An Examination of the Vulnerability of Groundwater to Climate Change in Olympic Valley

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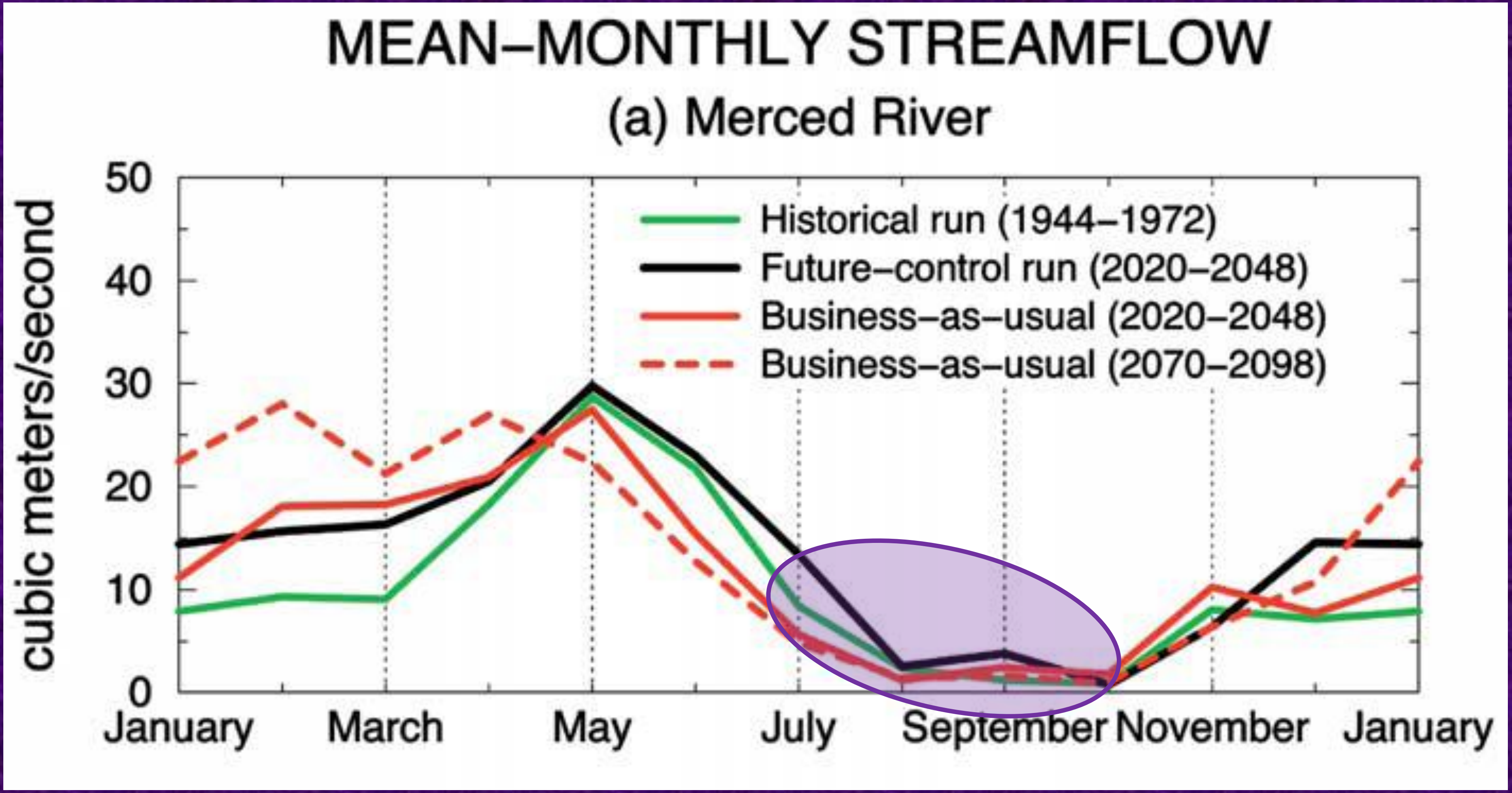
Presentation Outline

- Predicted effects of climate change on runoff and groundwater
- Effects particular to alpine/subalpine (snowmelt dominated) groundwater basins
- Dissolved gas and isotopic tools applied
- Results from Olympic Valley groundwater basin
- Implications for recharge under warmer climate conditions

High Certainty for Earlier Peak Streamflow

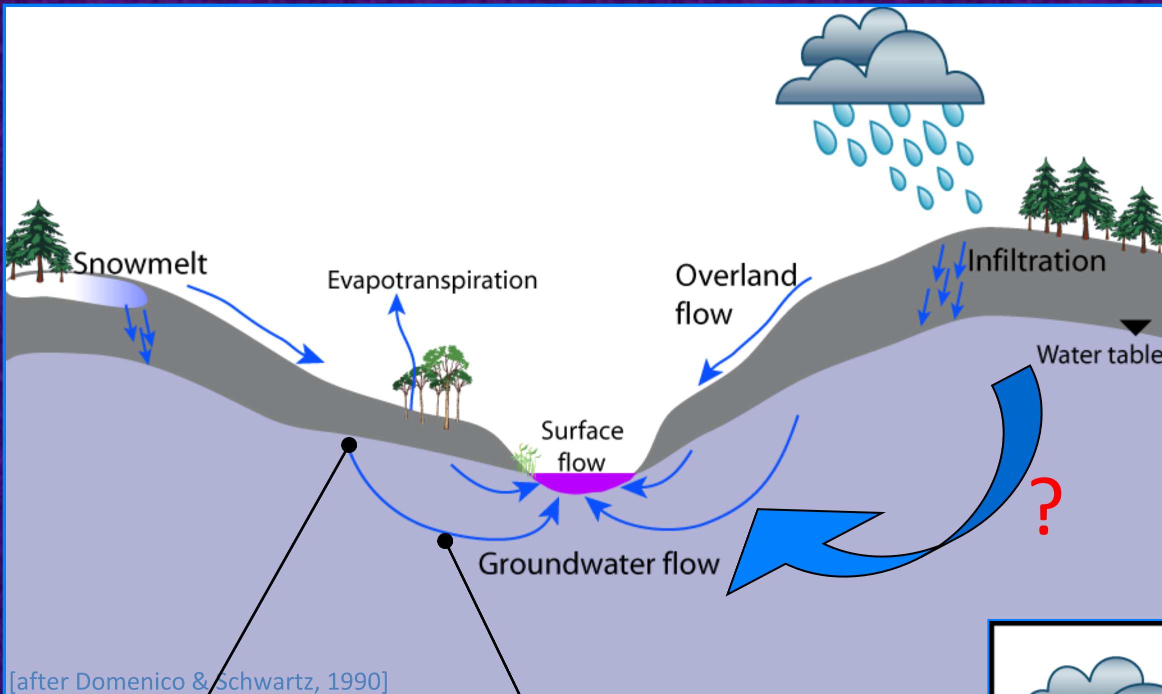


From: Dettinger et al., 2004

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

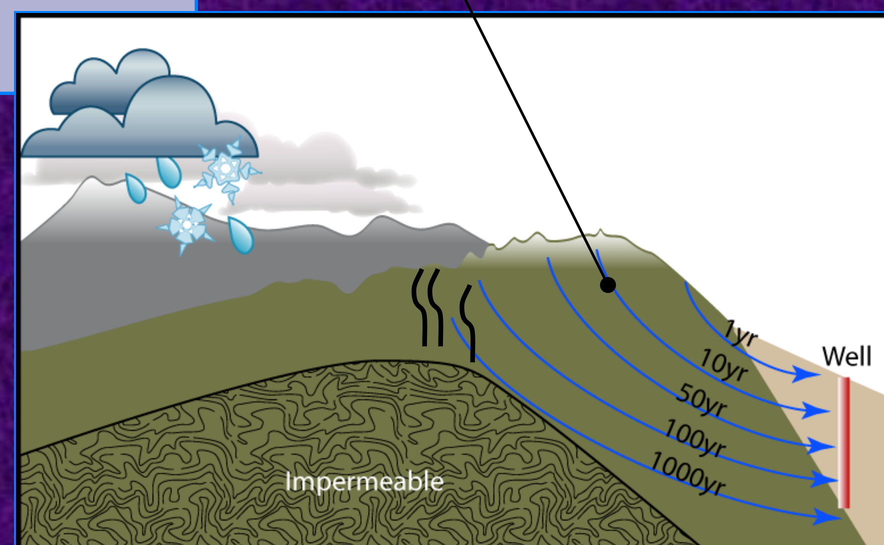


[after Domenico & Schwartz, 1990]

