Geomorphic Processes: Landforms and Landscapes
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Lecture - 9
Surface and Ground Water System and Management
(Part – III)

Welcome back.

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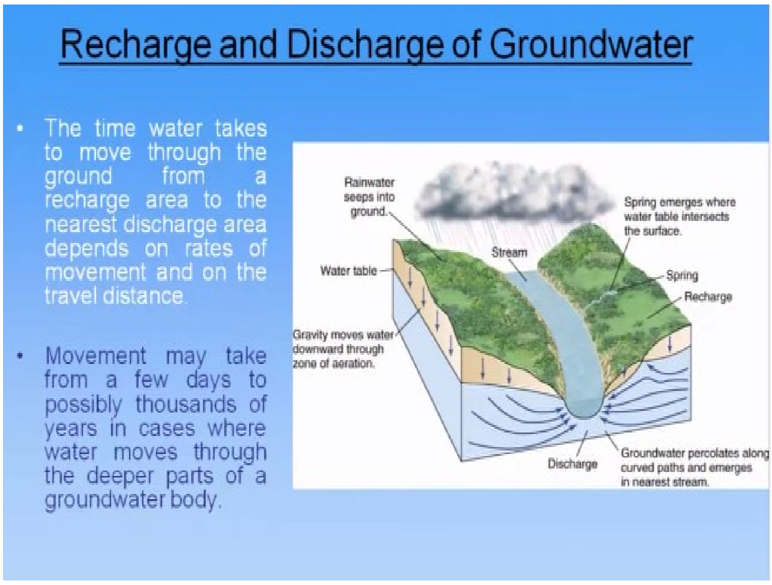

So, in previous lecture, we discussed about the movement of groundwater, where we learned that the groundwater if with respect to the water table, if it moves closer to the surface, then it moves faster, whereas the deeper portion will have the groundwater movement will take more years and to some extent it may take millennia.

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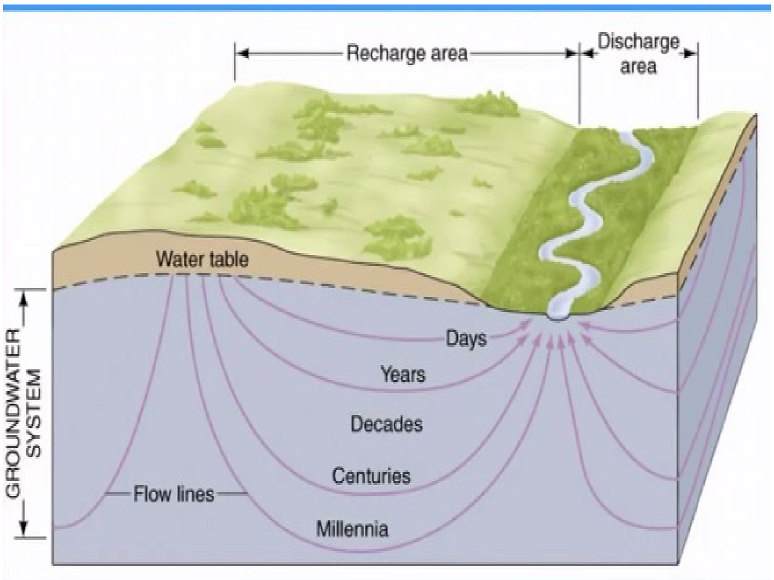

Like near to the surface it may take days, then years, further deeper, centuries, decades, and millennia.

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Estimate of the World Water Balance

Parameter	Surface area (km^2) X 10^6	Volume (km3) X 10^6	Volume %	Equivalent depth (m)	Residence Time
Oceans and seas	361	1370	94	2500	~4000 years
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~10 years
Swamps	<0.1	<0.01	<0.01	0.007	1-10 years
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	<0.01	0.13	2 weeks - 1 year
Groundwater	130	60	4	120	2 weeks - 10,000 years
Icecaps and glaciers	17.8	30	2	60	10-1000 years
Atmospheric water	504	0.01	<0.01	0.025	~10 days
Biospheric water	<0.1	<0.01	<0.01	0.001	~1 week

Now, few very important things, this we have already discussed in the previous lecture. So, I will just move ahead.

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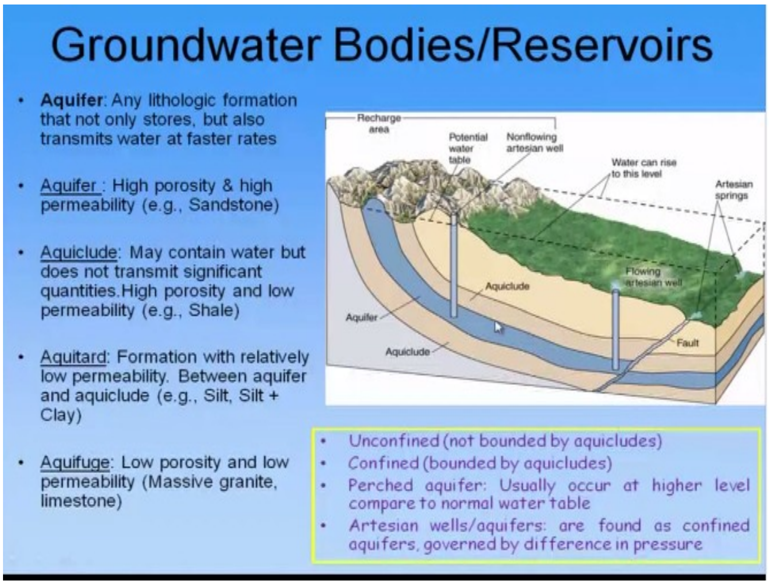

So, few important things about the groundwater bodies and reservoirs, which we will discuss now, mainly the aquifer, aquiclude, aquitard and all that and how they have been defined and what are the material properties, mainly we will see that and depending on the porosity and permeability, how they have been classified. So, first aquifer, is porous and highly permeable, example sandstone. So, if you define aquifer, then aquifer is defined as any lithological formation, that not only stores but also transmit water at faster rate and this is because the porosity is high and the permeability is also high.

So, porosity and permeability is high in aquifer and it can transmit the water much faster than other layers. So, if you remember when we discussed about the shale bed, so shale bed is porous but less permeable. So, those type of beds with the material similar to the shale that is clay material, it will have low permeability, so it will not allow the water to pass through, but the aquifer will have high porosity and high permeability. So, best example is if you take the rock, then it is sandstone.

Then coming to the next one, aquiclude. So, may contain water but does not transmit significant quantity, it is highly porous with low permeability. So, example is shale that what I was talking. So, if you see the diagram here it shows the location of water table. So, this one is the aquifer and this is your water table. So, potential water table has been considered with respect to it is from the higher areas and if you move to the lower ground or in the foreland areas, then we will get the artesian well, but let us look at the boundaries between the different bodies, groundwater bodies.

So, aquifer, what we were talking about highly porous and highly permeable layer which is confined between two aquiclude on the top and the bottom and the aquiclude has high porosity and low permeability. So, it will not allow the water to pass through and we have also discussed about what is permeability, what do you mean by porosity and all that and then we have the artesian well. So, in next coming slides, we will talk about the hydraulic gradient and because of the hydraulic gradient that the well which is located in the downstream area or in the foreland will automatically flow without pumping the water.

So, mainly the artesian wells will be because of the hydraulic gradient and also if you have a structure like fault, then you will have an artesian well or artesian springs we can say along the fault because the fault the zone of shale zone will act as a conduit which will supply the groundwater because if it is rupturing the aquifer, then it will supply the groundwater through the and it acts as and conduit the shale zone and will result into the formation of the artesian springs. So, aquitard further is the formation with relatively no permeability. So, you have low permeability. So, it ranges between aquifer and aquiclude.

