Engineering Geology
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Lecture - 28
Groundwater Related Engineering Issues

Hello everyone and welcome back. Today, we are going to talk about groundwater related engineering issues.

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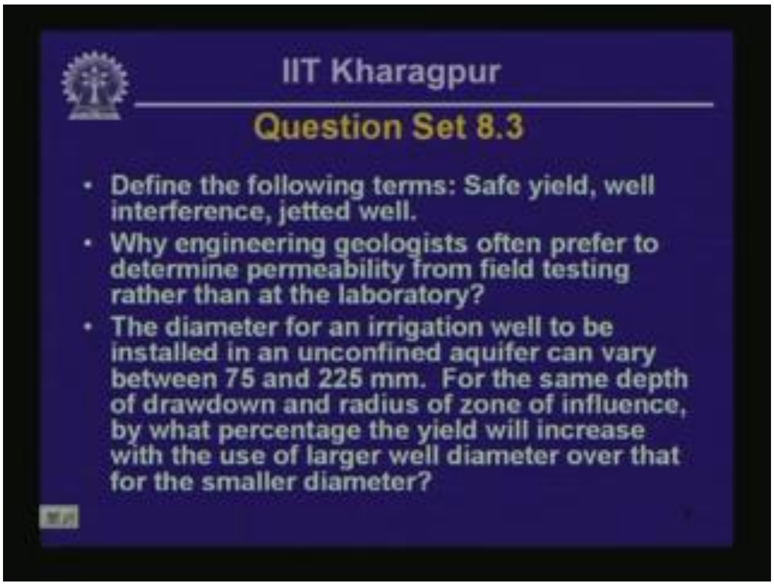

Before we head up with today's lesson, we look back at the question set of the previous lesson; here are the questions. First question that I asked was definition of a few terms safe yield, well interference and jetted well. What is meant by safe yield is basically the yield that you could draft from an aquifer without permanently depleting the aquifer. So, it depends really on not only the water, the amount of volume of water that is available for tapping within an aquifer, but also the amount of recharge that the aquifer goes through every year.

You cannot actually draft the amount of water over and above the recharge that is expected to be there every year. So, that is the concept of safe yield. Then the second one is well interference. So, basically what is meant by this term is that if your operating multiple wells within the zones of influences of each other, then the amount of draw down that is going to be caused by all the wells at an intermediate location is going to be much more than the draw down that is going to be expected for the operation of a single well. So, this particular concept is called well interference.

Then the third part of the first question was the definition of jetted well. So, what is meant by a jetted well is essentially a well point or a well screen and the well casing installed by jetting into the aquifer that is jetted well. Then we get back to the second question; why engineering geologists often prefer to determine the permeability from field testing rather than at the laboratory? Now what happens in the laboratory if you recall the two methods that we discussed in the lessons that we had before the last was that we have a relatively small cylindrical sample, which is essentially reconstituted in the laboratory, or you could use actually a cylindrical specimen of undisturbed sample for that matter.

But it is a small volume of soil, and you run the flow through the small volume of the soil, and you expect that you characterize the permeability property of an aquifer in the process. That is seldom true, because of the variability involved over a large extent of the formation laterally and vertically that you might have to deal with. As a result the property that we are going to get in the laboratory may not be representative of the large volume that comprises the aquifer to be characterized. So, because of this, engineering geologists generally prefer field methods for estimating permeability or hydraulic conductivity for that matter rather than laboratory testing, okay.

Then the third question was a numerical question; what I asked was you have to find out what is the relative yield or gain in the yield available when you use a well casing of 225 millimeter diameter instead of 75 millimeter diameter. What I also gave was that the aquifer geometry and draw down and the radius of the zone of influence; everything was used to be the same in case of both these wells. So, how do you proceed for the solution of this particular problem is like this.

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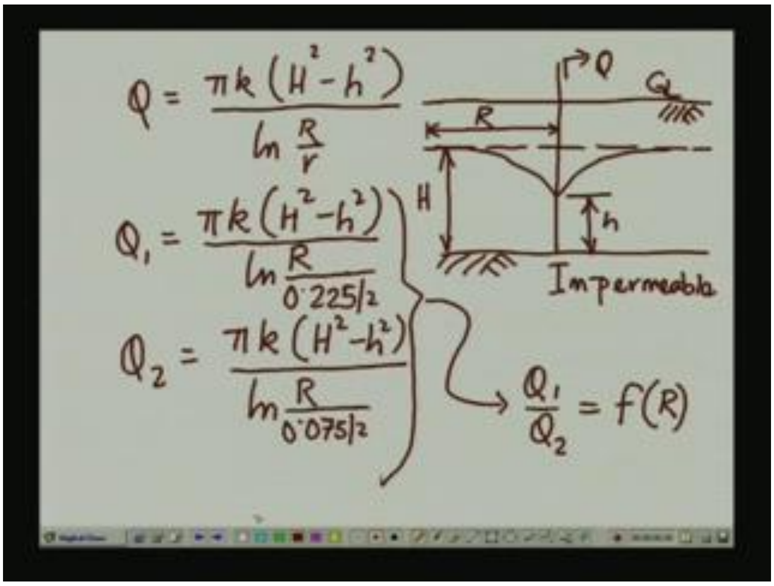

First of all you have to consider the equation which gives you the flow rate as a function of permeability k, the thickness of the aquifer h and the height of water at the well point of small h. So, capital h is the thickness of aquifer in this case, and everything is divided by the natural logarithm of r capital R divided by lower case r. So, if you recall from the lesson that we already have had; if you have got a well running like this and you are drawing the quantity of water equal to q from the well and let us say you have got an unconfined aquifer which is completely penetrated by the well.

So, this one is impermeable in this case; I am drawing this just to jog your memory a little bit. The original groundwater table was like this before the draw down caused by the well, and this height here is upper case h. And after the operation of the well, the water table goes down like this, and this dimension here is lower case h. And R in this case is the radius of the zonal influence capital R, and small r is the diameter of the well. So, actually the ground surface is this one. So, ground level is out here.

So, the question essentially gave you that in both cases involving the use of 75 millimeter diameter water well and 225 millimeter diameter water well in both cases; you have got h capital H and small h are the same. K is the same; upper case and lower case r are also the same. So, you want to actually find out what is the ratio of q 1 and q 2 in the two cases. So, we can call then q 1 to be equal to pi times k times h square minus h square divided by l n of r over let us say 0.225 because 225 millimeter is going to be actually that is the diameter. So, you have to divide it by two once again.

And q 2 is going to be like this; everything remains the same except the denominator in this case you have got this is your expression. So, what we have to find essentially is the ratio of q 1 and q 2; this is what we want to find. And what I did? Actually I developed a spreadsheet, because this particular ratio is going to be a function of r, the radius of the zone of influence. And you could actually express you could actually set up a spreadsheet and develop a solution of q 1 and over q 2 and what you are going to get is presented in this particular plot.

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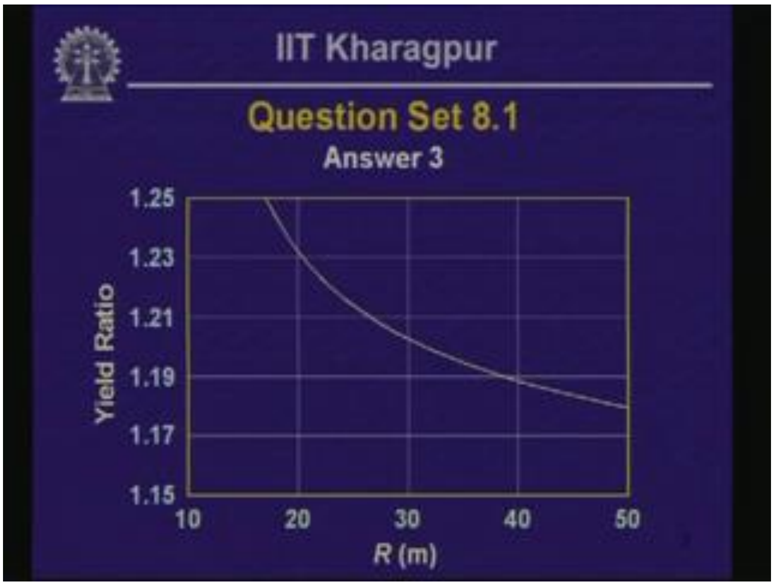

And you can see that the gain that you are going to get is going to get decreased as the radius of the zone of influence increases. That means, if the permeability of the layer decreases, then the amount of gain of yield that you are going to get by using a larger diameter well also is going to be smaller and smaller, okay.

