Uranium-Series Constraints on Radionuclide Transport and Groundwater Flow Beneath the Nopal I Uranium Deposit, Sierra Peña Blanca, Mexico

OCRWM Office of Science and Technology and International

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Outline

- Uranium in the saturated zone
  - Concentrations [U] and isotopics ($^{234}U/^{238}U$)
  - Modeling of groundwater velocity: one-dimensional (1-D) tank and advection/dispersion
- Uranium in the unsaturated zone
  - Constraints on uranium dissolution rates and rock-water interaction or residence times
- Short-lived uranium-series nuclides in the saturated zone
  - Retardation factors for Ra, Pb, and Po

Uranium Decay-Series Nuclides

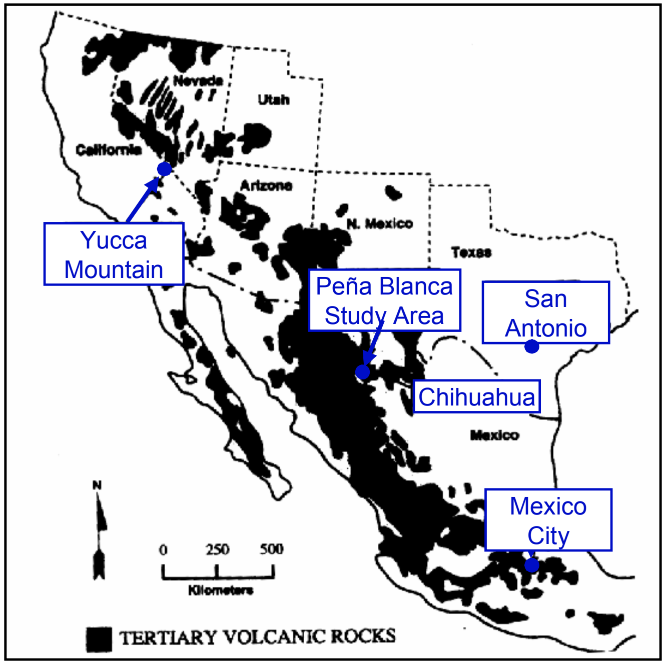
- **^{238}U series:** ^{238}**U** (α, 4.5 by) $\rightarrow$ ^{234}**Th** (β, 24.1 d) $\rightarrow$ ^{234}**U** (α, 248 ky) $\rightarrow$ ^{230}**Th** (α, 75.4 ky) $\rightarrow$ ^{226}**Ra** (α, 1.6 ky) $\rightarrow$ ^{222}**Rn** (α, 3.8 d) $\rightarrow$ **…** $\rightarrow$ ^{210}**Pb** (β, 22.3 y) $\rightarrow$ ^{210}**Po** (α,138.4 d) $\rightarrow$ ^{206}**Pb**

- **^{235}U series:** ^{235}**U** (α, 0.71 by) $\rightarrow$ ^{231}**Pa** (α, 32.8 ky) $\rightarrow$ ^{227}**Ac** (β, 22.0 y) $\rightarrow$ ^{227}**Th** (α, 18.6 d) $\rightarrow$ ^{223}**Ra** (α, 11.1 d) $\rightarrow$ **…**$\rightarrow$ ^{207}**Pb**

- **^{232}Th series:** ^{232}**Th** (α, 14.2 by) $\rightarrow$ ^{228}**Ra** (β, 5.75 y) $\rightarrow$ ^{228}**Th** (α, 1.91 y) $\rightarrow$ ^{224}**Ra** (α, 3.64 d) $\rightarrow$**…** $\rightarrow$ ^{208}**Pb**

