Groundwater Hydrology and Management
Professor Pennan Chinnasamy
Centre of Technology Alternatives for Rural Areas
Indian Institute of Technology, Bombay
Lecture 26
Groundwater level fluctuations

Hello, everyone. Welcome to Groundwater Hydrology and Management. This is week 6 lecture 1. In the past week lecture, we looked at the groundwater components and we are going to move into more focused groundwater applications. Before that, we are in need to understand the recharge and discharge process, which will be covered in this week.

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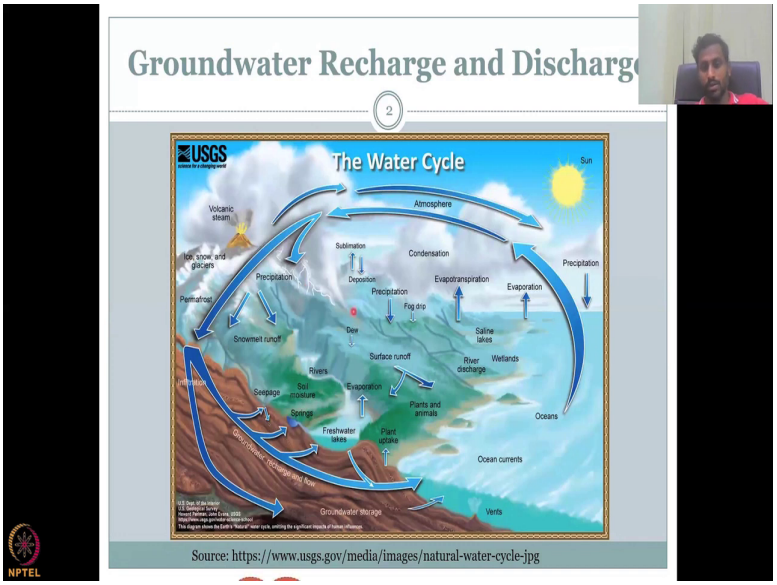

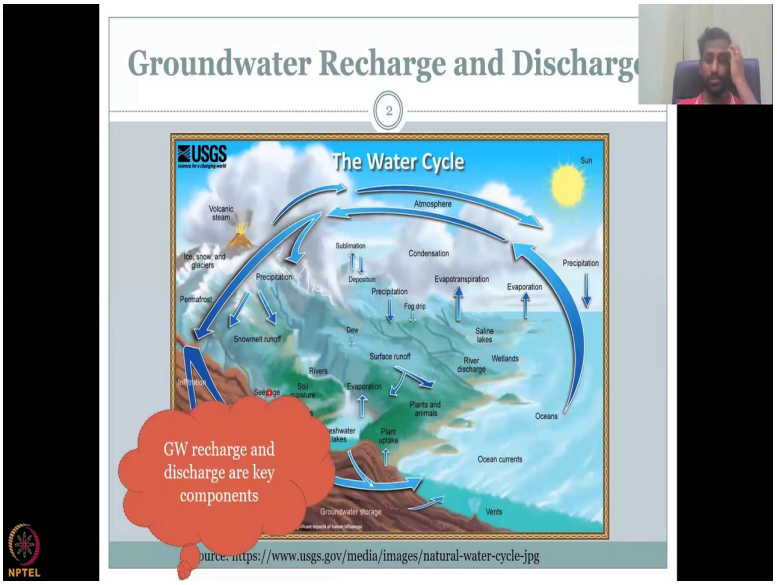

So, let us look at groundwater recharge and discharge from the water cycle perspective. You have the water cycle, in which you have your hydrological components, which has mostly your precipitation going into the atmosphere as clouds condensation and coming back to the land surface. It is important to understand the key paths in which groundwater gets into the system and out of the system.

So, for example, your ground is your base for understanding the groundwater hydrology and how water gets into is quantified as groundwater recharge. And how groundwater comes out in terms of natural which is seepage, into the freshwater lakes, springs etc., and also to the oceans are called groundwater discharge. Now, because of recharge, they can also be discharge same because of discharge, they can be recharge, we will come into how these two components are interlinked.

