RECHARGE PROCESSES IN THE MOJAVE DESERT: A COMMENTARY

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Presentation Overview

- Discussion of Some Dominant Processes.
- Brief summary of previous work and methods.
- Current uncertainties.
- Current important questions.
- Implications of recharge processes on monitoring efficacy in fractured rock.

Dominant Processes Controlling Recharge and Recharge Estimation

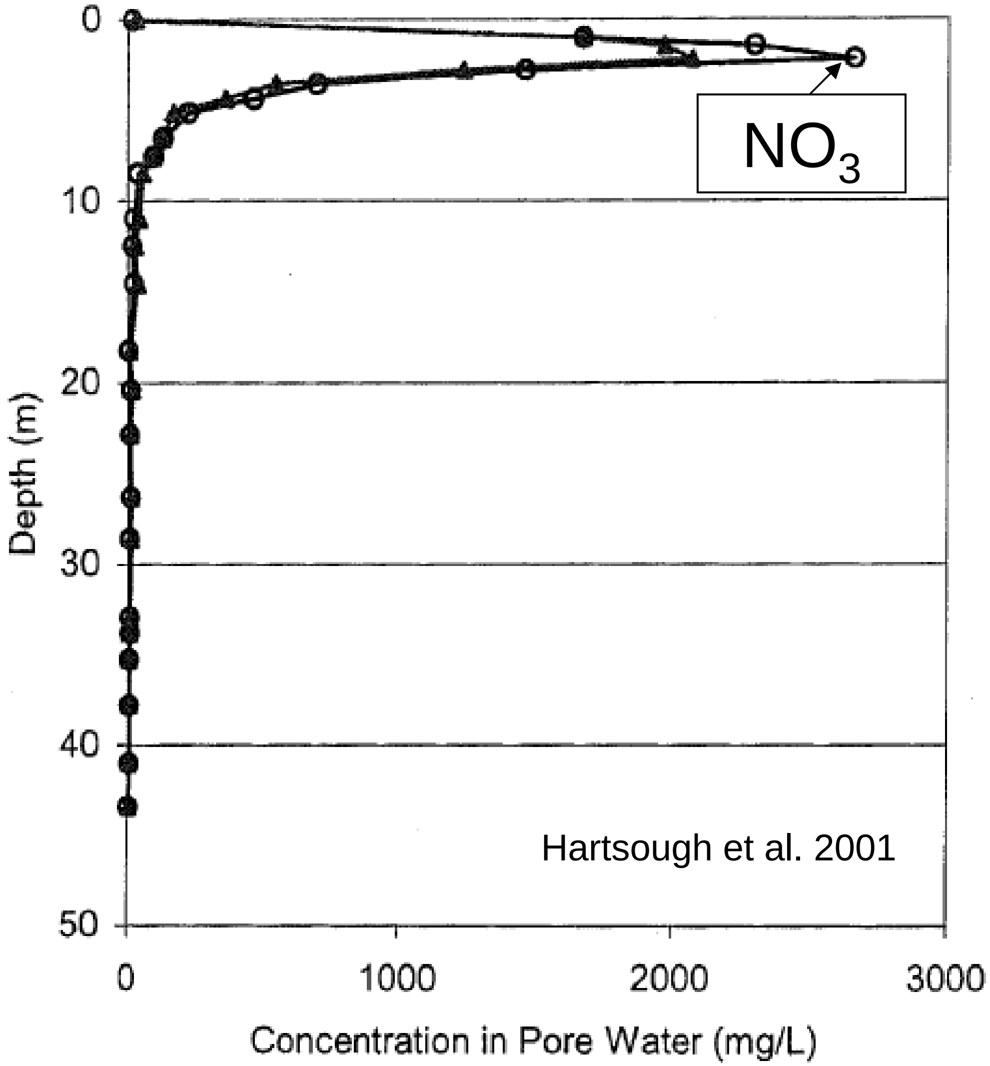
- The usual suspects: Precipitation and its timing, Temperature, Soil type, Solar Radiation, etc.
- The unusual suspects that must be considered in arid regions:

1. Vegetation Adaptation
2. Bare Soil Evaporation
3. Climate Variability
4. Depth to Bedrock
5. Fire

Vegetation Adaptation

- Arid species have adapted to climate regimes and its uncertainty.
- In the Mojave, winter precipitation is a much safer “bet”, therefore many species show a reluctance to utilize summer rainfall.
- Therefore changes to summer monsoon conditions could drastically change recharge conditions.
- Summer senescence also leads to exclusion of nutrients that would never be seen in more humid regions.

