U.S. Department of Energy
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Heterogeneous Seepage at the Nopal I Uranium Mine, Chihuahua, Mexico

Presented to:
10th Natural Analogue Working Group Meeting

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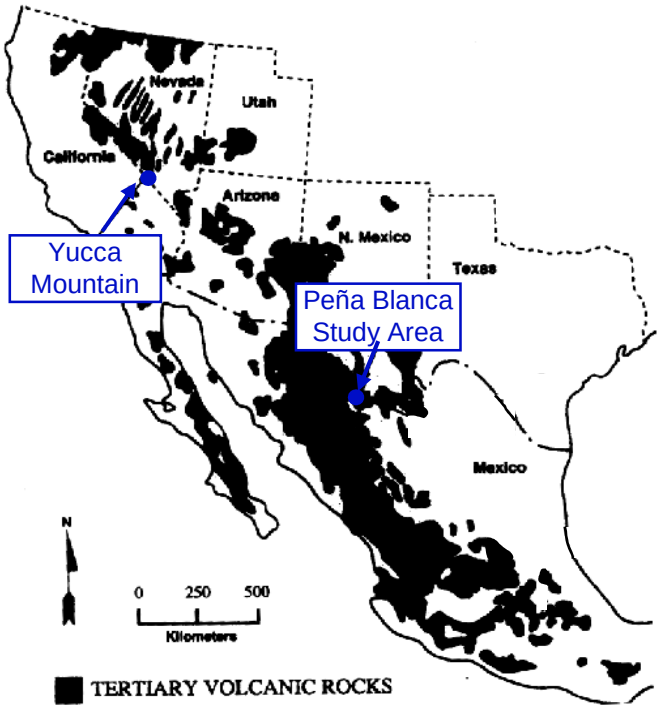
Objectives of Nopal Natural Analogue Study

- **Use Nopal I site as an analogue for Yucca Mountain**
- **Evaluate processes related to transport of radionuclides in fractured rock**
- **Seepage study presented here is one component of larger collaborative study**

Nopal I as Yucca Mountain Analogue

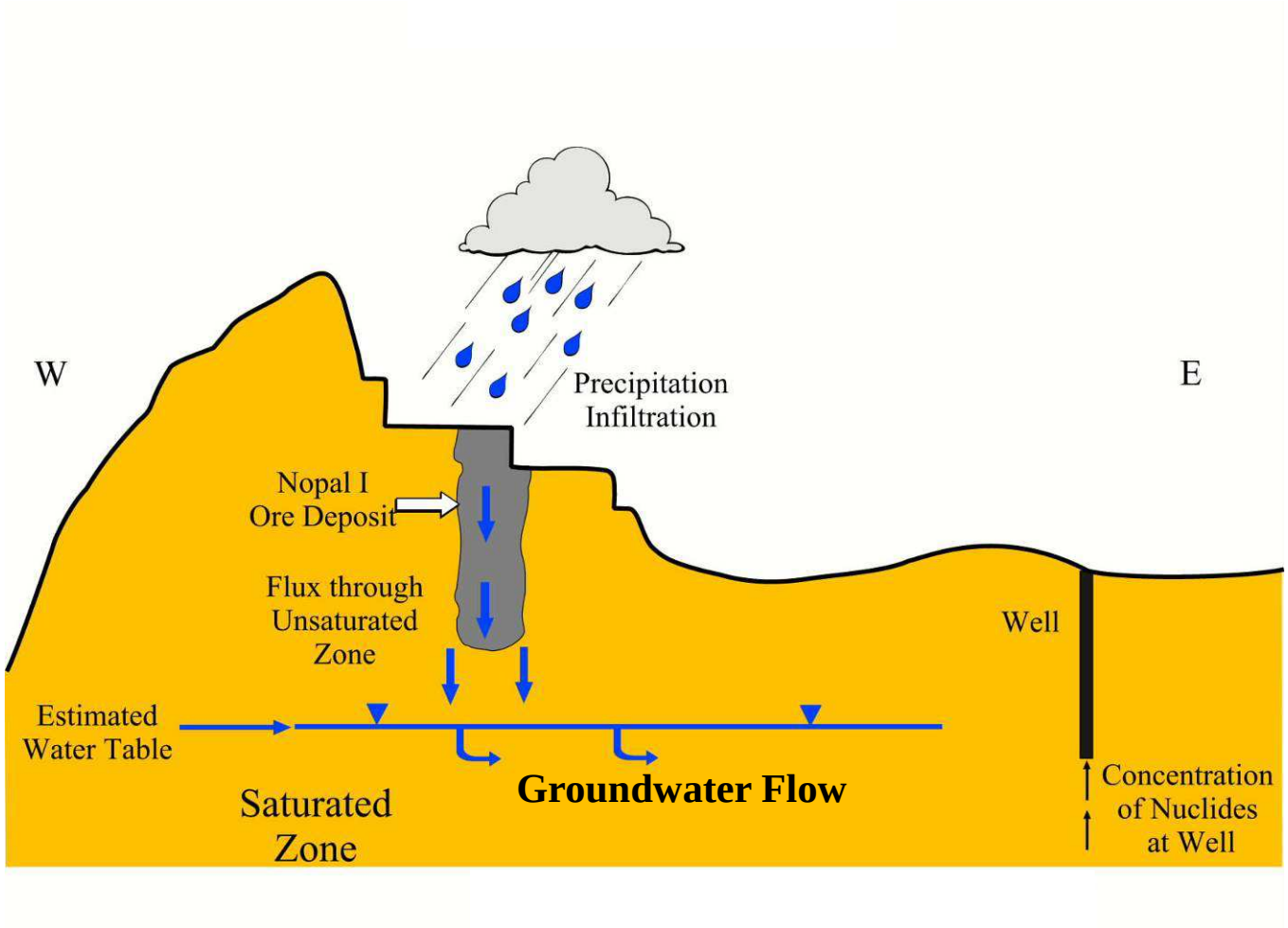
Nopal I is a prominent, exposed ore body within Peña Blanca uranium mining district



Site similarities include:

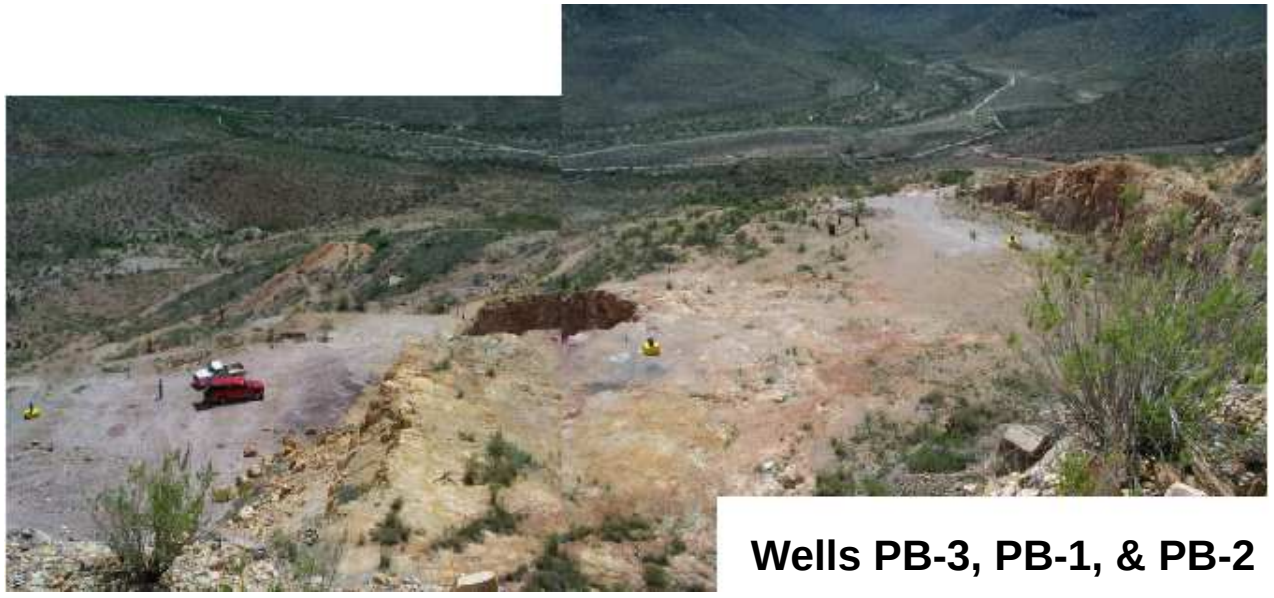
- Fractured rhyolitic tuff
- Limestone basement
- Basin and Range setting
- Unsaturated zone > 200 m thick
- Arid climate

