Compilation of prelicensing field observations related to infiltration at Yucca Mountain and future-climate analogs

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This document describes a series of 12 field expeditions to Yucca Mountain and analog locations over the period of 1994 through 2008 using the descriptions at the time of the trip. The entries were unedited or minimally edited for spelling. The intent of the document is to collect into one location trip reports, scientific notebook entries, field notebook entries, and personal notes by S. Stothoff and coworkers that relate to infiltration-affecting characteristics of Yucca Mountain and future-climate analog sites. Some of the trip reports and notebook entries are publicly available in the ADAMS site as of June, 2008, and the relevant accession numbers are provided. Other information arises from personal notes created at the time of the field expedition. The detailed information contained in field notebooks is cited and summarized; all field notebooks are publicly available. Footnotes are new, added to provide supplemental information.

The observations captured in this document reflect 14 years of field explorations aimed at understanding the physical processes involved with net infiltration under present and potential future climatic conditions. The discussions of different processes and their importance have evolved over time, and earlier opinions expressed regarding the relative importance of features and processes at Yucca Mountain do not necessarily represent the current level of understanding. Nevertheless, the independent observations and measurements documented in this document and its associated field notebooks provide information that informs the current level of understanding.

Each trip is documented with a separate section. The first paragraph is a short italicized summary of relevant information, including citations of publicly available documents (where available). The remainder of the section consists of the original field information, with italicized paragraphs and footnotes representing new or supplemental information not present in the original or, in the case of references, located elsewhere in the original document.

Table 1. Trip summaries			
Trip	**Dates**	**Trip purpose and activities**	**Pages**
1	4/18/94 to 4/22/94	Orientation to Yucca Mountain facilities and tests; visit to REECO facilities in Frenchman Flat; observation of regional hydrology sites (not discussed here)	3–7
2	5/13/96 to 5/16/96	Soil depth measurements and terrain observation in Solitario Canyon and on Yucca Mountain; Solitario Canyon channel cross-section measurements (not discussed here)	8–11
3	5/24/96 to 5/25/96	Tour of Exploratory Studies Facility; field visit to the area above the potential repository	12–12
4	11/24/96 to 11/26/96	Orientation to Yucca Mountain region for D. Groeneveld	14–15
5	3/26/97 to 3/28/97	Observe relationships between vegetation and site characteristics; measure soil permeability in shallow ridgetop soils and in the Solitario Canyon channel	16–21
6	6/5/96 to 6/9/97	Gather field data related to hillslope characteristics (scree, talus, soils); check vegetation rooting in shallow soils; perform a reconnaissance of future-climate analog sites (the Prow of Yucca Mountain; Shoshone Mountain)	22–27
7	9/25/97 to 9/26/97	Reactive visit to Yucca Mountain to observe the hydrologic response from Hurricane Nora	28–29
8	1/26/98 to 1/29/98	Measure soil depth profiles, observe vegetation rooting patterns in calcite, collect stem samples for dating, investigate Shoshone Mountain as a climate analog	30–34
9	4/4/98 to 4/8/98	Reconnaissance of future-climate analogs (Rainier Mesa, Timber Mountain; N. Pahroc Range; Phinney Canyon in the Grapevine Range) for potential fieldwork	35–40
10	5/13/98 to 5/15/98 5/17/98 to 5/18/98	Vegetation transects, permeability measurements, channel characteristics, alluvial-terrace transects, soil depth measurements in Split Wash; field identification of potential infiltration hotspot locations in upper washes between Highway and Antler Ridges	41–44
10	5/16/98	Observations of soil depth and texture, and vegetation characteristics, in Phinney Canyon (a future-climate analog site)	45
11	10/3/99 to 10/6/99	Observations of future-climate analog sites at Rainier Mesa, 3 Springs Basin in the Kawich Range, and Timber Mountain	46–58
12	4/3/08	Spot check of surface characteristics at Yucca Mountain for locations with infiltration inferences available at depth (Mile High Mesa, above Alcove 1, Drillhole Wash, seeps at South Ramp, Antler and Coyote Washes, Yucca Crest)	57–66

Trip 1: Unpublished personal notes by S. Stothoff in the form of a trip report. The original file was dated 4/28/94. The text was slightly edited for spelling. At times the participants formed two groups (A and B). Only the activities by S. Stothoff are presented here. No activities were recorded for Day 1, which was a travel day for Group B.

SUBJECT:

Regional Hydrology, Sub-regional Hydrology, and Performance Assessment Research Field Trip.

PLACE/DATE:

Yucca Mountain region, April 18-22, 1994.

PERSONS PRESENT:

CNWRA
R. Baca
A. Bagtzoglou
S. Mohanty
S. Stothoff
D. Turner
G. Wittmeyer

NRC
N. Coleman
P. Justus
T. Nicholson
J. Poole

University of Arizona
R. Bassett
S. Neuman
P. Weirenga
E. Hardin
A. Guzman
<others>

SUMMARY OF PERTINENT POINTS:

The field trip had three purposes, to examine various facilities and test sites in Area 25 of the Nevada Test Site (NTS) developed specifically for the Yucca Mountain Project, to look at the measurement facilities maintained by Reynolds Electric and Engineering Co., Inc. (REECO) in the alluvium of Area 5 of the NTS, and to investigate geologic and hydrologic features pertaining to regional flow system recharge and discharge.

SUMMARY OF ACTIVITIES:

1. DAY ONE

2. DAY TWO (Group B)

The CNWRA participants in this portion of the field trip were Bob Baca, Sitakanta Mohanty and Stu Stothoff, all of whom were visiting the site for the first time. Description of some features seen during this day's activities are available in the November Field Trip report of Wittmeyer et al. (1993), and such details are only summarized herein.

2.1b

CNWRA field trip participants Bob Baca, Sitakanta Mohanty and Stu Stothoff, along with NRC participants, University of Arizona (UAZ) participants, M. Mifflin, and <some other NV person>, all arrived at Gate 501 at 7:45 am to obtain badges and meet their Q-cleared escort Phil Justus (NRC). The assembled group traveled to the Field Operations Center (FOC), where training on safety procedures in the Exploratory Studies Facility (ESF) borehole was provided. Following this, the group traveled to the ESF North Portal, where hard hats, steel-toed boots, flashlights, and safety respiration equipment was provided. Ned Elkins (LANL) led the group into the starter tunnel for the ESF, discussing construction techniques and answering questions.

The starter tunnel is now 200 feet in length, and the one experimental alcove has now been completed. The current configuration was constructed using drill and blast techniques. Further ESF tunnel construction awaits delivery and assembly of the Tunnel Boring Machine (TBM). The drill bits for the TBM were outside the portal; these were the only components of the TBM actually in the staging area. The primary work occurring at the portal is construction of the TBM pad external to the portal. It is anticipated that the TBM will start drilling at the end of the summer.

The experimental alcove had partial shotcrete sealing, although much of the alcove was left as bare rock, including an extensively fractured region cutting diagonally across the alcove. A crew was drilling boreholes at the end of the alcove, which are to contain monitoring devices.

In an apparent change of plan from last November's trip, N. Elkins stated that the proposed ESF tunneling practice will only shotcrete portions of the tunnel requiring this step for safety reasons; where possible, the remainder is to be left unsealed. Whenever sealing is to occur, the areas to be sealed will be photographed by the US Bureau of Reclamation.

2.2b

The NRT-1 and T-14 trenches on Bow Ridge were visited next. These trenches are located approximately above the starter tunnel for the ESF, and were dug to examine the Bow Ridge fault and investigate possible complications with the tunneling effort. Dan Souter (USGS) and Dave Kessel (SNL) discussed the implications of the T-14 trench, containing the famous carbonate veins in the brecciated zone of the northern extension of the Bow Ridge fault. These veins are postulated by J. Szymanski (formerly of the DOE) to be caused by upwelling of hydrothermal solutions under seismic pumping. Most DOE researchers attribute these veins to infiltration of surface water.

2.3b

The group then proceeded to the UZ-14 (Unsaturated Zone) borehole in Drillhole Wash. This borehole was currently at a depth of 2019 feet, and had not yet hit the water table. Two perched zones had been hit, at a depth of 1580 feet and a depth of 1200 feet. D. Souter attributed at least part of the water in the upper perched zone to drilling fluids lost from borehole

G-1, which was constructed before the current dry drilling procedures were implemented. Apparently traces of polymers in the drilling fluids were obtained, with some difficulty; these are designed to break down over time. This same perched zone was found with borehole UZ-16. It is uncertain how much of the water in the perched zone was natural.

One of the purposes of the UZ-14 borehole is to provide information on the high-gradient portion of the water table north of Yucca Mountain. Prior to drilling, the expectation was that the water table would be hit at a depth between 1900 and 2000 feet, thus not hitting the water table is a source of some surprise.

2.4b

Departing slightly from the itinerary, the group went to the vicinity of the Ghost Dance fault and ate lunch. Following this, the group walked to a cleared region perpendicular to the Ghost Dance fault zone, extending approximately 700 feet by up to 30 feet along the south side of Antler Ridge. Several of the faults in the zone were examined, including the Ghost Dance fault itself and the known faults east of the Ghost Dance fault. D. Souter indicated that the maximum displacement along the fault was perhaps 30 feet, with displacements diminishing to the north. The faults are brecciated or rubblized zones. The hydrologic properties of the zones were speculated on by tour members, with S. Neuman noting that often such zones are associated with permeability reductions of several orders of magnitude compared to the parent formation, depending on the filling material.

The group then walked up the wash to observe the SD-12 (Systematic Drillhole) pad and $3,600,000 drilling machine. D. Souter briefly discussed how the highly automated machine operated. The wash in this area is composed of highly distinctive Tiva Canyon clinkstones, exhibiting numerous joints and gas escape vesicles.

2.5b

On the way to the Fran Ridge large-block site, the group stopped briefly at the UZ-16 pad, where D. Souter discussed rock coring and drilling procedures, using several demonstration drill bits and coring tools set up for tour demonstrations. The group then proceeded to the large-block test site, where the Jim Blink <Blind?> (LLNL) gave an overview of the proposed block tests, which are intended to be a pilot study examining near-field heating effects under conditions resembling that of the proposed repository. The block will be disassembled at the end of the experiment to examine any chemical alterations occurring during the heating phase of the experiment. Moisture transport through the vertical faces will be prevented using water-impermeable paint.

The area above the block was cleared, and a crew using a limestone saw had just outlined the 3 foot by 3 foot by 4 foot block with four vertical cuts. Interestingly, a few apparently unfilled fractures were visible along the side of the block, despite the near-surface location of the block. The process of clearing excess rock from the sides of the block had not yet begun. Some of this excess rock is reportedly available for the use of interested agencies.

2.6b

The last stop for the group was the Yucca Mountain crest, passing to the north of the proposed south portal location while proceeding up Highway Ridge. D. Souter gave a brief overview of the terrain and selected facilities visible from the crest. From here, the group briefly revisited

the Field Operations Center, returned badges at the Lathrop Wells gate, and returned to Beatty for the night.

DAY FOUR

4.1

The CNWRA group of G. Wittmeyer, D. Turner, and S. Stothoff met Mike Sully of Reynolds Electrical and Engineering Co., Inc. (REECO) at the Mercury gate at 7:05 am for badging. The combined group proceeded to the REECO facility in Mercury for a briefing on the REECO experiments in the Frenchman Flat area. From here, the group went to the Radioactive Waste Management Site (RWMS) in Area 5 of the Nevada Test Site to sign in and examine the lab facilities at the RWMS.

4.2

The group went to a trench less than a mile to the northwest of the RWMS, dug to examine the soil morphology of alluvium in Frenchman Flat. The trench was characterized by quite uniform hydrologic properties over the depth of approximately 8 feet and length of perhaps 100 feet. Along the sides of the trench, roots were visible, with roots from the existing plants extending perhaps two to three feet from the surface. Fossil roots were also evident, perhaps a millimeter or two in diameter, extending past the depth of the trench. These have been dated to be on the order of 10,000 years old. The implication is that current conditions are sufficiently dry that there is no usable water at depths of greater than a few feet; however, in the last glacial period moisture was able to penetrate several times further than currently.

4.3

The group proceeded to a site about half a mile to the west of the RWMS. The site features a pair of weighing lysimeters, each 2 m deep by 2 m wide by 4 m long. One is maintained with bare soil and one replanted with three types of plants representative of the surrounding area. The site also contains a single-level meteorological station within twenty feet of the lysimeters, a double-level meteorological station about 150 feet from the lysimeters, and an experimental plot maintained by the Desert Research Institute. M. Sully treated the group to an extensive discussion of the capabilities of each of the REECO facilities, and gave a tour of one of the lysimeters. Based on testing prior to installation, each lysimeter is capable of resolving moisture differences on the order of 0.5 mm of water. The lysimeters were bought complete from Precision Lysimeter for $65000 each. The meteorological stations measure wind speed and direction, solar and net radiation, relative humidity, temperature, barometric pressure, and precipitation. The single-level meteorology tower is also equipped with Bowen ratio instruments, although M. Sully feels these are of limited use in such a dry climatic regime. Associated with the instrument cluster, soil temperature at 2 and 6 cm depths is measured, along with soil heat flux. Also, a set of time-domain reflectometry (TDR) probes are installed in the lysimeters to measure moisture profiles at several depths.

4.4

The group returned to Mercury for lunch, and walked back to the REECO facilities to discuss performance assessment with M. Sully and Dale Hammermeister <?>. REECO has begun to consider performance assessment and code configuration management questions, and was quite interested in the experiences that CNWRA has had with such issues, as well as particular

computer codes that have undergone benchmarking, verification, and configuration management. Unfortunately, the REECO representative responsible for these issues, Curtis Muller, was not available. However, a dialogue was initiated that may prove fruitful in the future. The group returned to the Mercury gate at 1:30 pm to return the badges.

4.5

The group then proceeded to the intersection of US 95 and NV 16, taking a graded dirt road 15 miles southwest across the Amargosa Desert towards Fairbanks Spring, the northernmost spring in the Ash Meadows spring system, trending NNW to SSE along a 10-mile line. At Fairbanks Spring, sand boils from the discharging groundwater are visible. As is common with such discharge points in the Ash Meadows area, in Death Valley, and in the Oasis Valley near Beatty, nearby ground surfaces have a thin crust of salt deposited by evaporation. In more humid environments, such salts are washed back into the ground by infiltration.

The group continued to Devils Hole, which discharges from the Paleozoic carbonate aquifer. Devils Hole is the sole habitat for a particular pupfish (*Cyprionodon Diabolis*), about one inch in length, with nearly 300 individuals as of the last census on April 17, 1994. There is a water level strip recorder at the water surface, which demonstrates a four-inch tidal effect, according to a park ranger attending the chart. Apparently the National Park Service feels Devils Hole is hydraulically well-connected to adjacent valleys, as one of the purposes of the strip chart is to provide background readings, in order to resolve water-right contentions should Las Vegas start using groundwater from north of Las Vegas, on the order of 50 to 100 miles to the northeast of Devils Hole. The group inspected Crystal Pool, a discharge point for the Paleozoic carbonate aquifer approximately 2 miles west of Devils Hole, before returning to Las Vegas via Pahrump and the Spring Mountain Pass.

IMPRESSIONS/CONCLUSIONS:

All participants felt the field trip was extremely beneficial, particularly those that had not been to the site before. It is clear that most photos of Yucca Mountain are not taken in the spring, as the familiar drab brown was overlain with a much greener hue. An apparent change in strategy for the ESF tunnel is welcome news, where reportedly only the portions of the tunnel requiring shotcrete sealing for safety reasons will receive such sealing. The possibility of obtaining data from the REECO lysimeters and meteorology stations should be explored, as this will provide a good analog, within 25 miles of Yucca Mountain, for testing numerical models of infiltration processes.

Trip 2: Extract from scientific notebook #163 by S. Stothoff, available in ADAMS (ML040690351). The original entry was dated 5/18/96 (pages 2-9 to 2-13). The text was not edited. Pages 1–15 of field notebook 175, available in ADAMS (ML043630294), describe soil depth measurements and wash characteristics.

5/18/96 Summary of field trip observations

This past week, Ross Bagtzoglou, Gordon Wittmeyer, and I went to Solitario Canyon to obtain field measurements and observations. Ross and Gordon concentrated on surveying wash cross-sections for the mid- to lower-canyon reaches, while I concentrated on walking the mid- to lower-canyon from rim to rim taking spot measurements of colluvium depths and trying to make observations useful for comparison with computational models. My field observations are documented in a field book, CNWRA Controlled Copy number 175.

The first field day, May 13, we spent basically getting together procedures and familiarizing ourselves with the site and equipment. Ross and Gordon wrestled with the surveying equipment and data logger all day, finally becoming comfortable with the equipment after successfully surveying a motel room that evening. During the day, they located well USW H-7 (on the other side of the road from Plug Hill) as a benchmark and made one cross-section at a stream-gage station adjacent to Plug Hill. Additional cross-sections were stymied by a recalcitrant data logger, apparently confused by a mixup in coordinates input for the first two locations.

I spent part of the first field day making measurements of alluvium to the west and northwest of the USW H-7 pad, walking up a sideslope to the crest and returning down a small wash. Wherever I took alluvium depth measurements, I marked a nearby bush with surveyor's tape with the idea of having the points surveyed in subsequently. As it turned out, we did not get a chance to survey the points due to delays caused by unfamiliarity with the equipment. In order to estimate shallow alluvium/colluvium depths, I brought a tile probe with the idea of poking a hole into the alluvium until further advances were rejected. The tile probe is a metal rod with a diameter of 1/2 in, with a metal tip 4 cm long and a padded handle. The base of the adapter attached to the handle is 124 cm from the tip. I brought a 10-lb hammer attachment to replace the handle, in order to help drive the tile probe. I scored the probe, creating very distinctive grooves at 10, 20, 30, 40, and 50 cm distances from the tip, for quick depth and length estimates.

Proceeding up the slope from the USW H-7 pad to the west crest, point measurements ranged up to 44 cm. At one representative mid-slope location, depths were 27, 36, and 42 cm within 2 m; at another, depths were 17, 21, and 37 cm. At the crest, depths were typically 2 to 4 cm in places, at others 6 to 8 cm. Just below the crest, pockets of 12 to 18 cm colluvium were found, increasing with distance below crest to at least 37 cm. Walking down the rill, the channel was found to consist of bare rock in places, particularly at narrow and/or steep reaches. As the channel flattened, the scoured zones disappeared. Judging from the walls of the channel in scoured zones, alluvium depths could be as much as 2 m in places, but it is difficult to tell for sure. Certainly ridges between subwashes are up to 2 m.

It quickly became obvious that the idea of the tile probe was not going to work in alluvium over a certain depth or in regions with numerous chunks of rock, since rejection due to rubble was so likely compared to rejection due to bedrock. Accordingly, I concentrated use of the probe in

shallow zones generally less than 40 cm in depth. These zones are of the most interest for infiltration estimates anyway.

The second part of the first day, I walked north along the bottom of Solitario Canyon further than well USW H-6. The stream channel morphology is rather confused in the entire stretch I walked north from Plug Hill. It appears that there are typically two channels, one for the eastern side of Solitario Canyon and one for the western side, but the channels are not strongly distinct and tend to braid. The bottom of the channel is not uniform, with patches of similar materials ranging from very fine through gravel. There is brush in most of the channel, with somewhat less brush in the most active portions of the channel. There is a great deal of variability at a scale less than the 30 m x 30 m resolution provided by the DEMs we've been using, so that the cross-sections are essential. Unfortunately, in order to fully capture the stream channels, cross-sections would be required at a much higher density (every 20 to 50 m, I estimate) than Gordon and Ross set out to perform. Gordon and Ross were going by Woolhiser's estimates of one cross-section per side wash.

