WATER FACT SHEET

U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

FLOW IN THE UNSATURATED ZONE

TUCSON, ARIZONA

WHY STUDY THE UNSATURATED ZONE?

In 1981, ground water from a substantial number of municipal and private wells near the Tucson International Airport was found to be contaminated by the organic solvent trichloroethylene (TCE), other organic compounds, and chromium. At this location, a plume of contaminated ground water, in which TCE concentrations exceed drinking-water standards, is more than 4 mi long and more than 0.50 mi wide. At another location near the Phoenix-Goodyear Airport (formerly Phoenix-Lichfield Airport), concentrations in ground water of TCE as large as 86,000 micrograms per liter (μg/L), 1,1-dichloroethene (DCE) as large as 241 μg/L, and chromium as large as 1,300 μg/L have been reported. In both locations, contamination occurred despite a depth to ground water of about 100 ft. The presence of a thick unsaturated zone does not prevent the eventual migration of a contaminant to the regional ground-water system. Examples such as these have increased public awareness of the need to protect ground-water quality.

Protection of ground-water quality is complex and requires information about all components of the hydrologic system. Potential sources of ground-water contamination are commonly located at or near the land surface and are separated from the underlying ground-water reservoirs (aquifers) by the unsaturated zone. The U.S. Geological Survey is conducting field studies in Tucson, Arizona, to learn more about the way that solutes move through thick layers of poorly sorted alluvial sediments. The unsaturated zone in much of the Tucson basin and other alluvial basins of the desert Southwest is composed of these sediments. Potential ground-water contaminants may be attenuated or transmitted as recharge water passes through the unsaturated zone. Potential contaminants either may originate or accumulate in the unsaturated sediments and could be mobilized by activities that occur at the land surface, such as artificial recharge. To better understand the potential for ground-water contamination in an arid climate and the controls on downward movement of recharge water, knowledge of the flow characteristics of water in the unsaturated zone is essential.

HOW IS THE STUDY BEING CONDUCTED?

A pulse of water containing a tracer was monitored as it passed through the unsaturated zone by using six soil-moisture samplers (lysimeters) that were installed beneath a shallow, manmade, 3/4-acre recharge basin. The samplers are installed at depths ranging from 11 to 45 ft below the bottom of the basin and are about 10 ft apart. Potassium bromide was selected as a source of the bromide ion, Br^-, for use as a tracer. A constant water level was maintained in the basin throughout the tracer test. For 7 days, tracer-laced water was allowed to infiltrate into the ground. Water was collected from each sampler and from the basin near the samplers at 12-hour intervals for about 30 days. The concentration of tracer in each sample was determined and breakthrough curves were developed by plotting the concentration of tracer over time for each location. Analysis of the tracer breakthrough curves provides an indication of the effects of dispersion (mixing and spreading of the tracer) and a measure of the average rate of water movement at each location. Differences in the times of breakthrough, peak concentrations, and shapes of the curves indicate the variability of dispersion characteristics and rate of water movement in the unsaturated sediments underlying the basin.

HOW ARE WATER SAMPLES COLLECTED?

Pressure-vacuum soil-water lysimeters (fig. 1) were installed to collect water samples from the unsaturated alluvial deposits that underlie the basin. The intake section of the lysimeter used in the study consists of a round-bottom porous ceramic cup. The lysimeters were installed by drilling a hole to the desired depth with a hollow-stem auger, lowering the lysimeter to the bottom of the hole through the center of the auger, and then carefully removing the auger from the hole without disturbing the placement of the lysimeter or pinching the access tubes. In order to collect moisture samples from unsaturated sediments using a porous-cup lysimeter, a good hydraulic connection between the formation and the porous cup is necessary. Fine-grained silica flour was installed as a slurry in the annular space surrounding the ceramic cup to establish the hydraulic connection. Samples are obtained by creating a partial vacuum in the lysimeter with a hand-operated pump; then, after allowing enough time to elapse for a sufficient sample volume to collect in the sampler, the vacuum is replaced by a positive pressure to lift the sample to the surface.

