Environmental tracers and how they are used to understand the aquifer

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Environmental tracers are natural and anthropogenic (manmade) chemical and isotopic substances that can be measured in ground water and used to understand hydrologic properties of aquifers (Alley, 1993; Cook and Herczeg, 1999). These substances occur in the atmosphere or soil and are incorporated into precipitation and into water that infiltrates through the soil to recharge the aquifer. Different types of environmental tracers can provide different types of information about an aquifer. For example, the concentrations of environmental tracers in ground water can be used to identify water sources, trace directions of ground-water flow, measure the time that has elapsed since recharge (ground-water age), and interpret environmental conditions that occurred during recharge. The most useful environmental tracers in hydrologic studies (fig. *I.1*) do not react chemically in the aquifer after recharge, have concentrations that vary according to source and(or) age of the water, and can be measured analytically with sufficient accuracy to allow detection in the aquifer.

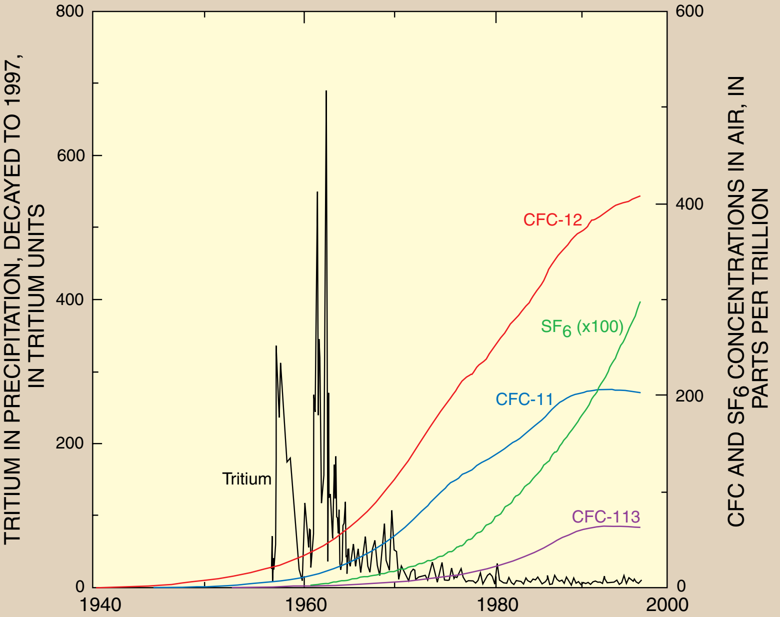

Figure I.1.—*Concentrations of tritium (^3H) in precipitation, chlorofluorocarbons (CFC-11, CFC-12, and CFC-113) in air, and sulfur hexafluoride (SF_6) in air over North America, 1940–97. The tritium concentrations in precipitation were decayed to 1997 for comparison with tritium concentrations (expressed as tritium units [TU]) measured in ground water as part of this study. A sample of water containing 1 TU has one tritium atom in 10^{18} hydrogen atoms—that is, 1:1,000,000,000,000,000,000. CFC and SF_6 concentrations in air are expressed as parts per trillion by volume (pptv). One pptv is one unit volume of the gas in 10^{12} volumes of air—that is, 1:1,000,000,000,000 by volume.*

Environmental tracers take several forms. Some are anthropogenic gases like chlorofluorocarbons (CFC's, Freon compounds). CFC's, first manufactured in the 1930's for use in refrigeration, air conditioners, and many other uses, were released into the atmosphere over time. Very small quantities have dissolved naturally in water and, because of extremely low analytical detection limits, are detectable in ground water recharged since the 1940's. Because CFC's allow scientists to find water that recharged recently, they improve the capability in the Middle Rio Grande Basin to trace seepage from the Rio Grande and recent recharge from arroyos and mountains and to detect leakage from landfills, industrial wastes, and septic tanks.

