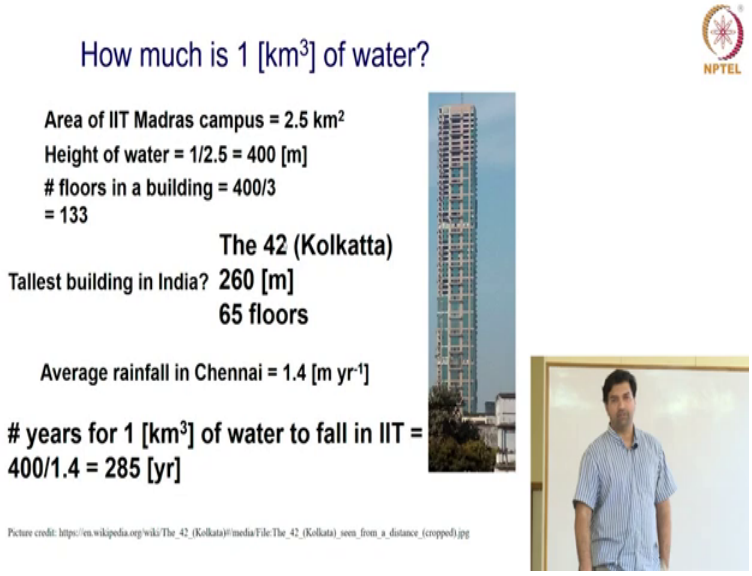

So, what is the tallest building in India? Does anybody know? anybody know what the tallest building in India is? Yes, can you be louder please? So, the tallest building in India at least according to Wikipedia is the 42.

So, it was recently constructed. its about 260 meters. its about 65 floors. So, its actually taller than the tallest building in India. The amount of water we have to stack it up is much taller than the tallest building in it. This is the really huge number I mean. So, when we throw these numbers around when we say like 500 cubic kilometers of water per year. its a large amount of water that is being moved annually.

So, let us say in terms of annual average precipitation in Chennai. So, its about 1.4 meters. So, about 140 centimeters every year we get on an average around this area. So, how many years does it have to rain to get 400 meters of water? So, its about 285 years. So, if it rains for 285 consecutive years and every drop of water is saved. That falls on campus is safe, and that amounts to 1 cubic kilometer, its a really huge water, huge amount of water.

So, I am going to go back to the next slide and let you get a feel for the numbers. Look at these numbers and you know just soak it in see what the storages are. See what the fluxes are, and you know in relation to your 1 cubic kilometer of water you know which is about 400 and meters of water all over IIT campus, you get a feel for these numbers. So, you know its very hard to think about 500 cubic kilometers per year is being evaporated from the ocean, its a really large number, annually every year.

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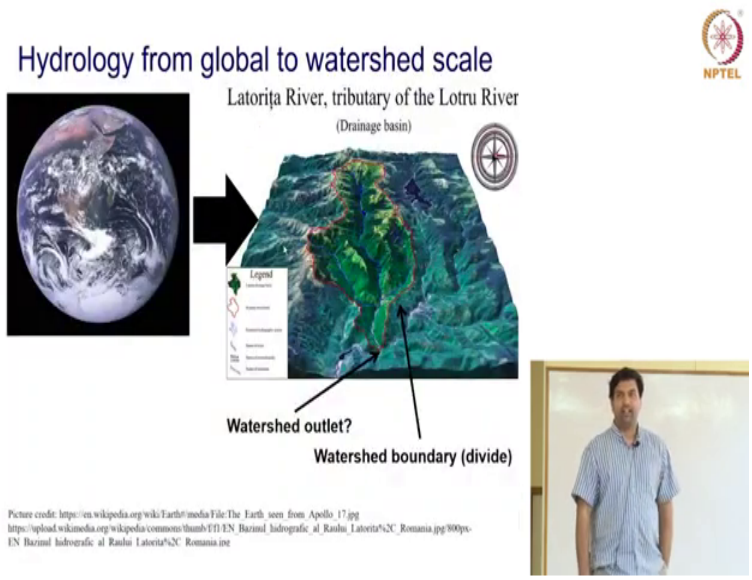

So, now let us go from global scale to more manageable scale. Let us say catchment scale or a watershed scale. So, we looked at fluxes. You know, I had at the global scale. Now let us see what kind of fluxes happen at the catchment scale or at a more manageable scale. So, here is an example of a catchment. So, the green highlighted region is actually the catchment area. The red line is the catchment boundary or watershed boundary. And the bottom of the red line is a watershed outlet.

