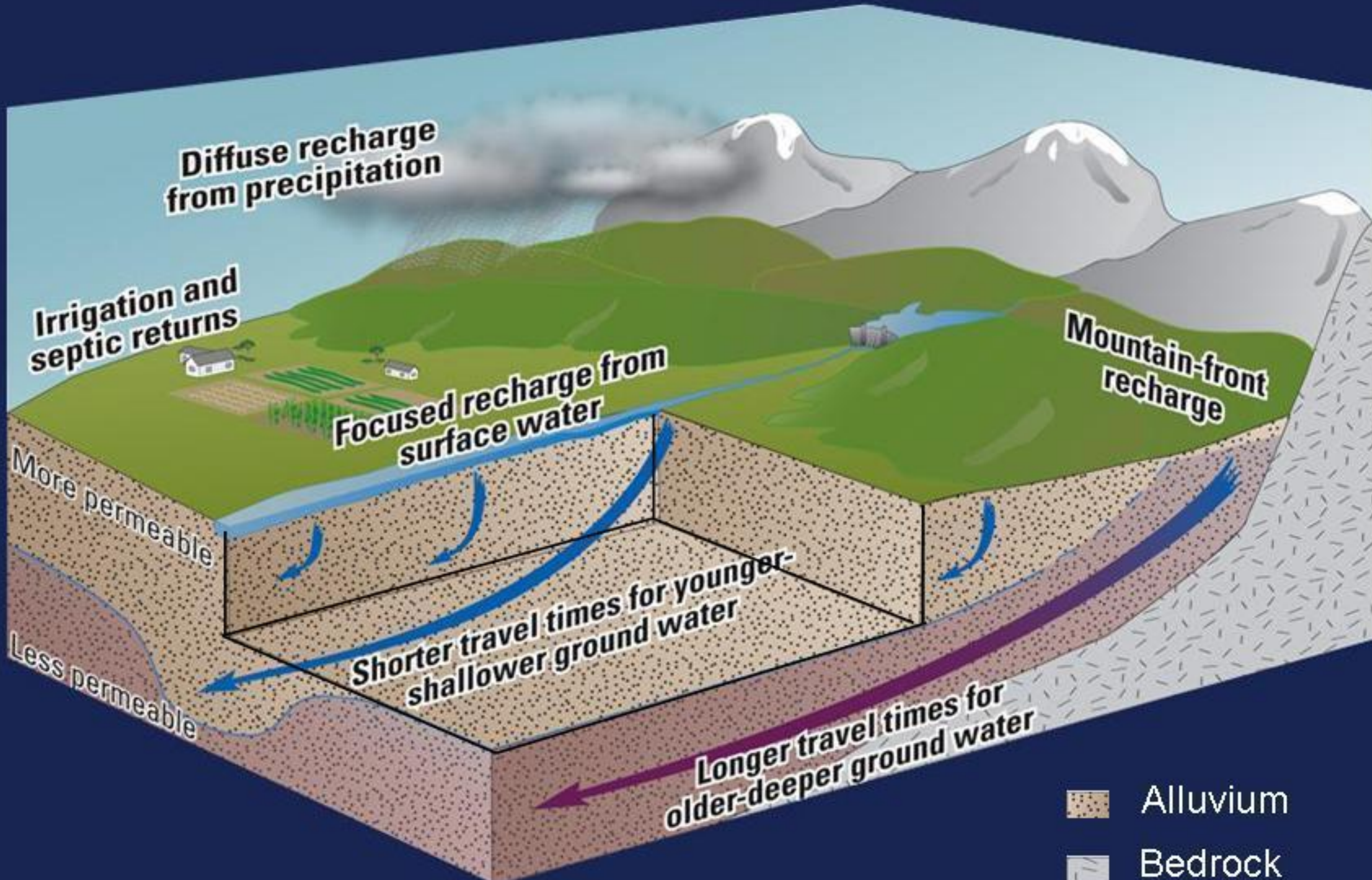
Collaborative Research on the Future of Groundwater Resources in California

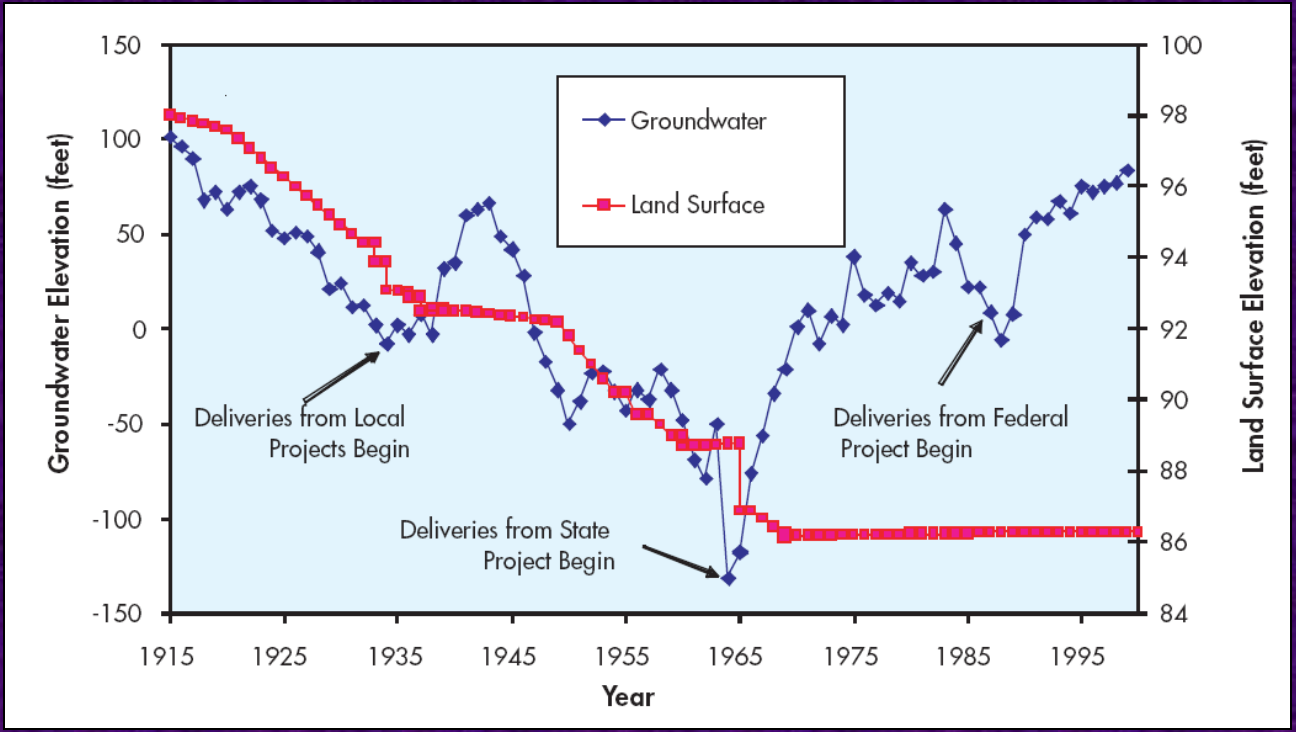
Jean E. Moran (California State University East Bay)
in collaboration with
Lawrence Livermore National Laboratory and
the State Water Resources Control Board GAMA Program

