ENVIRONMENTAL GEOSCIENCES

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Lecture-38

Groundwater Fluctuations

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are continuing the module seven. In the module 7, we have discussed law of groundwater movement, Darcy's law and applications from lecture one to lecture three. Today, we will cover the lecture 4, that is groundwater fluctuations. In this lecture 4, the important concepts we will cover like different environmental factors, that influence the groundwater levels, how the stream flow and the groundwater level are connected in water sets, and what are the effects of global climate change on the groundwater.

So these concepts will be covered. Now, in the last three lectures, we have learned about the groundwater resources. Now. Now, the measurement of water level fluctuations in piezometer and observation well is an important facet of many groundwater studies. A groundwater level, whether it be the water table of an unconfined aquifer, because this we have learned already, that the water table always remain with the unconfined aquifer, or the piezometric surface, which remains with the confined aquifer, indicates the elevation of atmospheric pressure of the aquifer. So the water table in any unconfined aquifer and piezometric surface in a confined aquifer always tells us about the elevation of the atmospheric pressure within an aquifer.

Any phenomenon that produces a change in pressure on the groundwater will cause the groundwater level to vary or the variations of the groundwater level. So difference between supply and withdrawal of groundwater cause levels to fluctuate. When we are taking out the water from the well or we are supplying water to the well, then the fluctuations of water table take place. Stream flow variations are closely related to the groundwater levels. Other diverse influences on the groundwater levels include meteorological and tidal phenomenon, urbanization, earthquakes and external loads etc.

Finally, subsidence of the land surface can occur due to changes in the underlying groundwater conditions. Now see the time variations of the levels. The first is the secular variations. Secular variations of the groundwater levels are those extending over periods of several years or more. Alternating series of wet and dry years.

Wet year is the year in which we are getting the rainfall much more than the average annual rainfall of the area. And dry year is the year in which we are getting the rainfall amount much below the your average annual rainfall of the area. So, alternating series of wet and dry years in which the rainfall is above or below the mean will produce a long-term fluctuation of water levels. So, rainfall is not an accurate indicator of groundwater level changes. Recharge is the governing factor.

Assuming annual withdrawals are constant, It depends on rainfall intensity and distribution and amount of surface runoff. In other instances, pronounced trends may be noted. In overdeveloped basins where draft exceeds recharge, a downward trend of groundwater level may continue for many years. Now second is the seasonal variations.

Many groundwater levels show a seasonal pattern of fluctuation. This results from influences such as rainfall, irrigation, pumping that follow well-defined seasonal cycles. The variations are typical for areas subject to frozen ground in winter. Highest levels occur in late spring and are lowest in winter. In irrigated areas where frozen ground is not a factor, lowest levels normally occur during fall at the end of the irrigation season.

The amplitude depends on recharge, pumpage and the type of aquifer. Confined aquifers normally display greater range levels than do the unconfined aquifers. Short term variation is the third one. Groundwater levels often display characteristic short-term fluctuations governed by the primary use of groundwater in a locality. Clearly defined diurnal variations may be associated with municipal water supply wells.

Similarly, weekly patterns occurs with pumping for industrial and municipal purposes. Now we will see the relationship between the stream flow and the groundwater levels. Where a stream channel is in direct contact with an unconfined aquifer, the stream may recharge the groundwater or receive discharge from the groundwater depending on the relative levels. A gaining stream is one, this is the gaining stream, is one receiving groundwater discharge So this stream, gaining stream will receive the groundwater discharge.

Whereas a losing stream, this one, is one which is recharging the groundwater. So these are the two different cases. One is the gaining stream in which it is receiving the discharge and second is the losing stream which is just recharging the groundwater.

Stream is recharging the groundwater. So often a gaining stream may become a losing one and conversely, as the stream changes, it changes.

So you can see gaining stream receive water from the groundwater system in this case. Losing stream lose water to the groundwater system. And losing stream are separated from the saturated groundwater system by an unsaturated zone. So these generally take place in the earth system. Now this figure you see it is illustrating the dynamic interface between groundwater and streams.

So the groundwater direction is mentioned here and the stream is also you are seeing the stream channel. So the dynamic interface between groundwater and streams have been shown and these are the interface of groundwater flow system. Here you can see hyporheic zone, the water table, stream and the direction of the groundwater flow. Now, fluctuation is also because of the evapotranspiration processes. So, we will see the fluctuation due to evapotranspiration.