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

Noble Gases
Recharge Temperature
Excess Air

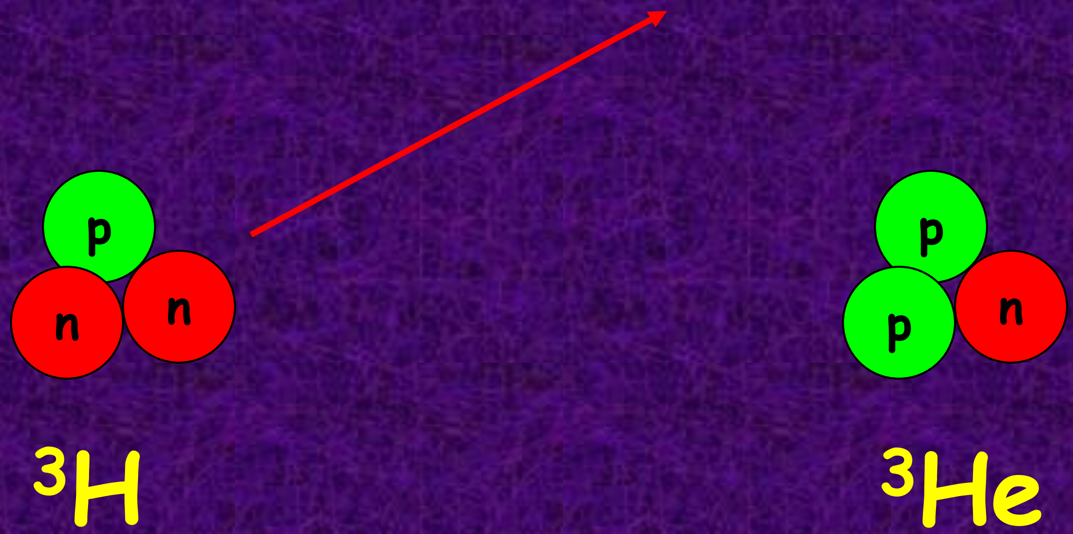
Groundwater Age
^{3}H-^{3}He, $^{4}He_{rad}$



Climate change effects that are particular to alpine/sub-alpine GW basins

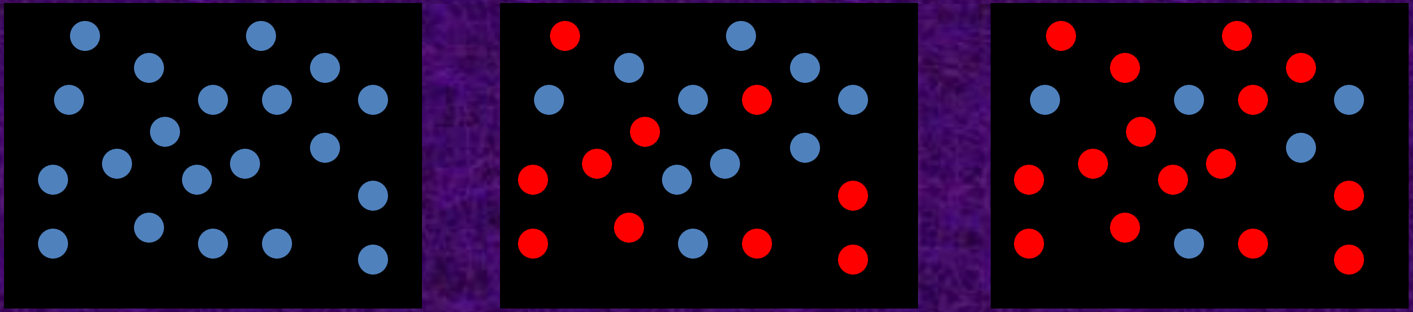
- Occur at elevations where change in form of precipitation will be important
- Rain on snow events generate flooding events
- Down-scaling of GCMs important to capture basin physiography
- Disparate recharge mechanisms possible (mountain block/fractured rock, influent streams, diffuse snowmelt)

Tritium decays to ^3He



Tritium (^3H) is an unstable nucleus and ejects an energetic electron to become an atom of helium-3 (^3He)

The ^{3}He from ^{3}H decay starts to accumulate once the water has become groundwater

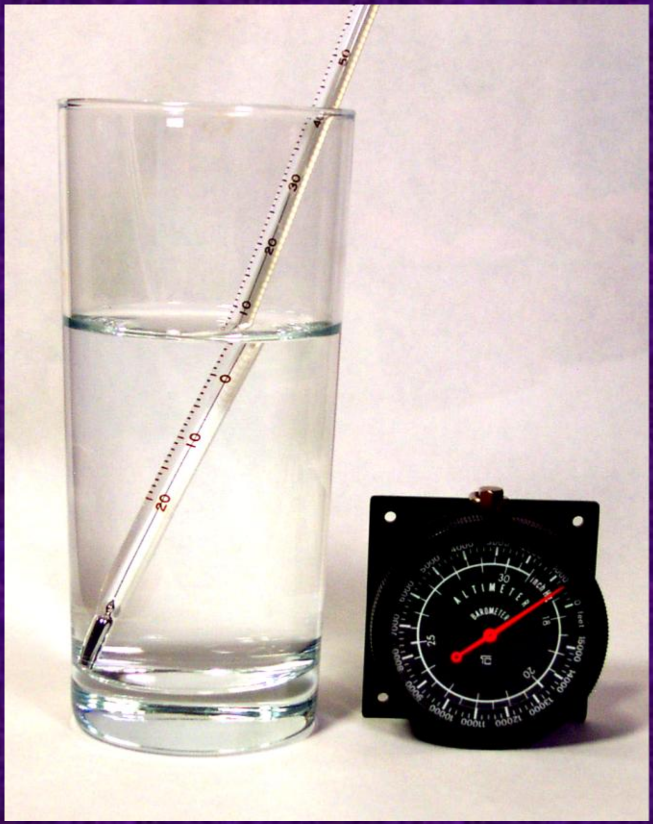


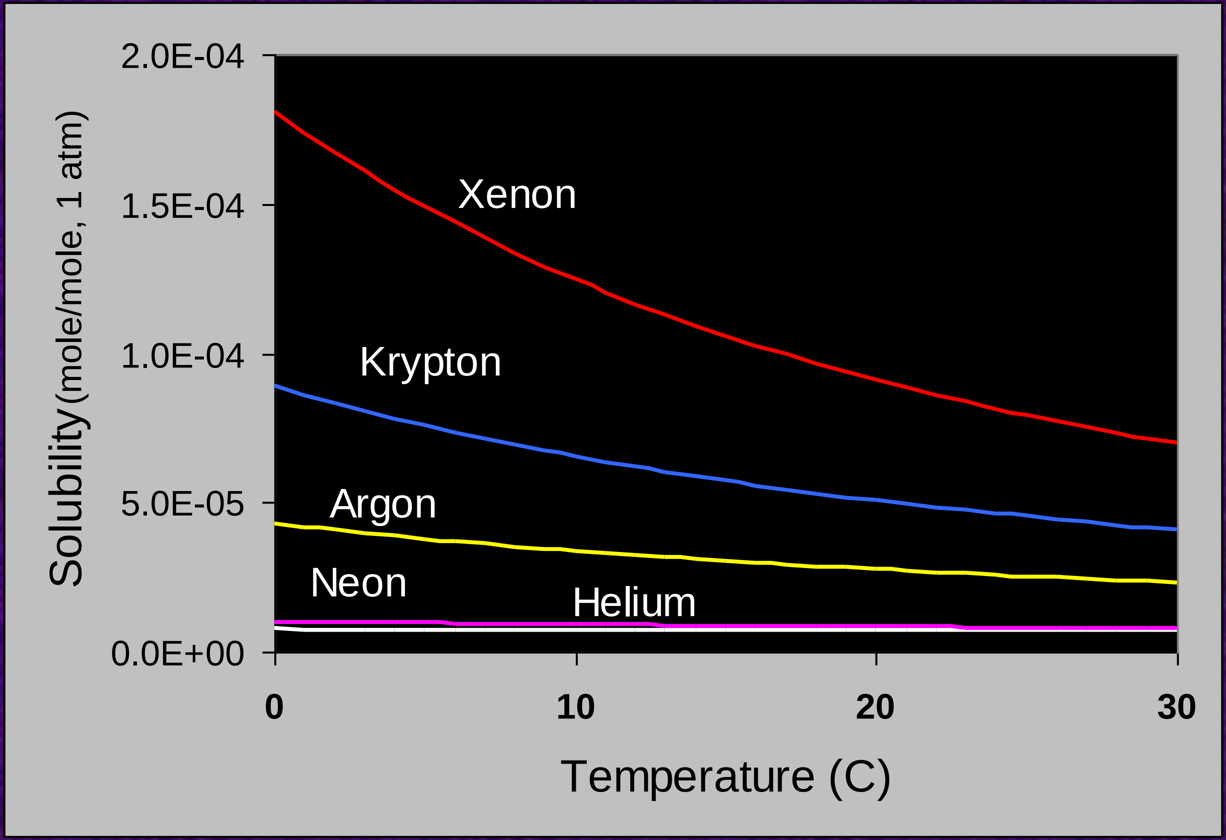
0 years   12 years   24 years

Age (years) = 18 x ln(1 + ^{3}He / ^{3}H)

Temperature of recharge is determined from noble gas concentrations

A reasonable range in pressure (altitude) is assumed and temperatures are calculated from equilibrium solubility component

