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Objectives

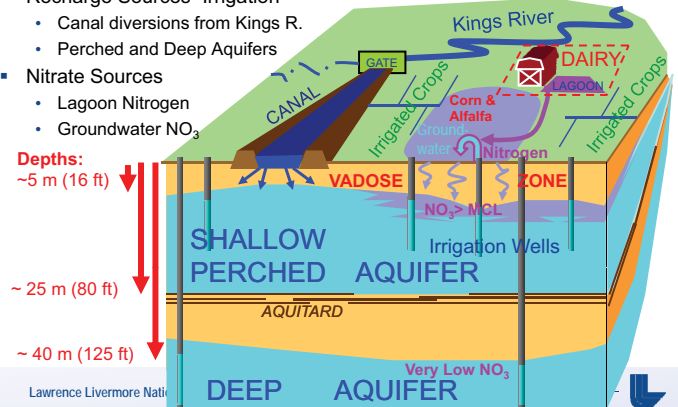
- Determine denitrification rate in shallow groundwater adjacent to a dairy in San Joaquin Valley, CA
 - Nitrate (NO_3) and excess nitrogen (N_2) data
 - Mass of NO_3 converted to N_2 (denitrification)
 - Location of denitrifying bacterial population
 - Tritium Helium-3 (^3H - ^3He) groundwater age
 - Groundwater recharge and flow rates
- Three Components to Determining Denitrification Rate**
- Improve interpretation of ^3H - ^3He age data
 - Account for ^3He "loss" in vadose zone
 - Explain why inferred ^3H source concentration is higher in groundwater than in surface water

Outline

- Dairy Site Setting and Data Collection
- ^3H - ^3He Age Processes and Modeling of Dairy Site Data
- Estimation of Denitrification Rate
- Conclusions and Key Consequences

Groundwater Hydrology of a Dairy Site in San Joaquin Valley, California

- Recharge Sources=Irrigation
 - Canal diversions from Kings R.
 - Perched and Deep Aquifers
- Nitrate Sources
 - Lagoon Nitrogen
 - Groundwater NO_3



Irrigation of a corn crop using shallow groundwater mixed with dairy lagoon water containing nitrogen

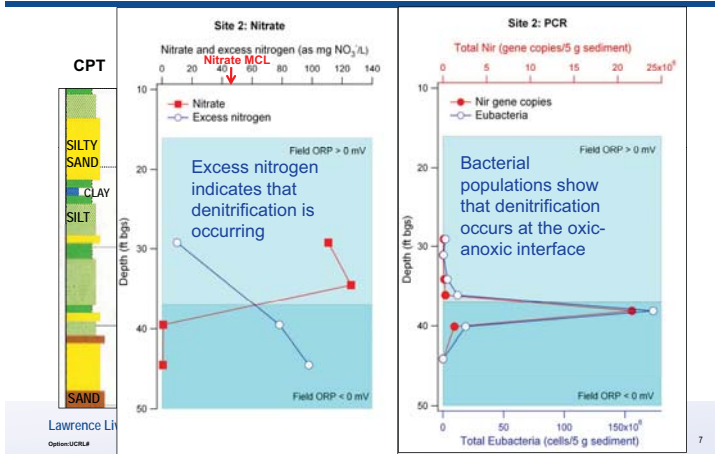


Dairy Site Characterization for Denitrification



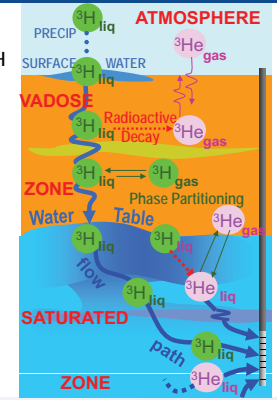
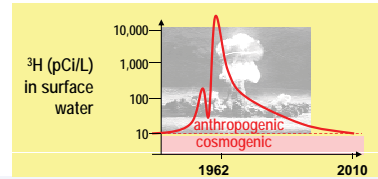
- CPT and Direct Push Sampling
 - Hydrostratigraphy/lithology
 - NO_3 and bacterial profiles
 - Redox conditions
- Multiple depth monitoring wells
 - Tritium Helium-3 Age
 - Excess N_2 (indicates denitrification)
 - Water Levels

