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# Climate Change Effects on Recharge in Headwater Catchments

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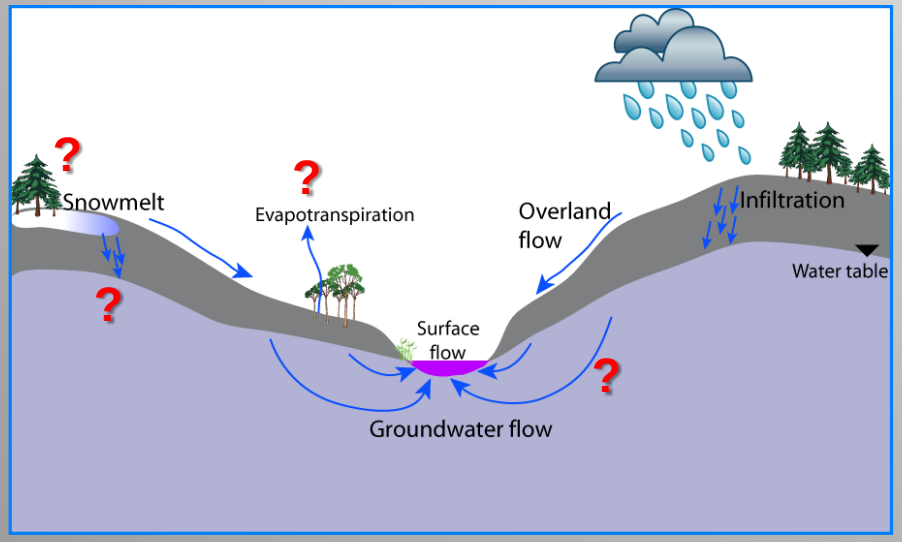
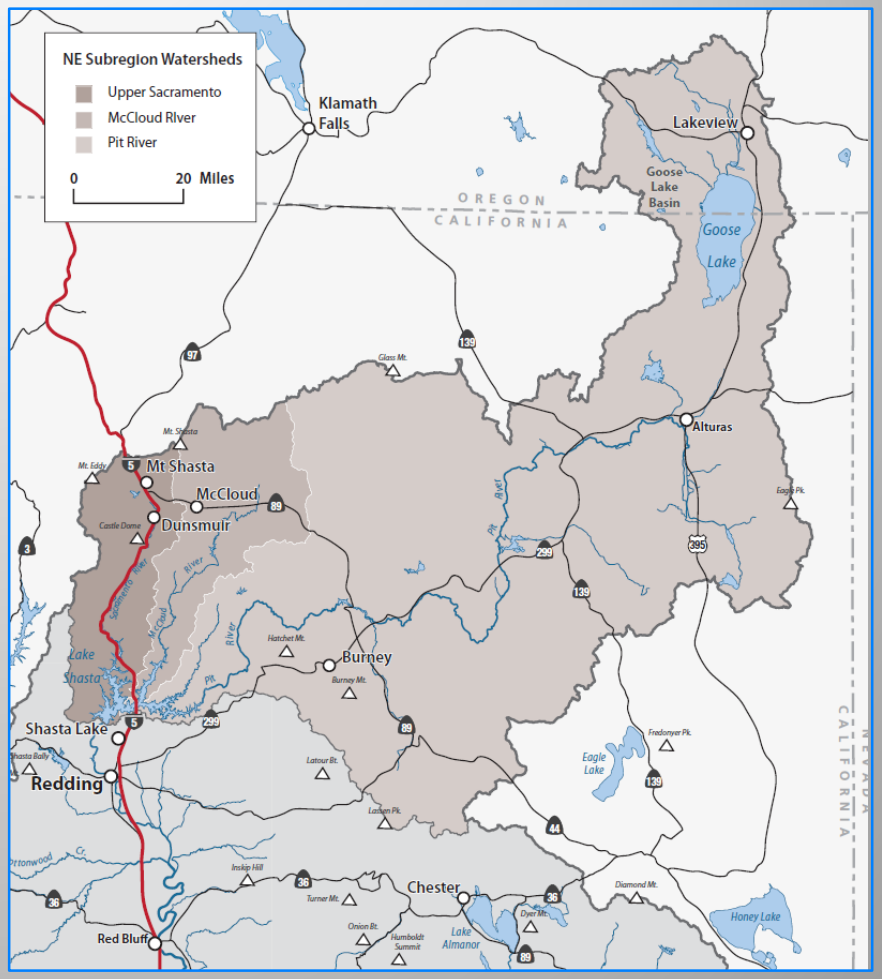
# California AB 2480:

- "…it is state policy to recognize and define source watersheds as integral components of California's water system, and eligible for financing on an equivalent basis with other water infrastructure projects."
- "…(funding for) projects with a demonstrated likelihood of increasing conditions for water and snow attraction, retention, and release under changing climate conditions."



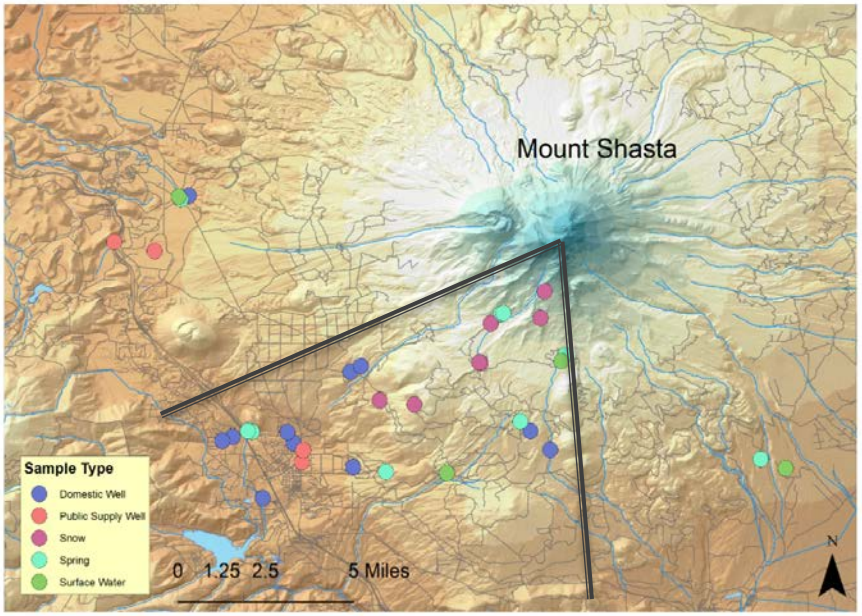

# Volcanic, alpine hydrologic setting

- Highly permeable surface materials
- Stream generation from springs
  - Upper Sacramento, McCloud, and Pit River headwaters
  - Springs and wells provide supply for logging operations, towns of Mount Shasta and Weed, bottled water facility, etc.
- ET likely energy (rather than water) limited

