Availability and Management of Groundwater Resources
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Lecture - 25
Law of Groundwater Movement, Darcy's Law and Application (Continued)

Welcome you all in the 6th module of the course availability and management of groundwater resources. The part one concept we will take in the form of law of groundwater movement Darcy law and its application.

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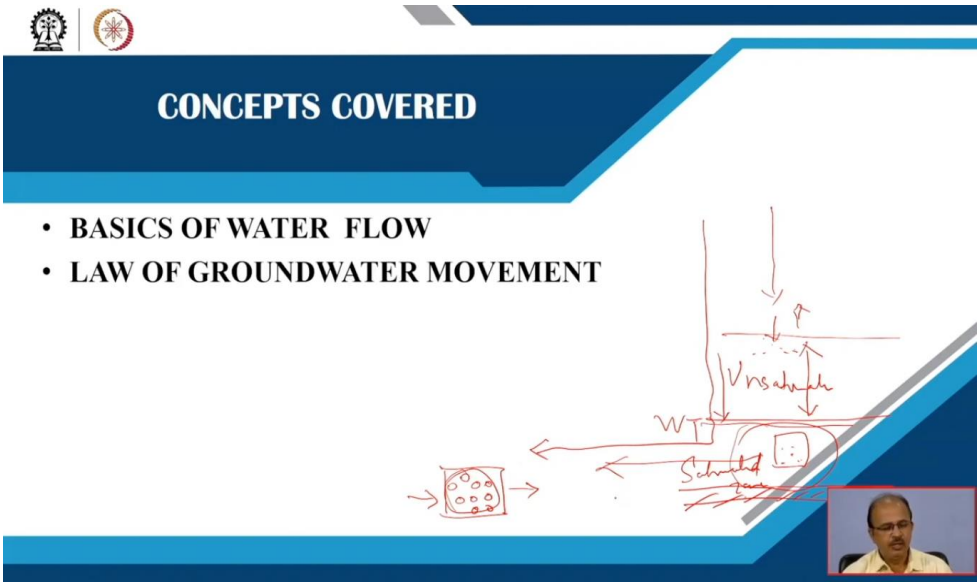

Now if you just recall the previous lectures, we have started from the hydrological cycle because our course objective is how to know about the availability of groundwater resources in any area and second how to manage this groundwater resource. So, with these basic objectives we have started from the concept building from hydrological cycle we have seen that the precipitation is the only recharge source to the aquifer.

The groundwater which we are getting from underneath the earth's surface is basically being recharged by the precipitation. We have also seen that the aquifer, what the term any rocky formation holding the water is basically a type of different types of rocks the characteristics of these types of rocks are a little bit different from those rocks which do not hold the groundwater. So, we have started from the hydrological cycle then we have seen the formations.

The different formations which can hold the groundwater resource or which are the best rocks formations which are having the availability to store the water to allow to move the water from one aquifer to another aquifer. So, secondly, we have touched the basics of the formations different formations then we have seen that the vadose zone, what is vadose zones last concept also we have built in the past lectures.

So, we have started from precipitation then we reach to the formation, this is the formation which is holding the water. When precipitated water is just infiltrating and percolating down first of all it is reaching to the soil underneath the soil layer. So, from the earth's surface to the water table of any area water table of any area is termed as unsaturated zone. This is unsaturated zone and this is a saturated zone.

Since, saturated zone, what is happening in this zone it will remain filled up with water and after that some confining beds impermeable beds will remain so that this water can hold in this place. This area will become the saturated area. So, the upper part of this saturated area is termed as water table. So, from the earth's surface to the water table the zone is defined as the vadose zone we have discussed in detail in the very lectures.

After that, after knowing about the top concept then the intermediate concept and the bottom concept, then we have entered into the details about this formation. So, for this for knowing about the details of this permission we have studied the porosity and permeability, how the water will come from one aquifer to this aquifer and from this aquifer how the water will move to another aquifer.

This is permeability and the volume total volume being stored by the formation that is the aquifer is generally termed as porosity. So, this also we have discussed in better detail in the lectures. Now from here to here we have reached from this to this now we want to have the idea because I have to find out how the groundwater remains underneath the earth's surface. So, with this concept now we have to know is there any law for the movement of the groundwater underneath the earth surface.