Conceptual Model for Radionuclide Transport



Peña Blanca Hydrology

- **Thick unsaturated zone at Nopal I**
  - **Elevation for +10 level is 1463 meters above sea level (masl)**
  - **Water level in wells PB-1, -2, -3 is 1235-1240 masl**
  - **Depth to water table is ~225 m**
- **Regional groundwater flows east**



Wells PB-3, PB-1, & PB-2

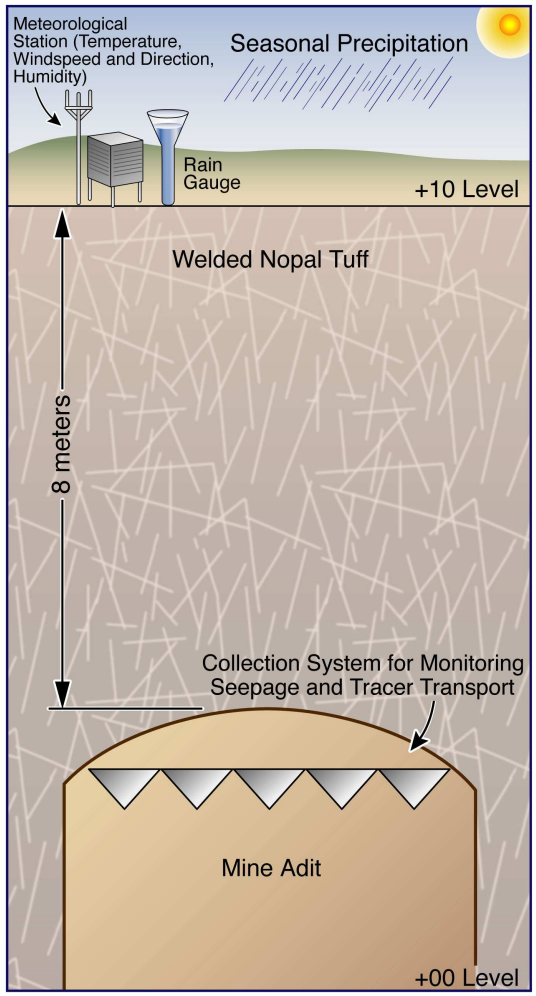
Fracture Flow Paths

- **Nopal tuff cut by numerous fractures**
- **Pearcy et al. (1995) demonstrated preferential migration of U along fractures intersecting Nopal ore body**

Mineralized EW fracture of Pearcy et al. (1995) in +00 adit

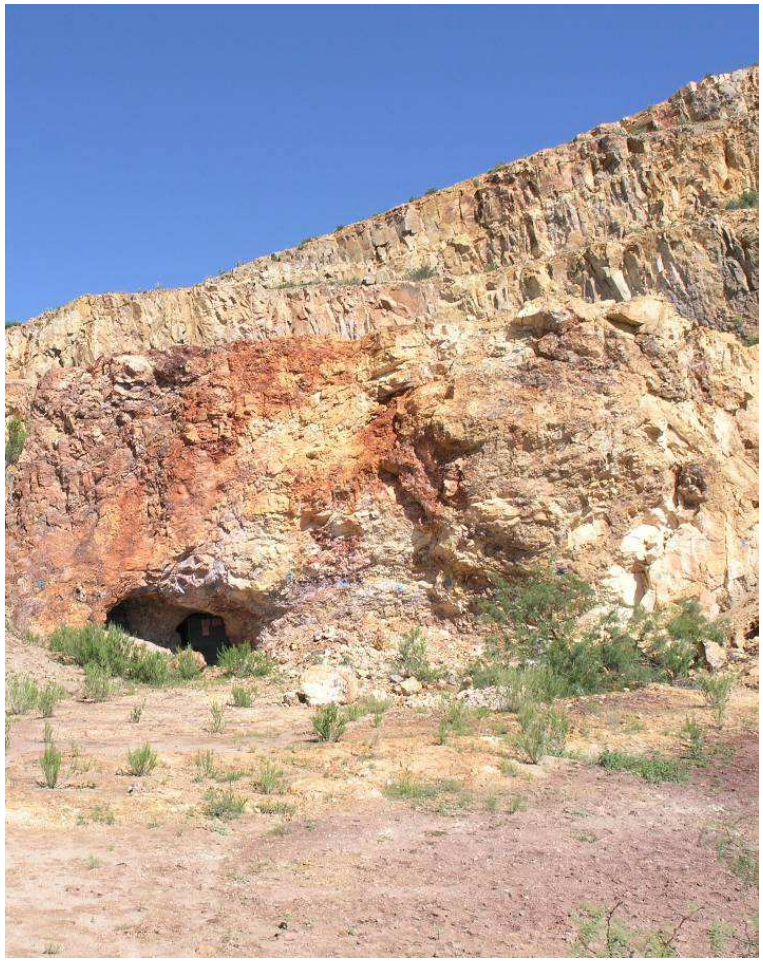
Infiltration/Seepage Study Objectives

- **Evaluate interaction between matrix and fractures, heterogeneity of flow process, and radionuclide transport**
- **Evaluate effects of fractures on localization of seepage**
- **Develop conceptual and numerical models for infiltration and seepage**



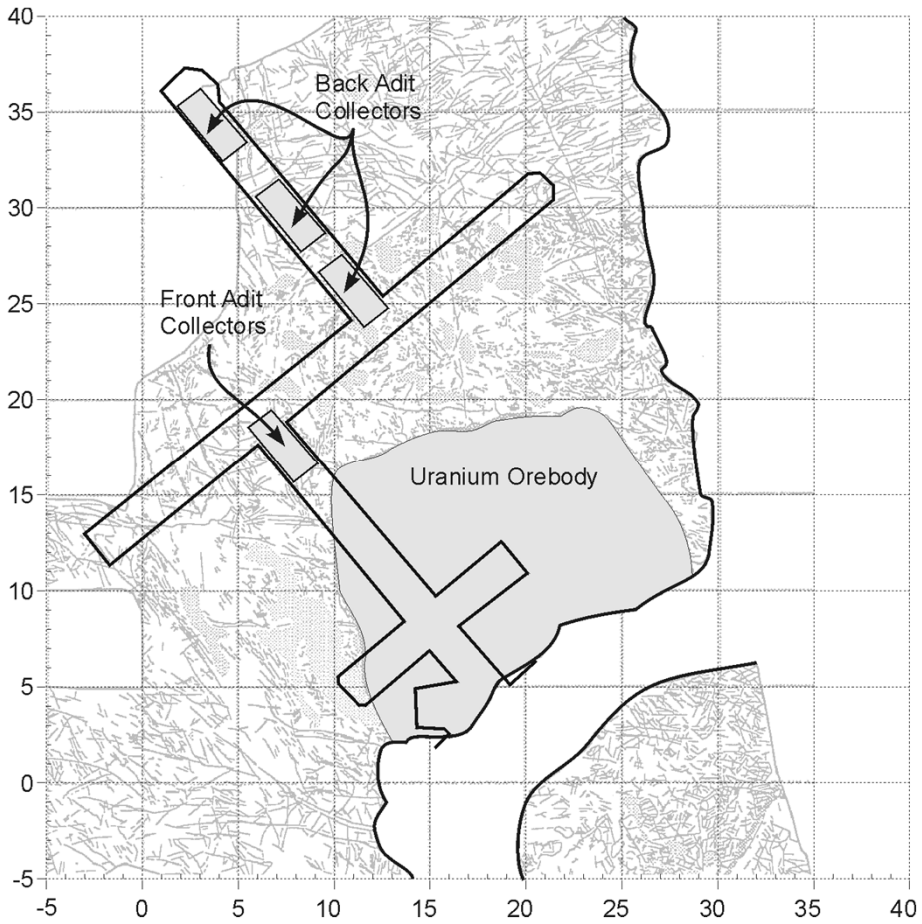
Nopal Seepage Study Plan

- **Install robust seepage collection system inside mine**
- **Periodically measure seepage volumes and sample waters**
- **Record rainfall and compare with automated collectors**
- **Evaluate chemistry of seepage waters**



Water Collection System

- System deployed in +00 adit
- 240 collectors (0.3 x 0.3 m)
- 6 collectors with pressure sensors
- 2 temperature and relative humidity sensors
- 1 barometric pressure sensor
- 1 data logger (data collected every 2 hours)

