Groundwater flow and contaminant transport through the epikarst in two karst drainage systems, USA

NOEL C. KROTHE

Faculty of Geological Sciences, Indiana University, 1001 E. 10th St., Bloomington, IN- 47424, USA; E-mail: krothen@indiana.edu

Abstract: Lemon Lane Landfill has limestone cropping out at the surface with an extensive developed lateral epikarst contaminated with polychlorinated biphenyls (PCB). The Ammunition Burning Grounds contaminated with RDX has a sandstone cap and the karst development in the limestone beneath occurs only where joints dissect the sandstone. The results of geophysical and hydrochemical studies show that contaminant transport differs in the two areas.

Key words: epikarst, polychlorinated biphenyls (PCB), DNAPL, karst, hydrograph

INTRODUCTION

Epikarst refers to the top of the carbonate bedrock where it is covered by soil material above the main mass of mostly unweathered rock. This zone is the upper part of the vadose zone, which is solutionally modified by soil waters charged with carbon dioxide. If the infiltration of rainwater to the epikarst is greater than the vertical leakage through the vadose zone, pockets of water form and coalesce to create an epikarts perched aquifer. Water in this perched aquifer will flow in the direction of the hydraulic gradient in the epikarst to points of enhanced vertical permeability (joints). The water then moves quickly to the phreatic zone, where it supplies significant water to karst springs during the storm. After the storm event, the epikarst water is slowly released to the phreatic zone. In humid climates, the frequent storm events usually sustain the water in the epikarst except during extreme droughts.

RESULTS AND DISCUSSION

The karst development in the two study areas differs due to the geology of the area. The Lemon Lane Landfill area has Mississippian Age limestones cropping out with a thin soil cover (Figure 1). Precipitation passes through the soil, which has a large carbon dioxide content due to organic decay and plant root and animal respiration. The water dissolves the CO_2 thus creating a more acidic solution. The carbonate bedrock is intensely dissolved at the soil/bedrock interface. As the water infiltrates deeper into the bedrock, the CO_2 is used causing the water to be less aggressive.

An extensive laterally developed epikarst occurs (Figure 2). Polychlorinated biphenyl (PBC) contamination occurred at this site due to past landfilling practices. PCB's are dense non-aqueous phase liquids (DNAPL). The PCB's sink into the many pockets in the epikarst where it is stored. Each rain event raises the water level in the epikarst, moving some of the PCB laterally to large joints, which carry the contaminants rapidly to the phreatic zone. Figure 3 shows this type of contaminant transport.

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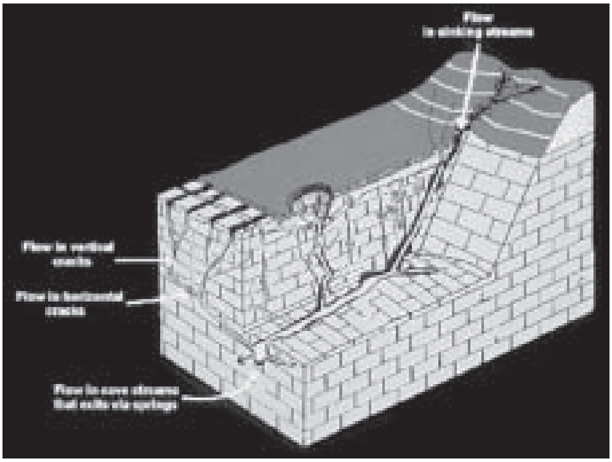

Figure 1. Diagram showing limestone with thin soil cover

Figure 2. Photograph showing intense epikarst formation in area of Lemon Lane Landfill

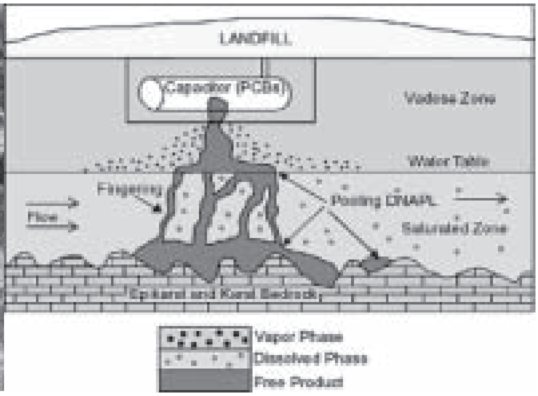

Figure 3. Schematic showing contaminant transport in epikarst in Lemon Lane Landfill area

Figure 4 shows a graph of PCB concentration with discharge (KROTHE ET AL., 1999). It should be noted that instead of dilution occurring a large PCB pulse occurs at the spring on the recession limb of the hydrograph.

The Ammunition Burning Grounds (ABG) is a military base contaminated with RDX, TNT and other residuals due to past thermal demolition of spent munitions. The geology is different than Lemon Lane Landfill since the limestone forming the Karst is covered by a sandstone cap. Therefore, carbon dioxide laden soil water can only reach the limestone in areas where joints dissect the sandstone causing dissolution at focused area. Dye traces from the ABG show that water will travel to a spring located 1.25 miles from the site in 18 hours at low flow and 7.5 hours at high flow (BAEDKE & KROTHE, 2000).