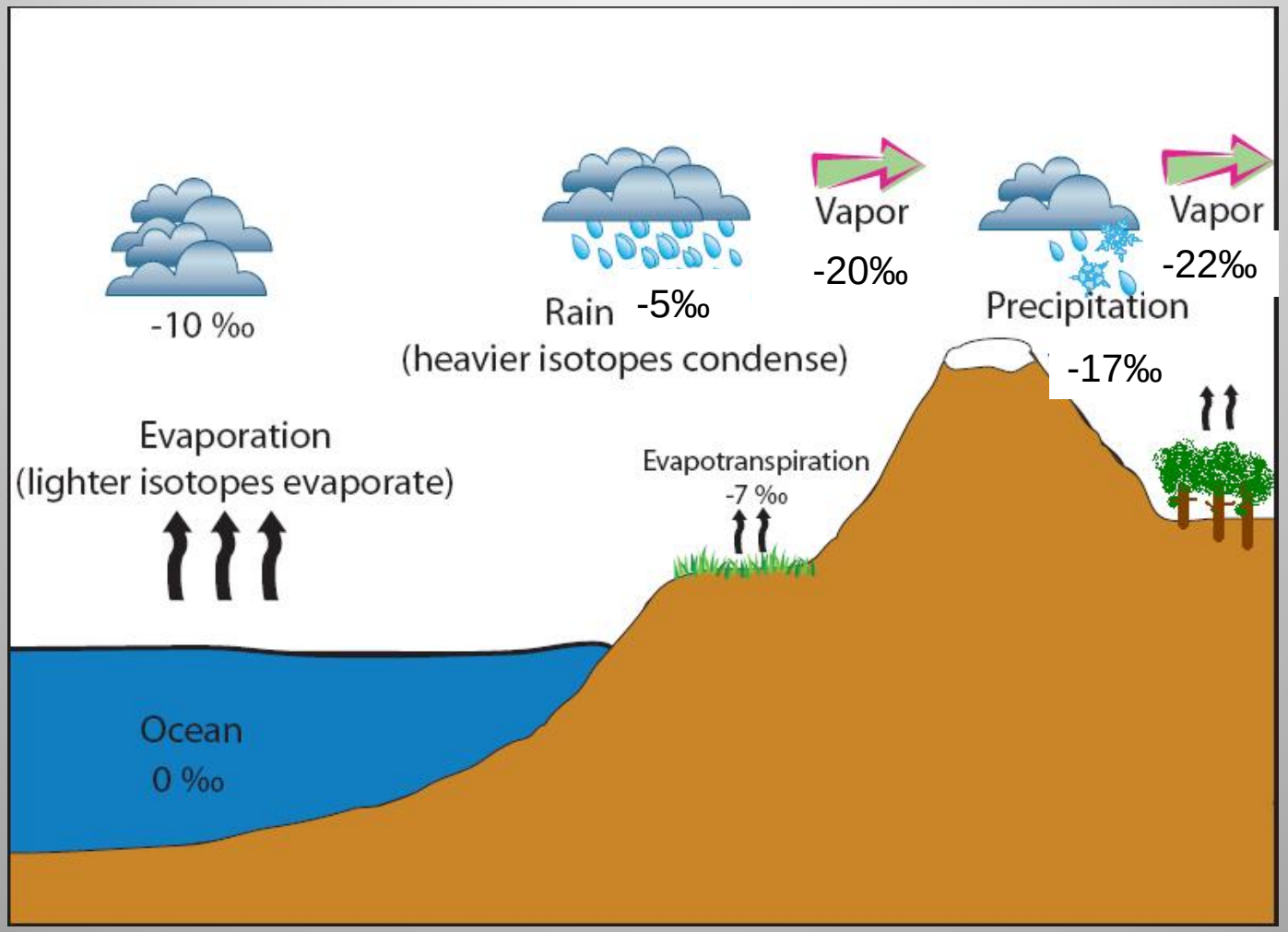


# Sampling in headwater areas

- Limited sampling locations
- Sampled during extreme drought (May and Sept. of 2015)