Accumulation of Nitrogen in an otherwise N limited ecosystem.



- Dominant Vegetation is showing exclusion of both chloride <u>AND</u> nitrogen.

- Nitrogen must be leached down during summer events, when deep rooted species are dormant.

Bare Soil Evaporation

- Rarely an important process in humid regions.
- Sparse vegetation can lead to large exposed soil surfaces.
- However, most deep rooted species also show extensive root development in intershrub zones.
- Still, these root systems may not be active during summer months.

Typical Mojave Leaf Area Index

A-1. View of a FACE ring from a 50 ft crane boom

Courtesy of Nevada Desert FACE Site

Climate Variability

- Precipitation in the Mojave in highly variable.
- Variability is not only seasonal, but has much lower frequencies of variation.
- The ecosystems have evolved, and recharge modeling must account for this evolution, both in above and below-ground biomass.
- Plant dynamical coefficients are not as well developed as our numerical methods are.

Strong Seasonal and Lower Frequencies in Vegetation Dominance

Winter

Late Spring of high precip. year

Courtesy of Nevada Desert FACE Site

Importance of the Shallow Subsurface on Recharge

- A Tale of Two Sites at the Nevada Test Site

- Frenchman Flat is located east of Yucca Mountain, while Cane Spring is found just south and west of Frenchman Flat. Little difference in elevation or climate

- *Frenchman Flat:*

  P= 124 mm/yr;

  PET = ~2000 mm/yr

- *Cane Spring:*

  P =~ 150 mm/yr;

  PET = ~1800 mm/yr

Frenchman Flat on the NTS

Photo courtesy of National Nuclear Security Administration / Nevada Site Office

Vegetation Typical of Cane Spring on the NTS

Photo courtesy of National Nuclear Security Administration / Nevada Site Office

The Similarities End There…

- Cain Spring is a flowing spring, and is supplied solely by modern recharge from low elevation.
- Portions of Frenchman Flat has not seen recharge since 15,000-120,000 years ago.
- Difference: Cane Springs catchment is characterized by thin (<~1 m) soils overlying fractured volcanic.
- Frenchman Flat catchment contains thick (>200 m) of alluvial sediments and well developed desert soils.
- Cane Spring catchment has little to no storage for ET, while Frenchman Flat has an over-abundance of storage.
- Study of such Yucca Mountain analogs, while simple to perform, appear to have been significantly under-utilized for model process development and serious testing.

Results from Yucca Mt-like Environs

- Scanlon et al. (2006) reports ~8 out of a fairly complete compilation of recharge studies (98 in total) from arid climates have probed recharge in thin soils or fractured rock environments.

- These 8 studies show a wide range of fluxes, with thermal and numerical modeling showing the smallest range, while tracers show the largest range of variability.

- The high variability has serious implications for both recharge and monitoring at Yucca Mountain.

Recharge at Yucca Mt. (Generalized)

- There appears to be a positive (non-linear) correlation between reported recharge and time of studying at Yucca Mt.
- 1981: 0.5 mm/yr
- 1984: Negative Recharge to ~0.5 mm/yr
- 1996: ~6 mm/yr
- 2000: ~10 mm/yr
- 2003: ~10-20 mm/yr

- I postulate that the causality results from focused data collection, rather than any changes in recharge.

Selected Recharge Results from Yucca Mt.