A similar pattern of denitrification was observed throughout the dairy site, irrespective of lithology



Tritium Helium-3 (³H-³He) Groundwater Age Processes - Groundwater age depends on flow rates

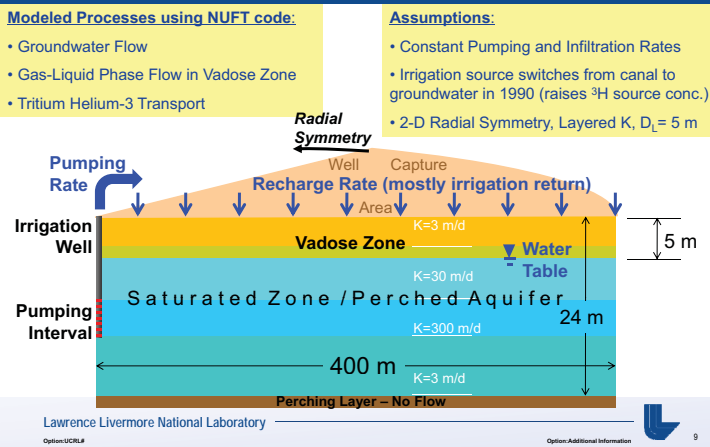
- Age (years) = 17.8 log(1 + ³He/³H)
- ³He accumulates by radioactive decay of ³H
- Clock starts at water table (not surface!)
- Non-Idealities:
 - Variable ³H source concentration
 - Vadose zone processes
 - Mixing in subsurface and at wellscreen



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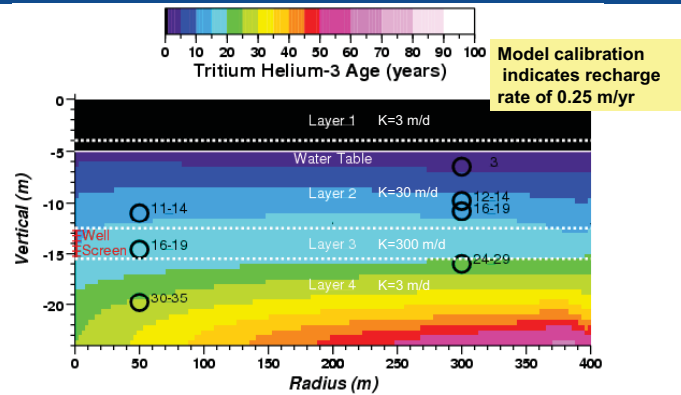
Option:Additional Information

Hydrogeologic Conceptual Model of Groundwater Flow System for Irrigated Dairy Crops



Model Results:

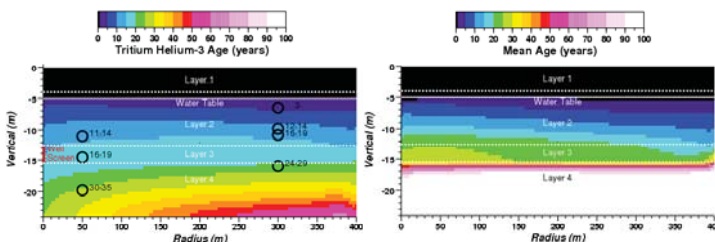
³H-³He Age compared to Dec 2004 and Feb 2005 Data



Model Results: Comparison of ³H-³He and Mean Groundwater Age

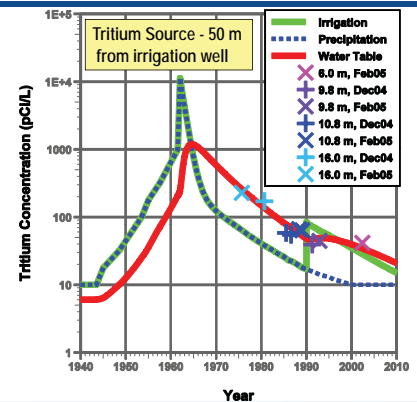
Our Gas-Liquid Phase ³H-³He modeling enables:

- Accurate calibration to the actual ³H-³He data
- Direct comparison ³H-³He age to mean groundwater age for same groundwater flow conditions



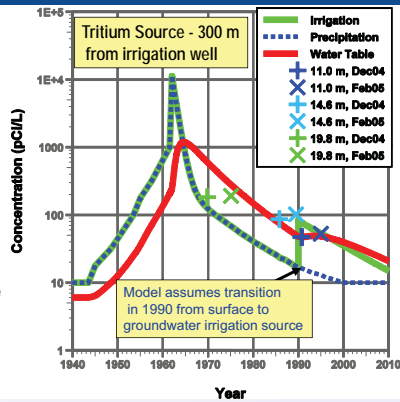
Modeled ³H concentration at water table matches ³H source concentration data near irrigation well

- {³H + ³He} indicates concentration of ³H source at year of recharge
- {³H + ³He} data are consistently 3-4 times higher than ³H in precipitation source
- Interpretation of ³H source requires consideration of vadose zone



Modeled ³H concentration at water table matches ³H source concentration data far from irrigation well

- Mismatch of deeper, older (~1970) groundwater may be explained by higher water table in past
- Increase in ³H source concentration relative ³H in precipitation can be explained by vadose zone and/or transition from canal to groundwater irrigation source



Estimated Denitrification Rates at Dairy Site = 4 to 50 g/yr-m³ bulk volume

- 50-200 mg/L decrease in NO₃ from denitrification
 - From multi-level sampling of NO₃ and excess N₂
- 1 to 3 m thick denitrifying zone
 - From PCR bacterial population data
- 0.25 m/year recharge rate (from irrigation return)
 - From model calibration to multi-level ³H-³He data

"Site 2" Data:

$$\left\{ 120 \text{ g NO}_3 / \text{m}^3 \text{ water} \right\} \times \left\{ 0.3 \text{ m}^3 \text{ water} / \text{m}^3 \text{ bulk volume} \right\} \times \left\{ 0.25 \text{ m} / \text{yr} / 0.3 \text{ porosity} \right\}$$

$$\frac{10 \text{ g NO}_3}{\text{yr} \cdot \text{m}^3 \text{ bulk volume}} \times 3 \text{ m} = \frac{30 \text{ g NO}_3}{\text{yr} \cdot \text{m}^3 \text{ bulk volume}}$$

From all sites:
4 to 50 g NO₃
yr · m³ bulk volume

Scientific/Technical Conclusions

- Denitrification is occurring in shallow groundwater beneath irrigated corn and alfalfa crops at the dairy site
 - ³H-³He, NO₃, excess N₂, and eubacteria population data can be used to estimate denitrification rate in the field
 - Our 4 to 50 g/year-m³ estimate is consistent
 - e.g., 3 to 54 g/year-m³ in a shallow sand/gravel aquifer (Smith and Duff, Appl. Environ. Microbiol., 1988)
- Non-idealities of ³H-³He age interpretation are addressed by our gas-liquid phase modeling framework
 - ³H-³He age does not necessarily coincide with mean age
 - Tritium (³H) data should be interpreted to assess
 - Vadose zone effects
 - Recharge source (e.g., surface water, shallow/deep groundwater, precipitation)

Key Consequences for policy/policy makers/decision makers

- Plan, monitor, and set policy knowing about denitrification
 - Ag-groundwater pumping network design
 - Multi-level monitoring wells – NO₃, excess N₂, redox
 - Local conditions/characteristics can mitigate NO₃ impact
- ³H-³He data should be included in nitrate studies
 - Available through California GAMA program
 - Knowledge of groundwater flow rates (e.g. from ³H-³He) is essential to assessment of nitrate transport and denitrification rates