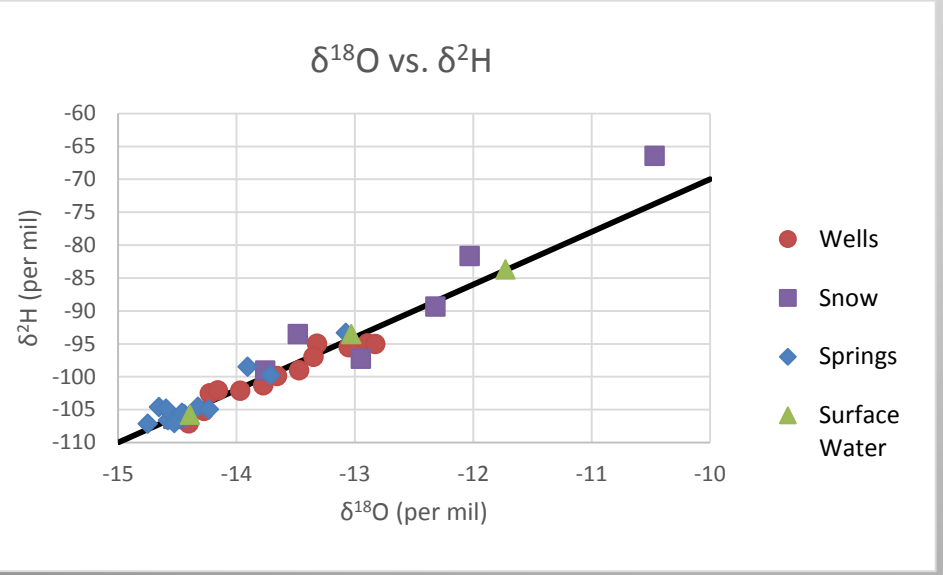


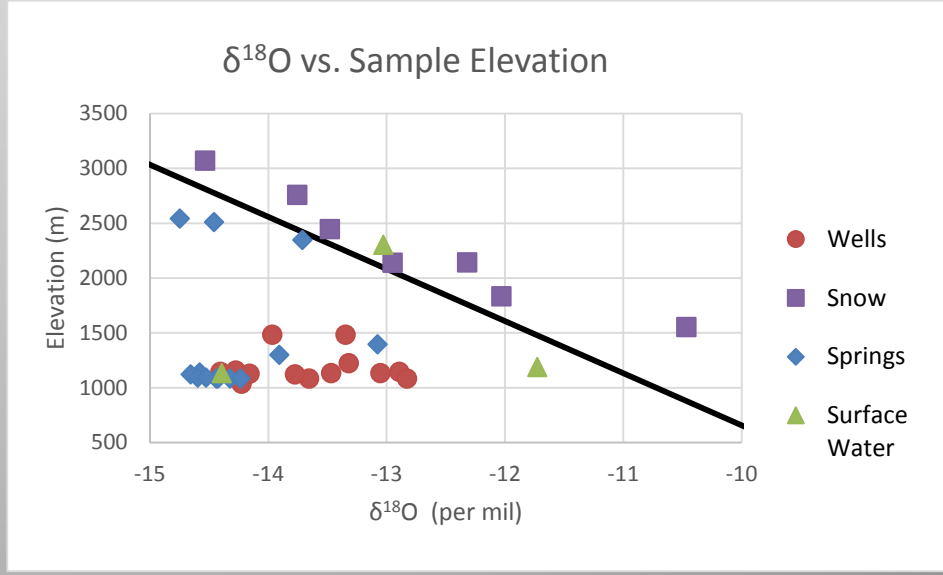
# Stable isotope signature: How it works



# Stable isotopes: recharge elevation

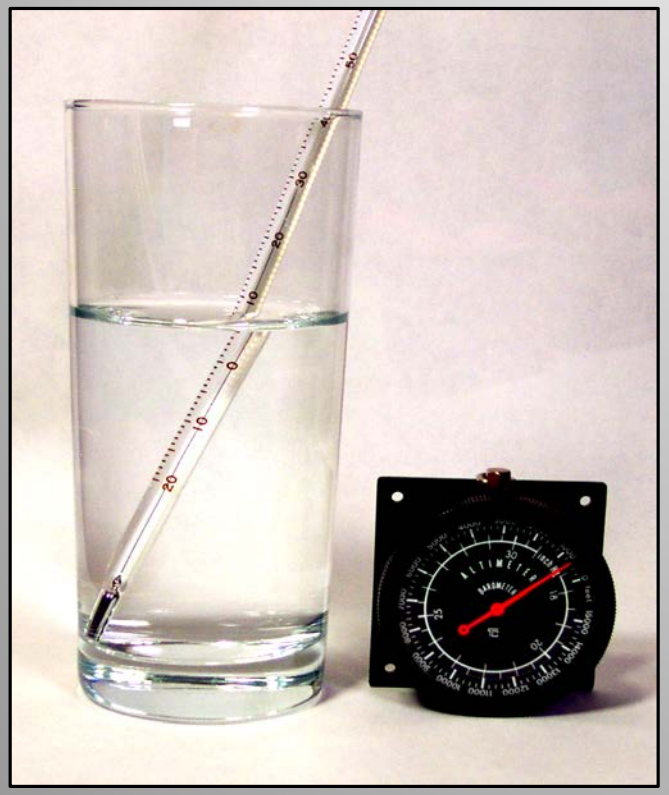
- All samples fall on or near the Global Meteoric Water Line
- No $\delta^{18}O$ results < -15‰
- Precipitation (snow) follows 'lapse rate' (from Rose et al., 1996)
- Points that fall below the line indicate a source area at higher elevation

