Regulation of Injected Ground Water Tracers

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Abstract

Ground water tracer tests are routinely performed to estimate aquifer flow and transport properties, including the determination of well capture zones, hydrogeologic parameters, and contaminant travel times. Investigators may be unaware of tracer test reporting requirements and may fail to notify their regulatory agency prior to conducting tracer tests. The injection of tracers falls under the jurisdiction of the federal Underground Injection Control (UIC) program, which regulates the introduction of substances into underground sources of drinking water as part of the Safe Drinking Water Act. The UIC program is administered by the U.S. Environmental Protection Agency (EPA) and by states with EPA-approved programs. The federal UIC program requires that tracer tests must not endanger underground sources of drinking water, and all tracer tests must be reported prior to injection. We contacted the UIC program administrator for every state in early 1997. Some states report having more stringent requirements, while some states do not meet minimum federal requirements. Although the primary responsibility for ground water tracer selection and use rests on the investigator, national guidance is required to assure compliance with the UIC program. To assist investigators, we present acceptable tracers that have been identified by two states, Nevada and South Carolina, that require no further regulatory review.

Introduction

The use of tracers has substantially increased our understanding of ground water flow and transport mechanisms (Gelhar et al. 1992). The need to license nuclear waste disposal sites has motivated new uses of ground water tracers that are used to evaluate the regulatory suitability of proposed sites. Tracers now routinely determine ground water travel times, delineate capture zones, and estimate aquifer flow and transport properties (Reimus and Turin 1997; Birgersson et al. 1993). While some ground water tracer studies employ natural or anthropogenic substances already present, other studies use injected substances because control of the amount and time of the injected substance aids in the interpretation of flow and transport behavior.

The injection of foreign substances into subsurface water supplies can and does raise environmental and public health concerns. Tritiated water is an example of a scientifically useful but controversial tracer. Although tritiated water is a radioactive form of water that ideally mimics water movement, it is unacceptable from a regulatory perspective because of real and perceived risks to drinking water. Injected tracers are primarily regulated at the federal level by the Underground Injection Control (UIC) program, which is part of the Safe Drinking Water Act, administered by U.S. Environmental Protection Agency (EPA) regions. Additional regulations may apply, however, depending on the state where the tracer study is conducted.

This paper focuses on the regulation and use of injected tracers. We do not consider the regulatory control of naturally occurring tracers because their presence or absence in the subsurface is not directly influenced by ground water testing. We first examine the federal regulatory environment, primarily the UIC program, and then expand our analysis to state programs governing the injection of ground water tracers, the current use of those regulations at the state and federal level, and the need for more uniform regulations and enforcement. To better identify the current status of regulatory efforts, we contacted all EPA regions and states with primacy or parallel programs related to the regulation of ground water tracer tests. While we cannot assure that the states' current programs are as reported here due to recent changes in regulations, we use these findings to recommend improvements to federal oversight of the selection and use of ground water tracers.

Reasons for Tracer Use

In a now classic document that summarizes ground water tracers, Davis et al. (1986) define a ground water tracer as "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 . . . Tracers can also help with the determination of hydraulic conductivity, porosity, dispersivity, chemical distribution coefficients, and other hydrogeologic parameters." Tracers are useful tools for defining aquifer parameters necessary for ground water characterization and remediation such as recharge rates, well capture zone analyses, preferred flowpaths, volume and quality of water, and susceptibility to contamination. Effective remediation of contaminated sites also depends on accurate information about the trajectory of the plume and types of reactions affecting pollutants. The efficacy of tracer test methodology is due, in part, to the large aquifer volume that can be sampled with tracer tests as compared to methods such as core sampling, cone penetrometer sampling, and geophysical logging (Jin et al. 1995).

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Received October 1998, accepted December 1999.

Tracers can be divided into two general categories: environmental tracers that exist in the subsurface due to natural or anthropogenic causes, and tracers that are deliberately introduced or injected into a ground water system for the purpose of aquifer characterization. Environmental tracers are, by definition, already in the subsurface prior to site characterization. Relying on environmental tracers when conducting ground water investigations therefore allows one to bypass regulatory concerns about adding constituents into a ground water system. Examples of environmental tracers include the use of tritium for dating ground water and estimating rates of dispersion (Robertson and Cherry 1989); the use of temperature anomalies more than 8 km from the source indicating the spread of waste water from the Hanford Reservation (Davis et al. 1986); the use of chlorofluorocarbons to show whether sewage effluent was a major source of contamination in surface water (Busenberg and Plummer 1992); the use of naturally occurring ^{226}Ra concentrations to demonstrate the extent of ground water recharge to coastal waters of the South Atlantic Bight (Moore 1996); and the determination of flow pathways in shallow saprolite and fractured rock flow systems at the Oak Ridge National Laboratory in Tennessee using dissolved gasses (Cook et al. 1996).

From a regulatory perspective, injected tracers are of concern because they have the potential to compromise the integrity of current or future underground sources of drinking water. Examples of injected tracers include using dyes and rare earth metals to study flow in deep-lying fractured rock, the same type of rock that will house proposed high-level radioactive waste sites in many countries (Birgersson et al. 1993); using rhodamine WT dye to determine the quantity of purge water needed after rotary drilling to ensure that water samples are representative of ground water conditions (Schilling and Hoyle 1996); injecting chloride, bromide, and a selection of organic solutes varying in mobility and biodegradability into the Borden aquifer in Ontario to describe transport, transformation, and fate of contaminants (Mackay et al. 1986); predicting ground water solute transport in a heterogeneous aquifer using multiple tracers including bromide, pentafluorobenzoic acid, *o*-trifluoromethylbenzoic acid, and 2,6-difluorobenzoic acid to increase the accuracy of solute transport models (Boggs et al. 1992); as well as studies of preferential flow using colloid-size bacteriophage (viruses) in weathered and fractured clay till (McKay et al. 1993).