Whether it is moving through, certain law or it is moving haphazardly. Certainly, groundwater movement law is there and this law we will discuss in this module. First of all, we will discuss the basics of the water flow, how the water flow takes place and secondly how what is the law of groundwater movement.

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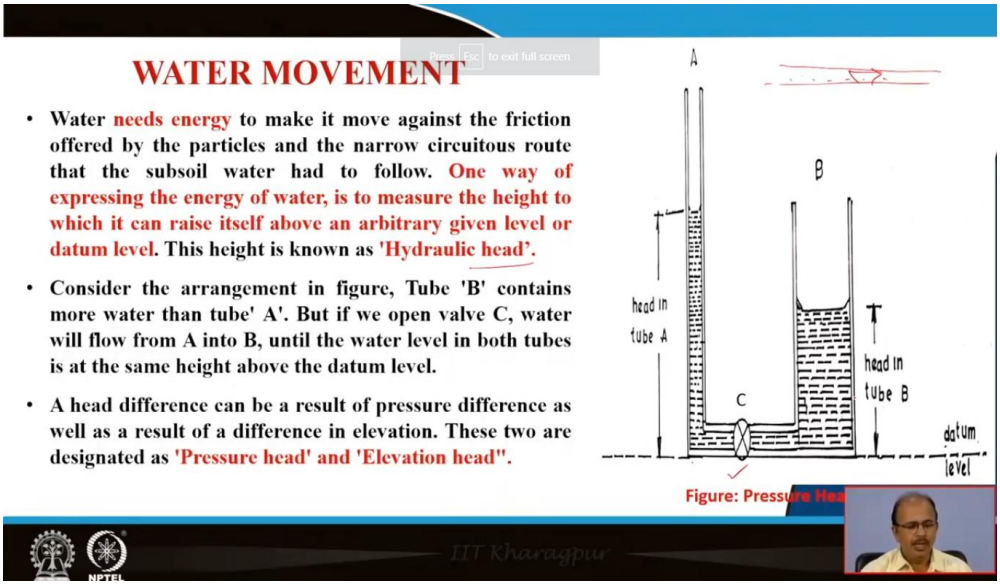

So, we have seen that water needs energy to make it move against the friction from wherever it is moving, say if water is moving from this pipe. So, it needs certain energy to flow against the friction offered by the particle, definitely the particle will resist it but the water movement is there. So, similar case generally happens in the sun subsoil also, which is also having some sort of friction offered by the different sand particles.

One way of expressing the energy of water since water needs energy to for its movement. So, one way of expressing the energy of water is to measure the height to which it can raise itself above an arbitrary given level or datum level and this is known as the arbitrary level or the datum level is basically known as the hydraulic head, this is known as the hydraulic head. Just with this figure I will try to explain; consider the arrangement these two arrangements we can consider.

These are the different types of tube; tube B contains more water than tube A clearly shown here tube B contains more water than tube A. But you are also seeing that one valve C is here which

is closed now, so if we open this valve C what will happen? Water will flow from A to B up to when; until the water level in both the tubes, tube B and tube A is at the same height above the datum level.

So, if it will remain closed definitely the level will be something different but as soon as it will be open the cab will be open the level of the water in both the tube will remain at equal height so this height is generally known as the hydraulic head this height is generally known as the hydraulic head. We can just think, this experiment the two types of soil having different thickness the different your storage of water is there different amount of storage water there.

So, movement will take place from a movement will take place until it will the level will remain same, then it will if the water will come from other side in both the soil structure or your rock structure the level will be the same similar case is happening here also in the two tubes are remaining, in these two tubes the waters water is being filled up and one cap is just enclosing the area.

As soon as the cap is opening the level the water moves and it will move until the level of in both the tubes will become the same. So, this height to what we are seeing is generally known as the hydraulic head. Now the head difference can be a result of pressure difference, so why it is coming to the same level because we have seen that it remaining with the atmospheric pressure. So, the head difference is a result of pressure difference as well as a result of difference in elevation.

These two are designated as the head difference is designated as pressure head and the elevator difference in elevation is designated as elevation head. So, this is the basic points related to the water movement generally; water moves it needs energy for its movement and the hydraulic head is a very important concept for the movement of the water.

