Hydrological and Geological Features Contributing to a Seepage Event at Yucca Mountain

Randall Fedors, U.S. Nuclear Regulatory Commission, Washington, DC; rwf@nrc.gov
Kevin Smart, Geosciences and Engineering Division, Southwest Research Institute®, San Antonio, TX; ksmart@swri.org
Jack Parrott, U.S. Nuclear Regulatory Commission, Las Vegas, NV; jdp1@nrc.gov

Paper Number H43A-03
Poster Presentation
2006 American Geophysical Union Annual Spring Meeting,
Baltimore, MD, May 25-26, 2006

INTRODUCTION

The occurrence of an unusual seepage event in the Exploratory Studies Facility (ESF) tunnel at Yucca Mountain (YM) in 2005 provides an opportunity to further understand the hydrological system associated with flow in fractured rocks and seepage into tunnels.

Understanding the contributing factors for this seepage occurrence in the ventilated tunnel will assist U.S. Nuclear Regulatory Commission in its assessment of Department of Energy (DOE) flow models.

The seepage event began in the later portion of an El Nino winter (February 2005) predominantly along a 40-m section of the south ramp of the ESF tunnel, and stopped seeping into the tunnel in June 2005. A smaller seep area was located closer to the South Portal. These two seep locations are referred to as the primary and secondary locations throughout this poster

Hydrogeology

Analysis of the geological characteristics associated with the seepage locations suggest the contributing factors that may have constrained seepage to these particular locations in the tunnel include:

- Small distance to the ground surface (~80 m) and thin soil cover increase likelihood of percolation event reaching the tunnel
- Only nonlithophysal tuff units are present in the rock column above the primary seepage location
  - These rocks have low storage capacity and permeability, thus are amenable to fast flow in the fracture network
- Upslope and downslope capping by lithophysal rock units at the ground surface above the primary seepage location
  - These rocks have higher storage capacity and permeability, thus are better able to imbibe water and dampen episodic events compared to nonlithophysal units
- Gently dipping strata with lithological contacts that may have laterally diverted water
- Presence of faults, fractures, and rock bolts may enhance focusing of flow

Precipitation

Analysis of hydrological information indicates that precipitation associated with the El Nino/Southern Oscillation Index was unusually heavy near YM for the 2004/2005 winter.

Other Relevant Events

Portions of the South Ramp were noted as wet during construction of the ESF. On a comparable location of the North Ramp of the ESF, no seepage was observed. Also, during an earlier El Nino winter (1997/1998), the fracture network appeared have become saturated based on records from monitoring in boreholes at nearby Pagany Wash (LeCain, et al., 2002).

BACKGROUND

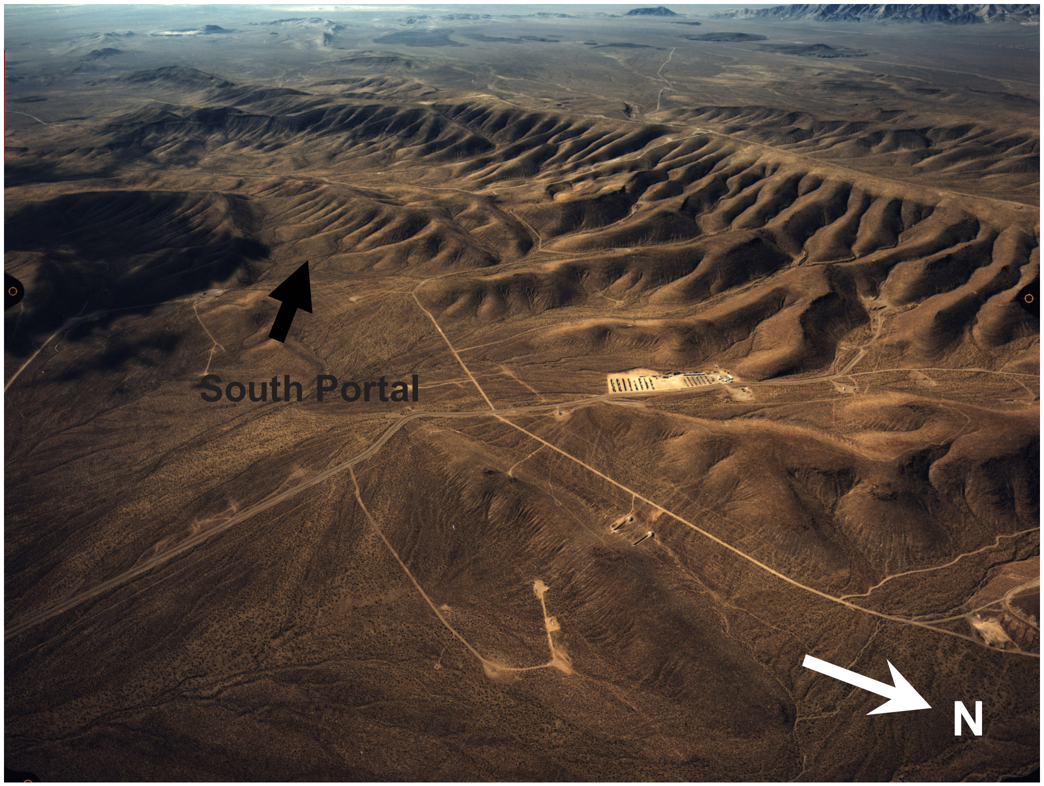


Figure 1. Photograph of east flank of YM looking southwest. Arrow indicates approximate location of south portal of ESF. Note the photograph was taken prior to construction of the ESF.

Yucca Mountain (Figure 1)

- Located in southern Nevada, approximately 90 miles northwest of Las Vegas
- Potential site for storage of high-level (radioactive) waste
- Bedrock consists of sequences of welded and nonwelded tuffs

Hydrology

- Semi-arid climate
- Long-duration, winter frontal storms more likely to lead to significant infiltration events than short-duration, high-intensity, convective summer storms
- Estimates of average net infiltration for the modern climate range from 1 to 10 mm/yr according to DOE (BSC, 2004)
- Unsaturated flow in matrix and fracture network
- Episodic flow above the nonwelded Paintbrush Tuff, steady state flow assumed below (DOE, 2002)

Exploratory Studies Facility (ESF)

- ~7-km long, 7.6-m diameter tunnel in the unsaturated zone completed in 1997
- Active ventilation capable of extracting moisture at rates much larger than the ambient percolation rate; a prominent dryout zone extends into the tunnel wall rock
- No recorded post-construction seepage events prior to the February 2005 event near the South Portal of the ESF, although parts of South Ramp were notably wet during construction

Seepage in Tunnel of South Ramp

Photographs (Figure 2) of seepage during a site visit in March 2005 illustrate effects on seepage by fractures, rock bolts, and evaporation driven by forced ventilation.