Geologic Overview

History of the Peña Blanca Uranium Deposit



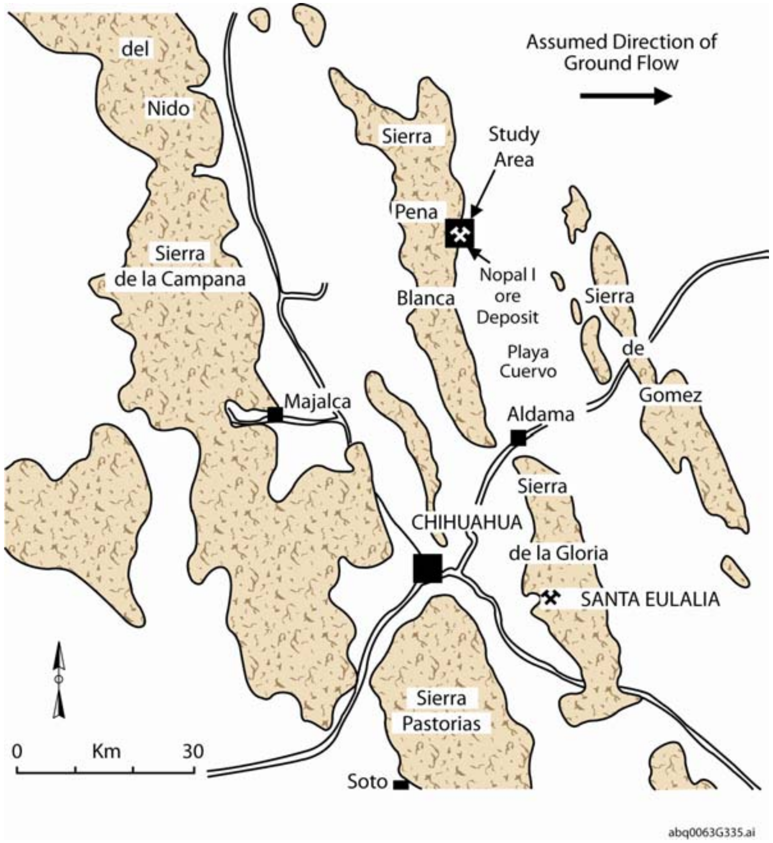
- Tuff … *44 Ma*
- Uraninite deposit … *<32 Ma*
- Oxidation … *<3 Ma*
- Uranium transport … *400 Ka*
- Opal deposits … *50 Ka*
- Mining … *1960-1985*

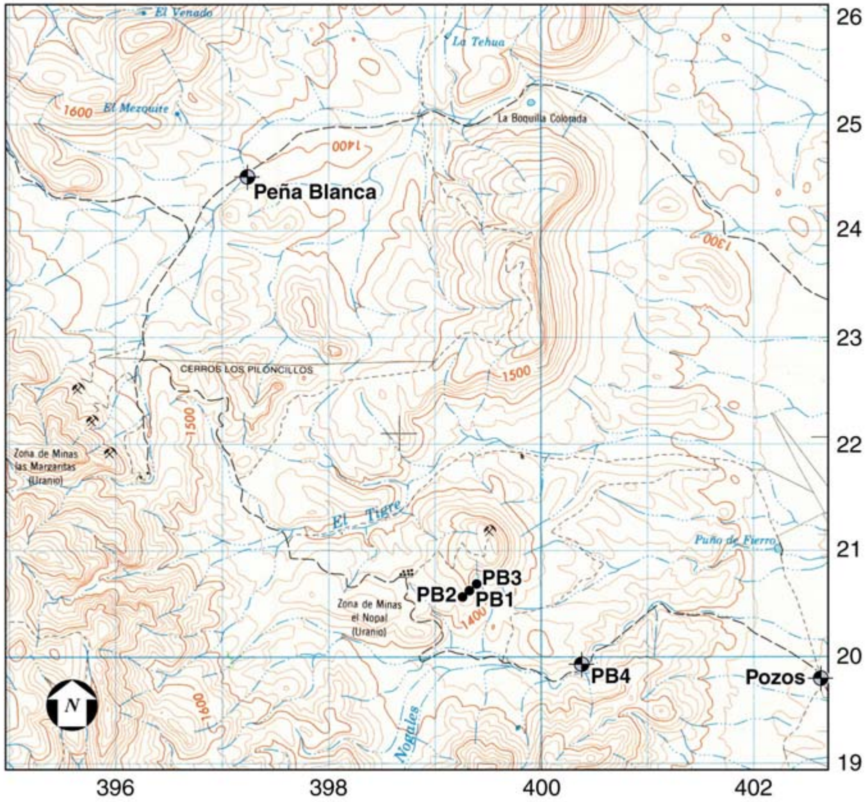
Peña Blanca U deposit similar to Yucca Mountain - rhyolitic tuff, unsaturated zone, semi-arid climate

Relationship to Yucca Mtn.

- Peña Blanca is a good natural analogue for understanding radionuclide transport at Yucca Mountain over a variety of timescales.
- Groundwater velocity, rock-water interaction, and retardation factors are important parameters influencing radionuclide transport at Peña Blanca and Yucca Mountain. Groundwater hydrology at Peña Blanca is poorly understood: UZ residence times, SZ speed and direction.
- Specifically identified need: conduct artificial tracer studies at Peña Blanca to detect SZ groundwater flow and transport. This study uses natural U as a tracer of groundwater residence and flow.
- Groundwater and nuclide velocity information is directly used by models of radionuclide transport, including Peña Blanca TSPA.