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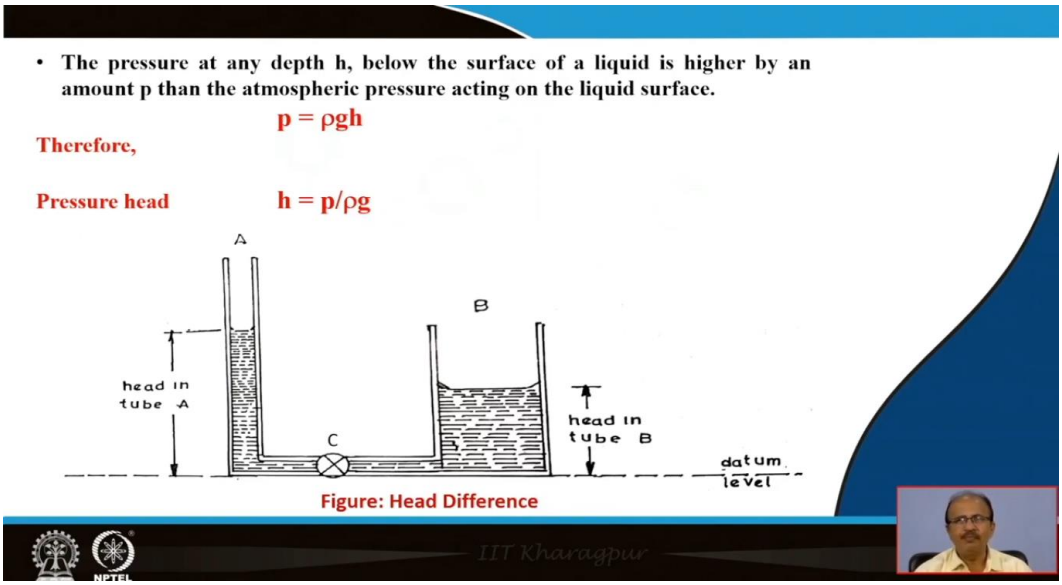

Now the pressure at any depth at whatever the pressure below the earth's surface of a liquid is higher by an amount p than the atmospheric pressure acting on the liquid surface. Then we can write

$$p = \rho g h$$

where **ρ** is the density and g is the gravitational acceleration due to moment. So, accession due to gravity is the g and head is the pressure. So, pressure head will be h pressure head h

$$h = p/\rho g$$

So, this head difference we can see from this tube also here again the cap is here. So, as per the height of the level of the water this is because of the head difference what pressure head is remaining in the tube A and tube B if the cap C will open the level will become C because of making the your pressure difference or head difference to the same level from the datum.

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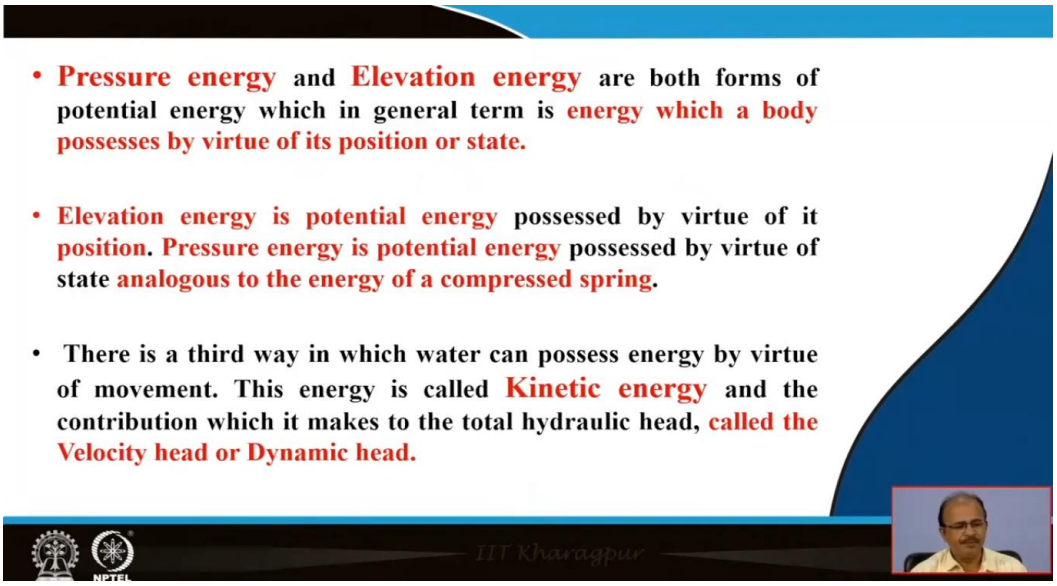

Now pressure energy and elevation energy since water needs energy, so pressure energy and elevation energy are both forms of potential energy. Generally, these are the forms of potential energy which in general term is energy which a body poses by virtue of its position or state, generally this type of energy is being possessed by virtue of its position or state. So, elevation energy is potential energy processed by virtue of its position.

