Research Brief from the
Western Region Hazardous Substance Research Center

Brief #9 October 2005

A Novel Approach for Determining Transverse Dispersion

WRHSRC researchers have created two novel devices to measure pore-scale transverse dispersivity, an aquifer property that facilitates dilution and mixing of contaminants in groundwater. Their experiments with helical and cochlear devices suggest that the rates of pore-scale transverse dispersivity may be greater than the values often assumed in aquifer modeling and cleanup simulations.

Figure 1 helps illustrate the concept of pore-scale dispersion. As solute moves through the pores of an aquifer it travels along multiple flow paths. Differences in pathway lengths, widths, and orientation, as well as local velocity variations, cause the solute to spread and mix with the surrounding groundwater. Rates of dispersion are controlled by average flow velocity, molecular diffusion, and by the dispersivity of the aquifer media, a property that describes the interconnectedness, size, and shape of aquifer pore-spaces.

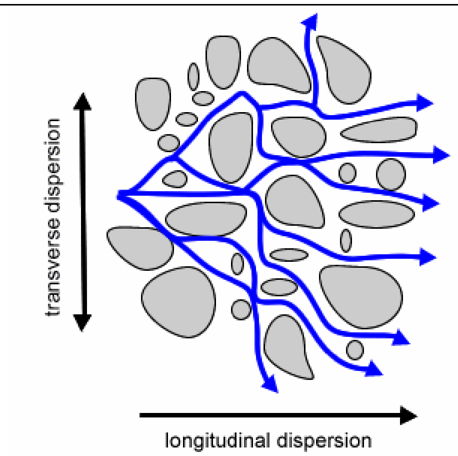

Figure 1. The illustration above shows some of the causes of pore-scale dispersion. Solute traveling more tortuous pathways between sediment grains will move more slowly than that moving along more direct pathways. Diverging pathways will also cause the contaminant to spread perpendicular to the aquifer flow direction. (Illustration based on Fetter, 1999)

Summary of the Problem

Contaminants in groundwater tend to disperse – that is they tend to spread and create a diffuse plume rather than move as a front with a constant concentration. Dispersion perpendicular to the aquifer flow direction is called transverse dispersion and plays an important role in the remediation of contaminants. It helps to dilute their concentration and to mix the contaminants with reactive compounds and microbes in the surrounding groundwater.

Despite its importance, dispersion is difficult to measure and is poorly understood. This research brief describes work by WRHSRC researcher **Peter Kitanidis** and his research team at Stanford University to develop novel devices that can accurately measure pore-scale transverse dispersion.

About the WRHSRC

The **Western Region Hazardous Substance Research Center** (WRHSRC) is one of five university-based **hazardous substance research centers** in the United States. The Centers are **funded by**

grants from the US EPA Office of Research and Development and Office of Solid Waste and Emergency Response. Our Research Briefs are designed to enhance our communication with environmental professionals and others interested in emerging technologies for hazardous substance cleanup. For more information about the WRHSRC visit: **http://wrhsrc.orst.edu** or call 541-737-2751.

Longitudinal dispersivity is parallel to the flow direction and can be measured in laboratory column experiments. When a tracer is introduced continuously at one end of the column, all of the tracer does not simultaneously arrive at the other end of the column. Instead, the tracer "breakthrough curve" shows spreading – with concentration gradually increasing (**Figure 2**). The width of the breakthrough curve is proportional to the longitudinal dispersivity. Unfortunately, a simple concentration breakthrough curve obtained at the outlet of a column experiment does not permit measurement of dispersivity perpendicular, or transverse, to the flow direction.

But what if the column was curved? In 2000, Stanford University professor **Peter Kitanidis** and his post-graduate researcher **Olaf Cirpka**, proposed measuring transverse dispersivity in a helix-shaped device (Cirpka and Kitanidis, 2001). The device makes use of the radial velocity differences created by shear flow in the helix. A solute will move more quickly along the inside of the curve than along the outside. When a tracer is introduced, this velocity gradient will enhance spreading of the breakthrough curve. Since transverse dispersion acts perpendicular to the flow direction, it will cause mixing in the helix transverse to the main flow direction and reduce the spreading of the breakthrough curve. The relationship between these two quantities is exact and allows transverse dispersivity to be calculated from the amount of spreading of the breakthrough curve. In fact, because the relationship is inverse, very small transverse dispersivities can be measured accurately -- the smaller the transverse dispersivity, the larger the spreading of the breakthrough curve.

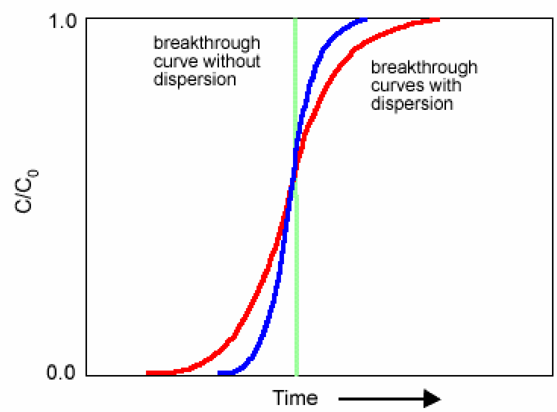

Figure 2. Illustration of spreading in breakthrough curves. Without dispersion (the green curve), the tracer arrives at the column outflow as a sharp front. With dispersion the concentration increases gradually. The red and blue curves show the affect of increasing dispersivity. As the dispersivity increases, the breakthrough curve becomes stretched horizontally.