The second field day, I walked or crossed each of the washes in the watershed draining to the north of the USW H-7 pad. The watershed consists of 6 or 7 washes to the north and west of the pad. Proceeding to the north, I walked the Boomerang Point crestline, crossed to near the Jet Ridge crestline, and dropped back into the USW H-6 watershed. This day, I used Global Position System (GPS) pack to provide approximate latitude and longitude at selected locations. The GPS equipment is supposed to place one within 100 m of the correct location; if a second station is used, differential methods are supposed to yield sub-meter accuracy. Our original intent was to use a reference station and a rover station; however, we found that the supplied batteries were only good for 4-1/2 to 5 hours and we did not have four batteries to cover the full day. Upon return, I hear that motorcycle batteries might do the trick for a reference station.

The third field day, I was in Las Vegas and received a NTS badge and GET training.

The fourth (and my last) field day, I walked up the east part of Solitario Canyon to Yucca Crest, arriving not far from USW-UZ6. Again I used the GPS equipment without a reference station. I started at a trench apparently dug to expose the Solitario Canyon fault, and passed some terracing exposing the upper half of the PTn outcrop. Once at the Crest, I proceeded down the wash north of Highway Ridge to the first of two sets of trenches scraping away the alluvium cover from bedrock. The trenches extend from ridgetop to ridgetop. Due to time constraints, I only examined the southerly trench closely. This trench shows very little alluvial cover at the channel bottom, increasing to 1 or 1.5 m within 10 m of the bottom, and gradually thins to less than 10 cm at the top. Returning to the crest on the southern side of the roadway, I was able to observe the wash to the south as well. I returned to Solitario Canyon slightly north of USW H-3. Upon my return, judging from aerial photographs I was able to observe terrain typical of the western and central portions of the repository footprint; further to the east, the wash channels become wider and have little in the way of scouring in the channel bottoms.

During the four field days, Gordon and Ross completed on the order of 15 cross-sections, extending up Solitario Canyon most of the way from Plug Hill to USW H-6. The original plans to survey the entire canyon channel were discarded due to the messy nature of the channel above this point and due to time constraints. The day after I left, Gordon and Ross visited the ESF.

Based on the three days of walking around and poking colluvium, it is clear that there are some problems with the colluvium model hooked together with the infiltration response surface, although the basic approach is sound. In general, even on ridgetops there are very few places

that have less than 3 or 4 cm colluvium cover, and these places are usually exfoliation shards overlying bedrock. TC caprock boulders are generally massive and unfractured. Along crestlines, TC caprock exposures cover 50 to 90 percent of the surface (visually estimated). Moving downhill easterly from the crests, TC caprock boulders on the order of meters in length appear, get smaller and sparser, then disappear. In the cracks between TC caprock outcrops at the crestlines, it is typical for fine sand through loess to be present with depths at least 3 cm and less than 6 cm. Depths increase with distance from the crestline, averaging 10 cm or so between the larger boulders and increasing to 15 to 20 cm as the boulders decrease in size. There are occasional pockets with deeper colluvium, typically less than twice the average depths for the area. I saw few washes cutting directly into the caprock, aside from the western portions of crestlines, although it was not uncommon for caprock boulders to be sliding along other TC units into washes to the east.

Most of the exposures east of crestlines are TC units. Generally these are not highly fractured near the caprock but increase with depth. Any TC units below the caprock do not appear distinctive to my admittedly untrained eye. Chunks of the lower TC tend to be much smaller than the TC caprock boulders, generally being less than 50 cm. In the steepest portions of washes cutting TC units, bare country rock may be exposed, particularly in wash channels and up to 10 m above the channels in places. The washes on the west of Solitario Canyon tend to be steeper and shorter than the washes on YM proper. The YM washes tend to develop long regular reaches with uniform sideslopes, very nice for modelling. Based on a trench north of Highway Ridge, maximum alluvium depth on sideslopes should not be much more than 1 to 2 m, near the channel bottom. It appears that the long regular slopes are steepened at the base, due to removal of colluvium due to stream action during rainfall. It may be possible to estimate the depth of alluvium by projecting sideslopes out to midchannel in the upper portions of the washes.

All along the steep portions to the west of Yucca Crest, pockets may be as much as 40 cm, but generally are in the 5 to 15 cm range. A considerable amount of bare outcrop is present, as much as 50 percent or more of the surface area. Even partway down the flatter slopes, depths may not be more than 50 to 100 cm.

There are distinctive stripes of dark, highly varnished scree alternating with light, clean scree on many of the wash slopes. Stripes may be as little as 1 to 2 m on center and may be tens of meters on center. Invariably the dark scree is raised relative to the clean scree, suggesting that runoff is focused on the clean scree and washes it. It may be safe to assume that the darker the scree, the higher it is relative to the adjacent light scree.

Two difficulties arise when comparing the infiltration conceptual model work with field observations. The first difficulty is in treating the regions near the crestlines. Although colluvium depths, where present, are generally greater than I've been assuming, the areal average might not be too bad. However, the flow modelling assumes that there is uniform depths of colluvium everywhere, while the actual situation is patchier and deeper. An obvious way of treating the actual situation is to decrease the porosity to account for the proportion of surficial area that is impermeable boulder. It may be that reducing porosity is essentially equivalent to reducing depth, since the volume available for flow is reduced by either approach. If so, accounting for boulder size and area may not be tremendously important in the colluvium model.

The second difficulty is in treatment of wash channels. The colluvium model breaks down when factors other than gravity become important, such as overland water flow. It should not be

difficult to include a factor increasing colluvium fluxes due to streamflow, which will get rid of the (arbitrary) 20 m depths in upper channels. Unfortunately, all of the action is on a scale that is subgrid compared to the DEM measurements. The channels are only 1 to 2 m wide where the rock is bare, yet the grid is 30 m on a side. It may be necessary to overlay a refined grid on wash bottoms to properly capture infiltration, at least in upper portions of the washes. As the channel bottoms are relatively narrow, there may not be a great deal of infiltration relative to ridgetops.

Trip 3: Extract from scientific notebook #163 by S. Stothoff, available in ADAMS (ML040690351). The original entry was dated 5/28/96 (pages 2-13 to 2-15). The text was not edited; footnotes were not in the original text, and were added for explanation. Note that discussions with Alan Flint were in the context of an onsite-representative interaction, without formal notes being made of the interaction.

5/28/96 Summary of second field trip observations

As an adjunct to a Technical Exchange on the NRC audit of the DOE TSPA-95 performance assessment document, which was held in Las Vegas, a group of 8 NRC/CNWRA/consultant personnel took a tour of the ESF at YM (myself, C. Glenn, B. Behlke, M. Bell, A. Campbell, R. Manteufel, J. Walton, G. Stirewalt). The tour took place May 24, 1996. The tour was led by Alan ? of the DOE mapping team and hydrologic input was provided by Alan Flint of the USGS.

One of the more important observations that Alan Flint made regards lateral diversion in and near the PTn bedded tuffs. Previous TSPA analyses have assumed that lateral diversion may be strongly impacted by a very low permeability unfractured layer just below the PTn. However, the ESF borehole exposes a section of PTn that appears to be rather frequently, on the order of every 10 to 20 m by my observation, punctuated by small-offset faults. The offsets tend to be less than a meter, and may easily have been missed in boreholes. The following day, I took a walk up from Solitario Canyon to Yucca Crest and noticed some small (10 to 20 cm) offsets at one PTn exposure. Alan Flint's observation is that lateral diversion is probably not going to be very significant, because the frequent offsets in the low-permeability unit should minimize the most significant source of lateral flow.

Along the way in the ESF tour, various chlorine-36 sampling locations were pointed out by A. Flint and A. Campbell from the Fabryka-Martin et al. (1996a)[1] draft report. We also saw the heavily fractured zone, 1 km in length and still being encountered by the TBM. The fractures seemed to alternate between zones of fracture spacings less than 10 cm to zones where the spacing is more on the order of 30 to 40 cm.

As it rained (fairly heavily in spots) on May 24, I was inspired to take another walking tour of YM on May 25. Based on wetting front observations, which penetrated roughly 3.5 to 6.5 cm in various representative areas, and on water in exposed lithophysae, I estimate 1 to 2 cm of rain took place. I noticed that on Yucca Crest, enhanced wetting took place in the gaps between outcrops (10 cm and larger in spots), while under rubble scree on sideslopes less wetting took place (dry soil was not uncommon). While walking about, a storm cell drifted overhead and roughly a half hour of rain occurred. A total of no more than 5 minutes of reasonably heavy rain occurred, with most of the interval light to nearly non-existent. Exposed rubble faces were definitely wet; however, vertical sides tended to be dry with wetting fronts occurring at the top of perhaps 1 to 3 cm. Fifteen minutes after rain ceased, little or no trace of the event could be detected.

I also examined four of the trenches that are exposed in what I think is Split Wash or the next wash north (the wash with the Ghost Dance pavement and the wash immediately north of this wash). Each of these are sufficiently downstream that the wash bottom is at least 10 m wide.

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[1] Fabryka-Martin, J. T., P. R. Dixon, S. Levy, B. Liu, H. J. Turin, and A. V. Wolfsberg. 1996. *Systematic Sampling for Chlorine-36 in the Exploratory Studies Facility*. LA-CST-TIP-96-001, Los Alamos National Laboratory, Los Alamos, NM.

In this region, what I believe Alan Flint refers to as channel terraces are exposed. It appears that currently active wash channels are cutting into the terraces. Depth to bedrock at the deepest point in the trenches ranged from 2.5 to 4 m, as best as I could estimate. However, once the slope of the ground increased from the relatively flat terrace to side slope, cover decreased to the more typical 10 to 50 cm. It should be possible to identify these deeper zones simply by the slope or break in slope.

I also had the opportunity to talk with Alan Flint about his site-scale modelling work. He demonstrated time-traces of moisture content in various neutron-probe boreholes. In one channel terrace probe, lateral subsurface flow was clearly evident. He is currently using a 3-event (upgrading to 5-event) Markov-chain model to generate daily precipitation and daily mean temperature readings. Each rainfall event is redistributed to essentially perch on the colluvium/bedrock interface at the end of the day, where it infiltrates according to matrix and fracture properties. Each Scott and Bonk (1984)[2] layer has matrix properties assigned, either from direct measurement or from analog. Fractures are grouped into 3 size classes, and further subdivided into filled/unfilled areal fractions. Pixel size is 90 m on a side; no lateral diversion is considered. Evapotranspiration is a part of the model.

Pondering the site visit, it seems that the DEM is somewhat unwieldy for colluvium-flow calculations, as it completely misses meter-scale features such as wash channels. Ideas of quasi-1D flow-tube analyses occurred to me as being particularly appropriate for YM. Each flow tube would carry along local information on topography, width, depth, shape, vegetation, etc., in the form of integer categories or classes. Accordingly, the information could be encoded very compactly in the form of bit substrings within a few integers. Vegetation is another tricky topic inspired by discussions with Alan Flint, which it would be very nice to have a better handle on.

[2] Scott, R. B. and J. Bonk. 1984. *Preliminary Geologic Map (1:12,000 scale) of Yucca Mountain, Nye County, Nevada, with Geologic Cross Sections*. Open-File Report 84-494, U. S. Geological Survey, Denver, CO.

Trip 4: Unpublished personal notes by S. Stothoff in the form of a trip report. The original file was dated 11/27/96. The text was not edited; footnotes were not in the original text, and were added for explanation. Note that the discussion related to Alan Flint was in the context of an onsite-representative interaction, without formal notes being made of the interaction. Additional documentation of this trip is contained in pages 2 to 8 of the supplement to Scientific Notebook #268 (D. Groeneveld), available on ADAMS (ML040530130).

SUBJECT: Trip to Yucca Mountain (20-5708-861)

DATE/PLACE: November 24 through 26, 1996; Berkeley, CA[3]

AUTHOR: S. Stothoff

PERSONS PRESENT:

The trip to Yucca Mountain November 24 and 25, 1996, was attended by S. Stothoff and D. Groeneveld (Natural Resources, Inc.). An informal technical exchange[4] in Las Vegas on November 26, 1996, was also attended by A. Flint, L. Flint, and J. Hevesi [United States Geological Survey (USGS)], as well as C. Glenn (NRC).

BACKGROUND AND PURPOSE OF TRIP:

CNWRA has retained two consultants, D. Groeneveld and D. Woolhiser, to aid in characterizing aspects of shallow infiltration not considered in current CNWRA modeling efforts. Groeneveld is considering aspects of infiltration related to current and possible future vegetation, while Woolhiser is considering aspects of infiltration related to overland flow. The planned intent of the trip was to orient the two consultants to YM and to foster scientific interchange between the consultants and CNWRA staff. Unfortunately, D. Woolhiser was unable to make the trip due to illness. As part of the trip, an informal technical exchange with USGS staff familiarized Groeneveld with measurements and modeling of vegetation at YM, which he compared with similar efforts in Owens Valley, CA.

SUMMARY OF PERTINANT POINTS:

A one-day field examination of Bare Mountain, Solitario Canyon and YM familiarized Groeneveld with vegetation and soil characteristics characteristic of YM. A second day was spent discussing with USGS staff measurement and modeling techniques appropriate for arid-zone vegetation. Planning activities for work to be performed by Groeneveld were also undergone.

SUMMARY OF ACTIVITIES:

A one-day field examination of YM-area vegetation and soil characteristics was followed by an informal technical exchange with USGS staff regarding the impact of vegetation on shallow infiltration.

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[3] The location was actually Yucca Mountain and Las Vegas; the original document used a previous trip report as a template.

[4] This meeting was actually in the context of an onsite-representative interaction, without formal notes taken.

IMPRESSIONS/CONCLUSIONS:

1. Overall Impressions

The trip was extremely useful in orienting Groeneveld to the YM site and work that has been performed by the USGS related to shallow infiltration characterization. The trip was also useful in planning future activities with Groeneveld.

2. Noteworthy Highlights

A cursory field examination revealed a site in Bare Mountain that might be a good surrogate for YM for the purposes of estimating vegetation changes that might be expected under glacial conditions. The site is located approximately one-half mile northwest of Fluorspar Canyon Road, in a region of bedded tuffs with augmented runoff due to exposed rock surfaces and somewhat higher elevation than YM.

Examination of trenches exposing the Solitario Canyon Fault provided indications that vegetation may have extended at least 2 m into the subsurface under glacial conditions. Field examination in YM washes briefly addressed topography control of vegetation, surface cover of vegetation, fracture densities, and depth of soil cover.

Discussions with USGS staff were quite informative and frank regarding data collection techniques and modeling approaches for arid-zone vegetation impacts on infiltration. Particularly fruitful discussions centered on modeling techniques for vegetation, including seasonality, rooting depths, and adaptivity of vegetation to soil moisture conditions.

Trip 5: Reproduction of trip report transmitted to NRC, original available on ADAMS (ML033580481). Detailed observations are recorded in pages 16–24 of field notebook 175 (S. Stothoff), available in ADAMS (ML043630294), in pages 9–31 of the supplement to Scientific Notebook #268 (D. Groeneveld), available on ADAMS (ML040530130), and in pages 1–31 of the supplement to Scientific Notebook #217 (J. Winterle), available on ADAMS (ML040530058).

SUBJECT: Trip to Yucca Mountain for Hydrology Field Work (20-5708-861)

DATE/PLACE: March 26-28, 1997, Yucca Mountain, NV

AUTHOR: S. Stothoff and J. Winterle

PERSONS PRESENT:

The trip to Yucca Mountain (YM), on March 26-28, 1997 was undertaken by S. Stothoff and J. Winterle (CNWRA), D. Groeneveld and J. Thompson (Natural Resources, Inc.), and D. Or (Utah State University).

BACKGROUND AND PURPOSE OF TRIP:

CNWRA is working with D. Groeneveld, D. Or, and J. Thompson to aid in characterizing the impact of vegetation upon shallow infiltration. Transpiration is a process included in DOE models but not considered in CNWRA modeling efforts to date. The intent of the CNWRA work is to incorporate vegetation into infiltration-modeling efforts in a plausible and defensible manner, with appropriate modeling of soil-moisture uptake by plants of particular interest. The trip was inspired by the need for field-checking hypothesized relationships between vegetation and bedrock type, soil cover, slope, and solar loading. In a parallel effort, watershed-scale modeling is being performed by D. Woolhiser. Soil permeability in the wash channels is one of the critical parameters in the watershed-scale model. J. Winterle accompanied the group to obtain soil permeabilities in Solitario Canyon channels, which will be used in the watershed-scale model.

SUMMARY OF ACTIVITIES:

The field work was split into three activities: (i) a spot-check vegetation survey verifying the more-detailed TRW vegetation work and examining factors governing the distribution of individual species (D. Groeneveld and J. Thompson); (ii) a spot-check of soil-permeability measurements to verify more-detailed United States Geological Survey (USGS) work, as well as examination of plant rooting distributions (D. Or and S. Stothoff); and (iii) channel permeability measurements in Solitario Canyon (J. Winterle). The vegetation survey was conducted over four days while the remaining work was performed over two days. Prior to the main trip, D. Groeneveld flew a photographic airborne survey of plant distributions, augmenting a collection of coarser-scale photographs taken previously by EG&G.

OVERALL IMPRESSIONS

The trip was extremely useful in orienting Or to the YM site and to identifying and refining hypotheses regarding the spatial distribution of plants and plant uptake patterns. Soil measurements taken during field activities will provide direct input into modeling activities. The trip was also useful in planning future activities with Groeneveld and Or.

INTERPRETATIONS BASED ON FIELD OBSERVATIONS

Prior to the field excursion, aerial photographs were examined and it was noticed that linear vegetation features could be identified, particularly along Yucca Crest[5]. As a working hypothesis, it was felt that these linear features represent fissures in the bedrock that the plants were able to take advantage of for water uptake. To verify this hypothesis, several pits were dug adjacent to flourishing plants. Two pits were dug along an apparent linear feature in the Tiva Canyon caprock. Bedrock was reached at a depth of approximately 30 to 40 cm under the plants and in both pits a fissure of approximately 5 to 15 cm was identified, aligned with the vegetation feature, that was densely populated with roots. In one of the pits, a carbonate layer was identified within the fissure at a depth of roughly 5 cm below soil/bedrock contact; in the other, no distinct carbonate layer was identified to a depth of about 20 to 30 cm but there did appear to be increasing carbonate concentrations in the soil with depth.

Plant roots were exposed at three additional sites with shallower soil. At one site, in caprock, both plants exposed had roots predominantly within fissures or extending to fissures. At the second site, in caprock, the plant selected was in the center of a pocket of soil several meters across, with bedrock cropping out on three sides and a soil depth of at least 30 to 40 cm directly under the plant. Although a fissure existed, the plant did not appear to take special advantage of the fissure but appeared to take advantage of runoff from the surrounding bedrock. Nearby plants in fissures between bedrock outcrops appeared more verdant. At the third site, on a side slope in the upper lithophysal unit of the Tiva Canyon formation, the plants were rooted in rubble with 30 cm of cover. For these locations, typical of ridgetops and side slopes, the use of unrestricted rooting systems reported in the literature is precluded due to the strong influence of bedrock.