Unconfined aquifers with water tables near ground surface frequently exhibit diurnal fluctuations that can be ascribed to evaporation and oblique or transpiration. So when we are combining these two processes, that is evaporation from the open surface water source and transpiration from the leaf surface of the plant, then it is combinedly called as evapotranspiration. Both processes cause a discharge of groundwater into the atmosphere and have nearly the same diurnal variation because of their high correlation with the temperature. Now see the evaporation effects. Evaporation from groundwater increases as the water table approaches to the ground surface.

The rate also depends on the soil structure which controls the capillary tension above the water table and hence its hydraulic conductivity. Computation of actual evaporation from bare soil is complicated by variation in external evaporative conditions at the soil surface. For isothermal conditions, upward movement is essentially all in the liquid phase, but a soil may have a high surface temperature, causing it to dry out, establishing upward vapor movement in response to a vapor pressure gradient. Field measurements of groundwater evaporation from tanks filled with soil, generally known as lysimeters, have been made. Water tables were maintained at prescribed depths below the ground surface.

Results expressed as in the percentage of pan evaporation at the ground surface as shown in the figure. So this is the percentage of pan evaporation and this is the depth to water table in meter. For water tables within 1 meter of ground surface evaporation is largely controlled by atmospheric conditions but below these soil properties become limiting and the rate decreases markedly with the depth. Transpiration effects you can see, where the root zone of vegetation reaches the saturated stratum the uptake of water by roots equals to the transpiration rate. Magnitude of transpiration fluctuations depend on the type of vegetation, season, and the weather.

Hot, windy days produce maximum drawdowns, whereas cool, cloudy days show only a small variation. Fluctuations begin with the appearance of foliage and cease after killing frosts. Cutting of plants eliminates or materially reduces amplitudes. Transpiration discharge does not occur in non-vegetated areas such as plot fields or in areas where the water table is far below the ground surface. After rain, on high water ta, table vegetated land, the water table rises sharply as the increased soil moisture meets the transpiration demand and reduces the groundwater discharge,

but on cleared land or when vegetation is dormant, little or no rise is evident. However, transpiration of groundwater by plants around the perimeter of the wetland can cause water to seep from the wetland, creating cones of depressions. Seepage from wetlands commonly is assumed to be the groundwater recharge but in this case the water is actually lost to the transpiration. This process results in depressions of the water table.

The transpiration induced depressions in the water table commonly are filled by recharge during the following spring and then form again by late summer almost every year. Now third is the evapotranspiration effects. Evapotranspiration effects shows that from a practical standpoint, it is often difficult to segregate evaporation and transpiration losses from the groundwater, therefore the combined loss which is referred as evapotranspiration or consumptive use is typically the quantity normally measured or calculated. The variation of evapotranspiration with water table depth is sketched in this figure for three different groundwater cover conditions. You can see the first condition is the bare soil, second condition is the shallow rooted vegetation and third is the deep rooted vegetations.

Now, even with relatively deep water tables, evapotranspiration does not necessarily become zero because upward transport can still occur albeit minimally in the vapor phase. The pattern of diurnal fluctuation resulting from discharge of groundwater is nearly identical for evaporation and transpiration. The maximum water table levels occurs in mid morning as shown in the figure. Also this figure, if you will see, the maximum water table level occurs in mid morning, in the mid morning, this is the mid morning, this one is noon, this is the evening and this is the midnight, this one also represents the midnight.

So the maximum water table level we are seeing in the mid morning. Represents a temporary equilibrium between discharge and recharge from the surrounding groundwater levels. From mid morning, from mid morning.

Until early evening, early evening, losses exceed recharge and the level falls . The steep slope near midday indicates maximum discharge associated with highest temperatures. The evening minimum again represents an equilibrium point while the rise during the night hour is recharge in excess of discharge. So, this figure is telling us about the interrelations of water table level, recharge, and evapotranspiration fluctuations. Now, W. N. White suggested a method for computing the total quantity of groundwater withdrawn by the evapotranspiration during a day.

It is assumed that evapotranspiration is negligible from midnight to 4 AM, that is, very early morning, and further that the water table level during this interval approximates the mean for the day then the hourly recharge from midnight to 4 AM may be taken as the average rate for the day.

If we, take h equal to the hourly rate of rise of the water table from the midnight to four AM. the upper curve in figure And if the net fall or rise of the water table during the twenty-four hour period, then as a good approximation, the diurnal volume of groundwater discharge per unit area will be V_{ET}, that is evapotranspiration,

$$\mathbf{V_{ET} = S_y\ (24h \pm s)}$$

Where S_y is the specific yield near the water table.