Federal Regulatory Requirements

The UIC program (40 CFR 144-147) was promulgated under the authority of Part C of the Safe Drinking Water Act (Pub. L. 93-523, as amended; 42 U.S.C. 300f et seq.) and to the extent that hazardous waste is involved, the Resource Conservation and Recovery Act (RCRA) (Pub. L. 94-580 as amended; 42 U.S.C. 6901 et seq.). The purpose of the UIC program is to "assure that underground injection will not endanger drinking water sources" (40 CFR 144.1). The UIC program, which regulates "any underground injection," governs use of ground water tracer test technologies. Exceptions include wells operated for RCRA or Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) approved cleanups, which are given latitude under the UIC program to inject contaminated water as part of the cleanup process (see 40 CFR 144.13(c)).

Under the UIC program, underground injections are highly regulated. "Any underground injection, except into a well authorized by rule or except as authorized by permit issued under the UIC program, is prohibited" (40 CFR 144.11). While there are no regulations which explicitly refer to tracers, the UIC program does cover tracer injections into a Class V well, which is any injection well "not included in Classes I, II, III, or IV" (40 CFR 144.6). Class V is a catch-all class and covers the type of well that is most likely used for tracer injection in the study of ground water. Table 1 describes well classes as defined under the federal UIC program. The Class V category has recently been revised to include 23 categories, including an experimental technologies category which includes wells used for tracer tests (EPA 1999).

Table 1
Classification of Underground Injection Control Wells (40 CFR 144.6)

Class	Description
I	Wells used by generators of hazardous waste or owners or operators of hazardous waste management facilities to inject hazardous waste, and industrial and municipal disposal wells that inject fluids, beneath the lowermost formation containing an underground source of drinking water within 400 m (¼ mile) of the well.
II	Wells injecting fluids: 1. Brought to the surface in connection with natural gas storage or conventional oil or natural gas production 2. For enhanced recovery of oil or natural gas 3. For storage of hydrocarbons which are liquid at standard temperature and pressure.
III	Wells injecting for the extraction of minerals.
IV	Wells used by: 1. Generators of hazardous waste or of radioactive waste, by owners or operators of hazardous waste management or radioactive waste disposal sites to dispose of hazardous or radioactive waste into, or above, a formation containing an underground source of drinking water within 400 m (¼ mile) of the well 2. Generators of hazardous waste or owners or operators of hazardous waste management facilities to dispose of hazardous waste which are not otherwise classified as Class I or IV wells.
V	Wells not included in Classes I, II, III, or IV. Includes, but is not limited to, wells used in experimental technologies, sand or other backfill wells, radioactive waste disposal wells, geothermal energy recovery wells, brine return flow wells.

The overall requirement of the UIC program is that any well injection or activity must not "allow the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR 142 or may otherwise adversely affect the health of persons" (40 CFR 144.12). In addition, UIC regulations require that owners and operators be notified about the need to submit well inventory information using a method of notification that assures awareness of the requirement.

The condition that constitutes violation of primary drinking water standards is not uniform among states. EPA uses the term "endangered," which is left for the states to interpret. Some states, such as Wisconsin and Nebraska, require that tracer use does not violate primary drinking water standards at all points within an aquifer, including the point of injection. Other states, such as Utah, impose point-of-use constraints that allow attenuation or dilution of the tracer within the aquifer so that drinking water standards are met at all downgradient drinking water facilities.

UIC Class V wells in a federal program (or an equivalent state program) may be regulated by permits or authorized by rule if certain requirements are met. Class V well injections are autho-

Table 2
Minimum Inventory Requirements for Class V Injection Wells Used in Experimental Technologies (40 CFR 144.26)

Required[1] of all UIC wells on national form "Inventory of Injection Wells" (OMB 158-R0170)

- Facility name and location
- Name and address of legal contact
- Facility ownership
- Nature and type of each well
- Operating status of each well

Required of UIC wells in areas administered by EPA

- Location of each well or project
- Date of completion of each well
- *Identification and depth of the formation(s) of injection*
- Depth of each well
- Well completion for each well, including casing and cementing record, tubing size, and packer depth
- Nature of the injected fluids (*Chemical name, CAS #, injected concentration, injection volume, exposure limits, incompatibilities and reactivities, degradation products*)[2]
- Wellhead injection pressure, average and maximum, of each well
- Injection rate, average and maximum, of each well
- Date of last mechanical integrity test of each well

[1] Minimum information required. Requirements for states with primacy vary; the state agency is authorized to request more detailed information. Contact the appropriate state program for details.

[2] Federal regulations require only the nature of injected fluids. EPA regions can and do require more information than listed here. Our suggestions for specific requirements are in italics.

rized by rule if they meet the following requirements: (1) underground sources of drinking water are not endangered; and (2) well inventory data for the injection well are submitted prior to injection. If underground sources of drinking water are deemed to be endangered, investigators must apply for a permit, which will be given or denied based on the requirements of the UIC program. Minimum inventory requirements for Class V wells used in experimental technologies, outlined in 40 CFR 144.26, are listed in Table 2.

For EPA administered programs, the regional administrator may require an owner or operator to submit more information if there is reason to believe that injection(s) "may be endangering an underground source of drinking water in violation of 144.12 of this part" (40 CFR 144.27). States and EPA regions may require more detailed inventory information than the requirements listed in 40 CFR 144.26. Currently, some EPA regions and states request more information if an aspect of the proposed test raises concerns, while others require more information from the outset.

While state programs must meet all standards of the federal statute, they are not precluded from developing requirements that "are more stringent or more extensive," and "operating a program with a greater scope of coverage" (40 CFR 145.1). Each state that develops its own UIC program that meets or exceeds the requirements of the federal statute can "obtain primary enforcement authority for the UIC program in that state" (40 CFR 144.1). EPA headquarters is responsible for granting primacy to each state. A state must request primacy status and provide information showing that their program meets or exceeds the federal program requirements. Regional EPA offices govern states that lack their own programs.