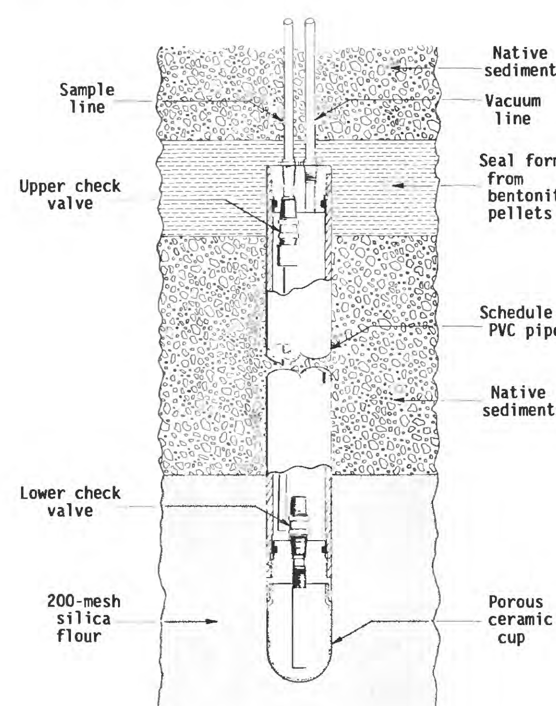

Figure 1.--Sketch showing pressure-vacuum lysimeter for collecting water samples from the unsaturated zone.

WHAT DO THE RESULTS INDICATE?

Well-defined tracer peaks were observed for all but one of the lysimeters installed at the site (fig. 2). Maximum tracer concentrations, however, showed no consistent relation with depth; tracer breakthrough sometimes occurred earlier in deep sampling locations than in shallow ones. Similar observations have been previously reported. Apparent dispersion, as indicated by the shape of the breakthrough curves and maximum tracer concentration, also show no consistent relation with depth. Rather than moving straight down, water movement occurs along preferential flow paths, probably at low soil tension, which occurs when the soil is near saturation. Preferential flow probably is due to the water following paths of higher hydraulic conductivity at the existing moisture conditions. It is commonly referred to as bypass or macropore flow and has been observed in laboratory column tests and in field investigations. Bypass flow has been observed in seemingly homogeneous materials and has been shown to occur under natural rainfall conditions and in fields subject to trickle irrigation and flood irrigation.

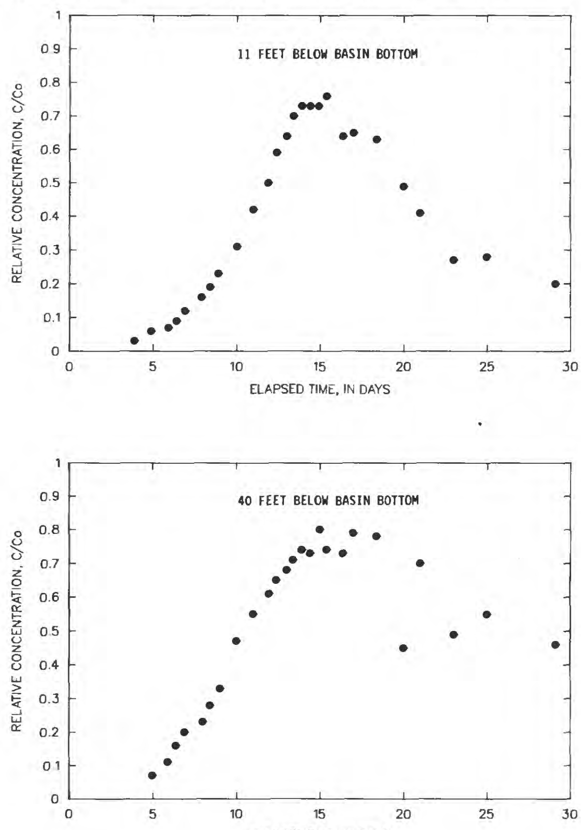

Figure 2.--Graphs showing tracer breakthrough curves. Relative concentration, C/Co, is a ratio calculated by dividing the tracer concentration in a sample by the tracer concentration in the water introduced into the test basin.

WHY IS THIS SIGNIFICANT?

