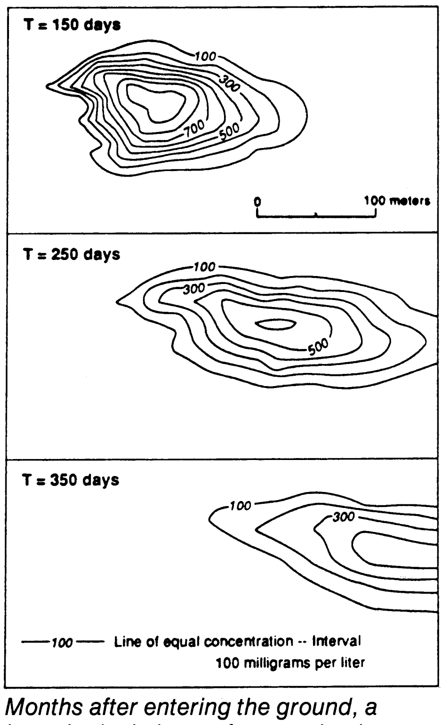
What's Going on Down There?

Pervasive groundwater contamination prompts new cleanup approaches

By CHARLES E. KNOX

Who says we don't recycle our hazardous wastes? Chemicals washed, spilled or leaked into underground reservoirs can come pouring back through faucets. According to an October report by the U.S. Geological Survey (USGS), wells in every state in the United States — where drinking water for more than half the population comes primarily from groundwater — contain potentially dangerous substances exceeding acceptable levels set by the Environmental Protection Agency (EPA).

More than 10 million Americans probably now use tap water with contaminant levels that exceed EPA standards, says Jay H. Lehr of the Association of Groundwater Scientists and Engineers, in Worthington, Ohio. Although Lehr calls the EPA standards conservative and claims all U.S. public water supplies are safe for drinking, many scientists believe more Americans will be directly affected by polluted groundwater in coming decades. Occasional events severely threatening local water quality and a growing awareness that groundwater pollution will not simply go away have led researchers to seek innovative ways to clean up the hidden contamination. "Even if we stop polluting by 2000, the residual problem will be around until at least 2030," Lehr says.



Months after entering the ground, a hypothetical plume of contamination continues to drift away from its source and diffuse in groundwater (flowing to right). A Stanford University computer program generates maps like these as one step in designing systems for pumping pollution out of groundwater.

Every day, runoff tainted with hundreds of hazardous chemicals from city streets, fertilized fields and mining operations enters soil and aquifers, Earth's subsurface reservoirs. But hydrocarbons — such as crude oil, gasoline and creosote — leaked from storage tanks or spilled from vehicles have polluted more of the U.S. groundwater drinking supply by volume than has any other class of chemicals. Cleanup efforts have failed to keep pace with this toxic accumulation, in part because many physical and chemical properties of groundwater and aquifers — major influences on the success of cleanup strategies — remain poorly understood.

However, prospects for cleansing the nation's groundwater of contaminants appear brighter thanks to new computer programs that predict how effectively cleanup techniques will work at specific sites, and to a newly proven method for eliminating pollutants in soil above the water table. These approaches still need refining, but they could reduce the expense and increase the effectiveness of cleanup work in coming decades.

Many future cleanup efforts probably will harness the appetites of bacteria that thrive on hydrocarbon pollutants. Microbiologists have known since the late 1970s that microbes break down hydrocarbons in soil and groundwater into carbon dioxide and methane gases. These gases then escape to the atmosphere, leaving cleaner water and soil behind. Scientists wondered whether the bacteria entered the ground with the pollution or resided there naturally until recent experiments showed the microbes can be native to aquifers (SN: 3/5/88, p.149).

More and more species capable of converting hydrocarbons to carbon dioxide in the presence of oxygen are being identified in ongoing laboratory and field studies at EPA's Robert S. Kerr Environmental Research Laboratory in Ada, Okla., Rice University in Houston and elsewhere. Other species that degrade hydrocarbons into methane under anaerobic conditions are being documented at facilities including the USGS Menlo Park, Calif., center and Stanford University.

