Tracking Groundwater Sources with Environmental Isotopes

View of Topock Marsh.

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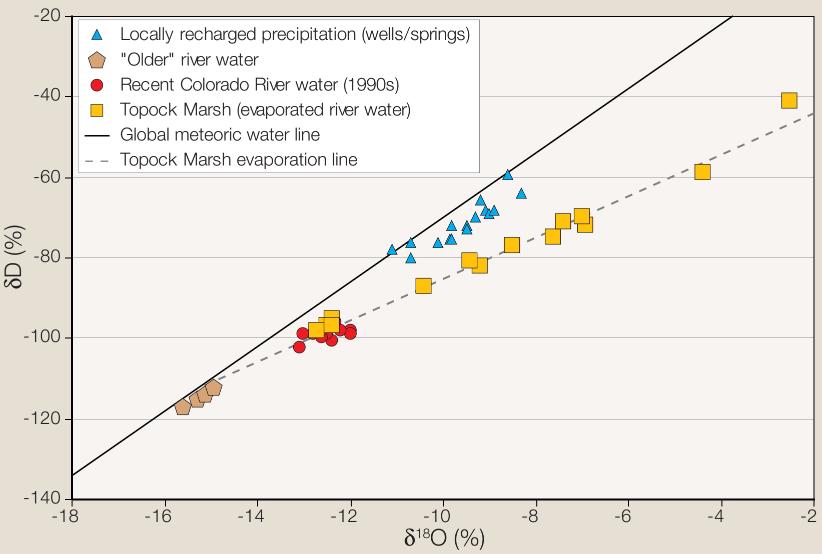
The application of environmental isotopes provides a forensic tool that could help resolve legal and water accounting disputes in the Lower Colorado River Basin (LCBR; see map). One such dispute involves the relationship between groundwater pumping in the basin and consumptive use of Colorado River water. Article I of a 1964 U.S. Supreme Court decree considered consumptive use to include "water drawn from the mainstream by underground pumping." The U.S. Bureau of Reclamation has presumed that wells located on the Colorado River flood plain and certain other wells on the surrounding alluvial terraces yield river water. With technical assistance from the U.S. Geological Survey, in 1994, Reclamation proposed an "accounting surface" method to address wells outside the flood plain. The method relies on a hydraulic criterion: wells that have a static water-level elevation equal to or below the published accounting surface are presumed to yield water that will be replaced by water from the river (Wilson and Owen-Joyce, 1994). There are several thousand such wells in Arizona and California. While the proposed changes in river water accounting have several operational advantages for Reclamation, one foreseeable criticism is that the method does not provide direct evidence that a well yields mainstream water. A method that could distinguish between withdrawals of mainstream or locally recharged tributary water would be a welcome advance.

Guay and others (2006) demonstrated the beneficial use of environmental isotopes in distinguishing groundwater sources along the LCRB. They found that stable hydrogen and oxygen isotopes and tritium provide an indication of the origin of groundwater in wells along the river. They published new isotope data for five surface-water and 18 groundwater sites around Topock Marsh, Arizona, near Needles, California. These data were compared with river-water data from 1974 to 2002 from 11 sites between the Utah and Mexico borders and with groundwater data from previous LCRB studies.

This research revealed essentially three groundwater sources along the LCRB. Representative data from Mohave Valley illustrate (below) the relative plotting positions of $\delta^{18}O$ and δD pairs (see sidebar, opposite page) from waters throughout the LCRB. First, there is locally recharged precipitation, usually winter rain. This was easily confirmed with several water samples that were taken from wells and springs above the elevation of the nearby river. The isotopic values plot slightly below the global meteoric water line (GMWL) and have δD values that are about 20 parts per thousand (per mil) greater than those of recent river water, consistent with precipitation data from Friedman and others (1992) and Smith and others (1992). The GMWL is defined by the annual average isotope compositions of precipitation at locations around the globe.

Next and somewhat surprising was the finding of "older" (pre-1950) UCRB river water in the LCRB river aquifer. It appears that pre-1950 and possibly pre-dam water, with isotopic values similar to modern and relatively unevaporated UCRB water, is still present in some wells. This finding was confirmed using



Representative $\delta^{18}O$-δD pairs from groundwater and surface-water types collected in the 1990s in Mohave Valley, CA. Locally recharged samples came from wells and springs above river elevation and a few deeper wells on alluvial terraces. Local recharge is generally derived from winter rain, with δD about -71‰ (Friedman and others, 1992). Older Colorado River water has values similar to UCRB river water, derived primarily from snowmelt (Wyman, 1997). Recent Colorado River samples were collected in Laughlin, Nevada and near Needles, California. For clarity, mixed waters, although common, are not shown.