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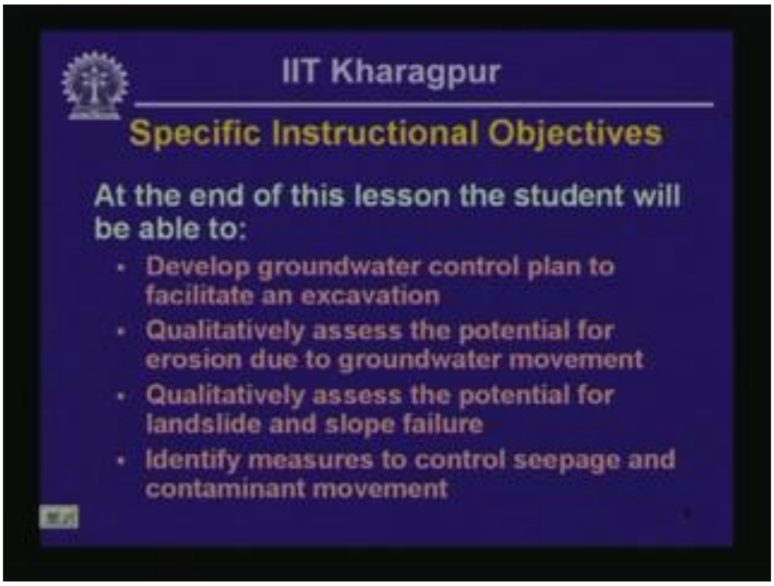

So, now we move on to the subject matter of this particular lesson. What we want to gain, what we want to learn from this lesson are as follows. We would like to be able to develop a groundwater control plan to facilitate an excavation. We should be able to qualitatively assess the potential for erosion due to groundwater movement. Similarly, we should be able to assess qualitatively once again the potential for land slide and slope failure because of groundwater. And we would like to be able to identify the measures to control seepage and contaminant movement that takes place, because of groundwater movement, okay. So, these are the objectives and now we hop into the subject matter.

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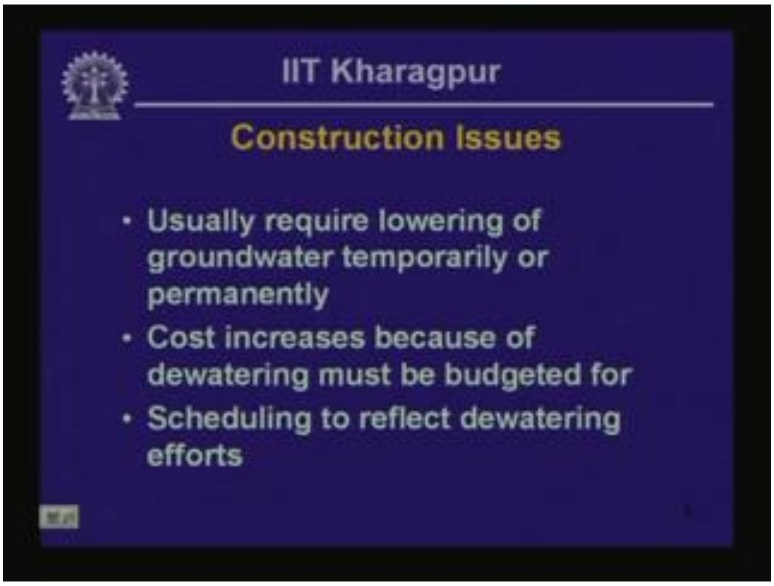

So, what are the first question that arises comes to mind actually are what are the construction issues that you need to consider related to groundwater movement. What are the problems that you might encounter in a construction because of the presence of groundwater? Now groundwater actually is going to impede, say, in a construction, you want to excavate an area or you want to cut a slope. So, in that case, if you have got groundwater seeping out of the system, then that is going to impede the construction work. It is going to actually going to affect the ease with which you are going to be able to complete the construction.

So, what is the consequence of that? The consequence of that is that the cost of the construction is going to increase, and the time that you will require for completing the construction is also going to increase. And both these aspects need to be assessed beforehand in order to have an effective project management. So, you need to have the considerations taken into account while you are in the planning stage itself, okay.

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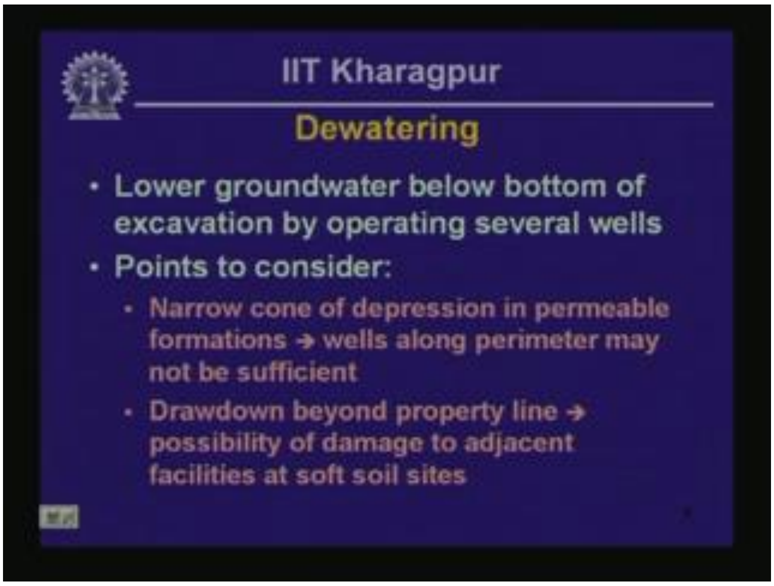

Now the first thing the first aspect that you need to consider here is the amount of dewatering that will be necessary for undertaking the construction. If you have got too much of water coming out into an excavation for that matter, then you will require a larger effort to dewater the excavation to facilitate the excavation process. Now if you call the tender, if you ask a contractor to do the construction, then if he or she comes up with a pump that has got lower capacity than the amount of dewatering required, then the construction is going to be affected because of the under capacity.

So, we need to have some idea about how much water to expect when doing the excavation below the groundwater table. So, what are the major points in this respect? The major points include essentially is the permeability of the aquifer material. Now if you have got a highly impermeable aquifer, then the cone of depression; let us say you are going to start dewatering by digging a small pit inside the excavation and lowering a foot valve of a pump and start dewatering the aquifer.

Now if you have got a highly permeable aquifer, then the cone of depression that you are going to cause is going to be relatively narrow. So, if you want to dewater a large area, then you will require e a number of wells not only along the perimeter of the excavation but also within the foot print of the excavation itself. We will actually try to understand this thing later on in little bit greater detail as we look at typical schemes of dewatering that you are going to be undertaking in the event that you require to construct something underneath the groundwater table.

Now another point that you need to consider in this case is that if you cause excessive draw down, then that is also detrimental. So, you have to actually ensure that you dewater, you lower the water table only up to the extent that is required just for the construction itself. Because if you dewater an area which is way beyond the property line, then you are likely to cause detrimental effect to the facilities nearby, and those effects may include uneven settlements in the areas if the area is underlain by soft deposits because of the increase of effective stress caused by the dewatering effort or alternatively, what could happen is that a neighbor could be operating a groundwater well.