Accelerated water movement caused by bypass flow has implications relevant to assessing the effect of recharge on ground-water quality especially when the recharging water contains solutes, which may include contaminants. Preferential flow allows solutes to move rapidly through the unsaturated zone. Under such conditions, contaminant arrival times can occur sooner than would be expected if flow was assumed to occur as a uniform wetting front that pushes ahead of it the water previously stored in the pores of the unsaturated sediments. Much of the water stored in the soil profile is not involved under conditions of bypass flow, and less interaction will occur between the recharge water and the solid matrix of the unsaturated zone. Therefore, certain substances such as chlorinated hydrocarbons (TCE, pesticides), other refractory organic compounds (detergents, humic acid), and microorganisms (bacteria) could pass into the underlying ground water. Results of this study have applicability throughout the southwestern United States as well as in other parts of the country where the practice of artificial recharge is being considered.

SELECTED REFERENCES

Bowman, R.S., and Rice, R.C., 1984, Chemical tracers--their use in measuring deep percolation rates, in Proceedings of the Deep Percolation Symposium, Scottsdale, Arizona: Arizona Department of Water Resources Report 5, p. 41-58.

______1986a, Accelerated herbicide leaching from preferential flow phenomena and its implication for groundwater contamination, in Proceedings of the Conference on Southwestern Ground Water Issues, October 20-22, 1986, Tempe, Ariz.: Dublin, Ohio, National Water Well Association, p. 313-425.

______1986b, Transport of conservative tracers in the field under intermittent flood irrigation: Water Resources Research, v. 50, p. 855-859.

DeSmedt, F., and Wierenga, P.J., 1984, Solute transfer through columns of glass beads: Water Resources Research, v. 20, p. 225-232.

DeSmedt, F., Wauters, F., and Sevilla, J., 1986, Study of tracer movement through unsaturated sand: Journal of Hydrology, v. 85, p. 169-181.

Ecology and Environment, Inc., 1986, Phase I data summary/report, Phoenix-Lichfield Airport area remedial investigation: San Francisco, Calif., Ecology and Environment, Inc., v. 1, 65 p.

Fried, J.J., 1975, Groundwater pollution: New York, Elsevier.

Gelhar, L.W., Mantoglou, A., Welty, C., and Rehfeldt, K.R., 1985, A review of field-scale physical solute transport processes in saturated and unsaturated porous media: Palo Alto, Calif., Electric Power Research Institute Report EA-4190, 103 p.

Kies, B., 1981, Solute transport in unsaturated field soil and in ground water: Las Cruces, New Mexico State University, doctoral dissertation.

Leake, S.A., and Hanson, R.T., 1987, Distribution and movement of trichloroethylene in ground water in the Tucson area, Arizona: U.S. Geological Survey Water-Resources Investigations Report 86-4313, 40 p.

Ongerth, H.J., Spath, J.C., and Greenberg, A.F., 1973, Public health aspects of organics in water: Journal of the American Water Works Association, v. 65, p. 495.

Robertson, J.M., Toussaint, C.R., and Jorque, M.A., 1974, Organic compounds entering ground water from a landfill: U.S. Environmental Protection Agency, EPA-660/2-74-077.

Starr, J.L., DeRoo, C.R., Frink, C.R., and Parlange, J.-Y, 1978, Leaching characteristics of a layered field soil: Journal of the Soil Science Society of America, v. 42, p. 386-391.

Sharma, M.L., and Hughes, M.W., 1985, Groundwater recharge estimation using chloride, deuterium, and oxygen-18 profiles in the deep coastal sands of western Australia: Journal of Hydrology, v. 81, p. 93-109.

U.S. Environmental Protection Agency, 1988, Cleanup of TCE contaminated groundwater, Tucson Airport Superfund site: U.S. Environmental Protection Agency Fact Sheet No. 4, February 1988, 8 p.

Van de Pol, R.M., Wierenga, P.J., and Nielson, D.R., 1977, Solute movement in a field soil: Journal of the Soil Science Society of America, v. 41, p. 10-13.

Walker, W.H., 1973, Where have all the toxic chemicals gone?: Ground Water, v. 7, no. 1, p. 9-16.

For further information, contact:

District Chief
U.S. Geological Survey
Water Resources Division
Federal Building, FB-44
300 West Congress Street
Tucson, Arizona 85701-1393