Until recently, there has been no judicial interpretation or EPA guidance for states that implement the UIC program. Consequently, interpretation of the UIC code varies by region and state. Once a state has been granted primacy, the regional EPA office is responsible for oversight. While the regional EPA offices are responsible for determining if states continue to meet the requirements of primacy, the extent of enforcement varies among regions. In some instances, states choose not to regulate ground water tracer tests, despite federal regulations of state UIC program requirements outlined in 40 CFR 145 requiring states to enact regulations that are as strict as federal regulations.

Current Application of the UIC Program

All UIC program administrators in the United States were contacted in early 1997. UIC program administrators from all EPA regions and administrators from states with primacy and parallel programs were interviewed. The required procedure for tracer test authorization in their jurisdiction was requested. Specifically, regulators were asked about the process required for obtaining approval for ground water tracer tests. Each state received a written copy of their comments for review and comment. Most states responded with either corrections or verification.

States without primacy, but with parallel programs (i.e., programs that require investigators to meet state criteria for tracer injection and/or ground water standards), were also surveyed. Investigators must meet state and federal requirements if the state does not have primacy. Some regulators, however, indicated that their states have an understanding with their EPA regional office giving the state unofficial jurisdiction over the approval of ground water tracer tests and other Class V UIC concerns. States are categorized according to the formality of the tracer approval process and the similarity between state UIC implementation and federal requirements. States are categorized as follows: (a) no process, (b) informal process, (c) equivalent to federal UIC regulations, d) more stringent than federal regulations, and e) no state primacy. These categories are indicated in Figure 1. Because the survey was conducted in early 1997, and because continual changes in program administration result in differences between actual and reported results, we urge individuals who intend to conduct tracer tests to contact their local UIC program administrator for current information prior to test design and implementation.

Classifications indicate the type of process administrators discussed. In some cases, the administrator's response was different from the process outlined in state regulations. The language of state regulations may be identical to the language used in the federal UIC code, but regulations may not be followed in practice (i.e., state code may require, as the federal code does, that inventory information be submitted prior to injection, but the UIC department may allow investigators to phone in information, or may not require tracer injection notification).

Twenty-four states meet or exceed requirements of the federal statute, of which four states operate UIC programs parallel to the EPA regional UIC program. State regulations and permitting processes are followed when parallel programs have been established. Implementation of regulations vary because of a lack of both judicial interpretations and EPA guidance. Thirteen states do not have primacy, and are subject to EPA regional UIC program implementation. The remaining 13 states have primacy, but their programs do not meet federal UIC requirements.

No Process

Some states lack a process for tracer test approval because: (1) tracers are not being used in their state; (2) the state is not interested in monitoring tracer injections; (3) the state has few Class V