Recharge sources and movement



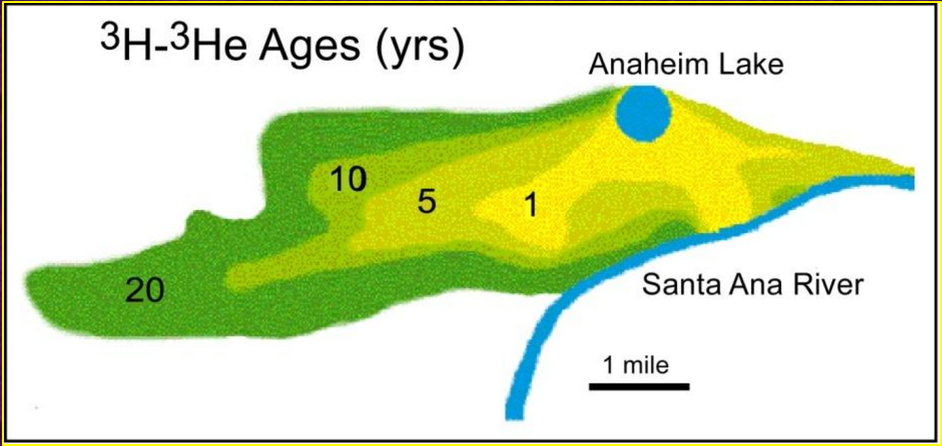
From Sierran to Central Valley and Coastal Basins

We know what happens when extraction exceeds recharge for decades

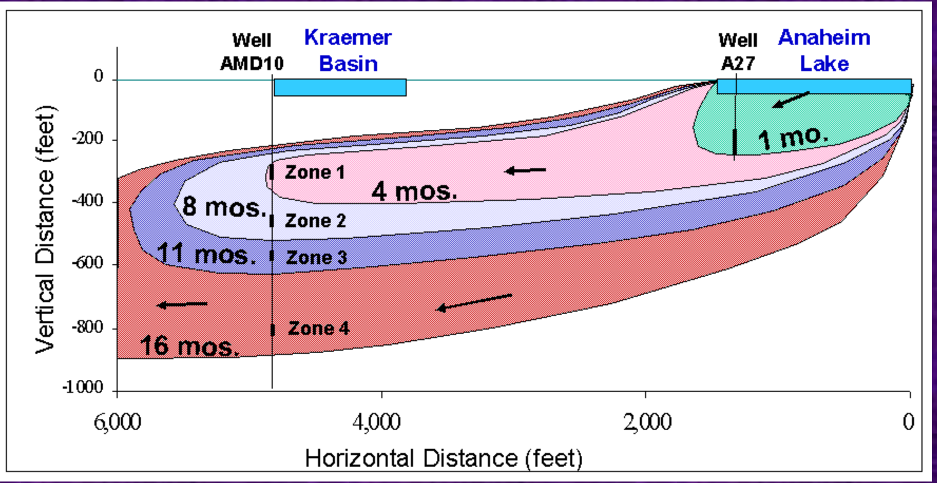


Groundwater banking science needs

- **Identification of suitable areas** for groundwater banking
- **Determination of travel times** for banking of recycled wastewater
- **Identification of recharged water** to establish ownership
- **Understanding water quality changes** associated with banking of high-quality surface water in the subsurface
- **Understanding transport of emerging contaminants** during groundwater recharge



