Locating Recharge Zones With Isotopes

The Tucson Basin Example

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Recharge to the upper 150 m of the regional aquifer in the alluvial sediments of the Tucson basin appears to originate largely near major washes that convey water from watersheds around the basin. Surface water in the major washes visibly infiltrates flood-plain sediment and commonly does not leave the basin. In order to understand the water budget of the basin, we need answers to questions such as:

- Does the amount of infiltrating water equal the amount of water reaching the regional aquifer?
- Does recharge to the regional aquifer occur uniformly along the washes?

Groundwater isotope studies are useful in addressing the second question. Surface water may be present in all of the major washes after heavy precipitation, and each wash presumably contributes some water to the regional aquifer. The question becomes one of relative rates of water movement between flood-plain sediment and the regional aquifer. We can determine the rates semi-quantitatively using radioactive isotopes with appropriate half-lives.

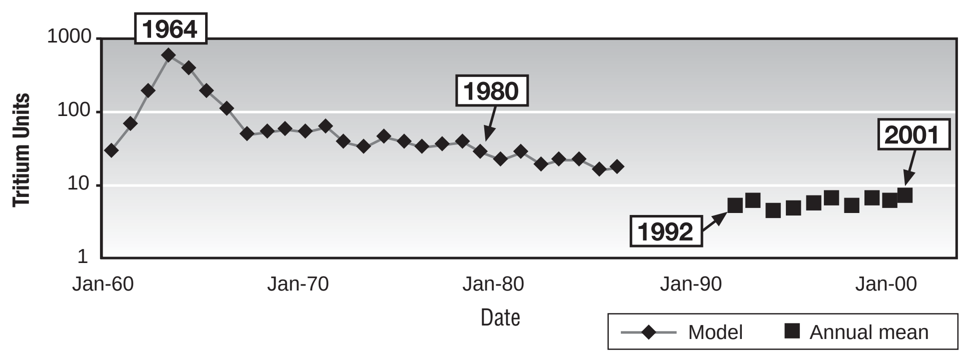
The radioactive isotopes tritium (^3H) and radiocarbon (^{14}C) have appropriate half-lives for the study of groundwater movement. Both isotopes are generated as a result of interaction between cosmic rays and ^{14}N in the upper atmosphere. The levels of both were also augmented by atmospheric testing of nuclear weapons, particularly between 1960 and 1972 (Fig. 1). Tritium in the local atmosphere was further augmented by releases from the American Atomics factory in central Tucson between 1970 and 1982.

Properties of Tritium and Radiocarbon

Tritium, which has a 12.4 year half-life, is incorporated into water molecules in the atmosphere. It is removed in rain, which currently averages 5-7 tritium units near Tucson. One tritium unit (TU) corresponds to 1 tritium atom per 10^{18} atoms of ^1H. Rain from years prior to 1955 was probably similar to present-day rain in tritium content. "Bomb" tritium rose to levels above 600 TU in rain during 1963 and 1964 (Fig. 1), and had been stripped from the atmosphere by 1992. Tritium in water that fell as rain or snow before 1955 has decayed to levels below our detection limit of 0.6 TU. Consequently, we can use tritium in the Tucson area to distinguish groundwater that precipitated prior to 1955, on the one hand, from groundwater containing a significant fraction of post-1955 water, on the other.

^{14}C is incorporated into CO_2 molecules, some of which are removed from the atmosphere as plant material by photosynthesis. Plant respiration and plant material decomposed in soil contributes to soil gas CO_2, which has a ^{14}C content close to that of concurrent atmospheric CO_2. Soil CO_2 dissolves in infiltrating rainwater, and is initially the principal source of bicarbonate in groundwater. Subsequent dissolution of carbonate minerals in the subsurface adds bicarbonate containing "dead" carbon, i.e. carbon with no ^{14}C, to groundwater.