So, any layer which is having relatively low permeability and it can be classified between aquifer and aquiclude, example the sediment size will be silt or silt plus clay, then it is termed as aquitard. Then comes a aquifuge. Aquifuge is again mostly seen in rocks, for example, it is massive granite with some fractures and limestone. So, it will have low porosity and low permeability. So, these types of groundwater bodies are classified as an aquifuge.

Now, confined and unconfined aquifer if we take and we have confined, unconfined aquifers not bounded by aquicludes. So, as it has been seen in this figure that you have the aquifer confined between two aquicludes, so unconfined will be not bounded by aquicludes, confined will be bounded by aquicludes. So, what the diagram source here is the figure is the example of the aquifer. Then comes the perches aquifer, we will see this example also of perched aquifer, usually occur at higher level compared to normal water table.

Such aquifers which occur at higher level compared to normal water table are termed as perched aquifers. Then artesian wells as it has been shown here, artesian well as well as artesian spring are found as confined aquifer, governed by a difference in pressure and this difference in pressure is because of the hydraulic gradient.

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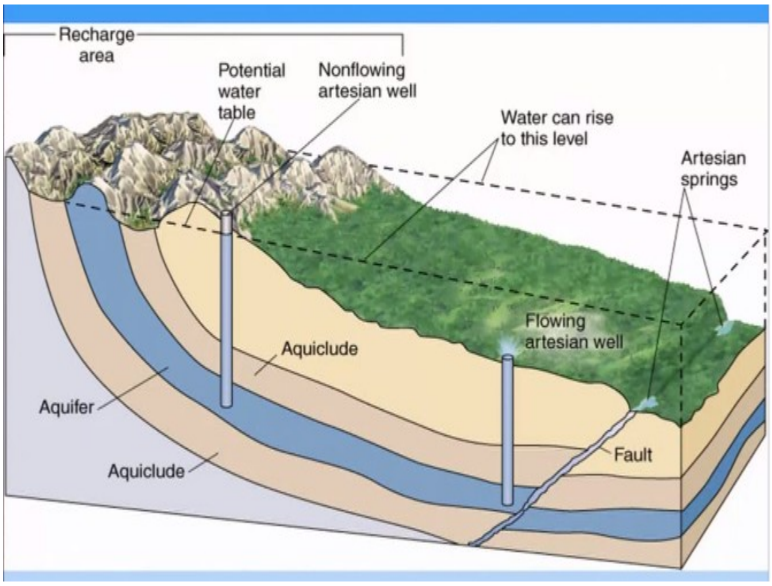

So, this is the same diagram, which you can go through, which talks about the different groundwater bodies, aquifer, aquiclude, artesian well, artesian spring, etc.

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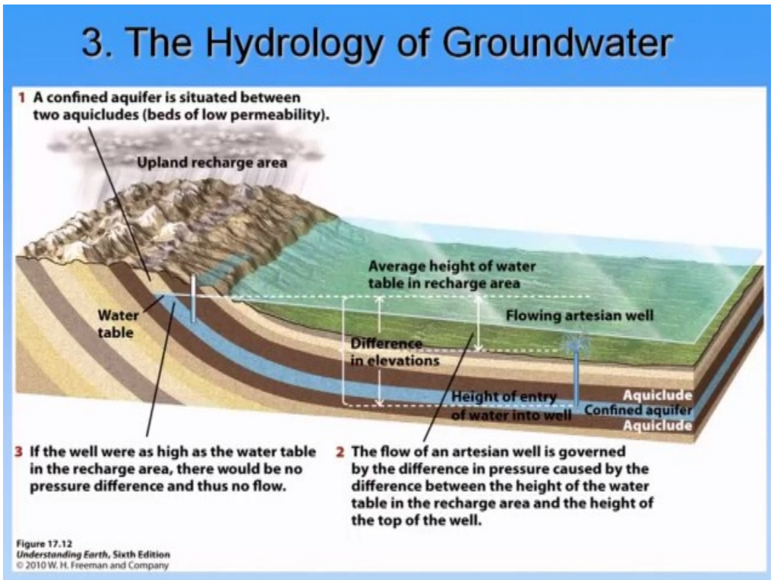

Now, another part further we can discuss this, what we have discussed in the previous slide, a confined aquifer is situated between two aquicludes and this is the bed of low, that is aquiclude is the bed of low permeability. So, we have the water table with respect to the upstream area and the artesian well that is the flow of an artesian well is covered by difference in pressure and this difference in pressure is caused because of the height of water table in recharge area, that is the upstream, and the height of top of the well in the low lying areas or the downstream area.

So, this difference in elevation, which has been shown here with respect to the water table in the upstream and the downstream or upper reaches and lower reaches, a difference in elevation will result into difference in pressure and that will result into the flow of artesian well and these are between two aquiclude, you term this as a confined aquifer. Now, if the well as high as water table in the recharge area, there would be no pressure difference and thus no flow.

So, if the well is as high as water table, so in this case, there would not be any water flow, but in the case of the lower reaches, you will find the formation of artesian and this also to some extent, what we are talking, we are talking about the hydraulic element here that is the difference between the height of the water table between the two wells in the upper reaches and the lower reaches.

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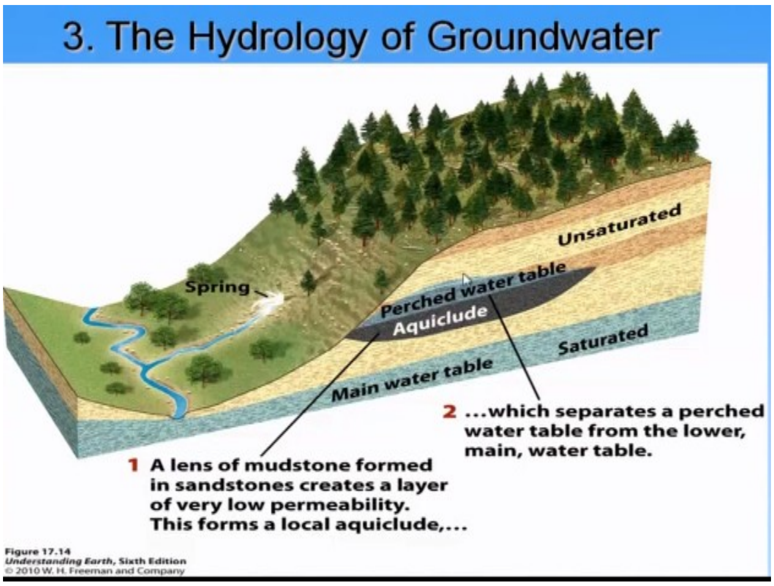

Now perched water table is so one is it is just above the normal water table. So, you have aquiclude and then you have a perched water table which separates, so this is the perched water table which separates the perched water table and the lower main water tables. So lower main one water table is over here and the perched water table is over here. So, it sits much higher than the main water table. So, these are termed as perched water table and this will occur mainly if you are having an body like aquiclude and a porous body which is similar to the saturated zone here, then you may have the perched water table.