The original burning activities occurred on the ground surface. The contaminant residuals were dissolved by precipitation and transported through the sandy soils to the underlying sandstone, some went directly into the limestone through joints. Since the change in burning practices, there is no new contamination of the aquifer. The contamination at the karst

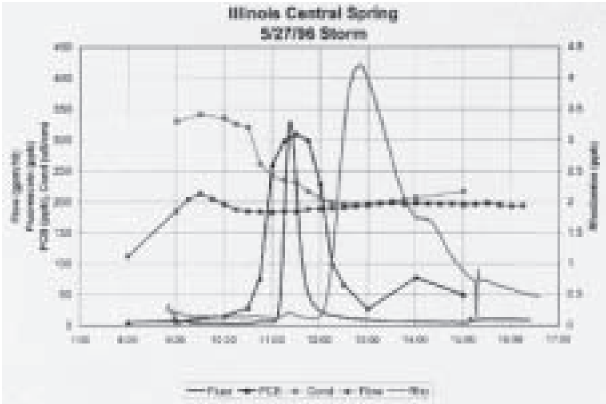

Figure 4. Graph of a storm hydrograph showing PCB concentration with discharge

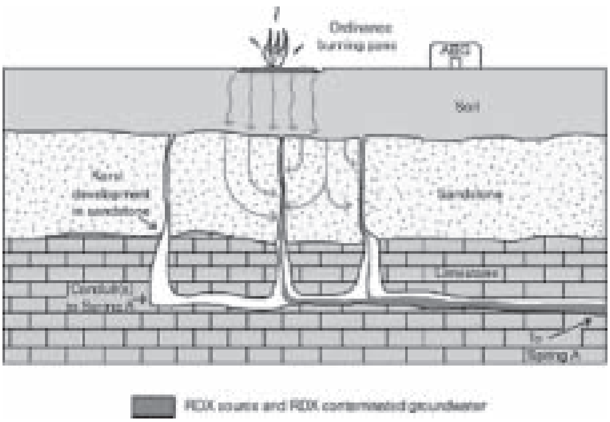

Figure 5. Schematic showing contaminant transport along joints in the sandstone to the underlying sandstone in the area of the ABG

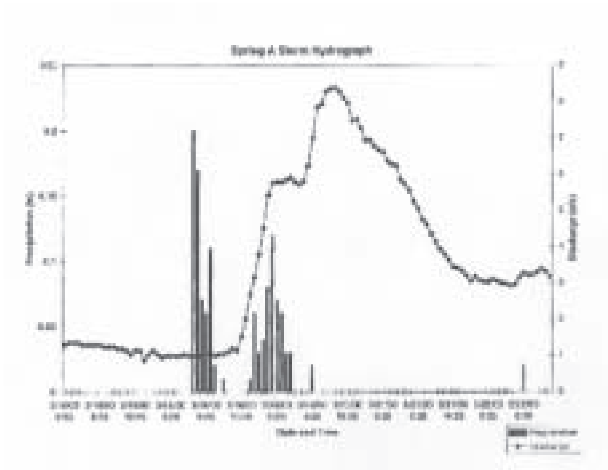

Figure 6. Graph of a storm hydrograph showing RDX concentration changes with discharge

spring down valley still occurs since the RDX, TNT and TCE are still present in the soil and sandstone above the Karst. During rain events, the contaminants in the soil and sandstone are released to the large fractures into the underlying Karst (Figure 5). Since the storage in this system occurs in the pore spaces of the sandstone, the release of water to the Karst does not contain large concentrations of the contaminants, therefore, the concentrations decrease due to dilution at the spring during a rain event.
Figure 6 shows a plot of RDX and discharge on a storm hydrograph. Note that the concentrations decrease during the event.

CONCLUSIONS

The type of Karst development controls the mode of transport and release of contaminants in the aquifer to Karst Springs. Karst developed at the soil/bedrock interface is very intense due to carbon dioxide laden water dissolving the limestone. A very extensive epikarst is formed creating a large capacity for storage of contaminants. DNAPL's are especially problematic since they sink into undrained pockets in the epikarst and are mobilized and transported rapidly to the spring with each rain event. When the rain subsides, the DNAPL will sink again into pockets. Remediation of this type of aquifer is difficult.
Karst developed in areas where the limestone is capped with a sandstone and soil only develops intensive Karst where fractures penetrate to the limestone. Storage of the contaminants occurs in the pore spaces of the soil and sandstone since there is not an extensive lateral Karst development. The contaminant release from the soil and sandstone is to the fractures and vertically into the Karst. The release is more gradual than the prior example, thus dilution occurs at the spring during storms. Although this type of aquifer will take time to remediate, it does not pose a strong environmental threat since concentrations show little variation. After release from the spring it is diluted as it flows into the main tributary.

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