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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

- Evaporation (lighter isotopes evaporate)
  - Ocean: 0‰

- Rain: -5‰ (heavier isotopes condense)
- Vapor: -20‰
- Precipitation: -22‰
- Evapotranspiration: -7‰
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

- Horse Camp Spring
- McBride Campground Well
- Mt Shasta Big Springs

4:1 VE
Land cover in the recharge area

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

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

Tritium vs. Elevation Difference (Recharge - Discharge)

Tritium Age vs. Groundwater Flow Distance

Mount Shasta

Tritium Activity (pCi/L)
- 0.00 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 74
Land coverage, ET, and recharge

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

Effects of climate change on ET and groundwater recharge

- Higher temperatures
  - Longer growing season
  - Expansion to higher elevation
  - Increased growth
  - Higher CO₂

- Higher temperatures
  - Earlier snowmelt
  - Soil water low when ET high

- Higher stomatal closure

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