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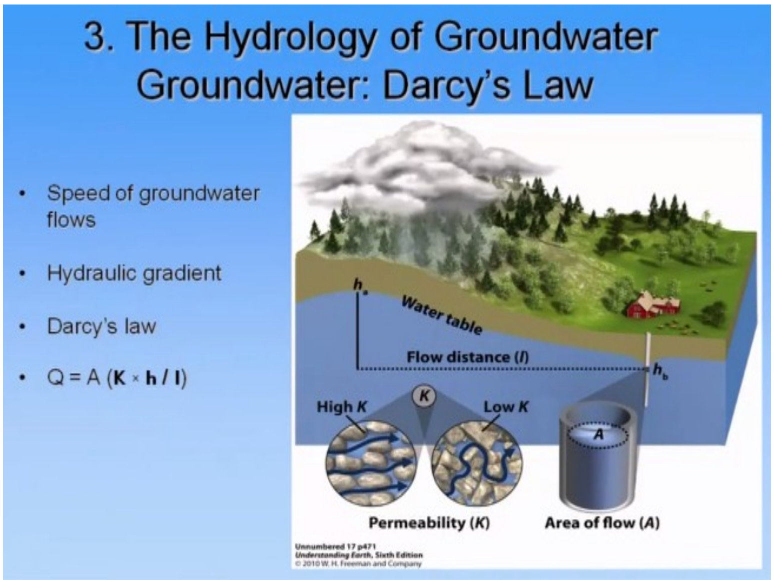

Then groundwater and Darcy's law, what is the relation between thirst, we will quickly look at. So what we have here is the water table in the upper reaches and the lower reaches. So, the height difference between these two and the distance of flow between the two wells and the amount of permeability what you will measure and then the area of flow. So, if you have this information, you can calculate the discharge.

So, the speed of groundwater flow you can calculate based on hydraulic gradient that is your Darcy's law and it has been given as Q that is hydraulic gradient is equal to A into the bracket k which is permeability, h is the height difference, and l is the distance between the two wells. So, based on this, we can talk about the hydraulic gradient. Now, we will see if there is excessive removal of groundwater, then what feature we will be able to envisage in terms of the water level and all that. So this is termed as cone of depression.

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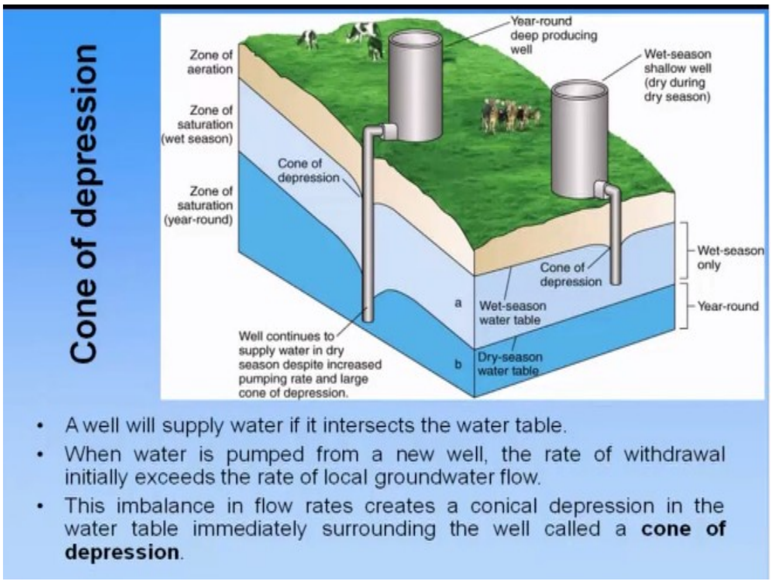

So cone of depression what we have zones, like we have zone of aeration, zone of saturation that is the wet zone and zone of saturation round the year. So, this is the level of ground water, which will remain round the year, but during the wet seasons, the zone of saturation will increase and well continue to supply water in dry season despised increased pumping rate and large cone depression is formed.

So, this is basically what will happen to wet dry season, you will have this water table and dry or another season round the year you will have this water table and during the dry season, the zone of aeration will increase and the water table will fall down, but you are having the pumping of the groundwater is through both the levels, that is the wet season water table and dry season water table, so excess removal of groundwater. So a well will supply water if it intersects the groundwater or water table.

When water is pumped from a new will, the rate of withdrawal initially exceeds the rate of groundwater flow. So this imbalance in flow rate creates a conical depression in water table immediately surrounding the well and it is called us cone of depression. So this cone of depression will be close to the well. So this is mainly because of excess removal of groundwater during dry season or during the wet season also and that is because the influence by the inflow and outflow, the inflow is not so much, that is the recharge, recharge is slower than the removal of the ground water.

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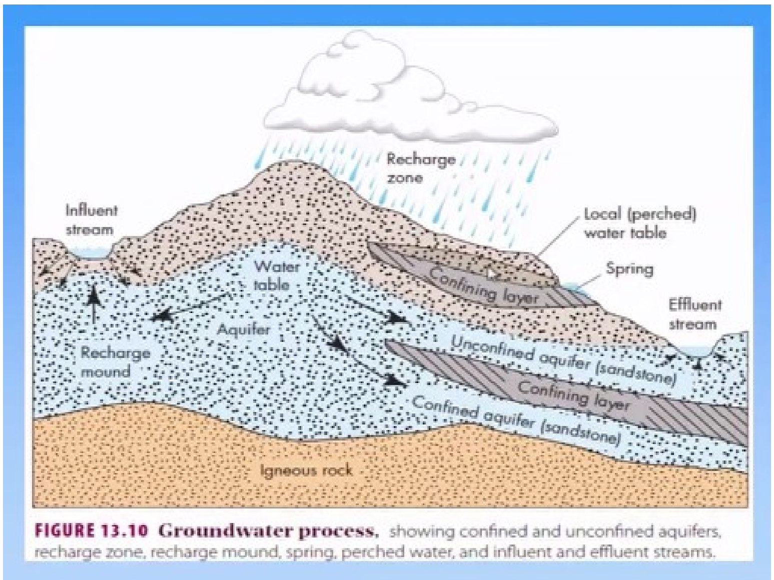

FIGURE 13.10 Groundwater process, showing confined and unconfined aquifers, recharge zone, recharge mound, spring, perched water, and influent and effluent streams.

So, this is a similar figure which talks about the influent and the effluent streams. This is an effluent stream, whereas this is the influent stream in the upper reaches and then we have different units, which is resting over the rock, igneous rock. So, we have confined aquifer, we have unconfined aquifer between the different layers and of course it shows also the perched water table which is above the normal water table as we can see here. So, this is the water table and above the normal water table is the perched water table.

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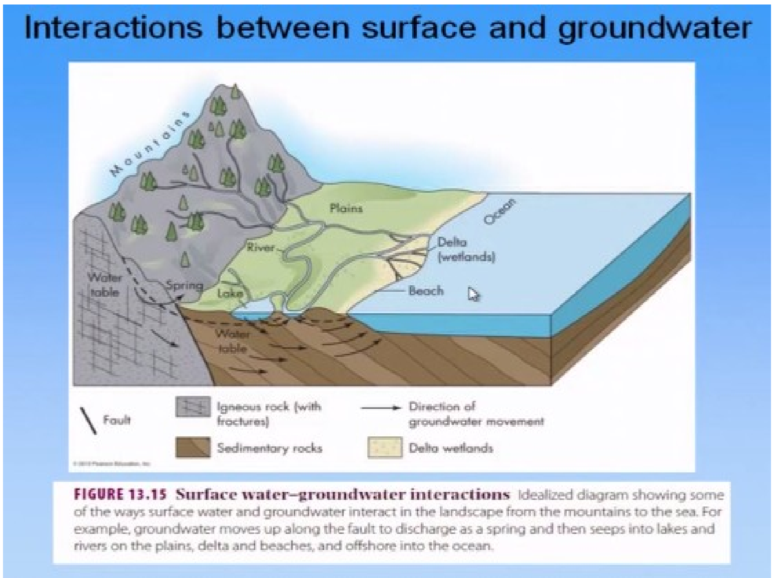

FIGURE 13.15 Surface water–groundwater interactions Idealized diagram showing some of the ways surface water and groundwater interact in the landscape from the mountains to the sea. For example, groundwater moves up along the fault to discharge as a spring and then seeps into lakes and rivers on the plains, delta and beaches, and offshore into the ocean.