- Darcy's law calculations using measured potentials and permeabilities in non-welded units (the only units where such measurements are sufficient for calculations). (Flint et al., 2002-2003)
- Numerical simulation to match measured water potentials.
- Matching temperature profiles to include both thermal conduction AND advective heat transport from recharge.

- However, almost all properties of fractures, the dominant flow pathway in the welded units, are inferred, not measured.

What are the Questions?

- Chloride Mass Balance for Recharge: Our current models of chloride (and N) accumulation in the vadose zone typically fail to account for real root zone behavior. Still robust, but the simplicity misses some biology and ecology.

- Matching Thermal Profiles: The assumptions of thermal equilibrium between fractures and matrix under transient infiltration events may limit analysis in fracture dominated conditions.

- A limited of probing of fracture flow behavior at Yucca Mountain. As recent as 2006, recent Yucca Mt. publications indicate that:
  - *Fractures dominate the flow regime at Yucca Mountain, but fracture density and apertures are not well characterized…*
  - *Bulk rock permeability data are scarce…*
  - *The only fractures that have been hydraulically characterized are those that are filled…*

Uncertainty in Recharge and its Impact on Monitoring Performance

- The range of possible recharge rates at Yucca Mountain is only about 150 mm/yr.
- Current studies have narrowed that down by about a factor of ~5-10.
- However, we are unable to consistently measure the spatial or temporal variability in recharge, particularly at the repository horizon, where flow is almost surely in the fractures.
- Existing studies of recharge in fractures and structured soils continue to show very large variability in fluid velocities.
- Finally the Repository Monitoring Program must be designed around existing data and existing understanding of key processes, most of which coincide with the processes affecting recharge.

Monitoring the Vadose Zone at the Repository Horizon

Key Elements of any Monitoring Plan

- Monitoring equipment must be capable of detecting a leak at low concentrations (critical for rad.)
- Capable of detecting a leak in time to stop it from moving far and identifying its source.
- Monitoring plan must have in place, defined courses of action should a leak be detected.
- Monitoring equipment must provide sufficient information to determine which of the several PRE-DETERMINED courses of action are to be followed.

Questions for the Monitoring Plan

- What is the mechanism of fluid flow in the fractures? Episodic, chaotic, creeping, etc. Critical information for designing sensors and sensor frequency, yet few experiments have been done anywhere in unsaturated fractures.
- If recharge flux (as well as condensate flux) is primarily in fractures, how will monitoring equipment detect it there?
- What monitoring tools are available to measure activity in fractures?
- What monitoring tools are available (or perceived) to detect radioactivity confined to less that 0.01% of the rock mass?
- At typical fracture velocities, a leak can easily transit 1 meter in Order(1 day). What reliable tools are available for this frequency of measurement?

Questions for the Monitoring Plan (continued)

- What monitoring tools are available to reliably (e.g.,< ~0.01% failure) measure over 50-100 years?
- Finally, what are the draft Courses of Action, if a leak is detected?
- *For each question, I ask the audience to compare your answers if the repository horizon consists of fractured unsaturated welded tuff, or unsaturated, low water content alluvial sediments.*
- *Our ability to accurately measure the recharge flux presages our ability to monitor the repository vadose zone.*

Summary

- We have progressed considerably in our ability to measure recharge in arid regions underlain by porous media (sands, alluvium, etc.), but fundamental questions do remain.
- Recharge estimates at Yucca Mountain have matured and benefited from field data collection.
- Studies of recharge in which fractures or macropores are present, while few in number, have typically shown higher rates of recharge, and much more rapid migration of water and contaminants.

- Our technology for monitoring in fractured unsaturated rock, whether for recharge or for repository performance remains largely untested and is hampered by our continued lack of experience and experiments in the medium.

Closing

- Tom Eakin (of Maxey and Eakin) recently received a lifetime achievement award from NWRA. Contemplating his early work on recharge and the renewed focus on arid region recharge, I paraphrase the caution in his remarks:

“ *We can easily mistake our understanding of our models for a deeper understanding of the real workings of nature, so always keep that in mind and never stop trying new ideas and new experiments!”*