And your construction dewatering has pulled down the water table so much that his or her groundwater well goes dry in the process. So, these are the factors that you need to consider while coming up with the scheme of dewatering for facilitating a construction, okay.

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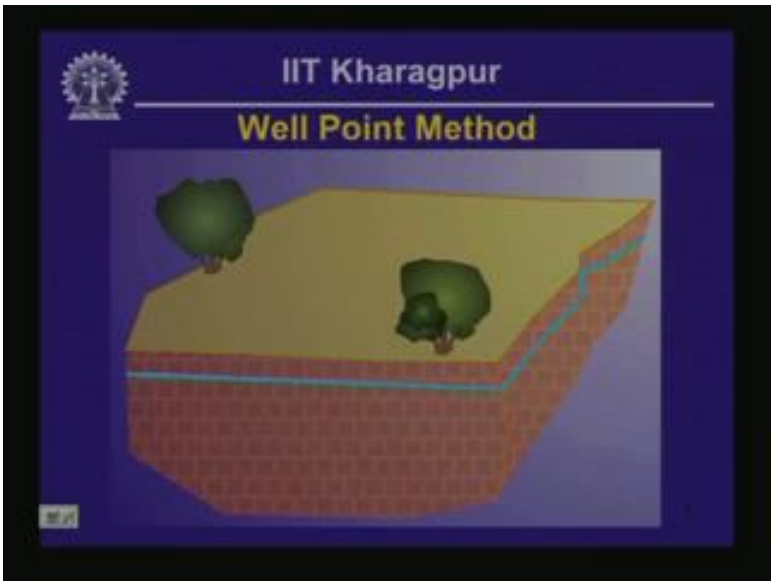

Now then the question comes what is a typical method of dewatering in a particular construction process. Now we are going to consider an animation in this particular case; the virgin situation in this case is like this, where you have got a relatively flat ground, and let us say you are trying to excavate a trench in order to install a tunnel underground tunnel which can be used for let us say housing and underground metro or an underground sewer line for that matter. And for excavating the trench, you have to draw the water down. So, what is going to be a typical process that is explained in this animation? So, here we have got an aquifer an homogenous aquifer going down to great depth and a flat surface topography as well as groundwater table is also relatively flat.

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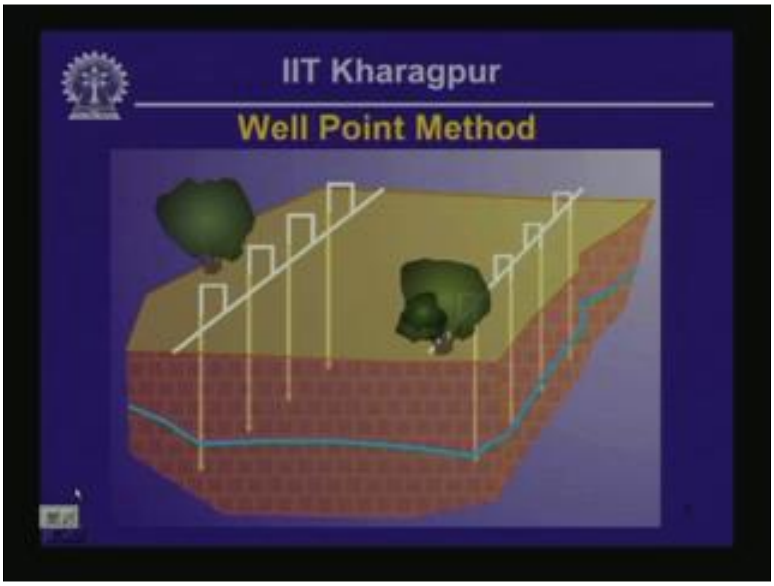

So, what we can do is to install actually a series of well points shown like that, and those well points are connected to each other by a header pipe which runs parallel to the excavation. And in this particular case, excavation proceeds from top right of this particular cartoon to bottom left of this particular cartoon. And once those well points are installed, then you can connect the header pipe to a series of high capacity pumps, and those high capacity pumps depending on the permeability characteristics of the aquifer itself, and then you are going to run the pumps.

And those pumps are going to pull down the water table like that shown in this particular case. The water table is shown by thick blue line in this case. We are going to get back once again; I am going to run this animation once again for you to have a closer look at this particular system. So, here the well points are vertical, and you have got a header pipe on both sides of the excavation or both sides of the proposed trench, and the lower groundwater table is shown on this particular slide, we proceed then. Now that the water table has been lowered below the bottom of excavation, we can excavate a trench without having any problem related to groundwater seeping into the system, and the excavation is going to look like this for instance.

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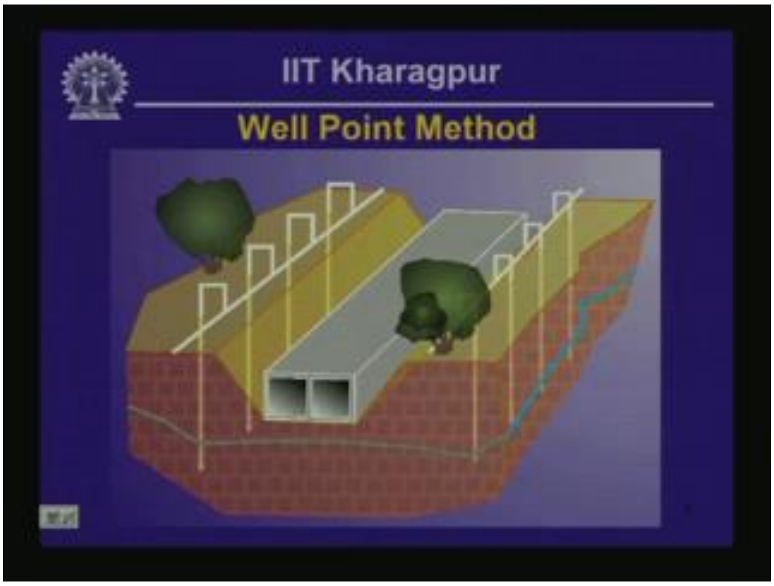

And then the box the tunnel can be installed or constructed inside the trench itself. And finally, what we are going to do is to back fill the trench.

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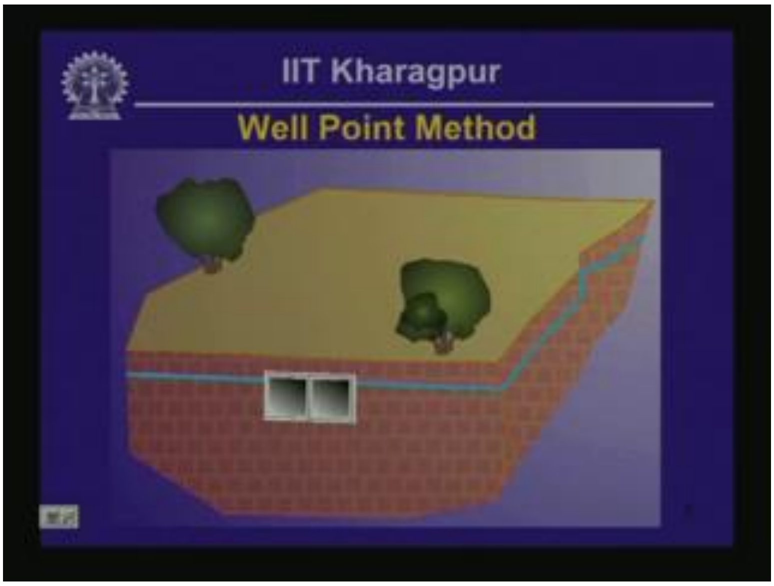

Remove the dewatering system that was initially in place, and the recharge that is going to take place over the years is going to pull the water table back to the original level when before we began the dewatering process. So, now the tunnel is underneath the water; you have a look that tunnel is partially submerged, and it can be constructed in a water type manner, and it can be designed for the buoyancy that is going to affect the mechanical behavior of the tunnel, and then there should be no groundwater related problem within this particular construction, okay.