Water dripping into the tunnel either:

- Drips onto invert or sidewalls
- Flows along the drift wall as thick films or rivulets
- Evaporates
  - directly from fracture or rock bolt
  - indirectly, i.e., from along-wall flow or drip destinations
- Flows along the tunnel wall and imbibes into matrix
  - the tunnel walls were extensively dried out because of prior, ongoing ventilation

Chemical and isotopic analyses of dripping water suggest interaction of precipitated water with soil and rock water (typical of matrix water), and engineered components (e.g., rock bolts, ribs, vent) (Oliver and Whelan, 2006). A prominent effect on chemistry due to evaporation was confirmed by the chemical analyses.

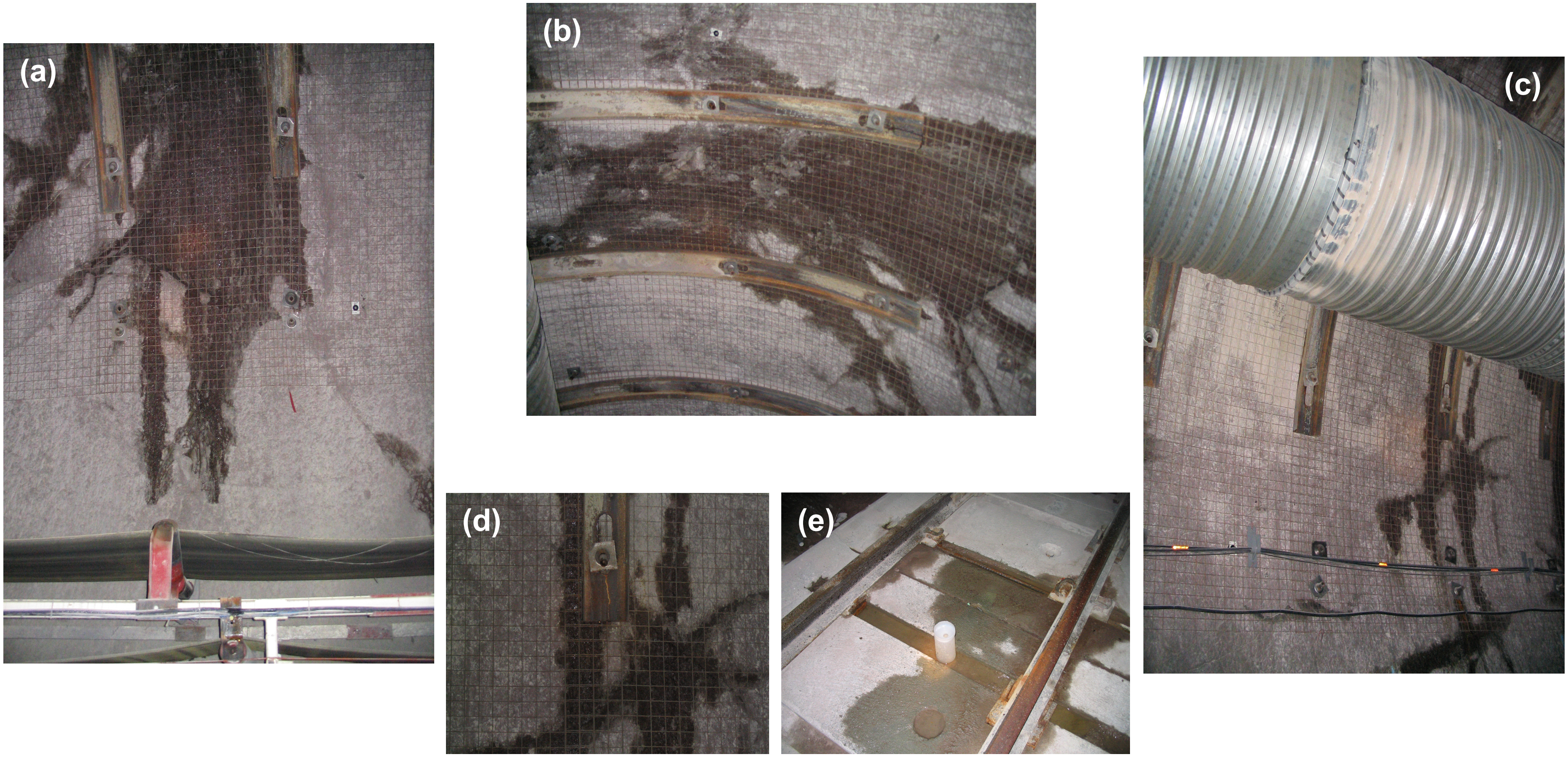


Figure 2. Photographs of seepage in 7.62-m diameter tunnel. The ventilation duct runs along the right-side of the ceiling in the tunnel and has a diameter of 1.67 m. Also for scale, the wire mesh has a 3-in by 3-in spacing. (a) Seepage along a ~1-m section of the left side of tunnel between a set of ribs installed for rock support. (b) Fractures and rock bolts influencing seepage along ~3 m of ceiling, note portion of ventilation duct in lower left of photograph. (c) Seepage from fractures of various sizes along the right side of a 4-m section of tunnel. (d) Close-up view of fractures and rock bolt (holding a rib in place) controlled seepage. (e) Example of wet invert and rail track caused by dripping, collection bottle used for samples described in Oliver and Whelan (2006).

HYDROGEOLOGY

Cross-section, tunnel maps, rock matrix properties, and surface topography are analyzed to help understand the underlying factors associated with the seepage event in the South Ramp.

Seepage occurred in two locations (see Figure 3):

1. Primary Seepage Location: A broad 40-m long section in the South Ramp at approximately 75+67m to 76+07m (NRC, 2005)
2. Secondary Seepage Location: A small zone closer to the South Portal at 77+52 m (Oliver and Whelan, 2006)

General Geohydrological Information

- Distance from the ground surface to the tunnel is approximately 60 to 80 m for the seepage locations
- Soil overlying the bedrock is thin (<0.5 m), uneven, sporadically not present, and highly transmissive
- The nonwelded Paintbrush Tuff (PTn) is located below the tunnel, thus does not impact flow above the tunnel
  - The PTn is often cited for dampening spatial and temporal variations in percolation such that steady state flow is assumed for flow in the Topopah Springs Tuff (e.g., DOE, 2002)
- Faults
  - Fault disruptions of rock unit at ground surface may facilitate infiltration
  - Fault disruptions at depth may facilitate fast path percolation and enhance possibility of seepage into a tunnel
- Fractures
  - The Detail Line Survey described in Eatman et al. (1997) accounts for fractures and faults greater than 1 m in length. Data from the Detailed Line Survey is shown in Figure 4. Many smaller fractures occur, and contributing to the seepage of water into the tunnel as can be seen in Figure 2(a) – (d).

