EXAMINE THE FATE AND TRANSPORT OF GROUNDWATER CONTAMINANTS BEFORE SETTLING LEGALLY

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When it comes to the assessment and remediation of impacted groundwater, common questions are "who is responsible?" and "who is going to pay?". In some cases, the responsible party is known, and the focus can turn to questions of risk. How long will it take for the contamination to reach a water supply well or a surface water body? Will the groundwater contamination adversely affect indoor air quality or impact utilities?

In other cases, determining the responsible party is difficult. For example, when you have multiple owners of a business over time, multiple potential sources in close proximity, or complex subsurface conditions, there may be some uncertainty about when and where the release occurred. In these cases, it is important to know the history of the site, groundwater flow conditions, and how contaminants move and what processes affect their concentrations.

Groundwater contamination frequently originates from surface or near-surface releases of chemicals or waste fluids, such as from underground storage tanks or pipes, spills, and landfills. When a contaminant release occurs, the contaminant moves downward through the subsurface soil or rock under gravity.

Spread of the contaminant into the subsurface from a release depends on many factors, including: the nature of the release (amount, duration, nature of the chemical, the subsurface geology, preferred pathways, and the depth to the water table). The water table is the top of the saturated zone where the pores in the soil or rock are filled with water. Other factors to consider include:

- Is the release a miscible or immiscible chemical (i.e., does it readily mix with water)? Chemicals such as chloride from landfills and road salt, and nitrate from agriculture, are miscible in water.
- If immiscible, is the release a chemical that is less dense than water (a "light nonaqueous phase liquid" or "LNAPL" such as gasoline or oil) or denser than water (a "dense nonaqueous phase liquid" or "DNAPL" such as trichloroethene [TCE])?
- Was the release large enough to

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migrate through the unsaturated zone (where the pores are not full of water) and reach the water table? Or will infiltration of precipitation gradually dissolve the trapped chemical and transport it to the water table in solution?

- Is the subsurface geology conducive to rapid vertical movement of chemicals (such as sandy soil) or does the subsurface geology inhibit vertical infiltration from a release (such as clayey soil)?
- Is the subsurface geology above the water table complicated, such that the contaminant is forced to migrate laterally before reaching the water table?
- Are there preferred pathways that complicate contaminant movement such as fractures in clayey soils or subsurface infrastructure such as sewers, old water wells, or exploration wells?

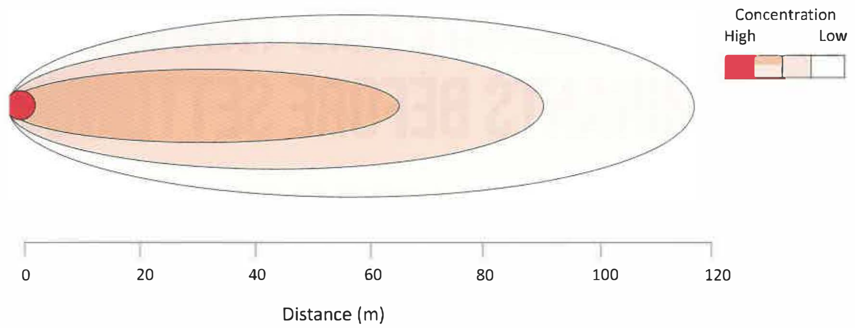

Figure 1: Schematic of a contaminant plume growth with time.

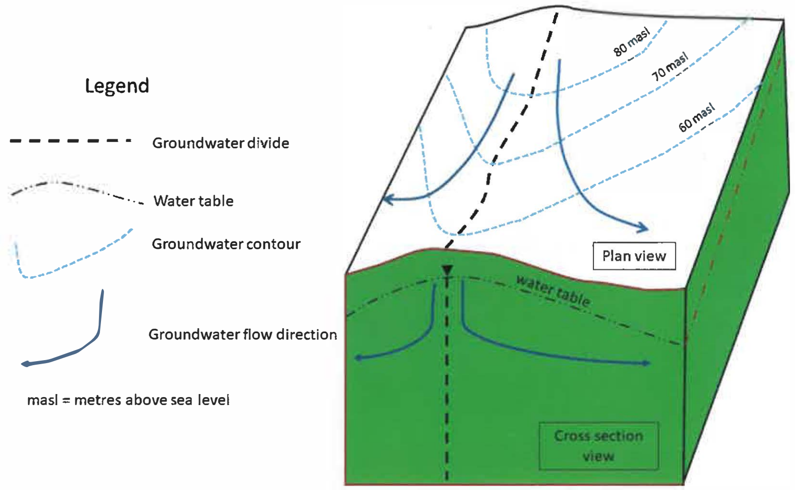

Figure 2: Schematic of a groundwater divide.

CONTAMINANT MASS TRANSPORT MECHANISMS

Contaminant mass spreads through groundwater due to advection, diffusion, and mechanical dispersion.

Advection is mass transport through flowing groundwater in which the direction and rate of mass transport is due to groundwater movement. For example, if the groundwater velocity is 50 m/year to the south, a conservative contaminant, such as chloride from road salt, will also move at 50 m/year to the south. Advection is important in permeable soils such as sand and gravel and permeable rocks such as fractured limestone.

Diffusion occurs due to a chemical concentration gradient. The contaminant moves from high concentration areas to low concentration areas. Diffusion is only important in low permeability soils such as clay and low permeability rocks such as massive limestone and even then, transport distances due to diffusion are very limited.

Nevertheless, diffusion results in stored contaminant in low permeability soils and rock that is a challenge to remediate. Diffusion can cause remediation to take longer than expected, as permeable materials clean up relatively quickly and then the diffusive transport direction (concentration gradient) reverses and contaminants move back from the low permeability material into the permeable material.