Groundwater Well Sample Locations





Legend

- Existing Wells
- New Peña Blanca Boreholes

0 1 Km

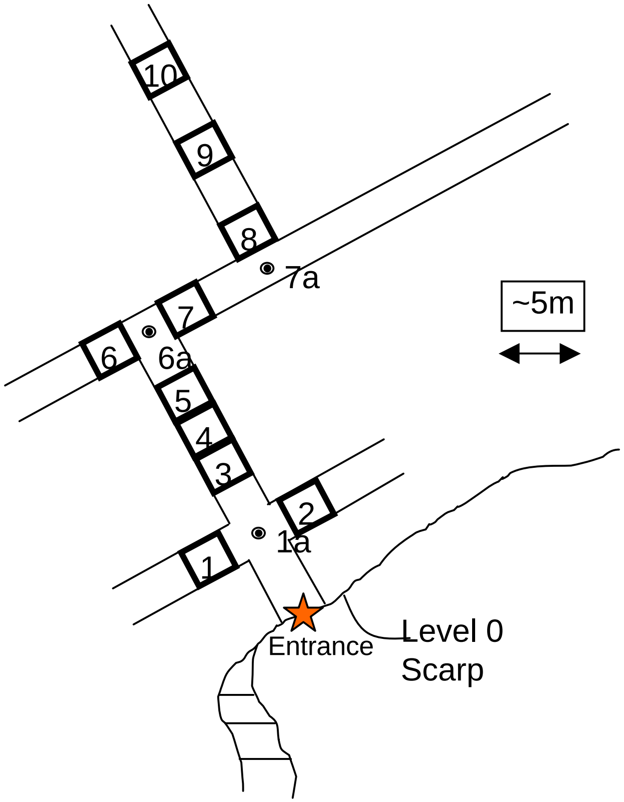
Contour Interval = 20 Meters

El Sauz 1:50,000 Topographic Map (H13C46)