Actually, the rate of groundwater discharge to the vegetated area varies inversely with the water table level. It is varying inversely. The difference between the recharge rate and the slope of the groundwater level curve gives the evapotranspiration rate. The lower portion illustrates the area between the two curves is a measure of the daily volume of water released to the atmosphere. So, the lower portion is indicating the daily volume of water releasing to the atmosphere. Now fluctuation due to meteorological phenomenon. The first phenomenon is the atmospheric pressure changes in atmospheric pressure produces sizable fluctuations in wells penetrating confined aquifers The relationship remains inverse that is increases in atmospheric pressure produces decrease in water levels and conversely. When atmospheric pressure changes are expressed in terms of column of water the ratio of water level change to pressure change expresses the barometric efficiency of any aquifer.

The formula we can see here

$$B = \frac{\gamma \Delta h}{\Delta p_a}$$

where

B is barometric efficiency,

γ is the specific weight of water,

Δh is the change in piezometric level, and

Δp_a Is the change in atmospheric pressure.

Most observations yield values in the range of twenty to seventy percent. The effect is apparent in data.The upper curve indicates observed water levels in a well. penetrating a confined aquifer. The lower curve shows atmospheric pressure inverted expressed in meters of water and multiplied by zero point seven five. A close correspondence of major fluctuations exists in the two curves. The equality of amplitudes indicates that the barometric efficiency of aquifer is about seventy-five percent.

So here you can see from March nineteen thirty-nine to April nineteen ninety-nine, the days of the month is given in x-axis. You can see the, the variations of the water levels at the different atmospheric pressures. So this is the atmospheric pressure and here it is the water level. For an unconfined aquifer, atmospheric pressure changes are transmitted directly to the water table, both in the aquifer and in a well, hence no pressure difference occurs.

Air entrapped in pores below the water table is affected by pressure changes, however causing fluctuations similar to but smaller than that observed in confined aquifers. Temperature fluctuations in the capillary zone will also induce water table fluctuations where entrapped air is present. Atmospheric pressure fluctuations do affect the water tables substantially on small, permeable oceanic islands. The response of sea level changes to atmospheric pressure is essentially isostatic. That is, sea level adjusts to a constant mass of the ocean atmosphere column.

This causes the ocean to act as an inverted barometer with sea level rising about one centimeter to compensate for a drop in atmospheric pressure of 1 mb. These fluctuations amount to about twenty centimeter in the open ocean and are transmitted as long-term tides to the water table. Second meteorological phenomenon is the rainfall. As discussed earlier, rainfall is not an accurate indicator of groundwater recharge because of surface and subsurface losses as well as travel time for vertical percolation. The travel time may vary from a few minutes for shallow water tables in permeable formations to several months or years for deep water tables underlying sediments with low vertical permeability.

Furthermore, in arid and semi-arid regions, recharge from rainfall may be essentially zero. Groundwater levels may show seasonal variations due to rainfall, but often these include natural discharge and pumping effects as well. Droughts extending over a period of several years contribute to declining water levels. Where the unsaturated zone above a water table has a moisture content less than that of the specific retention, the water table will not respond to recharge from rainfall until this deficiency has been satisfied. Therefore, the rise delta H will be the amount equal to

PI by SY, where PI is the portion of the precipitation that percolates through the water table and SY is the specific yield. An interesting phenomenon occasionally noticed in observation wells is a nearly instantaneous response of shallow water tables to rainfall. This may be explained by the pressure increase of air trapped in zones of aeration when rainfall sees surface pores and infiltrating water compresses the underlying air. If the zone containing interconnected pore that is air filled pores, H in the figure, you can see, is compressed to a thickness (H - m). Then the pressure above the water table is increased by [m/(H-m)] of an atmosphere causing the water level in an observation well to rise that is

$$\Delta h = [m / (H - m)] \times 10 \text{ meter}$$

For shallow water tables the rise which occurs only in the well can be an order of magnitude larger than the depth of infiltrating rainfall However, escaping air soon dissipates the effect. Similarly, when water is applied uniformly to the top of the dry column of sand in the laboratory, the air is compressed until released by spontaneous upward eruptions. In the figure, you can see the water table rise in an observation well. This is the observation well for, from infiltrating rainfall sealing the ground surface and the compressing air above the water table.

So these are the zone of compressed air. This is the water table. And this is the saturated zone resulting from infiltration rainfall. Third meteorological phenomena is the wind. Minor fluctuations of water levels are caused by wind blowing over the top of the wells.