Also, there is a human component or anthropogenic, wherein you do have groundwater recharge, because of augmented recharge, induced recharge, etc. On the other hand, there is groundwater discharge through human actions, most importantly, when you pump up. So, in this week's lecture, we will look at the key parts in which groundwater recharge and discharge happens. More importantly, we will look into methods to quantify groundwater recharge and discharge.

In the first class of this week, we also looked at how groundwater recharge and discharge forms key components in the hydrological cycle. If you look at the cycle here, for example, if groundwater recharge does not happen, or discharge does not happen, what do you think will happen is that this water will never get into the aquifers nor it gets out as baseflow.

So, the cycle would be more faster because every water that falls on the ground would either be stored on top as lakes and rivers or runs off back into the ocean. Whereas the groundwater recharge actually delays the water in completing the cycle, these are much much faster time steps compared to the groundwater movement. So, basically, your water goes through a slower cycle and it takes some time for recharge and discharge.

If you look at here clearly, when groundwater is coming into this face, for example, at this particular location, groundwater is recharging. And if it is taking this path to go out, it is discharging but in between like for example this point, ground water is recharging, because

water is flowing through it recharges, it does not stay long, but then it discharges out. So, this is where the connections happen.

But more importantly on this water cycle that we used to see a lot of these hydrological components, groundwater is a key component without which most of these cycles would not complete itself. And or it will be more flashy, flashy as in quicker. So, that is why I am again saying that ground water recharge and discharge are key components in the hydrological cycle.

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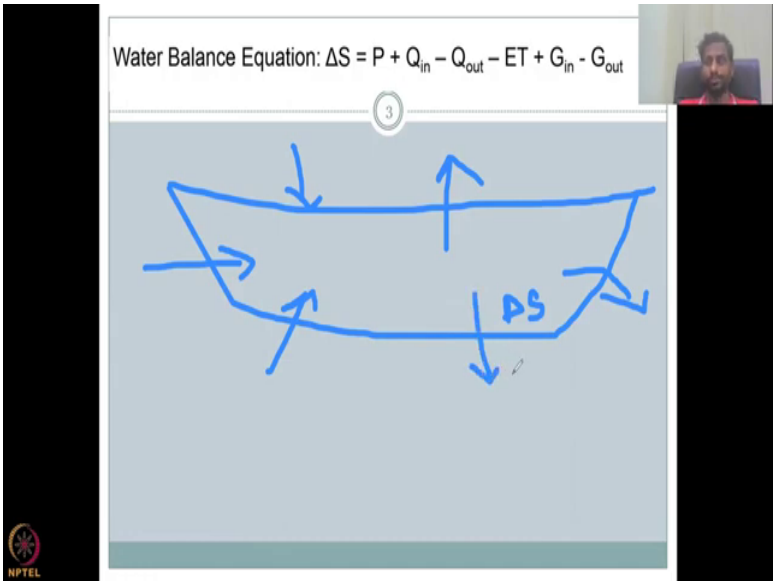

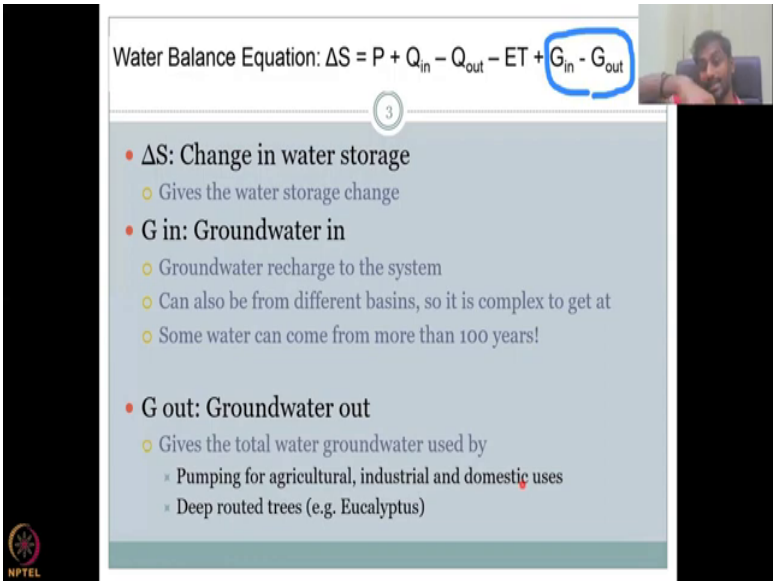

Let us look at what forms the basis from the Hydrological Cycle. Yes, the water balance equation How is groundwater defined here or ground water recharge and discharge. So, your Del S in your hydrological cycle is the net storage in the basin, let me draw a quick basin for you or area. So, this is your area maybe it will be your watershed basin, whatever it wants to be called. And you have Del S is a net storage within this basin Del S precipitation is what comes in P, Qin is what comes in as surface water, Qout is what goes as surface water, Et is loss, so, it goes out, all the minuses are going out.