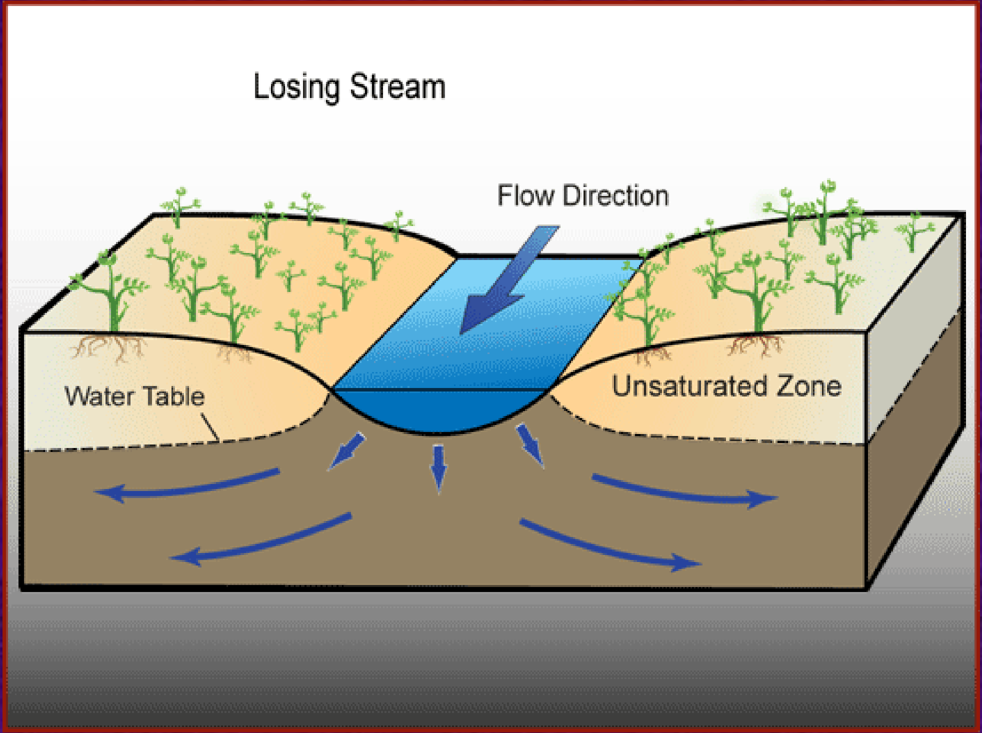




Analytical uncertainty is approximately +/- 1°C

Excess air concentrations reflect air entrainment and hydrostatic pressure during recharge

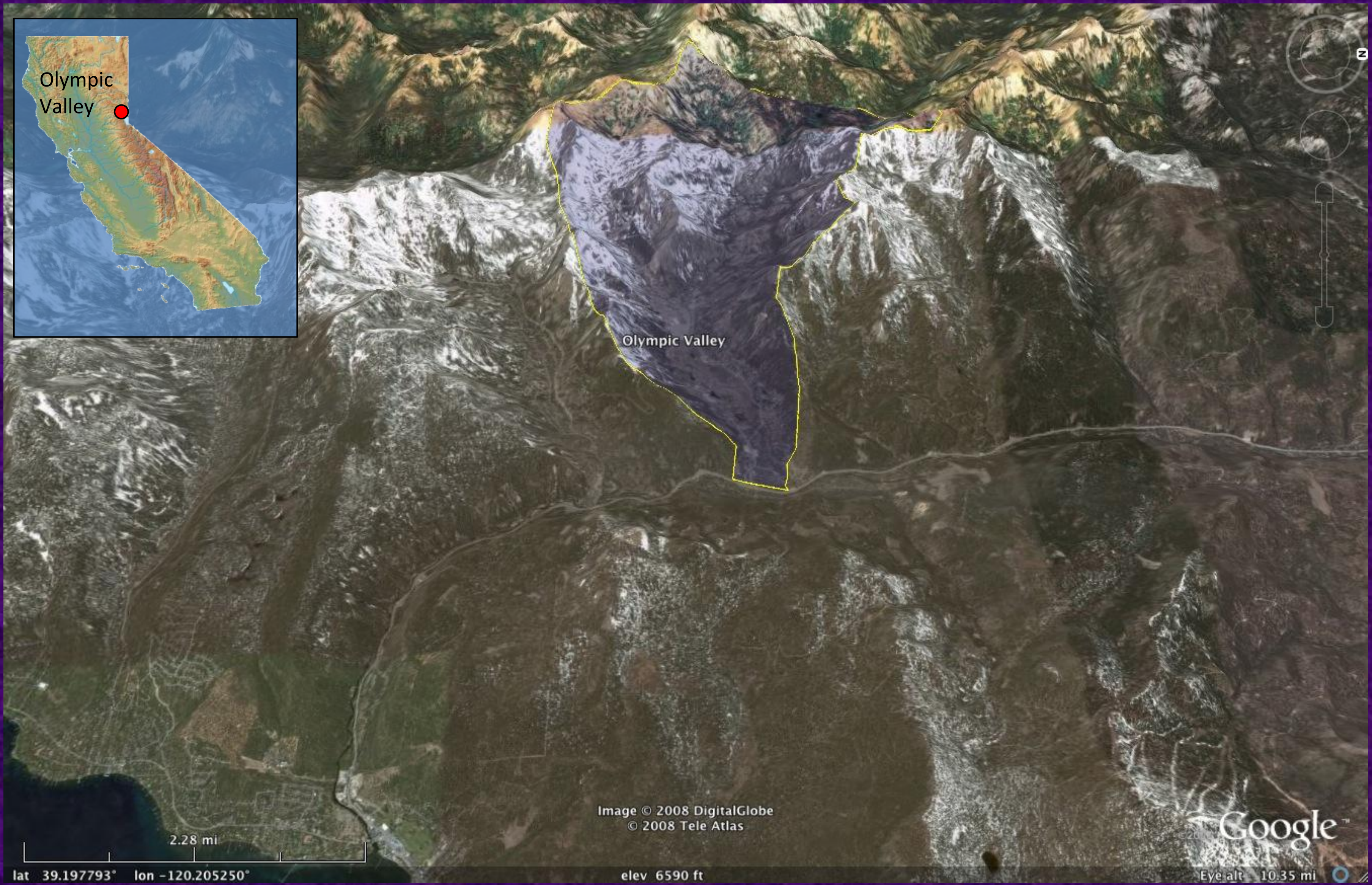
Artificial recharge and recharge through fractures adds a lot of excess air to groundwater due to large fluctuations in the water table