In all locations examined, the soil cover was sandy loam to loam with bedrock fragments, and was rather permeable. The fine portion of the soil appears to be eolian in nature wherever it was examined. Although permeabilities and soil depths were only determined at a few locations, soil samples were collected at scattered locations (including each vegetation transect). Roughly two dozen soil samples were obtained. The similarity of the samples suggests that it would be reasonable to assume that soils are reasonably similar over the entire mountainside (except perhaps in areas with sorting due to overland flow such as washes and wash channels), consistent with Flint et al. (1996).

Four ponded-head permeameter measurements were made at three sites with relatively shallow slopes along Yucca Crest and Highway Ridge. Measured saturated conductivity values ranged from 1.2×10^{-3} to 4.9×10^{-3} cm/s. The smallest reading occurred at a site where a large rock was subsequently found to lie directly under the disk; the next-largest reading was 2.9×10^{-3} cm/s. For comparison, Flint et al. (1996) reported soil conductivities in the YM area of 5.6×10^{-4} to 3.8×10^{-3} cm/s based on soil-texture analysis. Three tension-head measurements (two readings with different suctions at one site, one reading at another site) were also obtained, indicating consistent values. The measured values are remarkably similar.

Rock particles found in the soil ranged from small pebbles through cobble-sized blocks. In the pits and in trenches with bedrock exposed, the bedrock was considerably more irregular than the soil surface implying that vegetation may be preferentially located in locally deeper pockets of soil where water can be stored for longer periods after precipitation.

[5] Subsequent examination suggests that these features appear to be associated with the Tpcrn1 and/or the upper portion of the Tpcpul zones.

The welded Tiva Canyon units do not exhibit gullying along the side slopes of the washes over the proposed repository footprint, suggesting that erosional processes are not dominated by overland flow. The high permeability of the shallow soils and the dense carbonates existing in fractures exposed by trenches in the TCw units below the caprock further suggest that lateral flow is likely to be primarily along the soil/bedrock interface rather than as overland flow. The distribution of vegetation suggests that lateral flow may be significant; vegetation is relatively sparse at the top of slopes and relatively dense at points where slopes flatten. Note that the existence of subsurface lateral flow is also suggested by neutron-probe measurements.

Based on topography, soil depth, and bedrock materials, the ground surface over the repository footprint can be divided into four categories:

- Tiva Canyon caprock on ridgetops. Slopes are generally moderate (less than 10 degrees) with shallow soils (0 to 40 cm with pockets greater than 60 cm). The bedrock is generally massive with fissures spaced sufficiently far apart in places to provide significant organization to vegetation. The fissures are typically 5 to 15 cm in aperture, and appear to form by eolian soils filling between boulders. Bedrock is irregular in topography, with at least 40 cm variation possible within the space of 2 m. The bedrock is sufficiently permeable that moisture may interact significantly with it over periods of days to weeks. Soil fills the fissures to a depth of at least 5 to 30 cm, with carbonate fillings possible. Roots are common, almost ubiquitous, within fractures. Net infiltration may be quite significant due to shallow soils. Several vegetation transects were taken in this environment, 4 soil-permeability and 2 bedrock-permeability measurements were made, and 5 bedrock-exposure pits were dug.

- Tiva Canyon welded units (i.e., lithophysal units) below the caprock. Slopes are generally moderate to steep (10 to 45 degrees). Scree exists where slopes are greater than roughly 40 degrees. Bedrock is irregular in topography, although perhaps less so than for the caprock. There is some evidence of stairstepping in the bedrock surface that is not echoed in the soil profile, which may provide localized pockets for vegetation. Fractures are typically narrow in aperture (less than 1 cm) but closely spaced. The fractures appear to be filled with carbonates as a rule, and generally not penetrated by roots except for perhaps a few localized zones with wider apertures. Vegetation is predominantly Great Basin on the north-facing slopes and Mojavian on the south-facing slopes, with vegetation densities about twice as large on the north-facing slopes. Vegetation increases in density downslope. Net infiltration may be significant due to shallow soils. Lateral redistribution along the soil/bedrock interface may also be significant. Several vegetation transects were taken in this environment, a pair of soil-permeability measurements were taken, and several trenches and pavements were examined in detail.

- Alluvium-filled washes. Slopes are shallow and soils tend to be greater than 1 m in depth. Net infiltration may not be significant, due to the large storage capacity of the soils and the presence of vegetation. This environment was not examined in detail, aside from one or two vegetation transects.

- The west face of Yucca Crest. Slopes are quite steep, as much as 50 degrees. Numerous strata are exposed, ranging from densely welded to nonwelded. Soil pockets exist of as much as 50 cm even in the steepest slopes. Vegetation is dominated by crack-dwelling species. Overland flow should be significant, as evidenced by gully formation. Of the four environments this environment is by far the most complex to model however, relatively little of the repository footprint is overlain by this category. The environment was not examined in detail, aside from daily hikes up and down to Yucca Crest.

HYDRAULIC CONDUCTIVITY MEASUREMENTS IN SOLITARIO CANYON

J. Winterle obtained 13 hydraulic conductivity measurements for the stream beds in Solitario Canyon and its side canyons. These measurements were obtained using a Guelph Permeameter which is used by augering a hole 20 to 40 cm deep into the sediments and measuring infiltration of water out of the bottom of this hole while a constant water level is maintained in the hole. There were problems with this technique involving difficulty in augering holes due to the presence of large cobbles, and a tendency for the holes to collapse due to the lack of cohesiveness of the sediments. Nevertheless, 13 measurements were obtained with hydraulic conductivities on the order of 10^{-3} to 10^{-1} cm/s. These values are consistent with published values for silty sands and gravels. It should be noted that 10^{-2} cm/s is the upper limit of the range of hydraulic conductivities for which the Guelph permeameter is designed, thus the values outside of this range may not be as accurate as the lower values; however, they do represent a good order-of-magnitude estimate. Samples of sediments were obtained from the auger holes and their hydraulic conductivities are currently being measured in the laboratory. Locations of each of the conductivity measurements was recorded using a GPS unit. The GPS measurements are accurate to the nearest 100 m. The following table summarizes the data collected.

Sample #	GPS Loc. (UTM)	Hydraulic Conductivity (cm/s)	Notes
1	X: 546637 m Y: 4077467 m	0.04	silty coarse gravels with many large cobbles
2	X: 546517 m Y: 4077632 m	0.02	coarse gravel with fine silty sand
3	X: 546794 m Y: 4077389 m	0.07	sandy coarse gravel
4	X: 546826 m Y: 4077651 m	0.05	well-sorted, pea-sized gravel
5	X: 546772 m Y: 4077250 m	0.002	silty, sandy gravel with large cobbles
6	X: 546667 m Y: 4077103 m	0.007	silty, sandy gravel with a few large cobbles
7	X: 546612 m Y: 4076972 m	0.002	silty coarse gravel
8	X: 546593 m Y: 4076710 m	0.012	sandy gravel with a few large cobbles
9	X: 546597 m Y: 4076410 m	0.02	sandy gravel

10	X: 547186 m Y: 4079275 m	0.1	coarse sand and gravel
11	X: 547135 m Y: 4078848 m	0.04	well-sorted pea-gravel with coarse sand
12	X: 547121 m Y: 4078681 m	0.01	well-sorted pea-gravel with coarse sand
13	X: 547021 m Y: 4078283 m	0.002	silty overbank sediments (stream channel is well sorted pea-gravel)

PROBLEMS ENCOUNTERED:

The real-time differential GPS did not function properly, almost certainly due to operator error. Reported measurements are therefore only accurate to within 100 m.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

None.

REFERENCES:

Flint, A., J. Hevesi, and L. Flint. 1996. *Conceptual and Numerical Model of Infiltration for the Yucca Mountain Area, Nevada.* USGS Water Resources Investigation Report. Denver, CO. Draft dated September 20, 1996.

The following table is not included in the trip report; it was retyped from page 12 of the supplement to scientific notebook #268, documenting an analysis dated 17 April 1997 performed by USU Analytical Laboratories, Utah State University, on soil samples from Yucca Mountain received 4/7/97.

USU #	ID	EC mmhos/cm	Sand	Silt	Clay	Texture
2145	FP 1.1	0.4	77	16	7	LS
2146	1.2	0.6	57	33	10	SL
2147	2.1	0.3	57	30	13	SL
2148	3.1	0.4	72	23	5	SL
2149	3.2	0.2	69	24	7	SL
2150	RS 1.1	0.3	61	25	14	SL
2151	2.1	0.3	60	27	13	SL
2152	2.2	0.3	65	24	11	SL
2153	2.3	0.3	70	20	10	SL
2154	16.1	0.3	66	26	8	SL
2155	16.2	0.4	63	26	11	SL
2156	16.3	0.4	63	29	8	SL
2157	16.4	0.3	67	25	8	SL
2158	18.1	0.3	62	30	8	SL
2159	19.1	0.4	60	28	12	SL
2160	19.2	0.3	70	22	8	SL
2161	20.1	0.4	72	18	10	SL
2162	20.2	0.3	64	25	11	SL
2163	21.2	0.4	67	25	8	SL
2164	23.1	0.4	63	23	14	SL
2165	23.2	0.4	66	24	10	SL
2166	23.3	0.3	64	27	9	SL
2167	24.1	0.4	67	23	10	SL
2168	24.2	0.3	75	18	7	SL
2169	24.3	0.3	68	26	6	SL
2170	28	0.3	71	24	5	SL
2171	29	0.8	58	24	18	SL
2172	30 (10 cm)	0.2	73	22	5	SL
2173	30 (50 cm)	0.4	64	25	11	SL
2174	Yucca #1 surface	0.3	71	23	6	SL
2175	Yucca trench 20	0.3	66	23	11	SL
2176	Yucca trench 30	0.5	67	26	7	SL
2177	Yucca #2 surface	0.5	76	17	7	SL

Trip 6: Reproduction of trip report transmitted to NRC. Detailed observations are recorded in pages 25–37 of field notebook 175 (S. Stothoff), available in ADAMS (ML043630294), and in pages 52–58 of the supplement to Scientific Notebook #268 (D. Groeneveld), available on ADAMS (ML040530130). Color photographs are included in notebook #268.

SUBJECT: Trip to Yucca Mountain (20-5708-861)

DATE/PLACE: June 5 through 9, 1997; Yucca Mountain, Nevada

AUTHORS: Stuart A. Stothoff and Gordon Wittmeyer

PERSONS PRESENT:

The trip to Yucca Mountain (YM), Nevada, on June 5 through 9, 1997, was attended by S. Stothoff and G. Wittmeyer [Center for Nuclear Waste Regulatory Analyses (CNWRA)]; N. Coleman [Nuclear Regulatory Commission (NRC)]; D. Groeneveld (Natural Resources, Inc.); D. Or (Utah State University); and D. Woolhiser (self-employed consultant to the CNWRA).

BACKGROUND AND PURPOSE OF TRIP:

The objective of the field investigations described herein was to evaluate the validity of assumptions that underlie the modelling approaches that have been used by both the U.S. Department of Energy (DOE) and the NRC to simulate infiltration at YM. Questions regarding these assumptions were identified during the development of the Issue Resolution Status Report (IRSR) for shallow infiltration. Specific aspects that were to be evaluated by gathering field data include (i) the conservativeness of neglecting local surface run-off and run-on; (ii) the potential for scree or boulders on talus slopes to reduce soil-water evaporation; and (iii) the potential for current and future vegetation to affect net infiltration. Specific study areas were identified in earlier site visits where inferences could be made about these aspects.

The CNWRA retained D. Groeneveld as a consultant to aid in characterizing the impact, not considered in CNWRA modeling efforts to date, of vegetation upon shallow infiltration. In turn, Groeneveld retained D. Or for his expertise in soil physics. The CNWRA has also retained D. Woolhiser to aid in watershed-scale modeling of the YM area, particularly Solitario Canyon as an analog to YM proper. Each of these consultants were brought to YM to discuss the interplay of infiltration, overland and subsurface lateral flow, and evapotranspiration at the hillslope scale. In addition, field activities were designed to (i) assess the potential for locally high infiltration in scree; (ii) assess the potential for runoff and lateral flow in steep areas with shallow soils; (iii) assess rooting depths of desert shrubs, particularly in areas with carbonate-filled cooling joints; and (iv) reconnoiter previously identified analog sites for vegetation patterns under full-glacial conditions.

SUMMARY OF ACTIVITIES:

The field work was divided into three activities: (i) spot-check of the hydraulic characteristics of hillslopes (scree and talus slopes, shallow soils covering Tiva Canyon crystal-poor welded bedrock); (ii) spot-check of plant rooting depths under scree and in shallow soils overlying welded bedrock; and (iii) reconnaissance evaluation of vegetation at sites with bedrock and climatic conditions analogous to what would be expected under full-glacial conditions (i.e., the YM Prow and Shoshone Mountain).

IMPRESSIONS/CONCLUSIONS:

1. Overall Impressions

The trip was extremely useful. Field observations greatly clarified understandings of expected hydrologic behavior of scree piles. Well-developed scree is a trap for dust that fills the voids between rocks at depth and provides a substrate for roots. The observations suggest that these areas are normally very significant sources of moisture for surrounding vegetation and should have high recharge when other factors inhibit vegetation growth.

U.S. Geologic Survey (USGS) modeling exercises to date have assumed that roots are able to penetrate the carbonate-filled fractures and extract water from the carbonates, although little justification has been available for these assumptions. The rooting depths considered have also had little justification. On this trip, roots were observed to a depth of 1 to 2 m in carbonate-filled fractures exposed in drill-pad and fault-pavement exposures, with one root extending to a depth of greater than 6 m below the top of the bedrock within the carbonate-filled Ghost Dance Fault. These observations support the USGS assumption that roots can grow within the carbonate fillings.

Reconnaissance observations of future-climate-analog sites (YM Prow, Shoshone Mountain) suggest that, barring the effects of non-native vegetation species, juniper and pinyon pine would be able to move into the ridgetops and perhaps sideslopes of the repository block area. Juniper and pinyon pine are efficient at extracting soil moisture due to the large rooting systems for these plants. On the other hand, the widespread occurrence of eurasian grass species *bromus rubens* (red chess) at YM and *bromus tectorum* (cheatgrass) at higher elevations (Shoshone Mountain) suggest that these species may be able to invade the YM area as they have elsewhere in the Great Basin. These species are less efficient at extracting soil moisture than desert shrubs, and net infiltration would be expected to increase were these species able to outcompete the native shrubs.

2. Animal Sightings

Several animals were sighted on the trip. Aside from numerous rodents, small lizards, and a coyote, the following were identified.

- An unmarked male desert tortoise was carefully removed from the center of the road from Mercury to YM at about 11:00 a.m. on June 5, 1997, approximately 14.5 mi southeast of the deserted guardhouse near the Field Operations Center (FOC).

- Another desert tortoise, apparently female, was sighted in a burrow between the Prow and borehole UE-25 GA-1, at N 36° 53.66', W 116° 28.99' at about 5:15 p.m. on June 8, 1997.

- An apparently gravid female chuckwalla was sighted in a shrub next to the roadway entering Pagany Wash at about 2:30 p.m., at N 36° 51.58', W 116° 26.19'.

- A collared lizard (*crotaphytus collaris*) was sighted twice on June 8, 1997, at the primary talus slope study site.

- Six live snails (unknown genus) and numerous snail shells were found in scree piles. Each scree pile examined had evidence of these snails.

- A mule deer buck was sighted on Shoshone Mountain, at about 2:00 p.m. on June 9, 1997. There was evidence of deer on YM, particularly the Prow area.

- A glossy snake was sighted on the roadway about 0.5 mi east of Forty-Mile wash at about 9:00 p.m. on June 6, 1997.

3. Summary of Scree/Talus Slope Investigations

Several talus slopes were investigated to determine the hydrologic behavior expected for such areas. One talus slope with top rocks having heavy desert varnish was examined in detail as an example of a stable, well-developed environment, while the others were investigated to lesser extents in order to get a rough estimate of the variability and trends that might be expected.

The primary talus slope investigated is on the north-facing side of Abandoned Wash at approximately N 36° 49.53' and W 116° 27.52', about 100 m east of the 90° bend to the south. The slope is about 42 to 45 percent (measured by clinometer) and roughly 50 percent of the hillslope is scree or talus (estimated by eye). The selected talus slope is about 10 m wide and 40 m long, and overlies PTn bedrock. The heavily varnished surface layer is about 15 cm deep and is composed of sharp-edged densely welded rocks that appear to be clinkstone from the crystal-poor portions of the Tiva Canyon unit. The rocks appear to have been separated from the bedrock along cooling joints. Little or no dust is apparent on the surface layer of rocks. The top of the talus slope consists of about 5 m of relatively fine surface cover, with badger and squirrel holes in the fine area. The badger excavated chunks of rock with heavily calcited surfaces. The supply of rock for the slope has been cut off.

Site 1 at Talus Slope I

Particle size distributions were obtained at three depths in the process of uncovering the root structure of an *ephedra viridus* (Mormon tea) with a crown width of approximately 1.5 m, located at the edge of the talus slope about 20 m from the roadway at the bottom of the sideslope and about 5 m from the bottom of the talus slope. At each depth, the dimensions across the middle and smallest block directions were measured for 20 rocks. In the top 15 cm, individual rocks had dimensions across the 2nd (middle) axis of about 125 to 260 mm and across the 3rd (smallest) axis of about 23 to 142 mm.

Below the top layer, smaller rocks (apparently shards) form a layer with increasing amounts of dust present. The range of rock sizes at 15 cm depth is 50 to 118 mm (2nd axis) and 8 to 38 mm (3rd axis). The size of shards decreases with depth and the fraction of void space filled with loess increases. At 30 cm depth the range of rock sizes is 35 to 70 mm (2nd axis) and 5 to 50 mm (3rd axis), and the void space is essentially filled with loess. Also at 30 cm depth, a snail shell was found at this site. Living and dead snails were typically found at this horizon at other sites. At 45 cm depth, a horizon that appears to be an old soil horizon was contacted, and some of the rocks had carbonate coatings.

The *ephedra viridus* exposed in the excavation had an apparent buried branch at 20 cm depth, and the top of roots at 25 to 28 cm depth. At 45 cm depth, many fine roots were observed. The more major roots appear to follow contorted paths due to the many rocks. Mouse droppings were observed under the drip line, and shed stems were observed within a radius 20 cm greater than the drip line below several layers of rocks. Some question arises as to the rate that rocks

are moving in the scree pile due to the buried organic material and surface rocks being equally varnished on each side.

A disk-permeameter measurement was attempted at the bottom of the cleared opening at this site. At apparent steady state, water was leaving the permeameter at about 26 cm/hr, slightly faster than in areas with fewer rock fragments.

Site 2 at Talus Slope 1

The second site was selected to examine the slope far from plants. Site 2 is about 15 m upslope from Site 1, about 5 m from the nearest plant on either side of the slope. The vertical profile of the slope is quite similar to Site 1, with the top 15 cm having large clean rocks, the next 20 cm increasing in fine content and decreasing in size of rocks, and the next 25 cm having almost all interstices filled with fines. About 20 cm into the lower layer, moist roots occur (indicating that they are alive) despite the apparent dryness of the soil. Several sets of roots were found in a diameter of about 40 cm, with a maximum root diameter of 1 mm. A disk-permeameter test failed due to flow channeling (i.e., interstices washed out).