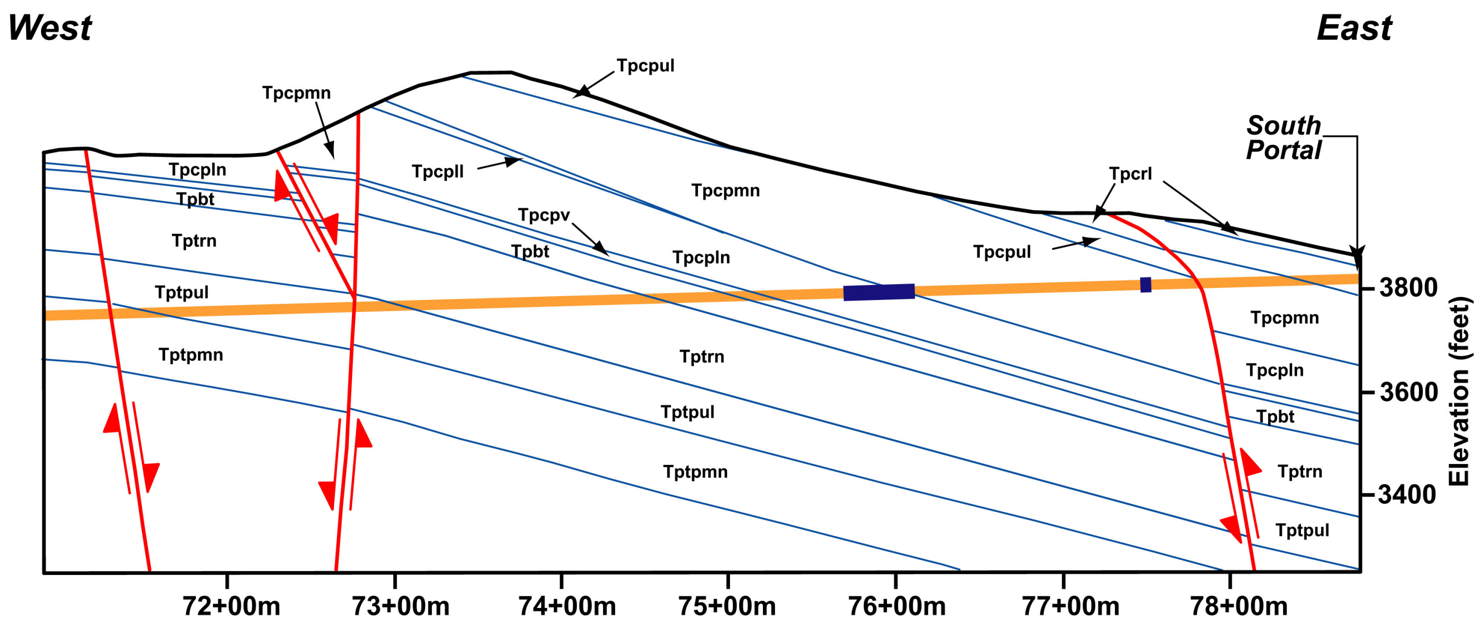


Figure 3. Cross-section along trace of South Ramp of ESF (orange). Blue sections along tunnel are approximate locations of seepage into tunnel. Table 1 contains unit definitions. Note vertical exaggeration. Figure is modified from Eatman et al. (1997).

Table 1. Stratigraphic column and description of units for Figure 3.

Hydrogeologic Group	Unit	Description
Tiva Canyon Tuff, welded	Tpcrl	Crystal-rich lithophysal
	Tpcpul	Upper lithophysal
	Tpcpmn	Middle nonlithophysal
	Tpcpll	Lower lithophysal
	Tpcpln	Lower nonlithophysal
Paintbrush Nonwelded Tuff	Tpcpv	Vitric, grading from welded to nonwelded
	Tpbt	Nonwelded bedded tuff
Topopah Springs Tuff , welded	Tptrn	Crystal-rich nonlithophysal
	Tptul	Upper lithophysal
	Tptpmn	Middle nonlithophysal

Features at Primary Seepage Location (75+67m to 76+07m)

- Two stratigraphic units occur in the area of seepage, the middle and lower nonlithophysal units of the Tiva Canyon Tuff. These units are Tpcpmn and Tpcpln on Figure 3. The contact dips gently to the east and is described by Eatman et al. (1997) as indistinct but "marked by numerous closely-spaced vapor phase partings above the contact"
  - Stratigraphic contact between Tpcpmn and Tpcpln may be amenable to focusing by lateral flow as suggested by a prominent subsection of seepage occurring near where the stratigraphic contact intersects the tunnel

- Only nonlithophysal tuff units are present directly above the primary seepage location
  - The nonlithophysal units are welded and highly fractured, thus amenable to transmitting pulses of water deeper and faster compared to more permeable and porous units
  - The implication that significant net infiltration occurred where the nonlithophysal units are exposed has repercussions for conceptual models of net infiltration
    - Typically, the crystal-rich caprock units (Tcr1,2) are believed to be associated with high net infiltration areas because of their large permeability compared to that of the crystal-poor nonlithophysal units (BSC, 2004; Stothoff, 1999)

- Upslope and downslope capping by Tpcpul (lithophysal rock) unit for the primary seepage location appears to limit the spatial extent of seepage in the tunnel; see Figure 3
  - Where the lithophysal unit is present at the ground, percolation rate or depth may be dampened
    - The presumption is that water more quickly percolates through the nonlithophysal unit and that the travel distance is dampened by the lithophysal unit
    - The lithophysal exposure at the surface does not act like an impermeable barrier, but the time scale for percolation through the lithophysal unit is much greater than that through the nonlithophysal units
  - Permeability of the nonlithophysal matrix is a factor of 200 greater than that of the lithophysal matrix (Table 2)
    - The nonlithophysal unit less readily imbibes water
    - Matrix flow in the lithophysal means less flow in fractures. Net infiltration would still occur in the lithophysal unit, but on a longer time scale as compared to net infiltration and percolation through the nonlithophysal zone
  - Storage capacity of the nonlithophysal matrix is half that of the lithophysal matrix
  - There is a question on size of exposure gap for the lithophysal unit at ground surface above the tunnel
    - The gap in the lithophysal exposure is approximately 50 to 60 m on the Day et al. (1998) map. Interestingly, the location appears to closely correspond to the 40-m span of the primary seepage location between 75+67m to 76+07m
    - The gap is approximately 115 m on the cross-section in Figure 3, which was modified from Eatman et al. (1997); i.e., no Tpcpul from ~75+05m to ~76+20m. This gap is larger than the seepage span in the tunnel

- Seepage in the tunnel occurs from a wide variety of fractures, small and large (see Figure 2(a)-(d))
  - It is clear that much of the seepage was emanating from fractures or rock bolts, and not from the matrix, thus suggesting an avenue of study
    - A correlation study of fracture characteristics in the tunnel and seepage has not been performed
    - Structural features in the bedrock above the tunnel, however, may have a dominating influence on seepage locations
  - Bedding-perpendicular, steeply dipping fractures are prominent (Figure 5), and may facilitate seepage into the tunnel. There is also a set of bedding-parallel, shallowly dipping fractures that may influence lateral diversion.

- Faults and other features
  - There are two faults noted on the tunnel map (Figure 4) of unknown vertical extent
  - There are also two "minor contacts or vapor phase partings" that also may have contributed to focusing of percolation and seepage.