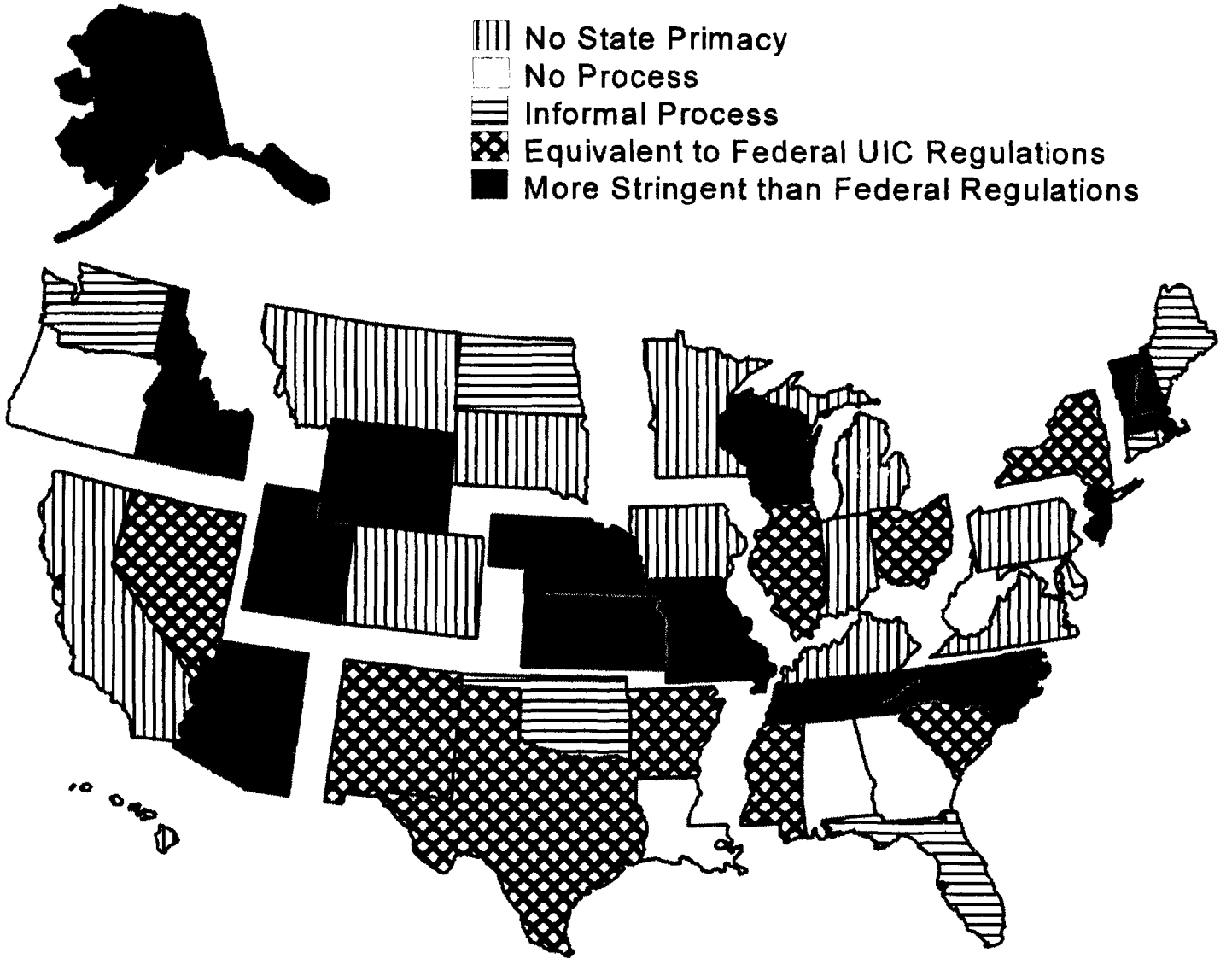

Figure 1. Comparison of Underground Injection Control (UIC) Program Implementation Strategies. States are grouped by EPA region.

wells; or (4) individuals conducting the test are not aware of their reporting responsibility. Rhode Island, Delaware, and Maryland have no known tracer use. Rhode Island has no permitting system, no process for the approval of tracer tests, and has never been contacted about tracer use. Delaware currently has no established process for approving tracer use, with no known tracer use; the UIC program has not been asked to approve a tracer test. Maryland has no written policy for approving tracer use. West Virginia, Alabama, Georgia, and Oregon indicated that they do not monitor ground water tracer injections. Tracers are being used in West Virginia (optical brighteners, fluorescein, and rhodamine are the most common), but there is no permitting process for the use of tracers. Responsibility for the proper use of the tracer rests with the individual conducting the test. Alabama requires a permit to discharge pollutants into ground water, but tracers are not considered pollutants and have never been permitted. Georgia has regulations consistent with the federal UIC code, but Georgia does not require a permit for tracer tests because the amounts injected are small and the time frame of injection is short. In Oregon, tracer injections are subject to state ground water rules, but no process is in place to approve tracer use. Most materials known to be used as tracers in Oregon are considered innocuous. Louisiana has no process for approving tracer tests because the state has few Class V wells. The state is not aware of any tracer testing.

Informal Process

States are classified as having an informal process if (1) investigators can call regulators for approval rather than submit a request in writing, and (2) investigators are asked to submit a request in writing but do not have a formalized process for tracer approval. Connecticut, Maine, North Dakota, and Washington allow investigators to call regulators for approval. In Connecticut, the law requires a permit for ground water discharges. The state requires a permit depending on the type of tracer and possible impacts to receptors (water supply wells, surface water bodies). If tracers are nonhazardous and nontoxic, usage may be authorized by phone. Maine regulations require a discharge license for injections that compromise the designated use of the water. The state agency is not aware

of any ground water tracer testing being performed in Maine. Tracer test information does not need to be submitted in writing, but investigators should contact the department to see if the state may have concerns about the specific tracer. North Dakota has no formal process. Investigators should contact the state if planning a tracer test. If the tracer is stable, inorganic, and nontoxic it may not need to be regulated. Decisions are made on a case by case basis. In Washington tracer use is governed by state ground water quality standards. Some tracers are no longer used and some are being phased out. Florida and Oklahoma ask for submission in writing for tracer test approval, but there is no formal approval process. Florida does not believe that the UIC applies to tracer use. The state UIC department does say, however, that investigators must approach the state for permission to conduct tracer tests. Proposals are reviewed on a case by case basis. In practice however, ^{131}Iodine, SF_6, bacteriophages, phosphate, and nitrate have recently been used as tracers in the Florida Keys, without permitting or state review. Oklahoma asks that investigators submit a proposal in writing. Currently, however, no process is in place for approving tracer tests.

Table 3
Ground Water Tracers Approved by the Nevada Division of Environmental Protection for Use at Yucca Mountain (January 1997)

Original Listing	Additional (1996 Modification)
Pyridone	Sodium tungstate dihydrate
Sodium chloride	Sodium molybdate dihydrate
Lithium bromide	Sodium fluoride
Fluorescent microspheres	Fluorescein, sodium derivative
Polystyrene microspheres	Potassium fluoride
Sulfur hexafluoride (SF_6)—gaseous tracer	Magnesium fluoride
Nitrogen	Magnesium iodide
"Suva" Cold-MP (tetra-fluorethane) (gas)	Helium
2,3-difluorobenzoic acid	Neon
2,4-difluorobenzoic acid	Krypton
2,5-difluorobenzoic acid	Xenon
2,6-difluorobenzoic acid	Argon
3,4-difluorobenzoic acid	Sodium iodide
3,5-difluorobenzoic acid	Sodium bromide
2,4,6-trifluorobenzoic acid	Potassium iodide
2,4,5-trifluorobenzoic acid	Potassium bromide
2,3,4-trifluorobenzoic acid	
2,3,6-trifluorobenzoic acid	
3,4,5-trifluorobenzoic acid	
2,3,4,6-tetrafluorobenzoic acid	
2,3,4,6-tetrafluorobenzoic acid	
Pentafluorobenzoic acid	

