**Sample for Abstract:**

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| **ABSTRACT** |

**Paper Title**

Complications associated with tritium-helium dating in artificial recharge areas

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## Introduction

California (USA) is home to several large scale artificial recharge areas that have been in operation for several decades. We have applied tritium-helium groundwater age dating at a large number of the production and monitoring wells available for sampling at these sites in close collaboration with the water managers and well owners. In basins where the groundwater flow field is dominated by focused artificial recharge and high volume pumping, a large collection of groundwater ages can be used to delineate the flow field, provide an estimate of travel times, identify recharge zones, and assess contamination vulnerability. Water managers have found ages useful for (in)validation of numerical flow model results, deciding the details of new well construction (location and screened intervals), and demarcation of a well's recharge source zone or contamination source zone.

## Effect of treatment of excess air on groundwater ages

The tritium-helium system is fraught with complications, chief among them making accurate adjustments to the measured $^3$He to accurately determine tritiogenic $^3$He. In the artificial recharge areas we have studied, excess air concentrations may be quite high (up to 0.05 cm$^3$ STP/g ($\Delta$Ne ~400%)), but the correction for terrigenic helium is not usually a major factor. Three physically-based models are used to interpret dissolved noble gas concentration data in groundwater: unfractionated air (UA model [1]), partial re-equilibration (PA model [2]), and closed system equilibrium (CE model [3]). The interpreted ages resulting from each of the three excess air models vary systematically as discussed by Peeters et al. [4]. The oldest age is calculated by PR, the youngest age by UA, while the CE model yields ages between the PR and UA models. This is because the interpreted excess air component of He is maximized for unfractionated conditions. A larger excess air component of He results in a lower interpreted tritiogenic He component for a given total measured amount of He, and a younger interpreted age. This pattern is observed in a large set (>300) of California groundwater samples (Figure 1). As expected, the difference between PR and CE calculated ages is more pronounced for samples having higher excess air: for California groundwaters, the mean difference is 4.1 yr ($n$ = 170) in artificial recharge areas versus 3.6 yr in non-artificial recharge areas ($n$ = 144). The differences in interpreted groundwater ages were greatest for: 1) younger samples, and 2) samples

with fractionated excess air. These results are consistent with the literature and suggest calculating groundwater age without considering gas fractionation will underestimate groundwater age, especially if diffusive degassing occurs.