Little or no vadose zone interaction results in very low excess air

Recharge via fractures in hard rock terrain would trap a lot of excess air

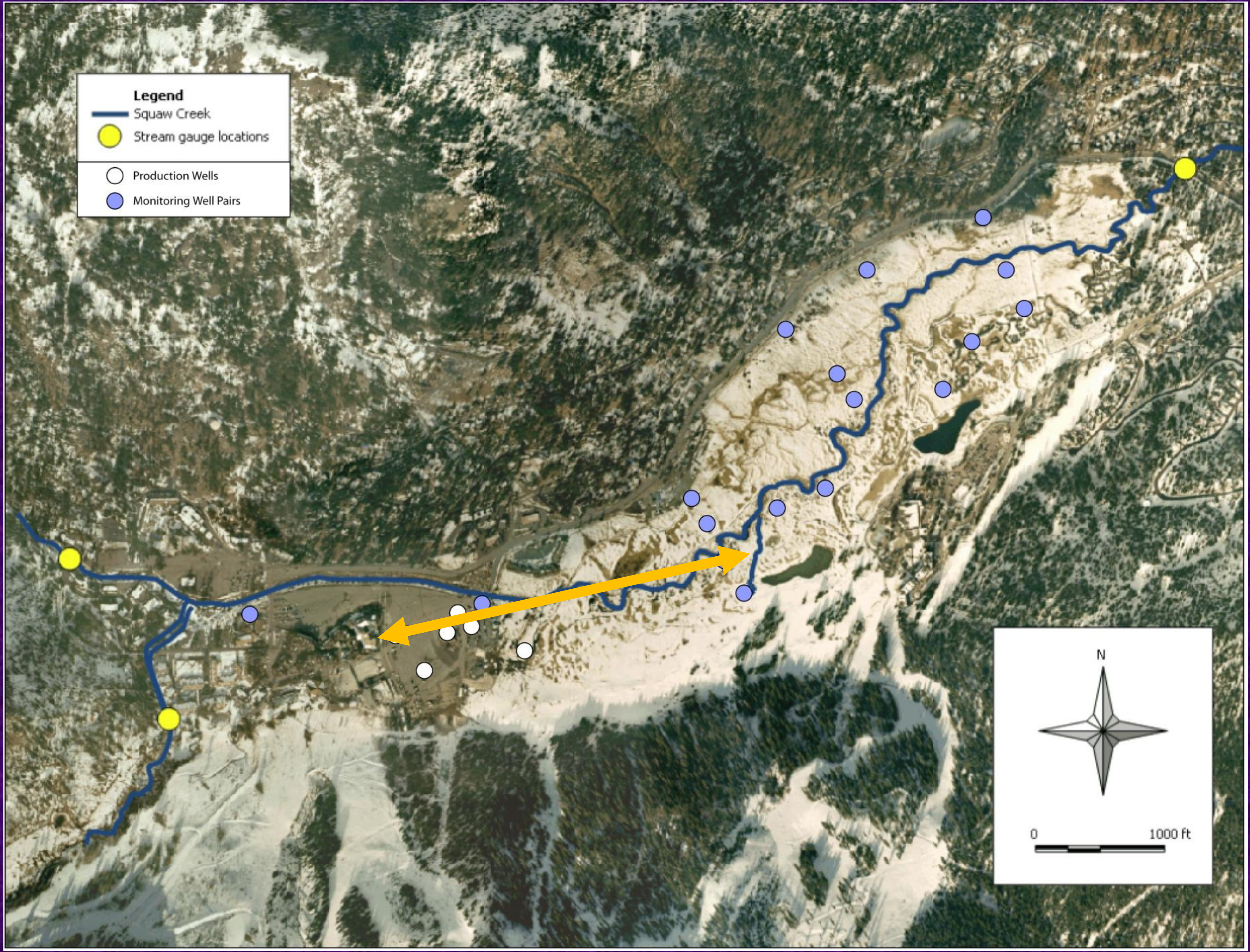
The Olympic Valley Basin



Wells Sampled

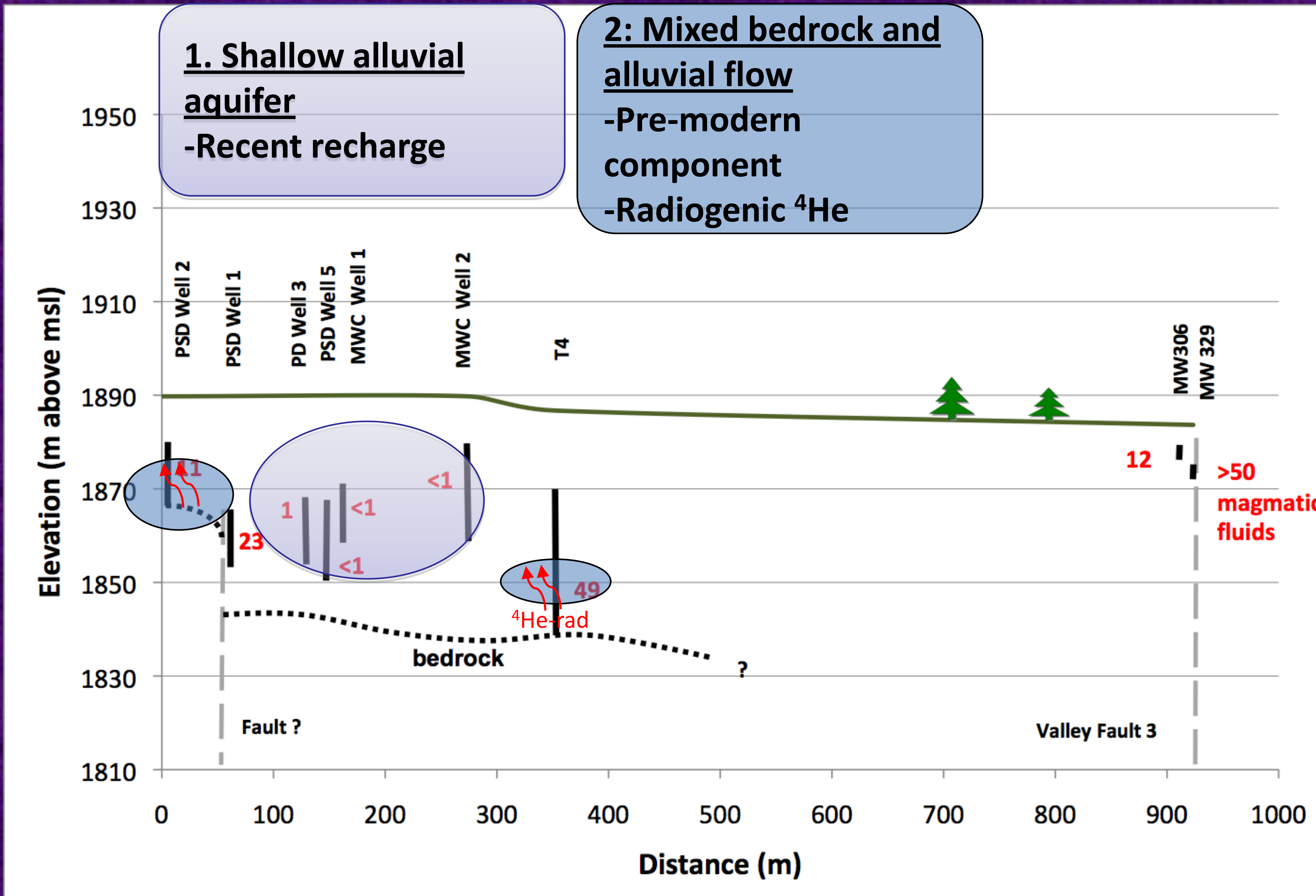
Olympic Valley

- 6 production wells
- 22 monitoring wells

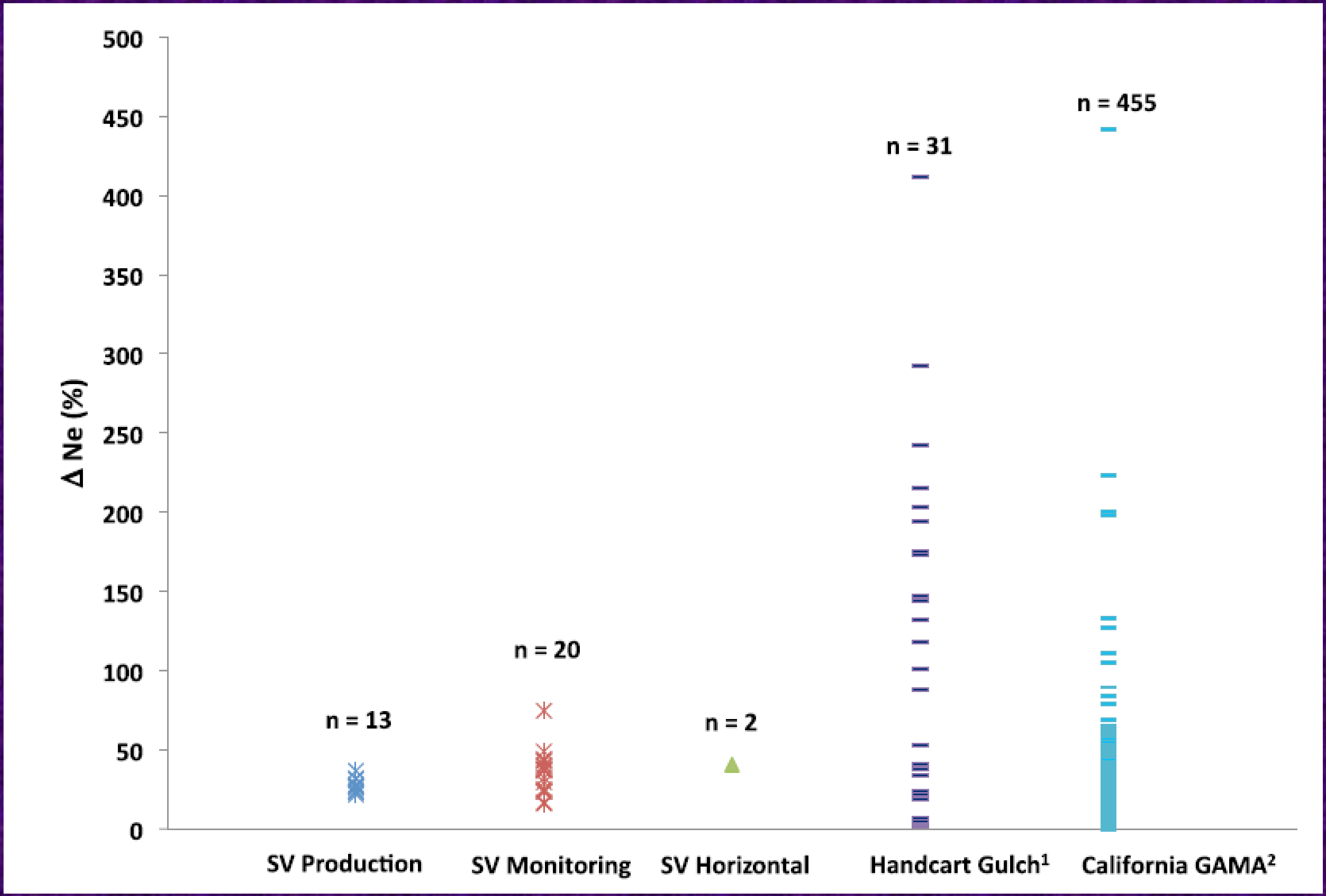


3 Stream Flow Gauges **2 Horizontal Wells**

Groundwater Ages - Cross Section



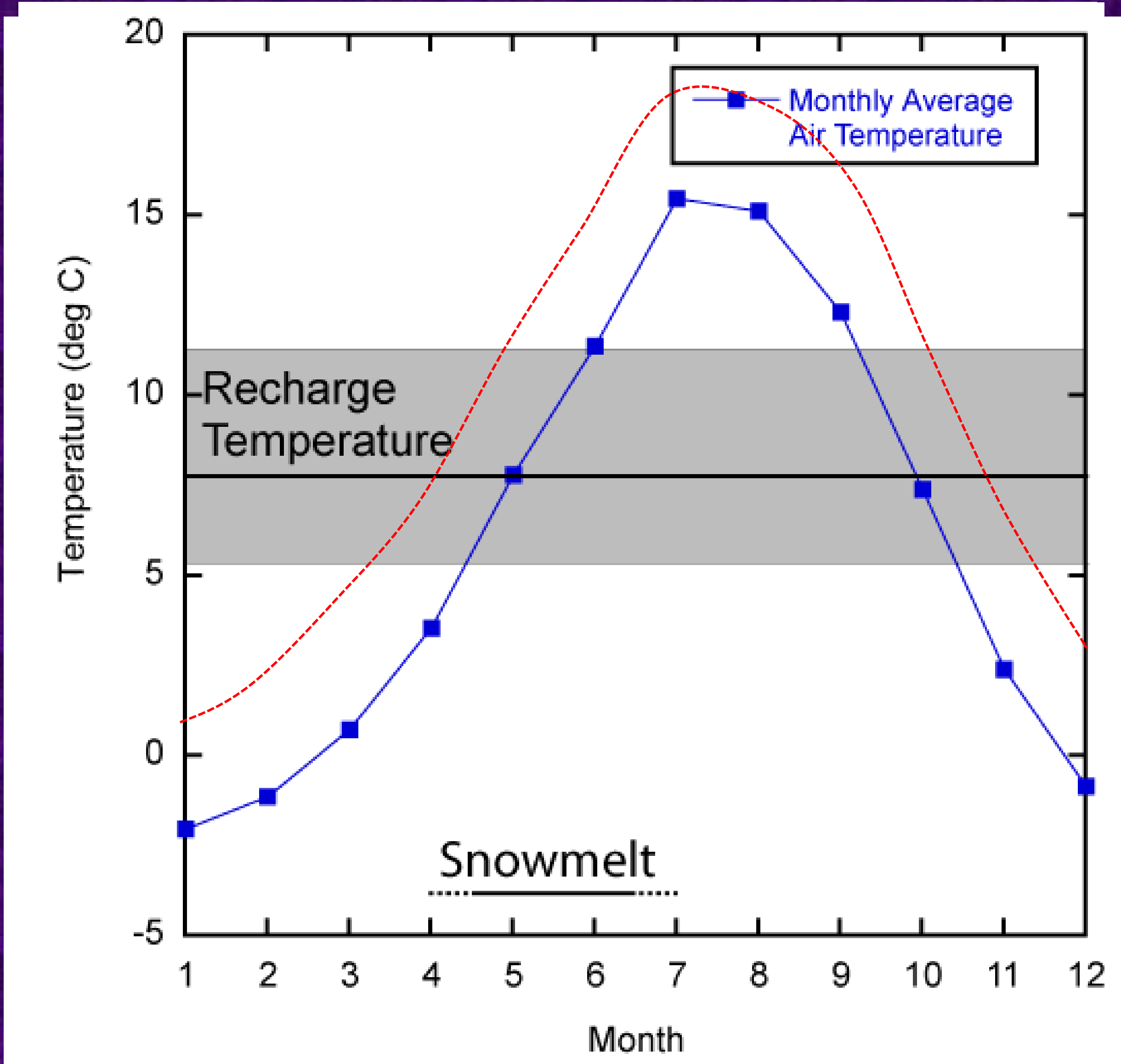