So, this is your Et loss, this is your Qout and then you have your groundwater in which is all from the basement I am saying, this is the groundwater coming in, and groundwater coming out. So, I will explain all these terms in the Hydrological Cycle. However, for our, this week lecture, these two components are very important, because they define what is Gin as ground water in which is your recharge, and Gout is the groundwater discharge coming out.

So, for a system, you have in the hydrological cycle, in the water balance equation, a groundwater coming in which is called recharge, because this is your system and ground water is coming in actually comes from bottom, but you can also show that just as a vector its moving in, then you have ground water out which you are taking out, ground water out can be from the bottom as a ground water seepage or pumps to take out.

So, Del S is changing water gives the total net water storage, it is the change in any of these components, you can have storage inside your basin by ways of soil moisture, surface storage or groundwater storage. Gin is groundwater in, ground water recharge to the system can also be from different basins.

So, it is complex to get that, which means it is not only from your hydrological basin, it could be from a different aquifer, different basin, because it moves under the basin, it is on the top rainfall cannot come from another basin to inside unless it is coming as Qin. So, please understand that Gin is a very complicated parameter, it cannot be just estimated using your basin boundary.

Some water can come from more than 100 years slash kilometers, 100 years means it took 100 years to travel. So, think about how far it should have traveled without all these

disturbances and get into the system. So, that is your ground water in which in this class we will be looking as recharge.

Groundwater out is the total water of groundwater used by pumping for agriculture, industrial and domestic uses. So, what happens is you have a pump and you take it out and that is discharge because you are taking out the water for agriculture, industrial, domestic use. The other is natural where you have deep rooted trees like eucalyptus and plants and other things which take water out that is also kind of a discharge, but it goes into evapotranspiration.

So, there is some part of double calculation in these. So, it is better to say Et is the water taken out by plants. However, when you pull the water out by trees, some water is raised up in the soil and it discharges out. So, not all water is going to be taken by plants. So, that is a small component in groundwater discharge. But most importantly ground water discharge happens naturally as shown in the previous water cycle by just seepage it goes and joins the ocean and goes joins the rivers etc.

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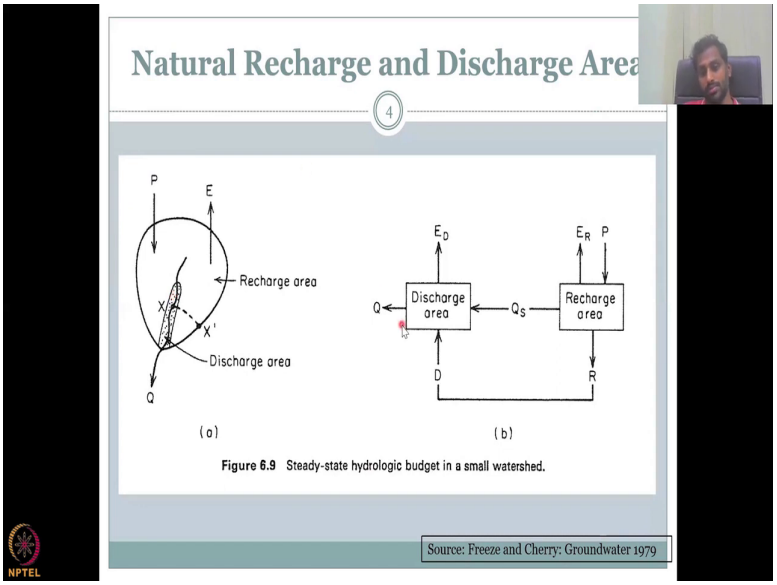