Equivalent to Federal

States implementing their UIC programs according to federal standards are classified as equivalent to federal UIC regulations. States with equivalent programs allow authorization by rule and require inventory information to be submitted before injection. States with federal nuclear facilities use tracer tests in association with ground water protection and waste remediation, resulting in the need for a formal, well-established process for authorizing tracer tests. Both New Mexico and Nevada are responsible for regulating federal nuclear facilities. In New Mexico, notice of intent must be submitted before conducting a tracer test, including an outline of chemical information about the tracer and the specific site conditions. Tracer tests at the proposed high-level nuclear waste facility at Yucca Mountain are covered by a project permit that lists approved tracers, shown in Table 3. Other tracer tests in Nevada are regulated by the federal requirements. New York, Illinois, Ohio, Arkansas, Texas, and Arizona UIC programs are equivalent to federal UIC regulations. New York does not have UIC primacy but it does have a parallel program with a Clean Water Act element. New York requires investigators to put proposals in writing and ensure that state water quality and effluent standards are not exceeded. Investigators using tracers in compliance with Ambient Water Quality Standards (New York State CRR Title 6, Chapter X Parts 700-705) bypass a lengthy permitting process. Illinois UIC requirements are the same as federal requirements. Illinois requires well inventory information be submitted before a tracer study. Tracer material must not result in a violation of the primary drinking water standards. Ohio requirements are also the same as the federal requirements. Tracer studies are permissible if the injected tracer does not violate drinking water standards or otherwise affect human health. Arkansas requires a letter of authorization before conducting tracer tests. Dyes are the most commonly used tracers. The Arkansas program administrator emphasized the importance of alerting regulators about tracer testing so that the public can be informed and questions can be answered quickly. Texas state authorization is required before injecting into ground water. Texas requires tracer test proposals to be submitted; whether or not a permit is required is at the state agency's discretion. Arizona does not have primacy, but operates a parallel program under the Arizona Aquifer Protection Program. Most tracer use in Arizona is at remediation sites that fall under the CERCLA and RCRA exempted programs. Tracer studies that are not governed by CERCLA/RCRA programs must meet the specifications of the Arizona Aquifer Protection Program, which include "a demonstration that the facility will not cause or contribute to a violation of Aquifer Water Quality Standards at the applicable point of compliance." In addition, investigators must demonstrate that they are technically capable of conducting the tracer test in full compliance with the permit conditions. However, short-term projects may not require permit approval. Mississippi has legislation pending that will enforce tracer study authorization identical to the federal UIC program requirements.

More Stringent Than Federal

States that enforce regulations more stringently than the federal UIC program requirements are categorized as being more stringent than federal regulations. States in the more stringent category can be classified as (1) having more stringent ground water standards or (2) having an approval process that requires every proposal for tracer injection to be submitted for a formal approval process, i.e., there is no authorization by rule. New Hampshire, Vermont, New Jersey, North Carolina, South Carolina, Wisconsin, Kansas, Missouri, Nebraska, Utah, Wyoming, Alaska, and Idaho have state ground water standards that are more stringent than the federal standards. New Hampshire regulates tracers according to the purpose for which they are used. Tracer tests related to remediation do not require permits, other tracer tests must be registered as nondomestic waste discharge. Tracers are considered on a case by case basis; regulated contaminants, e.g., benzene and tritium are not allowed. The Vermont UIC program does not allow authorization by rule. Tracer tests fall under the Vermont UIC jurisdiction unless they are used in remediation, which is regulated by the Hazardous Materials Program. Tracers not used for remediation require a per-

mit from the Vermont UIC program. The New Jersey Department of Environmental Protection operates a UIC program under the New Jersey Pollution Discharge Elimination System regulations. All tracer studies must be approved prior to implementation. Approvals for tracer tests are usually granted either in the form of a permit by rule letter or a permit. North Carolina enforces strict ground water regulations. In North Carolina, a permit is required for anything that goes into a well, with the exception of air for sparging (a ground water remediation technique), uncontaminated water, and water used with certain heat pumps. South Carolina has well established tracer tests authorization procedures due to the existence of the Savannah River Site, a federal nuclear facility. South Carolina adopted the federal UIC regulations with a few exceptions. South Carolina does not allow authorization by rule. Also, wells of Class I through IV are not permitted. Wisconsin allows no authorization by rule. Wisconsin Department of Natural Resources requires the approval of tracer use following the Wisconsin Adminstrative Code S. NR 812.05. Prior to approval, the Wisconsin Department of Health is consulted to determine potential health impacts. Wisconsin Department of Health prohibits the use of fluorescein and rhodamine dyes due to concerns about possible carcinogenic effects. Tracers are considered an injection activity in Kansas. A proposal must be filed with the Kansas Bureau of Water prior to conducting a tracer test. Proposals are reviewed on a case by case basis. The background concentration of the tracer, the type of tracer and the benefits of the tests are assessed for each proposal. Missouri Department of Natural Resources Revised Statutes of Missouri 1991 256.621 requires persons conducting tracer tests (injectors) to register with the state on an annual basis. In addition, registrants must submit a written proposal prior to the actual injection. The Nebraska Department of Environmental Quality requires investigators to petition the state for permission to inject into the subsurface. Proposals are reviewed on a case by case basis. In Nebraska, the concentration of tracer at the point of injection is not allowed to exceed drinking water standards. Utah has ground water and drinking water standards that are more stringent than federal standards. Tracers with maximum contaminant levels or health advisories are strongly scrutinized, although the rate of attenuation is considered for permitting. Wyoming ground water standards are stricter than federal standards. All tracer tests must be permitted and must meet state and federal ground water regulations. In Wyoming, federal UIC regulations are followed precisely. Alaska's rules are more stringent than federal regulations. They require permits for all injections except for approved septic tanks. In Idaho, permit applications must be submitted to the Idaho Department of Water Resources for anything injected more than 5.5 m (18 feet) into the ground. However, if the permit application demonstrates that the tracer will not remain in the aquifer, due to either removal or adequate degradation, and the tracer poses no threat to drinking water, the permit may be waived. Massachusetts and Tennessee do not allow authorization by rule, but operate UIC programs that are otherwise equivalent to federal regulations. Massachusetts requires a written request. Approval requires there be no threat to public health or safety; authorization by rule is not allowed. In Tennessee, tracers are managed as a part of the Wellhead Protection Program. Tennessee does not have primacy, but operates a program parallel to the regionally administered federal UIC program. Tennessee's Water Quality Control Act requires anyone who alters "physical, chemical, radiological, biological, or bacteriological properties of any waters of the states" to "file an application for a permit with the commissioner." Their program requests voluntary registration of tracer tests; however, unregistered dye traces visibly affecting state waters may be subject to enforcement action.