So, we run back this animation once again in order for you to have a closer look at everything. So, this is the original configuration, then we install the well points and start pumping and that is going to pull the water table down like this. And then we excavate, construct the tunnel, backfill, remove the dewatering system, and the water table is again going to be back at its original configuration after recharge over sufficient long duration. So, this is a typical procedure used in a construction site.

You may not have to use a well point for that matter. What you have to use if you have got a small excavation to content with, then you might actually require to just open a small pit at the bottom of the excavation, and you can just simply lower the foot valve of a pump down into the pit. And that should give you sufficient leeway in the process of groundwater draw down in order for you to complete the excavation, alright.

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Now then the second aspect that we looked at initially was controlling the draw down. You do not want to have groundwater drawn down way outside of the limit of your excavation, because that has got some detrimental effects in the form of uneven settlements in soft soil areas or a reduction of well yield within the properties that are adjacent to the excavation, okay.

So, what are the possible processes that you could bank on in order to control the extent of draw down? The first option that you could think about one of the options that, in fact, you could think about is injection of water adjacent to the location of the draw down, and the process is explained in this particular cartoon. So, the problem here is like what we considered before. We have got a flat topography to content with in an aquifer that goes down to great depth, and once again we have got a water table which is relatively flat. This is not to say that you can use these solutions only in this particular topographic or hydrogeology condition; you could actually adapt these procedures in other situations as well, but I am just showing these situations because they are very simple.

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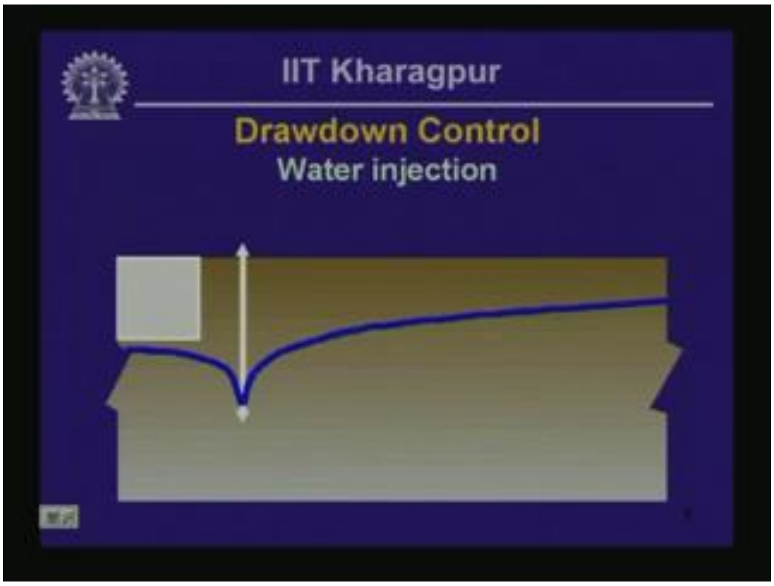

Now let us say in this particular problem we have to install a box like that. So, we are considering a cross section here a vertical cross section through the construction. So, this particular box is going to be partly submerged in the groundwater; the box could be of any purpose. It could be an underground garage or it could be in the form of an underground excavation that you are trying to open in order to construct some facilities underground.

Now in order to install this particular box, what we can do is install pumping water well a series of well points, in fact, on just a little bit outside of the perimeter of the box. So, the well point is shown here on this particular slide, and then we start operating this well point. And that is going to draw the water down to a lower elevation below the bottom of the box, and then we can excavate and open up a large area open up a sufficient large volume and construct the box inside the excavation.

So, that is a process, but if we do this, then you can see that the draw down extends or the zone of influence extends; it could extend a long way outside of the outer perimeter of the property area. So, our problem here is to control the lateral extent of the zone of influence. So, in order to do that, what we could do is actually install a percolated trench and run; it is essentially a trench backfilled with freely draining sand and gravel material. And inside that trench, we could have a perforated pipe, and if the pipe runs full or it runs intermittently and helps recharging the groundwater, then what we are going to get is a groundwater table of that configuration.

And here you can see easily that the extent of draw down has been minimized to a great extent by allowing percolation and recharging the groundwater aquifer, okay. So, this particular method is not going to work if the groundwater is flowing at a reasonably fast rate. So, that will require an unacceptably large recharge capacity which is seldom feasible. So, in other cases where the amount of recharge required is relatively small, then this particular method could be used very effectively, alright.

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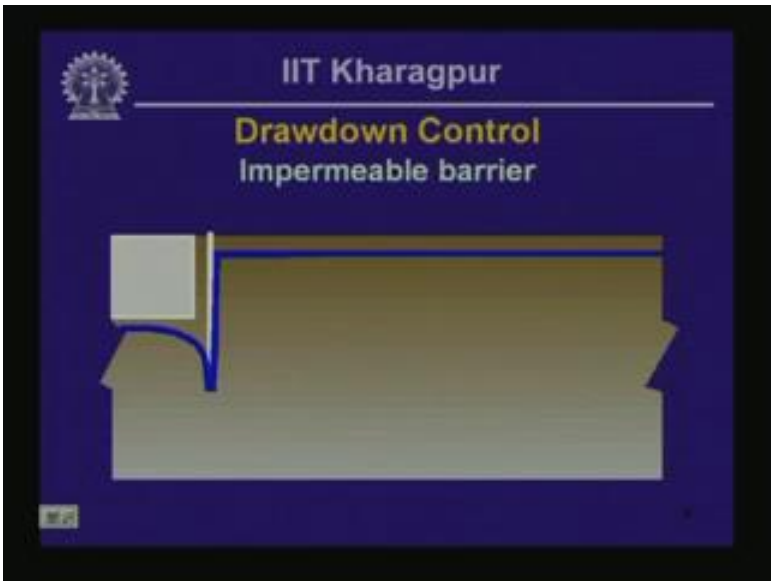

We are going to look at another option for controlling draw down, and that is installation of an impermeable barrier around the excavation. So, what we are going to consider here is essentially the same problem that we considered in the previous example, but here instead of using a recharge trench, we are going to use an impermeable barrier. So, let us say the impermeable barrier is constructed very close to the underground facility to be constructed, and that is shown in this particular cartoon.

And then we start dewatering inside from inside the excavation impermeable barrier, then the water table shown by the thick blue line once again is going to be drawn down like that. So, you can if you can ensure that the barrier that you have installed is sufficiently water tight, then the amount of draw down that is going to be outside of the impermeable barrier is going to be extremely small. So, that is another possibility. And then the question comes what you could use as an impermeable barrier.

You could use a vertical wall constructed on reinforced cement concrete installed within a vertical trench dark in the ground around the excavation or you could use a series of prefabricated or actually rolled steel sections; you could drive them down into the ground, which are interlocked with each other. And these sections are called ship pile sections; they look like this.