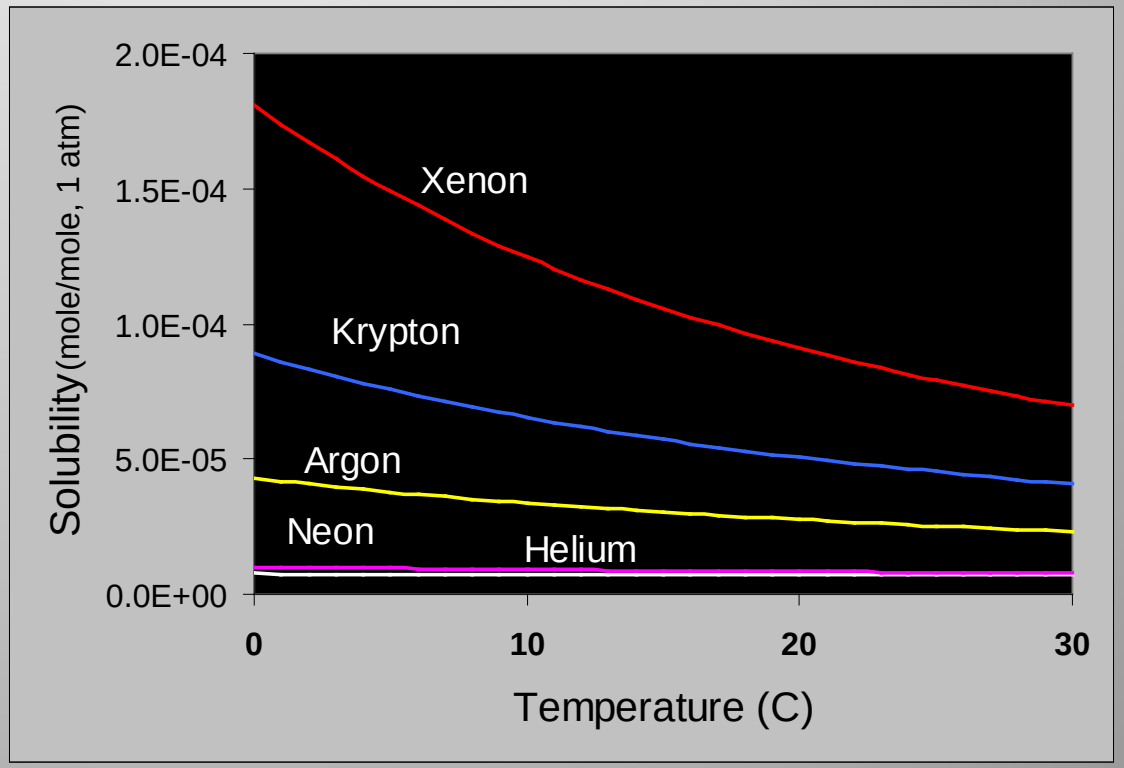


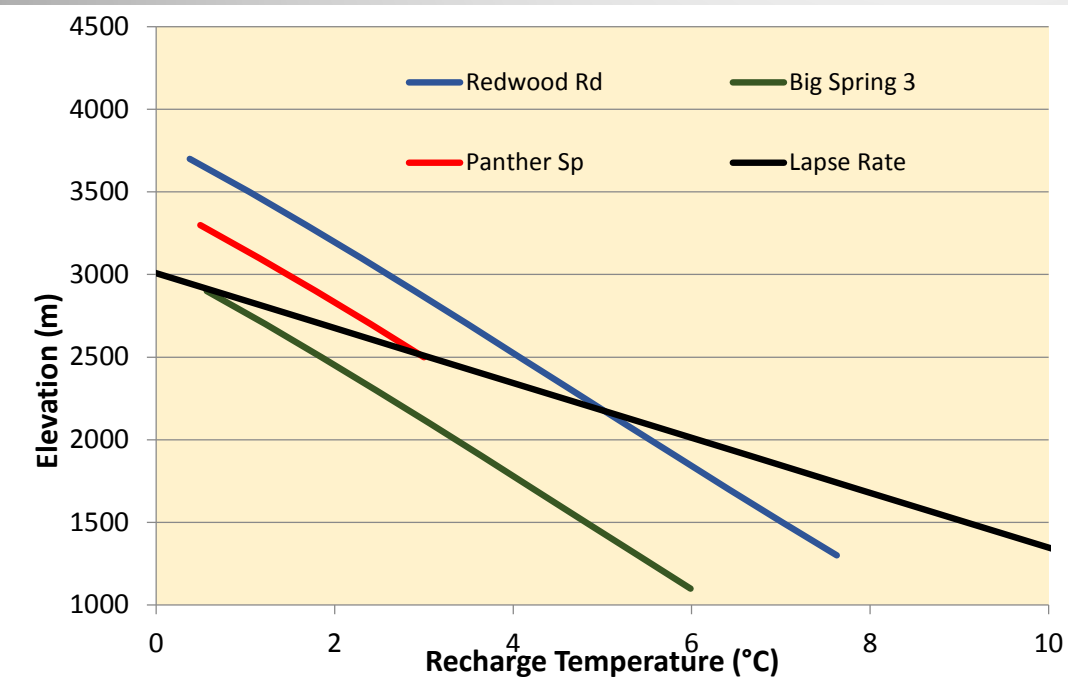
# Noble gas signature: How it works

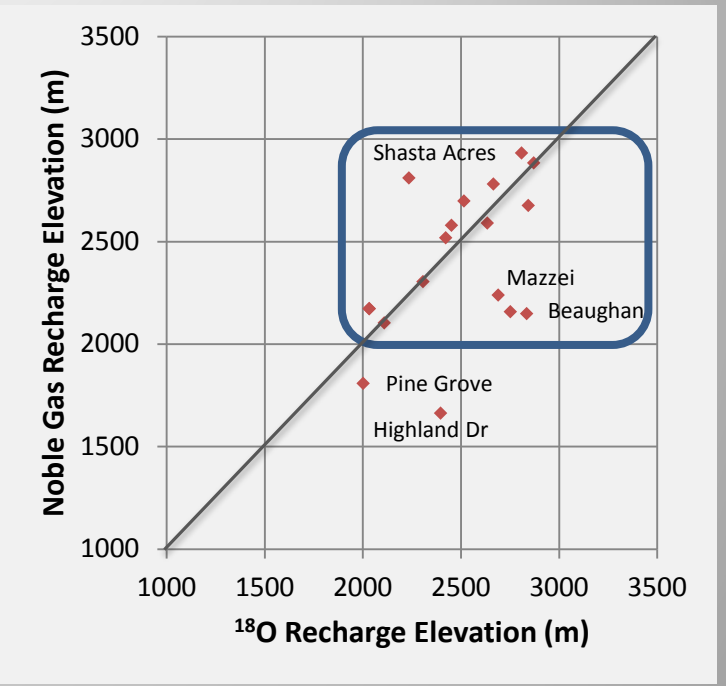
- Solubility depends on temperature and pressure
- Heavier gases have stronger T dependence