So, the interaction between surface and the groundwater as we have discussed that all recharge area where the infiltration will take place and finally, the recharge will supply the water run through underground movement to the lower reaches. So, idealized diagram showing some of the ways of surface and groundwater interaction in the landscape from mountain to sea or ocean, for example, the groundwater moves up along the fault.

So this was what we were talking about that when there is a flow from the upstream or the upper reaches, the fault will act as a conduit and we will see the formation of springs or artesian springs along the fault to discharge as a spring and then seep into lakes and rivers in the plain areas that is alluvial plain areas, deltas and beach. So, this is very much similar to what is happening in Indi, that is in Himalayas and then Indo-Gangetic plain and the ocean.

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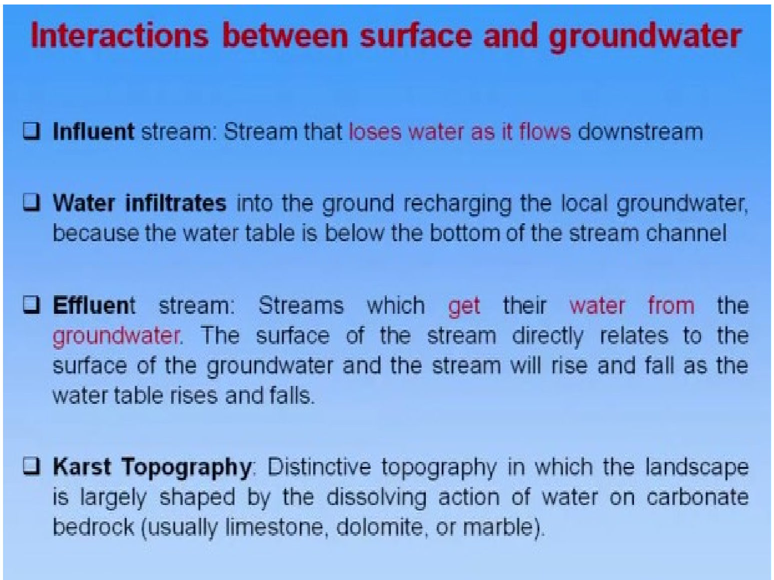

So interaction between the surface and groundwater further, so you have influent streams that loses water as it flows downstream. Then water infiltrates into the ground, recharging the local groundwater because the water table is below the bottom of the stream channel. So, whatever the water has been, there is a precipitation in the upstream is infiltrated and passed on to the downstream channel. Then effluent stream, stream which gets their water from the groundwater.

So, you refer the figure which I was showing in the previous slide, which will tell you the stream which gets the water from the groundwater is the effluent and the influent stream which loses the water. So, the surface of stream directly relates to the surface of groundwater. So, the groundwater level of the water table is similar to the water table or the water level in the effluent stream and the stream will rise and fall as the water table rises and falls. Then comes the Karst topography.

Now the Karst topography we will also discuss, we will show some slides separately also, written as distinct topography in which the landscape is largely shaped by dissolution activities of the water and carbonates bedrock, usually the limestone, dolomites, or marble. So, these some of the examples which talks about the dissolution activities.

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So, example of the Karst topography if you see it looks something like this. So formation of the sinkholes, now these sinkholes are because of the subsurface dissolution activity, which has taken place underground and resulting into collapse of the surface material resulting into the formation of sinkholes.

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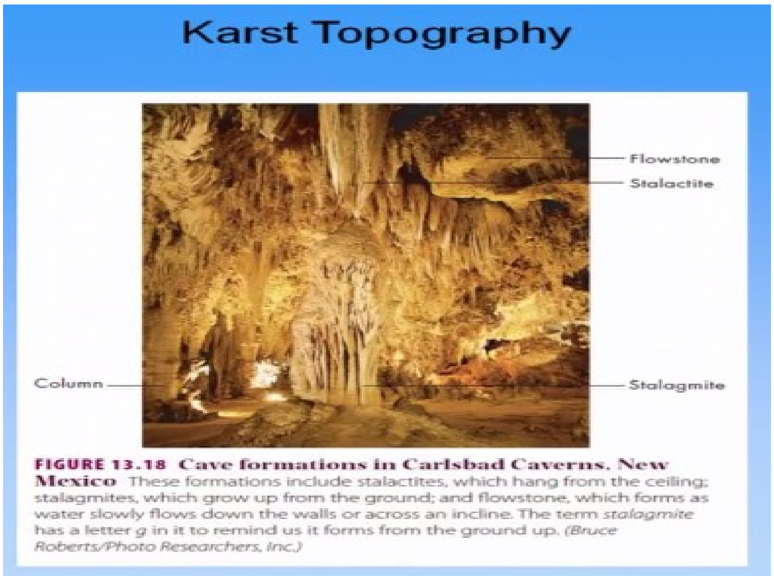

Another example of Karst topography is seen mostly in the caves and these are cave formation. So, mainly the formation of cave where you will see the formation of stalactites stalagmites. So stalagmites are again column like features which are seen from ground towards heading towards this the sky and whereas from the upper side coming towards the ground is your stalactites and the stalagmite is from the ground. So, this is again because of the flow of groundwater as well as seepage from the surface.

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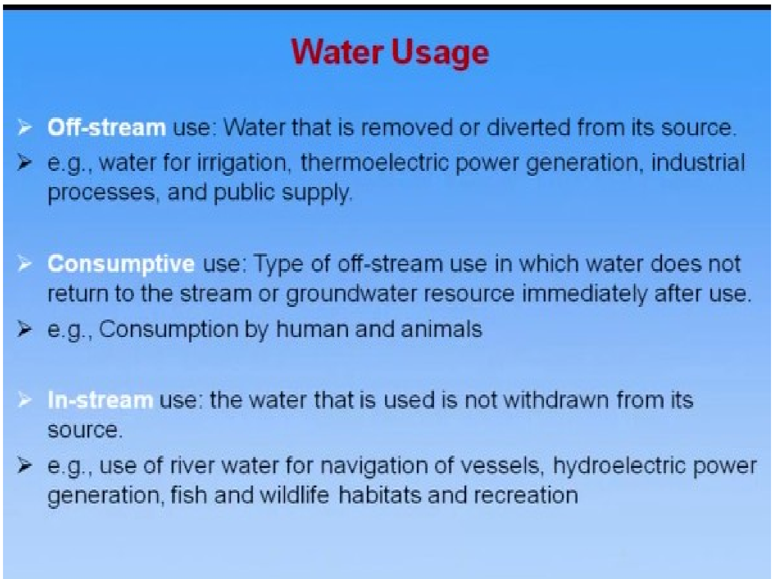

Water usage if you take, then off-steam use, water that has been removed or diverted from the source is termed as off-stream use. Example, mostly off-stream uses water for irrigation, thermoelectric power generation, industry processing, and public supply. Then second is water usage is consumptive use. Type of off-stream use in which water does not return to the stream because in some of the irrigation plants or the thermoelectric power generation plants, the water will return back to the stream, but in case of the consumptive usage, the stream or the groundwater is source.

It does not return to the stream or the groundwater resource immediately after the usage. Example is consumption by humans and animals. Then in-stream use, the water that has been used is not withdrawn from its resource. Example is use of water for navigation of vessels, hydroelectric power generation, fish and wildlife habitat and recreation. So, these are the few examples of water usage.