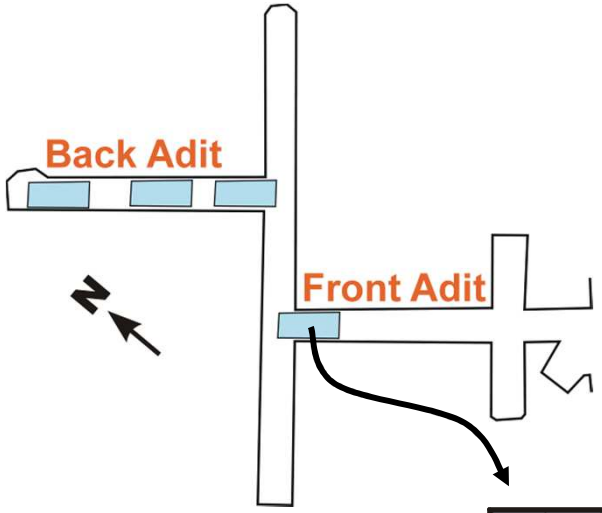


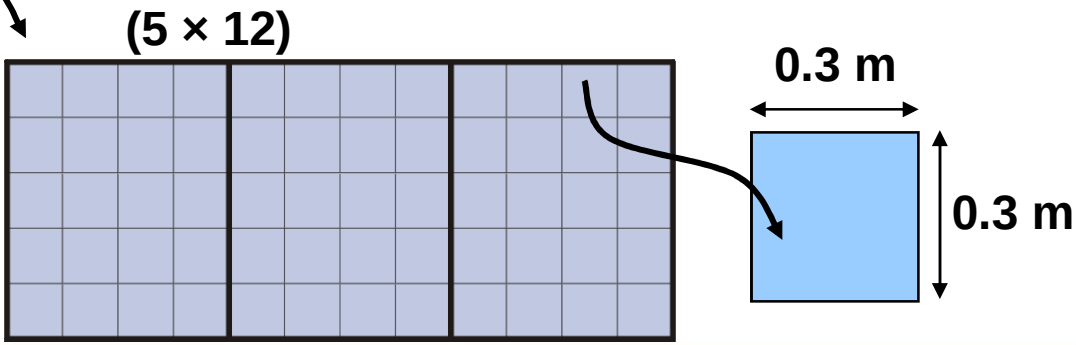
Fracture map from SWRI

Water Collector Layout

Back Adit

Front Adit





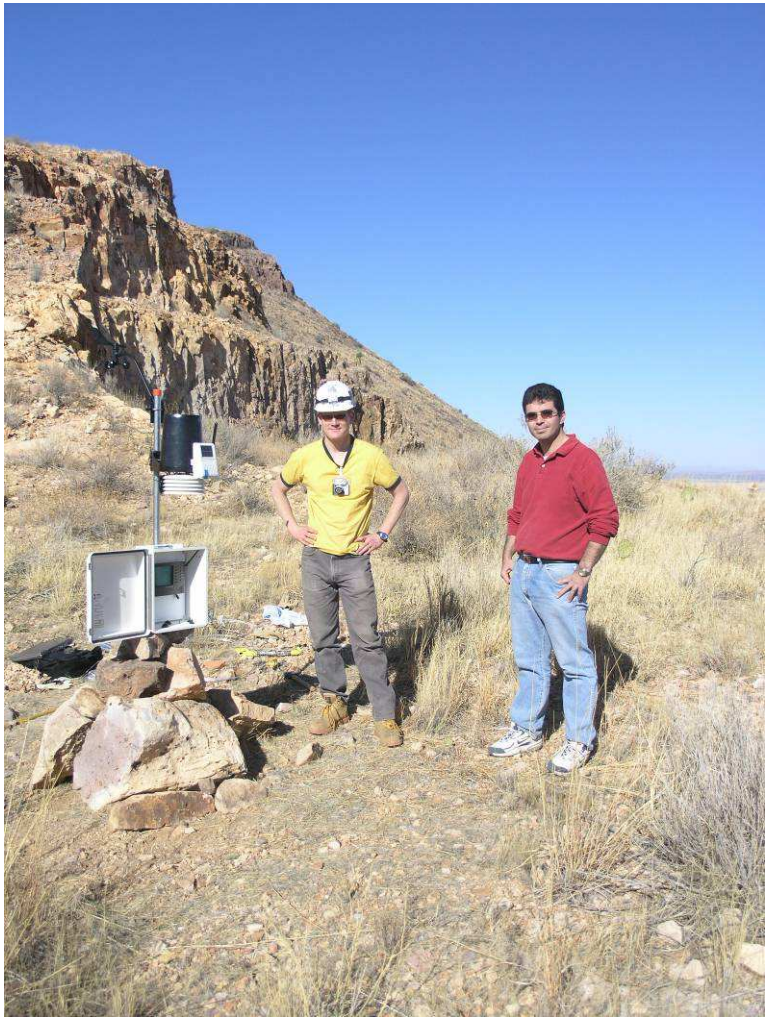
Water Collection System

125 ml collection bottles

340 ml instrumented columns

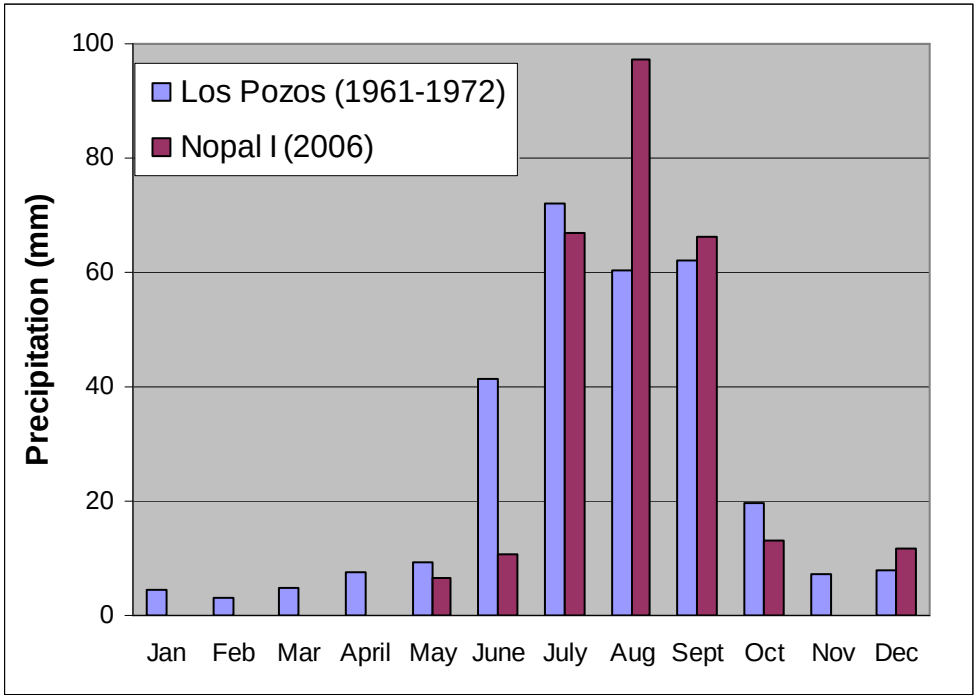
Nopal Weather Station

- **Installed on +20 level of Nopal I on 3/20/07**
- **Automated station recorded data every 2 hours:**
  - **Temperature**
  - **Barometric pressure**
  - **Wind speed and direction**
  - **Relative humidity**
  - **Rainfall**