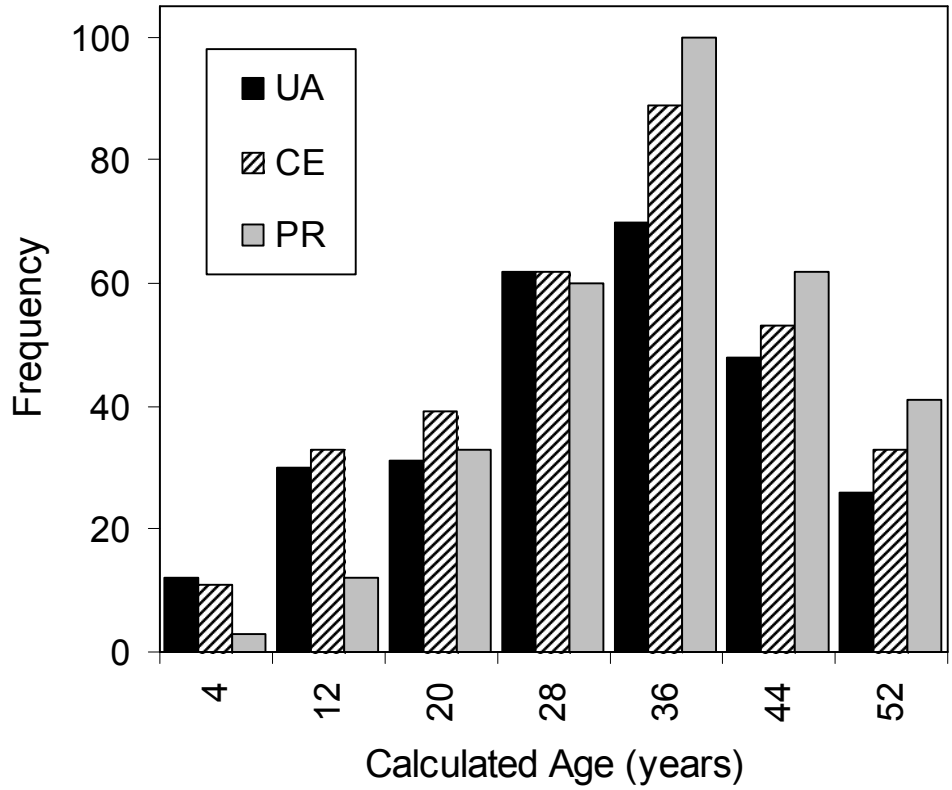


***Figure 1.*** *Histogram of calculated $^3H$-$^3He$ ages for each of three models of excess air formation, using data from California public supply wells.*

**Deconvolution of mixed groundwater ages**

A second major complication, which is not specific to the tritium-helium system, relates to mixing of groundwater ages during transport in a dispersive medium and during discharge in a long-screened well. We attempt to characterize the groundwater age distribution in samples from long-screened production wells in four ways: 1) application of introduced tracers (such as isotopically-enriched noble gases or $SF_6$) for examination of the fastest flow paths, 2) estimation of the percent pre-modern through comparison with tritium in precipitation records, 3) use of additional age dating isotopes that are relevant on long time scales, such as radiogenic $^4He$, and 4) development of flow and transport models that simulate the actual flow processes for both groundwater and the age dating tracer, including two phase (gas and liquid) transport.

Figure 2 illustrates the groundwater age simulation framework for a simple 1-D steady-state downward flow case. Liquid and gas phase concentrations of HTO and $^3He$ are assumed in equilibrium. Transient HTO concentrations are conditioned at the ground surface to replicate anthropogenic sources of HTO. Coupling of gas and liquid phase flow enables simulation of variably saturated flow above the water table with gas-liquid phase partitioning of HTO and $^3He$. HTO is decayed to $^3He$ using a first-order kinetic model. Within this simulation framework, an apparent

groundwater age can be determined from the ratio of liquid phase concentrations of tritiogenic $^3$He to HTO and directly compared to apparent groundwater ages calculated from measurement of groundwater HTO and dissolved noble gases. The simulation framework enables direct calibration of a variably saturated and transient groundwater flow model to tritium-$^3$He groundwater age data while accounting for spatial and temporal complexities such as vadose zone processes, variable HTO concentration at the ground surface, heterogeneity, dispersion, mixing, with transient flow conditions including fluctuating water table, pumping, and recharge.

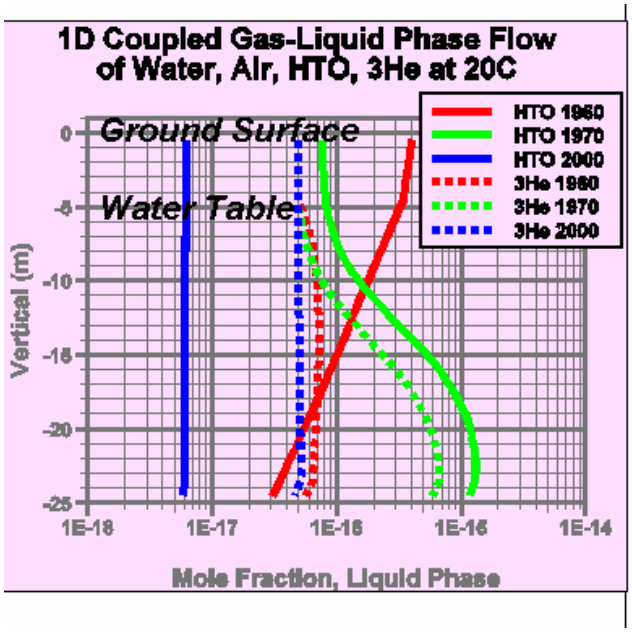


***Figure 2.*** *HTO and $^3$He model output for 1-D steady state downward flow.*

Given the inherent and observed complications with tritium-helium groundwater age dating, the importance of good spatial coverage and consideration of relative rather than absolute ages is stressed in our communications with water managers.

**References:**

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