Comparing excess air concentrations

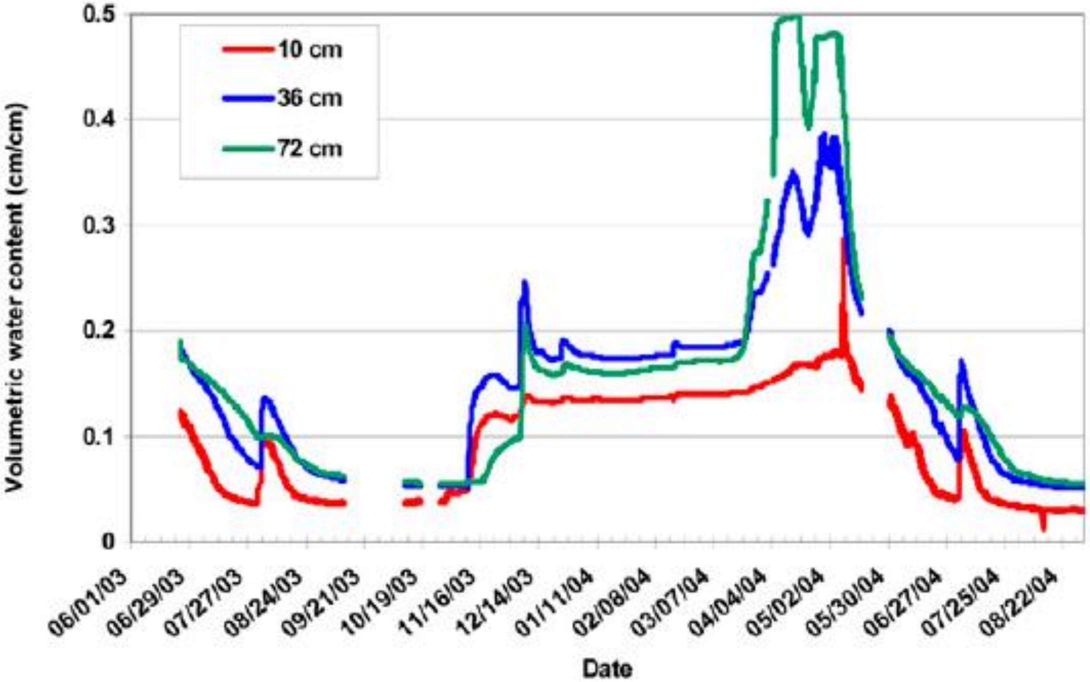


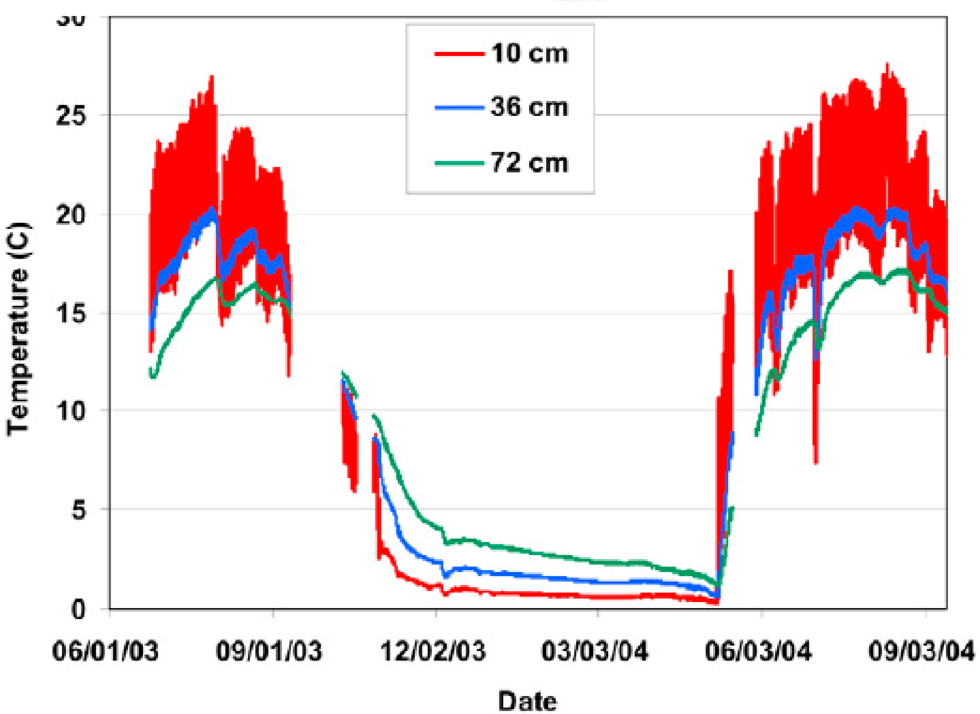
Singleton and Moran, WRR 2009

[1]Manning and Caine, 2007; [2]Cey et al., 2008

- 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 likely occurs during May-June







- Data from an instrumented soil zone at Gin Flat, Yosemite
- Rapid increase in soil temps and SWC once snowpack melts
- Nightly freeze allows soil to drain into weathered granite

Flint et al., 2008 Vadose Zone J.

