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Project Summary

An Introduction to Ground-Water Tracers

Stanley N. Davis, Darcy J. Campbell, Harold W. Bentley, and Timothy J. Flynn

An ideal tracer does not exist. Therefore, the selection and use of tracers is almost as much an art as it is a science. The full report (manual) provides a guide for the use of ground-water tracers to practicing engineers, hydrologists, and ground-water hydrologists. The manual is specifically concerned with the selection of tracers, their field application, collection of samples containing tracers, sample analysis, and interpretation of the results.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This research project was designed to develop a manual that could be used as a guide for the use of tracers in ground water. Specifically, the manual is concerned with the selection of tracers, their field application, collection of samples containing tracers, sample analysis, and interpretation of the results.

Certain hydrogeologic principles must be understood in order to design successful tracer tests, i.e., Darcy's Law, hydraulic conductivity, the direction of water movement, and the velocity of ground-water flow. Hydrodynamic dispersion and molecular diffusion also play an important role in the area of ground-water tracers.

Results

The purpose and practical constraints of a potential tracer test must be clearly understood prior to the actual planning of a test. Table 1 indicates some factors to consider in tracer selection. Choice of a tracer will depend partially on which analytical techniques are easily available and which background constituents might interfere with these analyses. Various analytical techniques incorporate different interferences, and consultation with the chemist who will analyze the samples is necessary.

The variety of tracer tests is almost infinite when one considers the various combinations of tracer types, local hydrologic conditions, injection methods, sampling methods, and the geological setting of the site. There are five common problems encountered with tracer tests: site selection for monitoring and injection wells, choice of drilling equipment, choice of casing diameter for monitoring wells, type of casing particularly if tracers are organic compounds or metallic cations, and choice of well construction (screens, perforation, slots, etc.).

The measured quantity which is fundamental for most tracer tests is the first arrival time of the tracer as it goes from an injection point to a sampling point. This conveys at least two items of information. First, it indicates that a connection for ground-water flow actually exists between two points. For many tracer tests, particularly in karst regions, this is all the information that is desired. Second, an approximation of the maximum velocity of ground-water flow between the two points may be obtained if the tracer used is conservative. Interpretations more elaborate than this depend very much on the type of aquifer being tested, the velocity of ground-water flow, the configuration of the tracer injection and sampling systems, and the type of tracer or mixture of tracers used in the test.

Table 1. Factors to Consider in Tracer Selection

Purpose of Study	*Tracer Type to be Used*
Determination of: flow path	
velocity (solute)	*Nonconservative*
velocity (water)	*Conservative*
porosity	*Conservative*
dispersion coefficient	*Conservative*
distribution coefficient	*Nonconservative*
Delineation of contaminant plume	*Constituent of plume*
Recharge	*Environmental isotope or anthropogenic compound*
Dating	*Radioactive isotopes*

Available Funds
Manpower and equipment to run tests to completion (e.g., drilling, tracer cost, sampling, analysis).

Type of Medium	*Tracer Type*
Karst	*Fluorescent dyes, spores, tritium, as well as other tracers*
Porous media (alluvium, sandstone, soil)	*Wide range of choices Dyes and particulate material are rarely useful*
Fractured rock	*Wide range of choices Dyes and particulate material only occasionally are useful*

Stability of Tracer	
Distance from injection to sampling point	*Must be stable for length of test and analysis*
Approximate velocity of water and approximate estimate of time required for test, given: distance from injection to sampling point, porosity, thickness of aquifer	

Detectability of Tracer
Background level
Dilution expected in test (function of distance, dispersion, porosity, and hydraulic conductivity)
Detection limit of tracer (ppm, ppb, ppt)
Interference due to other tracers, water chemistry

Difficulty of Sampling and Analysis

Factors to Consider	*Example of Difficult Tracer*
Availability of tracer	*Radioactive (must have special permits)*
Ease of sampling	*Gases (will escape easily from poorly sealed container)*
Availability of technology for and ease of analysis	*Cl-36 (only one or two laboratories in the world can do analyses)*

Conclusions and Recommendations

As used in hydrogeology, a tracer is matter or energy carried by ground water which will give information concerning the direction of movement and/or velocity of the water and potential contaminants which might be transported by the water.