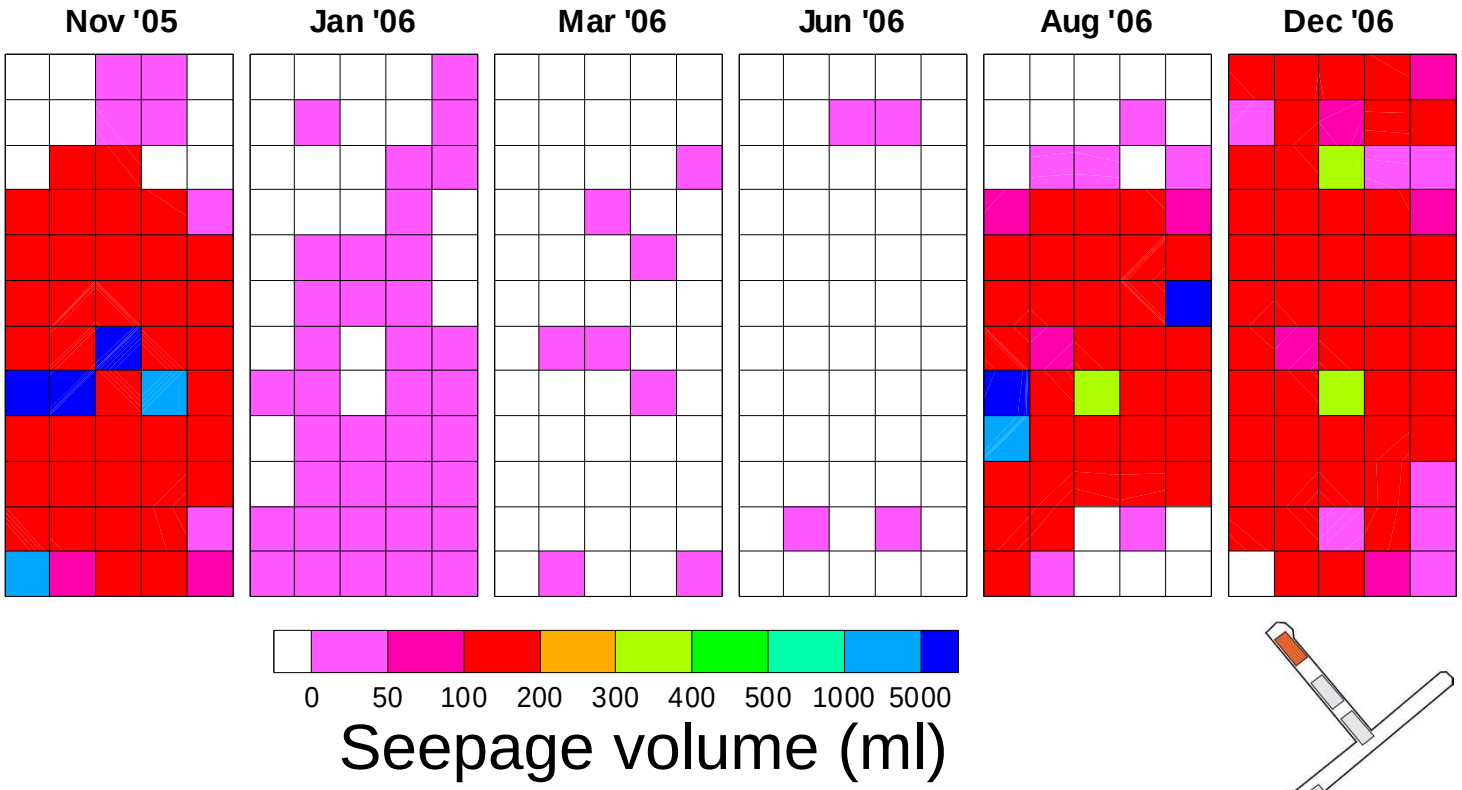
Peña Blanca Climate

- **Precipitation ~300 mm/year**
- **Annual temperature (average) ~18°C**
- **Rainy season predominantly during summer months**

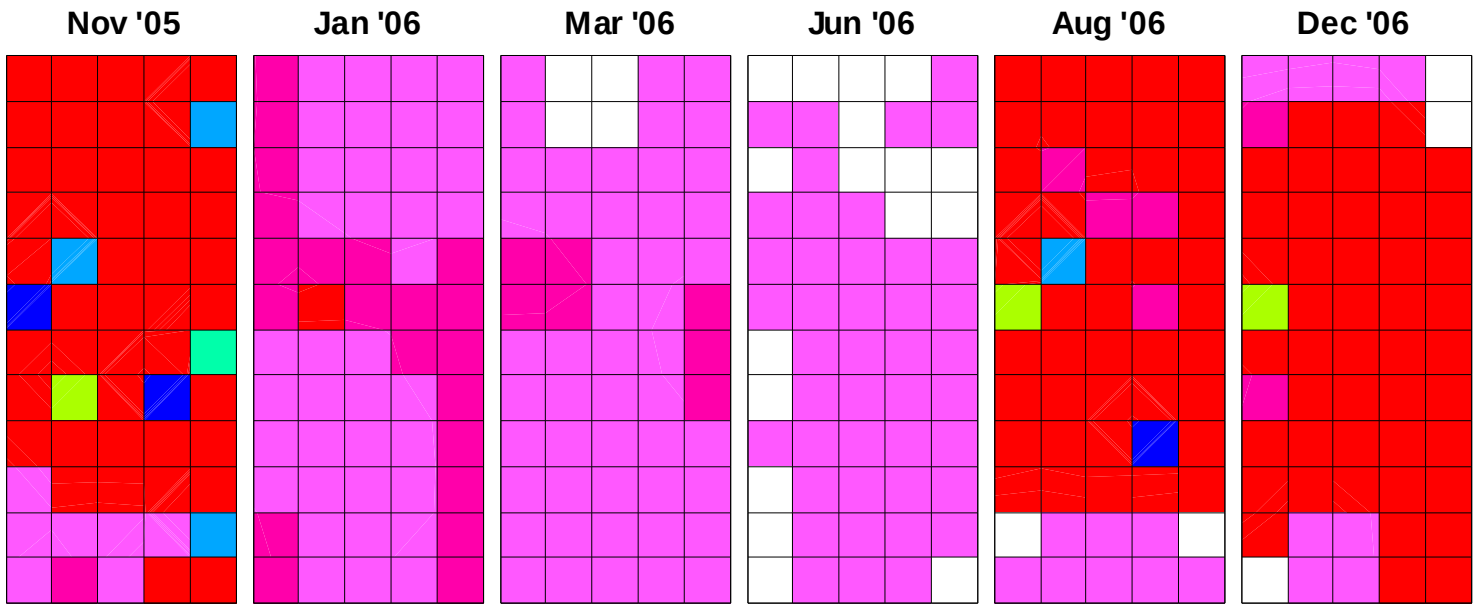


Los Pozos data from Servicio Meterológico Nacional
Nopal I data collected from March-December 2006