Layer	**Hydraulic Conductivity (cm/s)**	**Porosity**
Tpcpul	1.2×10^{-6}	0.162
Tpcpmn, Tpcpln	5.4×10^{-9}	0.082

Table 2. Summary of relevant matrix hydrological property values from Flint (1998)

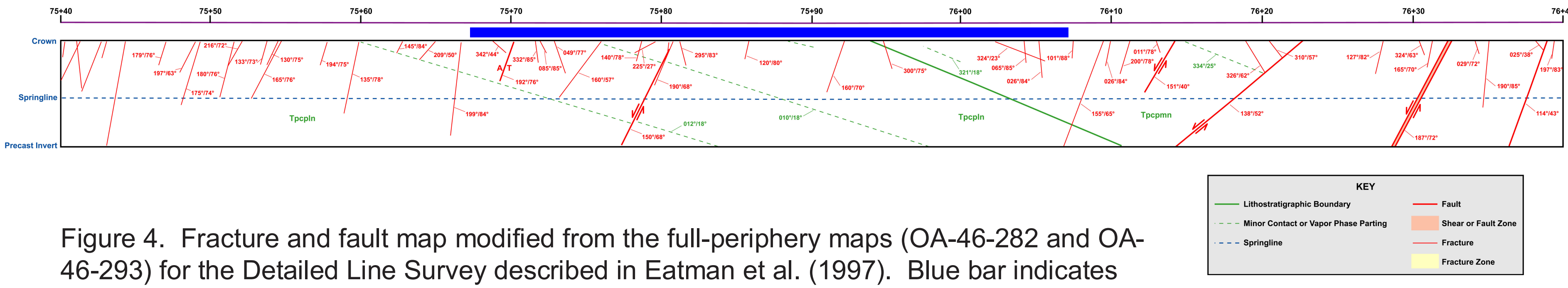


Figure 4. Fracture and fault map modified from the full-periphery maps (OA-46-282 and OA-46-293) for the Detailed Line Survey described in Eatman et al. (1997). Blue bar indicates approximate location of seepage based on NRC (2005).

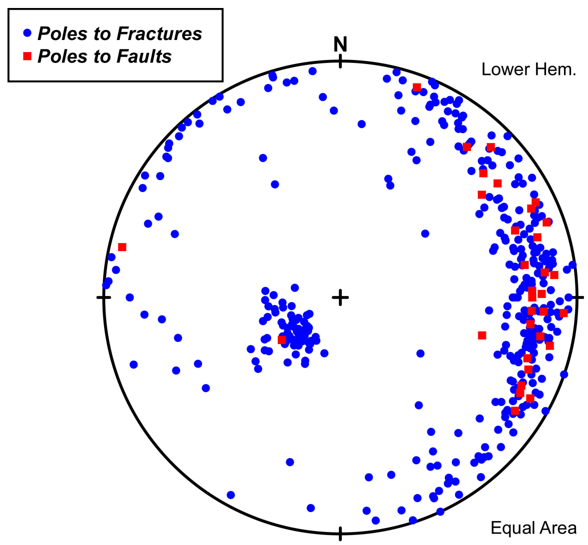


Figure 5. Stereonet of fractures and faults from Detailed Line Survey, adjusted for orientation bias (Smart, et al. 2006). Data are from the 75+00m to 77+00m and are described in Eatman et al. (1997).

Features at Secondary Seepage Location (77+52 m)

- Contrary to the primary seepage location further into the tunnel, lithophysal rock is present at the secondary seepage location
- The small, secondary seepage location at 77+52 m appears to be associated with the prominent fault shown at the ground surface in Figure 3
    - Fault and associated fracturing at the ground surface may have enhanced and propagated net infiltration
    - The fault in Figure 3 (modified from Eatman et al., 1997), however, was likely generalized and may not reflect details at a scale relevant for a better understanding of the seepage event
- The tunnel map in Figure 6 illustrates the complexity of the faulting in this section of the tunnel
    - Seepage water was collected from a fracture by Oliver and Whelan (2006), although there appears to be a connection with the mapped fault at 77+52m
    - The large fault shown in Figure 3 appears to correspond to the broad fault zone shown at approximately 77+85m in Figure 6

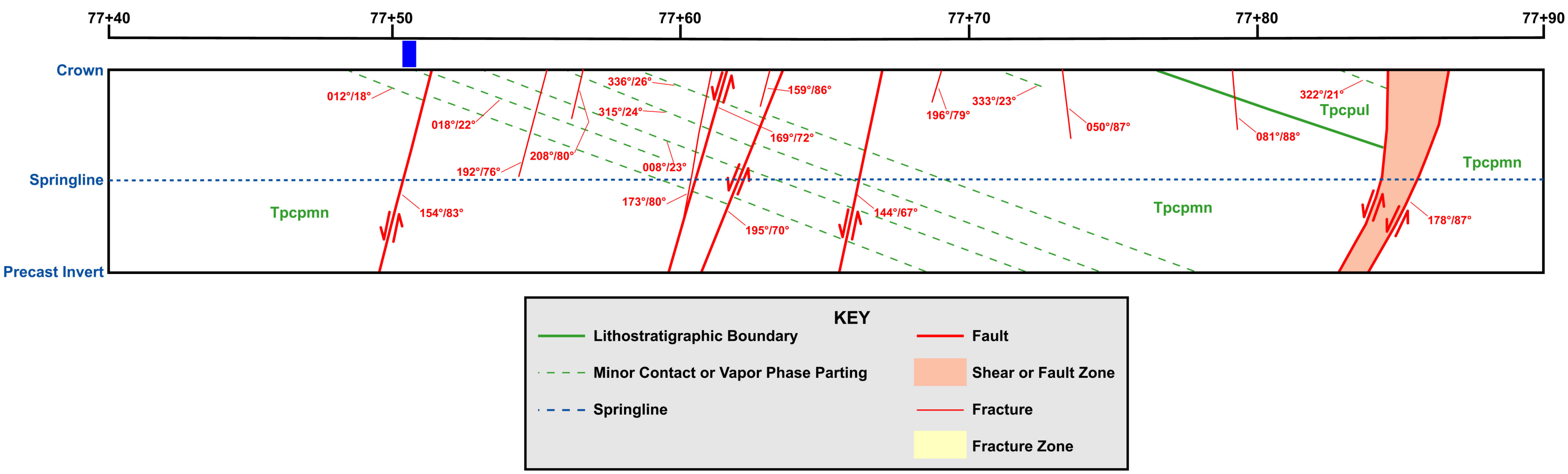


Figure 6. Fracture and fault map for the secondary seepage location modified from the full-periphery maps (OA-46-282 and OA-46-293) for the Detailed Line Survey described in Eatman et al. (1997). Blue bar indicates approximate location of seepage based Oliver and Whelan (2006).

Ground Surface Near South Portal

The geographic features at the ground surface above the seepage location are shown in Figures 7, 8, and 9. The trace of the south ramp of the ESF tunnel follows the top of a small, eastward-trending ridge top that terminates to the west at a north-trending ridge. An observation from Figures 7, 8, and 9 is that it appears there is only a small catchment area providing runoff to the seepage location; i.e., there is no local depression.