States Without Primacy

States not previously discussed do not have primacy and fall under regional EPA control. Tracer studies in Minnesota and Hawaii currently operate under federal UIC program jurisdiction, but they are working on achieving state primacy. California operates a state UIC program for geothermal and oil and gas wells, but does not have state primacy for the component of the UIC program that covers Class V wells. In states without primacy, the regional EPA office is responsible for enforcing the federal code. All states in EPA Regions I and VI have primacy. All states in EPA Regions II and X also operate their own UIC programs, either through primacy or parallel programs. Therefore, EPA regions I, II, VI, and X are primarily responsible for oversight of state programs within their regions. The other six EPA regions (Regions III, IV, V, VII, VIII, IX) are responsible for UIC programs governing Class V wells in at least one state.

As with the states, EPA regional implementation of the federal UIC program varies from region to region. In Region III, which is responsible for monitoring tracer use in Pennsylvania, Virginia, and Washington, D.C., and in Region IV, which is responsible for monitoring tracer use in Kentucky, UIC program coordinators reported no known use of ground water tracers. However, the Region IV administrator said that tracer use must follow federal regulations. The Region V UIC program administrator is responsible for monitoring tracer use in Indiana, Michigan, and Minnesota. The administrator reported that permits are not generally issued for Class V wells, and that monitoring tracer use is not a priority. While federal regulations for inventory requirement are followed in Region V, well inventory information is not frequently reported because many potential users are not aware of their reporting requirements, something which could be remedied with additional federal funding. The program administrator for Region VII responded that there had been no applications for tracer use in Iowa, the only state in his region that does not have primacy. However, Region VII is familiar with federal regulations and follows them as the need arises. Region VII reported that EPA was sued by the Sierra Club for failure to promulgate rules for Class V wells. Following the litigation action, EPA has agreed to establish new rules for industrial uses of Class V wells. Region VIII, which regulates tracer use in Colorado, Montana, and South Dakota, requires information about tracer tests to be submitted in writing; tracer information is forwarded to a toxicologist. A tracer of lower impact may be suggested, and permitting is required if there may be a threat to underground drinking water sources. In Region VII, investigators are expected to meet two conditions outlined in the federal code: alert the appropriate authority and allow time for the agency to ask for more information; and operate the well in a way that protects ground water. The Region IX UIC program administrator, who operates the UIC program for Hawaii and Class V wells in California, follows the federal regulations, and requires that investigators contact the EPA region about proposed tracer tests.

The Need to Regulate Ground Water Tracers

Ground water is an essential national resource. Of 338 billion gallons of fresh water used daily in 1990 for municipal, industrial, domestic, irrigation, and electrical power plant cooling needs, 23.5% came from aquifers (Fetter 1994). In Georgia, for example,

ground water use accounts for 49% of all water use, with 30% of public water systems and 90% of rural users relying on ground water as a primary source (Dorman 1996).

Tracer technology must be used in a way that assures the quality of ground water. While individual researchers may be genuinely concerned about the potential implications of their use, introduction, and possible migration in ground water, state and federal regulatory agencies have the responsibility under the UIC program to oversee their use. The toxicity and mobility of a tracer, important characteristics to regulators, are generally considered prior to the approval of a tracer study. The type of tracer proposed for injection determines which regulatory procedures must be followed. Two of the most common tracers are chloride and bromide, which do not have existing or proposed EPA Maximum Contaminant Levels for drinking water, although they may be subject to local and state regulatory discretion. Radioactive tracers are often the tracer of choice for researchers because they are readily detectible at low concentrations. Most regulators and ground water users, however, resist the use of radioactive materials as introduced tracers due to the potential of adverse public reaction.

Regulators have concerns besides the type of tracer proposed. They are interested in the investigator's ability to manage the test and control the tracer. Disposal of withdrawn water may be an issue, possibly requiring a surface water discharge permit. Regulators contacted as part of this study expressed the importance of their role as liaisons to the public and the importance of knowing about tracer tests so they can alert the public or appropriate government officials, if necessary. Proper notification of regulators was of particular concern in areas where dyes are commonly used as tracers due to the potential ability of the public to observe the tracer in their drinking water.

Ever increasing demands on water supply mandate that ground water tracers be used in a way that do not compromise ground water quality. Primary drinking water standards include only a small set of compounds that are potential tracers. When confronted with authorizing compounds not covered by primary drinking water standards, some states forward tracer test requests to toxicologists, epidemiologists, or health divisions for review. Agencies have also suggested investigators use different tracers or smaller amounts of tracer, and require or deny permits accordingly. Providing a list of compounds suitable for use in ground water would help to furnish more uniform guidance for ground water tracer use. The number of compounds included needs to be expanded to cover the many chemicals that could potentially be used for tracer testing.

Consideration of environmental and synergistic effects can further restrict the use of ground water tracers above those restrictions required for human health protection. Synergistic effects are encountered when an otherwise innocuous compound is converted to a toxic compound, or causes a toxic compound to be produced. The toxic compound could be formed directly by decay or reaction, or indirectly by changing the subsurface geochemistry. For example, a tracer that changes the pH of ground water can have an indirect effect on metals, which then become soluble. Degradation byproducts of injected substances can be predicted based on geochemical conditions at the injection well. Ground water contributes to surface water bodies, affecting the geochemistry in streams, lakes, and oceans (Freeze and Cherry 1979). Ground water geochemistry can also influence the strength of geologic materials (e.g., acids in ground water and surface water frequently cause holes and weaken limestone resulting in fractures and sinkholes in limestone aquifers). Regulatory guidance should consider not just the substance being added to ground water, but also any direct and indirect chemical and geochemical effects the substance may cause.