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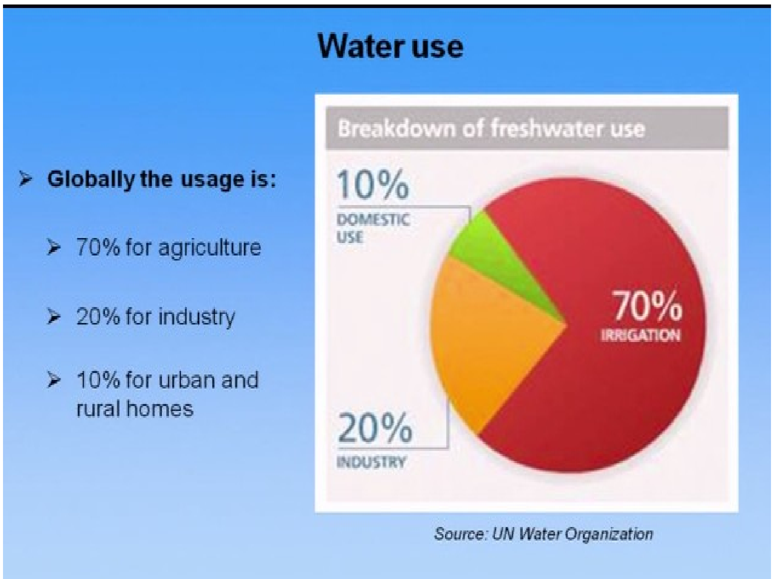

Further, if you look at the maximum amount of water has been used for irrigation, that is 70%, for domestic use it is hardly 10% and 20% is by the industry. So, global usage of water is 70% irrigation, 20% industry, and 10% for urban and rural homes.

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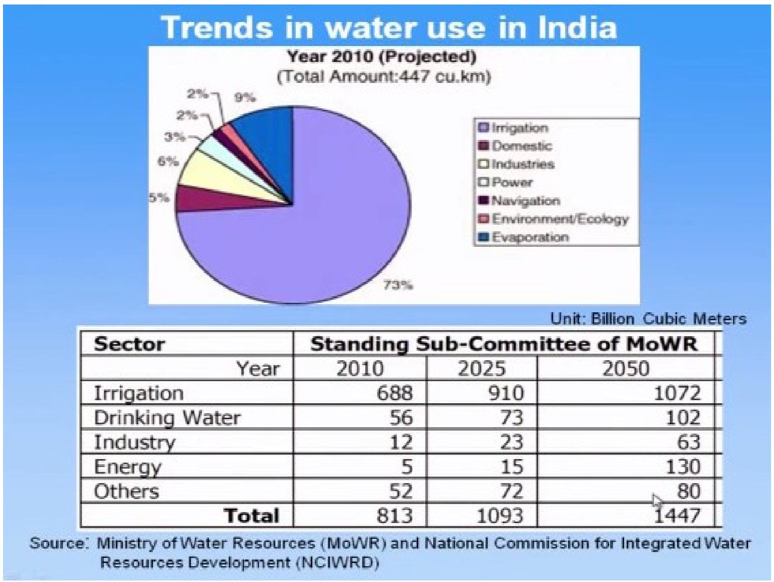

Trend of us in India if you look at, then you have 73% has been used by irrigation, then comes domestic, industry, power, navigation, environment, economic and evaporation. So, this is the table which has been given and also it has been projected that in future the demand is going to increase in terms of the irrigation, in 2050, the demand is going to be tremendously high. So, this has been given by Ministry of Water Resources which shows that the demand is ever increasing in terms of irrigation, in terms of drinking water, in terms of industry demand, and other, this demand is going to increase.

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Per capita water availability in India

Year	Population (Million)	Per capita water Availability (m3/year)
1951	361	5177
1955	395	4732
1991	846	2209
2001	1027	1820
2025	1394	1341
2050	1640	1140

Per capita water availability in India, which you can see here with respect to the population, so expected increase in population will be seen here in million by 2050 and then per capita availability will be this much. So, it will be difficult for us to cope up with the demand.

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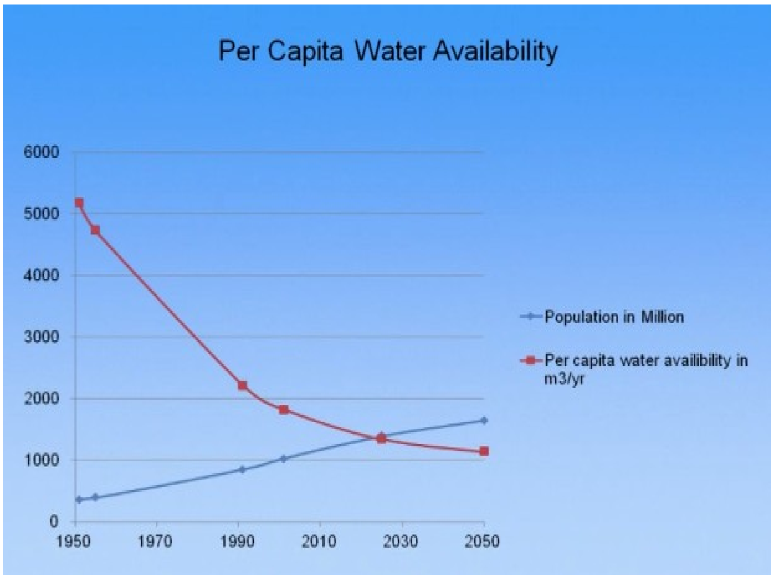

So, it will reduce the demand, the availability will reduce where is the demand will increase because the population is going to increase in 2050. So, the groundwater in Northwest India or Northern part because this is what has been projected that how it is going to decrease.

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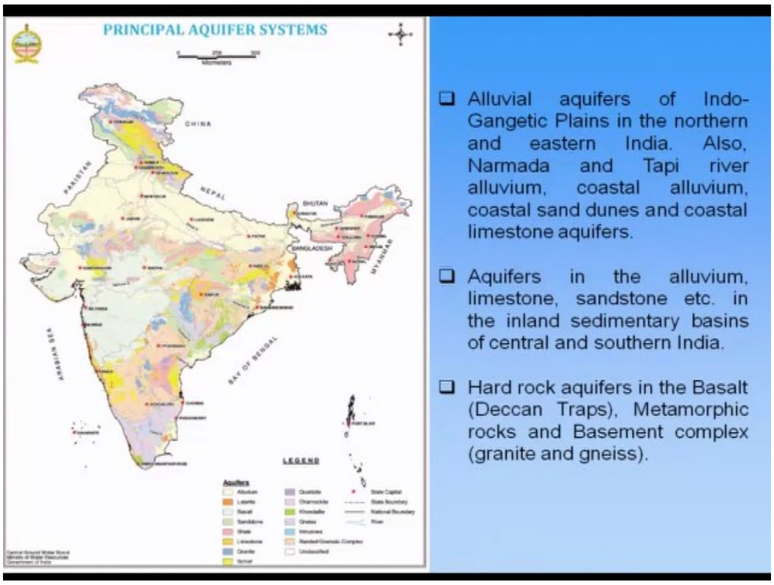

So, from some of the examples, which has been showed here is the aquifer conditions. So, aquifer conditions in India mainly where we have the good aquifer is the Ingo-Gangetic plain in the northern eastern India, they are the best and in Gujarat that is Narmada and Tapti river alluvial plains or the coastal alluvium, these are the best aquifers which are available. Aquifers in the alluvium and limestone and sandstone are also been observed in central and southern India because they do not have much of alluvium, but most of the aquifers are in hard rocks, mainly the limestone and sandstone.

Hard rock aquifer like Basalt and others are seen again in the central India and then those are mainly in the Basement complexes like granite and gneiss and Deccan Traps Basalt mainly. So hard rock aquifer in metamorphic, igneous rocks are being seen in the central part of the India.