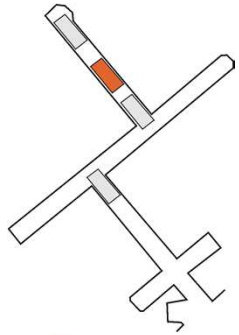
Seepage – Collection Zone #1



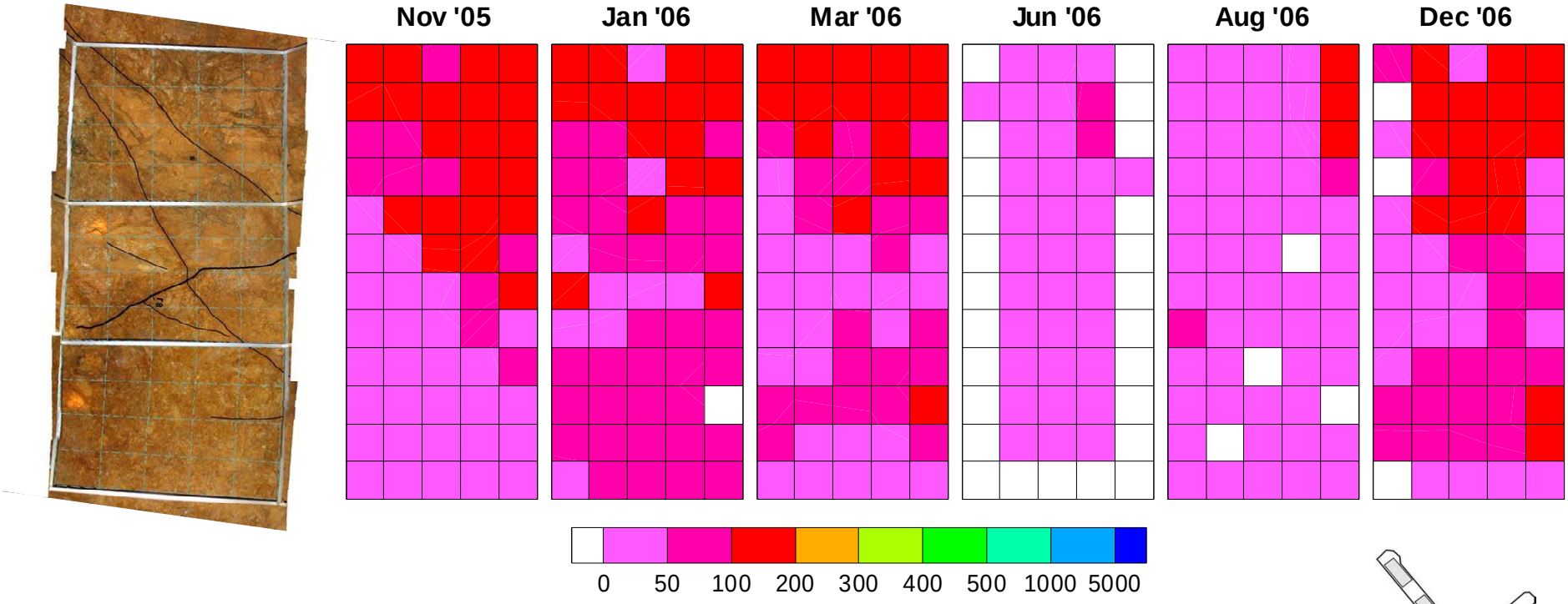
Seepage – Collection Zone #2



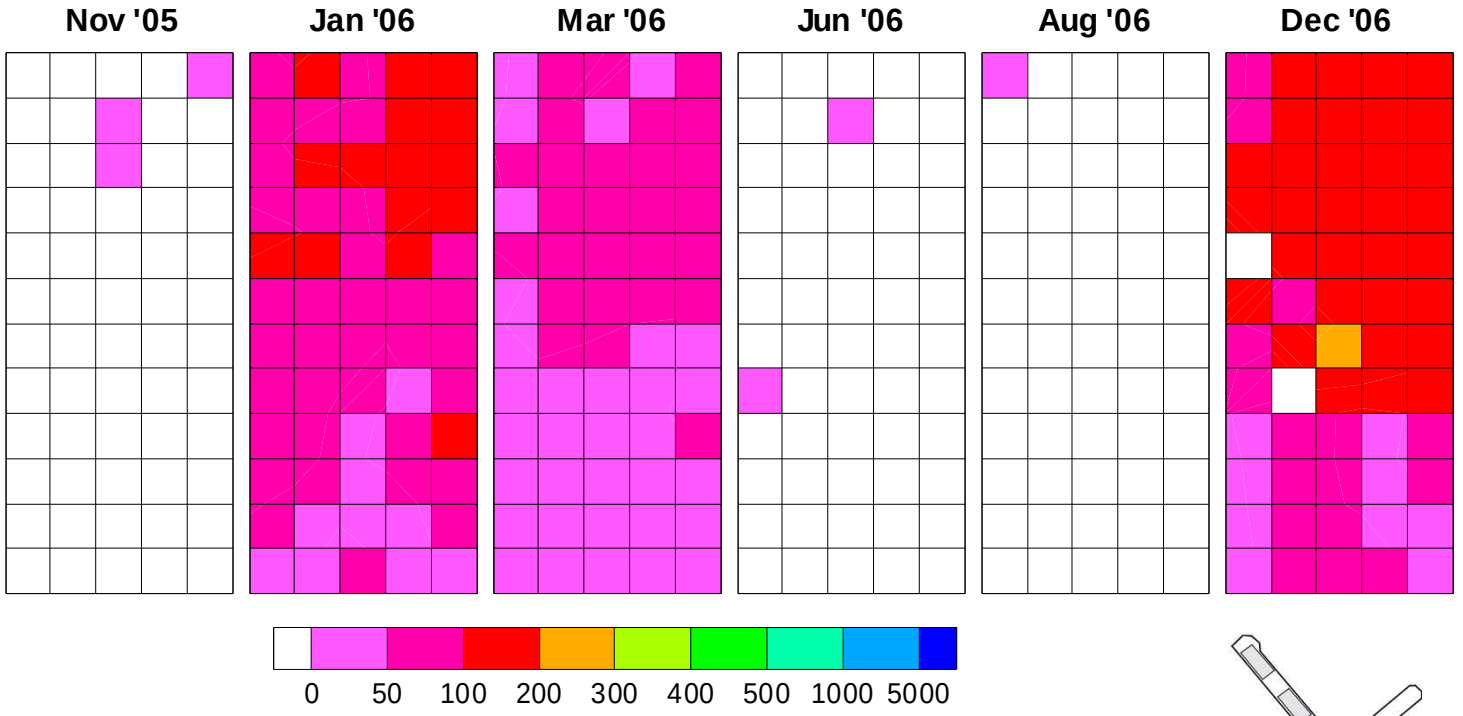
Seepage volume (ml)