Because of the very low natural concentrations of hydrocarbons below ground, "these bacteria are usually starving," says Calvin H. Ward of Rice. But when hydrocarbon pollutants flow into their realm, they flourish, feasting at will. Even so, explains John T. Wilson of the Kerr Laboratory, they can't consume enough hydrocarbons to restore water quality because they eat too slowly. Without human intervention, microorganisms typically degrade only about 1 percent of the hydrocarbon pollution flowing past, he says.

A lack of key chemicals in soil and groundwater slows bacterial digestion. To metabolize hydrocarbons more rapidly under anaerobic conditions, microbes need more nitrogen and phosphorus than naturally exist below ground. Aerobic microorganisms require more oxygen as well.

But if humans supply enough of these appetite-whetters, the microbes can eat "pounds of pollutants" quickly enough to restore the quality of water before it seeps beyond their reach, Ward says. To stimulate bacteria to gorge themselves, microbiologists have devised ways of pumping into soil and groundwater liquids containing oxygen and/or nutrients — sometimes increasing concentrations to more than 100 times their natural levels.

Working with EPA's Wilson, Rice environmental engineers Hanadi S. Rifai and Philip B. Bedient have developed a computer program to predict how fast stimulated aerobic microbes will consume hydrocarbons. They hope the estimates will help make many cleanup efforts more cost-efficient and thorough. Operating at more than 100 U.S. universities, regulatory agencies and consulting firms, the program works by calculating how quickly oxygen reacts with contaminants, and modeling where and how rapidly injected oxygenated water spreads underground.

In the October JOURNAL OF ENVIRONMENTAL ENGINEERING, the researchers report their program "reasonably" simulated the results of an actual two-year effort to speed removal of spilled aviation fuel at a Michigan site. The model predicted that with a specified amount of additional oxygen, microbes would consume about 1 percent of the remaining spill per day. Observations indicate the daily rate actually averaged about 1.25 percent. Wilson says pollutant levels at the site "are rapidly approaching concentrations not hazardous to human health." Rifai plans to expand the model so it also determines how strongly added nutrients supplement oxygen in speeding hydrocarbon consumption.

An important feature of the computer program is its ability to indicate how much added oxygen is too much, Wilson says. "There's a limit to how much the 'bugs' can use," so adding oxygen past that point wastes money. For future applications, EPA may switch to hydrogen peroxide. "It is much more soluble than oxygen, requiring orders of magnitude less time to flush a system," Wilson says.

Enhancing microbial munching just in small groundwater pockets may be enough to clean many polluted sites, says Stephen E. Ragone of the USGS Water Resources Division in Reston, Va. He cites new findings by Edward M. Godsy and his USGS co-workers in Menlo Park and by Dunja Grbić-Galić at Stanford that indicate microbes confined to areas as small as a cubic meter can clean contaminated regions up to 100 times larger by filtering groundwater flowing through the pockets they inhabit.

Microbes do not break down all groundwater contaminants. Efforts to remove these more-resistant pollutants involve wells that pump clean water into aquifers and others that pump out polluted groundwater, which is usually treated and returned to the ground. But cleanup crews can't flush out polluted groundwater until they find it, and locating contaminants proves very difficult.

Dozens of factors influence where groundwater flows, and these variables can change instantaneously and over tiny distances. To complicate matters, scientists usually possess little detailed information about the ground beneath a polluted site. To overcome this limitation, researchers seek ways to design effective pumping systems based mainly on groundwater samples, which are relatively easy to obtain.

Hydrologists at Stanford and USGS in Menlo Park have designed a computer program to establish the well locations and pumping rates that best clean specific sites. With more data to describe local groundwater flow, the model's solutions improve. But codeveloper Steven M. Gorelick of Stanford says its key innovation is providing good answers "when we really don't know much about the geology of the subsurface."

With data from a few groundwater samples, the model formulates thousands of possible maps for a single contamination plume. From these, the program randomly selects 30, an amount codeveloper Brian J. Wagner of USGS says virtually encompasses the area that all the possible plumes would cover. The model then produces a pumping plan that would reduce specified contaminants in each of the 30 possible plumes to acceptable levels within set budget and time limits.