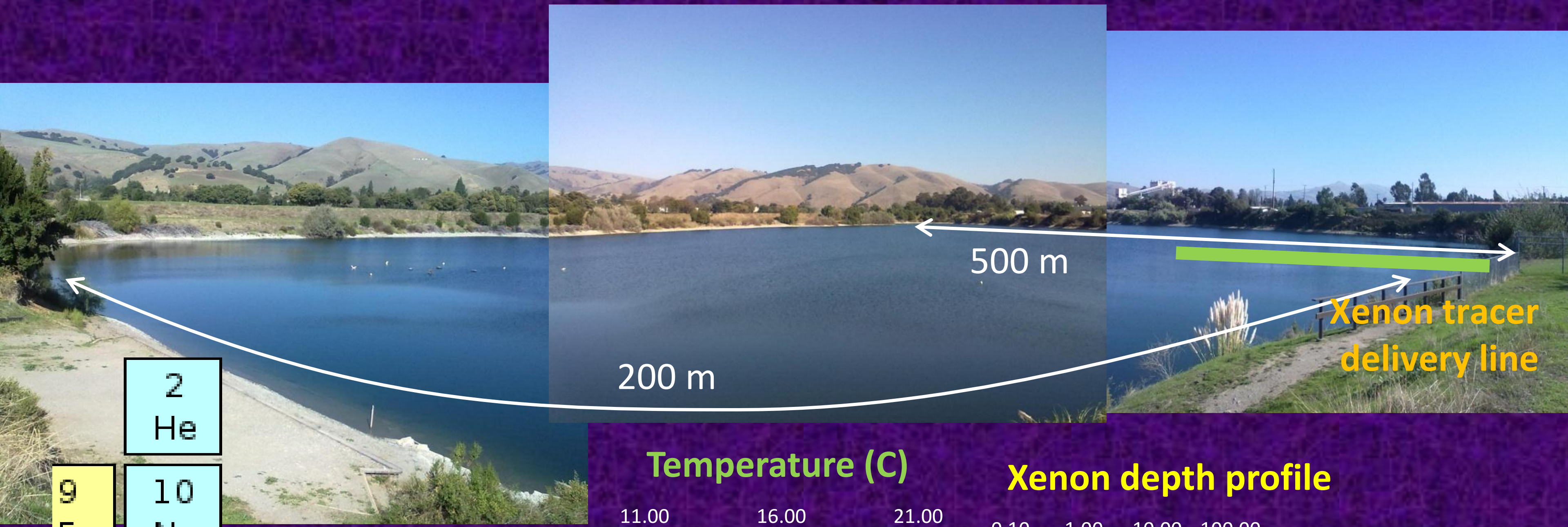
Natural age tracer

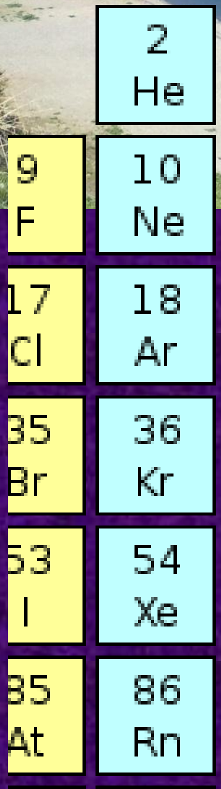


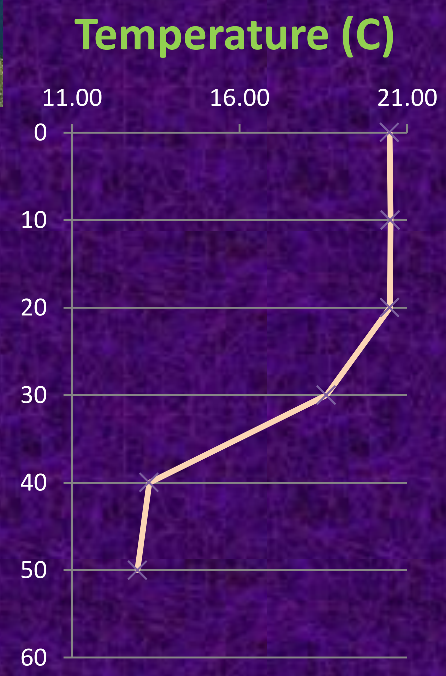
Introduced xenon tracer

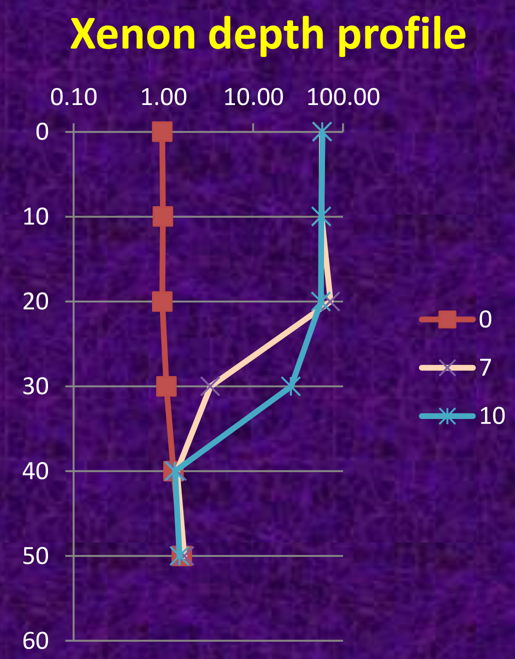
Groundwater recharge can be tracked using natural & introduced tracers