Whereas pressure energy is potential energy processed by virtue of state analogous to the energy of a compressed spring. Just like compressed spring the pressure energy remains it is also a form of potential energy. There is a third way in which water can possess energy by virtue of movement and this type of energy is called as kinetic energy and the contribution which it makes to the total hydraulic head is called as the velocity head or dynamic head this is called as velocity head or dynamic head.

So, three different types of energy we have seen required by water for its movement pressure energy elevation energy and kinetic energy.

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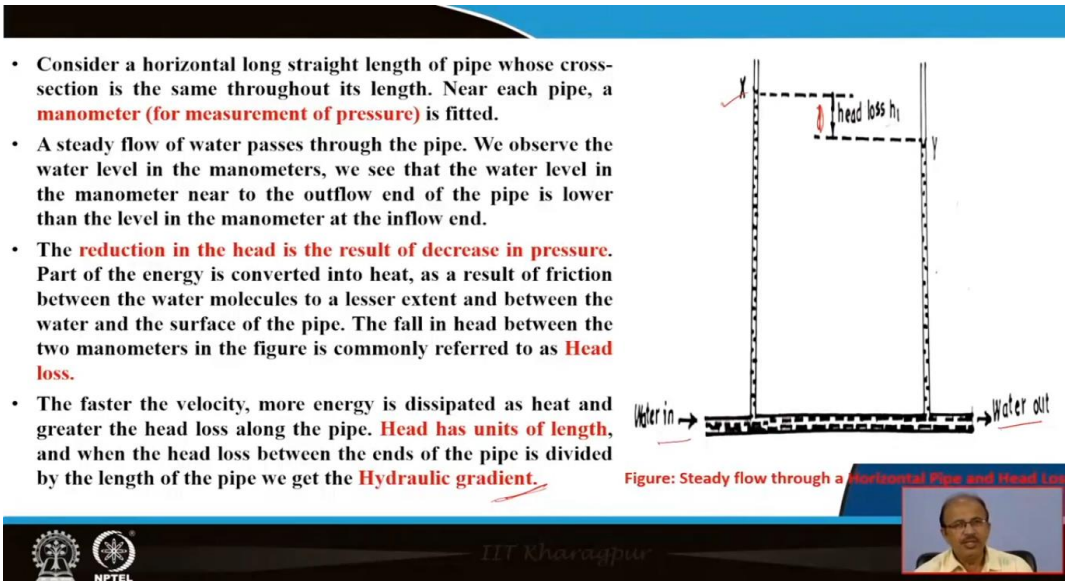

Now consider a horizontal long straight length of pipe long pipe, just by experiment I am trying to illustrate the problem. Consider a horizontal long straight length of pipe whose cross section is the same, throughout its length. Both the pipe; is having the same cross sectional area. Near each pipe a manometer is being fitted which is generally being used for the measurement of pressure. Now thin these are the long straight length of pipe cross sectional area remains the same and a one manometer will be heated at the top.

A steady flow of water passes through the pipe. Now a steady flow of water is being passed through the pipe. What we observe that the water level in manometers. We see the water level in the manometer near to the outflow end. So, this is the inflow end and this is the outflow end. So, water level in the manometer; we see that the water level in the manometer near to the outflow end of the pipe is lower than the manometer at the inflow end.

So, here you can see it is just this is the outflow, so here at the outflow end the level of the water is down whereas in the near to the inflow the level of the water is up. So, generally we see that the water level near to the outflow end is remaining lower than the level in the inflow end. The reduction in the head so this head loss the reduction in the head is the result of decrease in pressure.