Site 3 at Talus Slope 1

A third location, about 130 m uphill of Site 1, was selected to examine a location with shallow cover between active rock channels and a crack-loving shrub. The scree in this location is far less varnished than Sites 1 and 2. The root structure of a needle-leaved rabbitbrush (*chrysothamnus teritifolius*) with crown diameter of 2 m was exposed to a depth of about 50 cm. Bedrock ranged from 10 to 20 cm in depth below the crown. A root 1.5 cm in diameter was identified at 50 cm depth within a crack structure. A root, apparently from an ephedra viridus, was identified within the crown; the nearest ephedra shrubs were 2.5 and 4.8 m away.

Talus Slope 2

A second talus slope was selected on Boundary Ridge with the purpose of examining interactions in a large slope far from the boundary, particularly maximum root length. The site is located 10 m from the sides of the talus slope and more than 10 m from the bottom. The talus slope is northeast of Dune Road, perpendicular to Dune Road at 36° 49.232' N, 116° 26.797' W. Boundary Ridge faces 9° south of west at the site.

The rocks at the surface are about five times larger than the surface rocks at Slope 1, but the same general pattern of decreasing rock size with depth was observed. At the same general rock size that loess became significant at Slope 1, loess also became significant at Slope 2. At a depth of 50 cm, soil was moist enough to hold its shape when packed. No roots were found within the 20-cm diameter hole. Vegetation bordering the talus was not vigorous, and the only robust vegetation was needle-leaved rabbitbrush, which tends to be a crack-loving species. Very few *ephedra*, which we hypothesize to be particularly talus-adapted, were observed.

Talus Slope 2 is hypothesized to be a location with potentially very large infiltration, based on the moist soil and lack of vegetation. The site has much less vegetation than expected, although rodents and snails are present at the site. No satisfactory explanation for the anomalously low vegetation density has been derived.

Talus Slope 3

A rather young scree pile (little desert pavement) at the bottom of the northfacing slope just east of the SD-12 drillpad was briefly examined with the intent of running an infiltration experiment. Well-developed soil was absent to a depth of at least 50 cm; however, *ephedra viridus* was growing well in the vicinity.

4. Summary of Miscellaneous Hillslope Investigations

Several scoping observations were made to guide future work related to hillslope infiltration processes, particularly in the crystal-poor densely welded units (e.g., upper lithophysal unit of the Tiva Canyon formation) that tend to have numerous carbonate-filled cooling joints.

Exposures of crystal-poor units at several drill pads and pavements were examined to identify typical rooting depths within fractures, particularly carbonate-filled fractures. Roots were not seen significantly below 2 m into the bedrock. Based on relatively few exposures, north-facing slopes may support deeper root systems than south-facing slopes. Two particularly good exposures were identified-the UZ-7a drill pad and the SD-12 drill pad. The UZ-7a exposure features a taproot 6 m below the top of bedrock, within the carbonates of the Ghost Dance Fault, that continues below the level of the cleared drill pad surface.

The Ghost Dance Fault pavement in WT-2 Wash features numerous rabbitbrush shrubs re-establishing from root systems pre-existing within the heavily carbonate-filled fractures before the pavement was cleared. The shrubs are generally 10 to 20 cm in height after four growing seasons, even with root systems typical of much larger shrubs in place. Just upslope of the exposed pavement, several infiltration experiments were performed using the disk permeameter. Steady-state, water-loss rates of 14 and 19 cm/hr were obtained, typical of equivalent rates obtained in caprock (14 and 30 cm/hr), Highway Ridge sideslopes (18 and 22 cm/hr), and deposits at site 1 of Talus Slope 1 (26 cm/hr), further confirming the spatial uniformity of the fine components of the surficial deposits.

A rough confirmatory analysis of an empirical relationship between slope and percent scree/talus cover, derived during the previous field work, was performed in Drillhole Wash. The relationship states that no scree exists below 30 percent slope and the percent coverage increases linearly from 0 to 100 as the slope increases from 30 to 60 percent. Based on the confirmatory analysis, the relationship appears to be most appropriate for smooth bedrock (i.e., not stairstepping), and can break down at the higher slopes considered due to areas of bare rock.

5. Summary of Climate-Analog Investigations

Two locations analogous to YM under cooler and wetter conditions were investigated.

The Prow of YM is almost 1,800 m in elevation, and features a juniper forest of at least 100 individuals at the highest elevations. Joshua trees, blackbrush, and sagebrush are present on the Prow but nonexistent to sparse at the lower elevations over the potential repository. The Prow exhibits very shallow to nonexistent soils overlying fissured caprock similar to Yucca Crest. Cliff exposures suggest that fissures extend through the caprock.

Juniper is at the extreme low end of its elevation range on the Prow, and may only exist due to the isolation from fire provided by the topography and the concentration of water afforded by overland flow into bedrock fissures. A few juniper also exist at the upper portion of the underlying crystal-poor unit, within fissures where overland flow concentrates runoff. Each

juniper typically has several meters of uphill catchment. Judging from this site, juniper should easily be able to colonize ridgetops and sideslopes of YM under sufficiently cooler and wetter conditions.

Shoshone Mountain, located north of Gate 510 in Area 29 of the Nevada Test Site (36° 56.6' N, 116° 15.7' W, with peak elevation greater than 2,100 m) is analogous to YM under cooler and wetter conditions than currently exist at the Prow. A variety of welded and nonwelded tuffs comprise the bedrock. A cursory examination of vegetation revealed that juniper, pinyon pine, mountain oak, and *bromus tectorum* are present at Shoshone Mountain while not present at YM. These species were able to exist in the range of tuff bedrock; juniper also was able to grow in the alluvium at the foot of Shoshone Mountain. *Ephedra nevadensis* demonstrated a strong affinity for the edges of talus slopes, growing densely in a manner reminiscent of creosote in the first tier next to roadways.

There are numerous anthropogenic fire scars present in the vicinity of Shoshone Mountain. Within the scars, shrub recovery is variable and *bromus tectorum* is establishing a strong foothold. The ubiquity of *bromus tectorum* supports contentions that shrubs may be outcompeted in the YM area, thereby increasing net infiltration.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

None.

ATTACHMENTS:

None.

REFERENCES:

None.

Trip 7: Reproduction (capitalization adjusted for readability) of detailed observations recorded in pages 38–40 of field notebook 175, available in ADAMS (ML043630294). This trip was a reactive trip to observe the effects of a potentially large rainfall event offered by the movement of Hurricane Nora from the Pacific up through Nevada from the south. The hurricane dropped in magnitude during travel to Yucca Mountain, so that the actual rainfall did not represent an extreme event.

Trip to YM to observe effects of Nora 9/25-26/97

OBJECTIVES

Observe response of surface hydrology to major event (Hurricane Nora)
Scope out work for similar event in this El Niño winter

Page 39 (9/25/97)

Arrived at Gate 100 around 4 pm. Anecdotal observations by gate and FOC personnel were that rain had been occurring most of the day, but at generally light to light moderate rates.

Rain was generally moderate from Indian Springs to YM on trip up. Puddles on road from FOC to YM, some standing water in ditches. Rivulets by side of road and on gravel roads @ YM.

At 5:30 pm, wetting front @ 20 cm in alluvium in WT-2 Wash (not in channel). Some flowing water, but associated with anthropogenic features (roads, exposures).

Rain gauge @ N60 has about 1 in. water with sludge (dead flies, etc.) — this should reflect rain in current storm since gauge is uncapped.

At 5:30 Northern of 2 trenches just south of GDF pavement has two pockets of standing water, one w/ volume of ~1.2×1.2×0.1 m^3, the other ~1.0×1.7×0.17 m^3. No apparent overland flow.

6:00 No sign of water coming out of loose scree on northfacing slope E. of drill pad SD12.

6:20 Pattern of wet overhangs with dry other. Some dripping on wet rock (drill pad UZ-7a). Fracture wetness in dry areas conspicuous by near-total absence.

6:30 Trickle in small channel at base of scree pile @ road & Roy (?) Hill (N end of Fran Ridge). Why is the channel so small if lateral flow is significant?

7:30 Checked trench N Highway Ridge, YC. Puddles almost totally absent, even in trench (w/little cover over bedrock). Little or no sign of saturation-excess flow anywhere. Note additional water puddles on soil, seeps invisibly at side of rock.

Page 40 (9/26/97)

Rain probably not continuing for much longer after leaving last night. No running water anywhere along road up to WT2 Wash, & very few puddles along road. Nothing flowing Roy Hill.

9:00 In N trench of the 2 S. of GDF pavement in WT2 Wash. Reexamined puddles. Apparently same depth or close. In calm, noticed ripples from popping bubbles. Saw a few rise from bottom of puddle (2-3 mm dia). The smaller puddle has upstream pavement of 3-4 m, the larger 4 or 5 m. Wetting front erratic in trench wall, 25-50 cm deep.

Wetting front @ 30 cm in WT-2 Wash near measurement yesterday. Note location is in alluvium that looks like may be old channel but was not active.

9:20 GDF pavement has a few cavities w/ 2 cm trapped water, but almost all of pavement is lacking puddles. Little evidence of overland flow last night, dry today. Can fractures absorb winter storms? Note: some lithophysal cavities in vert. rock face have wet haloes of 2+ cm. Absorption or surface phenomenon?

10:30 At SC side of drill pad for H-5, some of the caprock blocks have natural bowls. Many of these are full or nearly full. One is roughly $0.7 \times 0.25 \times 0.15$ m^3 with a relatively small catchment and other potholes with a meter. Much more rain here? Or antecedent? Note potholes intersected by fractures tend to be dry.

11:15 Based on exposed pits (from last visit) in Abandoned Wash, wetting penetration is at least 50 cm and probably more. Soil damp to bottom of all pits.

Total rain cannot have been > 1.5 in. and probably less than 1 in. McCarren Airport report 0.66 in. and gauges here totaled 1.5 in. at both N60 and N50; however, the N50 and N60 gauges were filled with organic material to top of water.

Trip 8: This trip was to Yucca Mountain and Shoshone Mountain, continuing collection of field observations. R. Fedors assumed the duties of principal investigator prior to the trip, with S. Stothoff becoming a consultant to CNWRA. The summary of the trip is extracted from pages 59–63 of the supplement to Scientific Notebook #268, prepared by D. Groeneveld. The summary is not edited. Detailed observations from this trip are recorded in pages 41–50 of field notebook 175 (S. Stothoff), available in ADAMS (ML043630294), pages 1 to 37 of field notebook 255 (R. Fedors), available in ADAMS (ML040650582), and pages 59–73 of the supplement to Scientific Notebook #268 (D. Groeneveld), available on ADAMS (ML040530130). Note that opinions expressed are those of D. Groeneveld. Color photographs documenting the trip are located in Scientific Notebook #268 on pages 68 through 73.

January 26 through 29, 1998:

Soil depths, calcite in fissures, growth rates of shrubs and trees on south- and north-facing slopes on Yucca and Shoshone Mountains.

Trip Summary:

Yucca Mountain Study
Trip Report for Field Work, January 26-29
Prepared by David Groeneveld

Day 1, January 26

Dani Or, Randy Fedors and David Groeneveld began field work on Yucca Mountain in the unnamed canyon where the bedrock at Ghost Dance fault is exposed[6]. This site lays on the south side of Antler Ridge where the canyon forks.

GPS cross-check

We began field work by obtaining data to cross check the accuracy of three GPS units. The data show relatively poor agreement, especially for latitude.

Dani's:	36° 50' 36.70"	116° 27' 16.03"
Randy's:	36° 50 40"	116° 27 16.9"
David's:	36° 5041.1"	116° 27 16.32

At Yucca Mountain, the approximate scale meters to seconds is,

Latitude: 30.9 m
Longitude: 24.9 m

Converted to distance, the range recorded was:

Latitude:	41.1−36.7seconds = 4.4 sec x 30.9 m = 136.0 m
Longitude:	0.9 − .03 seconds = 0.87sec x 24.9m = 21.7m

Evidence of Root Dissolution of Calcite

[6] The canyon is Antler Wash.

Various tools (crowbar, wrecking bar, single-jack, cold chisel) were used to remove rocks to expose calcite fracture filling and in-situ roots. Samples were collected of root/calcite contacts. These were examined using a hand lens before and after wetting with water. The following was observed:

(1) needle-leaved rabbitbrush, ca. 3 years old, crown of 9 cm tall and 13 cm in diameter, taproot 11 cm long below the juncture with the crown, initially 8 mm wide then branching into several lateral roots that penetrated leaves of calcite filling the exposed fracture.

The roots penetrating the calcite were markedly flattened (as reported by other researchers). An upper weathering rind in the calcite (half circle with center at stem axis, radius ca. 15 cm) showed calcite that was very soft, moist, granular-to-friable and enriched with organic matter from roots. The overall appearance was that the roots had broken down the calcite in situ. Samples were obtained from deeper, ca 20-30 cm deep that clearly showed etching by a .8 mm diameter root across a flake of calcite. These were photographed.

Importantly, roots did not penetrate were the calcite fracture filling was solid. Instead, the roots appeared to penetrate only where the rock was already loose and where a space existed between the calcite filling and the tuff. An hypothesis emerges that all calcite fillings on these side slopes is continuous and will prevent both infiltration and root penetration. As weathering occurs on these slopes, rock blocks become loosened, thereby permitting penetration by roots. Roots then create "tanks" within the fracture by dissolution and breakdown of the calcite and enrichment with root-derived organic matter. These tanks fill up following precipitation.

There is no doubt that the fractures are promotional to growth of the plants that penetrate them, however, the amount of promotion is limited. This can be seen by comparison of seedlings of needle-leaved rabbitbrush that have started on nearby drill pads and trench spoils. Here the seedlings, judged to be of about the same age (samples collected for verification), are far more robust probably due to the lack of inter-shrub competition, freedom for root expansion in all directions, and a medium that is open to infiltration in all locations.

(2) the root system of a buckwheat (*Encelia farinosa*, a sub-shrub with woody base and mostly herbaceous stems) was examined in the same manner as the root system of the needle-leaved rabbitbrush. Root etching of calcite was found beneath this buckwheat (roots of 0.5 to 1 mm) (3) the root system of a perennial herb (*Stephanomeria pauciflora*) was also examined in the same manner. Roots growing within an open crack were in contact with highly weathered (powdered) calcite. Most roots were very fine and the etching on the calcite was only observable under 10x magnification; these being less than 0.5 mm across.

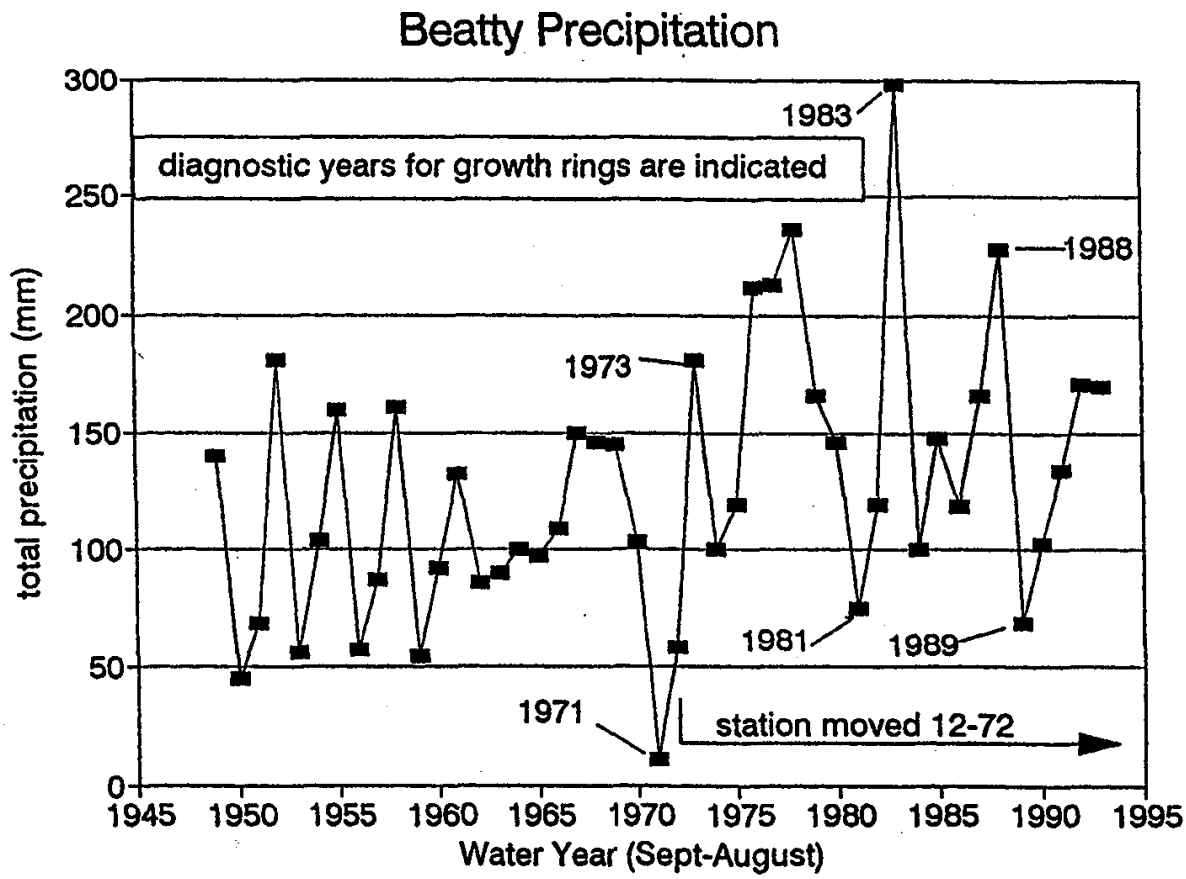
Shrub Stem Samples

Dani and Randy dug a series of pits up the south-facing slope of Antler Ridge along the fall line and beginning at the east margin of the cleared zone. Needle-leaved rabbitbrush (*Chrysothamnus teretifolius*) grows on this slope and on various north-facing slopes. In other work in the Owens Valley, I have found that rubber rabbitbrush (Chrysothamnus nauseosus), supported by shallow groundwater in the Owens Valley, California, grows annual layers in its stem. If the growth layers of needle-leaved rabbitbrush are also annual, this offers the opportunity to examine growth rates on north- vs. south-facing slopes to better understand the partitioning of precipitation water into evaporation or transpiration. This is of direct interest because plants that are coupled with fissures (in particular, needle-leaved rabbitbrush under the

present climate) offer the only means for removal of infiltrated water once it has passed a depth of about 0.5 m.

Twelve shrub stem samples that were collected on S-facing Antler Ridge with position relative to the soil pits dug by Dani and Randy recorded. The distance between each of the pits on this slope were measured on 1-27 by Stu and myself.

Shrub stem samples were obtained in anticipation that each growth ring represents one year. This will need to be confirmed in the laboratory by correlation of diagnostic wet and dry years with the patterns of thin and thick rings represented in the stem. Weather data from Beatty, Nevada obtained from Stu was sent to assist this analysis. These data are shown in the figure below.