So, what do I mean by watershed? So, I have identified in a map. So, this is a topological map or elevation map. In this map, I have drawn a line, a red line. And I have set whatever water that falls in is going to come out in this watershed outlet. So, basically, I have delineated a watershed based on a topological map or a elevation map and says, and I say that if a water falls inside this map ok. Inside this red green region, it is going to drain out at the watershed outlet.

So, how do I determine this watershed boundary or this watershed divide line? So, somebody said slope. So, how do you determine based on the slope? So, its the hunch you have based on some slope. But its basically based on elevation. So, its based on elevation differences.

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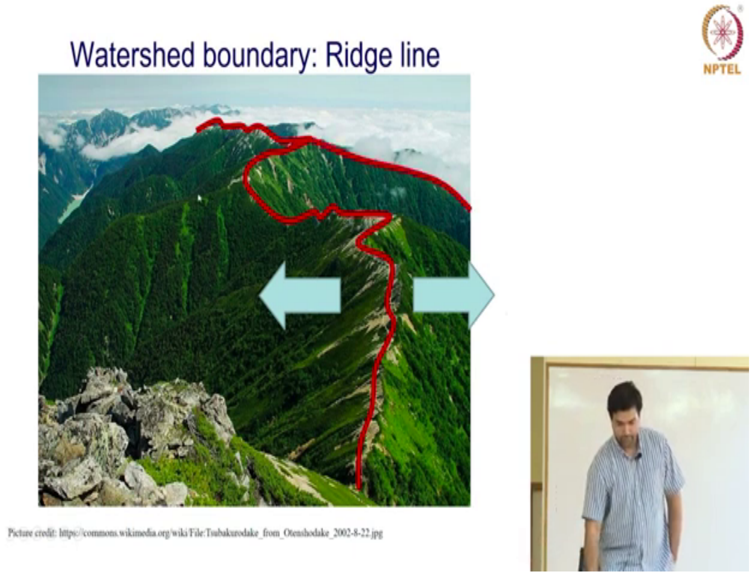

So, let us say we have a picture here. So, typically a watershed boundary is defined as a ridge line. So, how many of you know what a ridge line is? Anybody of you heard this ridge line before? No. So, what you are seeing right now is a ridge line. So, there is a hill you know. So, there is a series of hills and so the highest point around along which you can draw a contour is a ridge line ok.

So, any water that falls on this side of the ridge line, is going to go to my right. And any water that falls on this side of the ridge line is going to go to my left. So, this is a watershed divide. So, basically any precipitation that falls to the left is going to go left side. And any precipitation that falls to the right is going to go right side and they are not interacting.

And so, this ridgeline is a typical watershed divide and it deter it defines your watershed boundary. So, your watershed boundary is a watershed is where area is where if you have precipitation falling on that area on that defined bound defined area, you are going to have one particular point which is your watershed outlet where all the water is eventually going to drain.

So, you get a good feel for how you identify this ridgeline pictorially, right? So, here is another ridgeline. So, I will go back. So, here is another ridgeline right here. I mean there are many ridge lines. There is another ridge line here any water that falls here is going to drain out this way. Any water that falls on behind the slope is going to drain away from it.

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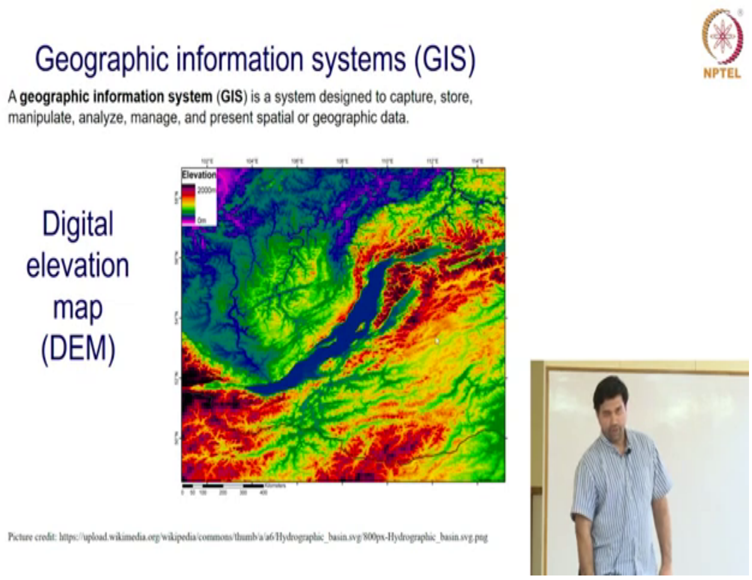

So, now how do we get these ridge lines? So obviously, you need elevation map. So, you cannot really do aerial like you know, land surveys and go and track ridge lines and then map them. So, we have sophisticated ways where we can do this. And so, one system that helps us do this is Geographic Information Systems, its also called GIS.