This is because of decreasing pressure because here the pressure was there more so the level is high. But as soon as it moves out, definitely the pressure decreases; head loss will be here and therefore the level of the water will come to this place. So, the reduction in this head is the result of decreasing pressure. It is also because of the decrease in pressure. Part of the energy is converted into it because we have, we know, law of conservation of mass law of conservation of energy.

So, the part of the energy is converted into heat as a result of friction between the water molecules to a lesser extent and between the water and the earth's surface of the pipe. So, what is happening is the fall in head between the two manometers in the figure is commonly referred as head difference or head loss. So, this is generally head loss; it is called as head loss. The faster the velocity, more energy is dissipated as heat and greater the head loss along the pipe.

So, this usually happens with the flow of the water that the faster if the velocity remains faster more energy will be dissipated as heat and greater will be the head loss along the pipe. Head has units of length and this head what we are talking is the having the unit of length and when the head loss between the ends of pipe is divided by the length of a pipe just the division of the head loss by length of pipe, what we are getting? We are getting the hydraulic gradient.

So, these are the few basic concepts for the flow of water and this happens with the flow of groundwater also inside the earth surface. The same your condition will remain there. So, the faster will be the velocity, more energy will be dissipated as heat and greater will be the head loss along the pipe and this head has nothing but it is the unit of length. And when the head loss between the ends of pipes, the two ends of the pipe is divided by length of the pipe, what we are getting? We are getting the hydraulic gradient, so hydraulic gradient.

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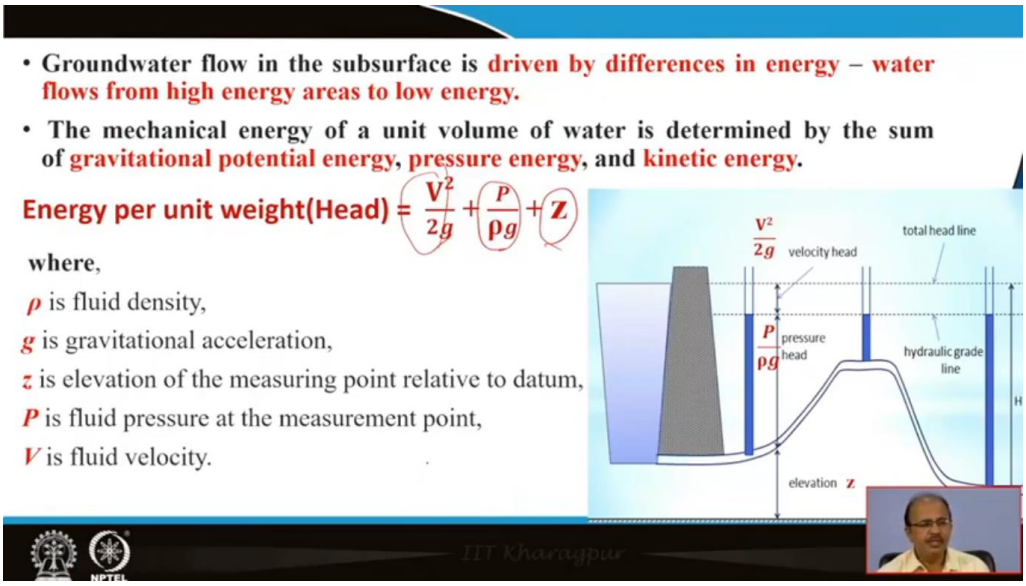

Now you can see that groundwater flow in the subsurface on the formations underneath the formation which we have discussed as aquifer is driven by differences in energy that is because of the difference in energy water flows from high energy to areas to low energy area. The mechanical energy of a unit volume of water is generally determined by the sum of gravitational potential energy what we have discussed in the earlier slide, pressure energy and kinetic energy.

So, these all the three type of energy plays very important role for the movement of the groundwater, we can compute the

$$\text{Energy per unit weight (Head)} = \frac{v^2}{2g} + \frac{P}{\rho g} + z$$

ρ is nothing but it is the fluid density, g is the gravitational acceleration accession due to gravity, z is the elevation of the measuring point related to the datum and P is the fluid pressure at the measurement point and v is the fluid velocity.