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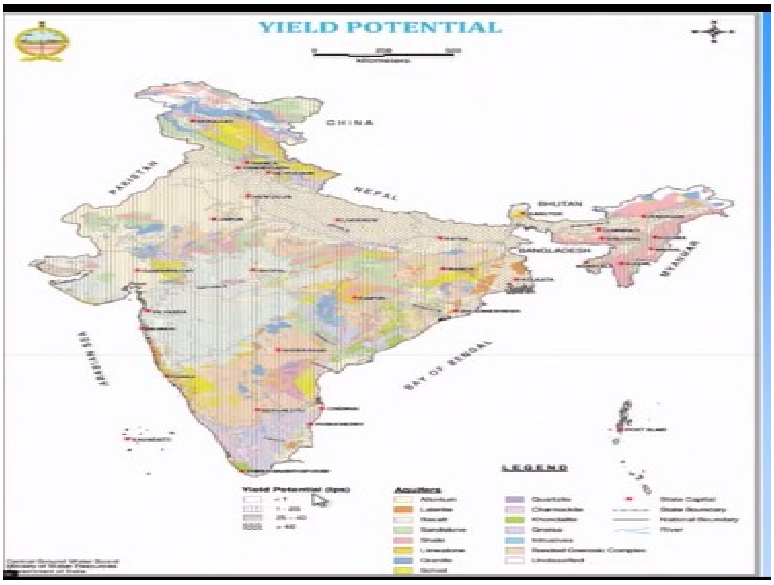

So, this is again a diagram which shows the potential yield of water and this is the way in terms of the aquifer.

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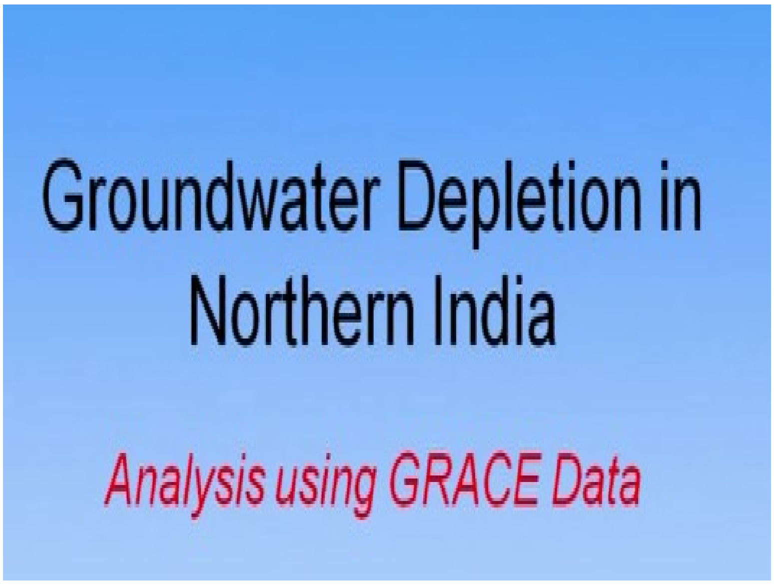

The groundwater depletion in Northern India analysis using GRACE data. So, this information is important to understand that how there is depletion of groundwater in Northern India,

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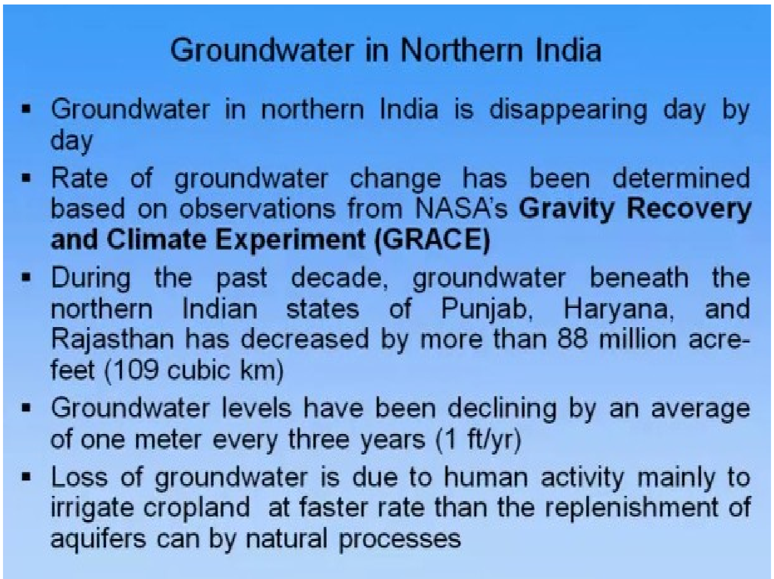

So groundwater depletion in Northern India. Now, this analysis or the results which came in was through the GRACE satellite and this is important for us when we are talking about the management of groundwater because as we saw in the previous slides that the groundwater the demand will increase, and if the demand will increase and if recharge is low, then we are going to lose the groundwater and there will be more crisis of water in our country.

So in particularly, the best aquifer or the aquifers which are available in India is the Indo-Gangetic plain and that is our fertile land, the most fertile land on the continent. So, the vast belt running east to west, the alluvial plains of the Indo-Gangetic or the Ganges and Brahmaputra river and other major rivers also hold the large amount of groundwater and the usage as we were talking about who are the consumers. So consumer maximum 70% has been utilized for the irrigation.

So irrigation, what we are doing is some of the water has been siphoned through the canals on the surface at most of the water throughout the year has been pumped from the groundwater. So, the depletion has been experienced and the depletion has been shown through the Grace satellite analysis. So the groundwater in northern India is disappearing day by day. Rate of groundwater change has been determined based on observations from NASA's Gravity Recovery and Climate Experiment, that is the GRACE satellite.

During the past decade, groundwater beneath the northern Indian states of Punjab, Haryana and Rajasthan has decreased by more than 88 million acre feet, that is 109 cubic kilometers. So, this is the amount of depletion or the decrease in the groundwater in Indian state basically

Punjab, Haryana and Rajasthan. So, groundwater levels have been declining by an average of 1 meter every 3 years, that is one feet per year. So, this is the depletion which has been observed irrespective of fairly heavy rain we have.

So, the irrespective of heavy rain we have in Himalayas or the upper reaches, the recharge is very slow. So, the groundwater levels have been declining by an average one 1 meter by every 3 years. So, loss of groundwater is due to human activity, mainly the irrigation for cropland at faster rate than the replenishments of aquifer can be natural process. So, as I was talking the recharge is slow and the consumption is much higher. So, the recharge and the consumption if they do not go side by side, then we are going to see the depletion in groundwater.

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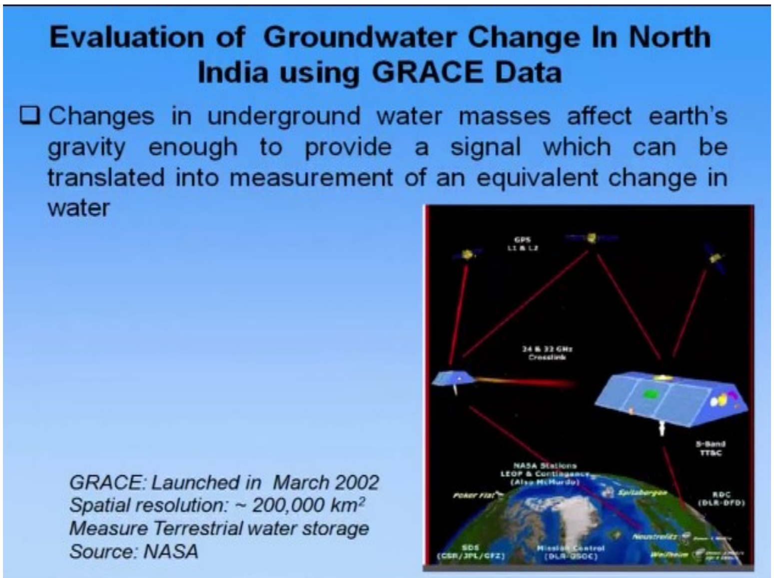

So, evaluation of groundwater change in North India.