A commonly-used unit of ^{14}C concentration is percent modern carbon (pMC). Up until about 1955, the



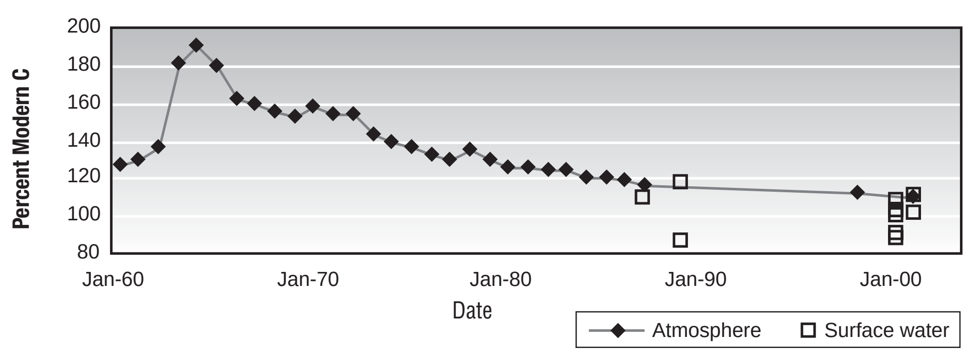
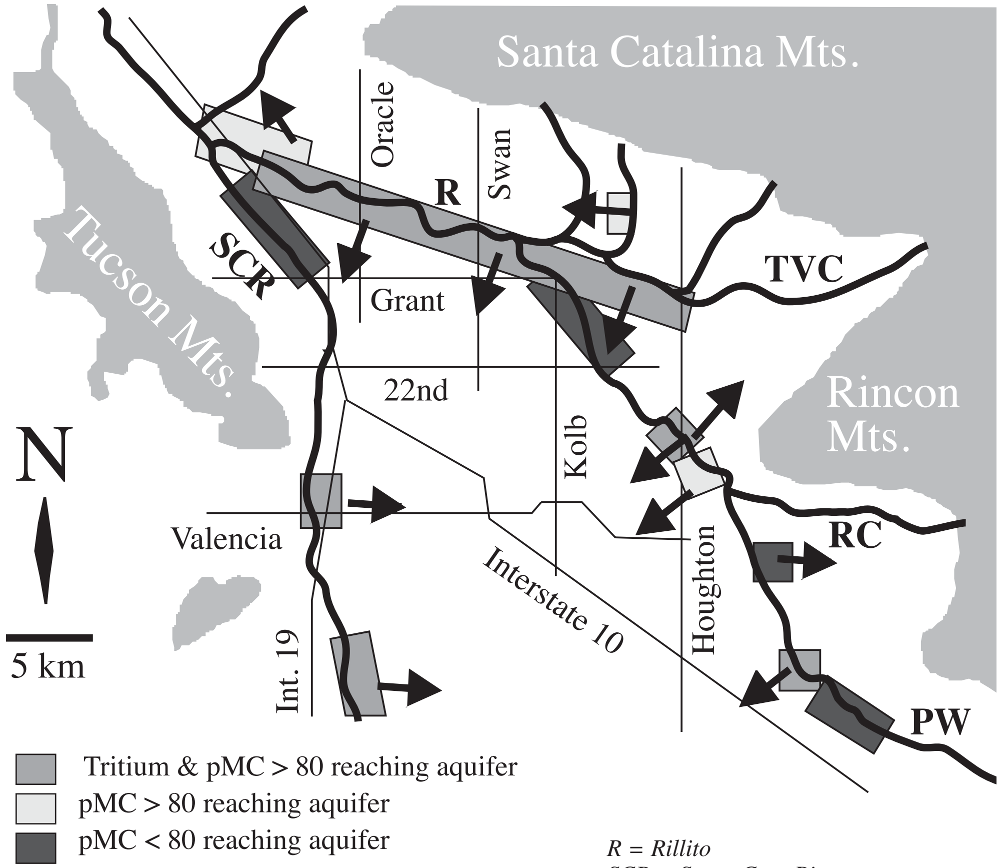