So, you can see here $\frac{v^2}{2g}$ in the formula also it has been mentioned that for measurement of the energy per unit weight that is head and $\frac{v^2}{2g}$ plus your $\frac{P}{\rho g}$ which is generally this $\frac{P}{\rho g}$ is nothing but this is the pressure head. So, then Z elevation; that is the elevation energy and this is your velocity head. So, in this way generally energy per unit weight is being measured for your movement of the water.

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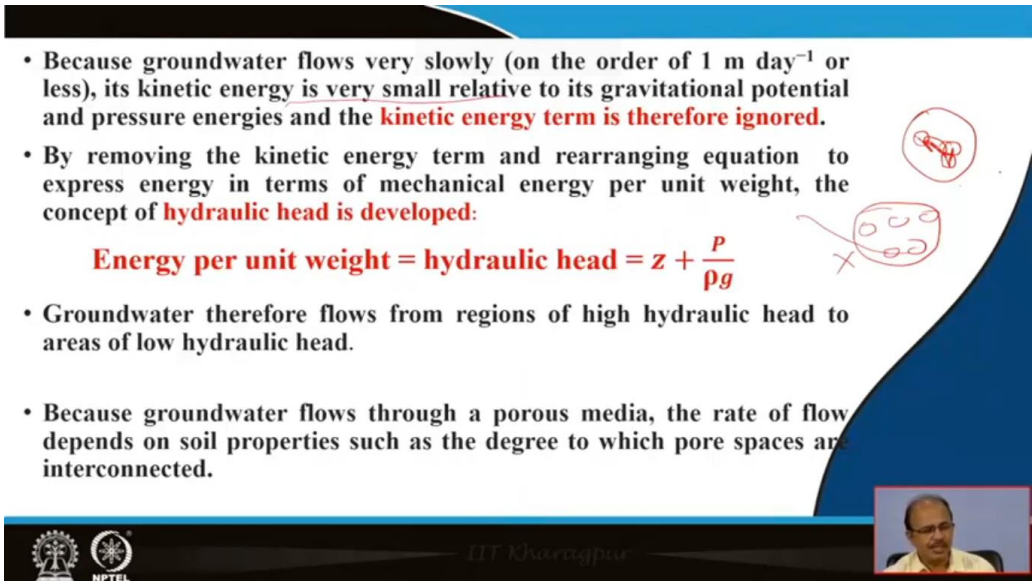

Now because groundwater flows very slowly it flows very slowly, say the order of 1 meter per day or even less than 80, so its kinetic energy is very small relative to the gravitational potential energy and pressure energy and the kinetic energy this term is therefore ignored in general. So, it is being ignored, in general only the gravitation potential, your gravitational inner potential energy and pressure energies are the important one with respect to the kinetic energy.

By removing the kinetic energy term and rearranging the equation to express energy in terms of mechanical energy per unit weight the concept of hydraulic head is developed. So, what we have seen in the earlier slide $\frac{v^2}{2g} + \frac{P}{\rho g} + z$, just if we will ignore the kinetic energy part then what is happening why ignoring because the movement of the ground water remains very slow underneath the earth surface.

So, generally the kinetic energy term is being ignored. So, the

$$\text{Energy per unit weight} = \text{hydraulic head} = z + \frac{P}{\rho g}.$$

So, what happens, groundwater flows from regions of high hydraulic head to the areas of low hydraulic head. So, now from the high hydraulic head to the low hydraulic head, why? Because one when you can see also in the; suppose in an area there are four or five dug wells.

And from the dug wells you are just withdrawing the water from each dug well. So, you can notice, also that in one or two ways the level of the water is reaching at the similar point or similar depth from where the withdrawing phenomena has started the level is the same it is coming to the same level. But in another few dug wells it is not reaching to that point; in some it is remaining at greater depth.

Why? Because inside also inside the earth surface also water flows from regions of high hydraulic head to the areas of low hydraulic head. So, because groundwater flows through a porous media we are knowing that the formations are remaining porous only. Then only it can hold the water or then from there if the media will even pour us then this poor pore will connect and make some path and then the permeability starts.

So, the formations which generally being called as an aquifer is having porous media. So, the rate of flow depends; rate of flow water depends on soil properties on the properties of soil. Such as the degree to which poor spaces are interconnected, how it is interconnected, so if the pores will remain connected uh then only there are chances to have the movement but here, we are not having the chances to have the movement.