So, its a system that can manipulate store arrange and process data which are spatial in nature or geographic in nature. So, they have some relation spatially. Some correlation spatially is your geographical information system allows us to do. So, here is a digital elevation map.

So, your red colors or darker colors are corresponding to higher elevation. Your blue colors are corresponding to lower elevation. So, you can see that you can see the low points and high points based on this digital elevation map. Now from this map how do we get your watershed boundary? So, I want to know what is a.

So, what the use of watershed boundary is you can kind of think of it as a unit which is separate in itself that is not interacting with your neighboring boundary. So, whatever precipitation that falls inside this watershed is kind of its own unique unit. And what falls outside the watershed is not going to influence directly, the processes that happen inside the watershed.

So now, if I want to study a part of your part of area and if it has many different watershed interspersed. Like I can put a you know, let us say I put a solid block square rectangle here. And say I want to look at the water fluxes in this area. So, then you are going to have fluxes that come through the surface, right. So, on either sides of your boundary your artificially defined square boundary, you will have fluxes coming in.

But if I choose my boundary as the watershed boundary, then there are not going to be any horizontal fluxes that come through the watershed boundary. Because, as we saw earlier any water that falls on the left is going to go this way, any water fall falls that is going to fall on the right is going to go the other way.

So, there is no cross flow of water across the divide. So, how do we find this? Watershed boundary using your digital elevation map. So, your GIS systems; Geographical Information System allows us to do that.

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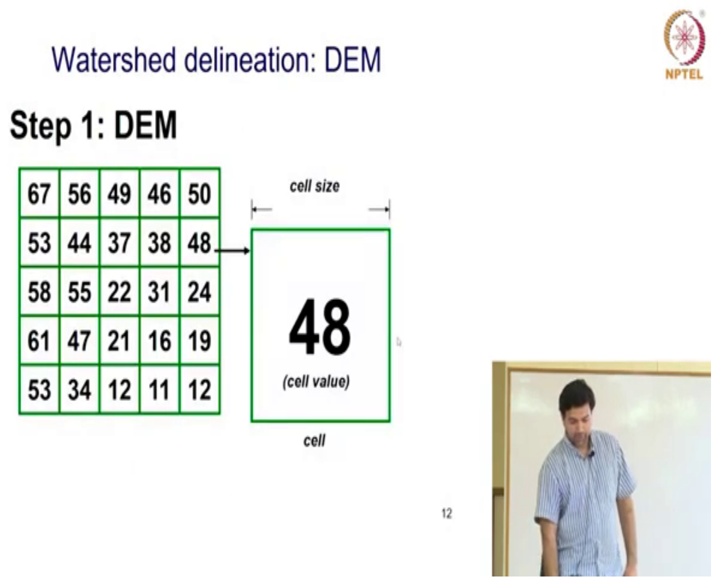

So, let us do some quick math. So, what your digital elevation map is, does is it has a its a raster of points, it is the pixels, it has different pixels and each pixel has a particular value. And that value is let us say elevation above mean sea level.

So, here I have a small section of your digital elevation map. You know, small snippet of that which has height above sea level, mean sea level at different points. So, now, you have your cell size. You know, here I have conveniently taken my horizontal and vertical cell sizes to be equal. But in general, you can have unequal sizes ok. So, now this is your DEM which is what I have projected as a color plot in the previous in this slide.

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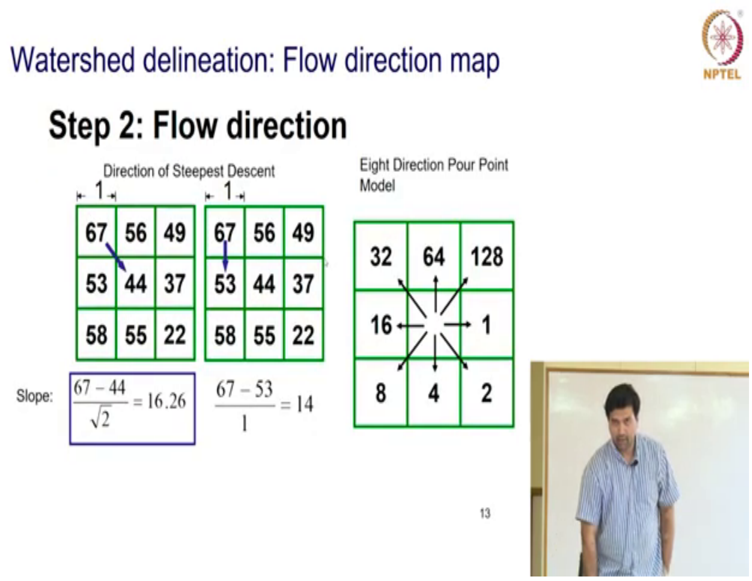

So, now how do we determine from this DEM your catchment or watershed boundary? So, first thing is you try to find your which direction your water flows. And the best way to do this is to find which is the direction of steepest descent. So, from point a to point b, so, each point has 8 surrounding points. You find out which direction is your steepest slope and that is the most likely flow of water ok.