North American 1927 datum

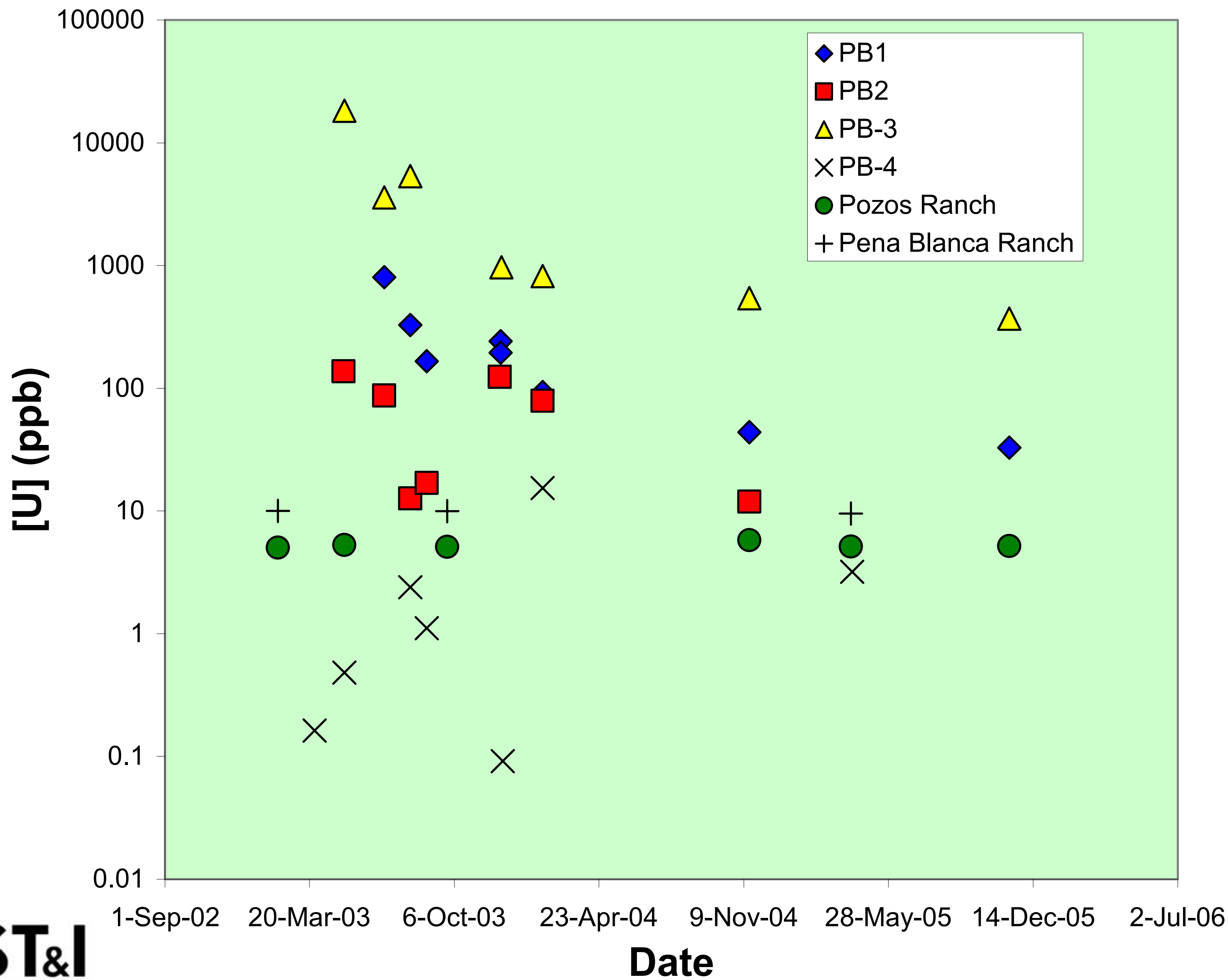
NA04-001

Panoramic View of New PB Wells

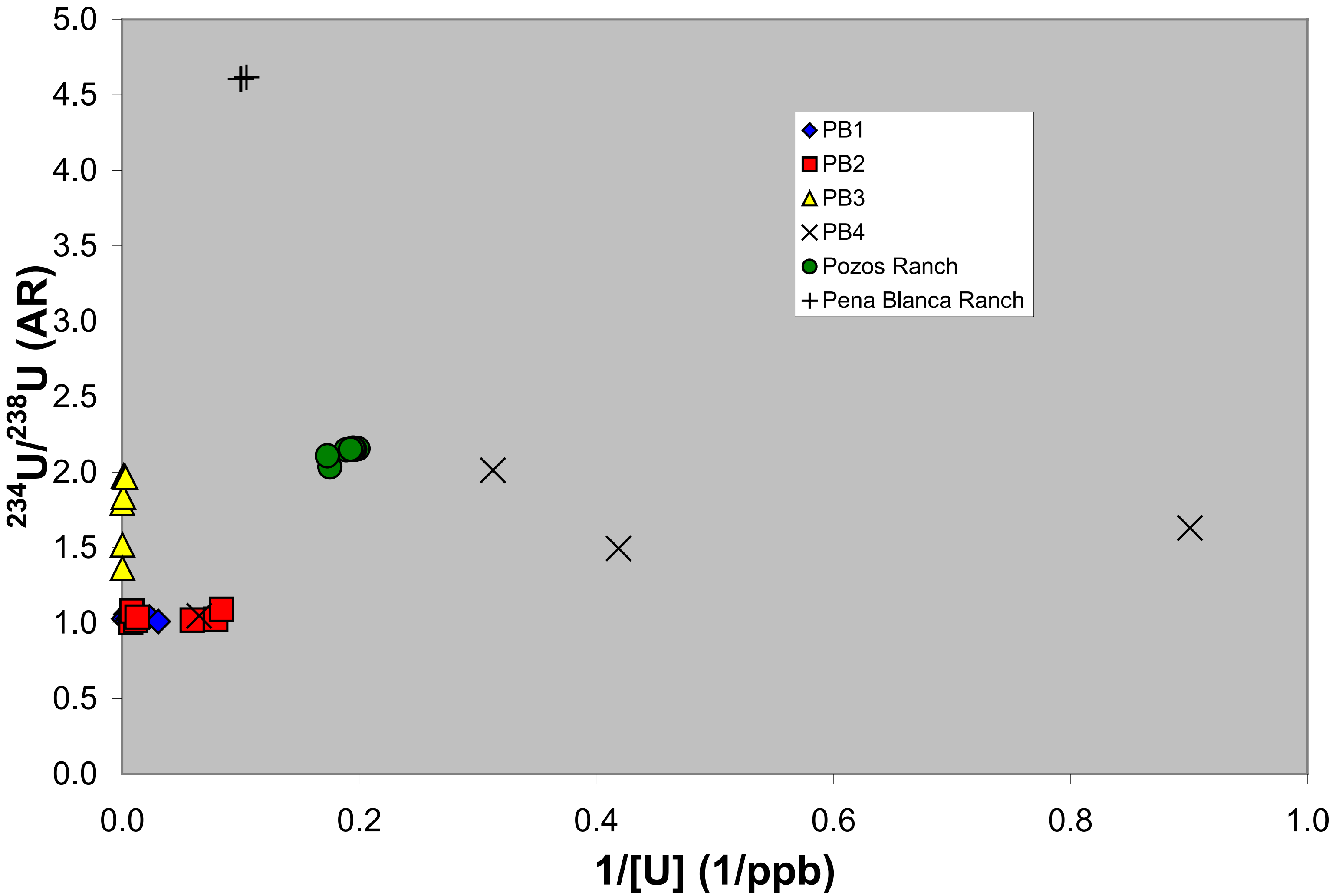
Unsaturated Zone Adit Water Sample Locations