The effect is identical to the action of a vacuum pump. As a gust of wind blows across the top of a casing, the air pressure within the well is suddenly lowered and as a consequence, the water level quickly rises. After the gust passes, the air pressure in the well rises and the water level falls. Fourth phenomenon is the frost. In regions of heavy frost, it has been observed that shallow water tables decline gradually during the winter and rise sharply in early spring before recharge from the ground surface could occur.

This fluctuation can be attributed to the presence of a frost layer above the water table. During winter, water moves upward from the water table by capillary movement and by vapor transfer to the frost layer where it freezes. Vapor migration occurs in response to the thermal gradient and to the fact that the vapor pressure over ice is less than that over liquid water at zero degree centigrade. In early spring, approximately when the mean air temperature reaches zero degree C, the frost layer begins thawing from the bottom. Consequently, melt water percolates downward to rejoin the water table.

Fluctuations due to tides. First is the ocean tides. You can see the diagram also which is showing about the groundwater level fluctuations produced by tides. First is the case, A is the case of confined aquifer, B is the case of unconfined aquifer and C is loading of a confined aquifer. So we will see that in coastal aquifers in contact with the ocean, sinusoidal fluctuations of groundwater levels occur in response to tides.

If the sea level varies with a simple harmonic motion, a train of sinusoidal waves is propagated inland from the submarine outcrop of the aquifer. With distance, inland amplitudes of the waves decrease and the fluctuation in ground water level is also decreases with respect to distance from ocean bank. You can see gradually the ground water level is just decreasing. Just as atmospheric pressure changes produce variations of piezometric levels, so do the pyro tidal fluctuations vary the load on confined aquifers extending under the ocean floor. Contrary to the atmospheric pressure effect tidal fluctuations are direct that is as the sea level increases the groundwater level does also increases.

Next is the earth types. Regular semi-diagonal fluctuations of small magnitude have been observed in piezometric surface of the confined aquifers located at great distances from the ocean. After correcting well levels for atmospheric pressure changes these fluctuations appear quite distinctly in certain wells where the phenomenon has been investigated. The figure shows the fluctuation of a lunar cycle from a two fifty meter well tapping a confined aquifer in Iowa city. These fluctuations result from earth tides produced by attraction exerted on the earth crust by the moon and to a lesser extent the sun.

Robinson's observations are there which are based on the analysis of well records that make convincing evidence. The first is the two daily cycles of fluctuations occur about fifty minutes later each day as does the moon. the average daily retardation of cycles agrees closely with that of the moon's transit; the daily troughs of the water level coincide with the transits of the moon at upper and lower culmination; and periods of large regular fluctuations coincide with periods of new and full moon, whereas periods of small irregular fluctuations coincide with periods of first and third quarters of the moon. All of these facts may be noted and Bredehoeft has pointed out that the wells serve as a sensitive indicator of this dimension of the earth crust. All times of new and full moon, the tide producing forces of the moon and the sun act in the same direction, then ocean tides display a greater than average range.

But when the moon is in the first or third quarter, tide producing forces of the sun and moon act perpendicular to each other and causing ocean tides of smaller than average range. The coincidence of the time of low water with that of the moon's transit can be explained by reasoning that at this time tidal attraction is maximum, therefore the overburden load on the aquifer is reduced, allowing the aquifer to expand slightly. Because of the urbanization, we will see the process of urbanization often causes changes in groundwater levels as a result of decreased recharge and increased withdrawl. In rural areas, water supplies are usually obtained from shallow wells, while most of the domestic wastewater is returned to the ground through cesspools or septic tanks. Thus, a quantitative balance in the hydrological system remains.

As population increases, many individual wells are abundant in favour of deeper public wells. Later, with the introduction of sewer systems, stormwater and wastewater typically discharge to a nearby surface water body. You can see in the figure also, which is showing the how the urbanization can cause lowering of the water table elevation. This is the rural situation. This is the case of rural situation.

And this is the case of urban development. Here three conditions disrupt the subsurface hydrological balance and produce declines in ground levels. First is the reduced groundwater discharge due to paved surface areas and storm sewers, second increase groundwater discharge by pumping of wells and third point is the decreased groundwater discharge due to the export of wastewater collected by sanitary sewers. The effects of urbanization trend are well illustrated in the figure given below, here the above conditions have all been present, leading not only to decline in water table, but also to groundwater pollution, seawater intrusion and reduced stream flow. Artificial recharge efforts are underway to counteract with these undesirable results of urbanization. Due to earthquakes, we can see how groundwater level fluctuates. Observation revealed that the earthquakes have a variety of effects on groundwater level fluctuations.