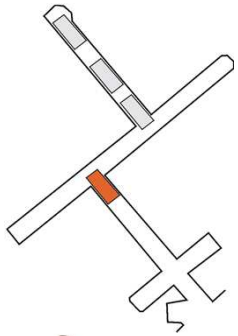


Seepage – Collection Zone #3

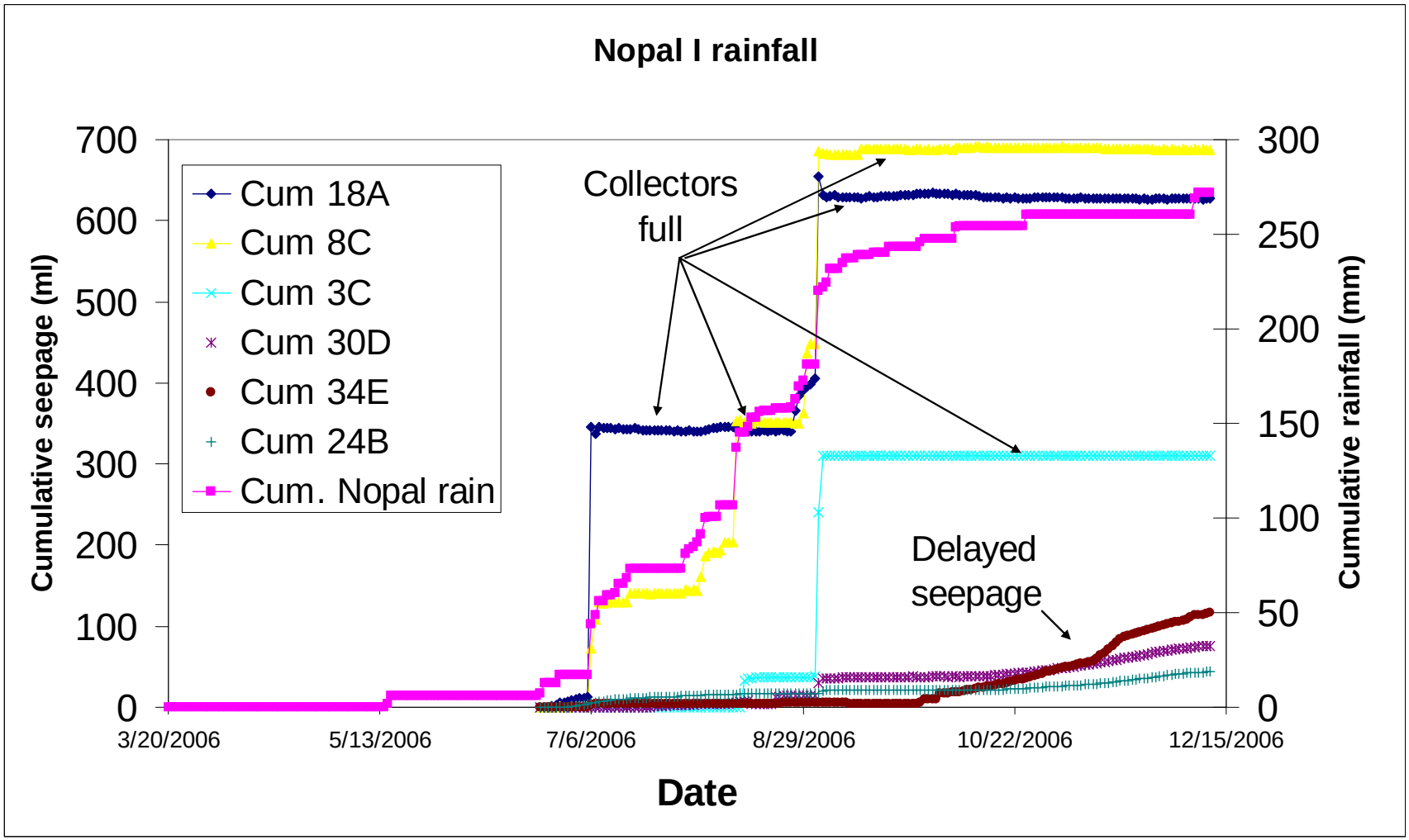


Seepage – Collection Zone #4





Relation Between Precipitation and Seepage



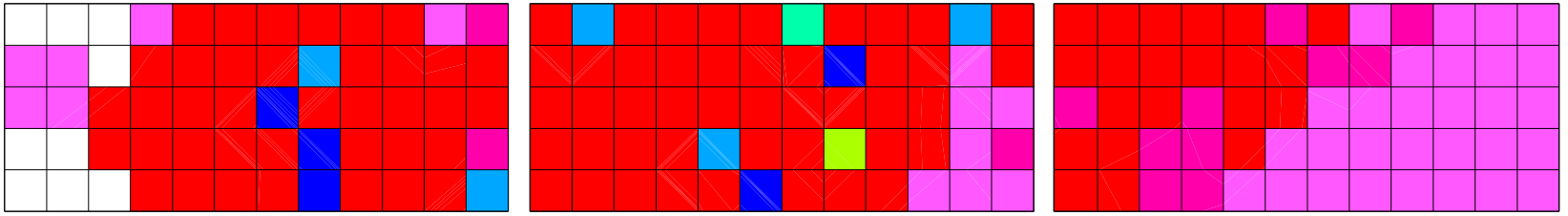
Fast-Path Seepage

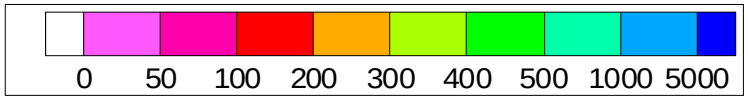
- **In 2 of the 6 automated collectors, seepage occurred within hours after start of each large (>25 mm) rain event**
- **Slight lag between smaller rainfall events and seepage in 8C collector**
- **Seepage amount at 8C significantly less than rainfall volume (July 29, 2006 – total seepage volume [141 ml] corresponds to 1.6 mm rain; cumulative seasonal precipitation = 73.4 mm)**
- **Major seepage at 3C collector only occurred after last major precipitation event**

Delayed Seepage

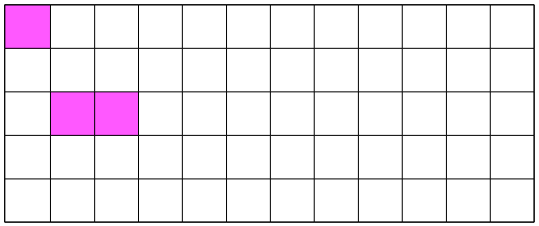
- **Significant time delay between start of rainy season and onset of seepage in four of the automated collectors (2-3 months)**
- **Longer time lag observed for collectors in front adit, front portion of back adit, and first few rows of back adit**
- **Areas with delayed seepage have smaller seepage volumes**

April – Nov. 2005 Seepage

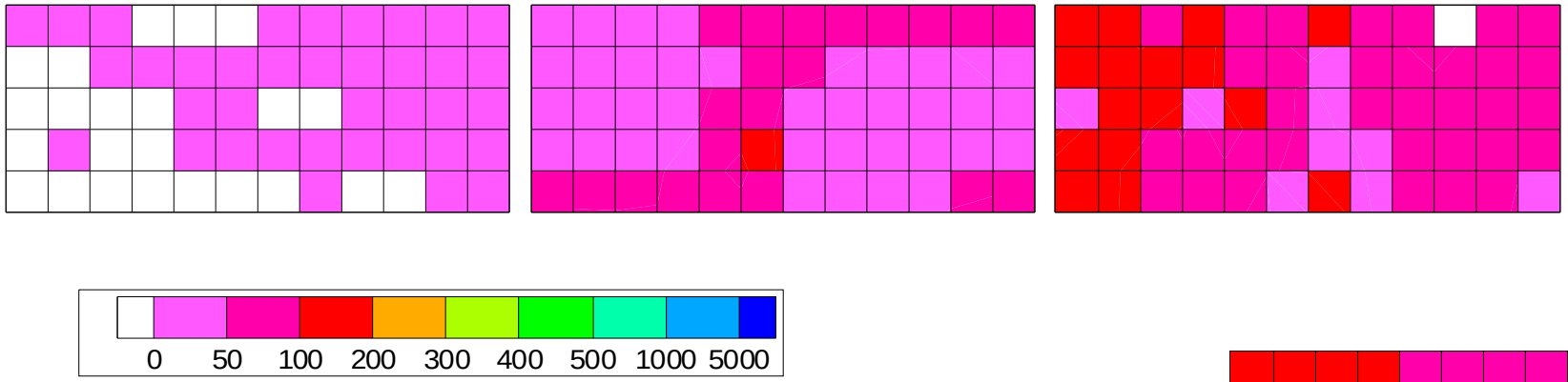




Seepage volume (ml)

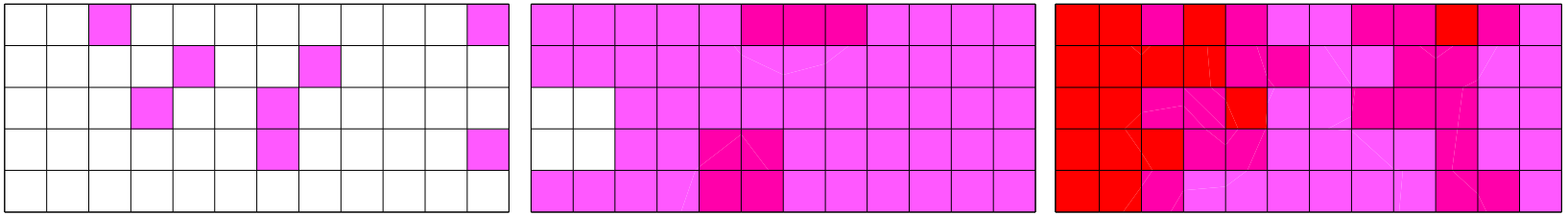


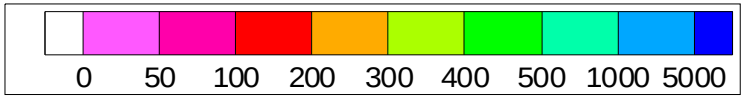
Nov. 2005 – Jan. 2006 Seepage



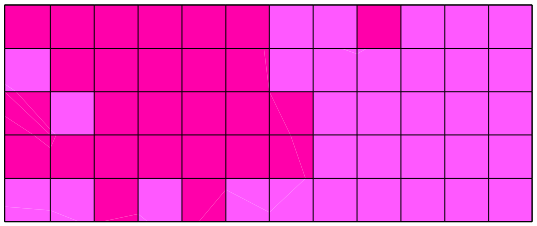
Seepage volume (ml)

Jan. – Mar. 2006 Seepage

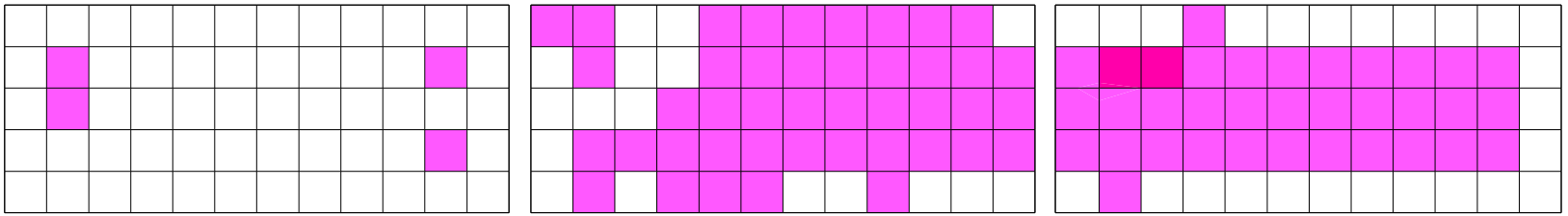


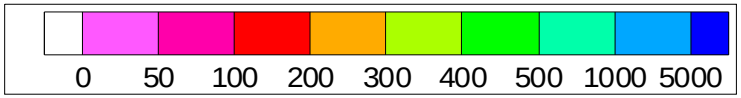


Seepage volume (ml)