# Noble gases: recharge elevation

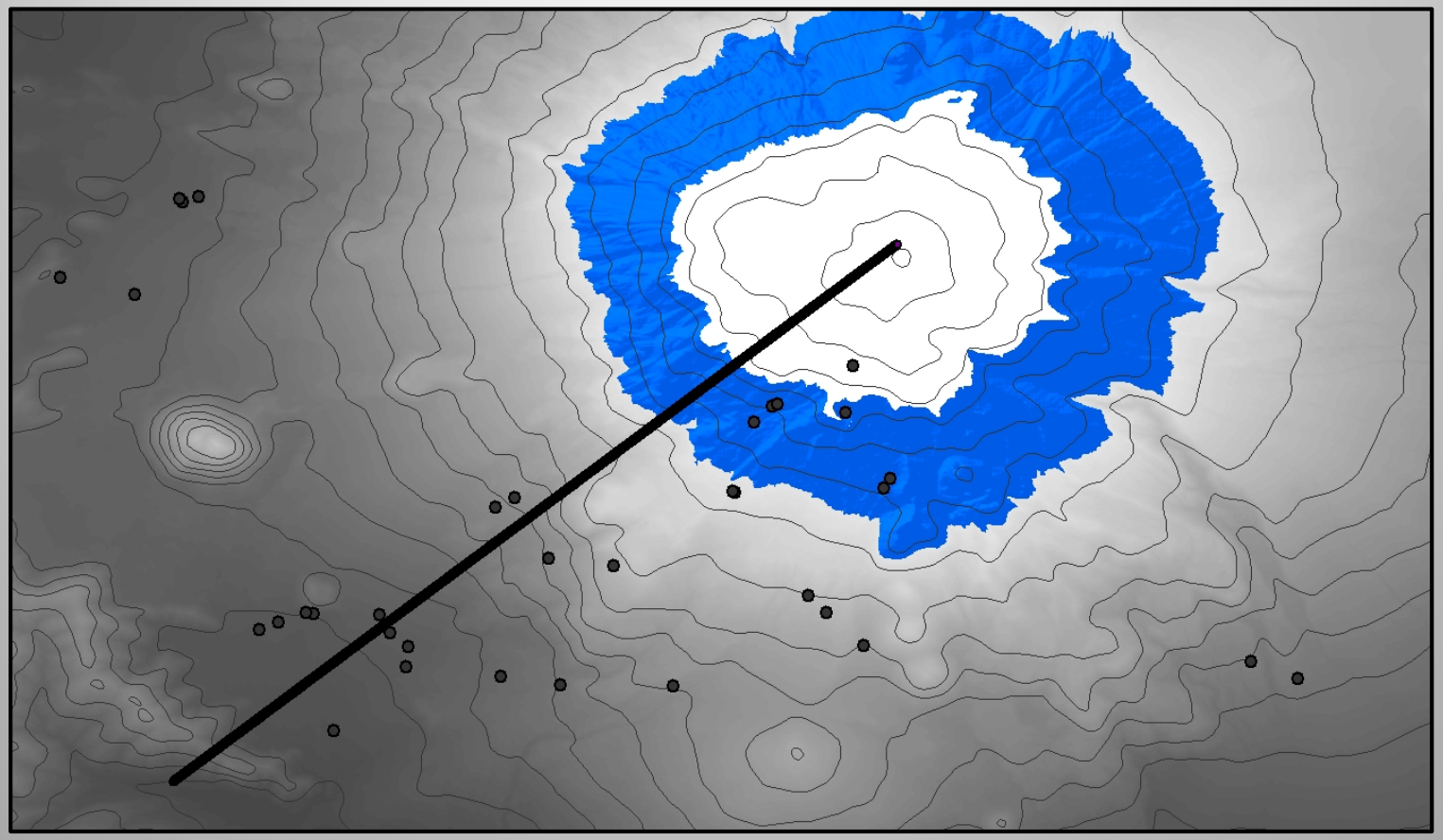



- 3 examples
- Constraints:
  - elevation (top of mountain to sampling elevation)
  - temperature (greater than 0°C, less than discharge temperature)

Good agreement between independent methods

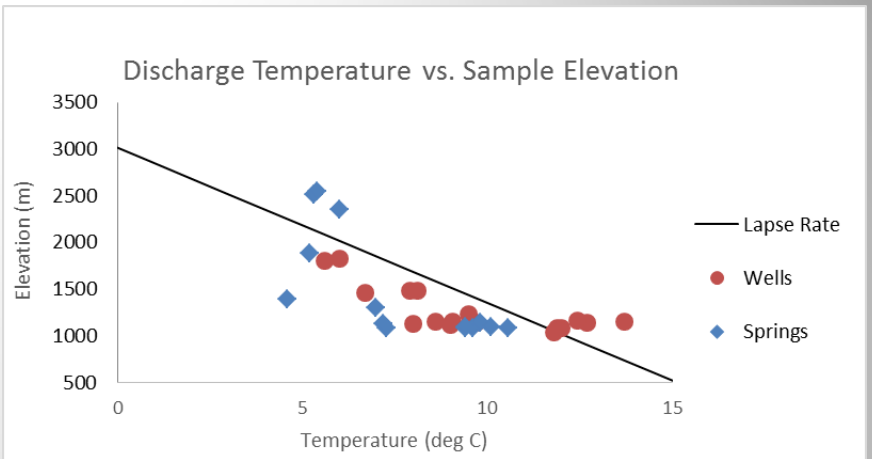
# Delineating the recharge area

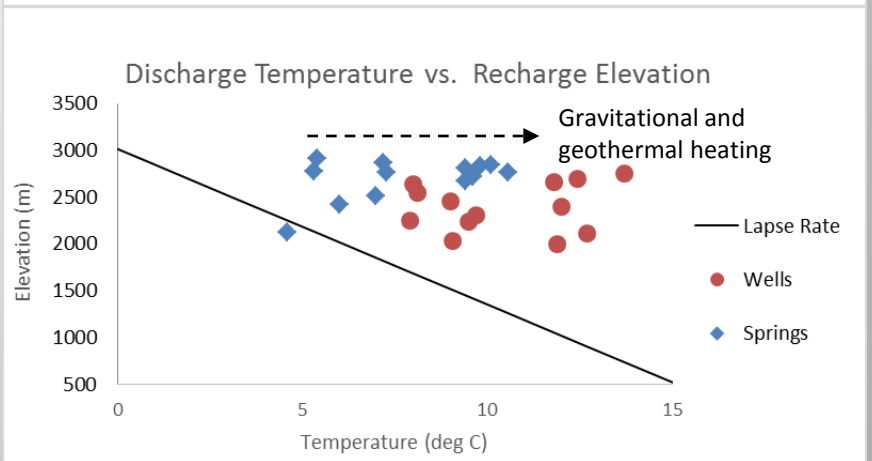


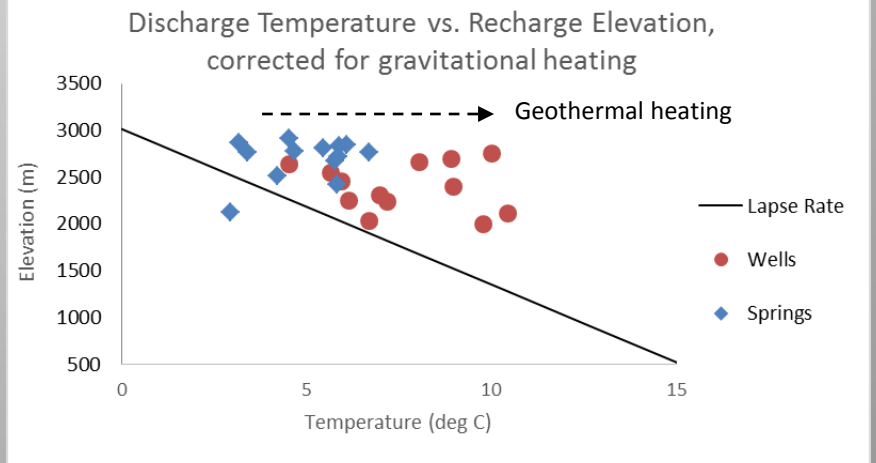
- Elevation range 2100-2900 m
- Do not observe signals from higher or lower elevations