Mechanical dispersion is the spreading of a contaminant from the release point in the groundwater to form a contaminant plume. Mechanical dispersion is due to the complex pathways that groundwater moves through in a porous geologic material. Mechanical dispersion causes lateral spreading of contaminants both parallel to (longitudinal dispersion), and perpendicular to (transverse dispersion) the groundwater flow path.

Figure 1 is a schematic figure showing growth of a contaminant plume with time from a continuous source. The plume increases in length and width with time and decreases in contaminant concentration with distance due to mechanical dispersion.

THINKING ABOUT GROUNDWATER FLOW

Groundwater moves from areas of high hydraulic head to areas of low hydraulic head. In order to determine groundwater flow direction, we need to install at least three monitoring wells that are arranged in a triangle and must be screened in (open to) the same aquifer at about the same depth.

Then, we determine the groundwater elevation in each well. In the next step, we create a groundwater contour map by interpolating groundwater elevations between the three wells and connecting the points of equal elevation. Finally, we determine groundwater flow direction, which is perpendicular to the contour lines.

The interpretation of groundwater flow direction becomes more complex in the areas where groundwater divides are present.(Figure 2)

Groundwater divides are linear features in a groundwater flow map from which groundwater moves in two different directions and groundwater and its contaminant load cannot cross. An analogy is the Rocky Mountains, whereby surface water either flows to the east or west, but cannot cross them.

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We were involved in a remediation project in Ontario that involved an overfill gasoline release that was well documented. However, during remediation, the extent of the release appeared to be much larger than anticipated. The underlying soil and aquifer were sandy and the resultant contaminant plume apparently spread beneath the adjacent property.

There were gasoline odours in a city sewer that crossed our client's property. The regulator asked our client to follow the plume onto the adjacent property, completely delineate the plume, and find the source of the gasoline odours.

We monitored the groundwater flow direction using the triangulation method noted above. However, we monitored groundwater elevations continuously over a one-year period using data loggers and found two unusual features on the resultant groundwater flow maps. First, our data indicated that the groundwater flow directions changed seasonally (by about 180 degrees) due to changes in the adjacent lake level and leakage into the sewer.

Second, we found that there was a groundwater divide between our client's property and the adjacent property, which meant that groundwater and its contaminant load could not move between the two properties. Third, although not a groundwater flow issue, we noticed on a fire insurance map that there was an old underground storage tank on the adjacent property.

Subsequently, our client was absolved of the responsibility to clean up the adjacent property largely based on the detailed analysis of groundwater flow direction.

THINKING ABOUT FATE AND TRANSPORT

Some contaminants, such as organic chemicals (e.g., gasoline and trichloroethylene) are affected by processes that "retard" (slow down) their transport. These chemicals adsorb to clay surfaces or organic carbon in the soil and the degree of retardation is related to the soil conditions and the contaminant properties. Retardation can be important in assigning responsibility for releases and in remediation.

We were involved in a litigation project that involved releases of gasoline over time from underground storage tanks (USTs) that caused both an LNAPL and groundwater plume (BTEX – benzene, toluene, ethylbenzene, and xylenes). The underlying soil and aquifer were sandy and the LNAPL plume and groundwater plume spread beneath an adjacent neighbourhood due to advection and mechanical dispersion.

Ownership of the gas station had changed hands over time and both owners had documented releases. Who was responsible for the plumes beneath the neighbourhood? An expert for the most recent owner claimed little responsibility because a gasoline additive exclusive to the most recent owner could not be found in the plumes.

However, the literature indicated that the exclusive additive is severely retarded in groundwater and as we calculated, would never show up beneath the neighbourhood even though contaminants such as BTEX would. The judge ruled largely in favour of the first owner due to this and other considerations.

Microorganisms in the soil and groundwater can break down certain contaminants into less harmful chemicals (biodegradation). Some minerals in the soil also react chemically with contaminants in groundwater and degrade them. In some situations, where contaminant plumes are close to the surface, volatilization of contaminants into the air occurs.

Knowledge of these processes is necessary to estimate contaminant transport rate and responsibility. Biodegradation can be important in assigning responsibility for releases and in remediation.

For example, we were involved in another legal proceeding in Canada that involved release(s) of a solvent (TCE) that formed a TCE plume in groundwater. It may have spread due to advection and mechanical dispersion beneath two properties and a busy road that separated them. The soil was thin, the underlying bedrock was fractured, and the water table was in the fractured bedrock.

The upgradient property had known TCE use and impact. The downgradient property had only anecdotal documentation of TCE use but had impacted groundwater. Consultants for the known user had investigated groundwater conditions on both sides of the road and had data that indicated there were two separate sources. However, the regulator's position was that in this fractured bedrock environment, one could not be sure all of the pathways (fractures) had been investigated.

We used two high-tech, high-resolution techniques to determine if there were two sources of TCE, or not. First, we used a grid of passive soil gas collectors to examine the distribution of TCE contamination beneath both properties and the road. This approach demonstrated two distinct source areas, one on each side of the road. Second, we examined the biodegradation trends in the TCE plume using compound specific isotope analysis (CSIA).

The CSIA approach can detect changes in the isotopic composition of the TCE as it biodegrades when it moves from the source. The CSIA data also indicated two distinct source areas, one on each side of the road. These data assisted the attorney in resolving the case.

CONCLUSIONS

Evaluating contaminant fate and transport in groundwater is a common problem for property owners and businesses and responsibility may only be settled through the legal system. To reach a scientifically defensible position, it is important to thoroughly understand the site history, groundwater flow conditions, and contaminant fate and transport processes. Sometimes advanced tools are required to reach that defensible conclusion. ■

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