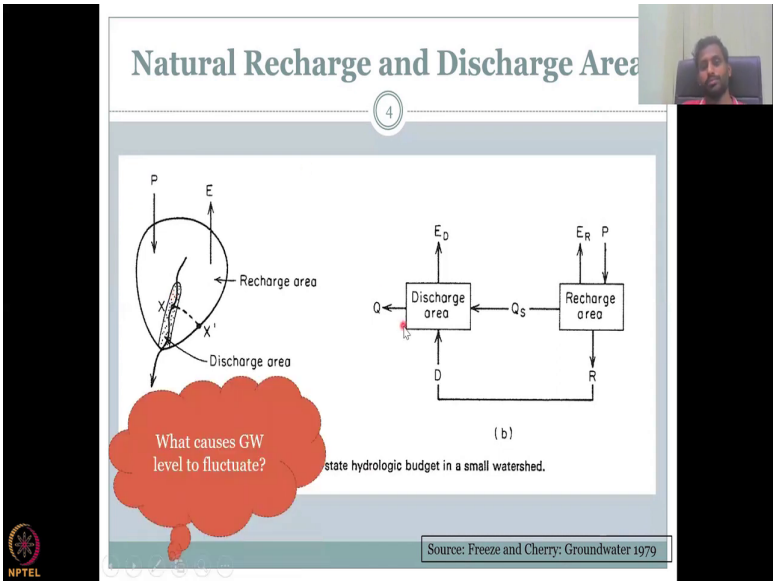

So, let us look at the area to give an idea of how it looks like in terms of a basin, so, you have a basin, and assuming that the water recharge is happening within the basin just this basin. So, you have basin boundary, and you have as the previous water balance equation I showed you have precipitation coming in and evapotranspiration going out, here it is called as this 1 equation. Then you have Qout which is your surface water going out, there is no Qin because it is a basin closed for the water to come in.

What do you see here is there is a recharge area? So, when precipitation is falling on a particular area, all this area is contributing to recharge. So, this is the area for recharge, whereas for discharge, it does not just discharge here, because there is no elevation gradient, or a water body that the groundwater wants to flow into, because ground water flows from high potential to low potential.

So, here there is no water body that flows like that, what happens is along the channel, because the channel is already in a lower elevation, and the groundwater potential is high in the groundwater low in the stream, the water would discharge out. So, it will move like this and come out into the river and that is what this area is called the dotted area is called the discharge area.

And look at the discharge area, you also have some evaporation on all the discharge area and transpiration whereas all the precipitation is very much less here because already discharge is

happening and if precipitation will still fall on this area, some recharge with all the recharge would just come out as discharge.

So, in a recharge area presentation is happening, your evapotranspiration is happening and there is a recharge into the discharge area. So, recharge and then recharge water goes and discharge is out of the discharge area. So, this clearly explains the steady state hydrological budget in a small watershed. Wherein Qin is equal to Qout and it does not change.

So, most important, what we need to understand here is the recharge area and discharge area can be within the same basin. However, they are differentiated because of the function and the function as a how precipitation comes in, how recharge happens and what is the area for discharge.

So, with this understanding, we have a bigger groundwater recharge area compared to discharge area, most, in most cases, the recharge area is bigger than the groundwater discharge area, how groundwater comes up. So, we know that when recharge happens, your storage changes, it goes up. Similarly, when you pull out water or water goes out of the system, the level goes down. So, there is a fluctuation in the groundwater level. It is important to understand why these fluctuations happen. So, let us look at a particular study.