# Subsurface Heating

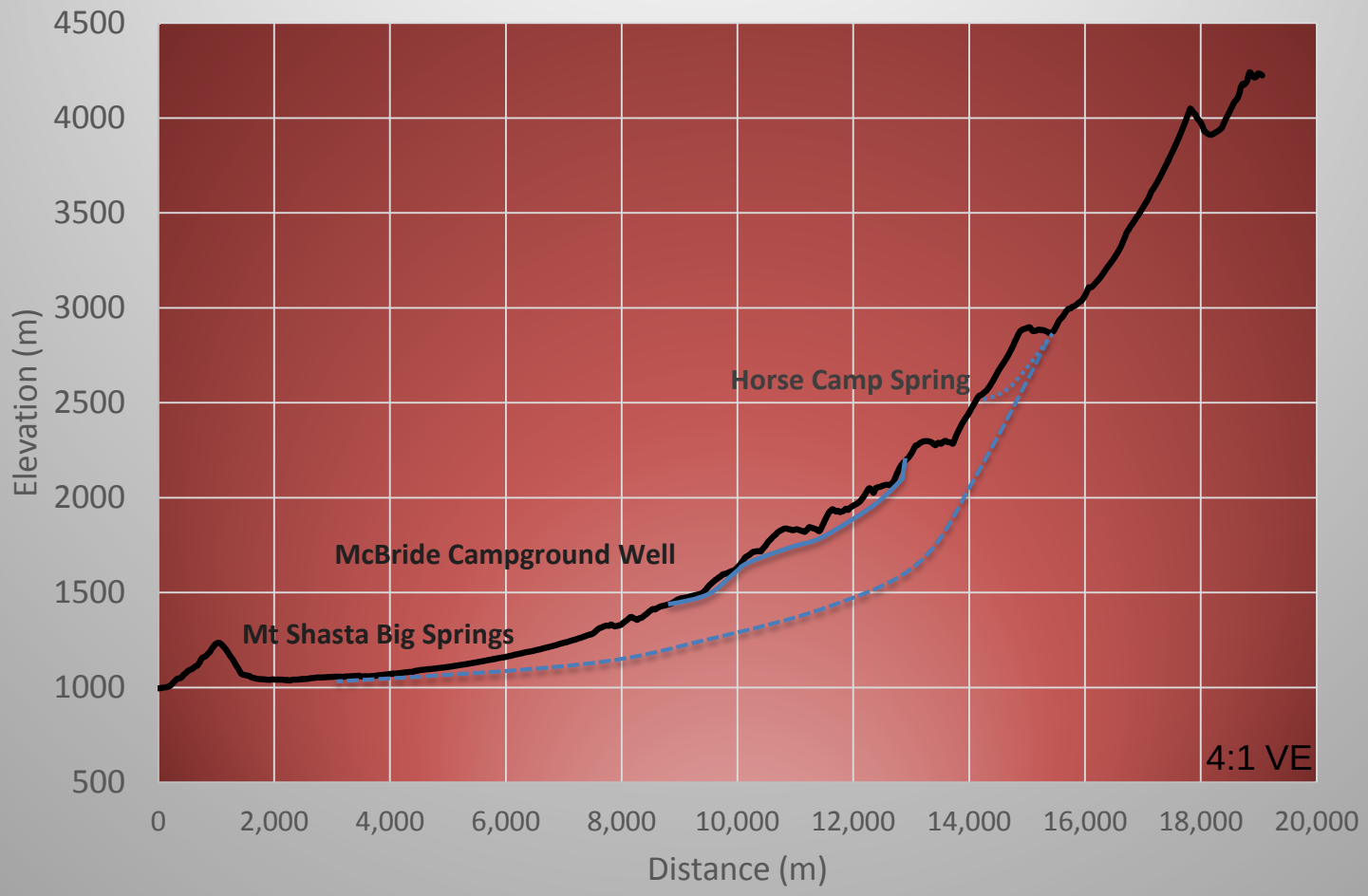
- The rate of change of thermal energy in a parcel of groundwater is the sum of (Manga and Kirchner, 2004):
  - gravitational potential energy dissipation
  - heat transfer to/from the surface by circulating water via conduction (negligible in this setting)
  - geothermal heating
- For a 8°C DT-RT difference and a geothermal gradient of 15°C/km, a maximum flow depth of appx. 500 m is calculated



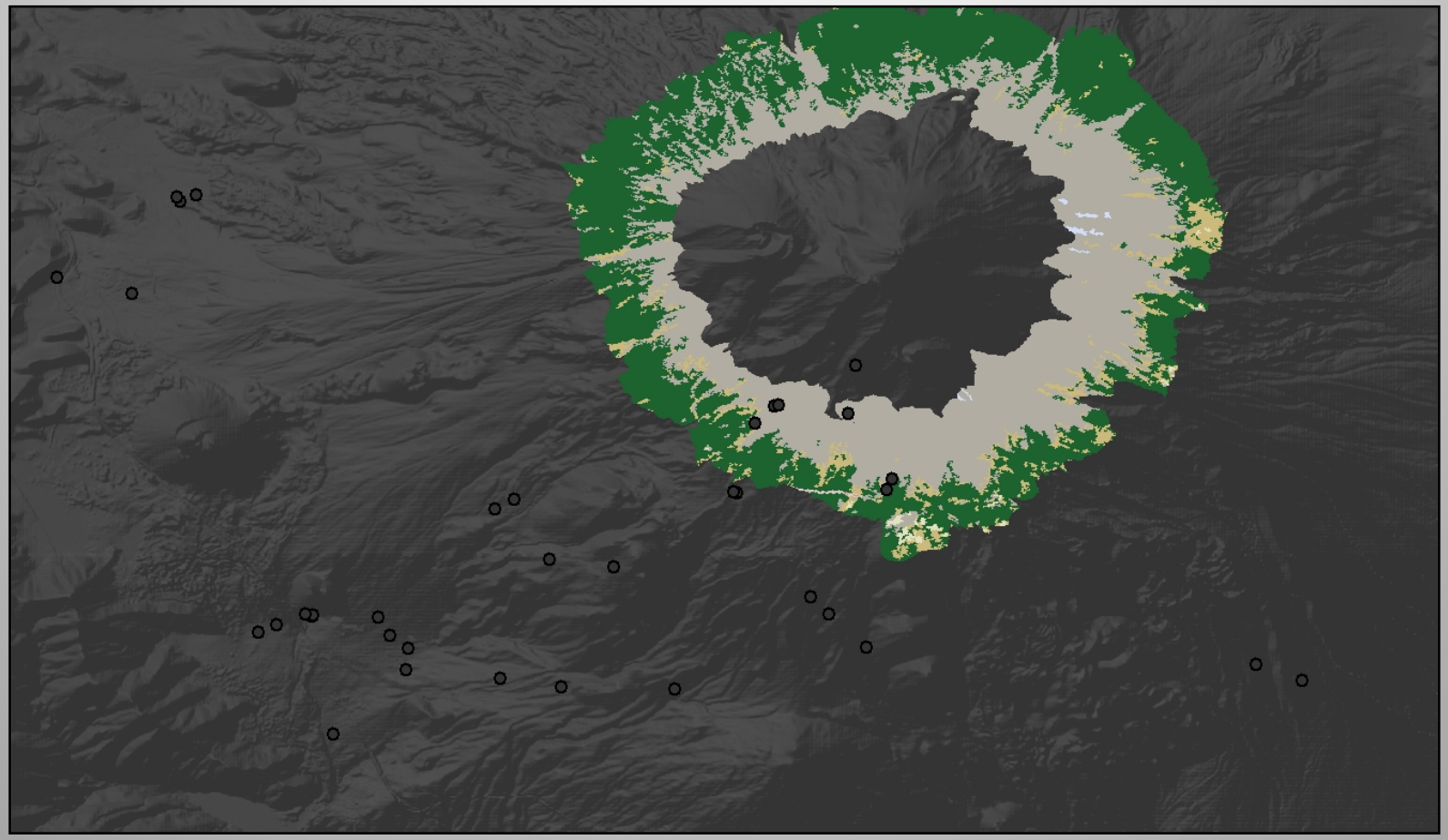



# Delineating groundwater flow on Mount Shasta



# Land cover in the recharge area



Forest ET likely plays a key role in limiting percolation and recharge

Coverage from: National Land Cover Dataset from the Multi-Resolution Land Characteristic Consortium, www.mrlc.gov, Homer, 2015