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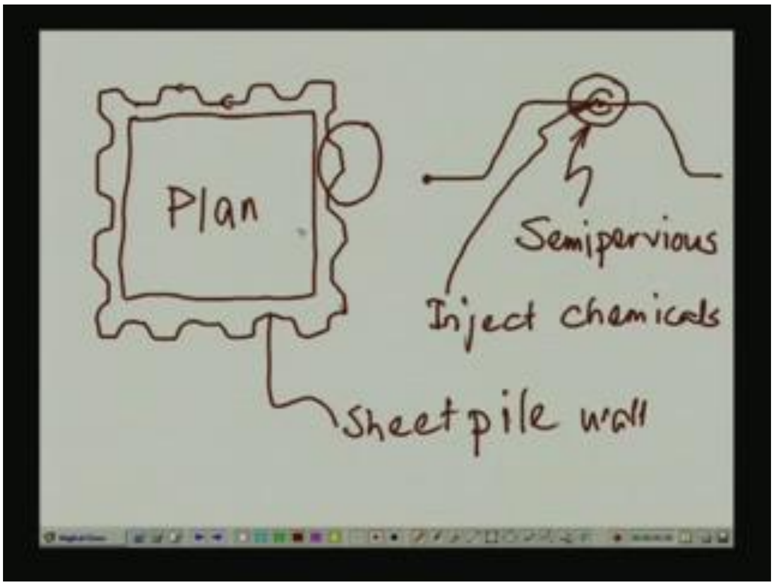

The first example that I gave was of a reinforced concrete wall. So, let us say you have to open up a plan a square area; you have to excavate a square area going down to great depth. So, what you could actually do is to install a vertical reinforced concrete wall of that type. We are not going to get into the constructional details of this particular type of wall. And they are called diaphragm walls or you could use a series of roll steel sections driven into the subsurface formation, and those rolled steel sections look like this. They look like that, and in the process, you construct a semi pervious barrier around the excavation.

And if you look at the details of these sections, they look like this; some of the sections look like this. So, they are driven in such a manner that the joint here is semi pervious and then you inject certain chemical inside the joint; inject chemicals to make these joints virtually impermeable. Typical permeability of these systems of a sheet pile, these things are called sheet pile by the way, sheet pile wall. So, typical permeability of a sheet pile wall for which the joint in between sheet pile sections are sealed with water tight chemicals is on the order of 10 to the power of minus 9 centimeter per second, and the permeability characteristics of diaphragm walls are also pretty much similar.

So, you can install a barrier around the plan area, a vertical barrier vertical impermeable barrier around the plan area of the excavation and then you can dewater from inside of the barrier installed, and that is going to minimize the extent of the dewatering in the manner shown on this particular cartoon, okay.

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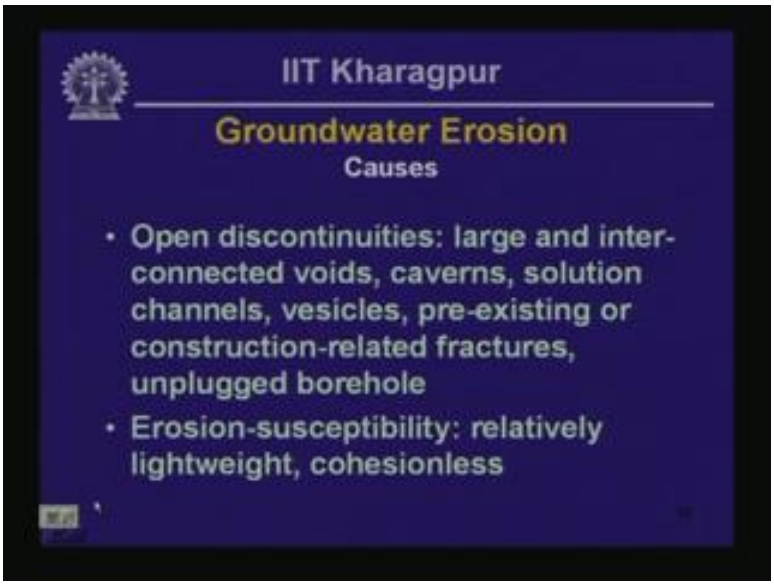

We now move on to the erosional aspect of groundwater; now what are the causes of erosion? If you have got open discontinuities through which groundwater is moving comprised of large or interconnected voids, caverns, solution channels, such as those in limestone terrains, vesicle, in vesicular volcanic rock, pre-existing or construction related fractures and unplugged borehole. So, if you have got open discontinuities like that, then fines or small particles within subsurface formation is likely to get carried through these openings, and that might create construction problems. Now if you have got erosion susceptible material used in your construction, then that is going to complicate the problem even further.

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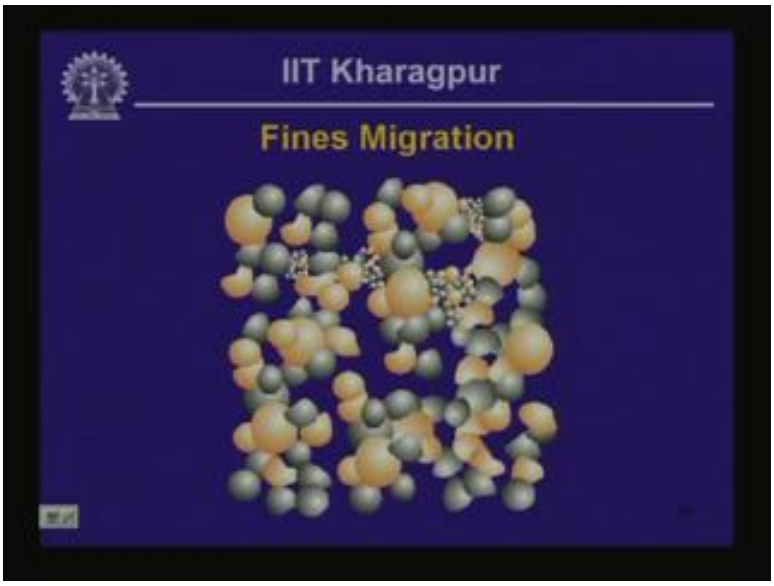

Now we look at the problem by considering a granular matrix shown on this particular cartoon here. Now here what you have got is a matrix of granular soil, and what you can see is that within a matrix comprised of relatively large grain sizes, you also have got final grain sizes within the channels interconnected void space through which the groundwater movement is likely to occur. What will happen in the process? If the groundwater flow is too high or if the velocity of the groundwater moving through this interconnected void space is too great, then these small particles they are going to be carried with the movement of the groundwater.

And that we are going to see in the next few seconds in this particular animation. So, you just look at the fine particles, and you can see that the fine particles are washed out by the movement of groundwater that might occur through these interconnected channels, okay.

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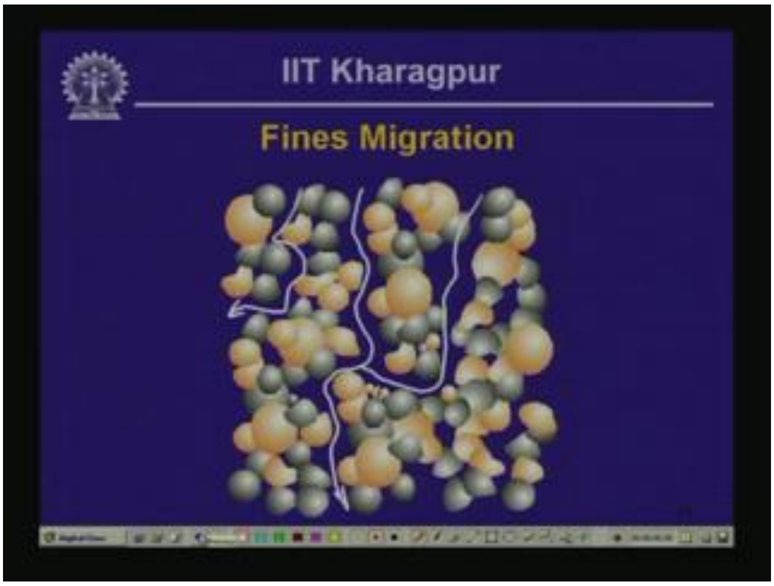

This particular phenomenon is called piping, okay.

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So, let us have a look at it once again; let us have a look at it once again, okay. So, that is how the fines are going to migrate through the coarser matrix. And this particular phenomenon is often encountered in situations where the fines are of very small weight or size; they can be readily carried away by the groundwater as well as if the fines are non-cohesive so that they can be easily covered by the groundwater that is moving through the matrix, okay.