So, now, for the top cell, the top left cell the elevation is 67. Your adjoining cells have elevations of 56, 44 and 53. Now if you want to compute the slope this way, ok. So, then you do 67 minus 53 divided by 1.

So, 1 is let us say, 1 kilometer or something like that. It is a unit and it is uniform. So, we take from this mid-point to this mid-point, its about 1. And so, you get slope as 14. Whereas, if you do diagonally, so then you have to do square root of 2 because its no in this case it is symmetric. So, you do a square root of 2 and you get a slope.

So, similarly you compute the slope at different directions and then you pick the steepest slope. The steepest slope will give you the direction of water. And so, basically there are some notations, mathematical notations to determine to indicate which direction the flow is happening.

So, if your value is 1 then it means that it moves from my left to my right. If the direction is 2 then it moves diagonally down. If the direction is if the value is 4 then that direction of flow is 4.

So, this is just a convention some notation where you stored the direction as numbers. So, now we can compute what is the direct what is the steepest slope and then from that we can get the direction of slope.

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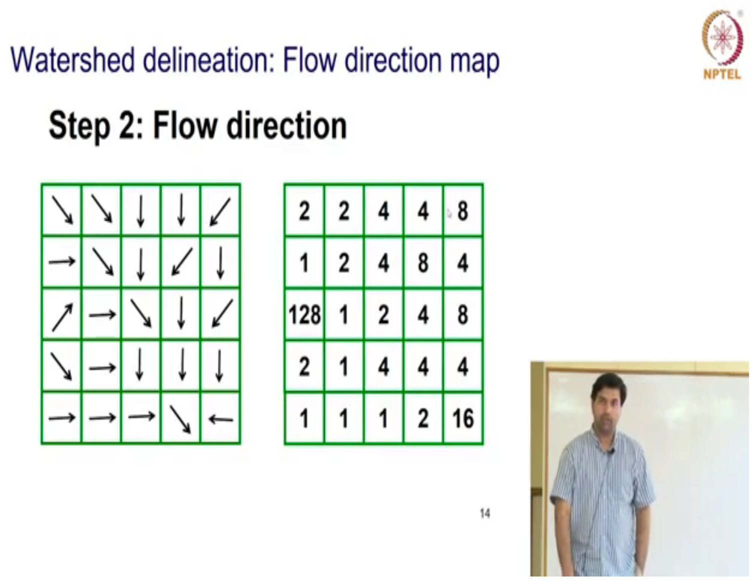

So, like that we compute for each and every cell and we get this flow direction grid. So, your flow direction map will give you what direction the flow is occurring based on your steepest descent. So, now, you put it in terms of. So, this is in terms of directions, in terms of arrows. And here you can represent it in numerics, in terms of number notation that we had described earlier eight direction four point model.

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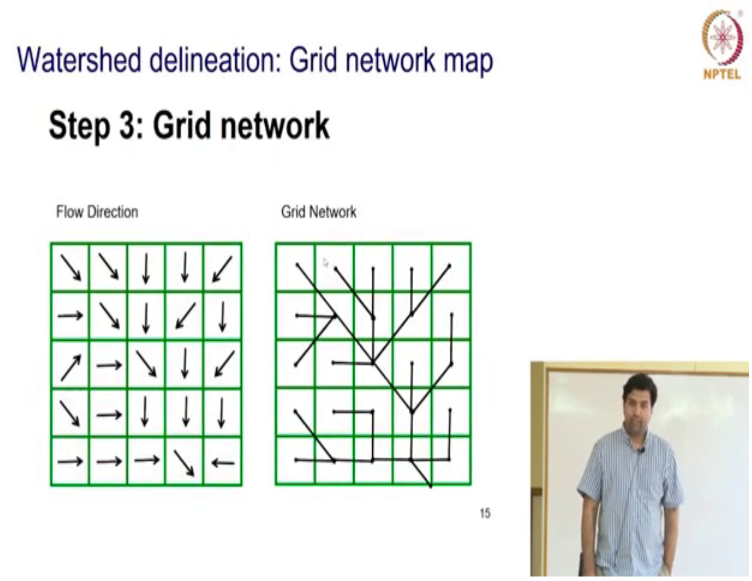

So, now it now our job becomes easy. So, since we know what direction water is flowing, we connect all the lines where water is flowing. So basically, you go from your flow direction map to your grid network map. So now you start seeing your origins or initial beginning of stream network.