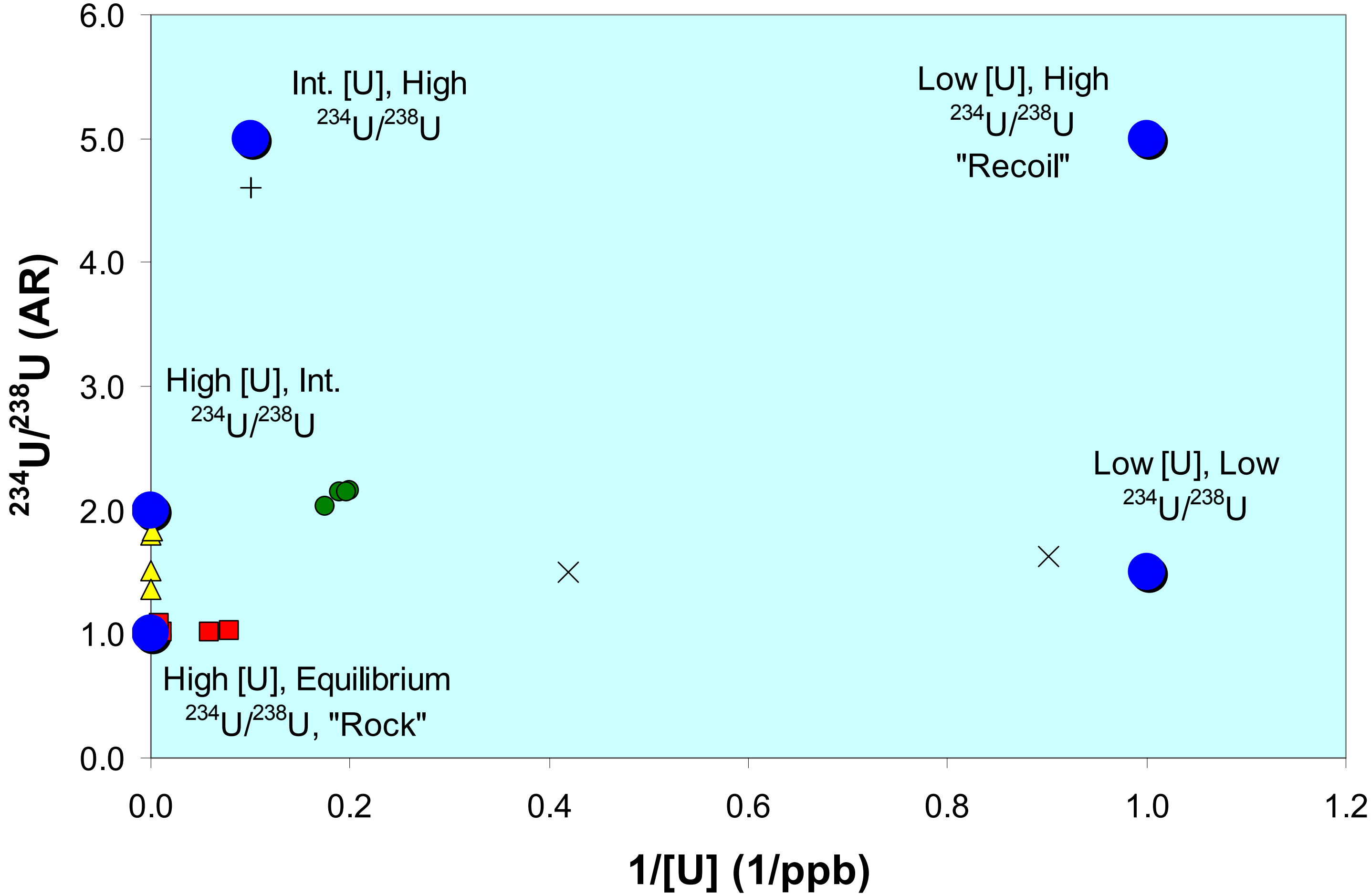
Uranium Time Series in Wells



Uranium Isotopic Results for Groundwater Wells



Multiple Components for U