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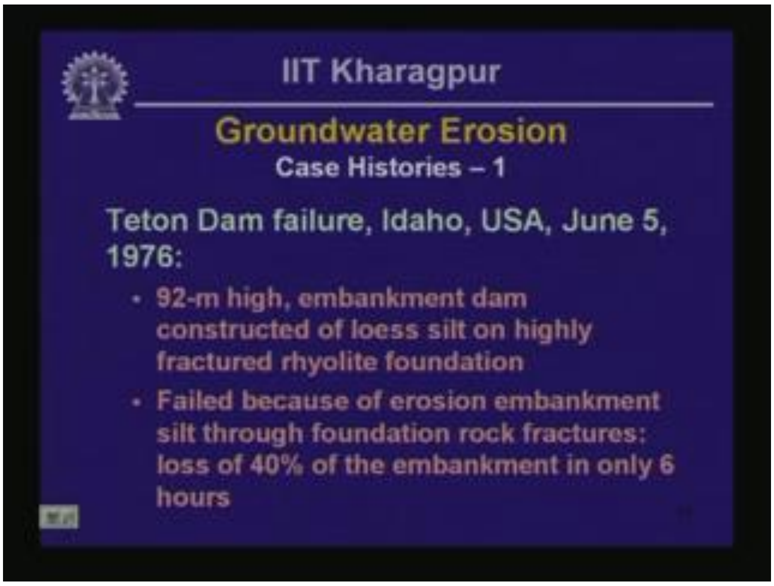

By far, piping is one of one of the largest causes of dam failures that have ever occurred globally. So, many dam failures, in fact, a great majority of dam failure; the main causes of those failures are piping the phenomenon that I explained a few seconds back. One of those high profile dam failure case histories involved Tetons dam in Idaho in north western united states; it was a 92 meter high embankment dam constructed using a silty material windblown silts called loess, which we have already discussed sometime back in this particular course. And the foundation condition included highly fractured rhyolite volcanic rock, and rhyolite is a type of rock which is notorious of having a very large size cavities sizes as large as a fully grown human being.

And this particular dam failed in June, 1976 because of erosion of embankment silt through the foundation rock fractures. And what happened? The failure was quite dramatic, in fact; forty percent of the 92 meter high embankment was destroyed in only a matter of six hours. There was some loss of life in this particular failure, because the water retained behind this dam washed away some facilities downstream. And in this particular case two things that actually added to the susceptibility of failure, and one of them was that the embankment dam was constructed of fine grained non-cohesive material loess slit, which is highly erodible and the existence of large open fractures in the rhyolite foundation.

And that is this particular failure took place in spite of the fact that an enormous effort was expanded by the agencies that constructed this particular dam is, in fact, a highly respected government agency in the united states. But in order to grout the open factures that might have been there in the foundation rock. But in spite of that the fractures were, obviously, not all plugged and piping took place those fractures.

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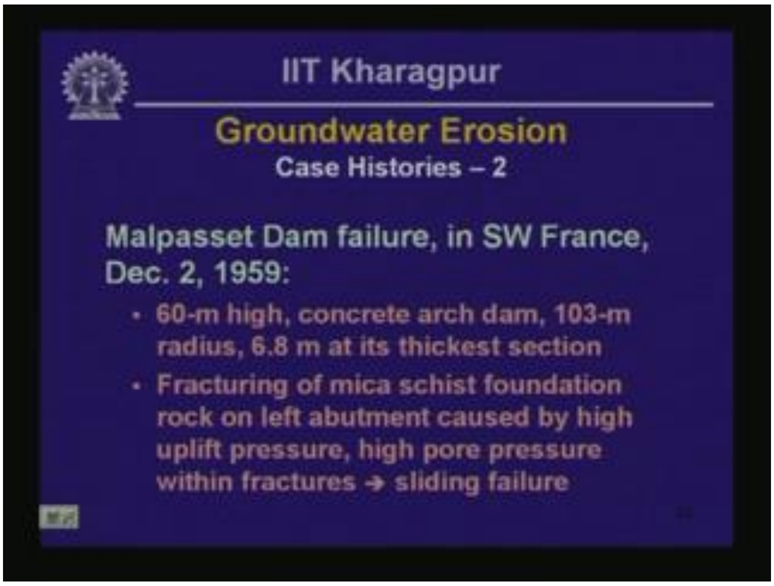

The second case history that I have presented here is this one. It is a dam in south western France; it is a sixty meter high concrete arch dam, the dimensions are indicated there. This particular dam also failed because of piping, and piping took place through open fractures that were opened by within the mica schist foundation rock on the left abutment. And this particular fracturing was caused by high uplift pressure because of the uplift pressure induced within the abutment because of the impoundment itself.

And, in fact, what happened later on is after the fractures were opened, the pore water pressure within the fractures were quite high, and this led to a remarkable reduction of sheer strength within the fractures and the dam slid; actually the dam failed because of sliding, okay. So, these are the two case histories that the first one was completely related to groundwater erosion. And in the second case, erosion was one of the causes, actually one of the contributory causes, for the failure of the second dam that we considered in this particular slide, alright.

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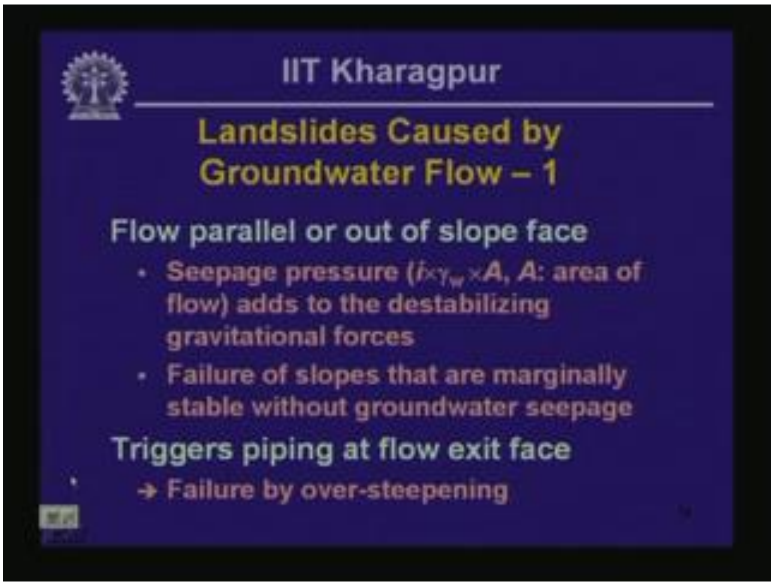

Now the third aspect that we need to consider is related to groundwater flow or the landslides caused by groundwater. So, landslides are often triggered immediately following a number of wet days or days in which excessive precipitation has taken place. And in that process, the seepage pressure within the formation increases, because if you note down the equation here, seepage pressure is given by i times gamma w times the cross sectional area of the flow, where i is the hydraulic gradient; gamma w is the unit rate of the fluid that is flowing through the formation. And this seepage pressure adds to the destabilizing gravitational forces provided seepage is taking place parallelly or out of the slope face.

If on the other hand, seepage is occurring into the slope, then we do not have to consider here is usually no problem. Now if you have got a seepage oozing out of the slope face, then where the groundwater is going to exit the slope face there, skewering is normally triggered if the soil is of the erodible type non-cohesive fine grain type, then erosion is going to get triggered; skewering is going to get triggered near the exit point of the seepage. And the slope phase is going to be over steepened, and over steepening is going to lead to the failure of the slope eventually.

