Lawrence Livermore National Laboratory

Denitrification at a Dairy Site Supported by Gas-Liquid Phase Modeling of ^{3}H-^{3}He Groundwater Age

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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 (^{3}H-^{3}He) groundwater age
    - *Groundwater recharge and flow rates*

Three Components to Determining Denitrification Rate

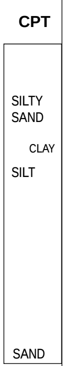
- Improve interpretation of ^{3}H-^{3}He age data
  - Account for ^{3}He "loss" in vadose zone
  - Explain why inferred ^{3}H source concentration is higher in groundwater than in surface water

Outline

- Dairy Site Setting and Data Collection
- ^{3}H-^{3}He 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

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

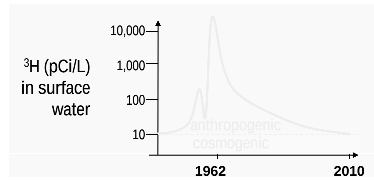


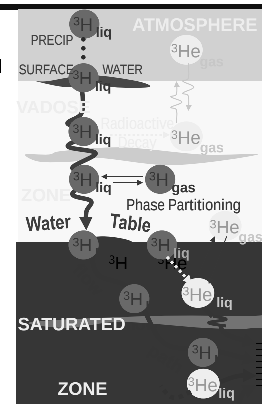
Excess nitrogen indicates that denitrification is occurring

Bacterial populations show that denitrification occurs at the oxic-anoxic interface

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

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

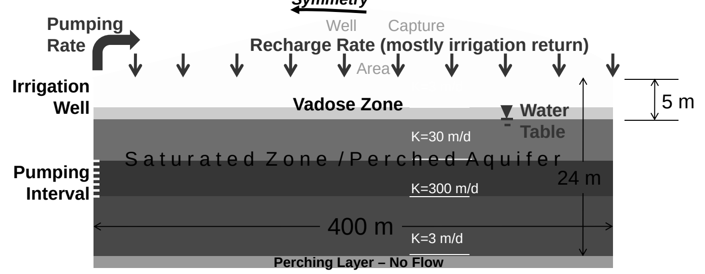




Hydrogeologic Conceptual Model of Groundwater Flow System for Irrigated Dairy Crops

<u>Modeled Processes using NUFT code</u>:
- Groundwater Flow
- Gas-Liquid Phase Flow in Vadose Zone
- Tritium Helium-3 Transport

<u>Assumptions</u>:
- Constant Pumping and Infiltration Rates
- Irrigation source switches from canal to groundwater in 1990 (raises ^{3}H source conc.)
- 2-D Radial Symmetry, Layered K, D_L= 5 m



<u>Model Results:</u> ^{3}H-^{3}He Age compared to Dec 2004 and Feb 2005 Data

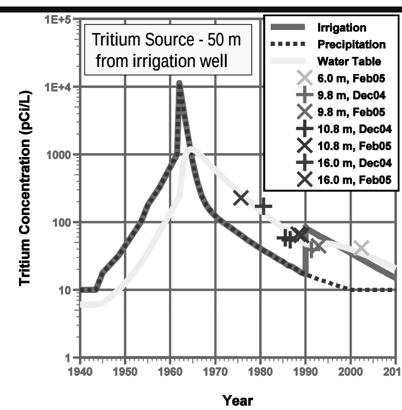
Model calibration indicates recharge rate of 0.25 m/yr

<u>Model Results:</u> Comparison of ^{3}H-^{3}He and Mean Groundwater Age

<u>Our Gas-Liquid Phase ^{3}H-^{3}He modeling enables:</u>
- **Accurate calibration to the actual ^{3}H-^{3}He data**
- **Direct comparison ^{3}H-^{3}He age to mean groundwater age for <u>same groundwater flow conditions</u>**

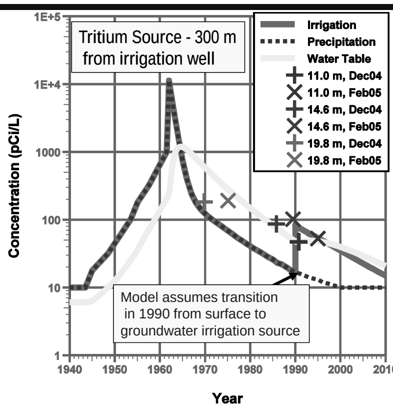
Modeled ^{3}H concentration at water table matches ^{3}H source concentration data near irrigation well

- {^{3}H + ^{3}He} indicates concentration of ^{3}H source at year of recharge
- {^{3}H + ^{3}He} data are consistently 3-4 times higher than ^{3}H in precipitation source
- Interpretation of ^{3}H 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-m^3 bulk volume

- 50-200 mg/L decrease in NO_3 from denitrification
  - From multi-level sampling of NO_3 and excess N_2
- 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:

$$\frac{\{120g\ \mathrm{NO_3}/m^3\ \text{water}\}\times\{0.3m^3\ \text{water}/m^3\ \text{bulk volume}\}\times\{0.25m/yr/0.3\ \text{porosity}\}}{3m}$$

$$=\frac{10g\ \mathrm{NO_3}}{yr\cdot m^3\ \text{bulk volume}}$$

From all sites:

$$\frac{4\ \text{to}\ 50g\ \mathrm{NO_3}}{yr\cdot m^3\ \text{bulk volume}}$$

Scientific/Technical Conclusions

- Denitrification is occurring in shallow groundwater beneath irrigated corn and alfalfa crops at the dairy site
  - ^3H-^3He, NO_3, excess N_2, and eubacteria population data can be used to estimate denitrification rate in the field
  - Our 4 to 50 g/year-m^3 estimate is consistent
    - e.g., 3 to 54 g/year-m^3 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 – NO_3, excess N_2, redox
  - Local conditions/characteristics can mitigate NO_3 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