Day 2, January 27

In the company of Stu, Dani and Randy I examined the cut into the S-facing slope above well NRG5. This cut intersects a series of debris fans? located at the break in slope between the hillside (45%) and the nearly level wash. The cut also intersected a fault running transverse to the wash. The tuff exposed is heavily cemented with calcite (samples collected). An apparent concentration of water occurs from runoff from the hillslope that infiltrates into the debris fans. This mechanism was apparent in the presence of wet calcite-cemented colluvium dissected by the western wall of the cut. The colluvial debris fans are an obvious site of water concentration and storage. Whether this is a site permitting infiltration into tuff fractures is up for question. The

appearance, though, is that this water is perched due to cementation by calcite. More discussion is due.

Exposure at UE25-NRG6

This site had poor calcite formation in relatively open fractures. The soil development here appeared to be greater than on steeper hill slopes: the hillside above this location was relatively shallow (not measured, but probably less than 30%). As a possible confirmation of the lack of cracks/calcite filling, needle-leaved rabbitbrush were rare on the surrounding hillslope (only 2 present in 1 hectare compared to 30-100/h on nearby hillsides).

Location of soil pits

Working with Stu, we measured out and marked sampling locations for soil pits on the N-facing slope of Antler Ridge and on the S-facing slope of Split Wash.

Day 3, January 28

Stu, Dani, Randy and I visited Shoshone Mountain with the intent to (1) evaluate this site as an analog for climate change and (2) gather botanical additional data. Dani, Stu and Randy looked at scree and soil pits while I concentrated on gathering botanical data.

Tree ring data for N- vs. S-facing Slopes

To add to our understanding of partitioning of precipitation into evaporation vs. transpiration, cores were obtained from 7 pinyon pine (*Pinus edulis*) growing on S- and N-facing slopes at the Shoshone Mountain crest. The site is located at approximately 6,700 feet elevation with north and south slopes aligned perpendicular to about 350° and 170°, respectively. The parent material is identical for both slopes: poorly welded tuff. The slope of the S-facing slope was a relatively uniform 41% while the N-facing slope was more variable: 40%, but variable by 5%.

Fires, Fire Frequency and Forest Regeneration

Shoshone Mountain has been burned repeatedly in recent years owing to human activity. Tree samples were obtained in order to help assess the year that two different fires occurred. Regrowth of native vegetation on the most recent burn (ca 3-6 years) appears to be severely hampered by the presence of cheatgrass. This is definitely of issue since a cheatgrass-dominated site will have much higher infiltration than one dominated by deeper rooted shrubs and trees. The older burn (40-50 years?) has had minimal regrowth by conifers and appears to be vegetated mainly with species that have resprouted from root crowns: Mormon tea (*Ephedra viridis*), Gambel oak (*Quercus gambelli*), and bitterbrush (*Purshia tridentata*).

Shoshone Mountain as a Climate Change Analog

Although this is an excellent site because of its proximity to Yucca Mountain, the much deeper soil afforded by (1) wet climate and (2) poorly welded parent material probably offer much better opportunity for growth than would Yucca Mountain under similar climate. Thus, although we are learning a lot from Shoshone Mountain, the extrapolation to Yucca Mountain may not be linear. Additional sites should be evaluated.

Cracks. Roots and Buildup of Root-derived Mulch

Dani and I excavated the roots of a rubber rabbitbrush growing within cracks in highly weathered/poorly welded tuff. We found that the cracks were the site of a large buildup of organic-rich (peat-like) material where roots had penetrated. This material resulted from many generations of roots living, dying and decaying inside the same crack. Their is a remaining question whether the fractures and cracks on Shoshone Mountain have calcite filling.

Day 4, January 29

Twelve stem samples were obtained from needle-leaved rabbitbrush growing on the N-facing slope of Antler Ridge to complete the samples necessary for ring-analysis. These samples were obtained with measured reference to the soil pits on this slope. Several samples of seedling needle leaved rabbitbrush were collected for comparison to the seedlings that can be found growing in the exposed cracks at the Ghost Dance fault exposure. One question to be answered is whether this species can resprout from a severed root (hypothesized earlier) or whether this species starts only from seed. The question is germane because of the apparent ease with which the needle leaved rabbitbrush were able to establish in the cracks with minimal soil. The samples collected can help answer this question.

Trip 9: Extract from scientific notebook #163 by S. Stothoff, available in ADAMS (ML040690351). The original entry was dated 4/12/98 (pages 2-55 to 2-62). The text was not edited; footnotes were not in the original text, and were added for explanation. This section of the notebook reproduces a trip report from a consultant to CNWRA as captured in a scientific notebook. Images in the original trip report were not retained in the scientific notebook. Detailed observations from this trip are recorded in pages 51–55 of field notebook 175 (S. Stothoff), available in ADAMS (ML043630294).

4/12/98 Documentation of future-climate analog trip

The following is a nearly verbatim copy of a trip report discussing a visit to potential future-climate analog sites in southern Nevada. The trip took place April 5 through 8, 1998, and was reported by S. Stothoff.

Background and purpose of trip

The majority of work characterizing infiltration at Yucca Mountain (YM) has assumed that present-day conditions exist and relatively little work has been performed that addresses infiltration under future climatic conditions. The infiltration model used in the NRC's TPA3 exercises conservatively neglects transpiration. Under current climatic conditions, the atmospheric evaporation demand is so much larger than precipitation that neglecting transpiration provides infiltration estimates that are only moderately conservative. However, under the cooler and moister conditions that are anticipated to occur in future glacial cycles, neglecting transpiration is expected to have a much more significant impact on infiltration predictions.

An infiltration model incorporates transpiration by specifying total soil-water uptake and the distribution of that uptake with depth. In order to calibrate an infiltration model, it is necessary to identify the vegetation expected for the particular climate and geomorphic environment. Given the expected vegetation, it may be possible to estimate appropriate plant rooting depths and uptake patterns from the literature.

Analogs to YM under future climatic conditions, if found, will be used to calibrate the vegetative patterns used as input to the infiltration model. As information on the hydrologic behavior of the sideslopes at YM is least well characterized of all environments at YM, the washes are the primary analog environment that is sought. Analogs to the caprock environment are also sought, with secondary importance. Analog sites were identified within sight of YM in earlier fieldwork (i.e., the Prow, Shoshone Mountain), but the analogs are not sufficient to characterize the range of climatic and geomorphic environments encountered at YM under a glacial cycle. Additional potential analog locations were identified from topographic maps, geologic maps, and aerial surveys. These locations include Rainier Mesa, on the Nevada Test Site (NTS); Timber Mountain and the North Pahroc Range (both in Lincoln County); the Grapevine Range (near Beatty, NV); and the Montezuma Range (near Goldfield). The current trip assessed the viability of these potential sites for future field work, with particular regard to matching bedrock, soil, vegetation, slope, annual precipitation, and mean air temperature to expected future conditions at YM. It is expected that not all of these characteristics will be matched perfectly.

Summary of activities

The fieldwork was intended to quickly identify potential sites for subsequent follow-up studies in greater depth. It is difficult to characterize soil and bedrock characteristics from aerial surveys,

so the primary emphasis for this trip was to identify appropriate soil and bedrock characteristics. A primary criterion was that elevations were generally in the range of 6,000 to 8,000 ft, providing precipitation and temperatures similar to anticipated future climates at YM. After elevation, the next criterion used in screening was to identify formations with densely welded tuffs, which are fairly rare. Appropriate slopes and soil depths were secondary criteria for matching.

Several good analog locations were identified, in the Grapevine Mountains, Timber Mountain, and Rainier Mesa. The North Pahroc Range was found less useful for analog work, while the Montezuma Range was not investigated due to time constraints.

The geomorphic characteristics of portions of lower Phinney Canyon, in the Grapevine Mountains, are strongly analogous to YM washes, featuring densely welded and quite fractured tuffs, north- and south-facing slopes, and thin soils with plentiful rock shards. The Phinney Canyon site may have slightly lower fracture densities and slightly thicker soils than YM. Ground access requires 4WD vehicles and nearly 1-1/2 hr driving from pavement; however, within the canyon access is equivalent to that obtained in YM washes. Air access is unlimited.

Timber Mountain, north of Hiko in Lincoln County, offers outcrops of moderately welded tuff, nonexistent to shallow soils, and general characteristics strongly reminiscent of the caprock at YM. The soils appear to be developing in situ, with perhaps less æolian component than apparent at YM. Ground access requires 4WD vehicles and 10 mi driving from pavement. The last 1/2 mi was hiked, due to mud and uncertain conditions; it should be possible to move closer later in the year. Moderate hiking (1/2 mi) may be required to visit prime sites. Air access is unlimited.

Rainier Mesa, approximately 1 hr drive north of Gate 100 in the NTS, is capped by moderately welded tuffs strongly reminiscent of Yucca Crest. Below the mesa top, sequences of densely welded to nonwelded tuffs form long slopes reminiscent of the west flank of YM. Soil thicknesses also appear to be similar to YM, although the soils appear to have much greater organic contents. Further, infiltration estimates are available, based on measurements of dripping into the N tunnel. Ground access is on pavement, perhaps with some dirt roads. Unlike the other sites, air access may be limited or unavailable due to NTS restrictions, and camping is not an option, requiring 1-1/2 hr drive to the nearest motel.

The North Pahroc Range, between Hiko and Caliente in Lincoln County, offers north- and south-facing sideslopes at angles similar to YM washes and soils generally similar to YM soils. However, the bedrock is not as densely welded as the Tiva Canyon welded units, thereby is less fractured. Also, the easily accessible slopes are generally at a lower elevation than the other sites, yielding an analog to a warmer and drier future climate than the other sites. Areas with what appears to be densely welded tuff are visible from the road, but access would require extensive hiking on steep terrain. Ground access requires 4WD vehicles, but is better than either Timber Mountain or Phinney Canyon. Air access is unlimited.

Impressions/conclusions

Overall impressions

The trip was useful in identifying analog sites. The trip successfully identified several good analogs for future work, although it is desirable to have additional reconnaissance from the air (particularly at Timber Mountain and Rainier Mesa). Fieldwork will not be possible for some

time, however, as snow exists at higher elevations (up to 1 m thicknesses were observed) and soils are frozen.

Juniper and piñon pine are efficient at extracting soil moisture due to the large rooting systems for these plants. Packrat midden studies (Brown et al., 1997)[7] indicate that juniper was present at elevations below 500 m in the Great Basin during the last glacial period (significantly lower than the base of YM). During the visit to Nevada, juniper was found at elevations less than 6,000 ft in some locations but piñon/juniper associations were absent at significantly higher elevations in other locations along the periphery of the NTS and Nellis AFB. If the 6,000-ft elevation represents a representative future-climate analog, both cases with and lacking vegetation should be examined to ascertain whether YM would be expected to have these species present in future conditions.

The presence in April of significant amounts of snow and frozen soil, with snowdrifts of up to 1 m in depth, suggests that it may be important to consider snow when modeling infiltration under future climates. None of the YM infiltration modeling to date has considered snow, as snow is not important at YM under current climatic conditions. Under current conditions, most infiltration occurs during the winter; if the ground is frozen, however, infiltration would be expected to peak when the snow melts. It may be that larger infiltration pulses would occur under such conditions, if the total winter precipitation infiltrated over a few weeks.

Summary of field observations

Timber Mountain

Timber Mountain is located approximately 35 mi northwest of Caliente and 40 mi north of Alamo, in Lincoln County, Nevada. Timber Mountain is located far enough east to significantly attenuate the effects of the Sierra Nevada rain shadow. Ground access to the Timber Mountain site is via a 4WD dirt road proceeding 10 mi northwest from the White River Narrows. Air access is not restricted.

The Shingle Pass Tuff (Tsp) unit, identified as densely welded by du Bray et al. (1987)[8], is of primary interest for analog studies. The Tsp unit, described as pinkish-gray to pale-red-purple by du Bray et al. (1987), is a crystal-rich tuff similar in welding and fracturing to the caprock at YM. The peak of Timber Mountain is 8,600 ft in elevation. Areas with Tsp outcrops range from 6,000 to 8,100 ft in elevation, with the most accessible areas (within 1/2 mi of the roadway) roughly 6,600 to 7,000 ft in elevation. Areas outside this range in elevation would require hiking several miles, although the hiking does not appear to be strenuous. A northeast-southwest trending ridge, at approximately latitude 37° 57' 30" N and longitude 115° 5' W, appears to be a good analog site for the YM crest.

Soils in the Tsp outcrop areas are thin to nonexistent. Much of the soil appears to be forming in situ, and first impressions suggest that a smaller æolian component is present than at YM.

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[7] Brown, T., S. Conrad, S. Wirth, J. Cochran, and J. Emery. 1997. *Plausible Future Climate States at the Area 5 Radioactive Waste Management Site, Nevada Test Site*. Sandia National Laboratories, Albuquerque, NM.

[8] du Bray, E. A., D. O. Hurtubise, and C. A. Bannister. 1987. *Geologic Map of the Weepah Spring Wilderness Study Area, Lincoln and Nye Counties, Nevada 1:50,000*. Miscellaneous Field Studies Map MF-1922, United States Geological Survey, Denver, CO.

Frost heave is evident in spots. Traces of overland sheet flow were also observed. Plentiful piñon and juniper are present.

North Pahroc Range (Boundary Wash)

The Pahroc area is also in Lincoln County. The North and South Pahroc Ranges are separated by US Route 93 approximately 25 mi west of Caliente. The primary ground access to higher elevations in the Pahroc ranges is through Boulder Wash Road, a 4WD road cutting through the North Pahroc Range from Dry Lake Valley to White River Narrows roughly 25 mi southwest of Timber Mountain. Accessible areas are all less than 7,000 ft in elevation, with the roadway less than 6,000 ft in elevation. Air access is unlimited.

Sideslopes north and east of the roadway feature moderately welded crystal-rich tuffs, and slopes that are generally shallower than the washes at YM. Two types of bedrock were observed within 1/4 mi of the road, a pale lavender tuff and a reddish-brown tuff, with the reddish-brown tuff appearing more welded and more suitable for future work. Fractures appear to be more widely spaced than the Tiva Canyon welded (TCw) unit at YM. Soils appear to be fairly comparable to those at YM. Appearing and disappearing streams where soil pinches out were observed, providing evidence of downslope lateral subsurface flow. Juniper were present, but much more sparsely than at Timber Mountain. Ground access to the base of the slopes is easy, but significant uphill hiking is required to reach higher elevations.

A bowl at higher elevations was noted south of Boundary Wash Road, with bedrock apparently more welded than the sideslopes northeast of the road. Snow was present, particularly on north-facing slopes at the bowl elevation. A hike to the bowl was abandoned partway due to time constraints, but portions of the hike were quite steep and strenuous and would be difficult to attempt with significant equipment. Other ridges south of the road might serve as an analog, but again would require significant effort to reach.

The Boundary Wash area is an adequate analog site, although other analog sites were identified with better characteristics. Unattractive features of the site include significant hiking, moderate welding, and low elevation. It may be worthwhile to consider limited study of the area as a supplemental analog for partial glaciation. Any studies would be likely be most practical if aerial analysis were the primary study mode, with limited ground confirmation.

Grapevine Mountains (Phinney Canyon)

Phinney Canyon, an east-draining canyon in the Grapevine Mountains, is located between Scotty's Castle (in Inyo County, California) and Beatty, Nevada. Phinney Canyon is in Nye County, several miles east of the junction between Inyo County, Esmeralda County (Nevada), and Nye County. The Grapevine Mountains are likely to feel significant effects of the Sierra Nevada rain shadow. Ground access to the Grapevine Mountain site is via a series of 4WD dirt road proceeding west from Rhyolite, north past Bullfrog Mountain to Sarcobatus Flat, and west to Phinney Canyon. Travel time from Beatty to Phinney Canyon is between 1-1/4 to 2 hr. Air access is not restricted.

Portions of the lower Phinney Canyon appear to be rather analogous to the washes at YM, especially two stretches of south-facing slope and at least one stretch of north-facing slope between the elevations of 6,000 and 6,600 ft. In these areas, the tuff is densely welded, with shards exhibiting the characteristic clinkstone clatter. Fracture patterns are quite reminiscent of densely welded TCw sideslopes, as best as can be ascertained from outcrop observations.

Soils were also quite reminiscent of the YM washes, with similar sizes and percentages of rock shards, although the soils may be somewhat thicker.

A small snowmelt stream on the southfacing side of the canyon was located along a small fault, forming a waterfall. Under the waterfall, a cave was hollowed out to perhaps 2-m depth. Dripping from ceiling fractures was observed at numerous locations within the cave, apparently arising from stream infiltration several meters above.

The vegetation was somewhat anomalous in the lower portions of Phinney Canyon. Typically, juniper is observed at lower elevations than piñon, but in Phinney Canyon juniper was much sparser at the lower elevations than was piñon. Juniper was primarily observed on sideslopes, with thin soils. Piñon was quite dense in the wash bottom, reaching several meters in height.

The roadway was impassable due to snow at roughly 6,200 ft elevation. Drifts were as deep as 1 m at higher elevations, although deep depressions in the snow cover were formed at the base of most plants.

The Phinney Canyon site appears to be an excellent analog to YM washes, certainly the best of any site examined. Fractures may be slightly further apart than at YM, and soils may be somewhat thicker, but overall the site is highly recommended.

Rainier Mesa

Rainier Mesa, in the north-central portion of the NTS, rises to an elevation of roughly 7,000 ft. Rainier Mesa is topped with a moderately welded tuff caprock quite reminiscent of Yucca Crest with more boulders. Estimates of fluxes into the N-tunnel drifts provide information on net infiltration at Rainier Mesa, which can be used to calibrate infiltration models. Access to Rainier Mesa is by paved road, although camping at the site is unlikely to be allowed so that roughly 3 hr of driving will be required each day. Also, air access is strictly controlled and it may not be possible to obtain the aerial photographs required to quantify vegetation densities.

A carpet of snow up to 1/2 m thick covered the top of Rainier Mesa, closing the road and limiting observational opportunity. It appears that soils are similar to Yucca Crest, albeit with much greater organic content. Piñon, juniper, and mountain oak were found on the mesa caprock.

Long slopes extend from the mesa caprock to the valleys below, featuring hundreds of meters of densely welded through nonwelded tuffs. These slopes are reminiscent of the portions of the western flank of YM that lie above the Paintbrush Tuff nonwelded (PTn) outcrop. Densely welded tuffs, visible in road cuts, appear to be almost identical to the densely welded portions of the TCw tuff. These slopes may serve as an analog to the Solitario Canyon side of YM, although the lack of gully formation limits the analogy to Topopah Spring welded (TSw) exposures at YM. The slopes may also serve as an analog to the washes, but may suffer from the lack of a wash bottom collecting water. Perhaps the contrast between Rainier Mesa slopes and Phinney Canyon slopes may provide insight into lateral flow processes in the washes.

Conditions are currently very moist on the NTS. Yucca Lake is currently full to beyond the playa dimensions, and the alluvium at various locations on the Test Site is essentially saturated.

Problems encountered

None.

Pending actions

None.

Recommendations

Use the Phinney Canyon site for an analog to the YM washes, concentrating resources into evaluating the relatively poorly characterized sideslope environments. The Phinney Canyon studies should receive the highest priority for fieldwork. Analysis of aerial photography should be the primary study tool for the remaining sites, with limited ground confirmation of aerial observations. As much use should be made of aerial observations as is possible, as data acquisition is relatively fast, informative, and inexpensive.

Attachments

Annotated photographs of the potential analog sites examined during the trip were attached to the trip report. These are not included here.