Xenon Tracer Experiment

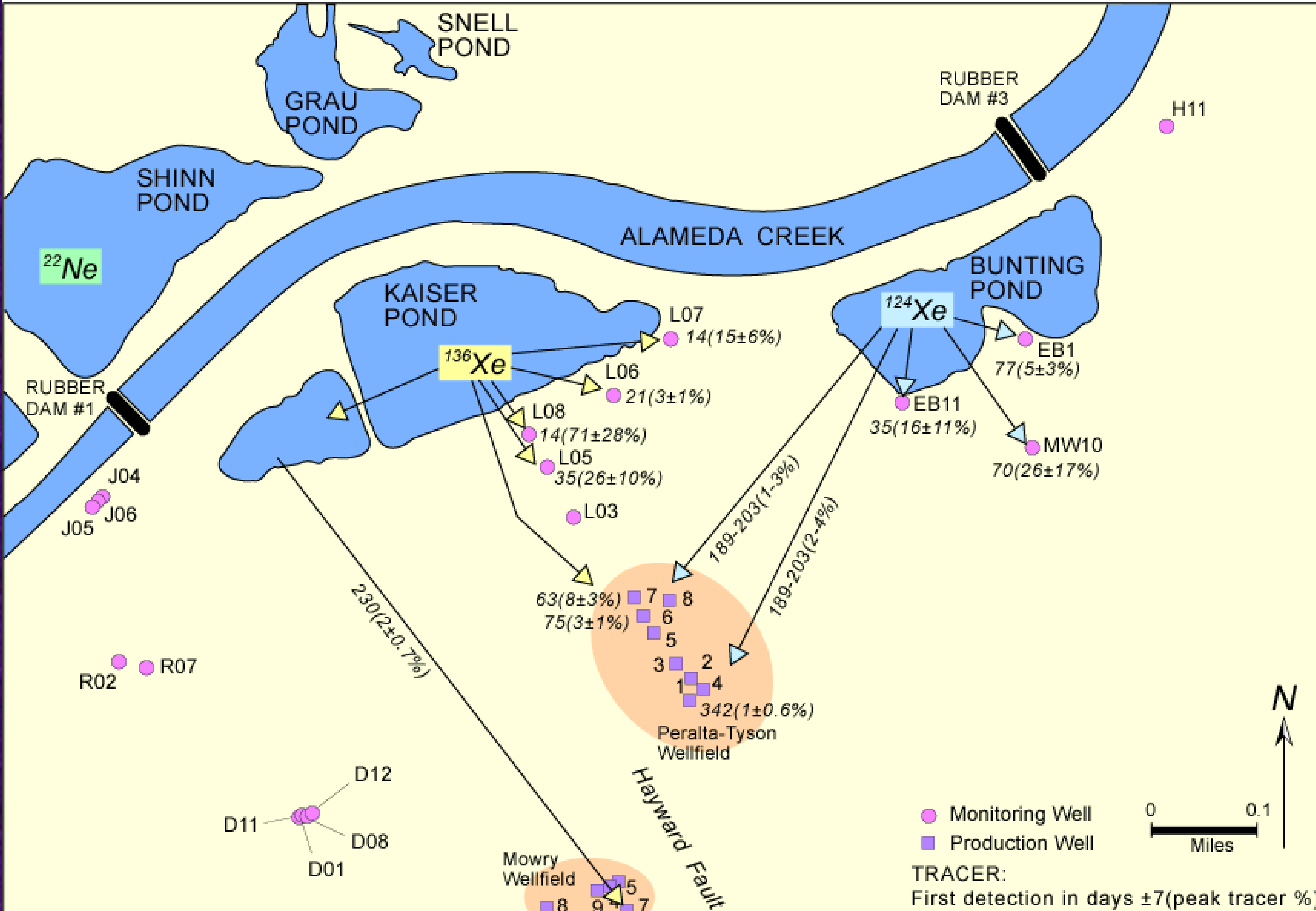


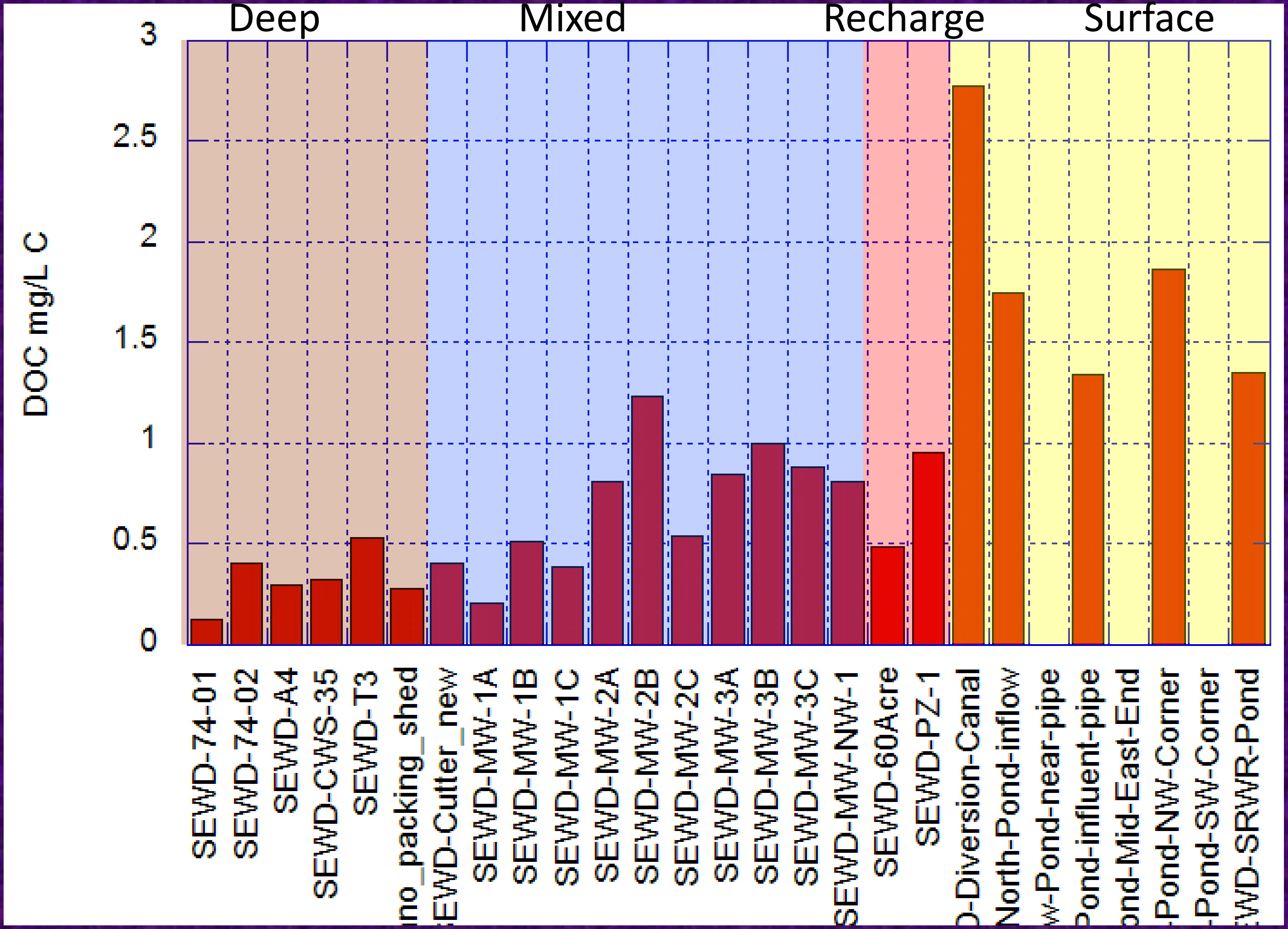




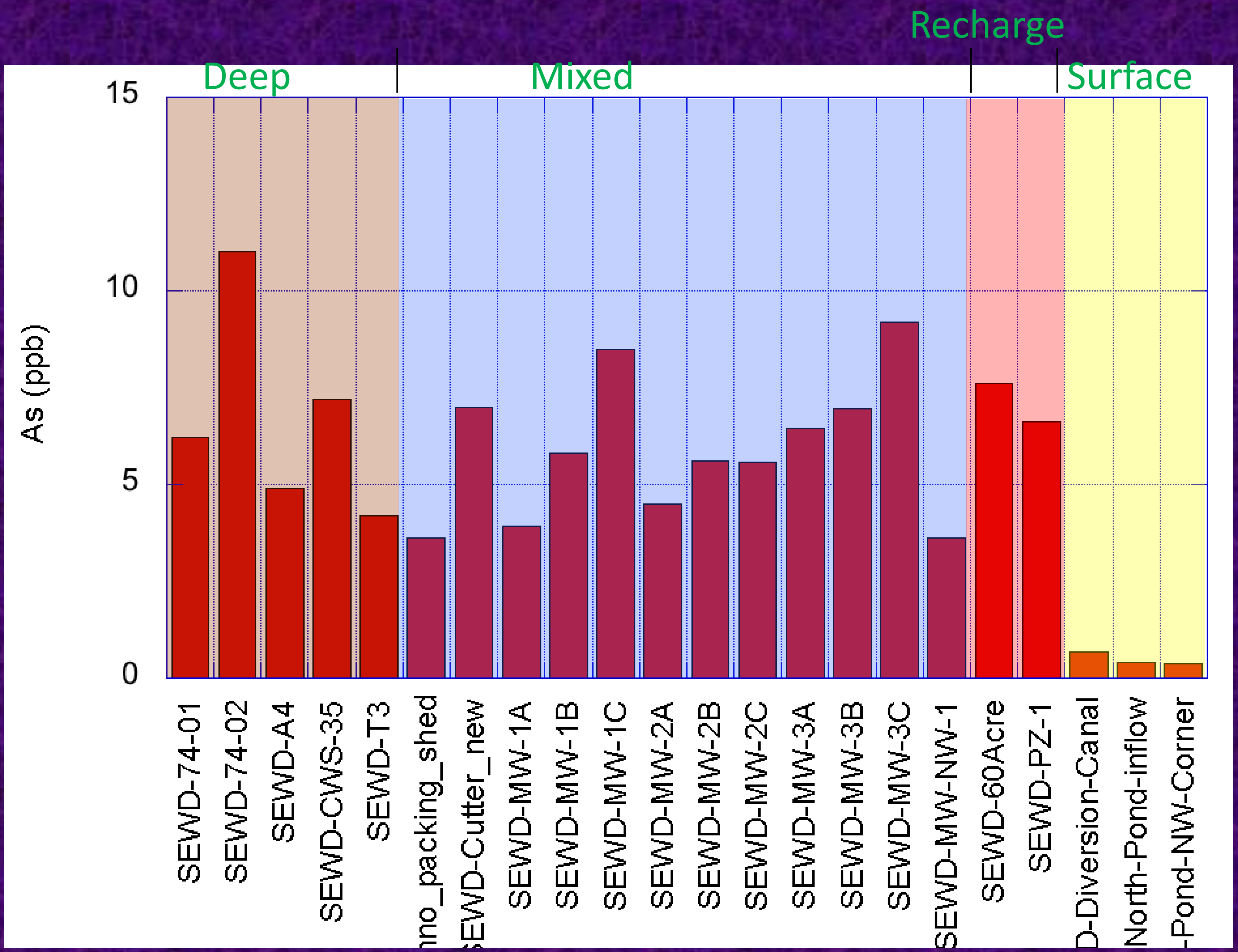


ALAMEDA COUNTY WATER DISTRICT WELLS





Documenting improvements in water quality during artificial recharge



Cautionary tale of Arsenic mobilization

Comparison of Methods to Determine Retention Time to drinking water wells

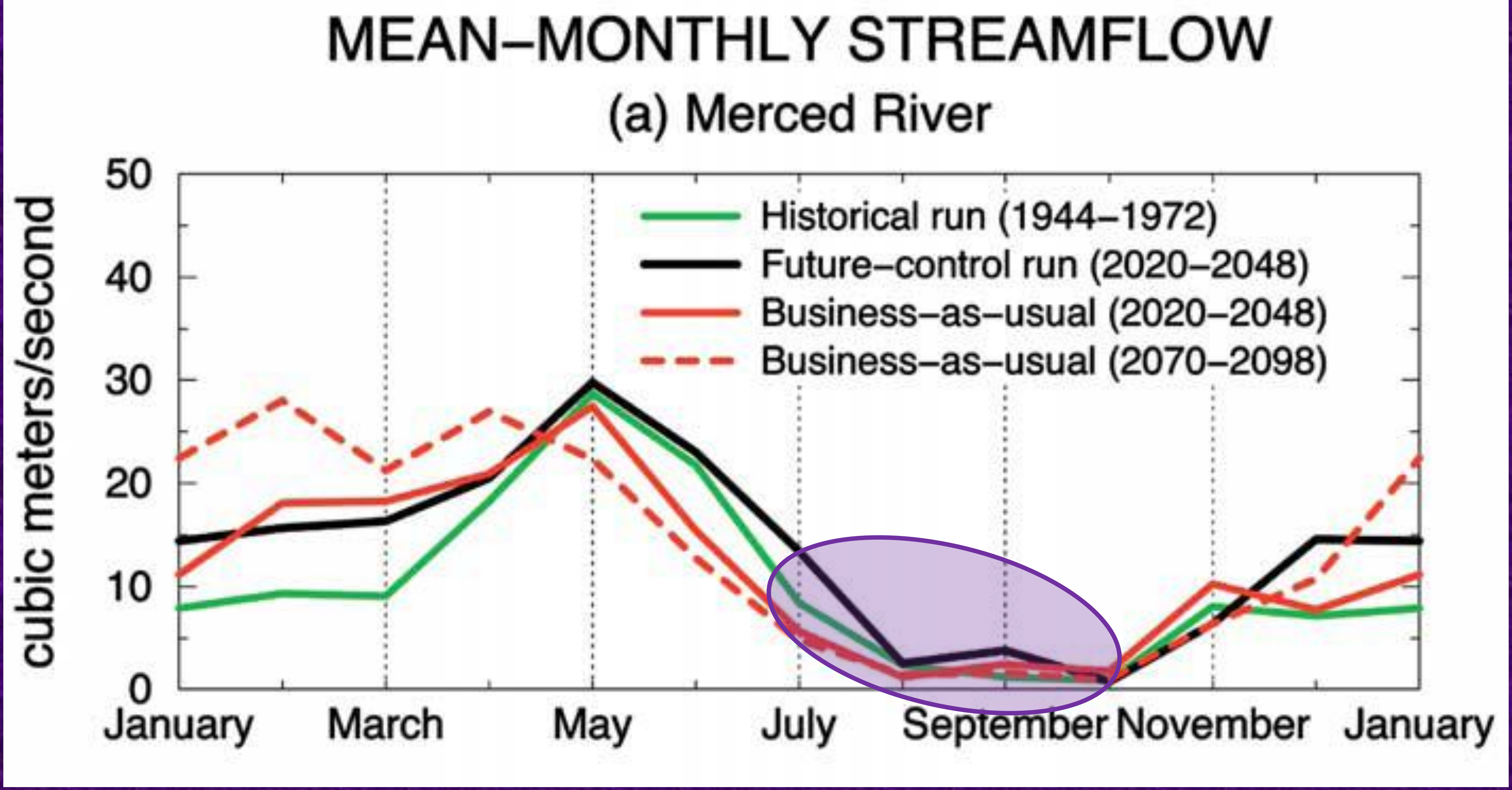
Planning and Engineering Report Effort vs. Retention Time				
Method	General Accuracy	General Level of Effort	Retention Time (months)	Safety Factor
Formula (Darcy's)	Poor	some info on aquifer	24	4
3-D model	Fair	lot of info on aquifer	12	2
Intrinsic Tracer	Better	sampling of existing indicators	9	1.5
Added Tracer	Desired	track added tracer	6	1.0

Tracers for groundwater banking

Locations of noble gas tracers experiments

- Noble gases are ideal groundwater tracers
- Can generate detailed measurements of groundwater movement
- Determine groundwater velocity, dispersion, with a large dynamic range
- Safe, readily accepted, cost effective