Some environmental tracers differ naturally in their isotopic composition, such as isotopes of hydrogen and oxygen in the water molecules themselves or isotopes of sulfur or carbon dissolved in ground water. Isotopes of a particular element have the same number of protons in the atomic nucleus but different numbers of neutrons. Thus, isotopes have the same atomic number but different atomic weights—a difference that permits precise

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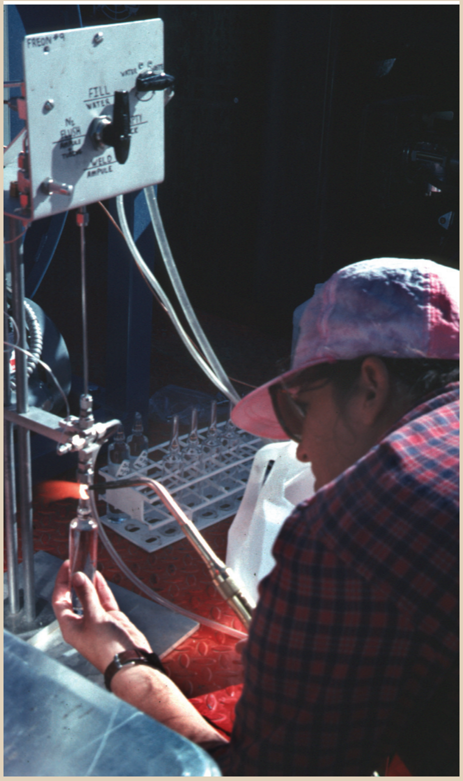
analysis of their relative abundance. On Earth, most of the element hydrogen is in the form of ^1H (or hydrogen-1), called hydrogen; only 0.015 percent of all natural hydrogen on Earth occurs as the isotope ^2H, called deuterium; and less than 10^{-14} percent occurs in the form of ^3H, called tritium (Coplen, 1993), yet stable isotopes of hydrogen (and oxygen) are important environmental tracers in hydrology because their local abundance varies significantly with environmental factors such as temperature and altitude of precipitation, source of moisture, amount of rainfall, and extent of evaporation.

Stable isotopes of hydrogen and oxygen are particularly useful in the Middle Rio Grande Basin because water has recharged the aquifer at different altitudes and under different climatic conditions. For example, winter precipitation has less deuterium than summer precipitation in the basin. Also, ground water originating as seepage from the Rio Grande contains water from high-altitude snowmelt in southern Colorado and northern New Mexico and has less deuterium than precipitation falling in the relatively lower Albuquerque area or even in the Sandia Mountains east of Albuquerque. In addition, precipitation that fell 20,000 years ago during the last glacial period was colder than today and had less deuterium than today's precipitation (Drever, 1988; Wright, 1989). Therefore, the isotopic composition of hydrogen (and oxygen) has large variation in ground water of the Middle Rio Grande Basin. In combination with other environmental tracers and dissolved substances in ground water, these tracers have been used successfully to recognize sources of recharge and trace flow throughout the basin (see Box *K*).

Finally, some environmental tracers are radioactive—that is, they are unstable isotopes that radioactively decay naturally into more stable isotopes. For example, tritium, the radioactive isotope of hydrogen, is part of the water molecule along with hydrogen and deuterium. Tritium, produced mostly from above-ground testing of nuclear weapons in the mid-1960's, but also occurring naturally, continues to be in rainfall but undergoes radioactive decay at a known rate (half-life). Every 12.4 years, half of the tritium in a given amount of water decays to an isotope of helium. By measuring the amounts of tritium and helium isotopes, the approximate length of time since a parcel of water fell as precipitation can be determined.

In the Middle Rio Grande Basin, CFC's and tritium and helium isotopes were used to date ground water and to locate areas where recharge has occurred within the past 50 years, such as in the inner valley of the Rio Grande and along some arroyos and mountain-front areas. The resulting ground-water ages also provide calibration data for ground-water-flow models. Other environmental tracers that have been used in the Middle Rio Grande Basin include (1) carbon-14 (^{14}C, a radioactive isotope with a half-life of 5,730 years), which has been used to date ground water recharged during the past 30,000 years (see Box *N*), (2) sulfur-34 (^{34}S, a stable isotope of sulfur), which has been used to trace water from the Rio Grande near Albuquerque, and (3) sulfur hexafluoride (SF_6, a trace atmospheric gas that also occurs naturally in granites and other rocks), which has been used to trace recharge from the Sandia Mountains.



A USGS hydrologist collecting a water sample for chlorofluorocarbon analysis. To prevent contamination of the sample, water is collected without atmospheric contact and flame sealed in a glass ampoule.