But here each pore is interconnected by another pole, so each core is interconnected by another pole. So, what is happening; here there are chances of the movement of water, so this is very important concept. What we have started today how the groundwater or water moves inside the earth surface. Because it is important to have to build the concept because now, we are just in; we have entered into the formation which is holding the water.

So, now how it moves from one aquifer to another it is following, certain law, yes, it is following a law then law the name of the law is the Darcy law. So, we will discuss in the coming lectures. So, because groundwater flows through a porous media the rate of flow depends on soil properties or the medium such as the degree to which pore spaces are interconnected.

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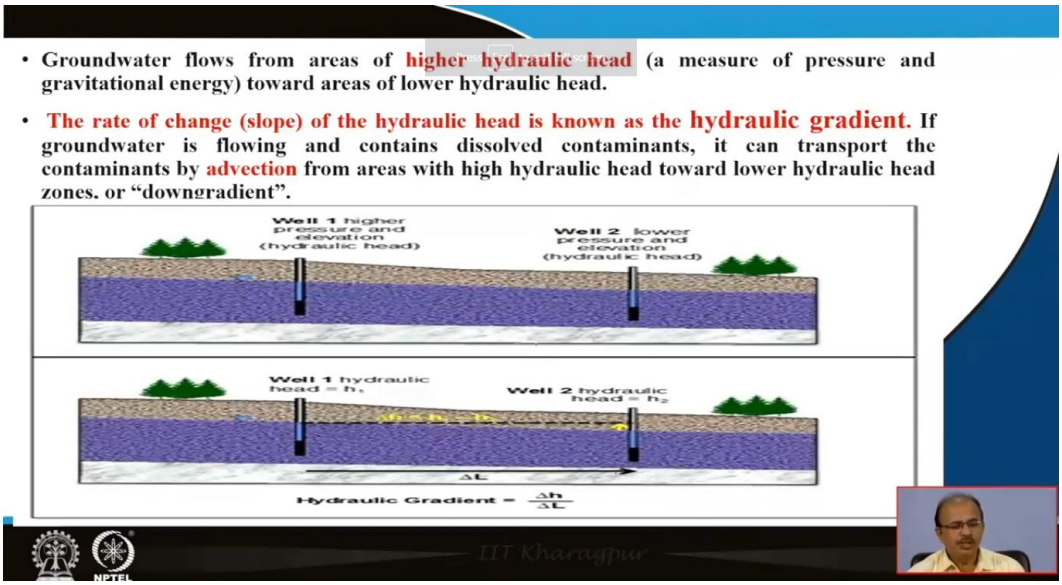

Now what happened? Groundwater flows from areas of higher hydraulic head towards areas of lower hydraulic head we have seen from higher energy to low energy, so higher hydraulic head to lower energy head. So, the rate of change of the hydraulic head is generally known as hydraulic gradient. So, this is very important, the rate of change of hydraulic head is known as hydraulic gradient and these two words hydraulic head and hydraulic gradient is very important in the concept of Darcy law.

So, if groundwater is flowing and contains some dissolved contaminants generally through the groundwater movement some contaminants are also being added at several points within the earth surface. So, when the groundwater is flowing and contains dissolved contaminants it can transport the contaminants, how? By advection process. From where? From areas with high hydraulic head towards the area of lower hydraulic head or we can say down gradient.

So, we can see through the diagram also, so this is the you can see well 1, well 2, higher pressure and elevation in this well, we are we have noticed here lower pressure and equation we are we have noticed since level is slope is in this way. So, now well one and well two you can see hydraulic head h 1 is here hydraulic head h 2 is here and this difference this difference because the rate of change of the hydraulic head so rate of change of the hydraulic head is generally defined as the hydraulic gradient.

So, this is also a very, very important concept that how the level of the water remains underneath the earth's surface from higher elevation elevated portions or the media through which it is passing to the lower. So, it will follow the same pattern because on the earth surface also we have seen that generally water follows the topography of the area. Inside also the same pattern remains; water flows from higher energy to lower energy or higher hydraulic head to lower hydraulic head.

So, this is all about the details of the water movement underneath the earth's surface generally water moves through these different types of your concept. The concept is of the hydraulic head hydraulic gradient and the level of the water remains because of the difference in different materials or different types of formations because of the change in the hydraulic head or the hydraulic gradient. So, thank you very much to all.