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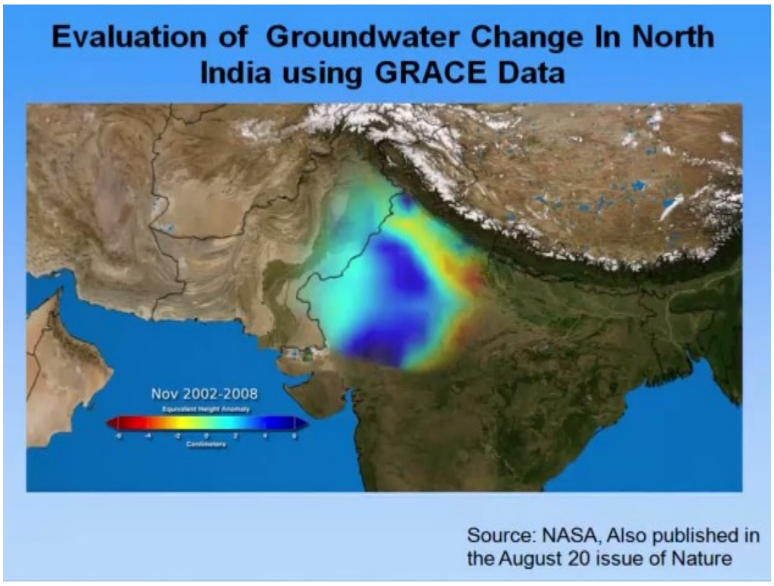

These are the changes which have been shown here, that we are having the depletion in the groundwater in this area mainly, so evaluation of the groundwater change in northern India.

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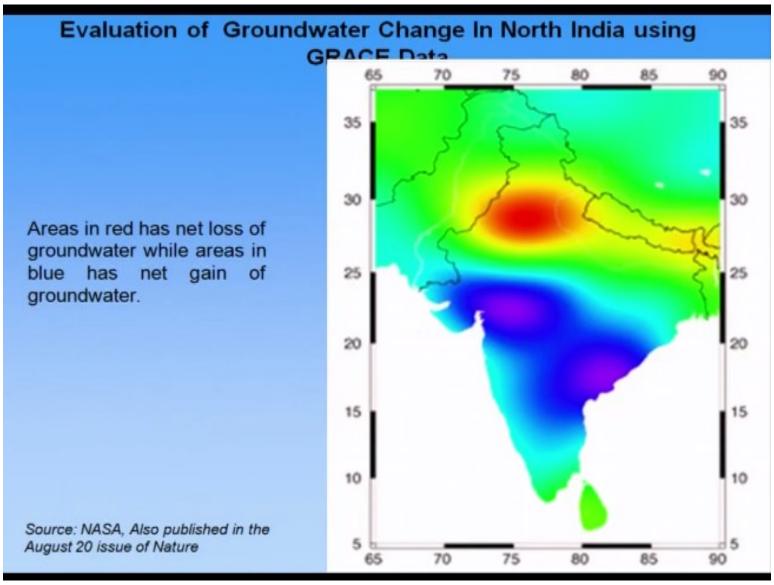

So, the red portion which you see here is showing the depletion of groundwater in the northern or we can say in the Gangetic plains and this is going to be very dangerous in terms of the future requirement, which is projected either 2025 or 2050, that is two thousand fifty.

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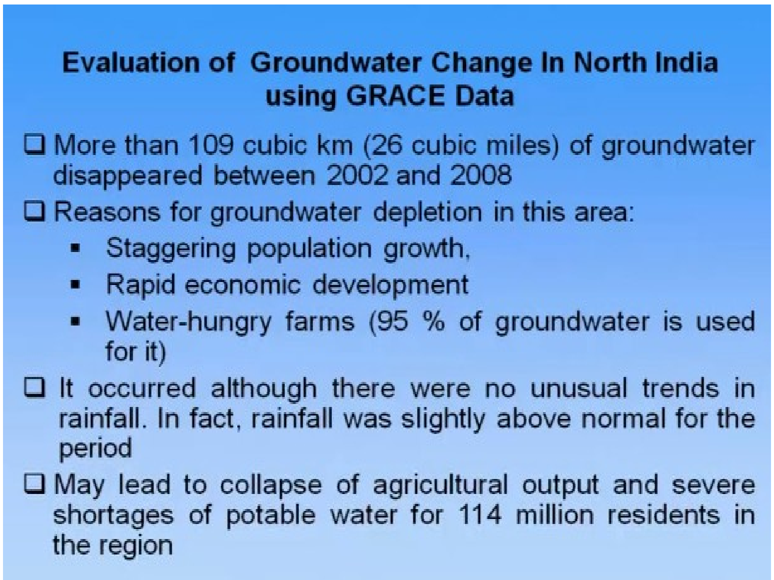

Evaluation of the ground water change in India using GRACE satellite. More than 109 cubic kilometer of groundwater disappeared between 2002 and 2008. So, between 2002 to 2008, more than 110 cubic kilometer groundwater disappeared. Reason for groundwater depletion in this area is mainly staggering population growth, rapid economic development, water-hungry farmers, 95% of the groundwater has been used for irrigation, and of course, if we are developing, then we need more and more waters and resource to develop more cities are developed more area.

So, urbanization is also consuming more and more water and the water which is available on surface, but excess requirement, is sufficed by pumping the water out from the groundwater and that is resulting into the depletion. So disappearing of such a large chunk of groundwater is mainly because of the population growth, rapid economic development, and irrigation purpose. So, it occurred although there were no unusual trends in rainfall.

In fact, rainfall was slightly about normal for the period which has been given above, but this is mainly because of the overconsumption and this may lead to collapse of agricultural output and severe shortage of potable water 114 million residents in the region. So, the depletion will affect not only the population, that is the day to day requirement by the people, but also the agricultural output.

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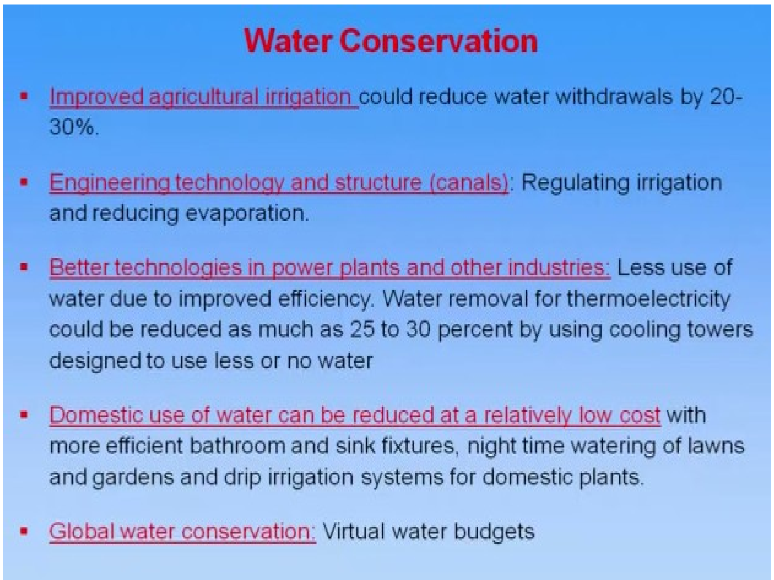

So, the part of the water conservation if we take, then we should improve certain things to have the better management of the groundwater. So the improved agricultural practices, that is irrigation could reduce water withdrawal by 20 to 30%. Then comes the engineering technology and structure that is the canals which connects the rivers and siphoning the water to different areas for irrigation purposes. So, regulating irrigation and reducing evaporation, because while transferring water from river to canal through canals to different areas, you will have lot of evaporation also.