Hydrology is still an inexact science in many ways, and predicted outcomes may not match reality. Several state UIC program administrators relate anecdotal stories of unexpected tracer results. Large margins of safety are considered worthwhile when permitting radioactive and hazardous tracers. In this case, the margin of safety is used to compensate for uncertainty. Trade-offs, such as increased project costs or restricted experimentation possibilities, are important considerations.

Recommendations

Federal laws require that state UIC programs (including regulation of tracer use) must be as stringent as the federal UIC statute. Information required for states under EPA programs (states without primacy) should be the minimum required by all states, including states with primacy. The first step, for any state, is to follow the first condition of the federal statute and require well inventories for tracer test injections. Inventory data about wells in the area of influence should also be required along with the necessary data about the injection well. Tracer test inventories provide regulators with the ability to establish a database of tracer tests and injection well inventories. Keeping track of tracer tests allows states to meet the 40 CFR 144.26 and 144.27 requirements to inventory wells and request more information about the tests, if needed. A database developed from required inventory information would be a useful tool for characterizing and investigating the waters of a state. In addition, a well inventory and tracer test database provides information for ground water management and protection purposes, including halting a tracer test that could pose a threat to drinking water, and preventing cross contamination from multiple tracer tests. This is especially important because primary drinking water standards include only a small set of compounds that are potential tracers. Identification of potential environmental and synergistic effects should also be mandated. Proposals for state or federal approval should clearly state the necessity of the test. Furthermore, alternative sites of investigation should be considered if the site of interest is subject to additional legal controls.

An important need is to develop a nationwide definition for the endangerment of an underground source of drinking water. 40 CFR 144.12 requires that "No owner or operator shall conduct any . . . injection activity in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR part 142 or may otherwise adversely affect the health of persons. The applicant for a permit shall have the burden of showing that the requirements of this paragraph are met." The cited regulation does not address whether or not attenuation can be considered. Some states, such as Wisconsin and North Carolina, have interpreted the statute to mean that drinking water standards can never be violated, even at the point of injection. With this interpretation, an investigator must use a tracer for which a ground water standard has not been established, or is existing at low enough background levels and detectable in small enough quantities to be used without violating regulations. This strict interpretation is suited for regulation of hazardous substances such as tritium.

When defining the endangerment of an underground source of drinking water by hazardous substances, regulators should also

consider wellhead protection issues, such as population or drinking water well distributions surrounding the point of injection, and the size and flow regime of the aquifer. In addition, physiographic regions of a state have different types of aquifer systems, so regulations should be region specific. The determination of whether tracer use poses a danger or not should be established such that it is consistent with other EPA programs, such as CERCLA and RCRA, that address this issue. A key attribute of this process is to provide a suitable margin of safety to account for tracer and subsurface transport uncertainties.

State agencies require information about the injected fluid to evaluate the proposed test. Compounds not regulated by primary drinking water standards may be considered on a case by case basis, with approval and permitting dependent on the type and amount of tracer used, or may be subject to another regulatory approach. One such approach, used by the state of Nevada, is to present a list of tracers suitable for ground water injection (Table 3). The South Carolina Department of Health and Environmental Control goes one step further by establishing a list of three categories of tracers (Table 4). The A Category includes tracers that are not known to have adverse human or environmental effects. A-Category tracers are authorized by rule as long as well inventory information is submitted for the injection well along with wells in the area of influence. Tracers in the B Category are those that are not currently approved, but may be approved depending upon additional state review. Tracers in the C Category are not suitable for underground injection, except for unusual circumstance, and then under controlled conditions. The use of multiple categories of tracers simplifies permitting processes and aids researchers in choosing regulatory acceptable tracers.

While listing tracers may not be as flexible as considering them on a case by case basis (one UIC administrator expressed concern about restricting a specific tracer because there may be an instance when use of that tracer is necessary), the listing approach does provide advantages for UIC staff who do not have a working knowledge of tracer technology. A formal list of regulatory acceptable tracers allows investigators to choose a tracer which requires less time for authorization or permitting, and has minimized monitoring requirements. Also, acceptable maximum tracer mass and concentrations would assist in tracer test design.

Two options are available for a list of suitable tracers. One option is for the individual states to continue to take the lead (as intended by EPA), while the alternative option is to establish a national listing program. While we acknowledge an advantage of state-delegation is the flexibility and adaptability associated with local control, the problem with local control is the lack of financial and technical resources at the state level. Also many states have higher priorities than tracer regulation. We recommend that EPA provide centralized support, establish a set of guidelines at the national level, and provide linkages to other ground water programs.

Table 4
Ground Water Tracers Categorized by the South Carolina Department of Health and Environmental Control