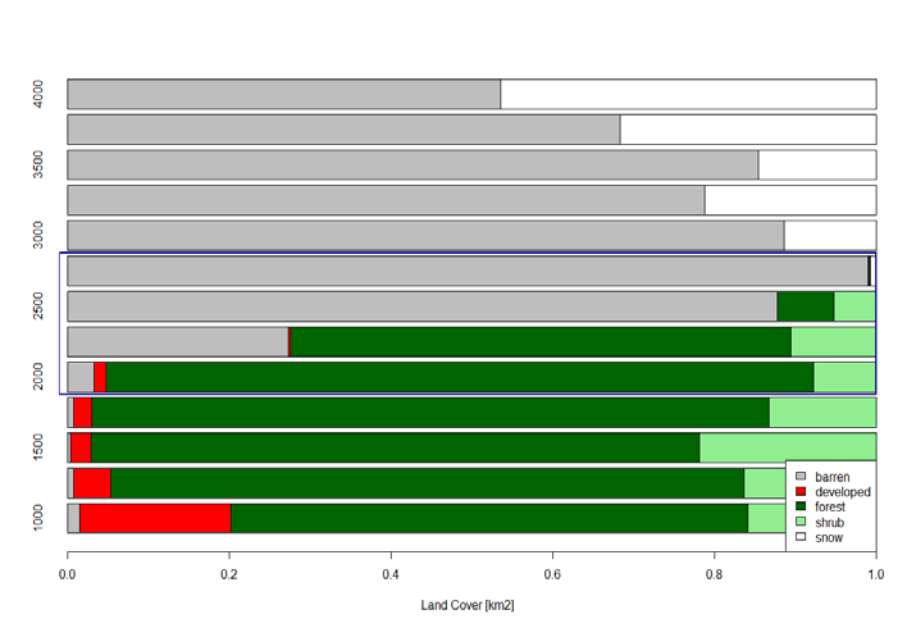
# There may be a ‘sweet spot’ in tree coverage

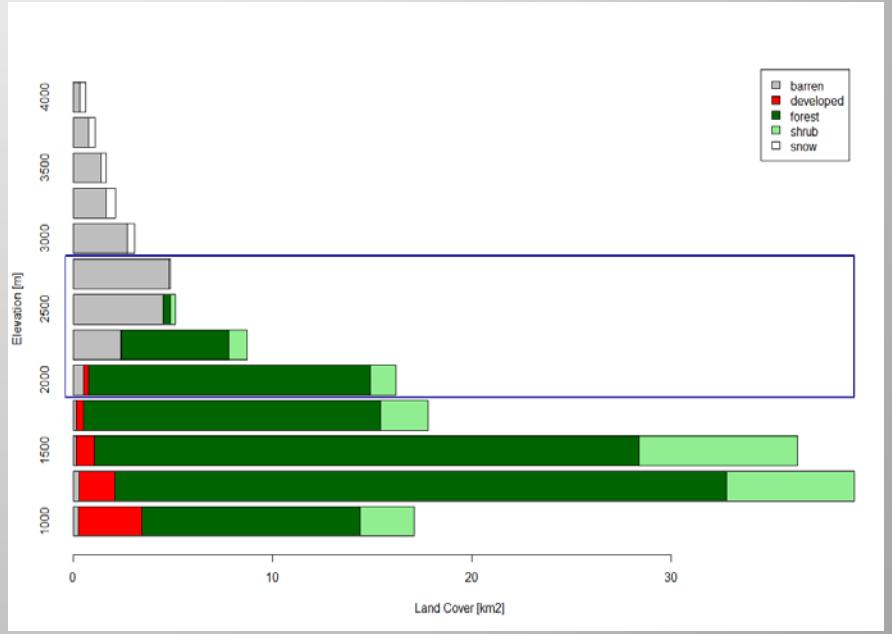
- Too many trees
  - Increased ET
  - Decreased groundwater flow to streams
  - Insufficient openings for snow accumulation
- Too few trees
  - Increased runoff
  - Increased sediment
  - Increased stream temperature
  - Not enough shade to extend snowmelt season

# Conclusions

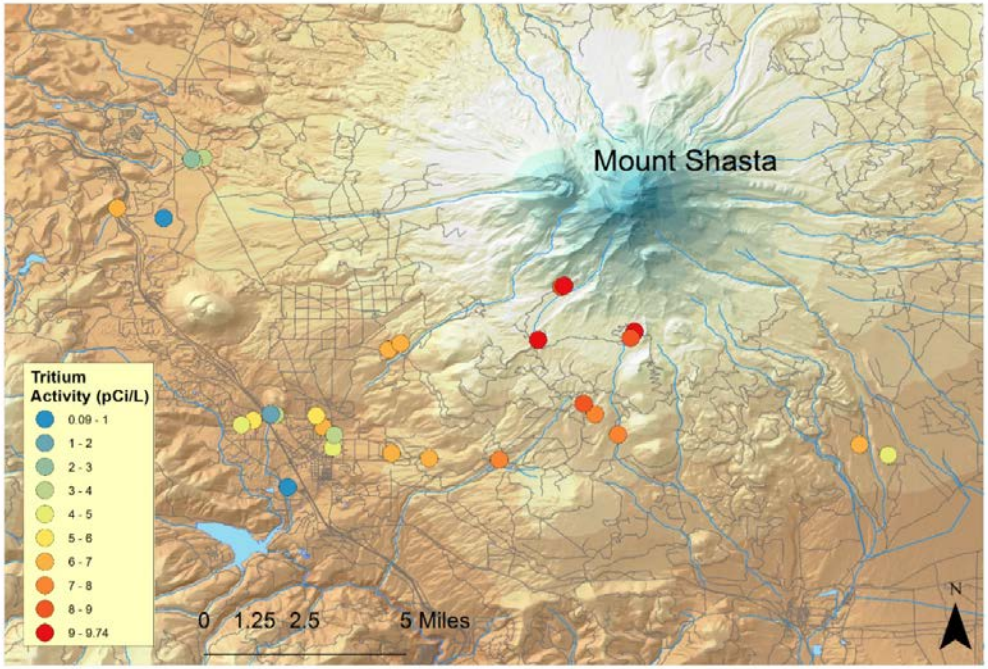
- Headwater areas provide critical late season flow and ecosystem functions
- On Mount Shasta, stable isotopes and noble gas recharge temperatures indicate that recharge occurs predominantly over the elevation range 2200-2900 m (7200 ft to 9500 ft)
- Higher elevations are disproportionately represented because of high precipitation rates and low evapotranspiration over bare ground
- The warmer future will bring a higher treeline, smaller area of bare rock, and likely lower recharge rates.