PHOTO: Brad Guay

Map of Colorado River watershed showing the Lower Colorado River Basin (shaded) and Topock Marsh study area

tritium, as water that predates 1950 contains no measurable tritium whereas water that postdates the bomb pulse has measurable tritium. These UCRB waters plot on or near the GMWL and are

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distinct from local rainfall and recent river water. River-water tritium has declined steadily from its peak of 716 tritium units (TU) in 1967 to about 8 TU in 2007.

Third, there is "recent" (post-1950) Colorado River water, which includes Topock Marsh samples. Recent river water values naturally vary slightly and plot below and away from the GMWL. However, once this water experiences significant evaporation, as in Topock Marsh, its isotopic values attenuate along a distinctive evaporation trend. Large floods, as in 1983, complicate this interpretation by routing less evaporated Upper Colorado River Basin (UCRB) water into the LCRB. Mixtures of all three groundwater sources are common in more comprehensive datasets. In addition, a potential fourth water type, which was not recognized in the LCRB study but has been detected elsewhere, is recharge from ancient precipitation.

The unusual robustness of isotopic data from the LCRB derives from the river basin's physical geography and modern hydraulic controls. As more data are accumulated, isotope measurements of $\delta^{18}O$, δD, and tritium may provide a useful supplement to Reclamation's accounting surface method. Without isotopic data, the accounting surface falls short because it can only demonstrate the physical *potential* for water movement from the river toward a well. Conventional geochemical data are useful but rarely provide a direct indication of a water's source. Isotopes, on the other hand, can and have resolved water resource disputes in many situations. In the short term, isotopes are unlikely to indicate capture of river water as a result of pumping at a distance from the river, but long-term monitoring of isotopic values could signal basin-scale shifts (or lack of predicted shifts) in the boundary between groundwater derived from tributaries and from the river. Such information could be used to promote water conservation and resource planning in rapidly growing Southwestern communities.

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Intro to Isotopes

Isotopes of a particular element have the same number of protons but a different number of neutrons, resulting in different atomic weights. When light elements such as oxygen, hydrogen, carbon, nitrogen, and sulfur undergo biogeochemical and physical processes, the difference in mass can cause one of the isotopes to be preferentially selected over the other, resulting in a product with a different isotopic ratio than the original. This selection process is called fractionation. An example is evaporation from a stream, where the water vapor will contain more of the lighter oxygen isotope than the stream, which in turn becomes "enriched" in the heavier isotope.

Stable isotopes do not change their atomic structure. Hydrogen has two stable isotopes, ^1H and ^2H (deuterium, D), with the numbers referring to the atomic weight. The most common isotopes of oxygen are ^{18}O and ^{16}O. Stable isotope data are reported relative to a standard material (ocean water in the case of hydrogen and oxygen isotopes) using the delta (δ) notation. The delta values represent deviation from the standard in parts per thousand (per mil, ‰). The values of δD and $\delta^{18}O$ (and other stable isotopes) measured in water samples can provide information on the processes (such as evaporation) that have affected it and suggest its source.

Radioactive isotopes undergo spontaneous radioactive decay to form new elements or isotopes, and are used to determine the relative or absolute age of water. Large amounts of tritium, a radioactive isotope of hydrogen (^3H), were introduced to the atmosphere by thermonuclear weapons testing from 1952 to 1972, and then entered the subsurface in precipitation. Thus, groundwater samples that contain measurable tritium are considered to be evidence of "post-bomb" recharge. Tritium is measured in tritium units (TU), in which one TU equals one tritium atom per 10^{18} ^1H atoms. Tritium has a half-life of 12.3 years, and its usefulness is declining, as it will become harder to distinguish decayed post-bomb samples from pre-bomb samples. Other radioactive isotopes, such as ^{14}C and ^{36}Cl, have much longer half-lives and are useful for dating groundwater less than 40,000 (^{14}C) to more than one million years old (^{36}Cl).