Tracer Types	Category
1. **Suspended Solids**	
1.1 *Biological Tracers*	
a. bacteria	B
b. yeasts	B
c. spores (lycopodium)	A
d. viruses (macrophages)	B
1.2 *Synthetic Microspheres*	
a. silica colloids	A
b. polystrene	B
c. laponite materials (clay)	B
2. **Dissolved Solids**	
2.1 *Nonionic Tracers*	
a. sugars	A
2.2 *Weak Acids*	
a. fluorobenzoic acids	B
b. fluorotoluic acids	B
c fluorosalicyclic acids	B
d boric acid	B
e. silicic acid	B
f. phosphoric acid	B
g. acetic acid	B
2.3 *Common Cations*	
a. lithium	B
b. potassium	A
c. magnesium	A
d. manganese	A
e. nickel	B
f. sodium	A
g. ammonium	B
2.4 *Common Anions*	
a. chloride	A
b. sulfate	A
c. nitrate	B
d. nitrite	B
e. bromide	B
f. iodide	B
g. fluoride	B
h. dichromate	B
i. thiocyanate	B
2.5 *Rare Earth Metals*	
a. europium	B
b. gadolinium	B
c. terbium	B
d. dysprosium	B
e. holmium	B
2.6 *Fluorescent Dyes*	
a. uranine	B
b. pyranine	B
c. lissamine FF	B
d. eosine	B
e. amino G acid	B
f. photine CU	B
g. elbenyl	B
h. rose B	B
i. phloxine B	B
j. duasyn	B
k. tagged bacteria	B
l. optical brighteners	A
m. rhodamine dyes	B
3. **Liquids**	
3.1 *Organics*	
a. toluene	C
b. benzene	C
c. xylene	C
d. bromoform	C
e. dichloroethane (DCA)	C
f. dichloroethylene (DCE)	C
g. trichloroethane (TCA)	C
h. trichloroethylene (TCE)	C
i. tetrachloroethlyene (PCE)	C
j. hexachloroethane (HCA)	C
k. carbon tetrachloride	C
3.2 *Alcohols*	
a. ethyl alcohol	B
b. glycerol	B
c. isopropanol	B
d. 2,3 dimethyl 2-butanol	C
4. **Gases**	
4.1 *Noble Gases*	
a. helium	A
b. argon	A
c. neon	A
d. krypton	A
e. xenon	A
f. radon-222	C
4.2 *Fluorocarbons*	
a. Freon 11	B
b. Freon 12	B
c. Freon 13	B
4.3 *Other Gases*	
a. oxygen	A
b. nitrogen	A
c. sulfur hexafluoride	A
d. carbon dioxide	A
e. nitrous oxide	A
f. carbon monoxide	B
5. **Isotopic Tracers**	
5.1 *Stable Isotopes*	
a. deuterium (^{2}H)	A
b. nitrogen (^{14}N, ^{15}N)	A
c. oxygen (^{18}O)	A
5.2 *Radioactive Isotopes*	C

A = No review required, B = Limited review, C = Extensive review

Summary and Conclusions

Ground water tracers are increasingly being used to estimate subsurface flow and transport parameters. It may come as a surprise to some that the injection of tracers falls under the federal UIC program which limits the introduction of substances into underground sources of drinking water as part of the Safe Drinking Water Act. The UIC program requires that underground sources of drinking water are not endangered, and that well inventory data be provided prior to tracer injection.

Using information collected from UIC program managers nationwide in early 1997, we show that states and EPA regions regulate ground water tracer tests in a variety of ways. Twenty-four states meet or exceed requirements of the federal UIC statute, with four of these states operating programs parallel to their EPA regional programs. Thirteen states do not have EPA-approved programs, and are subject to EPA regional UIC program implementation. The remaining 13 states have EPA-approved programs, but do not meet minimum federal requirements for tracer tests. While UIC implementation by states undoubtedly changes over time, our survey demonstrates the need for establishing guidance

for tracer test regulations.

Based on our discussion with UIC program managers, we found that the toxicity and mobility of a tracer are important characteristics to the regulator. Injection of hazardous tracers, even with good reason, may not meet with regulatory approval due to the regulator's concern for protecting public health. Regulators emphasize their role as liaisons to the public. The intent of the reporting requirement is to provide them with the opportunity to alert the public and appropriate government officials, if necessary. Prior reporting is especially important when visible tracers (e.g., dyes) that may be detected in drinking water are used. Regulators are also interested in the investigator's ability to manage and control the tracer test. Disposal of withdrawn water may be an issue, possibly requiring a surface water discharge permit.

Investigators have responsibilities and concerns that may or may not coincide with regulator concerns. Investigators are, first and foremost, responsible for test planning, which includes considerations about test efficiency, public and environmental health, costs, and uncertainties. Investigators conducting tracer tests should be, and generally are, aware of potential consequences of their tests, including their effects on underground sources of drinking water. Also, investigators may benefit from the UIC reporting requirements if previous tracer testing in the area may interfere with planned testing.

We propose specific measures to help investigators interested in designing and conducting tracer tests, and to assist UIC program managers streamline the permitting process. To facilitate the approval process, proposals by investigators for state or federal authorization should clearly state the benefits of the proposed tracer test. Careful site and tracer selection are particularly important due to reports of unexpected tracer pathways, requiring large margins of safety. Alternative sites should be considered if the site is located in a sensitive area, especially if the test has the possibility of affecting an underground source of drinking water. Because the regulatory point of compliance (whether at the point of injection or at some point of use) with drinking water standards varies by state and region, the investigator must consult with their local regulator. Regulatory difficulties can be avoided by selecting tracers with low detection levels or which lack drinking water quality standards. Tracer test applications should provide, at a minimum, the information listed in Table 2. Applications should also provide, if possible, any information related to the effects of the tracer on human health and the environment, and if any synergistic effects are possible.

To assist with the selection and use of ground water tracers, we also recommend that national guidance be provided related to the efficacy, safety, and reliability of tracers. Such guidance would be helpful for scientists and professionals who conduct ground water tracer tests by removing uncertainties related to the selection and use of appropriate tracers. We provide tracer selection guidance for two states, South Carolina and Nevada. The South Carolina program assists researchers by indicating which tracers are and are not suitable, as well as those tracers that must be reviewed on a case by case basis.

Acknowledgments

This research was sponsored by the U.S. Department of Energy, Westinghouse Savannah River Corp., through the Education, Research and Development Association of Georgia Universities, Task Order 97-086. The technical monitor was John Reed of Westinghouse Savannah River Co. Additional technical support was provided by David Wenner, Amanda Parker, and Bobbie Cox of the University of Georgia, Russ Land of the Nevada Department of Environmental Protection, Robert Devlin of the South Carolina Department of Health and Environmental Control, Jake Turin and Paul Reimus of Los Alamos National Laboratory, and Jonathan Williams of the Environmental Protection Division, Region X.

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