So, basically this sail cell is going to drain to this cell and so you have a connect from here to here this cell is going to drain all the way up to here. So it goes from here to here. So, each cell you can kind of connect to the next neighboring cell based on your flow direction and get your grid network. So if I track this water, if I track a water that falls on my top left cell. So, its going to go all the way down here down here and it is going to empty up to this point.

So I know this is going to be my some kind of outlet. Now this is not my real outlet, because I have taken an arbitrary square grid and I have computed the grid network in this one.

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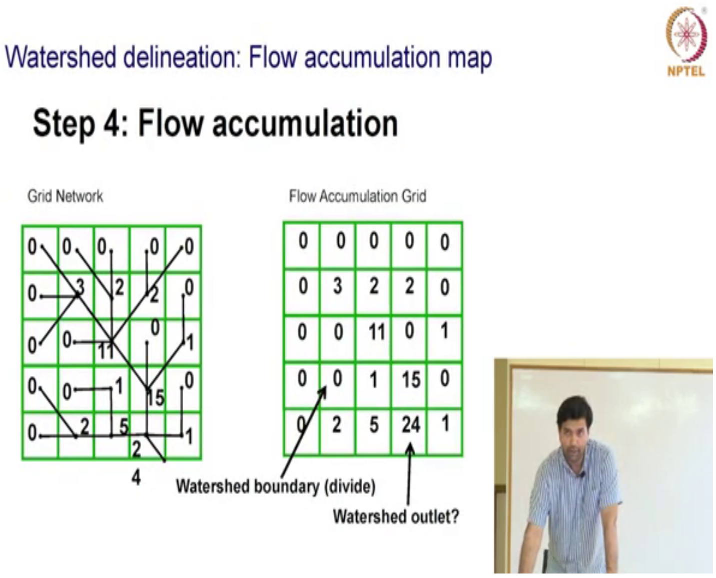

So, if I expand this and then compute what my flow accumulation is. So, what my flow accumulation map will tell me is, it is going to count the number of cells that are going to drain into the current cell. So, let us say let us say we consider this top left cell. No cell is draining into this cell so, it is 0. Now if you consider the cell at the bottom, there are 3 cells draining into this cell. So, one is here, one is from here and then the other one is from here

So and now if you consider this cell 11 cells are draining. So this 3 plus 1, 4 is coming from here, these three are coming from here, this one is coming from here, these 3 as are coming from here. So, you have your flow accumulation number is 11. So systematically you can do these calculation and see what how many cells actually drain into this cell.

And so, higher the number you get more number of cells are draining into this particular cell. So it you are kind of going downstream with higher numbers ok. So, eventually you can get the largest number is going to be, sorry about this. So, the largest number is going to be your watershed outlet and your 0s are going to be your watershed boundary.

So, it has to be flipped here, ok. So, here in this case I have taken a square grid. So, you have to really expand on the digital elevation map. And look at if some other cells are draining into this. So, if your flow accumulation number is 0; that means, no cell is going to be draining into that particular cell. So, that is a good potential for being a watershed divide.

So, you connect all your 0s. it. So, in this case your 0 is in the boundary cell so, you cannot include the boundary cell 0. But if you have set of lines set of 0s in the interior cell that will be your watershed boundary, ok. And your maximum value will be your watershed outlet.

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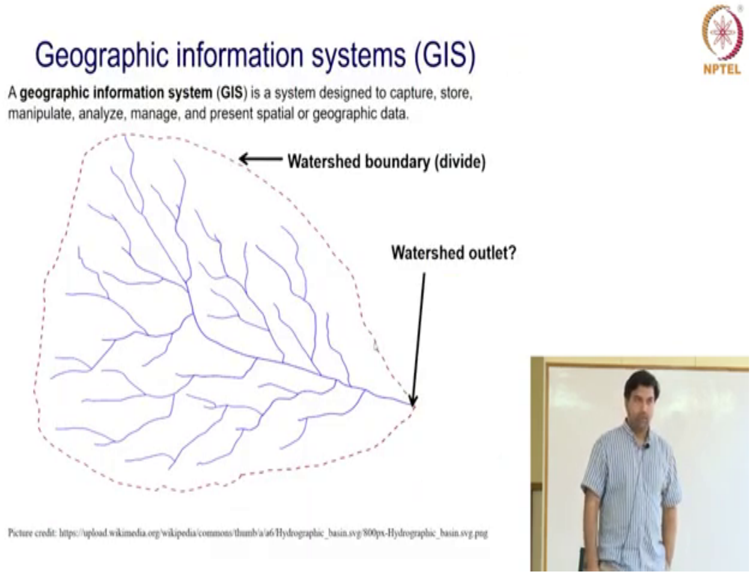

So, you can have some stream networks. You can develop stream networks based on your flow accumulation grid. So, you can say that after about 20 cells drain into one particular cell you can start forming some small streams. You know, really manual stream.