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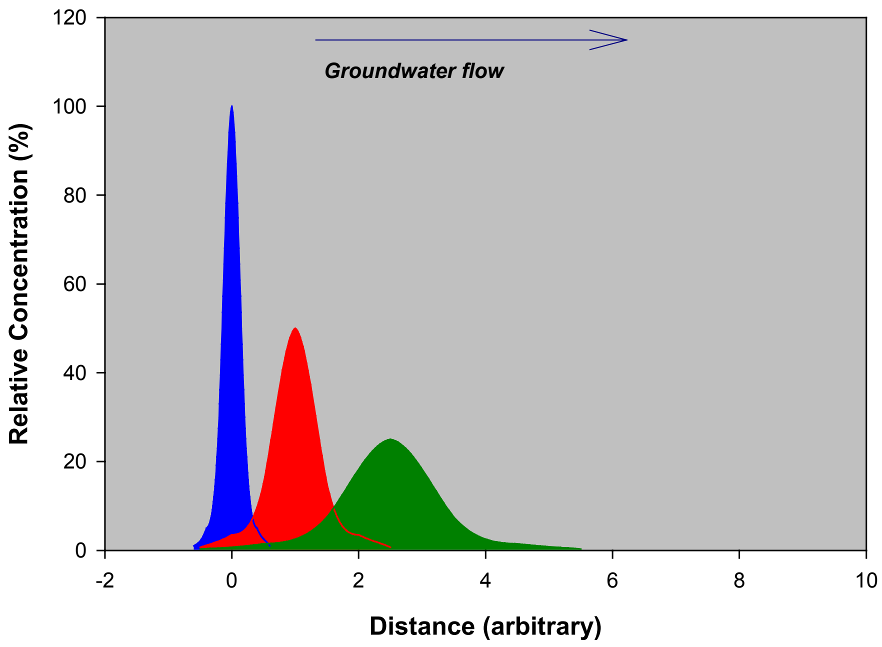
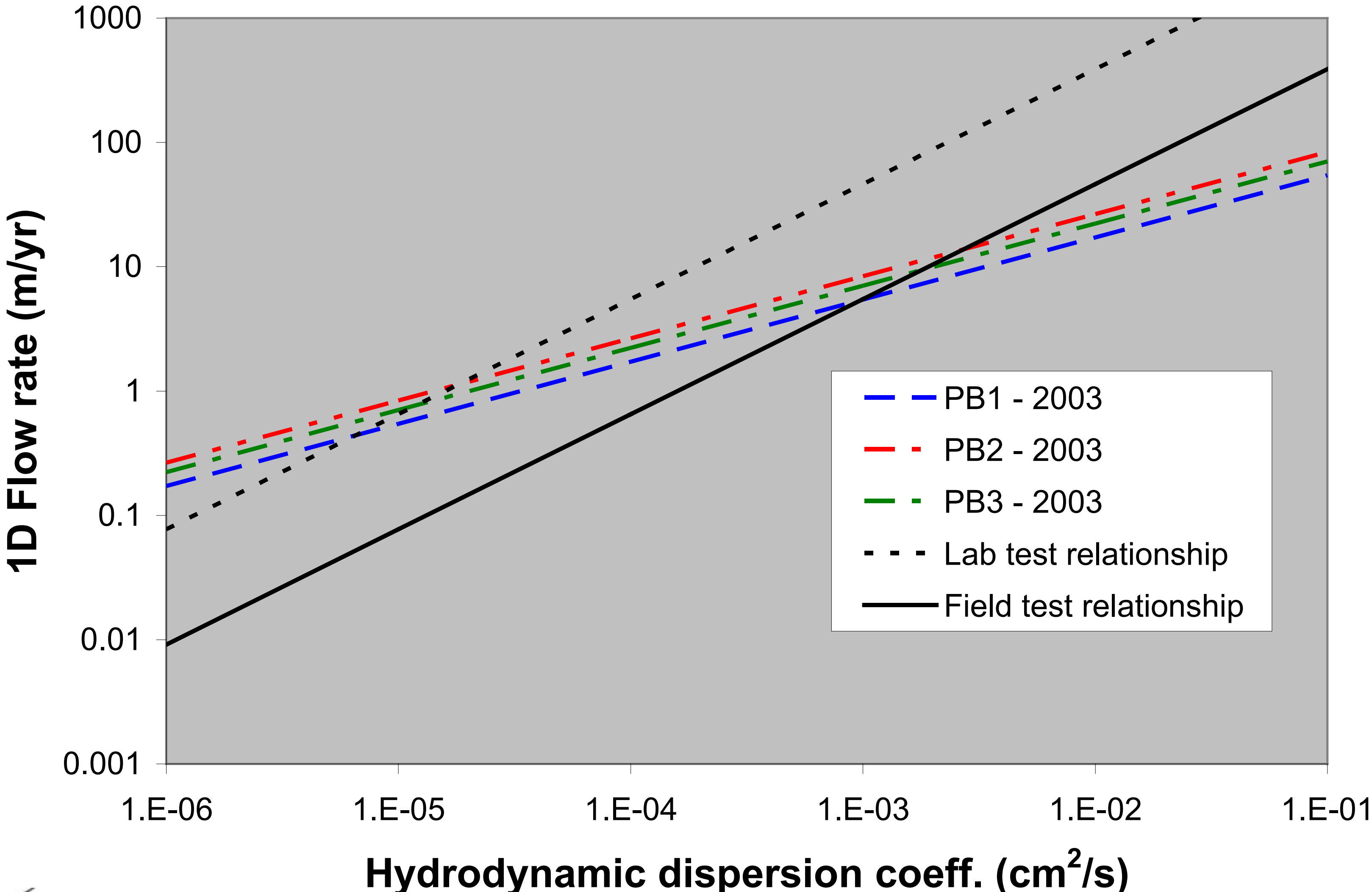
1-D Advection-Dispersion Model