Stanford graduate student **Ioannis Benekos** made dispersion experiments with the helix and a different spiraling device, a cochlea, the focus of his dissertation (**Figure 3**). Benekos ran multiple trials with the cochlea and helix and varied the types of tracers, glass-bead media, and flow rates. For each, he compared the experimentally determined breakthrough curve with a numerically predicted breakthrough curve and used an optimization process to adjust the numerical parameters until the curves matched. This process allowed him to estimate transverse dispersivity for each trial.

The helix and cochlea experiments were successful. The dispersivities that Benekos estimated with the helix matched those that he estimated with the cochlea and the confidence intervals within each set of experiments overlapped. Importantly, he found that his estimates for transverse dispersivity agreed with the high end of estimates reported in the literature for similar sized glass beads. He also found that the ratio of transverse dispersivity to longitudinal dispersivity was usually 1/2 to 1/3 – instead of the ratio of 1/10 that is assumed.

The team's findings have implications for the prediction of reaction rates, solute transport, and plume remediation times. For example, suppose that a groundwater model is used to predict the timeframe for natural attenuation of a contaminant plume. Use of a higher dispersivity ratio in the model would lead to a prediction of more mixing and faster dilution of the plume. This in turn, might decrease the remediation time predicted for the site.

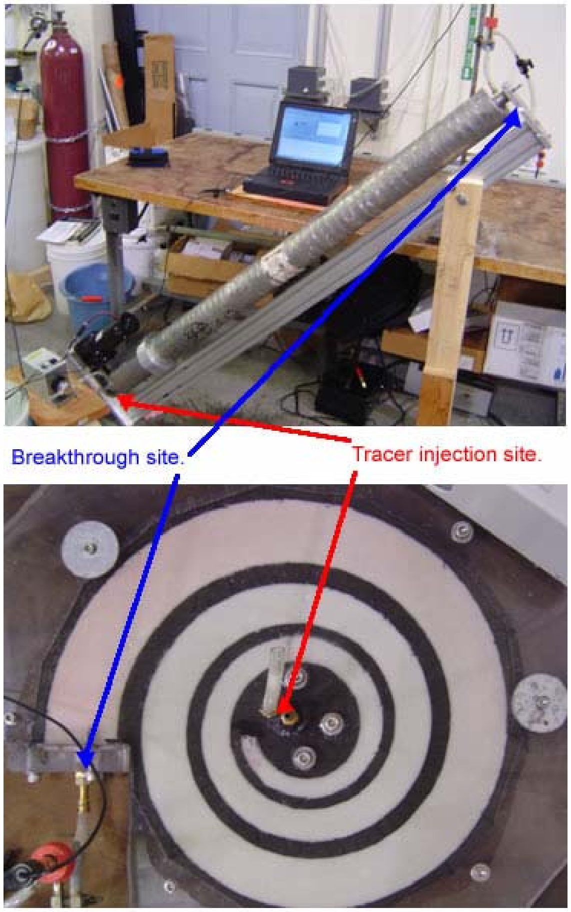

Figure 3. Photographs of the helix and cochlea devices.

The helix and cochlea methods are appealing for their simplicity. They allow accurate measurement of the illusive property of transverse dispersion with a procedure similar to a classic column experiment.

For More Information

Contact **Dr. Peter Kitanidis**, or refer to the following:

Benekos, Ioannis D. (2005) On the Determination of Transverse Dispersivity: Experiments and simulations in a helix and a cochlea. PhD dissertation, Department of Civil and Environmental Engineering, Stanford University, 122 pages.

Benekos, I., and P.K. Kitanidis (2004) Experimental Determination of Transverse Dispersivity in a Cochlear Device, Western Pacific Geophysics Meeting, August 15-21, Honolulu, HW.

Benekos, I., and P.K. Kitanidis (2004) An Optimization Approach Using Tracer Concentration Breakthrough Curves for Determining the Transverse Dispersivity in a Cochlear Device" EPA-HSRC Workshop on Risk Assessment and Monitoring Research, November 4-5, Las Vegas, NV.

Benekos, I., P.K. Kitanidis, M.A. Rahman, and O.A. Cirpka (2001) Experimental and Mathematical Studies of Pore-Scale Transverse Dispersion in a Helical Soil Column, AGU Fall Meeting, December 10-14, San Francisco, CA.

Cirpka, O.A. Kitanidis, P.K. (2001) Theoretical basis for the measurement of local transverse dispersion in isotropic porous media. Water Resources Research 37(2):243-252. **Link to pdf**.

Please send comments and questions to: **wrhsrc@engr.orst.edu**