Most spectacular are sudden rises or falls of water levels in wells, changes in discharge of the springs, appearance of new springs and eruption of water and mud out of the ground. More commonly, however, earthquake shocks produce small fluctuations, which is known as hydroseisms, in wells penetrating confined aquifers. Most earthquake magnitudes were small within the range of one point five to four point four on Richter scale. It is believed that the mechanism by which fluid injection triggered the earthquake stems from a reduction of frictional resistance to faulting, a reduction that occurs with increase in pore pressure. Knowledge of this phenomenon has stimulated research into the possibility of injecting water into potentially dangerous fault zones.

This might trigger minor earthquakes, ease stresses along a fault, and hence prevent the sudden reach of accumulated energy that results in a disastrous earthquakes. Now due to external loads, the elastic properties of confined aquifers result in changes in hydrostatic pressure when changes in loading occur. Some of the best examples are exhibited by wells located near railroads, where passing trains produce measurable fluctuations of the piezometric surface. The figure shown here illustrates changes in water level produced by a train stopping and starting near a well. So here the train stops, here the train starts.

You can see the fluctuation of the water level. The application of load compresses the aquifer and increases the hydrostatic pressure. Thereafter, the pressure decreases and approaches its original value asymptotically as water flows radially away from the point where the load is applied. So, this is the figure which is showing the water level fluctuation in confined aquifer when a train is stopping and starting near an observation well. Initially the load is shared by the confined water and the solid material of the aquifer.

However, as the water flows radially outward, an increasing proportion of the load is borne by the structure of the aquifer. The figure shows the effect, that is, here a point load is instantaneously applied. The lower surface of the aquifer is assumed fixed. Lengths of arrows indicate the relative magnitudes of the flow velocity at various distances from the load. So here you can see the hydrostatic pressure variation and the aquifer deflection resulting from a point load.

applied and later removed from the ground surface above a confined aquifer. During the interval from A to B, this is A and this is B, the hydrostatic pressure decreases and the deflection of the upper surface of the aquifer increases. Subsequently, when the load is removed, the pressure drops to a minimum and then recovers toward its initial value as shown by times C and D. Effects of global climate change on groundwater. Here you can see the earth's temperature is affected by numerous influences including the incoming solar radiation which is absorbed by the atmosphere and the earth's surface.

The characteristics of the matter that absorbs the radiation and the part of long wave radiations emitted by the surface absorbed by the atmosphere and then re-emitted as long wave radiations either in upward or downward direction. The so-called greenhouse effect is caused by the net change of the internal radiation, balance of the atmosphere due to the continued increased emission of greenhouse gases, resulting in both the atmosphere and the Earth's surface becoming warmer. The magnitude of the greenhouse effect is dependent on the composition of the atmosphere with the most important factors being the concentration of water vapor and carbon dioxide and less importantly on certain trace gases such as methane. Several worldwide studies have reported on the evidence of the global warming using statistical analysis of long-term temperature records and analysis of climatic and environmental variations in the polar regions. In general the hydrologic effects are likely to influence water storage patterns throughout the hydrological cycle and influence the exchange among aquifers, streams, rivers and lakes. The effects of climate change on groundwater sustainability include:

changes in groundwater recharge resulting from changes in the average precipitation and temperature or in the seasonal distribution of the precipitation, more severe and longer lasting droughts with the effects of drought, changes in evapotranspiration resulting from changes in the vegetation, and possible increased demands of groundwater as a backup source of water supply. Now just summarizing the lectures, That is, first we have discussed about the groundwater level, whether it be the water table of an unconfined aquifer or the piezometric surface of a confined aquifer, it indicates the elevation of atmospheric pressure of the aquifer. Differences between supply and withdrawal of groundwater generally causing the levels to fluctuate. Secondly we have discussed about the different environmental factors which are influencing the groundwater levels. First the time variations of levels, Second the stream flow and groundwater levels, then the fluctuation due to evaporate transpiration and the fluctuation due to a meteorological phenomenon, fluctuation due to tides, then due to urbanization, then due to earthquakes, and then due to the external loads.

And lastly, we have discussed about the effects of global climate change on groundwater. We have seen the effects of climate change on groundwater sustainability generally includes first the changes in groundwater discharge resulting from changes in average precipitation and temperature or in seasonal distribution of precipitation. More severe and longer lasting droughts with the effect of droughts, changes in evapotranspiration resulting from the changes in vegetation, and possible increased demands of groundwater as a backup source of water supply. Thank you very much to all.