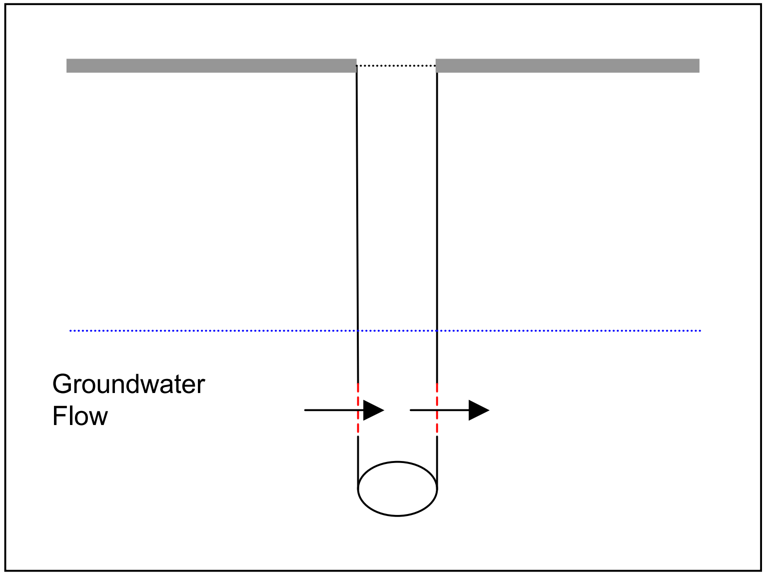
- **Model Assumptions**
  - **U introduced as a slug at t=0, x=0**
  - **U is a conservative tracer over short timescales (months-year)**
  - **Analytical solution in Bear (1979)**
- **Relative U concentration (*c*) controlled by position (*x*), time (*t*), groundwater velocity (*v*), and dispersion (*Dh*).**
- **Knowing *c2*, *c1*, *t2*, and *t1*, one can obtain a relationship between velocity and dispersion for each of the three wells:**