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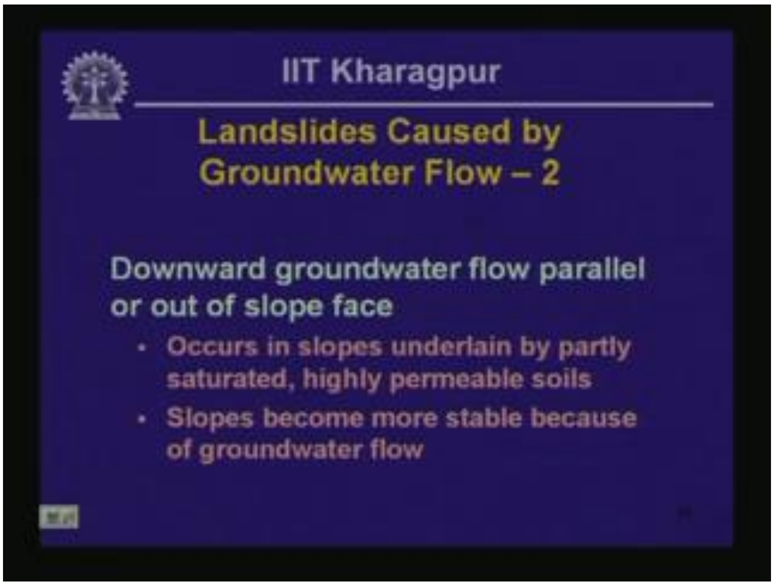

As I mentioned just a few minutes back, if you have got groundwater flow taking place into the slope face, then we do not have any problem. And if groundwater flow is taking place out of the slope phase, then only you have the problem of instability of the slope.

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Okay, seepage problems complicate the construction and functional aspect of a facility because of the fact for instance if you consider an irrigation canal, then loss of water is going to take place because of seepage that is coming out of the bottom of the irrigation canal. Then if you consider a mine waste dump, then if you have got seepage taking place from the bottom of the mine waste that might actually release hazardous material into the groundwater, and that is also not acceptable. So, in these circumstances, you need to control the seepage that is going to be developing at the bottom of these facilities.

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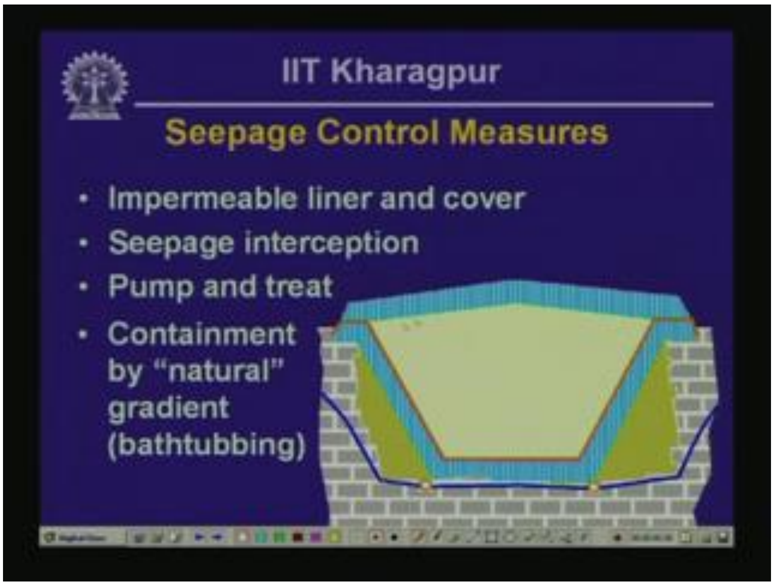

Seepage control measures include impermeable liner and cover. In this particular case impermeable liner and cover is indicated by hatched blue shaded area.

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So, impermeable cover is this one; this is cover, and this one here is the impermeable liner. This is actually a cross section of a landfill that is constructed and was under operation near the Toronto Ontario Canada. Here what we have got this is the waste material shown with light off white shading, and the thick orange line here is a impermeable plastic material that is used in order to control a downward seepage through the waste material.

And then you have got a series of pipes at the bottom of the landfill. So, these pipes they are perforated pipes; they normally intercept the groundwater that is going to try to seep in to the hole or excavation that was dug in order to station this particular landfill site, okay. So, these are the measures that can be used in order to control the downward seepage through the waste material stored in a municipal landfill site. The cover actually prevents water from seeping through the after precipitation seeping through the waste material and the under seepage that might actually get generated from within the waste material itself is intercepted by having a geosynthetic or plastic liner as well as impermeable liner underneath.

Impermeable liner typically is comprised of very fine clay typically montmorillonite clay that have permeability on the order of 10 to the power minus 8 centimeter per second. And here another interesting aspect that you should notice is that because of the drawing down of the groundwater by intercepted pipes, the direction of groundwater movement is going to be upward rather than downward, and that effect called bath tubing in many cases is also going to contain the likelihood of under seepage.

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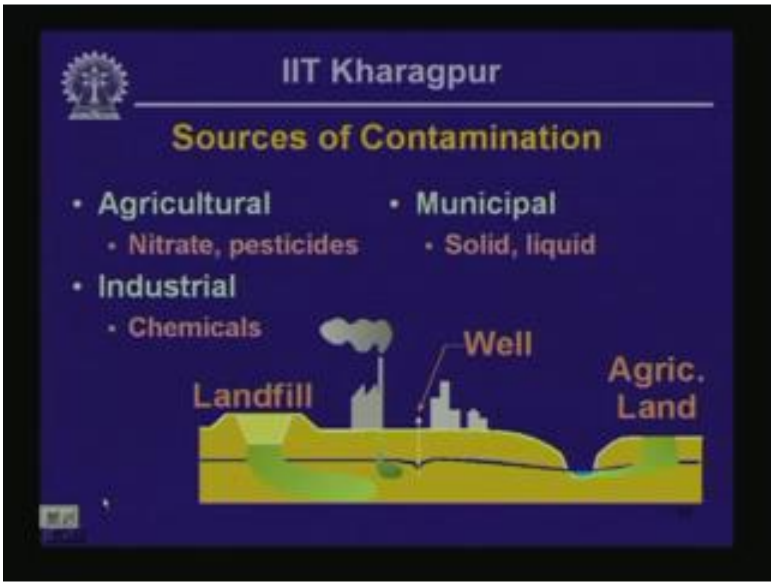

Sources of contamination, you have to consider while considering setting up of a groundwater well, for instance, we have looked at this particular issue sometime back. You do not want to construct a groundwater well downstream of a source of a contamination; source of contamination could be agricultural source which might actually introduce nitrate, nitrites and pesticides into the system. Sources of contamination could be industrial; there could be various minerals chemicals, chemicals introduced down into the groundwater because of industrial operations and source of contamination could be municipal such as a landfill site. And there could be actually liquid municipal waste as well; they are additional sources of contamination.

So, basically contaminants are going to move downward through the vadose zone into the groundwater underneath and then the ground together with the movement of the groundwater, they are going to be carried down gradient. And that is schematically shown on the cross section on this bottom of this particular slide. In this particular case, the movement of the groundwater is going to be towards the river that is near the right end of this particular cartoon.

So, the movement of contaminates is going to take place towards the river in this particular case. So, if you actually prefer to have a well installed at the location there; that is not really advisable, because the operation of well is going to cause drawdown of groundwater locally adjacent to the well. And that itself is going to increase the gradient of groundwater movement, and that in turn is going to suck the contaminants in this particular case from the landfill and the industrial site into the water well. So, that is not an advisable location of water well in this particular scenario.