Figure 7. Location of South Portal (SP) and projected trace of ESF. The trace was only projected to top of the north-trending ridge; note that the tunnel continues to the west. Dirt roads and cleared areas have been photo-adjusted to be dark.

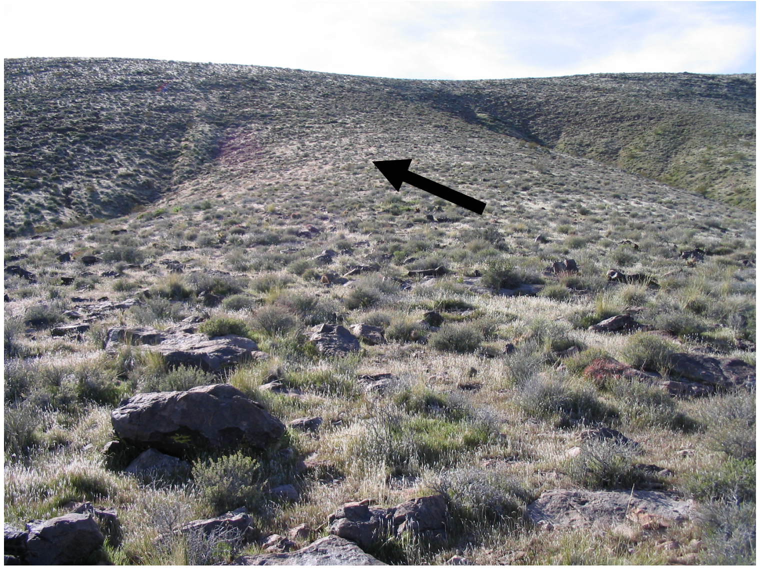


Figure 8. Photograph looking westward up the ridge from point A on Figure 6. Arrow points to approximate projected location of seepage in tunnel. At point of arrow, approximate distance between bottoms of washes is 90 m.

Topographic Considerations

Focusing of runoff is often a cause of preferential flow into the bedrock. Two hypotheses are put forth. Until more work can be done, hypothesis 2 appears to be more reasonable than hypothesis 1.

Two Hypotheses:

1. Focusing of runoff in wash channels on either side of ridge and lateral diversion towards tunnel
    - Washes ~30 m and ~60 m offset to the south and north from the tunnel; note that depth to tunnel is only about 60 to 80 m; hence significant lateral diversion would be required
    - No known structural features capable of lateral diversion to north or south; note that stratigrahic contacts dip at a low angle to the east.
2. Water infiltrated in a distributed manner on the ridge through extensively fractured nonlithophysal unit.
    - The topography above the seepage location suggests that little runoff could have been contributed from upslope areas
    - Possible focusing of percolation may have occurred within the bedrock because of lithologic contacts or faults and fractures.

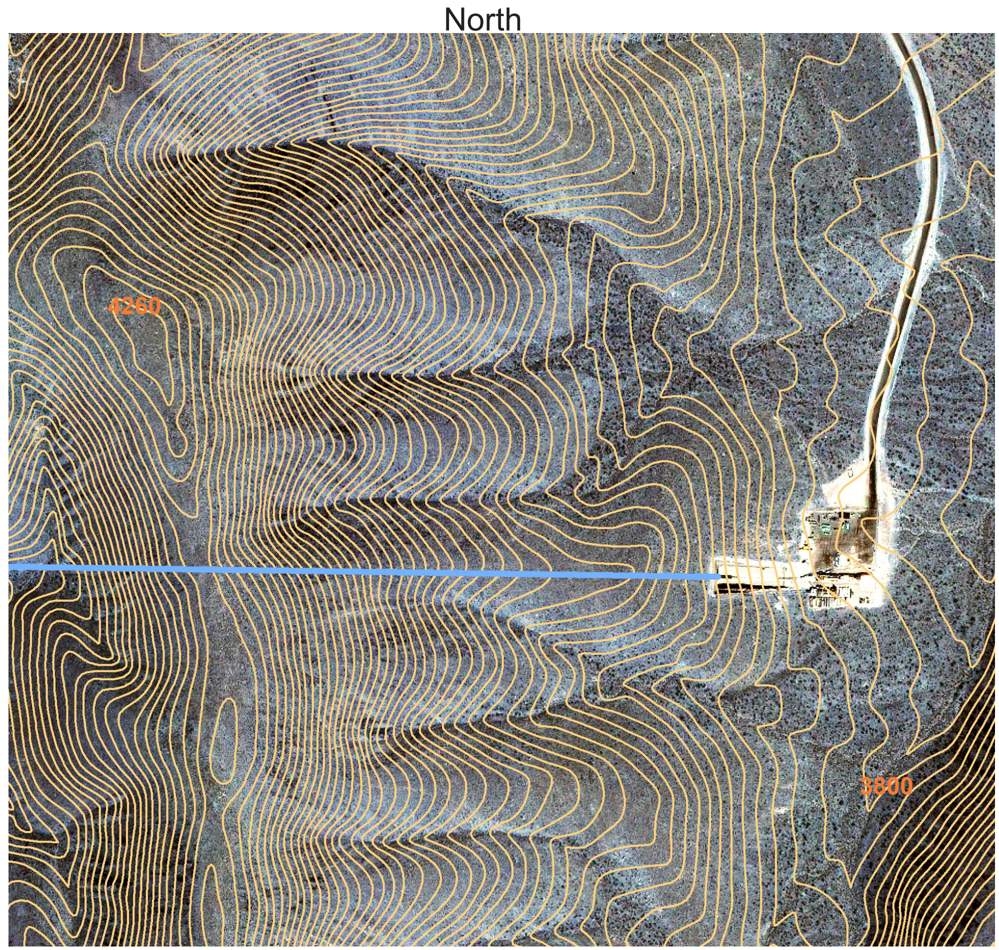


Figure 9. Contour lines (10-ft intervals) draped on satellite image of South Portal area of ESF. Width of image is approximately 1 km. Two contours spanning the relevant range are labeled.

PRECIPITATION

Local Precipitation Records

Seepage into the tunnel started during a period of several consecutive days of precipitation, though a significant contributing factor was the presumed high antecedent moisture conditions resulting from a unusually wet El Nino winter. To illustrate the supposition that prior climatic conditions were a factor leading up to the February 2005 seepage event, data from local meteorological stations were analyzed.

Three YM meteorological stations (Site 1, Site 2, and Site 3) are closest to the South Portal of the ESF. No data, however, is publicly available for the period of 1998 to the present for these 3 YM stations. In addition, these 3 YM stations have short periods of record, which limits identification of unusual periods of precipitation.

Nearby Nevada Test Site (NTS) and National Oceanic and Atmospheric Administration (NOAA) meteorological stations have record lengths of up to 52 years. Attributes of the NTS, NOAA, and YM stations are shown in Table 3.