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

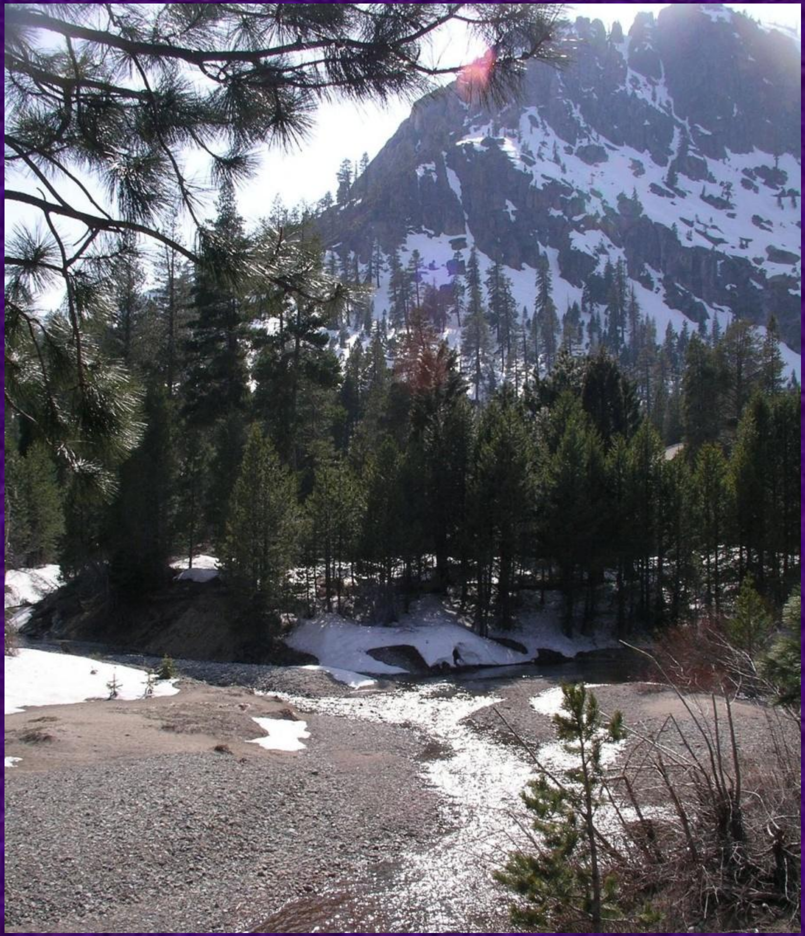
Climate Change Scenarios	Effect on Recharge and Discharge
• More precip as rain, extended period of runoff	• More recharge, if precip rate is lower than current snowpack melt rate
• Earlier runoff • More rain on snow events • More nights above freezing temp.	• Early decreased baseflow (fast drainage) • Increased overland flow, less recharge to alluvium • 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

- Squaw Valley Public Services District
  - Derrik Williams
    (Hydrometrics LLC)
- Friends of Squaw Creek
- The Resort at Squaw Creek
- Squaw Valley Mutual Water Company
- Matt Reeves , Desert Research Institute
- Tony Ferenzi, Placer County Water Agency

- Students:
  - C. Cox, C. Tulley, C. Barton, G. Rhett, D. Meyer, H. Bigman , Elizabeth Derubeis
- LLNL Labs:
  - Noble Gas Lab (D. Hillegonds, M. Sharp)
  - EMRL (R. Bibby, E. Guthrie)
  - Stable Isotope Lab (S. Roberts)
- Funding: LLNL Climate Initiative and SWRCB GAMA program

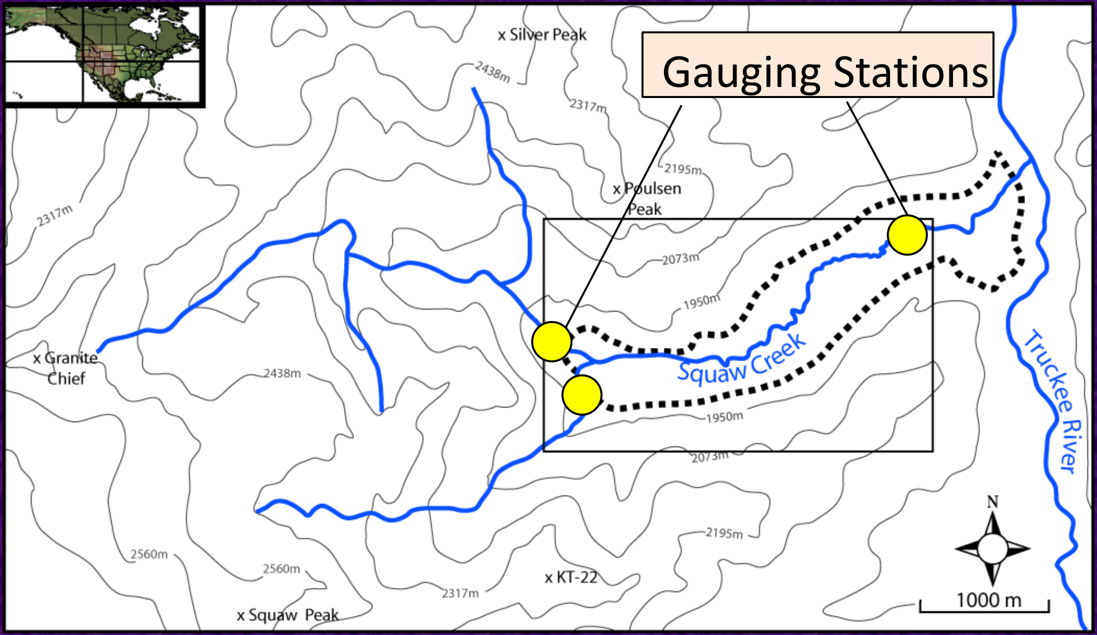


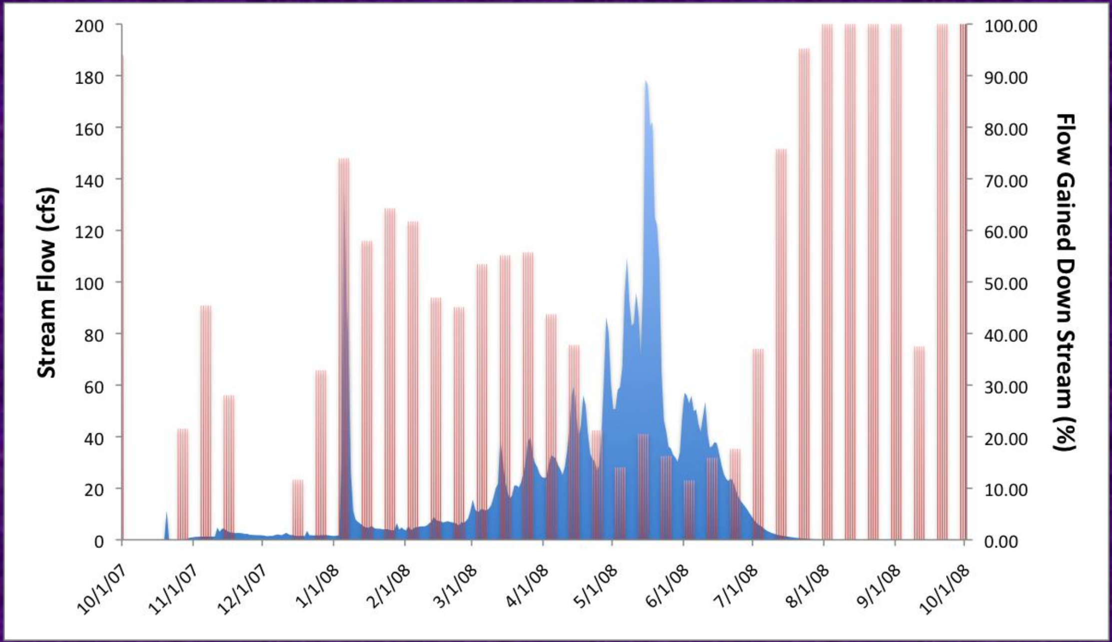
Comparing three high elevation basins

	Drainage Area / GW Basin Area	Max depth to bedrock	Valley floor elevation	Max elevation in drainage	Max discharge during study	Average annual discharge	Average Annual Precip
Olympic Valley	22 km^2 / 2.6 km^2	55m	1898m – 1853m	2750m	5.2 m^3/s	$2x10^7$ m^3/yr	1016-1650 mm
Yosemite Valley	465 km^2 / 31 km^2	600m (mean 300m)	1224m – 1100m (540m)	3997m	235 m^3/s	64 $x10^7$ m^3/yr	1277 mm
Martis Valley	433 km^2 / 142 km^2	320 m	1737m-1798m	2624m	28 m^3/s	$50x10^7$ m^3/yr	584-1910 mm