High Certainty for Earlier Peak Streamflow

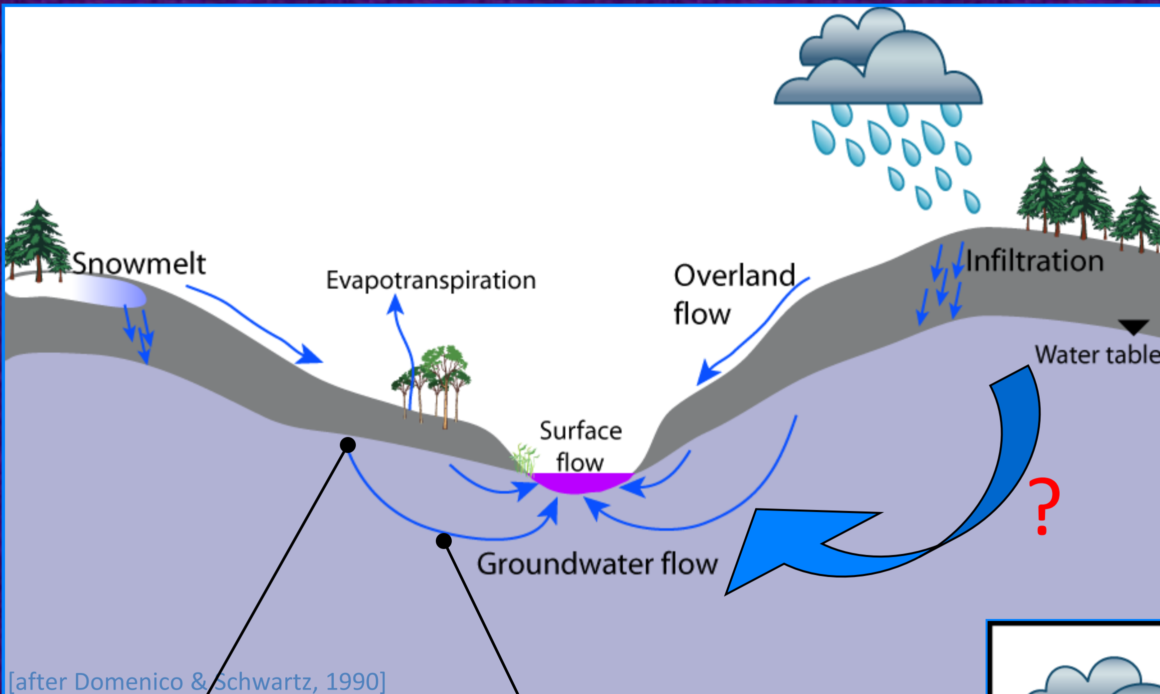


From: Dettinger et al., 2004

Challenges in predicting effects of climate change on groundwater

- Recharge is strongly influenced by changes in precipitation amount, which is not as well-predicted as temperatures
  - Small changes in precipitation may result in large changes in recharge in semi-arid, arid climates
- Downscaling is major issue for predicting GW response
- Wide range in subsurface residence times of complicates response of surface water-groundwater interaction
- Non-climatic drivers exert large influence on recharge and groundwater levels