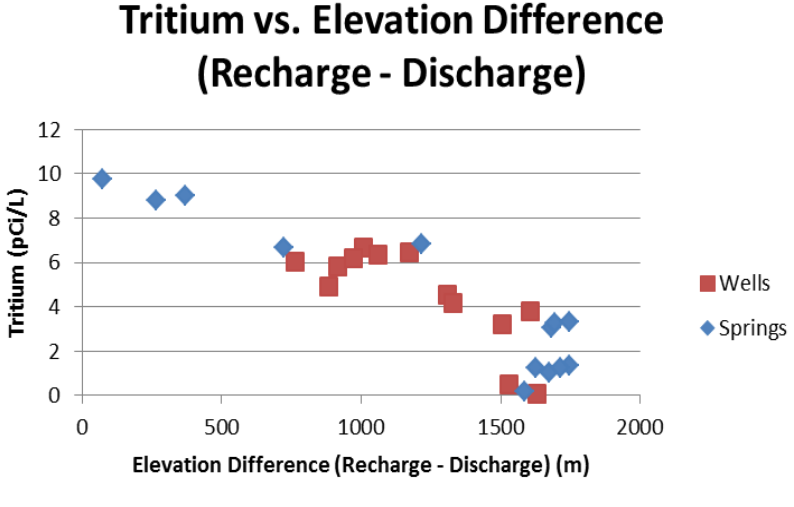
# Relationships between elevation and land cover/area

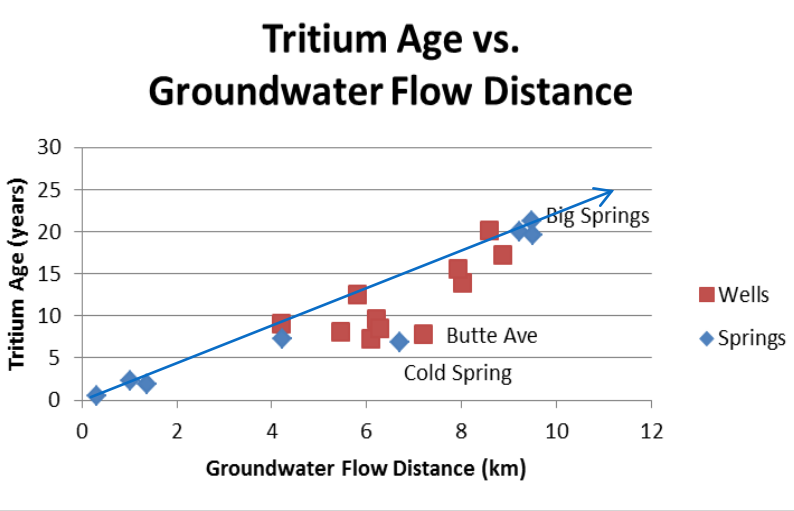


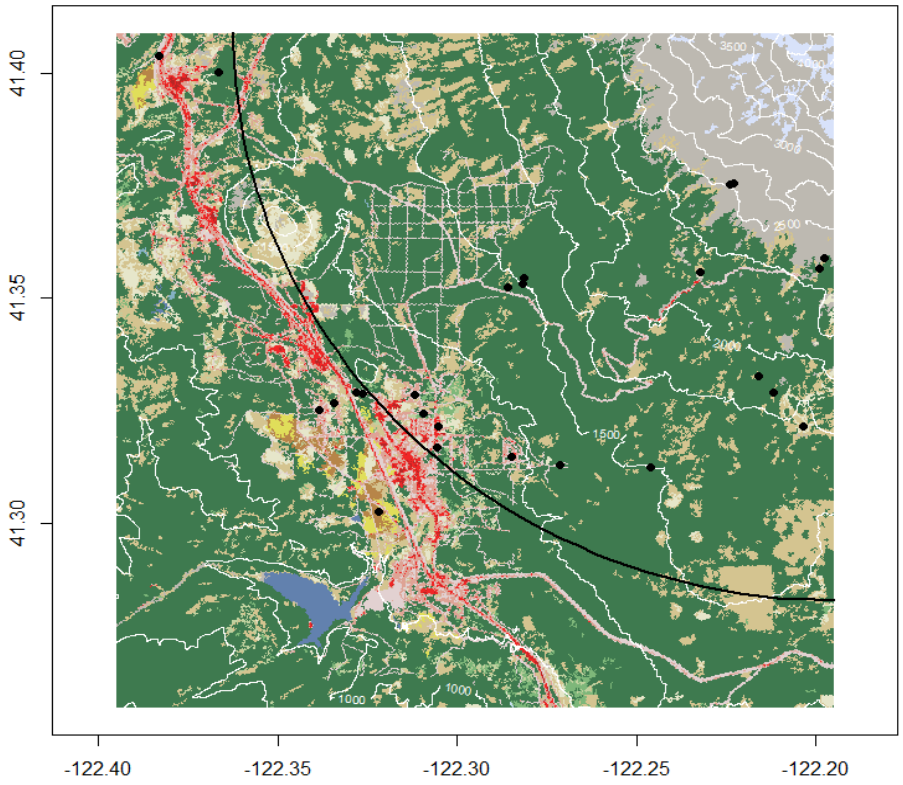
# Groundwater ages and flow rates



# Land coverage, ET, and recharge




- How much of the melting snow goes to ET instead of infiltrating?
- Changes due to warming climate?

Coverage from: National Land Cover Dataset from the Multi-Resolution Land Characteristic Consortium, www.mrlc.gov, Homer, 2015

# Effects of climate change on ET and groundwater recharge