The Environmental Corner

By: Steve Henshaw

Groundwater Flow

"Water runs downhill." That old catch phrase is true. A hydrogeologist, however, is more likely to say that groundwater runs downgradient. What's the difference? One we can see and the other we infer. That is the essential difference and why some in the 1850's said that understanding groundwater flow was an occult practice instead of a science. This article will go into how we simplistically determine the direction of groundwater flow, why tetrachloroethene (perc) enters groundwater, and how perc "goes for a ride", sometimes in a different direction than the groundwater flow.

Groundwater is below our feet flowing in the sediments or rocks. The points of observation are wells that tap the groundwater. When wells are placed, it is important to survey their exact location. EPA guidance documents state that monitoring wells should be surveyed horizontally to within 0.1 foot and vertically to within 0.01 foot. Scientists measure the depth to water in wells to 0.01 foot. That depth to water is subtracted (it is lower) from the elevation of the measuring point to get the elevation of the groundwater. That groundwater elevation is plotted on a map that has the wells accurately located.

You all know that two points define a line. Three points are the minimum needed to determine the orientation of a plane, the simplest form the water table can assume. We sometimes call this the three point problem, which can be solved for the orientation of a plane which fits the three points. We can then find the greatest sloping downward line on that plane. This line is the maximum gradient and is the one that is assumed to be the overall groundwater flow direction. Fortunately, most hydrogeologists can place the elevation of the water in the three wells on a map and draw lines of equal elevation – contours - on a map, saving a boring calculation with artistry. Reason-

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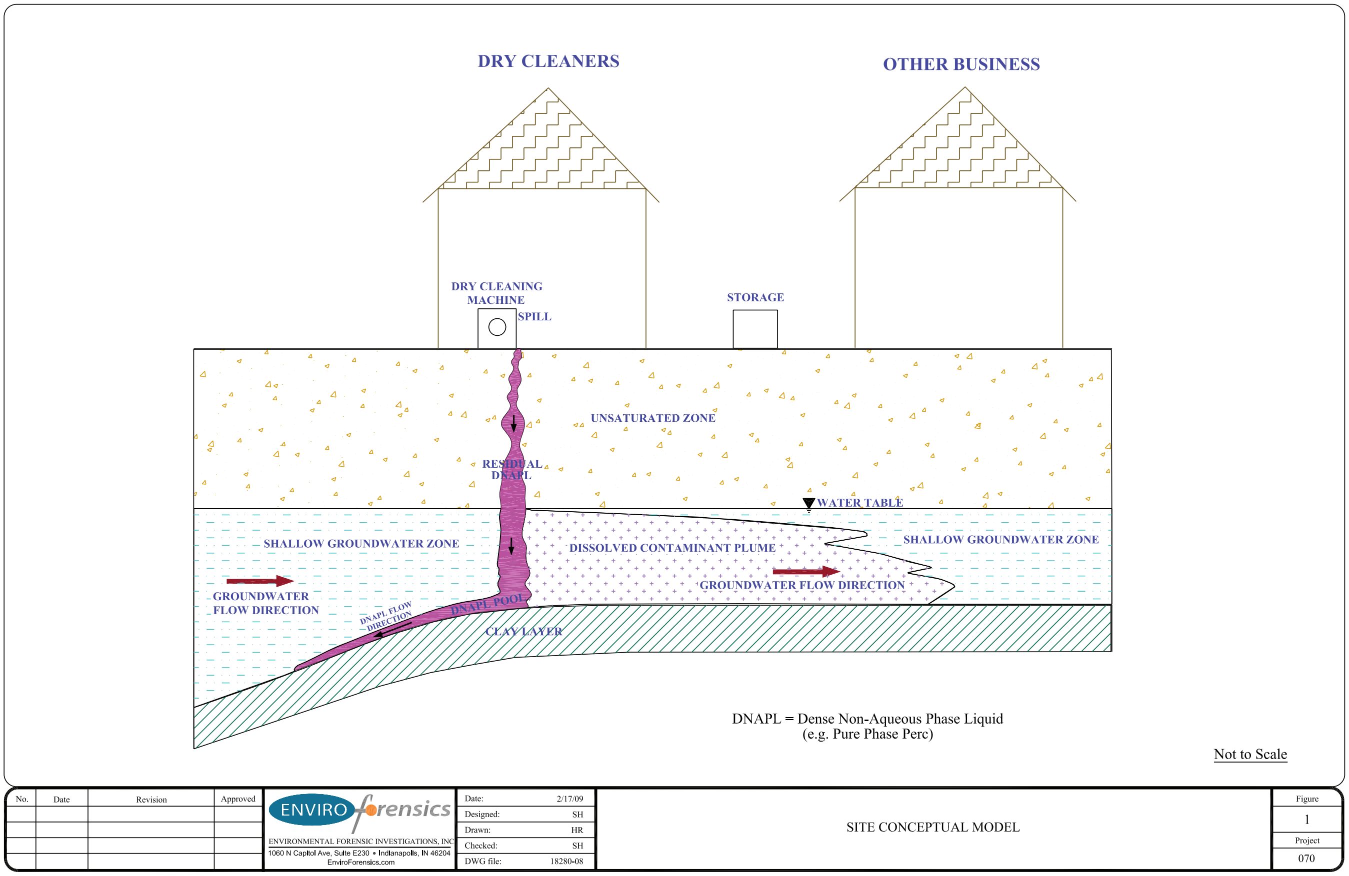