So, you can set a threshold where you want to pick how many cell what is the smallest stream that you want to track. So, if you say your flow accumulation number is about your threshold is about 100. So, you want to only track streams which are fairly reasonably in size. So that 100 cells have to drain into that cell to form a particular stream.

So, here there are some thresholds that have been chosen. And you start seeing how your grid network or river network can be formed based on your digital elevation map. So, all this can be done using your geographical information systems framework where you can do these math and calculations systematically, and keep your geographical or spatial relationships on top of it. And overlay it and then get your watershed boundary and watershed outlet.

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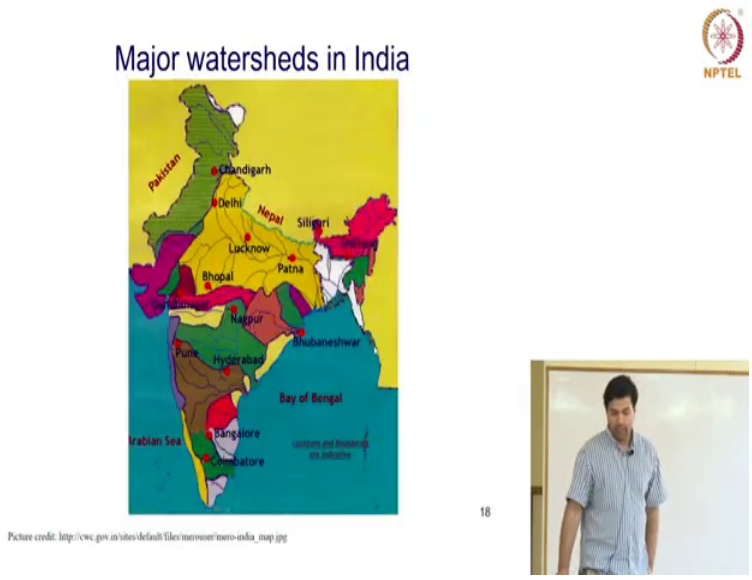

So, here are some major watersheds in India. So obviously, people will know about your Ganges, your Narmada, your Brahmaputra, your Krishna, Godavari. So, these are your key watersheds. And so, each one is colored and your watershed boundary is being defined based on your flow accumulation grid. So, you get your boundaries for the watersheds and your river network is also computed based on your flow accumulation grid.

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So, now so, here are other another picture that talks about major rivers in India.

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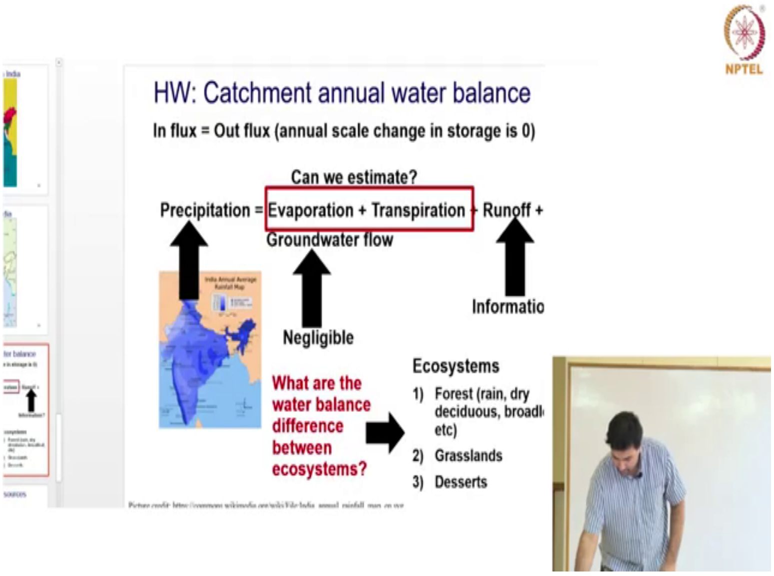

So, I am going to leave at this. So, catchment annual water balance ok. So, basic is your in flux equal to out flux. So at an annual scale, let us say there is no rate of change of storage. So, if you talk about your fluxes your in flux is precipitation your out fluxes are evaporation and transpiration, evaporation is surface evaporation. Transpiration is coming out through the plants and the surface runoff which is liquid water that is flowing on the surface and your ground water flow that goes deeper.