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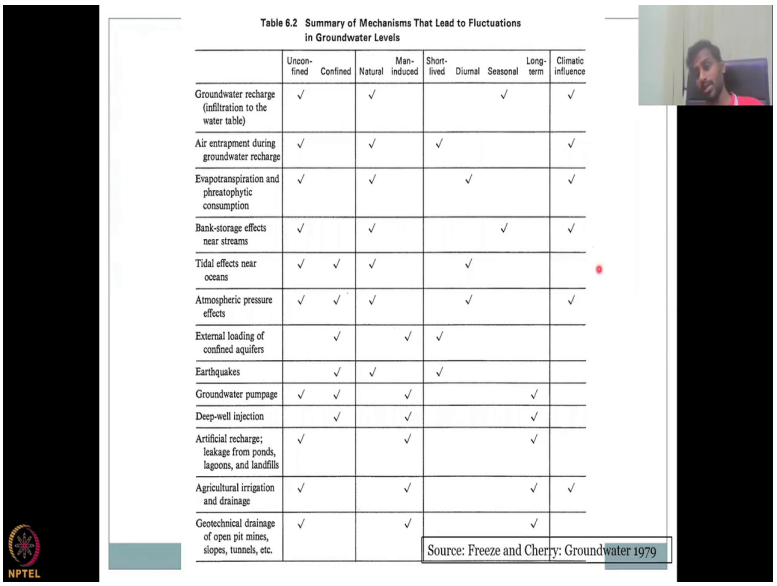
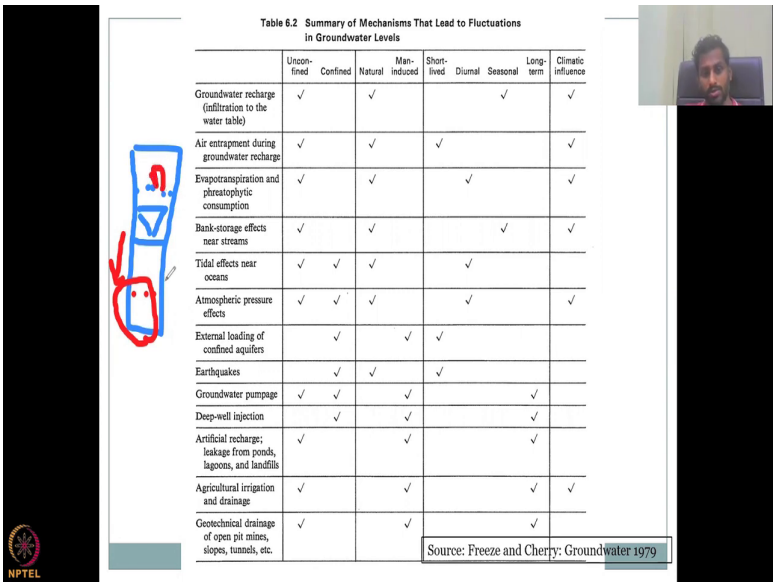


Table 6.2 Summary of Mechanisms That Lead to Fluctuations in Groundwater Levels

	Uncon-fined	Confined	Natural	Man-induced	Short-lived	Diurnal	Seasonal	Long-term	Climatic influence
Groundwater recharge (infiltration to the water table)	✓		✓				✓		✓
Air entrapment during groundwater recharge	✓		✓		✓				✓
Evapotranspiration and phreatophytic consumption	✓		✓			✓			✓
Bank-storage effects near streams	✓		✓				✓		✓
Tidal effects near oceans	✓	✓	✓			✓			
Atmospheric pressure effects	✓	✓	✓			✓			✓
External loading of confined aquifers		✓		✓	✓				
Earthquakes		✓	✓		✓				
Groundwater pumpage	✓	✓		✓				✓	
Deep-well injection		✓		✓				✓	
Artificial recharge; leakage from ponds, lagoons, and landfills	✓			✓				✓	
Agricultural irrigation and drainage	✓			✓				✓	✓
Geotechnical drainage of open pit mines, slopes, tunnels, etc.	✓			✓				✓	

Source: Freeze and Cherry: Groundwater 1979



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Source: Freeze and Cherry: Groundwater 1979

From the Freeze and Cherry Groundwater book, where they look at how these important mechanisms that lead to fluctuations in the groundwater fluctuation means the water level fluctuates just to draw a small thing, what do you mean when you because this term would be coming often in your books and stuff for groundwater, so, this is your level, the initial level, the level can go up here or down here based on if it is recharge, which is this one, or discharge, which is this one.

So, discharge is lowering of groundwater table because you are pulling water out whereas recharge is raising all the water table because you are recharging water. So, this is your new water level. I hope this is clear, because it is important to understand the following notations. Let us go one by one and we know what is the difference between unconfined and confined aquifers. We know what is natural and man induced.