Connections between snowmelt and groundwater recharge are poorly understood

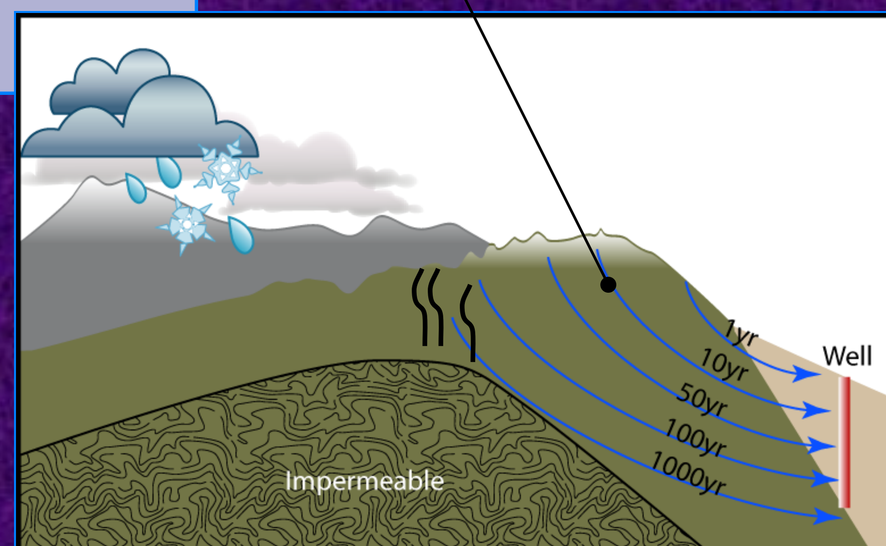


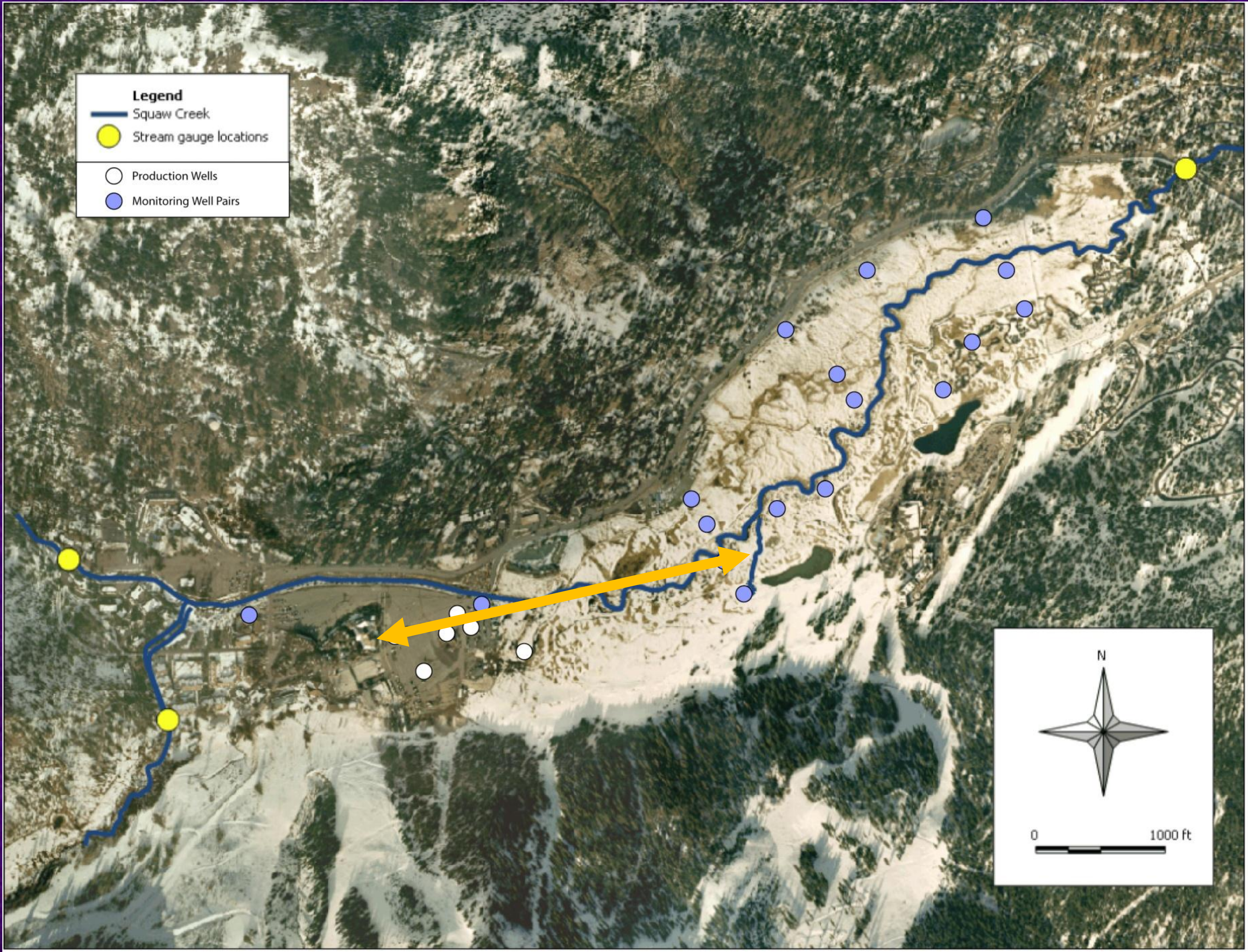
[after Domenico & Schwartz, 1990]

When and where does recharge take place? What is the residence time of groundwater?

Groundwater Age
^3H-^3He, $^4He_{rad}$

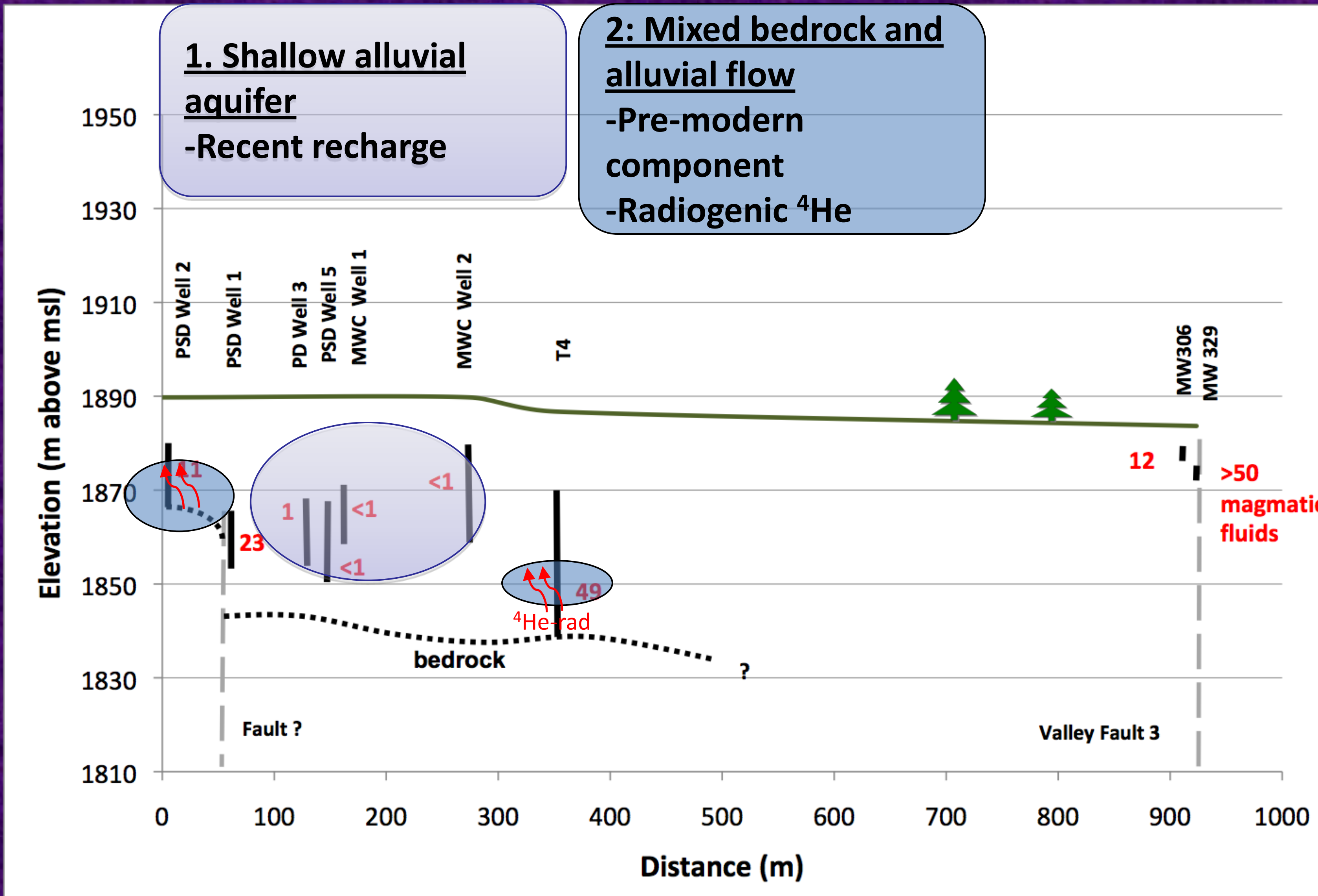
Noble Gases
Recharge Temperature
Excess Air