So now, if you have precipitation information as an input. So, you have rain gauges, you have radar stations that provide input values for precipitation. And let us say we already know that ground water flows are fairly small. In terms of magnitude, if you look at the global cycle the groundwater fluxes are much smaller compared to the other fluxes.

So let us say we ignore ground water flux. If we get some information about runoff. So, for example, let us say we want to pick the runoff from Ganges.

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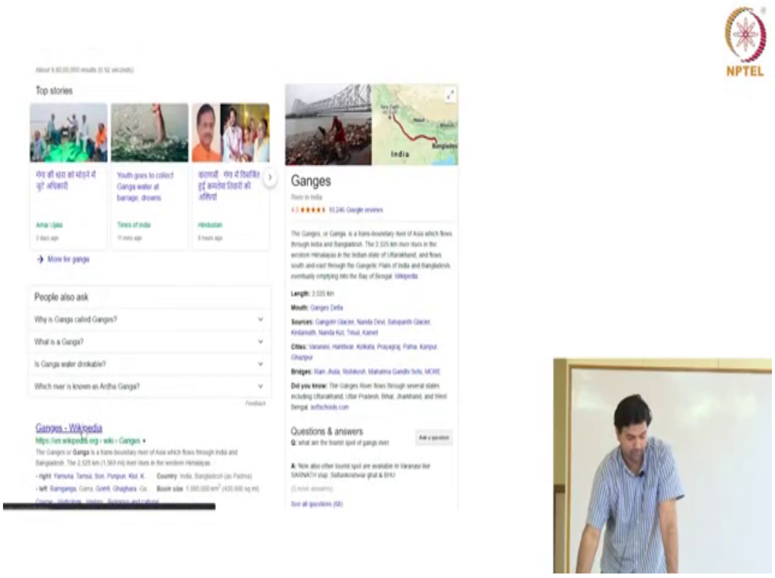

So let us say we want to get the annual flow out of the Ganges. So I am just going to go to the first link which is a Wikipedia.

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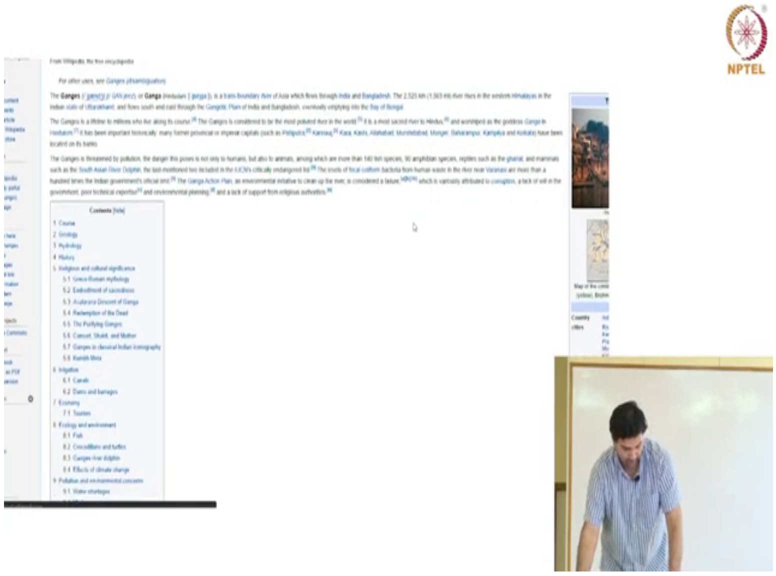

So, let us see we can see if we can see what the fluxes are.

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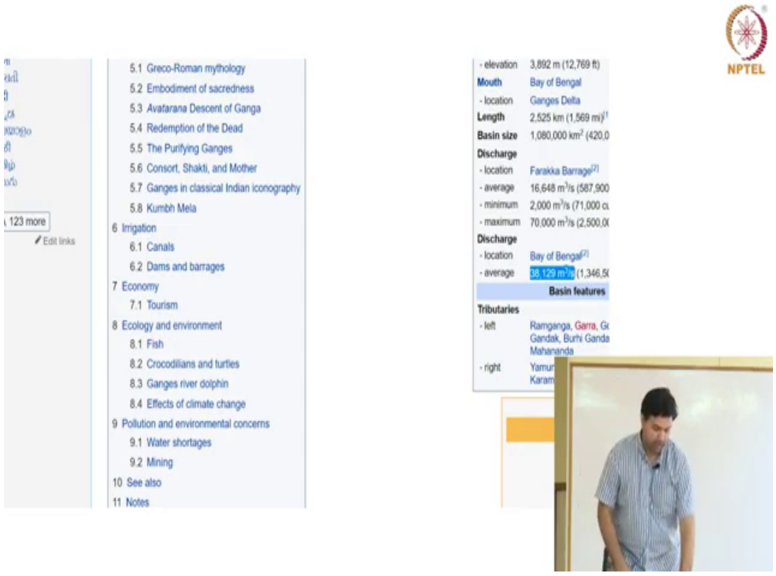