Elevation is a prominent characteristic of meteorological stations because of the correlation of elevation and precipitation. Orographic, or rain shadow, effects may also affect relevancy of nearby meteorological stations to conditions near the South Portal of the ESF.

Table 3. Local meteorological stations with location, elevation, and length of record. Elevations are from CRWMS M&O (2002). Note that the elevation of the ground surface above the seepage locations is approximately 1200 m.

Station	Distance from YM (km)	Elevation (m)	Available Years of Record	Number of Years of Record
Amargosa Valley	30 km South	747	1966-2005	29
Beatty/Beatty8N	25 km West	1007/1082	1948-2005	52
4JA	5 km ESE	1043	1958-2005	48
YM Site 1	1 to 2 km East	1143	1986-1997	12
YM Site 2	YM Crest	1478	1989-1997	8
YM Site 3	YM East Flank	1279	1989-1997	8

Table 4 provides a comparison of the precipitation records for all the stations

- Based on this analysis, both Stations 4JA and Beatty appear to be reasonable matches for YM Sites 2 and 3
  - The seepage location is located on the lower portion of the east flank of YM
  - YM Station 3 also is on the east flank of YM, but is at a slightly higher elevation
- YM Site 1 is the closest meteorological station, being located ~2 km NE of the seepage location. YM Site 1, however, is in Midway Valley east of YM and possibly may be exhibiting a rain shadow effect

Table 4. Comparison of averages between YM Sites 1, 2, 3 and nearby NOAA and NTS station data with longer records

Station	Number of Years in Total Record	Precipitation (mm)		
		All Years	1986-1996	1989-1996
Amargosa Valley	29	116	108	97
Beatty/Beatty8N	52	139	147	143
4JA	48	146	155	156
YM Site 1	12	-	127	125
YM Site 2	8	-	-	157
YM Site 3	8	-	-	160

El Nino/Southern Oscillation (ENSO) Effect

In the YM area, elevated winter precipitation is associated with negative (<-0.5) Southern Oscillation Indices, otherwise called El Nino condition. We used the lag suggested by Redmond et al. (1991) in comparing Southern Oscillation Indices (June to November) to YM winter (October through March) precipitation.

Why Are El Nino Winters Important for Net Infiltration?

Winter precipitation is generally from lower intensity and longer duration frontal storms compared to the high intensity, short duration convective summer storms. The winter-type precipitation is more conducive to net infiltration, particularly when the ground is pre-wetted by prior storms. Also note that lower temperatures and lower plant activity, meaning less evaporation and transpiration, during the winter are also conducive to net infiltration.

El Nino Events Over Past Half Century in YM Area

Figure 10 compares the magnitude of the 2004/2005 winter precipitation for the nearby NTS and NOAA stations over the last half century.

- For two of the stations, the 2005/2005 winter exceeded that of all other years
- For the third station, the 2004/2005 winter precipitation was on par with the highest recorded winter value

Figure 11 illustrates the prominence of El Nino winter precipitation averages compared to average annual and average (all) winter values for the NTS, NOAA and YM stations.

- Station 4JA, for example, exhibits more precipitation during El Nino winters on average than the average annual precipitation
- Correspondingly, La Nina winters exhibit much less precipitation than the average winter values
- The 2004/2005 winter values are plotted on Figure 10 to illustrate the unusual magnitude of winter precipitation that led to the unusual seepage event

Because of the short records and unavailability of recent records for the YM stations (YM Sites 1, 2, and 3), the nearby NTS and NOAA stations are used to illustrate the prominent El Nino winter precipitation leading up the February 2005 seepage event. An exact correspondence between station 4JA and the YM Sites 1, 2, and 3 is not known. Oliver and Whelan (2006), however, report a value of 32.4 cm for the October through February period, which is 26 percent higher than the corresponding value for station 4JA of 25.7 cm precipitation.

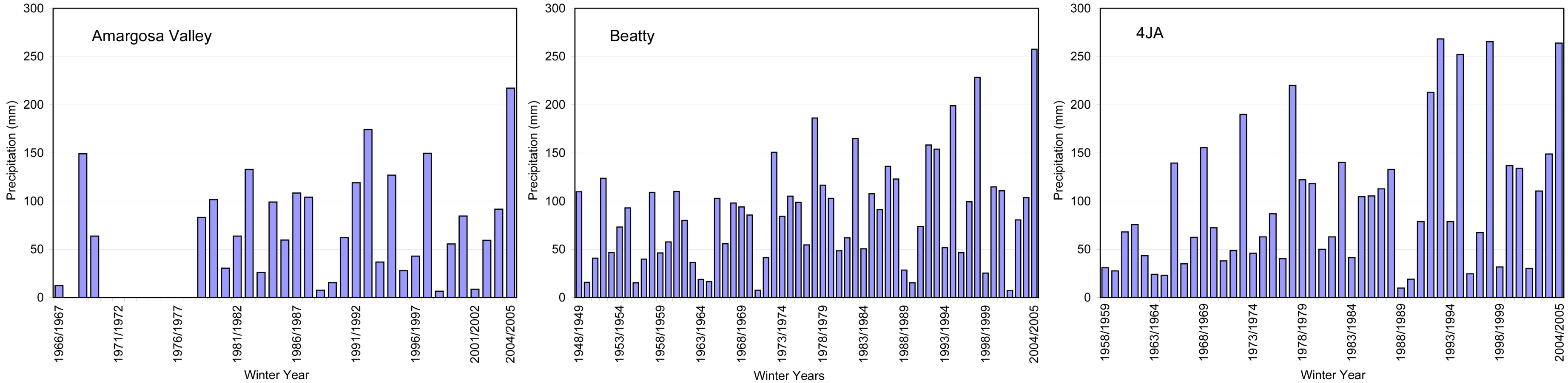
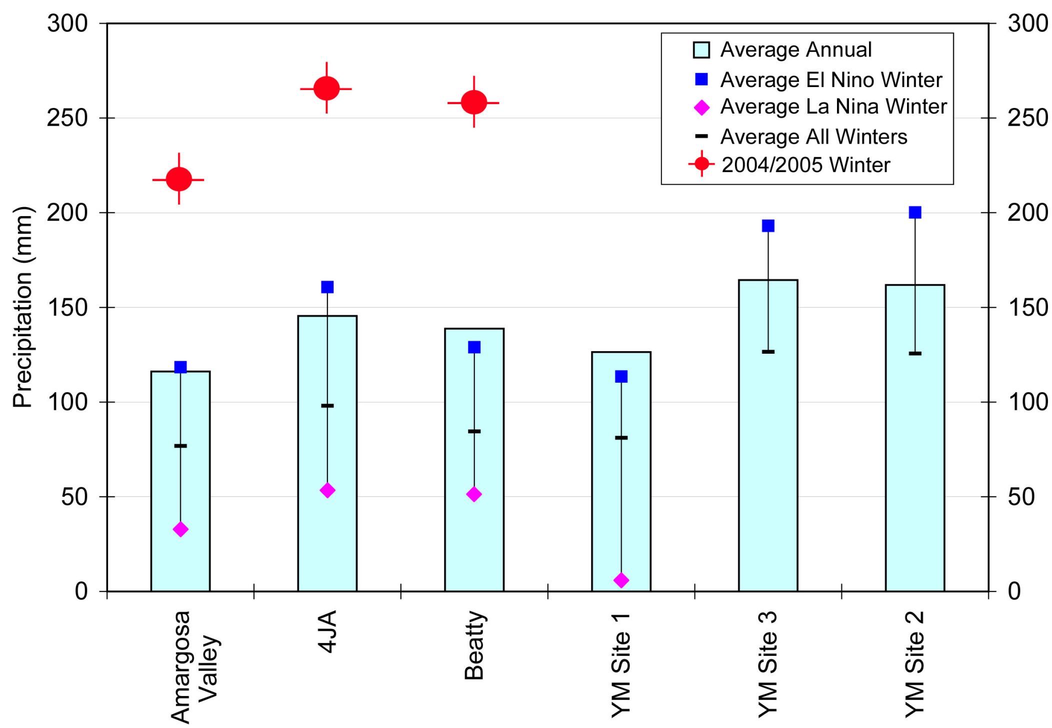