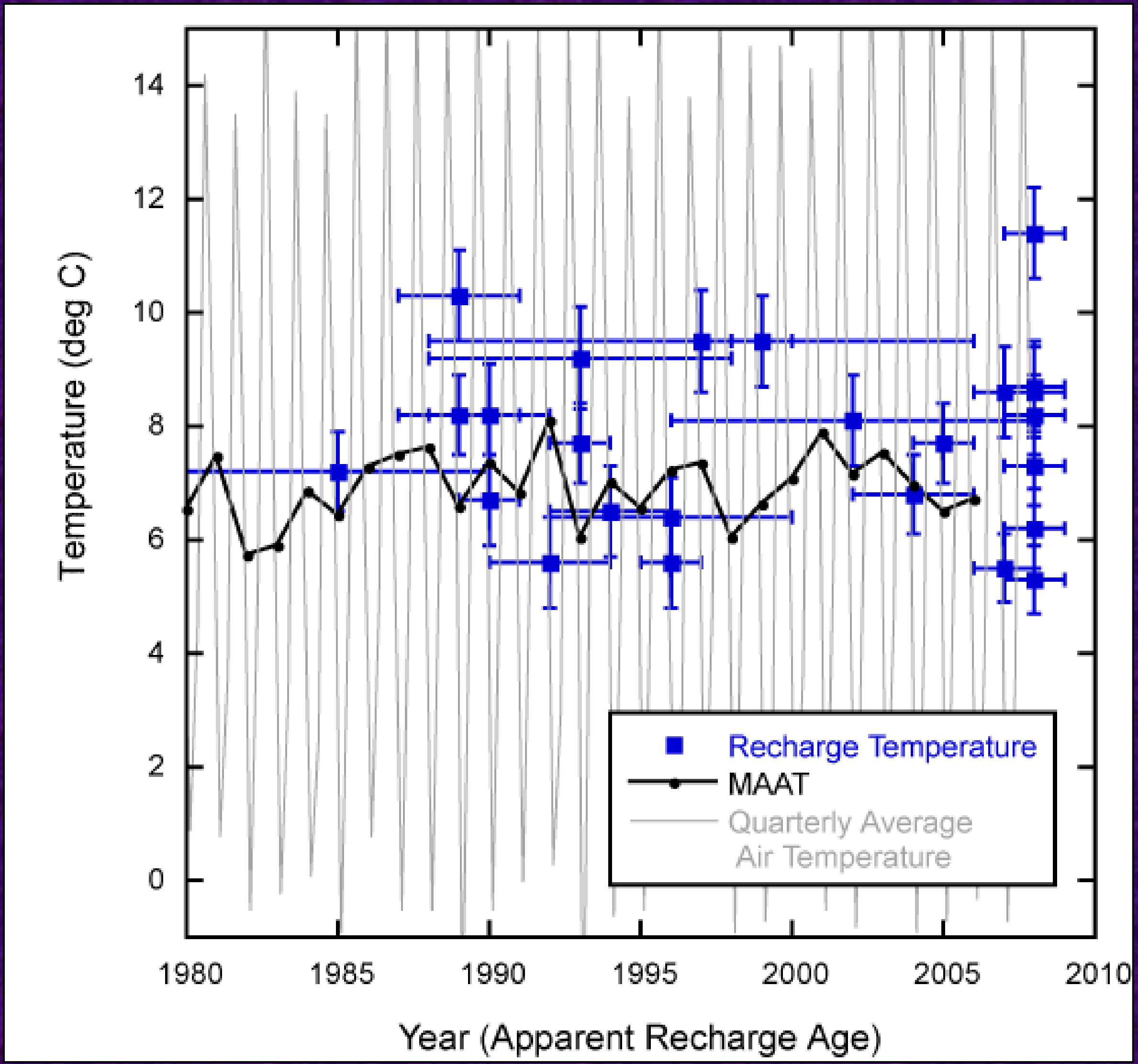
Olympic Valley: 6 production wells, 22 monitoring wells, 3 stream flow gauges, 2 horizontal wells

Groundwater Ages - Cross Section



Recharge temperatures reveal timing and location of recharge

- RTs consistent with or slightly higher than MAATs
- Mean RT (7.8C) matches monthly mean air temperature for May (7.7C)
- Under current conditions, most recharge occurs during May-June



Findings: Recharge location and residence time

- Recharge occurs on lower slopes of catchment
  - Recharge temperatures close to mean annual air temperature and higher than expected for direct infiltration of snowmelt
  - Low excess air – minimal recharge through fractured rock
  - $\delta^{13}C$ of DIC indicates exchange with soil gas CO_2
- Groundwater (even deep groundwater) in upstream portion of the basin is young

Effects of Climate Change

Climate Change Scenarios	Effect on Recharge and Discharge
More precip as rain, extended period of runoff	More recharge, if precip rate is lower than current snowpack melt rate
Earlier runoff	Early decreased baseflow (fast drainage)
More rain on snow events	Increased overland flow, less recharge to alluvium
More nights above freezing temp.	More saturation-induced overland flow, less recharge
Less total precip	Less recharge, near immediate effect on GW availability and streamflow

Effects will be immediate and drastic at Olympic Valley

Acknowledgements and Publications

- Squaw Valley Public Services District
  - Derrik Williams
    (Hydrometrics LLC)
- Alameda County Water District (Mikel Halliwell)
- Orange County Water District (Roy Herndon)
- Students:
  - C. Cox, C. Tulley, C. Barton, G. Rhett, D. Meyer, H. Bigman , Elizabeth Derubeis, Marianne Holtz, Pamela Beitz
- LLNL Labs:
  - Noble Gas Lab (D. Hillegonds, M. Sharp, A. Visser)

- Moran, J.E., Esser, B.K., Hillegonds, D. Holtz, M., Roberts, S.K., Singleton, M.J., Visser, A. (2011) Nitrate fate and transport in the Salinas Valley. LLNL-TR-484186, 38pp.
-
- O'Leary, D.R., Izbicki, J.A., Moran, J.E., Meeth, T., Nakagawa, B., Metzger, L.,
- Bonds, C., Singleton, M.J. (2011) Movement of Water Infiltrated from a Recharge
- Basin to Wells. *Ground Water* doi: 10.1111/j.1745-6584.2011.00838.x.
-
- Singleton, M.J. and Moran, J.E. (2010) Dissolved noble gas and isotopic tracers reveal vulnerability of groundwater in a small, high elevation catchment to predicted climate changes. *Water Resources Research* doi: 10.1029/2009WR008718.
-
- McNab, W.W., Singleton, M.J., Moran, J.E., Esser, B.K. (2009) Ion exchange and trace element surface complexation reactions associated with applied recharge of low-TDS water in the San Joaquin Valley, California. *Applied Geochemistry*, 24, 129-137.