$$v = \sqrt{\frac{4Dh \ln\left((c2/c1)\sqrt{(t2/t1)}\right)}{t1 - t2}}$$

Advection-Dispersion Model Results



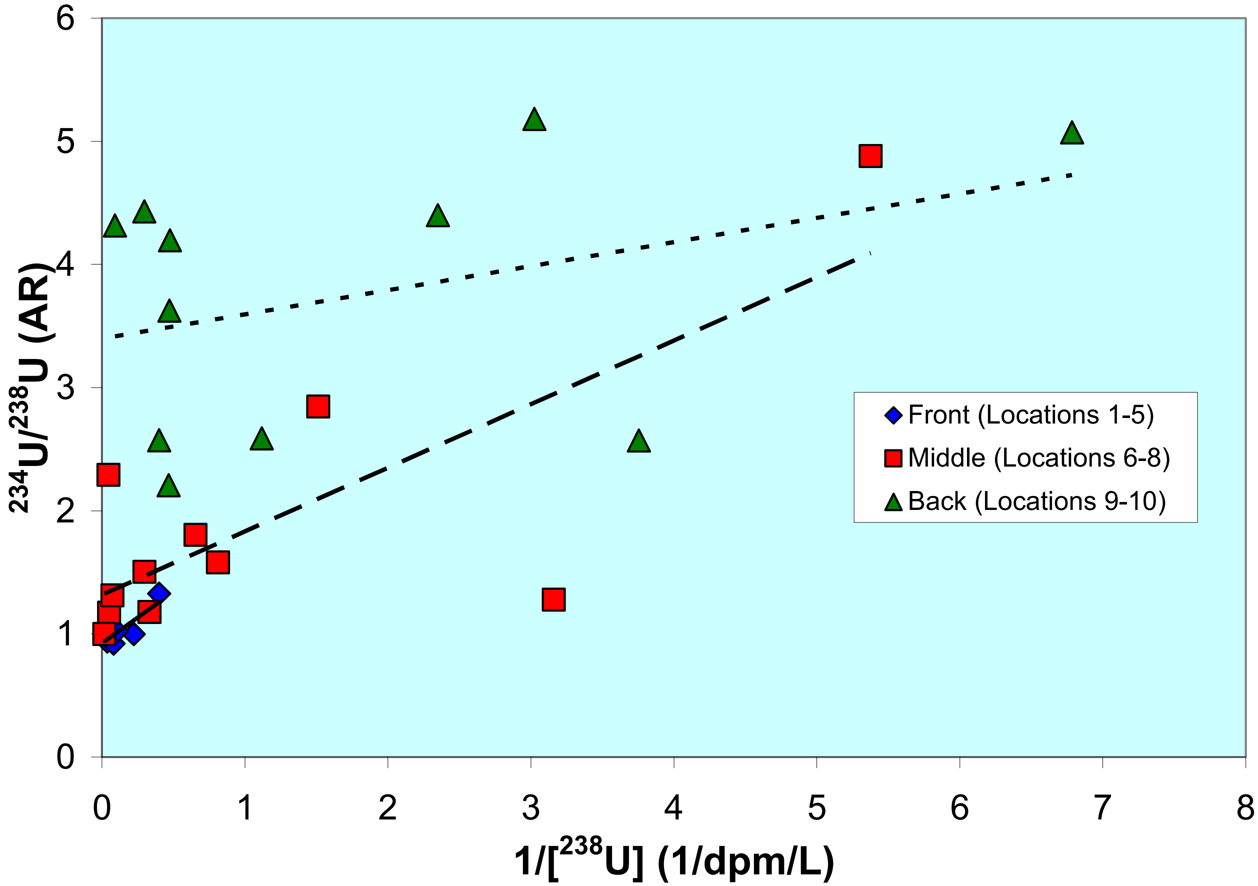
Tank Model



$$v = \frac{V}{2hr(t2 - t1)} \ln(c1/c2)$$

- One-dimensional
- Tank consists of saturated zone well volume
- Continuously diluted with groundwater of constant velocity, [U] ~ 0
- Velocity (*v*) is a function of saturated zone well volume (*V*), perforation height (*h*), drill hole radius (*r*), U concentration (*c1, c2*) and time (*t1, t2*)
- Calculated velocity ranges from 0.7 to 2.1 m/yr for the three wells

Uranium Isotopic Systematics in UZ Adit Water



Short-lived Nuclides: Retardation Factors

Well ID	R_f (Ra) (10^3)	R_f (Pb) (10^5)	R_f (Po) (10^6)
Pena Blanca Ranch	0.43 ± 0.02	0.59 ± 0.03	5.5 ± 0.4
Pozos Ranch	1.68 ± 0.08	6.1 ± 2.3	28 ± 15
PB4	1.19 ± 0.08	0.069 ± 0.005	0.068 ± 0.007

Results

- Decreasing U concentrations in newly drilled wells
- U isotope systematics for wells indicate multiple components for U with limited mixing
- Low groundwater flow rates
  - ~0.5 – 10 m/yr advection/dispersion model
  - ~0.7 – 2.1 m/yr advection tank model
  - Limited productivity of PB1, PB2, and PB3
- Spatial dependence of U isotope systematics for adit waters
  - Longer rock-water interaction times and higher U dissolution rates at the front of the adit where the deposit is located, consistent with observations
- High retardation factors calculated for Ra, Pb, and Po in local wells
  - Importance of colloidal transport for Th is currently being evaluated

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