able because over a long period of observation the precise direction of flow changes and the hydrogeologist takes into account other factors gleaned from experience which influence the direction of flow. These factors could include the direction to a stream, the depth of nearby utility trenches, the distance to nearby pumping wells and their seasonal pumping rates.

For the actual gradient, we calculate along the flow direction the difference in the elevation over the difference in distance. This is easily visualized if you think of stairs. Stairs go down from upstairs to downstairs and often are constructed so that you lose 7.5 inches in altitude for each 9 inches in lateral movement. These two numbers form a dimensionless number known as the gradient. For the stair example the gradient is 7.5 inches / 9.0 inches or a gradient of 0.83. Groundwater gradients rarely exceed 0.01 and can commonly be 0.001. Now you can understand why the geographic position and the elevation of the measuring point have the apparently strict requirements on them.

Groundwater gradients are pretty low. The gradient, the hydraulic conductivity and the effective porosity are all quantities that need to be measured or estimated in order to calculate the speed of groundwater flow. In practice, a groundwater velocity of a foot per day is generally not seen and most velocities are on the order of tenths of feet per day. It is instructive for you to calculate how far groundwater would move in a year at 0.3 feet per day, an actual groundwater velocity in nature.

Perc often times can find its way to the groundwater, particularly if the groundwater is relatively shallow (e.g. 10 to 30 feet deep) because it makes its way downward through the tiniest of openings. Just why is clear if you understand that perc weighs more than water, about 1.6 times more. If it reaches the groundwater it will move slowly with the natural groundwater flow. Perc is not very soluble in water, roughly only 150 parts per million. (For comparison, all of the degradation products of perc are roughly 6 times or more soluble.)

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That soluble perc that dissolves in the water does go along with the water but at a different pace than the water. Why that is will be explained next.

If you think of a sand body, there is a lot of solid stuff in the way of groundwater. The groundwater has to move in between and around sand and silt grains. This physical fact is a large part of why groundwater moves as slowly as it does. In most geological materials, there are clay particles and organic matter. Organic matter is stuff like decayed leaves, worm casts and wood particles. The same property that makes perc an excellent dry cleaning fluid, an overwhelming attraction to organic matter like grease, makes it attach to organic matter in sand or other sediments.

So the perc, moving in and around mineral grains, will encounter organic matter and attach just like it does in the dry cleaning machine. So perc moves through more slowly than water. In the jargon of the hydrogeologist, the perc is retarded with respect to the velocity of groundwater. In simpler terms, the perc moves through the aquifer and some will attach to organic matter, dropping out of solution for a while. Just how much slower the perc moves is generally dependent on the amount of organic matter in the aquifer. In general, perc in a sandy aquifer can move at a rate 25% slower than that of groundwater, while perc in a loamy, organic rich aquifer could move at a rate 60% slower than that of groundwater.

Finally, because perc is more dense than water, it can show up on the bottom of the water bearing unit or aquifer. It can drop through the aquifer and pool up on a clay lens or layer. This pool of perc is called DNAPL or dense non-aqueous phase liquid. DNAPL, which is essentially pure phase perc, can follow subsurface bedding planes and layers that may be sloping in one direction, while the groundwater is moving in another direction (see the attached figure). DNAPLS are not uncommon in investigations associated with dry cleaning sites and they can be difficult to remediate.

What does this have to do with me, a drycleaner? It means that your consultant needs to do all those seeming banal pieces that she does. It means that you may understand a bit better about what is going on with "the study." It also means that, unlike other issues such as vapor intrusion, you generally don't have to plunge into issues regarding immediate cleanup of groundwater contamination, until you understand how the contamination is distributed across the site. On the flip side, you shouldn't put off determining a solution because the problem will become worse. Your consultant should be able to guide you with respect to the urgency, but it is not something to decide on in a week or a month. Up front study costs will surely save you money down the road and prevent you from throwing good money after bad.

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