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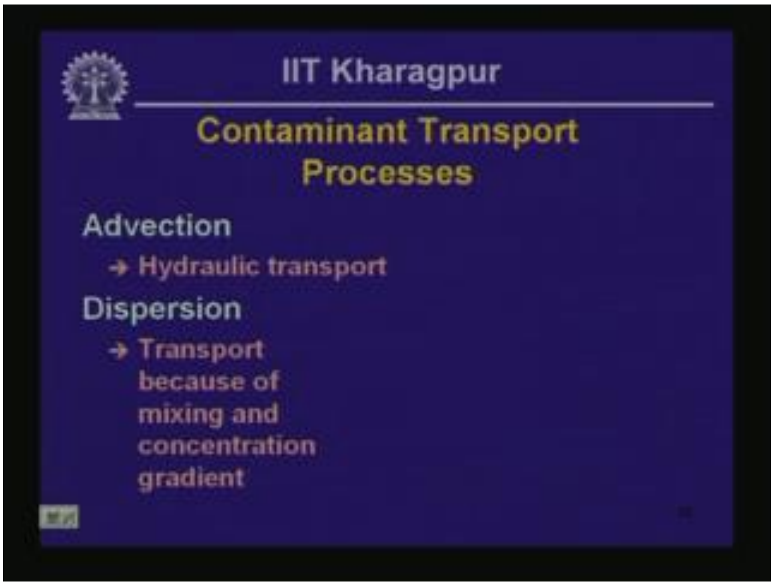

Now contaminant transport processes are essentially by means of the hydraulic movement of the groundwater itself, and that process is called advection. And there is another process involved in this particular case in which contaminant transport takes place because of mixing. And concentration gradient of the contaminant itself within various locations of the groundwater through which the movement is taking place and this particular scenario is for contaminant that is moving because of the movement of groundwater itself.

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Okay, let us look at an animation In this particular case, let us say we have got a groundwater movement taking place from the left of the cartoon to the right of this particular cartoon. And let us say we inject a contaminant at one point within this particular groundwater moving groundwater in the form of the orange dot near the left of this particular case. And what you should notice is that it is going to move together with the groundwater velocity towards the right as well as the size of the dot is going to start increasing because of dispersion. And the concentration in the process is going to diminish; that is going to get shown by the intensity of the injected dot.

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Just carefully have a look at the process schematic depiction of the processes of advection and dispersion, okay. So, this is actually a very crude ceramic description of the process.

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Now the question then comes, what are the possible counter measures in order to contain contaminant transport? They would include installation of monitoring wells to identify contaminant plume. Remove the source of the contamination. And isolate the contaminated groundwater within low permeable barrier like the ones that we discussed earlier. And treat the groundwater inside of the barrier to some compliance level, okay.

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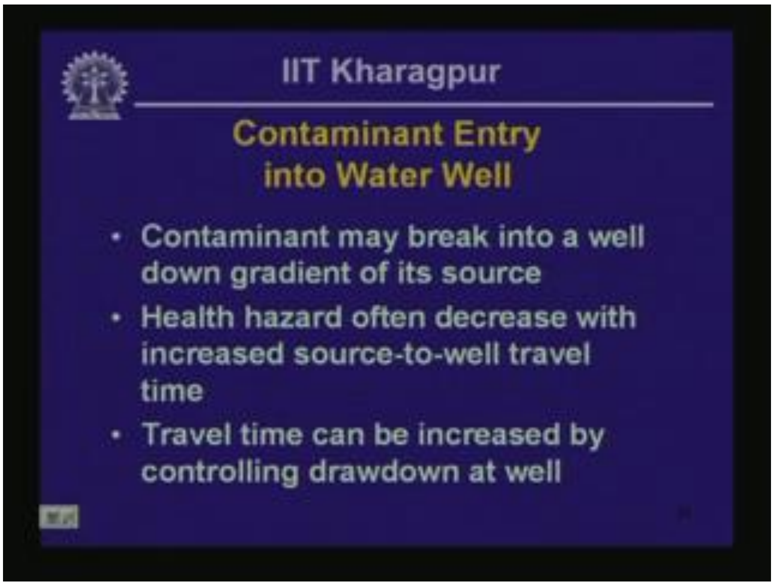

Now this you need to consider possibility of entry of contamination into water well; contaminant may break into water well, and this should be a prime consideration while sighting a water well around the location of the contamination. A health hazard, you need to also consider that that health hazard is going to decrease in many cases when source to well travel time is increased. So, if the well has got enough clearance from the location of the source of contamination, then you are not going to have much problem.

Now the amount of distance that is required is going to depend on the type of contamination as well as the speed or the velocity of groundwater flow. Travel time can be increased by controlling the drawdown of the well; that also you need to consider in this particular case.

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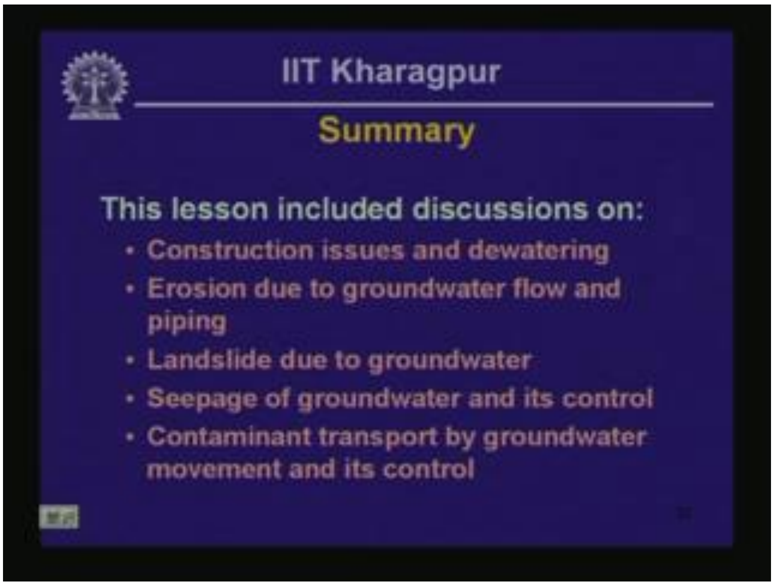

We need to summarize this particular lesson. What we learnt in this lesson include construction issues and dewatering, erosion due to groundwater flow and piping, land slide due to groundwater movement, seepage of groundwater its control. And contaminant transport because of groundwater movement, and the procedures for controlling those things.

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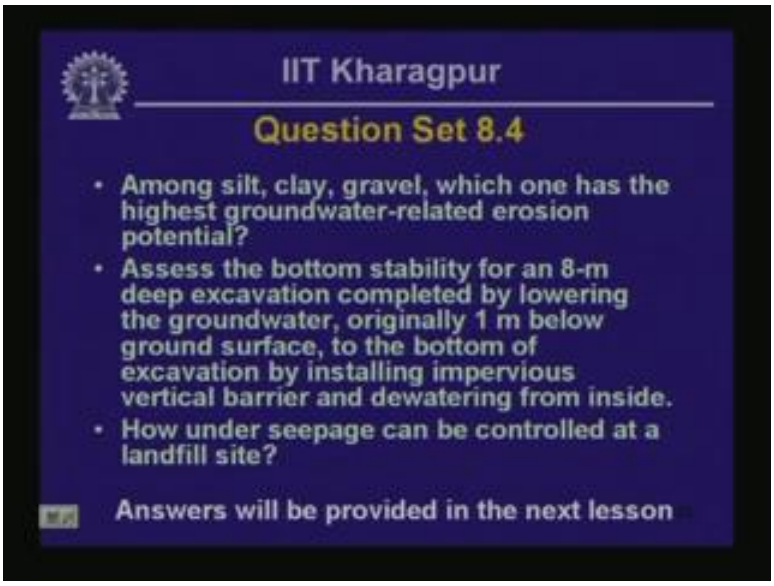

Finally, we wrap up this particular thing by a question set; these are the questions. The first one is that among silt clay and gravel, which one has the highest groundwater related erosion potential? Second one is asses; the bottom stability for an eight meter deep excavation completed by lowering of groundwater originally at one meter below ground surface to the bottom of the excavation by installing impervious vertical barrier and dewatering from inside. And the third question that I asked is how under seepage can be controlled at a landfill site. You try to answer these questions at your leisure. I am going to give you my answers when we meet again with the next lesson So, until then bye for now.