Trip 10: Extract from scientific notebook #163 by S. Stothoff, available in ADAMS (ML040690351). The original entry was dated 5/21/98 (pages 2-63 to 2-68). The text was not edited; footnotes were not in the original text, and were added for explanation. This section of the notebook reproduces a trip report from a consultant to CNWRA as captured in a scientific notebook. Detailed observations from this trip are recorded in pages 56–67 of field notebook 175 (S. Stothoff), available in ADAMS (ML043630294), pages 38–88 of field notebook 255 (R. Fedors), available in ADAMS (ML040650582), and pages 6–31 of Scientific Notebook #268 (D. Groeneveld), available on ADAMS (ML040530130). Notebooks 175 and 255 contain soil depth measurements and related observations at both Yucca Mountain and (in pages 63–70 of notebook 255) Phinney Canyon; notebook 268 contains observations related to vegetation and a second summary of activities.

5/21/98 Trip report

The following is an excerpt from my trip report to Yucca Mountain (YM) from the period of May 13 through 18, 1998, in which characterization fieldwork was performed. My field documentation for the trip is in CNWRA notebook 175.

Persons Present

The trip to Yucca Mountain (YM) and Phinney Canyon (PC) (a potential climate-analog site), on May 13 through 18, 1998, was undertaken by R. Fedors (CNWRA) and consultants S. Stothoff, D. Groeneveld, D. Or, D. Woolhiser, and O. Chadwick.

Background and Purpose of Trip

CNWRA is working with S. Stothoff to refine model estimates of mean annual infiltration (MAI) over the repository performance period. The modeling to date has considered one-dimensional (1D) simulations of coupled heat and moisture transport, with the results of the simulations abstracted to grid blocks covering the repository footprint. The approach is limited by neglect of lateral flow, transpiration, soil genesis, and snow dynamics. The other consultants were retained to help refine the infiltration model to incorporate these processes appropriately. O. Chadwick provides expertise in soil genesis processes. D. Groeneveld provides expertise in Great Basin plant ecology. D. Or provides expertise in soil physics and field-measurement techniques. D. Woolhiser provides expertise in watershed modeling in the arid southwest.

Split Wash is strategically located above the path that the east-west exploratory drift is following. D. Woolhiser will be performing watershed-scale modeling for the north branch of Split Wash, and D. Or will be performing hillslope-scale modeling. These newly initiated activities require data on soil depth and other factors affecting overland flow and interflow, and are intended to consider both current and potential future climatic conditions. Much of the data collected on the trip is intended to feed these activities.

S. Stothoff, D. Groeneveld, and D. Or are attempting to characterize the impact of vegetation upon MAI over the next glacial cycle. Transpiration is a process included in DOE models but not considered in CNWRA modeling efforts to date. The intent of the CNWRA work is to incorporate vegetation into infiltration-modeling efforts in a plausible and defensible manner. The trip was inspired by the need for field-checking hypothesized relationships between vegetation and bedrock type, soil cover, slope, and solar loading.

Soil depth and composition are significant factors influencing infiltration over the period of repository performance. Although soil depth and composition at YM are reasonably well understood under current conditions, significant changes in these factors may occur as climatic conditions change. O. Chadwick was retained for his expertise in soil genesis, with the anticipation that he may be able to identify likely past and future soil conditions. The field trip served as Chadwick's orientation to YM, with the trip to PC serving as an orientation to a site with climatic conditions similar to postulated future conditions at YM.

Summary of Activities

The fieldwork at YM was split into the following activities, performed primarily within Split Wash: (i) vegetation transects verifying the more-detailed TRW vegetation work and examining factors governing the distribution of individual species (D. Groeneveld and S. Stothoff); (ii) permeability measurements to characterize bedrock-fracture and soil properties (D. Or and R. Fedors), (iii) channel-characteristic measurements for the upper portions of Split Wash (D. Or and S. Stothoff), (iv) alluvial-terrace measurements (D. Or, D. Groeneveld, and S. Stothoff), (v) soil depth and composition measurements (O. Chadwick and R. Fedors), and (vi) field identification of potential infiltration hotspots in upper washes (S. Stothoff).

The fieldwork during the one-day trip to PC was split into the following activities: (i) orientation to the site (new to all but Stothoff), (ii) identification of vegetation study locations, and (iii) examination of soil characteristics.

Overall Impressions

The trip was extremely useful in orienting Chadwick to the YM site and in identifying and refining hypotheses regarding the soil depths and genesis processes. Soil and vegetation measurements taken during field activities will provide direct input into modeling activities. The trip was also useful in planning future activities with Chadwick, Groeneveld, Or, Stothoff, and Woolhiser.

Soil Genesis Interpretations Based on Field Observations

Significant insight was gained into the depth and composition of soils that might be expected over a glacial cycle at YM, both based on observations at YM (primarily in Split Wash) and at PC. The selection of Split Wash as a study location was fortuitous, as Split Wash may have the best-preserved deep alluvial terraces of all washes above the repository footprint. The stream channel has cut the terraces as much as 20 m to reach bedrock. In other washes, clearcut traces of deeper soils are not evident, having been nearly obliterated by erosion, but colluvial lobes along the sideslope toes are suggestive of soils that were deeper by up to 1 m. Similar erosional activities have been observed across the arid southwest that are dated to 8 to 15 ka, coincident with removal of vegetation as the climate became warmer and drier following the last peak in glaciation. The soils now present across YM are predominantly æolian in origin, and are relatively shallow and unweathered. At PC (roughly 700 m higher than Yucca Crest), on the other hand, soils are deeper, moister, more weathered, and have greater organic content.

Yucca Mountain soils are typically sandy loams in texture, while Phinney Canyon soils are more characteristic of silty loams. Simulations using the 1D BREATH code have been performed using properties similar to sandy loams and silty loams, allowing MAI to be roughly compared for YM and PC. The simulations predict that MAI may increase by 1 to 1.5 orders of magnitude as climatic change proceeds, if the soils are characteristic of those presently at YM. However,

assuming that soil increases in depth from 25 to 50 cm, rock fragments decrease from 50 percent to 33 percent by volume, and the fine component changes from a sandy loam to a silty loam, predicted MAI is approximately 2.5 orders of magnitude smaller at PC for the current climatic conditions. Most of the decrease is due to the textural change of the soil. It would be expected that the PC soils are more sensitive to changing climate than the YM soils, but even so the predicted net effect would almost certainly be a reduction in MAI. The predicted decrease in MAI does not account for vegetation, lateral flow, or snow dynamics. Due to the colder winter temperatures, substantial snow cover may develop and the ground may freeze. These effects would dramatically change the dynamics of recharge during the winter and spring and would likely substantially increase MAI.

The potentially significant impact on MAI of changing soil texture and depth points out the importance of soil genesis characterization. Without observations of remnant soils similar to those at PC, however, the existence of soil change is arguable. Buried soils similar to those at PC were observed at three locations, once on the ridgetop separating the uppermost forks of the north branch of Split Wash and twice on the caprock upgradient of Split Wash. These soil-texture observations are extremely suggestive that textural changes might be expected over a glacial cycle at YM, and these textural changes would be expected to reduce MAI. The rapidity of the textural changes is open to question, as it takes extended periods of time to weather sands into clays.

The rapidity of soil depth changes is also quite uncertain. Erosive tendencies vary with available moisture, with erosion occurring slowly when little moisture is available. Erosion increases with available moisture, but so does vegetation, until a point is reached where the increased stabilizing presence of vegetation counteracts the destabilizing influence of erosion. One would expect that changes in soil depth might respond exponentially to changes in climate, with rapid change decaying into a stable system. Soil texture also responds exponentially, but over a longer time span.

If the observations regarding soil depth and texture changes are correct, one might expect that MAI would increase relatively quickly as conditions become cooler and wetter, then would gradually decrease as transpiration increases, soil depths increase and soil textures become finer. As conditions become warmer and drier after the glacial maximum, one would expect that MAI might respond to shallower soils quickly but relatively slowly change due to textural change.

During the field work, enhancements to the existing CNWRA model for soil depth genesis were discussed. These enhancements would be intended to examine potential rates of soil depth and soil texture change at YM. The current model considers one generic soil in equilibrium with the environment, with soil generated through weathering and moving due to creep and ephemeral streamflow. Potential enhancements would include time stepping, several soil-article sizes, an æolian source of dust, and chemical weathering.

Observations of Potential MAI Hotspots

The remnant channel terraces in Split Wash are not the only anomalous feature of the watershed. The northern branch of Split Wash terminates with a small channel fork. The southern of the two channels is choked with talus and alluvium, and there is no sign of stream activity for several hundred meters. Evidence of streamflow is present above the area choked with alluvium. The Tcpmn unit (middle nonlithophysal unit of the Tiva Canyon formation) crops out along the walls in areas with gaping fractures and talus. In this area, the rocks appear to be

washed clean of dust and fractures tend not to have carbonate fillings. The vegetation in this area is particularly dense.

The combination of copious talus, nonexistent channel flow, gaping fractures, and dense vegetation are all factors suggesting that substantial infiltration may occur in this portion of the watershed. A total area of roughly 10^4 m^2 might be classified as a potential infiltration hot spot. Interestingly, the east-west drift currently under construction will pass close to this wash. If the drift passes under the wash, it would not be surprising to find that *in situ* water fluxes are much larger than elsewhere in the repository footprint.[9]

The observation that this particular wash area appears to be an infiltration hot spot while nearby washes do not appear to have such overt infiltration potential engendered lively discussion of the features that infiltration hotspots might exhibit. The existence of talus slopes is an obvious indicator, as evaporation is greatly reduced by talus. The presence of gaping fractures, particularly with minimal carbonate filling, is another indicator. Both talus and gaping fractures can be linked to the particular rock type cropping out. Densely welded units tend to form talus, as erosion removes blocks along fracture planes rather than removing grain by grain. The lithophysal units have fewer and finer fractures than nonlithophysal units, as the presence of lithophysae during cooling relieves some of the strain that forms cooling joints. Lithophysal units tend to spall, forming plate-like talus, while the nonlithophysal units tend to form bulkier talus. The lithophysal talus appears to be somewhat less resistant to further breakdown than the nonlithophysal units. Accordingly, locations with nonlithophysal units cropping out provide a heuristic indicator for both gaping fractures and talus, which are both strong indicators for high infiltration.

S. Stothoff examined eight of the sixteen upper-wash channels between Highway Ridge and Antler Ridge, all of which feature Tcpmn outcrops, to see if they also have other features indicative of high infiltration. Two of the washes, the Split Wash fork already mentioned and the north branch of WT-2 Wash (just south of Whaleback Ridge), appear to have notable high-infiltration areas while the remaining washes appear to be more typical. The WT-2 Wash area shares with Split Wash the characteristics of no recent runoff, copious talus, gaping fractures, dense vegetation, and minimal fracture fillings (at least near the bedrock surface). The nonlithophysal-unit outcrop areas in all of these washes appear to be generally more conducive to infiltration than the lithophysal areas, but the potential for infiltration is mitigated in many of the washes by limited outcrop area, shallow channel slopes, or shallow sideslopes.

In general, talus was more common on north-facing slopes and exposed bedrock fractures were more common on south-facing slopes. Densely welded nonlithophysal units in the examined washes rarely had exposed bedrock in the actual channel, while the lithophysal units often exposed channel bedrock for significant portions of the upper wash.

With the notion that deeper soils are indicators of reduced MAI, due to increased storage and opportunity for evapotranspiration, clues regarding soil depth during glacial periods were also sought during the infiltration hotspot survey. Many of the washes featured concave-down slopes to the channel, which indicates that the most recent activity has been degradational. Colluvial lobes are apparent along many of the washes, suggestive that deeper soils may have existed in the past. If these washes become aggradational in the future, it would be expected that the deeper covers would reduce MAI and thereby reduce the hotspot activity.

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[9] The east-west cross drift passes under the north fork of the northern branch of Split Wash, and does come within 200 m of passing under the area discussed.

Trip 10 (continued): Comments and summary of observations from pages 63–68 of field notebook 255 (R. Fedors), available in ADAMS (ML040650582). This summary provides information regarding the Phinney Canyon portion of the trip that is not contained in the summary trip report excerpted from Scientific Notebook #163.

Grapevine Mtn (Phinney Canyon)

36° 37' 07 N
117° 06' 51 W
+/- 100m
7043 ft elev +/-

Mid-slope 27° hillslope – south-facing slope

Road marginally drivable due to runoff

Stream in channel; origin is from seep on north facing slope but also has contributions from small north-facing drainage channels. Seep may be indicative of bedrock focusing of lateral subsurface flow in these otherwise broad slopes.

South-facing slope is a Sp, soil w/pavement w/o much vegetation between clumps & large plants (pinon/juniper).

The following table summarizes information from scientific notebook #255 but is not part of the scientific notebook. Six soil pits were dug, 3 on a south-facing slope and 3 on the opposing north-facing slope. Each set of three formed a downslope transect starting 25 m below the ridge top; pits were separated by 25 m. Observations are summarized in the following table:

Transect	Distance from ridge (m)	ID	Soil depth (cm)	Notes
South	20	PHA2	60 (to rubble)	fine sandy loam and loam
South	45	PHA1	55 (to rubble)	sandy loam and loam; clay translocation
South	70	PHA3	78 (to rubble)	sandy loam, loam, and clay loam
North	25	PHB1	90	sandy loam, loam, and clay loam
North	50	PHB2	70+	sandy loam and loam
North	75	PHB3	85+	sandy loam, loam, and clay loam

Trip 11: Copy of a trip report by R. Fedors, D. Groeneveld, and S. Stothoff, available in ADAMS (ML993140104). The text was not edited. Images were reproduced from the scanned records of the trip report, which has comparable quality.

SUBJECT: Field Work in Southern Nevada on Future Infiltration Analog Sites (20.01402.861)

DATE/PLACE: October 3-6, 1999
Rainier Mesa, Kawich Range, and Timber Mountain, NV

AUTHORS R. Fedors, D. Groeneveld, and Stuart Stothoff

PERSONS PRESENT:

The field trip to three watersheds in southern Nevada on October 3-6, 1999 was undertaken by Jeff Ciocco (Nuclear Regulatory Commission), Randy Fedors [Center for Nuclear Waste Regulatory Analyses (CNWRA)], David Groeneveld (consultant, Natural Resources, Inc.), and Stuart Stothoff (consultant, Stothoff Environmental Modeling). The three watersheds are under consideration as possible analogs for Yucca Mountain (YM) under pluvial conditions.

BACKGROUND AND PURPOSE OF TRIP:

CNWRA is working with S. Stothoff and D. Groeneveld to estimate shallow infiltration under future climatic conditions at YM. The current model for unsaturated flow at YM translates shallow infiltration directly into percolation at the repository horizon. An important component of the CNWRA work is to incorporate the effect of vegetation into the shallow infiltration modeling effort since the expected change in vegetation density and type will have a significant effect on the infiltration estimates. Current field efforts are focused on identifying the relationships between soil cover depths, bedrock type, vegetation, and slope orientation with infiltration under cooler and wetter climate conditions.

A number of sites are being considered as analogs for YM under cooler and wetter pluvial conditions. Since temperature decreases and precipitation increases with elevation, sites at higher elevations in southern Nevada with similar type bedrock (fractured, moderately to densely welded, rhyolitic tuffs) have been considered. Phinney Canyon on the east slope of the Grapevine Range and Shoshone Mountain on the Nevada Test Site northeast of YM (figure 1) have been determined to be reasonable analog sites. As no site is likely to be a perfect analog to YM under a range of pluvial conditions, multiple analog sites are needed to establish trends; 2 or 3 more sites were deemed to be necessary for the analysis. Previous scoping work indicated that Rainier Mesa and Timber Mountain may be reasonable analog sites for YM under pluvial conditions (Stothoff, 1998); the previous field work at these sites was completed under snowy conditions. In addition, the 3-Springs Basin in the Kawich Range is considered a potential analog site for YM by the U.S. Geological Survey (Lichty and McKinley, 1995) who studied the surface water hydrology and estimated recharge for the 3-Springs Basin from 1986 to 1994. At least 1 of the 2 meteorological stations is still in place, although it is unknown whether data are still being collected. Surface hydrology and recharge have also been studied at Rainier Mesa, which, along with the 3-Springs Basin, offers an excellent opportunity to both constrain and validate the shallow infiltration model. The general locations of Rainier Mesa, Kawich Range, and Timber Mountain are shown in figure 1.

SUMMARY OF PERTINENT POINTS:

SUMMARY OF ACTIVITIES:

The primary activity of this field work was to assess soil and bedrock features of three possible infiltration analog sites for YM under pluvial conditions. The first site, Rainier Mesa, is in Area 12 of the Nevada Test Site. Permission for access was arranged by Jade Woodruff of the Field Operation Center who also provided escort since general employee radiation training is now required for at least one member of the party for access to Rainier and Pahute Mesas. The second site is a watershed called 3-Springs Basin in the Kawich Range north of Nellis Air Force Range. The third site is located on Timber Mountain, north of Hiko, NV. Note that this latter site is not the same as the Timber Mountain located between YM and Pahute Mesa.

Cooler and wetter conditions occur with increases in elevation. The YM crest is at about 1500 m msl, Rainier Mesa is at 2250 m msl, Timber Mountain ranges from 1950 to 2600 m msl, and 3-Springs Basin ranges from 2150 to 2900 m msl. 3-Springs Basin, with an annual average temperature of about 8 °C, is comparable to the predicted full glacial climate of YM where the temperature is expected to decrease about 10 °C from the current average of about 17 °C. Mean annual precipitation at 3 Springs Basin was 336 mm/yr over the period studied, compared to a mean annual precipitation of about 160 mm/yr at YM. Precipitation is expected to at least double at YM in portions of the glacial cycle, although maximal increase may not occur at full glacial maximum; precipitation seasonality may also change as the position of the jet stream is affected by continental ice sheets.

The analog sites can be viewed from the perspective of YM hydrologic environments. The two environments of interest are the caprock (moderately welded, massive tuff with a gentle easterly slope and surficial covers thicknesses ranging from 0 to 60 cm) and hillslope (north- and south-facing slopes of about 30 degrees, densely welded and highly fractured tuff bedrock, and with surficial covers thicknesses ranging from 0 to 40 cm). Based on the field observations, Rainier Mesa and Timber Mountain are similar to the caprock environment and 3-Springs Basin has similarities to both the caprock and hillslope environments at YM.

Rainier Mesa

Studies of infiltration and percolation by Russell et al. (1987) and Wang et al. (1993) using both watershed and tunnel measurements indicate an average percolation of 23.7±8 mm/yr at Rainier Mesa. The tunnels were constructed for bomb tests; the N tunnel is marked on figure 2, the adits for G and E tunnels are located further south along the mesa's eastern hillslope. Their work also indicated that the geologic section at Rainier Mesa, though similar, differed from that of YM by the thickness of nonwelded relative to densely welded tuffs. The moderately welded caprock of Rainier Mesa, however, is similar to the caprock at YM based on observations during this trip and the earlier trip by Stothoff (1998).