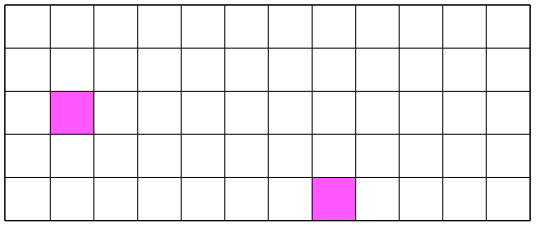


Mar. - June 2006 Seepage

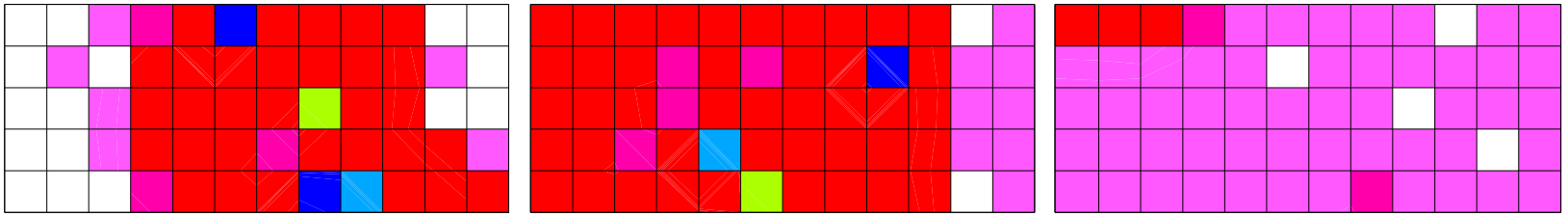


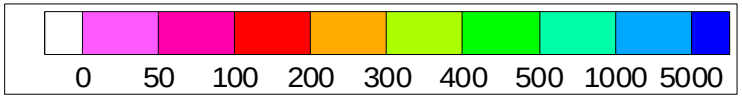


Seepage volume (ml)

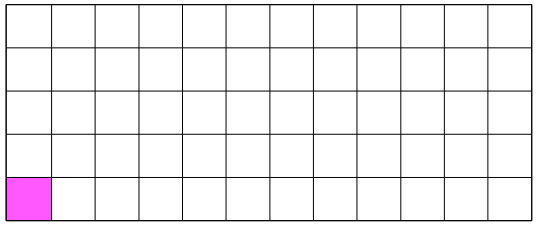


June – Aug. 2006 Seepage

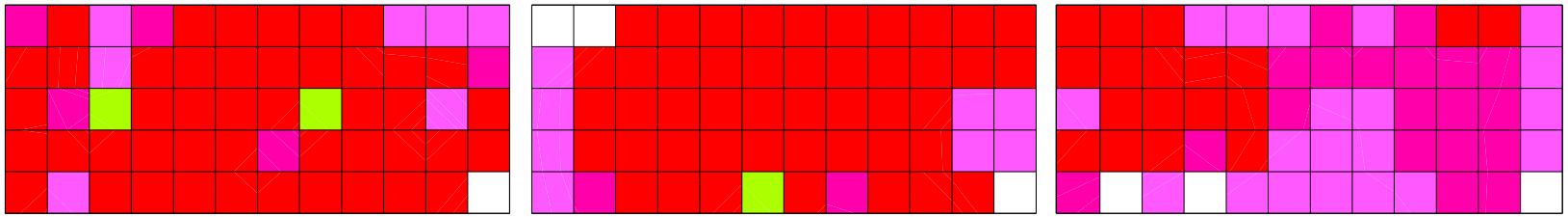


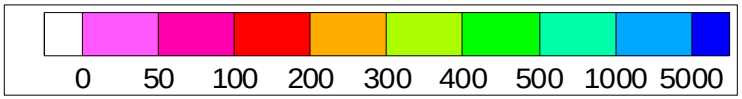


Seepage volume (ml)

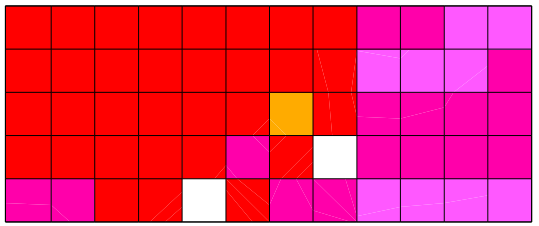


Aug. – Dec. 2006 Seepage

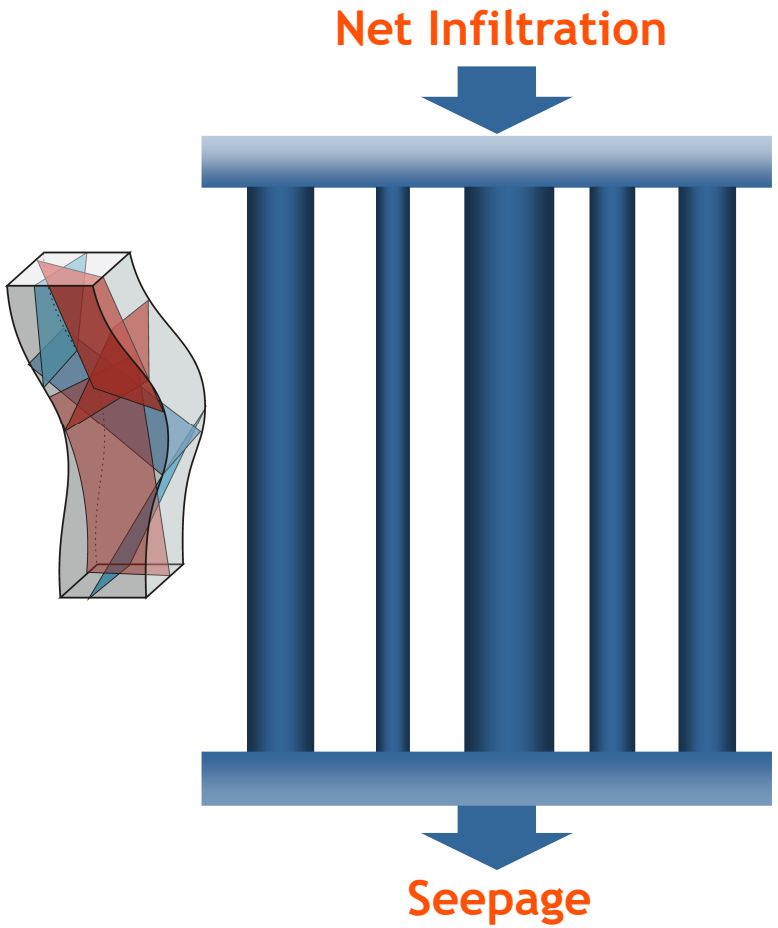




Seepage volume (ml)



Initial Seepage Modeling



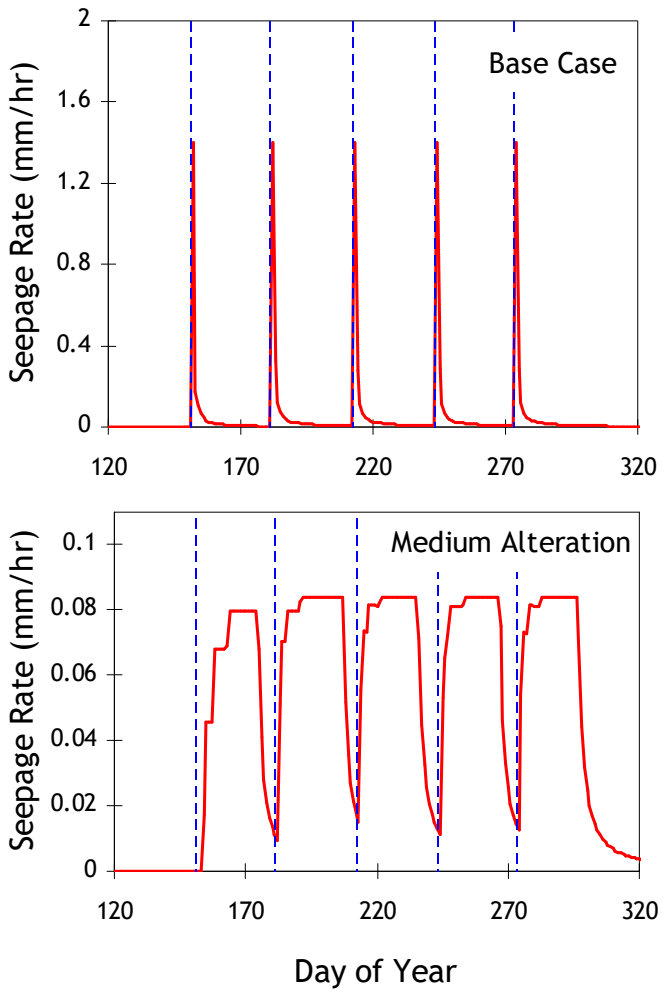
- Fracture network modeled as assemblage of 5 superimposed 1-D flow pathways
- Each pathway represents set of interconnected fractures
- Porosity, permeability and capillary strength of pathways estimated using prescribed effective fracture properties (aperture, density, tortuosity)
- 5 rain events (2 mm/day) applied to common upper boundary
- Seepage defined as volume of water that drips at the bottom boundary