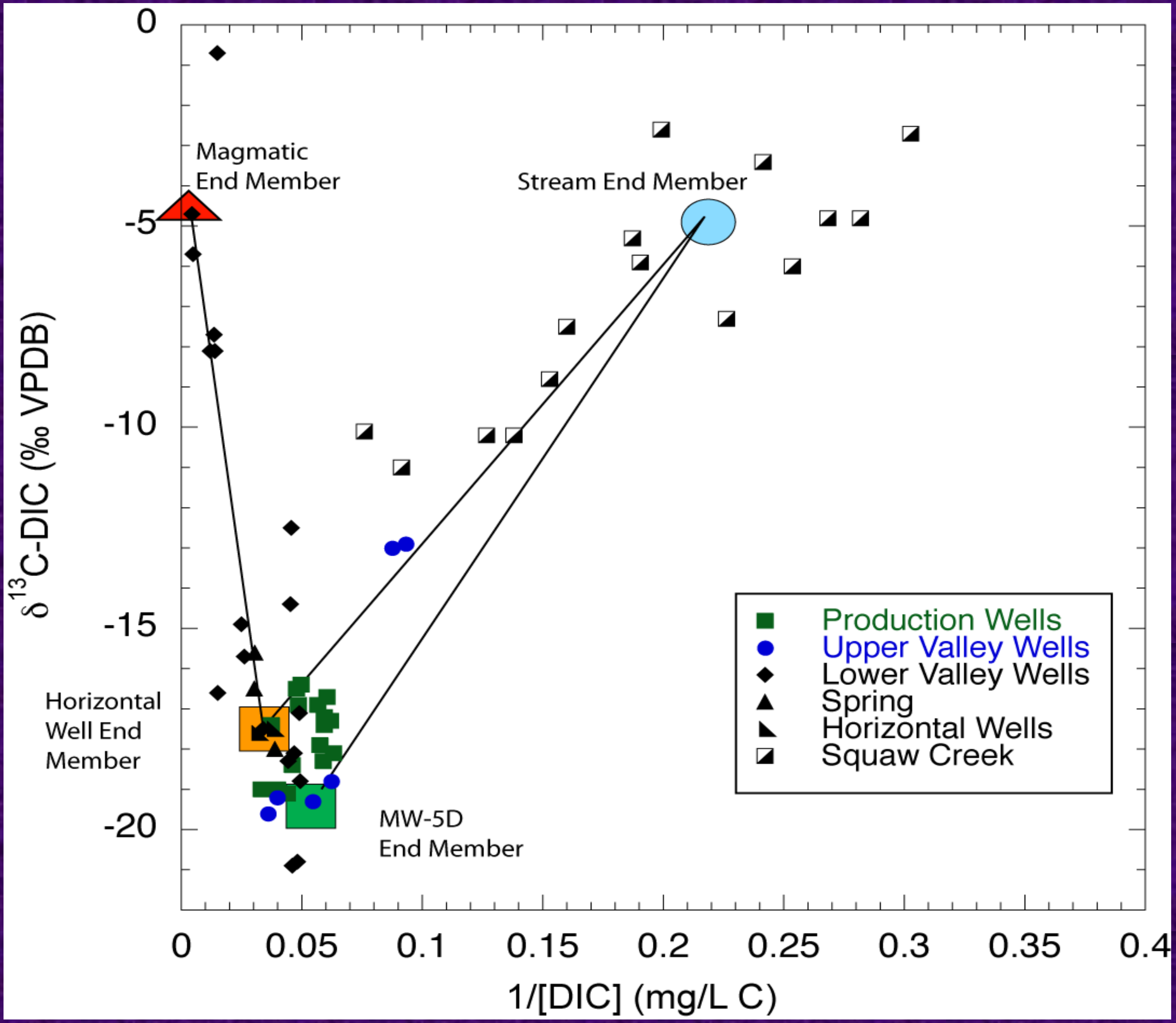
Squaw Creek

- Fed by two major tributaries
- Very low flow in the fall
- Gaining along the valley reach



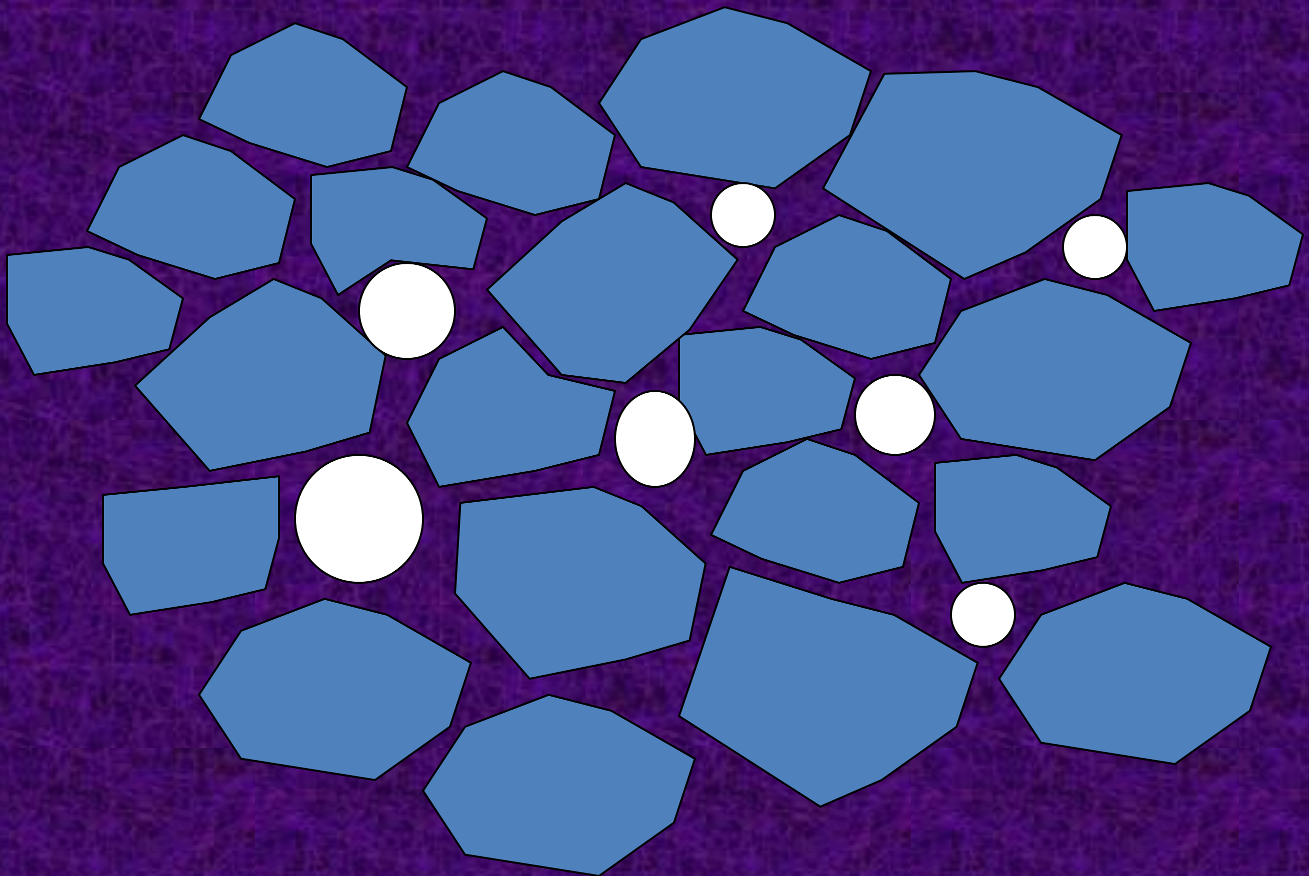


Carbon isotopes are consistent with the incorporation of soil CO_2 during recharge

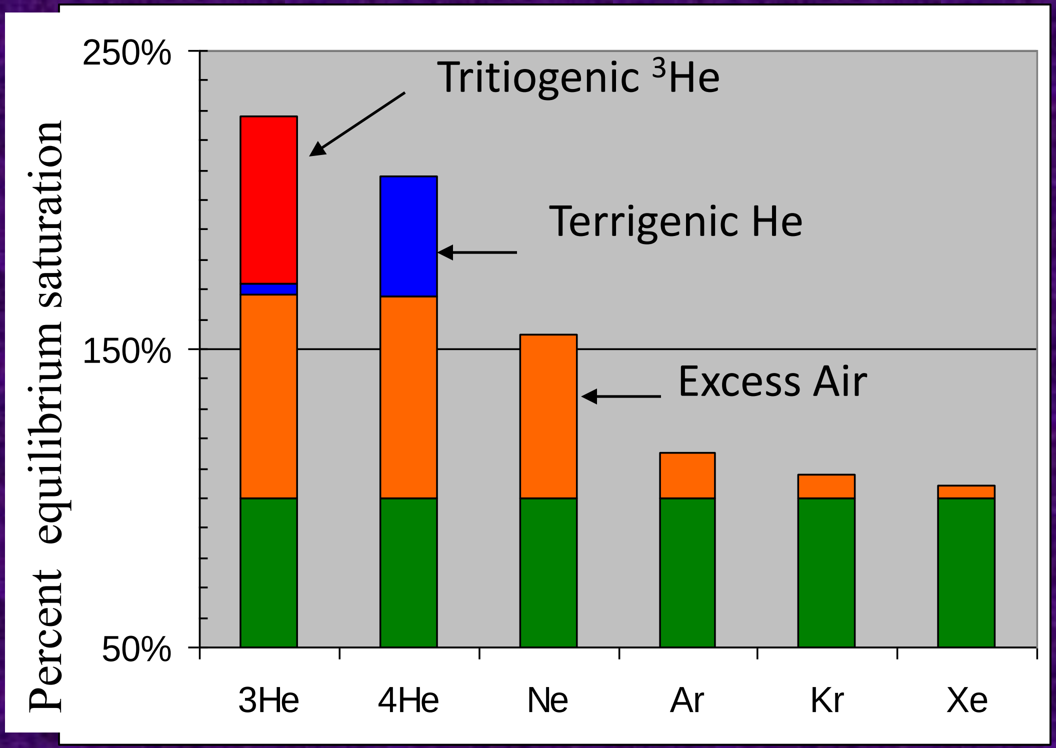


What is excess air ?