A tracer should have a number of properties in order to be generally useful. The most important criterion is that the potential chemical and physical behavior of the tracer in ground water must be understood. The objective is commonly to use a tracer that travels with the same velocity and direction as the water and does not interact with solid material. A tracer should be nontoxic, relatively inexpensive to use, and for most practical problems, easily detected with widely available and simple technology.

Table 2 provides a summary of some of the most important tracers presently available.

Table 1. *(Continued)*

Physical/Chemical/Biological Properties of Tracer	
Density, viscosity	*May affect flow (e.g., high concentrations of Cl^-)*
Solubility in water	Affects mobility
Sorptive properties	Affects mobility
Stability in water	Affects mobility

Physical	*Chemical*	*Biological*
radioactive decay	*decomposition and precipitation*	*degradation*

Public Health Considerations
Toxicity
Dilution expected
Maximum permissible level—determined by federal, state, provincial, and county agencies
Proximity to drinking water

Table 2. *Summary of Most Important Tracers*

Tracer	*Characteristics*
A. Particulates	
Spores	*Used in karst tracing; inexpensive* *Detection: high, multiple tests possible by dying spores different colors* *Low background* *Moderately difficult sampling and analysis (trapping on plankton, then microscopic identification and counting)* *No chemical sorption* *May float on water, travels faster than mean flow rate*
Bacteria	*Most useful for studying transport of microorganisms* *Detection: highly sensitive* *Sampling: filtration, then incubation and colony counting* *No diffusion, slight sorption*
Viruses	*Detection: highly sensitive* *Sampling: culturing, colony counting* *Some sorption* *Smallest particulate*
B. Ions *(Non-radioactive, excludes dyes)*	
Chloride	*Conservative* *Inexpensive* *Stable* *Detection: 1 ppm by titration, electrical conductivity, or selective ion electrode* *High background may be problematic* *In large quantities, affects density which distorts flow* *No sorption*
Bromide	*Inexpensive* *Stable* *Detection: 0.5 ppm by selective ion electrode* *Low background* *No sorption*

Table 2. *(Continued)*

Tracer	Characteristics
C. Dyes	
Rhodamine WT	*Used in karst and highly permeable sands and gravels* *Inexpensive* *Moderate stability* *Detection: 0.1 ppb by fluorimetry* *Low background fluorescence* *Moderate sorption*
Fluorescein	*Properties similar to Rhodamine WT, except:* *Degraded by sun* *"Chlorella" bacteria interferes* *High sorption*
D. Radioactive Tracers	
Tritium	*High stability* *Detection: > 1 ppt by weak β radiation* *Varying background* *Complex analysis (expensive field and lab equipment)* *Half-life = 12.3 years* *Radiation hazard* *Handling and administrative problems* *No sorption*
^{131}I	*High stability* *Detection: high sensitivity by measuring β and α emission* *Background negligible* *Complex analysis* *Half-life = 8.2 days* *Radiation hazard* *Sorption on organic material*
$EDTA\text{-}^{51}Cr$	*Moderately stable (affected by cations)* *Detection: highly sensitive, by radiation or post-sampling neutron activation analysis* *No background* *Half-life = 28 days* *Radiation hazard* *Little sorption*
^{82}Br	*High stability* *Detection: high sensitivity by measuring β emission* *No background* *Half-life = 35 hours* *Radiation hazard* *No sorption*
E. Other Tracers	
Fluorocarbons	*Expensive* *High stability* *Detection: 1 ppt by gas chromatography with electron capture detection* *Low background* *Difficult to maintain integrity of samples* *Non-degradable, volatile, low solubility, strong sorption by organic materials* *Low toxicity*
Organic anions	*Detection: few ppb by HPLC* *Low background* *Expensive analysis* *Very low sorption* *Low toxicity*

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Stanley N. Davis, Darcy J. Campbell, Harold W. Bentley, and Timothy J. Flynn are with the University of Arizona, Tucson, AZ 85721.
***Jerry T. Thornhill** is the EPA Project Officer (see below).*
The complete report, entitled "An Introduction to Ground-Water Tracers," (Order No. PB 86-100 591/AS; Cost: $22.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

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