Natural is it happens naturally in the ecosystem. Whereas man induced is the human interface is pushing that phenomenon to happen. So, what do you see on your first column is your phenomenon process. And then the next set of column is whether the aquifer is unconfined or confined. Moving on, we have a next column which is natural or man induced to show what is a key process driver for this phenomenon.

Then the next is your duration is short lived. Diurnal means mostly daily. Seasonal, you have a couple of months or long term and then you have climatic influences, the climatic influences could be natural or man induced, let us not get into that here it is climate, how the climate can induce it. So, let us look at the most important common processes that result in the fluctuation of the groundwater table or level.

The first one is groundwater recharge infiltration to water table. So, as I said, we do have groundwater recharge happening. So, let us take this as a land and then you have water coming in. So, let us change color of this one. Yes. The first one is groundwater recharge happening infiltrating into the water table and this is your water table for example.

So, the first process just documents the slow moment or infiltration and lateral percolation into the groundwater table, it can happen only in the unconfined aquifer, why? because let me

also draw the unconfined and confined aquifer. So, this is a second layer which has a thick impervious surface and this is your 1 and 2.

And this is your bottom layer bedrock great. So, let us move on the first groundwater table. The ground water recharge moves through from rainfall or some other water like irrigation you have a tank which is leading into a canal irrigation or just water flowing on top water can irrigate like gardening and etc. So, that water can infiltrate into the ground and raise the water level that can happen only in the unconfined layer because unconfined layer is open to infiltration whereas the confined layer is not going to change.

So, there is no tick mark, there is only a tick mark in the unconfined layer is it natural or man induced mostly. So, yeah there could be some man induced that you can push water through focused infiltration processes, but in general it is nature natural based process, because of soil because of rainfall, because of gravity, you have infiltration and that actually raises your water table.

For the man induced sources let me put a small tick here just to show that you can have groundwater recharge networks surface ponds, farm ponds etc. that we saw, we will be seeing everything is in. Is it short lived, Diurnal or seasonal, mostly it is seasonal, because rainfall happens not very short lived. It is not daily, just within a day it will change it is a seasonal pattern. Not long term, because every season you do have recharge.

Is it influenced by climatic factors? Yes, because when climate extremes happen, for example, your flood, there will be more rainfall happening and stagnation of water so water can recharge. What happens in the drought, which is also climate extreme, there is no water when there is no water, there is no recharge. Then what happens is you have extreme events also and a slow tapering event which is you are increasing rainfall not a flat I am saying, but rainfall is increasing and temperature is increasing.

So, when you have high temperature what was less infiltration is less because all the water be evaporated. So, all this is the first row which it talks about groundwater recharge through infiltration, which affects your fluctuation in the water table can happen through climatic factors. Moving on the second was air entrapment during groundwater recharge.

So, think that when groundwater is coming, your recharge is happening by one the first process, so when groundwater recharge is happening, and we have to thank Freeze and Cherry's book, which has documented everything very meticulously, these constitute all the major processes for fluctuation of water table in the water cycle. And we can differentiate that as recharge and discharge, so big thanks to that book. And we would look at the first thing which is air entrapment during groundwater recharge from the recharge.

So, the first one was the recharge and then while the recharge is happening, think about this, you have land inside you have soil with porous space, and this space has air or water or none, a combination of both or none, suppose the air is present in the porous space. So, when water comes in the air either has to be displaced? So, the air sometimes gets entraps during the groundwater recharge.

How does that influence your water table, basically, you have less water going into the water table to have fluctuation or the water bubble can go into the water table and raise it until the bubble breaks, so that is only in the unconfined layer only in the top layer, it happens it does not go in. It does not go in the confined layer because air moving that far it cannot because by the time it moves into the small pores and goes down, it is wrapped into very small particles, and it does not become a bubble kind of thing, for entrapment.

It is purely nature based because water is being pushed by the groundwater recharge. And it is very short length. In fact, it is one of the least important processes for groundwater fluctuation, however it fluctuates. And it is also influenced by climatic factors. Because if it is a wave hot surface, then all the water is taken out full of air is in the soil.

And then when rainfall happens suddenly, before the air can escape, a big rainfall pushes the air bubble inside so the air bubble gets attract. But what it tells is the entire process the of the fluctuation, the fluctuation of the water table is just shortly it just blip and then comes down. This is important to understand while you are in the field, because a lot of these field instruments will throw this error at you, sudden error.