Described by Wagner in a September Stanford doctoral thesis, tests of the model using hypothetical situations show its solutions decontaminate at least 92 percent of those plumes. He says in real situations hydrologists can test groundwater at locations unique to the few plumes a devised pumping system would fail to clean adequately. If those samples suggest such plumes might

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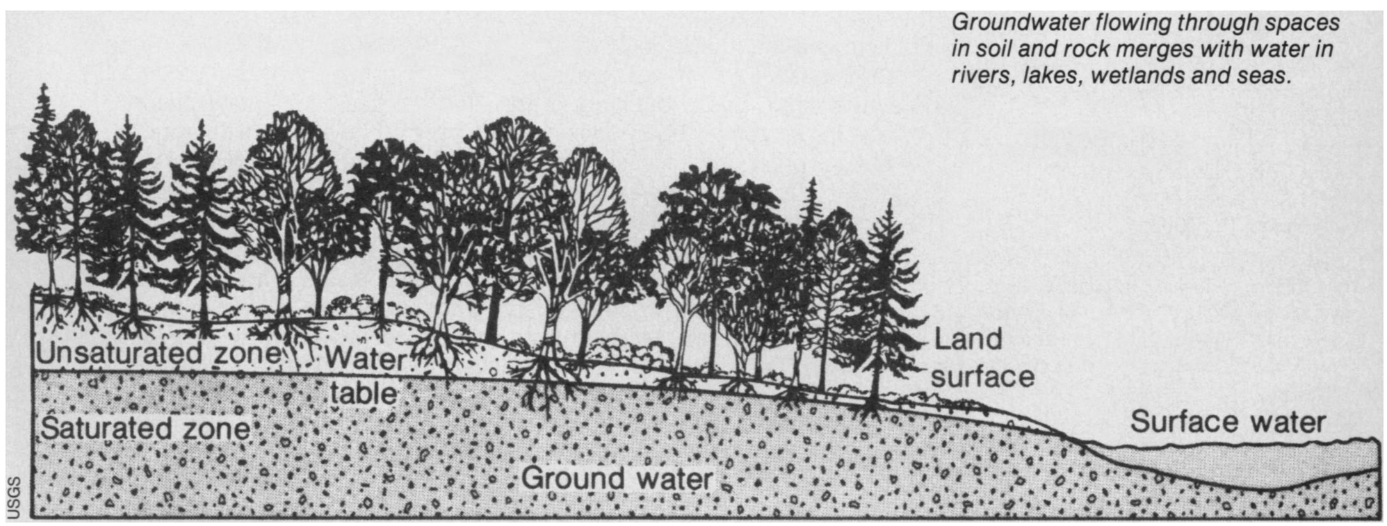

Groundwater flowing through spaces in soil and rock merges with water in rivers, lakes, wetlands and seas.

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really exist, another run of the model can come up with a new system that handles them. Wagner and Gorelick, who outlined the technique in the July 1987 WATER RESOURCES RESEARCH, say the program still needs improvement because it ignores vertical variations in aquifers.

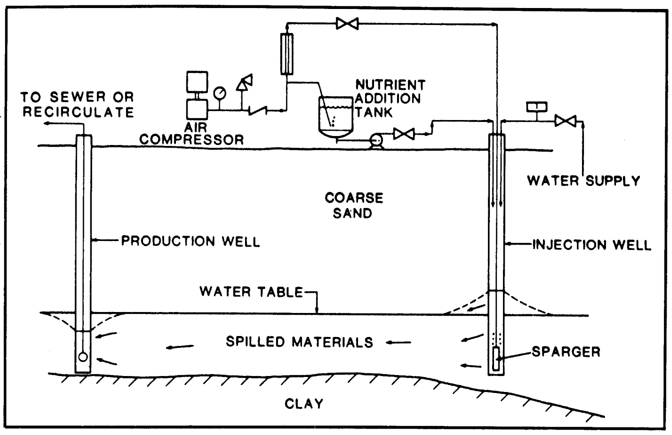
In some cases, pollutants adhere to soil above the water table despite flushing with clean water. In others, contaminants in that unsaturated zone comprise the entire problem. A process similar to water flushing, pumping air into ground above the water table can remove hydrocarbon pollutants trapped in the soil, according to new observations by researchers from USGS and the University of Connecticut in Storrs.