Figure 10. Calculated winter (October through March) precipitation from nearby NTS and NOAA meteorological stations over the last half century.

Figure 11. Cumulative precipitation for the winter of 2004/2005 superimposed on a plot of average precipitation for annual, all winters, El Nino winters, La Nina winters.



Temporal Details of 2004/2005 El Nino

The near-surface bedrock likely exhibited high levels of antecedent moisture content because of the prominent precipitation events occurring throughout the 2004/2005 winter. Figure 12 illustrates the magnitude of daily precipitation values that occurred during the October to June 2005 period. Figure 13 provides the cumulative winter precipitation with overlays of average annual, all winters, and El Nino winters for comparison.

- Seepage was first observed on February 28th, 2005, and may have started seeping days earlier
- Seeps stopped flowing in June 2005
- During 8 consecutive days of precipitation (February 17-25), a total of 5.4 cm fell at station 4JA
  - A exact correspondence between station 4JA and the YM Sites 1, 2, and 3 is not known because daily data sets from the latter are not publicly available for this period

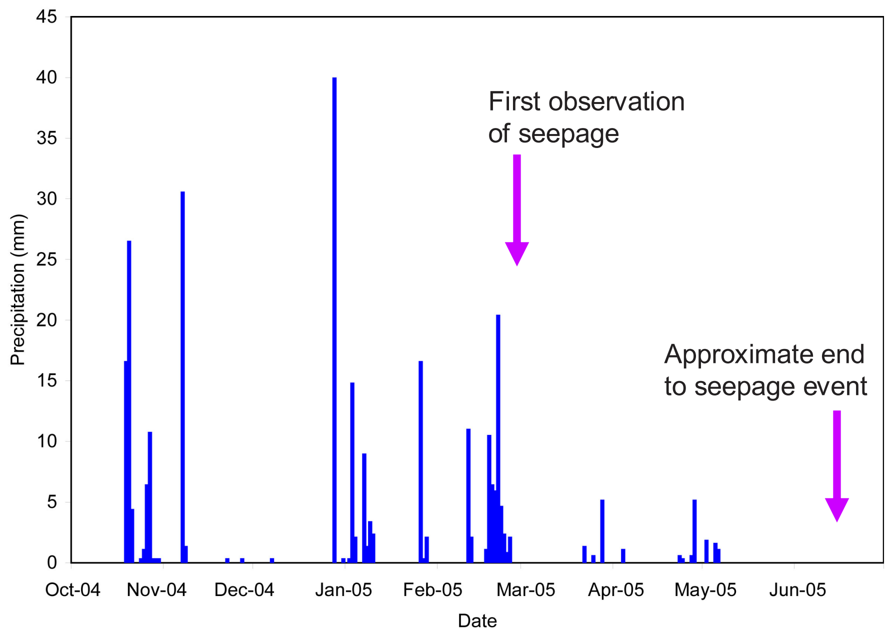


Figure 12. Daily precipitation for the 2004/2005 winter.

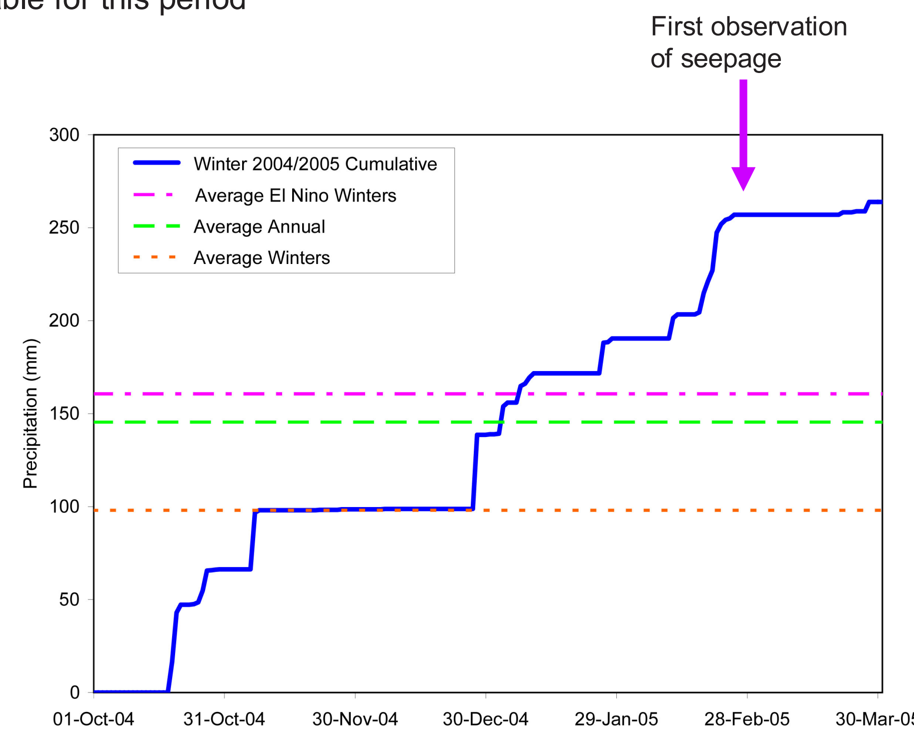


Figure 13. Cumulative precipitation for the winter of 2004/2005 at Station 4JA superimposed on a plot of average precipitation for annual, all winters, and El Nino winters.

OTHER RELEVANT EVENTS

No seepage events capable of overcoming active ventilation have been recorded for the ESF. This occurrence rate may reflect on the temporal variability of significant net infiltration events, though active ventilation makes any relationship tenuous. A conceptualization of net infiltration episodicity for YM is that significant infiltration events occur only once every 5 to 10 years, and that intervening periods exhibit scant infiltration.

Two previous conditions or events have some bearing on the probability of seepage occurring in the ESF.