Better technology in power plants and other industry. Less use of water due to improve the efficiency. Water Removal for thermoelectricity could be reduced as much as 20 to 30% by using cooling towers designed to use less or no water. Domestic use of water can be reduced at a relatively low cost with more efficient bathrooms and sink fixtures, night time watering of lawns and gardens and dripping irrigation system for domestic plants. Because we have not practiced, that we mostly open up the tap and allow the water to flow in our gardens and lawns, which can be reduced and can help in less consumption of groundwater.

Then, global water consumption, virtual water budgets. In some areas, like in our country, we do not charge the water, but in other countries, the water is charged. So, whatever the water you use, that is cubic meters or kilo cubic meter volume, you will have to pay for that water consumption. So, in India, we do not charge, but if we start charging the water, then the consumption will definitely reduce and better technology will also help us in less consumption of the groundwater or the water which is available with us, that is potable water.

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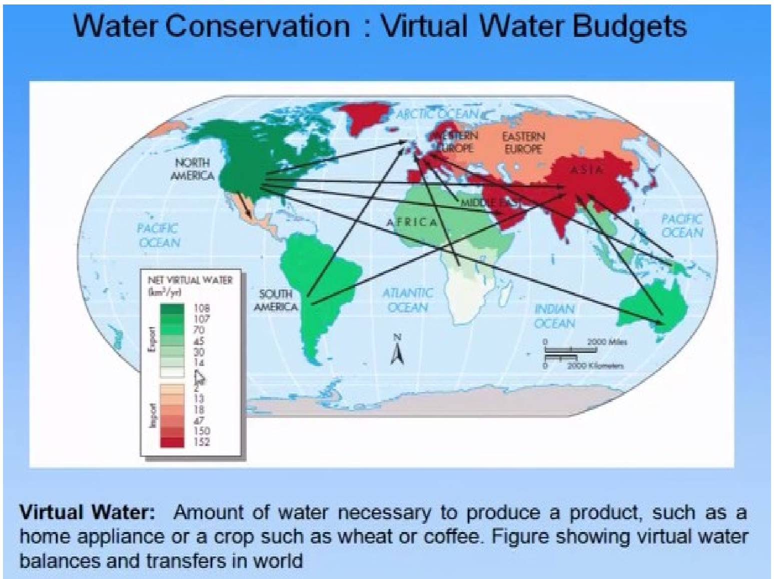

So, water conservation, virtual water budget, which has been shown here that the import and export. So the amount of water necessary to produce a product, such as home appliances or a crop such as wheat or coffee, figure shows virtual water balance and transfer in world. So, this will be the virtual water balance and transfer in the world in futures, at present also, this is what we see.

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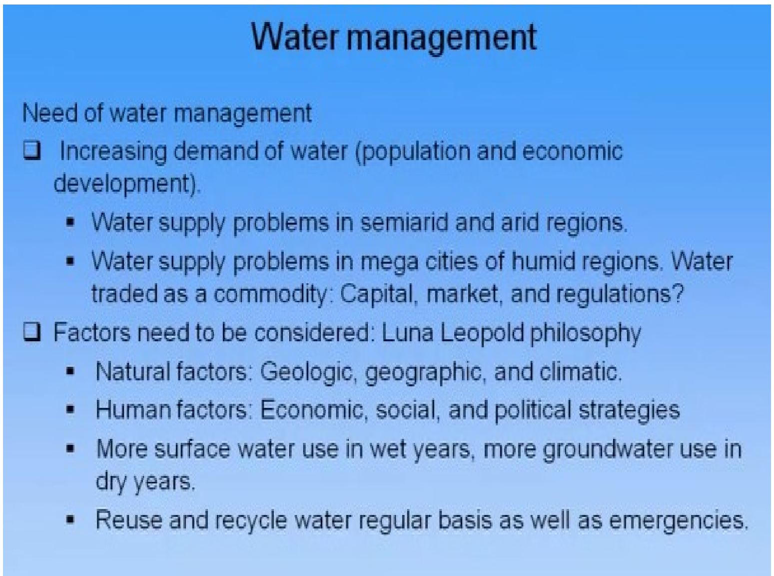

So, water management. Need of water management, increasing demand of water that is because of population, economic development, water supply problem in semiarid and arid regions, water supply problem in mega cities of humid region. Water traded as commodity. Capital, market, and regulation is not in proper order. Factors need to be considered, natural factors: geological, geographical, and climate. Human factors: economic, social, and political strategies.

More surface water use in wet area, more groundwater use and dry area. Reuse and recycle water on regular basis as well as during the emergencies. So, these are few tips which can reduce the water consumption and will have better management.

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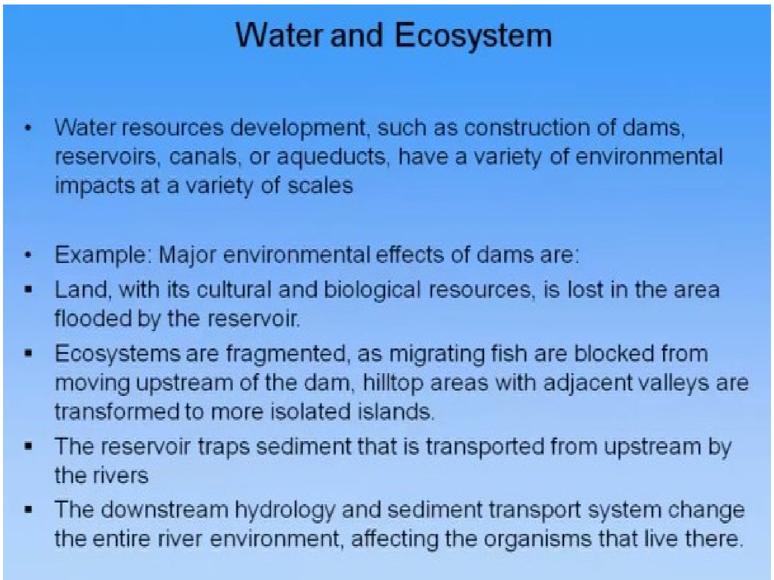

Water and ecosystem. So water resource development such as construction of dams, reservoirs, canals, aqueducts have a variety of environmental impacts at a variety of scales. Now, the example that is the affect of dam or environment what we usually faces in long term. So land with its cultural and biological resources is lost in the area flooded by the reservoir. So, this is the most common environmental effect or the impact of dam construction.

Ecosystem are fragmented as migrating fish are blocked from moving upstream of the dam and hilltop areas with adjacent valleys are transformed to form isolated islands. So the overall ecosystem is disturbed. There reservoir traps sediments that is transported from upstream by the rivers, so also has been blocked close to the dam or the reservoir structure. The downstream hydrology and sediment transport system change the entire river environment affecting the organism that lives there in the upstream and downstream area.

So, the hydrological cycle in terms of the water supply, if the dam has been constructed or any construction which has been done for the irrigation purposes, to some extent will have major environmental impact and that is on the ecosystem. Biological resources, cultural resources, and also the sediments which have been yield have been blocked along the dam structure. So, the downstream hydrology and sediment transport system changes the entire river environment affecting the organism that lives there.

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So, the problem is emerging global water shortage. Solution, control population growth and conserve water. Solution is possible, but it will take time and it will take a lot of proactive work. Thank you so much, I will stop here.