Prescribed Fracture Properties

- Seepage data suggests that different zones of the adit have different fracture properties
- Zones closer to U ore body are more altered
- Degree of alteration represented by reducing the base case fracture apertures

Base Case			
Aperture (μm)	Density (m/m²)	Degree of Alteration	Fracture Aperture (% of base case)
10	6	Low	40 %
30	2	Medium	30 %
50	1.2	High	20 %
70	0.9		
100	0.6		

Initial Modeling Results



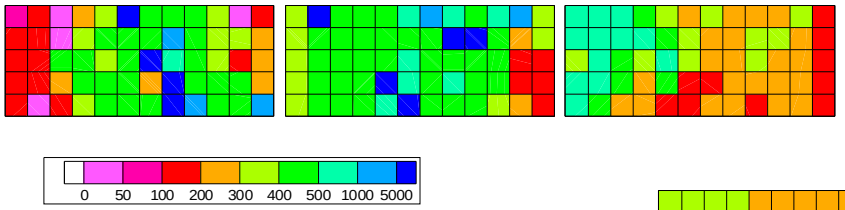
- Seepage in the base case arrives in bursts, shortly after rain events
- Seepage in the medium alteration case occurs steadily for extended period after rain ends
- The impact of the different fracture sets is shown by irregularities in the seepage rate of medium alteration case
- Observed delay in seepage for front adit area not captured by model

Condensation

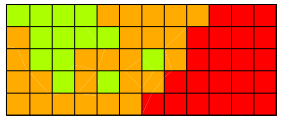
- **Collector with top deployed in area where condensation was previously observed**
- **Small amount of condensate was collected – this may also contribute to seepage**

Flow Diversion around Adit

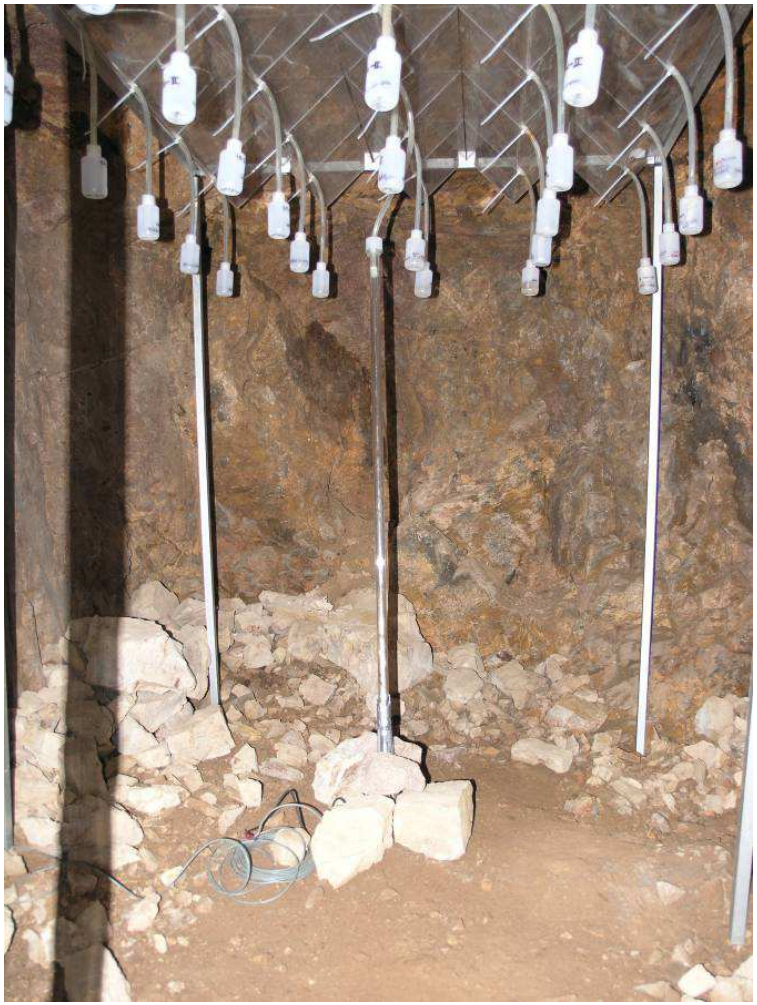
- **Seepage volumes much smaller than rainfall**
- **Back of adit has lowest total seepage**
- **Presence of three walls in back of adit may enhance capillary barrier effect**



Seepage volume (ml)



Cumulative seepage volumes (2005-2006)



Radionuclide Transport

- **Elevated U concentrations in PB-1, 2, and 3 wells (20-365 ppb), but low in regional wells (≤ 10 ppb)**
- **U concentrations in front adit seepage waters (1 -420 ppb) higher than those in rear adit (0.1 – 15 ppb)**
  - **Rear adit has faster infiltration, more seepage volume (less water-rock interaction)**
  - **Front adit closer to U ore body**
- **Detailed study of radionuclides in seepage and well waters (Mike Murrell and Steve Goldstein, LANL)**

Water sampling in PB-1 well

Conclusions

- **Seepage measurements indicate presence of heterogeneous flow paths within fractured tuff in unsaturated zone**
  - **Fast flow paths with large volume flow linked to large rain events**
  - **Slow flow has much smaller seepage volumes (affected by evaporation in rock mass)**
  - **Variable U in seepage waters indicates ongoing transport of radionuclides**
  - **Simple 1-D model does not capture complexity of fluid flow**
- **Lowest seepage volume in rear of mine may result from capillary barrier effect**

Acknowledgments

- **We thank:**
  - **Members of the Peña Blanca Natural Analogue Study Team (initiated by Ardyth Simmons, now led by Schön Levy, LANL)**
  - **Instituto de Ecología, A.C.**
  - **Facultad de Ingeniería, Universidad Autónoma de Chihuahua**
  - **DOE Office of Science**
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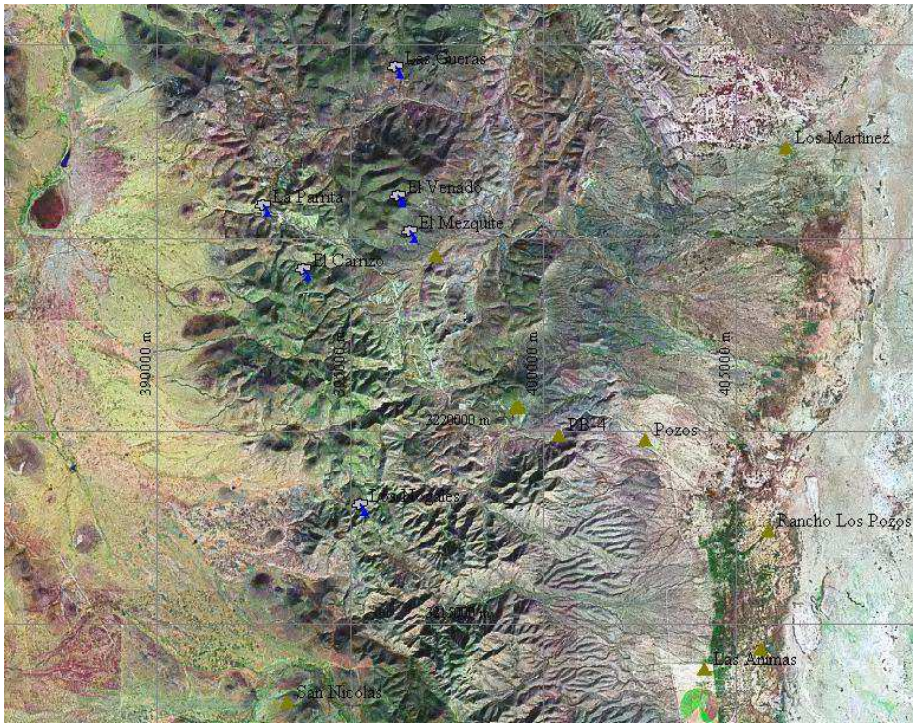
Regional Hydrology

- **Elevated water table (~1530 m) located in Encinillas Basin to W**
- **Lower water table (~1200 masl) located in El Cuervo Basin to E**
- **Springs in Sierra Peña Blanca located well above regional water table**



Stable Isotope Systematics

- δ18O compositions of well water samples samples considerably lower (-8 to -9‰) than weighted average rainfall value (-6.7 ‰)
- Rainfall composition as most depleted seepage water samples
- Wide range in seepage compositions; see temporal and spatial variation