Rocks weathered in situ on the mesa top are rounded and have created numerous pans that appear to lack drainage, suggesting that all or most of the incident water either infiltrates or is rapidly used up through evapotranspiration since no evidence of ponding was noted. Hence, infiltration must be relatively rapid. To evaluate the infiltration capability, soils and drainage features were examined. Like soils on Yucca Mountain, Rainier Mesa soils are mostly eolian-derived matrix, a sandy loam texture, with abundant rock fragments. On top of the mesa, the soil cover varied from 0 to greater than 60 cm thick based on qualitative observation and a few shallow holes. On hillslopes, soil thicknesses were found to be generally about 30 cm. In

order to qualitatively assess runoff/infiltration relationships, the main drainage that crosses Rainier Mesa from SW to NE was examined to determine whether it carries high flows. This examination was not conclusive partially because rill erosion and gullying indicated that significant storm discharge enters the dry streambed down bulldozer cuts that apparently provided corridors for laying various air, electric and seismic lines for the previous activities related to nuclear testing. Such disturbances were found throughout the area examined. The absence of these disturbances and the associated compaction would likely reduce runoff significantly, and hence increase infiltration and/or evapotranspiration, under the present-day climate. The likelihood of bomb-induced fracturing of the rock leading to increases in percolation to the tunnels has not been thoroughly described in the literature but is considered a possibility.

On Yucca Mountain, near-surface fissures are commonly partially to fully filled with caliche that acts to reduce permeability. Rainier Mesa, as an analog for a cold and wet climate at Yucca Mountain, might be expected to have less calcite filling than the near-surface fractures due to the greater infiltration rate flushing any calcite that may have precipitated in the fractures between precipitation events. The presence or absence of caliche under these conditions is highly relevant. The presence of caliche was examined at a number of geographic features. A level depression that appeared to lack drainage in the manner described above was excavated. The soil overlying the rock was about 8 cm deep. Several fissures were excavated to 6-8 cm to examine the filling material. No calcite was noted and the soil in the cracks was much richer in clay than the overlying soil, suggesting downward transport. Fine roots of bluegrass (*Poa sandbergii*) penetrated into the soil of the crack. Another location, where the rock was exposed by a road cut servicing a drill pad, was examined for calcite fillings within fissures; no calcite fillings were noted. The gently sloping (about 5-10%) road surface appeared to have up to several centimeters of rock material skived off by a bulldozer during construction.

Calcite (assumed to be the primary mineral of caliche) was noted in two types of locations. The first of these was fairly ubiquitous on large clasts removed where road surfaces crossed soil of sufficient thickness: lower surfaces were coated with a light rime of calcite (ca. 1 mm, or less). The other example was noted where excavation of a drill pad had cut into a relatively resistant rock outcrop. Here, calcite was noted on an overhanging wall of a fissure whose adjoining rock surface had been removed. This calcite rime was obviously undergoing dissolution and it was uncertain (though improbable) that the rime was dissolving while in situ prior to disturbance. Thus, it appears that under past and present climatic regimes of Rainier Mesa, infiltration rates have been sufficiently high as to leach calcium from the soil matrix. Apparently, only under special circumstances, where infiltration would be absent but a wetted rime would seep and the fluid trapped by gravity, could calcite form. An interesting and possibly definitive answer could be determined by whether calcite fillings exists within the rock penetrated by the tunnels into Rainier Mesa. Further confirmation is necessary.

The vegetation observed on Rainier Mesa consisted of single-leaf pine (*Pinus monophylla*), Utah juniper (*J. ostesperma*), Gambel oak (*Quercus gambelli*), big sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), an unknown species of rhizomatous, xeric sedge (*Carex* sp.), sticky rabbitbrush (*Chrsysothanmus viscidiflorus*), needle-leaf rabbitbrush (*C. teretifolius*), rubber rabbitbrush (*C. nauseosus*), a long-spined species of cactus (*Opuntia* sp.) and three-awn grass (*Aristida fendleri*). Very striking examples of both pine and juniper trees were observed growing out of rock fissures with little or no soil. The pines and junipers were both in heavy fruit. *Bromus tectorum* was noted in several patches of very heavy cover and in isolated plants within the scrubby forest vegetation. Such isolated plants have the potential for spread and dominance in the event of a forest fire.

The availability of low altitude air photos of the mesa was discussed with Jade Woodruff. Previous efforts to obtain photographs through DOE and their contractors in Las Vegas have not been successful. Onsite staff were contacted and will determine if any air photos are available. The air photographs would be used for efficient, quantitative assessment of the vegetation density.

3-Springs Basin in the Kawich Range

Based on the geologic mapping of Gardner et al. (1980) and the hydrologic studies of Lichty and McKinley (1995), the 3-Springs Basin was a prime candidate as a full glacial analog site for YM. Using chloride mass balance, recharge for the basin was estimated to be 32.8 mm/yr over the period of streamflow and meteorological measurements (Lichty and McKinley, 1995). The annual precipitation was 336 mm/yr over this period. Estimates of recharge using other methods led to values of 11.4 (numerical simulation) and 166 mm/yr (index-site extrapolation). Estimates of shallow infiltration at YM range from 1 to 10 mm/yr with a precipitation average of about 160 mm/yr.

The basin is located on east side of the Kawich Range and is the more southern of two basins that are nearly identical in size, lithology and physiognomy. The 3-Springs Basin begins on the flank of Kawich Peak while the neighboring basin to the north begins on the flank of an unnamed peak about ½ mile north-northeast of Kawich Peak (figure 3). Access to the site is a spur off the main dirt road traversing Reveille Valley. The confluence of the 2 basins was accessible using a 4-wheel drive vehicle on roads probably improved for the USGS work on the basin within the last decade.

Comparison of the pair of basins draining off of Kawich Peak is interesting. Although of approximately the same size, lithology and slope, the floor of 3-Springs Basin is covered by nearly continuous riparian vegetation while the neighboring basin to the north has comparatively little riparian cover in a spotty distribution (figures 4 and 5). The difference in riparian vegetation likely leads to differences in runoff and infiltration. Discovering the reason for this discrepancy would require further work, though it is presently considered unnecessary; the difference should be noted as caution on sampling bias.

The party hiked into the approximate center of the basin; the going was difficult. Although the floor of the valley has sufficient room to permit walking on mostly level ground, this was choked with thick riparian vegetation that prevented passage. The hillslopes above the drainage bottom were also difficult hiking because of the presence of deadfall, jutting rock outcrops, and loose soil. The difficulty is such that merely going about 1 mile upstream required about 2.5 hours. Because of this difficulty, the upper portions of the basin (an additional 2 miles) were not explored.

The bedrock lithology consisted of rhyolitic tuffs (Gardner et al., 1980), though the quality of the geologic map (available at Los Alamos National Laboratory only as a scanned pdf formatted file) made it difficult to determine geologic contacts in the basin. It appears that two units cover the basin. The Tkr intracauldron tuffs of Kawich Peak were described as gray, crystal-rich rhyodacitic welded ashflow tuffs with a pronounced streaked appearance and a maximum thickness of 250 m. The Tkt, older than the Tkr, consisted of densely welded to nonwelded rhyolitic ashflow tuffs with a maximum thickness of 1000 m. The Tkt tuffs were from within the Kawich caldera thus containing massive layers with large clasts of various rock types and layers of brecciated flows. The Tkt varied from massive to laminated and fissile. Jointing was prominent in the jutting outcrops, but an overall difference of fracture characteristics as

compared to YM units was not evident. The tuffs generally contained larger and more abundant crystals than the tuffs at Yucca Mountain where the ashflow units are always matrix supported when crystals are present. The abundance of crystals in the tuffs led to a different outcrop weathering morphology with the grains readily weathering out of the rock, suggesting hydrologic action: freeze-thaw, leaching and solution effects. The shape of the outcrops is as a series of rounded spires which jut upward from the surrounding slopes as seen in figures 6, 7, and 8.

Soils noted in shallow pits were essentially weathered bedrock with little or no secondary development. The soil matrix appeared primarily to be a fine sandy loam derived through eolian processes. Some of pits dug on hillslopes exposed a regolith at the soil bedrock contact, which may be a relic from wetter climates or may be reflective of present-day chemical degradation during wetter periods of the year; presently, the regolith was too dry for chemical weathering to be significant. Locally, mats of organic-rich layers interspersed with the fine sandy loam soil surrounded stable vegetation (trees) on the hillslopes. As at Rainier Mesa, trees were seen to grow within rock fissures. An example of root growth by a tree observed in 3-Springs Basin causing significant displacement of rock (3-10 cm) is shown in figure 10.

Vegetation on the uplands consisted of single-leaf pine and Utah juniper with big sagebrush, bitterbrush, mountain mahogany (*Cercocarpus ledifolius*), snowberry (*Symphoricarpos* sp.), and a bunch-forming bluegrass (*Poa sandbergii*). As at Rainier Mesa, pines and junipers were both in heavy fruit on the flats or north aspects but lesser on droughty south-facing slopes. Gambel oak was present but confined to occasional plants on the north-facing slope of the drainage. *Bromus tectorum* achieved very heavy cover in open locations within the bottomland and was present as single plants within the matrix of forest cover on the adjoining slopes. From observations made from the air, the upper portions of 3-Springs Basin (above 8800 feet elevation) contain limber pine (*Pinus flexilis*) on exposed ridges and otherwise almost a continuous cover of mountain mahogany.

The woody riparian species consisted of narrow-leaf cottonwood (*Populus angustifolia*), wild rose (*Rosa woodsii*), sandbar willow (*Salix exigua*) and arroyo willow (*S. lasiolepis*), serviceberry (*Amelanchier alnifolia*), and chokecherry (*Prunus virginiana*). A panorama of the vegetated valley bottom is shown in figure 8. Two seep areas, were noted in the bottomland, one of these with a trickle that was not measurable and one that apparently runs early in the year. No flow was seen in the main channel which was moist only near the springs. The seep containing water is shown in figure 9. The soils around the springs appeared to contain significant amounts of clay, absent in all other locations, suggesting secondary mineral formation that would indicate that these springs are relatively ancient.

Timber Mountain

Timber Mountain was accessed by a jeep trail that penetrates into the main drainage on the south flank, just east of the highest peak. The same area was visited earlier (Stothoff, 1998), though the previous visit was in the spring when snow was covering much of the ground. A description of the bedrock lithology published du Bray et al. (1987) was summarized by Stothoff (1998) who, based on field observation, noted the similarity in the jointing patterns between Timber Mountain and YM. The abundance of crystals in the moderately welded units and the presence of nonwelded units has led to a rounded outcrop weathering morphology (figure 11) that was more prominent than that seen at 3-Springs Basin; the weathering of the crystals and matrix was pervasive through large pieces of rock removed from outcrop suggesting a high imbibition of water into the rock. Where soil layers were present, the weathering of the tuffs also led to a soil comprised of an in situ mechanically weathered component along with the probable

eolian component. There is no evidence that in situ weathering of the bedrock forms a component of the soil at YM.

Large amounts of bare rock were noted that must give rise to overland flow that then may infiltrate into the fissures or focus flow into runoff channels. The major stream draining this region was examined. It appeared to be ditch that at times carries very high flows of short duration. No riparian vegetation was noted in the main drainage valley bottom. By contrast, however, the upland vegetation included serviceberry which was only found in association with the riparian vegetation in 3-Springs Basin. Thus, significant water must enter and be retained by fissures.

Other than the occasional serviceberry, the vegetation consisted almost entirely of single leaf pine and Utah juniper, an occasional yellow composite perennial (Genus unknown) with a smattering of senesced forbs, chiefly a mustard (probably *Streptanthus*) and a species of locoweed (*Oxytropis*). Both pines and junipers were in heavy fruit. Again, trees were noted to be growing out of rock fissures without benefit of soil overlying the rock faces (figure 11). These trees, chiefly single-leaf pine, were of moderate stature at maturity (ca. 14-16 feet tall). Water from the matrix likely helps to support the trees growing in the fissures; the matrix appeared to have a greater porosity and permeability than the moderately welded units of the caprock at YM.

CONCLUSIONS:

Based on the field observations, all three sites will be used to some extent as analogs to YM under future climates. Rainier Mesa and Timber Mountain are similar to the caprock environment and 3-Springs Basin has similarities to both the caprock and hillslope environments at YM. Hydrologic studies relevant to shallow infiltration have published for Rainier Mesa and 3-Springs Basin.

All analog sites exhibit some differences with YM. Bedrock lithologies at Timber Mountain and 3-Springs Basin differed from those at YM by the greater abundance and larger size of crystals, which led to a different outcrop morphology when weathered. The 3-Springs Basin has steeper hillslopes than the east flank of YM. The hydrologic pathways at Rainier Mesa may have been modified by bomb blasts and the associated man-made surface disturbances.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

None.

REFERENCES:

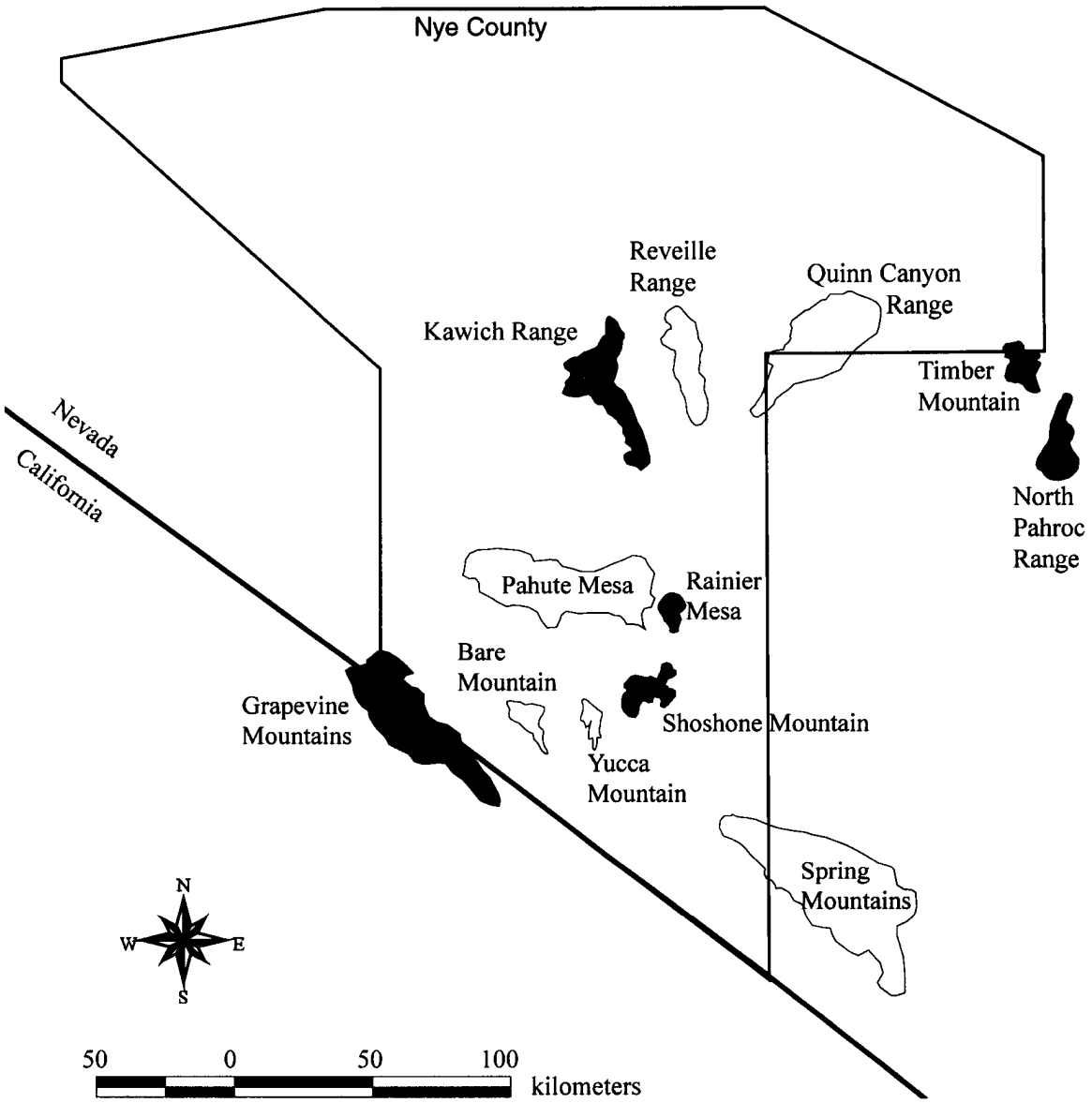

Figure 1. Analog sites (shaded) for Yucca Mountain under cooler and wetter climatic conditions along with other geographic reference features

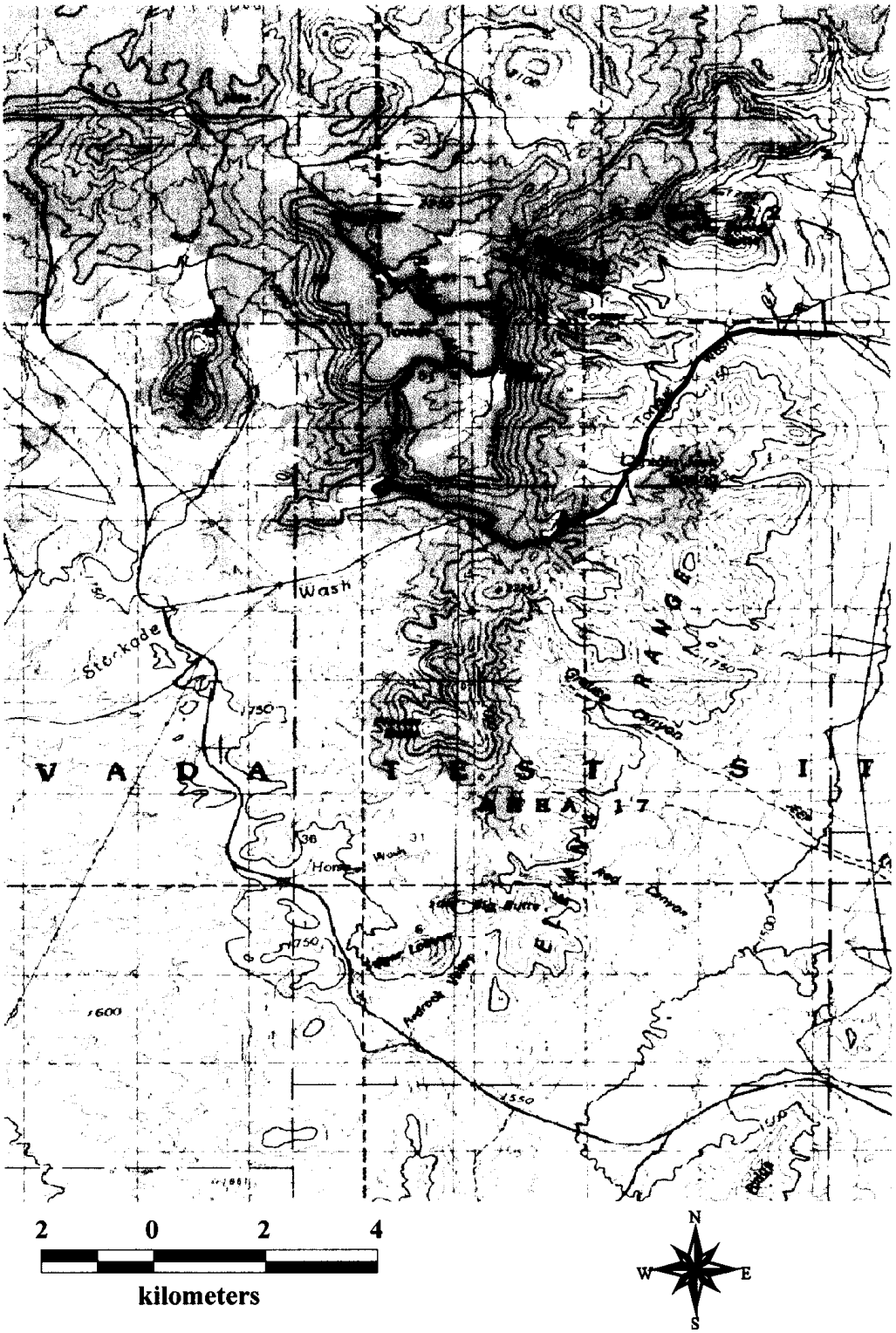

Figure 2. Portion of topographic map (contour interval 50 m) surrounding Rainier Mesa with access road and N Tunnel highlighted