Hydrologists have speculated that injected air could force volatile hydrocarbon contaminants to vaporize and escape from the soil. Although private engineering firms have utilized this concept since 1980, "a lack of study of this method has left researchers uncertain of its universal applicability," says Arthur L. Baehr of the USGS Trenton, N.J., office.

Baehr and George E. Hoag of the University of Connecticut led a team that used the technique, known as induced air venting, to decontaminate soil around a leaky tank at a Connecticut gas station. Their results, scheduled for publication early next year in the JOURNAL OF CONTAMINANT HYDROLOGY, indicate the venting may have forced all the pollutants out of the ground.

"Whether or not the gas has been completely removed, the soil has been completely rehabilitated," Baehr says. "No one's worried about the site anymore." He says although expensive methods exist for collecting the vapors, "discharging them to the atmosphere is not nearly as bad a pollution problem as the exhaust from diesel trucks, and certainly is preferable to leaving contaminants in the soil."

Baehr says air venting and other evolving methods, along with better understanding of the physics and chemistry of groundwater, will help regulators decide which sites pose the greatest threats to human safety and the environment and thus deserve high cleanup priority. Ironically, he says, in some cases the best decisions may involve *less* action: "It may eventually become possible for scientists and engineers to walk away from some sites," confident that groundwater cleanup efforts should be concentrated elsewhere. □



American Petroleum Inst. (Publication 44-30)

When properly stimulated, bacteria in groundwater can consume large volumes of pollutants. Getting microbes to restore water quality requires feeding them oxygen and/or nutrients, and recirculating these substances increases the technique's effectiveness.

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group, they achieved much higher levels of literacy than has previously been reported for deaf students. The top third, identified as good readers, had achieved reading levels of 10th grade or above. The bottom third averaged a fourth grade reading level. The study was designed to examine characteristics differentiating good and poor readers. All had learned to speak before they learned to sign.

Moores' letter is highly critical of these findings, but his arguments have no data to support them.

He contends that we "seriously misrepresented" data obtained by him for adolescents enrolled in total communication programs. Our study does not report data from his, and so far as we know no data from his study have been reported or published.

No subjects were eliminated from our sample on the basis of reading level. If Moores eliminated the 21 best readers from his study, as he states in the letter, then he did not comply with the intention of the contract to test good and poor readers. If any readers were to be eliminated, they should have been those scoring in the middle, since the purpose was to identify differences between the best and the worst.

Students who depend on sign language are often segregated into state schools and other special programs for the hearing-impaired throughout their education, making it easy to assemble them for testing in a project such as this one. However, most orally educated students, because they can talk and can lipread, are enrolled in high schools with their normally hearing peers. Since most of the subjects in this study were enrolled in their neighborhood public schools, they were scattered throughout the country. NIH commended us for the innovative idea of bringing the subjects to St. Louis for testing. Rather than biasing the sample, as Moores suggests, having NIH funds available to sponsor the testing meant that no subjects were eliminated because their families could not afford to send them to St. Louis.

Moores maintains that we intended to test only subjects enrolled in private residential schools for the deaf. This is not true. Since private oral schools, such as Central Institute for the Deaf, provide education only through the elementary grades, only one adolescent in the study was currently enrolled in a private oral school for the deaf. We were delighted to be able to recruit 10 subjects for this study from those who had attended CID and had since gone back to their home communities. The statement by Moores that "one-third to one-half" of CID graduates had transferred to total communication programs is false.

We can understand that the results of our study are distressing to those who have spent most of their professional careers believing that the oral method of teaching deaf children is invalid. We do not contend that this method is best for all deaf children. However, the data collected from this large, diverse sample of orally educated deaf adolescents indicate this method is very effective for many profoundly deaf children and deserves serious reconsideration.

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