So, you discharge you know, average discharge is about 38 cubic meters per second. So, we can get some annual estimates for what your runoff will be for a particular catchment. So, let us say we delineate the Ganges watershed. Let us say we can get some precipitation data, a spatial precipitation data and we can see what the precipitation is over the Gangetic watershed. Now we are going to ignore the groundwater flux.

So, we have some estimates on what the run off is. So, the runoff is about your watershed outlet is going to have your surface runoff. And so, that is going to be some 38000 cubic meters per second. So, multiplied by 365 days in the year. So, you will get some estimates for runoff.

So, can we estimate what your evaporation and transpiration rates are? So, what do we; what do we get with this? So, what can we get from this? So, we will get some good estimates for your. So, let me go back to your presentation mode. So, we can get estimates for what kind of water balance happens for different ecosystems.

So, you have your desert ecosystems, you have your forested ecosystems, you have tropical savanna. You know, you have different ecosystems and each ecosystem responds differently. You know, your transpiration and runoff characteristics can change quite a bit based on if you have vegetation, what kind of vegetation you have, what latitude you have what kind of precipitation you get.

Whether your precipitation is snow dominant; or whether your precipitation is water dominant. Based on those things, you can get some indicator of how your evapotranspiration is in relation to your precipitation and runoff. So, some of the major ecosystems at least in India are forest ecosystem.

So, you have your tropical rainforest, you have dry deciduous forest which is kind of what we have here. So, we have a specific monsoon season. Like you know, a particular season where you have a large amount of rainfall and then you have a dry season.

So, based on this you have something called a dry deciduous forest. So, quite a bit of the leaves actually shed during the summer dry months. And then they once the monsoon starts you have news sprouts. And there are broadleaf forests, evergreen forests and things pine forests and things like that. You know if you go at higher latitude or altitude, you have tropical savanna and you already have deserts.

So, I am going to leave this as a homework exercise. So, you know we can get some precipitation maps. I have some link for how to get annual rainfall. So, go play around get some numbers. Get a feel for what is a total precipitation in terms of how much is your catchment area.

You know, get some approx approximate numbers get your pick your favorite river, major river and see what your runoff is and how this evaporation and transpiration change. And then based on that can you have some indication of what kind of catchment this is.

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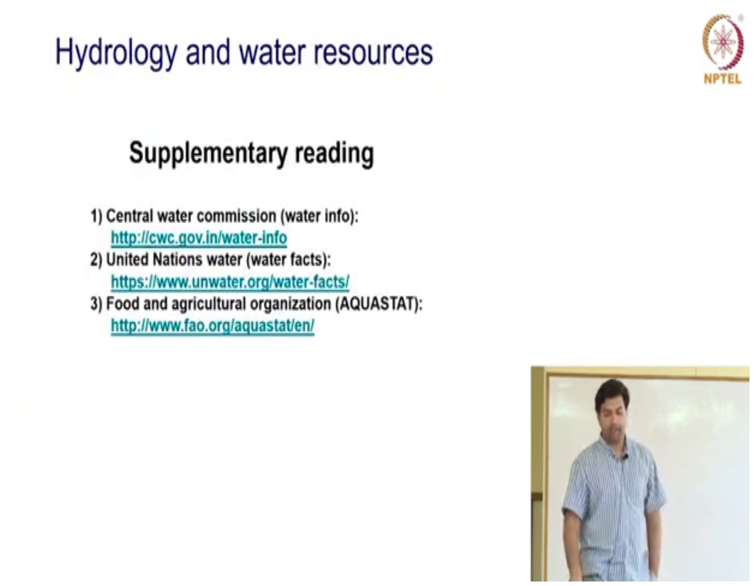

So, I will stop here with some supplementary reading. So, India has some central water commission, they have quite a bit of information on water resources in India. There is also very useful website United Nations from UN.

Water facts, they have quite a bit of information. Much more largest scale you know, what kind of water is used for agriculture versus what kind of water is used for you know irrigation and runoff and things like that. And then there is also FAO, Food and Agriculture Organization which has some information, some useful information.