1. South Ramp of ESF

A portion of the South Ramp was observed to be wet during construction (Eatman et al.,1997, see pp. 169-174). Construction of ESF was completed in 1997.

2. Pagany Wash

Monitoring of a net infiltration event in Pagany Wash during 1997/1998 El Nino winter is reported by LeCain, et al. (2002). Depending on the meteorological station analyzed (see Table 3), the 1997/1998 El Nino winter had the first or second largest winter precipitation value recorded over the last half century.

Readings from pressure sensors in a pair of boreholes were observed to lose connection to atmospheric pressure conditions, thus indicating a saturated fracture network as the net infiltration event percolated downward through the Tiva Canyon Tuff. One borehole was located on the flank of the hillslope above the colluvial wedge, and the other borehole was located in the wash bottom where alluvial sediments overlain the Tiva Canyon Tuff.

Why Didn't Seepage Occur in Comparable Location on North Ramp of ESF?

Observations of seepage were not reported elsewhere in the ESF during the El Nino winter of 2004-2005. At the North Ramp of the ESF, there is a comparable section of the tunnel with <80 m of overburden and no nonwelded Paintbrush Tuff between the ground the tunnel. The Tiva Canyon upper lithophysal and crystal-rich caprock, however, are present.

The matrix of lithophysal units of the crystal-poor section, like the caprock units of the crystal-rich units of the Tiva Canyon Tuff, have sufficient permeability and porosity to dampen the fast percolation of strongly episodic infiltration and to absorb a wider range of percolation because of greater storage capacity.

SUMMARY

The February 2005 seepage event occurred in a short section of the tunnel where there was less than 80 m of overburden. The seepage continued until June 2005 (Oliver and Whelan, 2006).

This was the only seepage event known to have occurred in the ESF. Note that any seepage event would have to overcome moisture removal by active ventilation, thus ventilation obscures estimates of seepage rates

- The evaporation effect caused by active ventilation was supported by chemical analyses of Oliver and Whelan (2006) and on visual observations
- The 8-yr period of only 1 recorded seepage event capable of overcoming ventilation has qualitative implications related to the conceptualization of significant net infiltration events occurring once every 5 to 10 years, or more.

A prominent contributing factor to the seepage event was the cumulative amount of precipitation that occurred during the 2004-2005 El Nino winter, thus priming the system by elevating the antecedent moisture content of the rock and soil.

The absence of a lithophysal unit from the crystal-poor section of the Tiva Canyon Tuff may have contributed to the seepage event. Correspondingly, infiltration into cystal-poor nonlithophysal units at this location may cause reassessment of net infiltration model conceptualizations for fractured rocks with low permeability matrix.

Structural control appears to have influenced the occurrence of seepage

- Seepage was observed in some, but not all, fractures
- Faults influenced the seepage locations in at least one case
- Stratigraphic contacts may have influenced the seepage
- Observations in the future should consider greater detail on the association of seepage with the characteristics of fractures; i.e., small or large fractures and fracture connectivity.

Rock bolts appear to facilitate seepage into the drifts.

Continuum models used to simulate this seepage event should account for:

- Evaporation in the tunnel
- Apparent importance of the lithophysal unit of the crystal-poor portion of the Tiva Canyon Tuff
- Structural control imparted by features between the ground surface and the tunnel walls.

References

BSC (2003). Geologic Framework Model (GFM2000). MDL-NBS-GS-000002 Rev 02. Las Vegas, NV: Bechtel SAIC Company, LLC.

BSC (2004). Technical Basis Document No. 1: Climate and Infiltration. Yucca Mountain Project. Las Vegas, NV: Bechtel SAIC Company, LLC.

DOE (2002). Yucca Mountain Science and Engineering Report. DOE/RW-0539-1. Las Vegas, NV: U.S. Department of Energy.

CRWMS M&O (2000) Yucca Mountain Site Description. TDR-CRW-GS-000001 Rev 01 ICN 01. Las Vegas, NV: Civilian Radioactive Waste Management System Management & Operating Contractor.

Day, W.C., C.J. Potter, D. Sweetkind, R.P. Dickerson, and C.A. San Juan (1998). Bedrock geologic map of the Central Block Area, Yucca Mountain, Nye County, Nevada. U.S. Geological Survey Miscellaneous Investigations Series. Map I–2601.

Eatman, G.L.W., W.L. Singleton, T.C. Moyer, D.L. Barr, A.L. Albin, R.C. Lung, and S.C. Beason (1997). Geology of the south ramp-station 55+00 to 78+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada, Bureau of Reclamation and US Geological Survey, DOE Report. MOL.19980127.0396.

Flint, L.E. (1998). Characterization of Hydrogeologic Units Using Matrix Properties, Yucca Mountain, Nevada. USGS Water-Resources Investigations Report 97-4243. Denver, CO: U.S. Geological Survey.

LeCain, G.D., N. Lu, and M. Kurzmack (2002). Use of Temperature, Pressure, and Water Potential Data to Estimate Infiltration and Monitor Percolation in Pagany Wash Associated with the Winter of 1997-98 El Nino Precipitation, Yucca Mountain, Nevada. USGS Water-Resources Investigations Report 02-4035. Denver, CO: U.S. Geological Survey.

NRC. 2005. Letter from B. Latta (NRC) and J. Parrott (NRC) to C.W. Reamer (NRC) July 12, 2005. U.S. Nuclear Regulatory Commission On-Site Licensing Representatives' Report on the Yucca Mountain Project for March 1, 2005, Through April 30, 2005.

Oliver, T.A. and J.F. Whelan (2006). Characterization of Seepage in the Exploratory Studies Facility, Yucca Mountain, Nevada. IHLRWM 2006 Conference, April 30-May 4, 2006, Las Vegas, NV: American Nuclear Society, LaGrange Park, Illinois.

Redmond, K.T. and R.W. Koch (1991). Surface climate and streamflow variability in the western United States and their relationship to large-scale circulation indices, Water Resources Research 27(9), pp. 2381-2399.

Smart, K.J., D.Y. Wyrick, P. Landis, D. Waiting (2006). Summary and Analysis of Subsurface Fracture Data for the Proposed High-Level Nuclear Waste Repository at Yucca Mountain, Nevada. Center for Nuclear Waste Regulatory Analyses (CNWRA), San Antonio, Texas. CNWRA 2005-04.

Stothoff, S.A. (1999). Infiltration Abstractions for Shallow Soil Over Fractured Bedrock in a Semiarid Climate. Letter Report to NRC. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Acknowledgements

This poster describes work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) and its contractors for the Nuclear Regulatory Commission (NRC) under Contract No. NRC-02-02-012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of High Level Waste Repository Safety. This paper is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC. The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of a license application for a geologic repository at Yucca Mountain.

The authors appreciate the useful discussions and comments amongst NRC and CNWRA staff, particularly those of Phil Justus of NRC.

Unit Conversions

1.6 km = 1 mi

0.3048 m = 1 ft

25.4 mm/yr = 1 in/yr

1.969 cm/s = 1 ft/min