Air bubbles can be trapped during recharge and subsequently dissolve because of the increased pressure

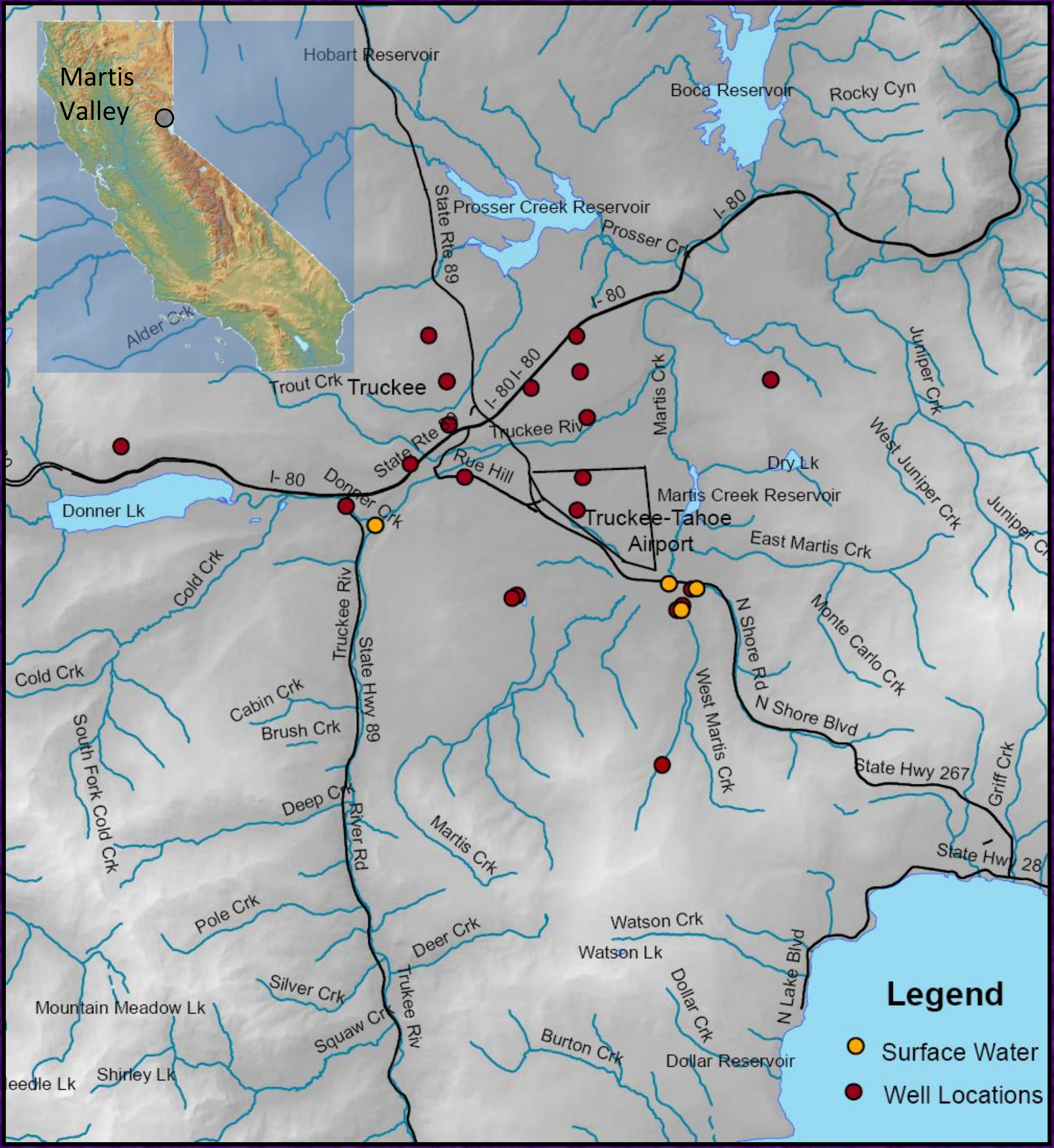


Components of dissolved noble gases



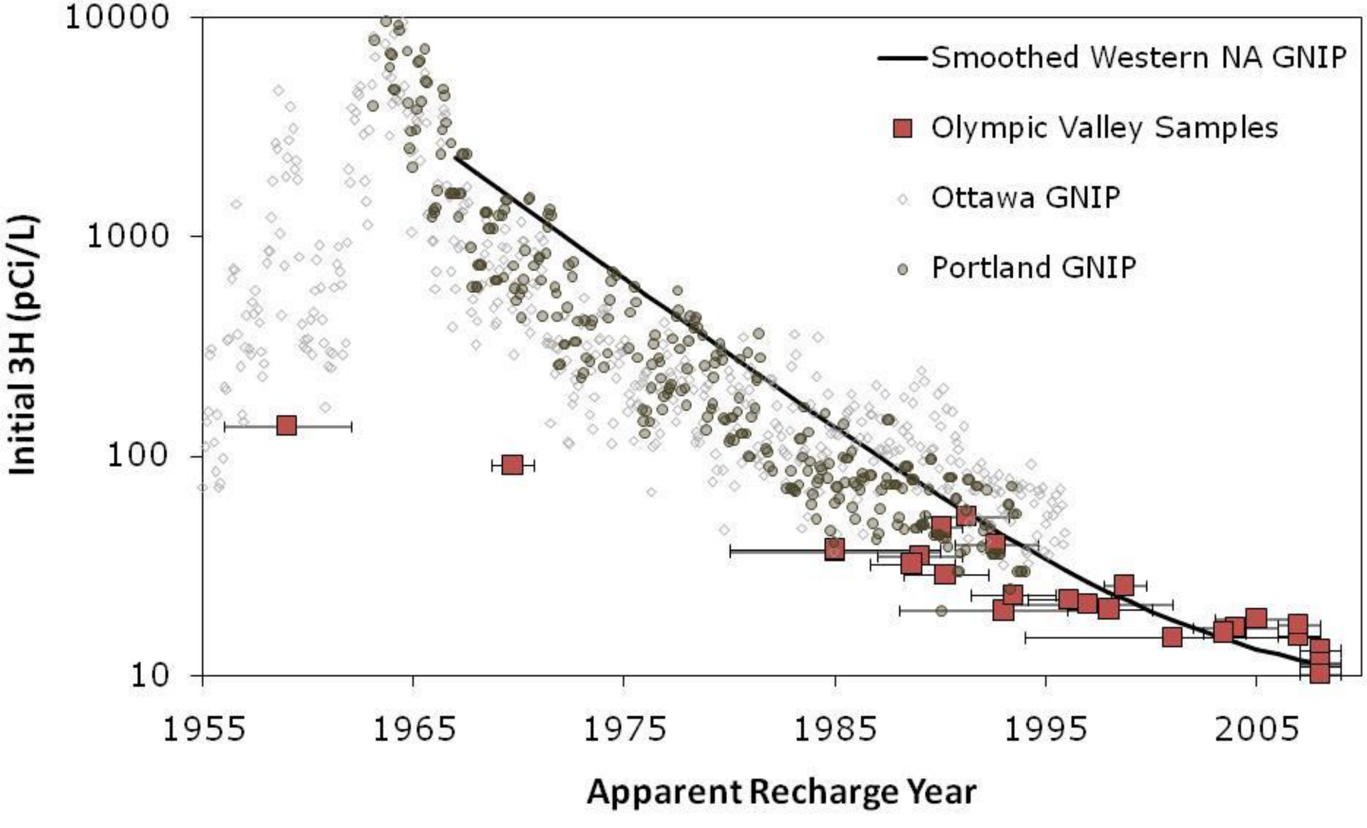
- Equilibrium solubility (dependent upon p, T)
- Excess Air
- Mantle Helium
- Terrigenic Helium
- Tritiogenic helium (for ^3H-^3He age)

Martis Valley sample locations



- 17 wells and 4 surface water locations sampled in Dec/Jan
- Most field work will take place this summer

Fraction pre-modern



Older groundwater is captured by wells during late summer