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Lessons Learned from Two Thousand Tritium-Helium Groundwater Ages in California, USA

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Study Design

A state-wide, comprehensive study of groundwater contamination vulnerability in California, USA uses ^{3}H-^{3}He groundwater age to assess the relative probability that drinking water aquifers will become contaminated with anthropogenic pollutants. Nearly all of the wells included in the study are public drinking water supply wells. There are ~16,000 public supply wells in California; wells sampled for this study are a subset (nearly 2000 to date) from large metropolitan areas (Los Angeles, Orange County, San Jose, and Sacramento), as well as several smaller population centers and rural areas that may rely entirely on groundwater for drinking water supply. The large data set for dissolved noble gases and tritium-helium age allows basin-wide and regional analysis of groundwater age, excess air, and recharge temperature not possible in typical studies with a small number of wells or low sample density.

Results

Forty percent of wells have tritium concentrations less than 4 pCi/L, indicating that at least 80% of the water produced recharged more than 50 years ago. In basins where focused artificial recharge dominates the flow field, relative groundwater ages are good predictors of the probability for wells to be contaminated with anthropogenic compounds (figure 1). Wells producing relatively young groundwater invariably are affected by low-level contaminants, while tritium-dead water is nearly always free of the same compounds. Analysis of a large number of spatially distributed samples is necessary to delineate the flow field and identify recharge areas using relative ages.

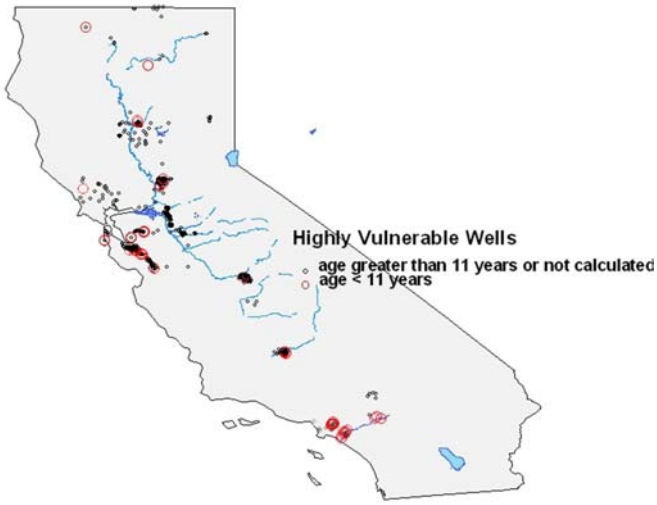

Figure 1. Map of California showing areas where tritium-helium age data has been collected and wells with ages <11 years.

Ten percent of wells have a mantle helium component. In mixed samples containing tritium, mantle helium is recognized as having more ^{3}He than can be supported by the tritium observed. Mantle helium is widespread in wells from volcanic provinces in northern California, but occurs rarely, along certain tectonic features, elsewhere in the state.

Comparing the calculated groundwater age and (decay corrected) measured tritium reveals useful information about the

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groundwater age distribution in wells producing mixed-age water (figure 2). Samples that fall below the curve indicate wells where a component of 'pre-modern' groundwater is present. Lines of equal percentage pre-modern can be calculated and used to estimate the degree of dilution of a contaminant that is captured in the post-modern component. Terrigenic He is examined and estimated for a geographic area in samples that are free of tritium. About 31% of the samples have radiogenic ^{4}He concentrations >5x10^{-8} ccSTP/g.

Excess Air Analysis

Noble gas concentrations were calculated based on the three physically-based conceptual models that have been used to interpret dissolved noble gas concentration data in groundwater (i.e., the unfractionated air model [1], the partial re-equilibration model [2], and the closed system equilibrium model [3]). For most samples, all models are able to adequately fit measured data within measurement uncertainty. Therefore goodness of fit is not a robust indicator for model appropriateness. The choice of interpretive model is important because parameters deduced from model output (recharge temperatures or ^{3}H-^{3}He ages) systematically differ between models.

Samples from certain locations contained significantly higher Ne and excess air concentrations than are reported in the literature, with the maximum amount of excess air tending toward 0.05 cm^3 STP g^{-1} (ΔNe ~400%). Samples not fit by the models tended to have greater than average Ne concentrations. The reason that models do not fit samples with large Ne concentrations may be non-equilibrium effects. Kinetic factors may control dissolved gas concentrations, especially in locations with high recharge flux. Excess air is less fractionated in samples with high excess air concentrations.

Trapping of gas present in the vadose zone via surface spreading during artificial recharge is the most likely source of the high excess air concentrations. The process by which artificial recharge dissolves significantly greater amounts of atmospheric gases has important implications for oxidation-reduction dependent contaminant degradation. An improved understanding of the physical processes controlling gas dissolution during groundwater recharge is critical for optimal management of artificial recharge and for predicting the changes in water quality that take place during artificial recharge.

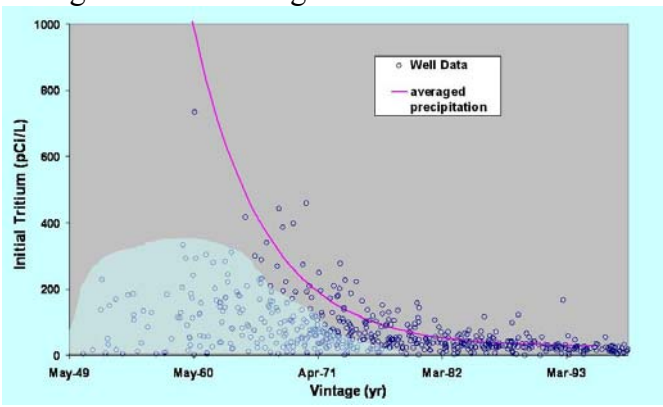

Figure 2. Curved line shows averaged tritium measured in precipitation at Santa Maria, California over the last several decades. Small open symbols represent wells from this study.

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