And you will be like oh! there is no rainfall or that was not big rainfall or why is it short length suddenly there is a blip and comes down and that is explained by air entrapment. And many other instruments also have this like for example the discharge measuring devices,

water flow, suddenly there is an eddy current or a water droplet which is stuck in the machine.

The next one is evapotranspiration and phretophytic consumption, let us just keep it as plant consumption. It happens in the unconfined layer again we are talking about plants and trees that are accessing water only from this layer. So, when they pull the water out eventually your groundwater table goes up and down. It goes up slightly when the water comes in because of the pool, but most importantly water is pulls down and the water level is coming down because more water is being sucked out.

So, this happens also as a phenomena in the unconfined aquifer. It is by natural based system because plants are natural based systems it is not short lived, it is Diurnal. Why Diurnal because the growing cycle is also seasonal Diurnal, because the planet sucks the water only in the day time, when transpiration happens after that it shuts down.

So, suddenly you see a groundwater plummet and then slowly comes up, comes down, goes up, comes down, goes up and this sinusoidal nature of the water table mimics your water use of the plant when the plant takes more water it goes down and when plant shuts down some shuts down there is no photosynthetic reaction taking place then the water recharges up.

Moving on, then, it is also influenced by climatic factors because when there is different climatic pressure on the plant the plant water consumption is different bank storage affects near streams. So, for example, you have a stream you have a river flowing near the river there could be some water stored because of the flood.

Your flood is coming in the bank is full of water that can also influence your unconfined aquifer the first layer in the aquifer because the water can rise based on the bank water storage amount. It is purely a nature based system and it is seasonal because your river would have water only during seasons. When there is no water flow in the season. There is no water in the river and it is drying so the water goes down.

Once water flows from your river channel from your bank, water will come down into the groundwater aquifer and recharge your aquifer. It is also influenced by climatic factors because based on the climatic factors you have water coming into the river because if there is

a big rain, lot of water will come in the river and that water will flow as flood and the flood will induce recharge.

Tidal effects near oceans similarly, similarly you have big water waves, big tides that will come and hit the coast and that happens in a cyclic pattern also, during certain periods of a month you have a bigger tide and then small tide big tide, small time. So, in this big tide comes more water reaches the shore and that water can recharge.

So, that is also a unconfined aquifer effect, but because the volume of water is too big and it pushes the water comes in a big force it can also impact your unconfined aquifer. So, both unconfined and confined aquifer can be influenced by this tidal effects. It is a purely nature based system even though man induced climate change and other things can happen and it is diurnal in nature if you go to the beach you will see that during the night the wave is high. During certain peaks of the month it is high.

So, it is not a seasonal it is between the seasonal and diurnal, diurnal is daily. Seasonal is a couple of months once, so, you could see that the water recharge through tidal can happen in a natural based system it is diurnal daily it happens because day night, day night, and it may or may not be influenced by climatic factors.

Atmospheric pressure effects. So, when the atmospheric pressure is different water can come out because water flows from high potential to low potential for example, outside the well if the atmospheric pressure is low compared to high pressure of the water inside then what flows from high pressure to low pressure you have automatically flowing Wells which are called artisan wells, we saw this in the first couple of classes.

And that is purely happening as a climate influence factor because the climate changes your atmospheric pressure it can happen from unconfined or confined aquifers basically where your well is placed. And it can happen from that aspect also. And also it is a very natural base system because of it can happen only from a deep well and because of that most efficient use of humans cannot control the atmospheric pressure it is diurnal in nature and can be influenced by climatic factors they will because every day in some aspects it can happen.

External loading of confined aquifers. So, you have unconfined and confined aquifers but external loading can happen you can put pressure on the aquifer. And as the name suggests it is only going to be in the confined aquifer only confined aquifer layer is there. And as a external loading happens, it can happen naturally, but only once it is not a big thing to record but it is a man induced part.

So, that happens in couple of times, then it is because of human induced. It is very, very short length. Suddenly you put some loading, for example, you bring a couple of tons of cement and blocks and put it on top of the aquifer, it just pushes your aquifer and suddenly you see a jump fluctuation. There is no climate and other things.