Fig. 1. A. Change in tritium content of Tucson rain since 1960. Model curve is from Doney et al. (1992). Annual means are data of the Laboratory of Isotope Geochemistry, University of Arizona. B. Change in ^{14}C content of the atmosphere, unaffected by urban pollution, and ^{14}C measurements on Tucson surface water. Data to 1985 from Burchuladze et al. (1989); subsequent data from the Laboratory of Isotope Geochemistry, University of Arizona.

atmosphere (disregarding industrial CO_2 emission effects) contained 100 pMC. Bomb ^{14}C increased to 190 pMC in the atmosphere in 1963-1964, and some bomb-^{14}C persists in the atmosphere today. In 2001, southern Arizona air contained about 109 pMC away from urban areas, and 106-108 pMC in Tucson.

The half-life of ^{14}C is 5730 years, and pre-bomb ^{14}C can be measured in natural material as old as 40-50 thousand years. In the case of groundwater, relating ^{14}C content to age is complicated by the addition of "dead" rock carbonate that is invariably present in the sedimentary fill of Tucson basin and other similar basins in semi-arid climatic zones. Nonetheless, ^{14}C content gives a useful indication of relative ages of groundwaters.

The process of adding "dead" carbon begins before surface water undergoes infiltration in Tucson basin. Surface water with as little as 85 pMC was collected in 2000 (Fig 1B). Consequently, we interpret pMC values greater than 80 as potentially indicating water recharged in the last few centuries. The presence or absence of tritium in such water brackets the age more closely. The mixing of older and younger waters after infiltration also complicates interpretations, and in particular precludes the calculation of ages from tritium data alone.



Map of Tucson basin showing semi-quantitative recharge rates near the major washes

Results and Conclusions

Three useful cases emerge from the discussion above:

1. Water with measurable tritium and greater than 80 pMC, containing a significant fraction of water that fell as rain since 1955 is present in the regional aquifer adjacent to a wash.

2. Water with tritium below detection level, and greater than 80 pMC, containing a significant fraction of water that fell as rain potentially as recently as the decade prior to 1955, is present.

3. Water with tritium below detection level, and less than 80 pMC, containing little or no water that fell as rain in the few centuries prior to 1955, is present.

Case 1 corresponds to the most rapid recharge rates, with surface water reaching the regional aquifer in less than 50 years. In cases 2 and 3, water that fell as rain prior to 1955 is reaching the regional aquifer. Case 2 corresponds to slower recharge than in case 1, and case 3 corresponds to very slow to non-existent recharge.

In the Tucson basin, tritium and ^{14}C were mapped in the regional aquifer adjacent to major washes and examples of all three cases were found (Fig. 2). Isotope maps showing all data points on which this figure is based are available at www.geo.arizona.edu /researchers/mbaker/AusinLong/. Rapid recharge occurs south of Rillito Creek and Tanque Verde Creek, east of the Santa Cruz River in the southern part of Tucson, and also in a limited area near the confluence of Rincon Creek and Pantano Wash. Slower recharge (case 2) appears to occur north of Rillito Creek near its confluence with the Santa Cruz River. Recharge beneath Pantano Wash downstream of Rincon Creek is extremely slow (case 3). In several intervals of the major washes, not enough data were available to constrain the recharge rate. A very large data set would be necessary to achieve full coverage.

At time scales relevant to the development of a city such as Tucson, recharge that takes more than 50 years to reach the regional aquifer is insignificant. As a consequence of pumping, water-table levels are likely to be falling faster than the rate of advance of water infiltrating from the surface. Only those areas where tritium is present in the regional aquifer are receiving significant recharge from the washes. Such rapid recharge is clearly not occurring next to every reach of wash in the basin. If gravity-driven artificial recharge is ever attempted from Tucson washes, the number of potential sites will be limited.

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References

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