Earthquakes, Earthquakes are the process in which the place very very deep near the bedrock near this area I am saying where the rocks and other things would move. So, when they move, the water table also fluctuates because if suddenly there is a crack, then this water will flow down, water will come down. Or if there is a crack and water flows out of the system, then this water level will go up.

So, these define the water level fluctuations because of an earthquake and it happens only in the confined aquifer because of the depth. It is a nature based process and it is very short length just couple of minutes that it. It is not going to be every day, it is going to shake or every season is going to shake earthquake.

Groundwater pumpage is the most important aspects in ground water fluctuation, pumpage can happen from unconfined or confined aquifer based on where you are putting the pump you can have one pump in the unconfined and one pump in the confined. So, you can pull the water out it can change and it is a human based process because you are the one who is going to control the pumps.

It is also long term effect because once you pull it the water still table will take long time to stabilize, It is not going to fluctuate and then stay there, it just takes slowly, slowly, slowly, easily you will pull it out. So, suddenly the water table will fluctuate down, but then the recharge happens very slowly.

Deep well injection, this is also a human induced process and injection you put in water, and it is in the confined aquifer. So, the confined aquifer is here you put in some water for some process fracturing or you want to put in a polluted water like some people do very bad you know polluting the environment or you want to actually recharge or keep it in the ground so, that you can use it during the later season like UTFI project I mentioned.

So, this deep well injection is based on a reverse of the pump instead of pumping out you are pushing water in using energy, it is a confined aquifer process manmade human influenced and it is also long term similar like your pumping it is also long term.

Artificial recharge leakage from ponds, lagoons and other landfills it is where you create or you induce more recharge and that happens mostly in the unconfined layer the top layer because that is where most of the small structures would push water in not to the deep aquifer. It is man made because it is artificial just note this word, it is artificial injection pumpage, all these are caused by humans. So, that is defines it as human or natural it is also long term. It is not very short term process because it takes time for it to go in and stabilizes the water level.

Then we come to agricultural, irrigation and drainage. So, agriculture itself is a man made or human influence process it is happening only in the unconfined region because agricultural irrigation not agriculture pumping, agriculture and irrigation you are going to put water on the surface and water recharges it recharges only in the unconfined layer because the roots are only here the plant roots will only grow till here, it does not grow much.

It is a man made because the agriculture is not a natural process forests are nothing but natural process and then it is also a long term like pumpage etc. Whatever it is human induced it is long term impact it can be influenced by climate because the climate factors influence how the plant grows.

Geotechnical drainage of open pit by mines, slopes tunnels etc. This is the geo technical drainage because you push water into these kinds of pits, mines etc it is a mind that mine when you have a mind where they collect the boards and stuff they have a specific space

where they can put all this dump all this water slopes tunnels also in the cut there is some space where the water goes in.

So, suddenly you see an influence on a confined aquifer. The unconfined aquifer changes the level it is a human induced process it is also long term. So, there is no climatic factors. So, what is the take home here there is multiple things that can change the water level either by recharge or by discharge taking out the water or putting in the water.

What do you see is the nature based processes are either seasonal, short term or Diurnal whereas the human based processes are long term. So, when you disturb a system and it takes long term to stabilize, that is not sustainable. We cannot do it continuously, for example, the man storage can happen continuously because every season the water comes, it is fine. However, you are pumping, injection, artificial recharge, agricultural irrigation, which is also artificial plants and vegetations you are growing not by natural process.

And geotechnical rents all this has an influence on the groundwater aquifer because you're pushing water or you are extracting water. And the more key driving home message or the drive home message is these take time. It is also influenced by climatic factors. But most importantly it takes a long time for the water to stabilize the fluctuations to stabilize. So, you cannot plan what is going to happen next. If I take too much water the water level comes down and before I know how much water is there, I can pump and I can pump and that is why the ground water resources are very low in the country, especially, India where most of the groundwater is extracted.

I hope these messages were clear to understand you know all the important process through which fluctuations happen. I will see you in the next class where we go on to discuss each one process in particular because recharge is different than discharge. So, we will go on into see how recharge happens and how are they estimated same way we will go to discharge and see how discharge happens and how it is estimated. Thank you. I will see you in the next class.