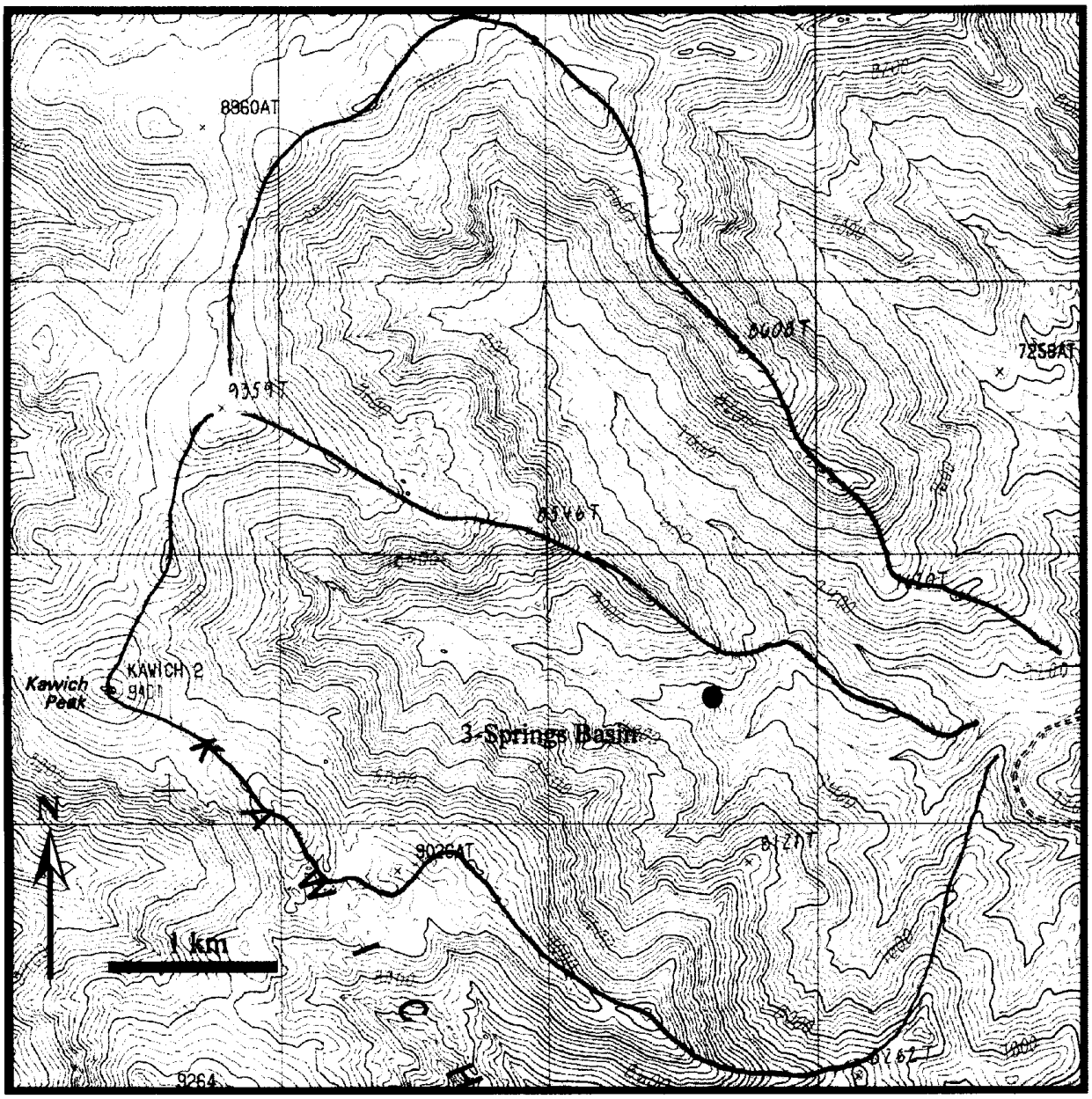

Figure 3. The watersheds of the 3-Springs Basin east of Kawich Peak and the neighboring basin to the north outlined on a portion of the Kawich Peak 7.5 min topographic quadrangle map (contour interval of 40 ft). The dot shown on the map is the farthest point reached upstream during this trip.

Figure 4. Upper 3-Springs Basin showing relatively continuous riparian vegetation. The haze in this air photograph, and in figures 5 and 6, is probably caused by large fires in northern New Mexico.

Figure 5. Neighboring basin to north of 3-Springs Basin, upper portion showing relative lack of riparian vegetation.

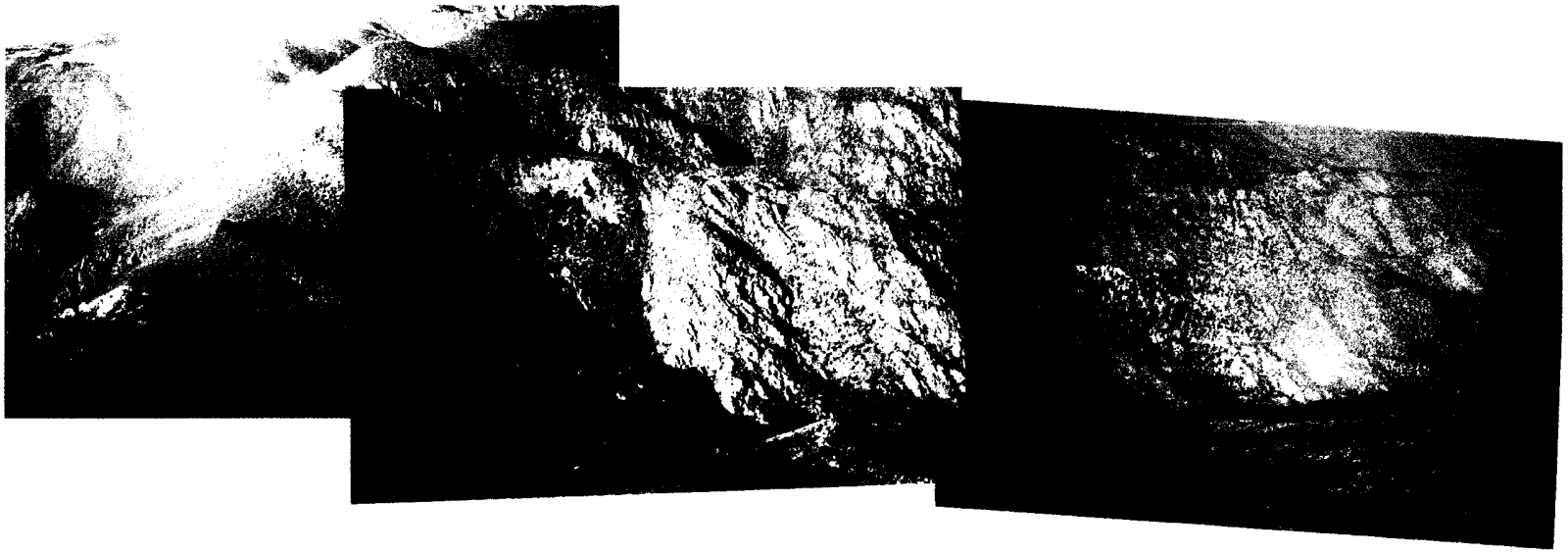

Figure 6. Air photo panoramic view showing 3-Springs Basin in the foreground with Twin Basin visible one ridge over. Note the large jointing pattern and exposed spire-like rock outcrops.

Figure 7. Panoramic view taken from the ridge separating 3-Springs Basin to the left and the neighboring basin to the north (right). Note the ripe seed-bearing cones on the single leaf pine in the foreground and the similarity of slope and lithology between the two basins.

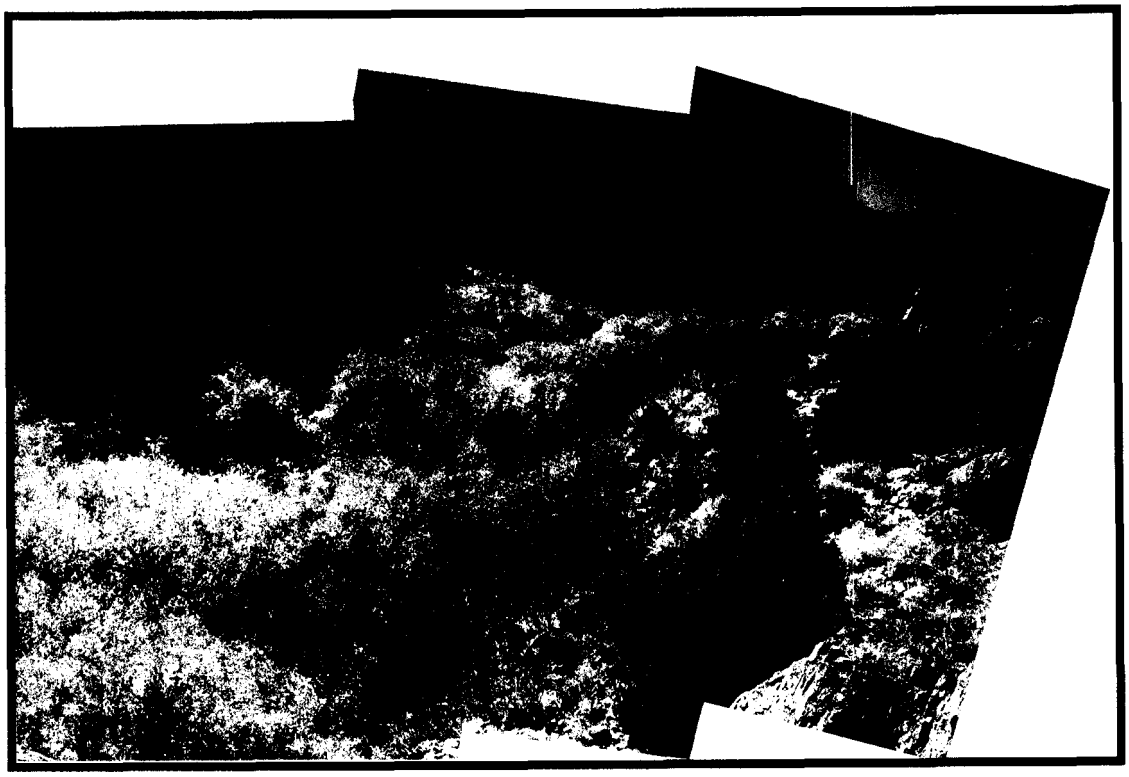

Figure 8. A panoramic view of the bottom of 3-Springs taken from the point indicated by the dot in figure 3. The light green canopy is arroyo willow and the orange canopy is choke cherry. The vegetation cloaking the peak in the background is dense mountain mahogany.

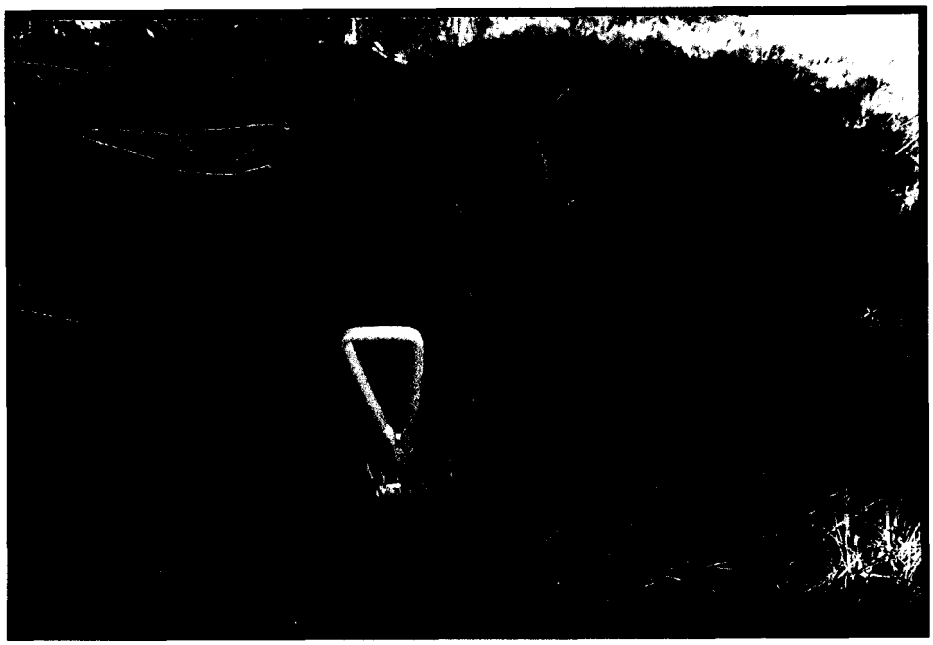

Figure 9. A seep located about ½ mile up 3-Springs Basin. The two water filled depressions were purposely dug. The adjacent stream channel, located about 30 m away, did not contain flowing water though the alluvial sediments were moist.

Figure 10. The displacement visible in this rock fissure indicates that it has been widened by between 3 and 10 cm by penetrating tree roots, The widening is occurring from the point of penetration by the tree prying apart from a hinge point located beneath the soil. This example is from the 3-Springs Basin in the Kawich Range.

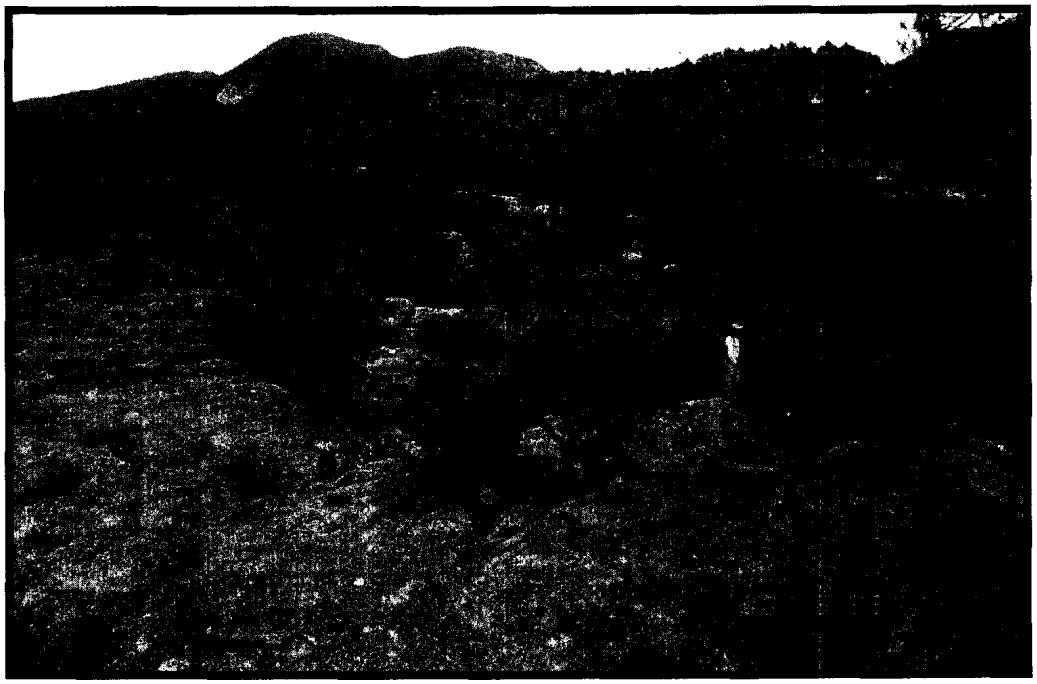

Figure 11. This view is on the south flank of Timber Mountain with healthy single-leaf pine growing out of fissures without the benefit of soil.

Trip 12: Extract from scientific notebook #563 by S. Stothoff. The original entry was dated 4/7/08 (pages 2-37 to 2-47). The text was not edited; footnotes were not in the original text, and were added for explanation.

04/07/08 Trip to spot-check Yucca Mountain infiltration

Overview

A field trip to Yucca Mountain occurred on 4/3/08 with the purpose of performing spot checks of areas with suspected high infiltration rates and several areas where mean annual infiltration (MAI) estimates differ significantly using different methods. I proposed the visit several months ago to Randy Fedors with the intent of visiting (i) the location at the ground surface where seeps occurred in the South Ramp of the Exploratory Studies Facility (ESF), (ii) the surface in Antler Wash and Coyote Wash above elevated chlorine-36 observations in the ESF, and (iii) the location of the Alcove 1 infiltration experiment. The first two locations appear to exhibit significant (although not necessarily widespread) fluxes at depth, but none of the MAI estimates from Infiltration Tabulator for Yucca Mountain (ITYM) or from U.S. Geological Survey (USGS) and Sandia National Laboratories (SNL) infiltration maps show elevated MAI above these locations. Water is generally thought to move predominantly vertically through fractured unsaturated rocks at Yucca Mountain (YM). Quite extensive lateral flow would be required to explain these observations at depth without an overlying local infiltration source above these locations. I had identified that an overlying exposure of the Tpcpmn (Tiva Canyon middle nonlithophysal) zone was a common element of these locations, and observations from previous field expeditions led me to hypothesize that this unit may be more conducive to infiltration than the infiltration models indicate. Note that Day et al. (1998)[10] map this zone as Tcpmn. The third location was to familiarize myself with the characteristics of the infiltration test, supplementing information provided in quarterly reports and other documentary materials.

As time permitted, I also wished to visit (iv) Mile High Mesa (G-2 and WT-24), (v) NRG-6 and NRG-7a, and (vi) G-3, in order to investigate surface characteristics where I had not looked at any expression of the surficial unit (iv), where a wide range of MAI estimates have been obtained (v), and where independent MAI estimates appeared lower than expected (vi) for the inferred surficial unit (which is outside the domain of the central block geologic map).

A technical exchange between NRC and DOE in Las Vegas regarding infiltration provided a convenient time for the field expedition from a logistical viewpoint, because both Randy and I were in Las Vegas for the exchange. While finalizing the field expedition with DOE, some of the Sandia researchers expressed an interest in observing the expedition, so the site visit was publicly announced. The group in the field included 5 NRC/CNWRA staff, 6 Yucca Mountain Project staff, and two representatives of Nye County. All of the intended locations were examined on the expedition, with an additional short stop at NRG-5 added to provide additional discussion points with the Sandia researchers. Locations near the ESF are indicated in Figure 2–7.

Observations regarding the visit are mine, except for specific comments and observations from R. Fedors that are explicitly noted.

[10] Day, W.C., C.J. Potter, D.S. Sweetkind, and C.A. San Juan. 1998. *Bedrock geologic map of the central block area, Yucca Mountain, Nye County, Nevada*. Miscellaneous Investigations Series I-2601, U.S. Geological Survey, Denver, CO.

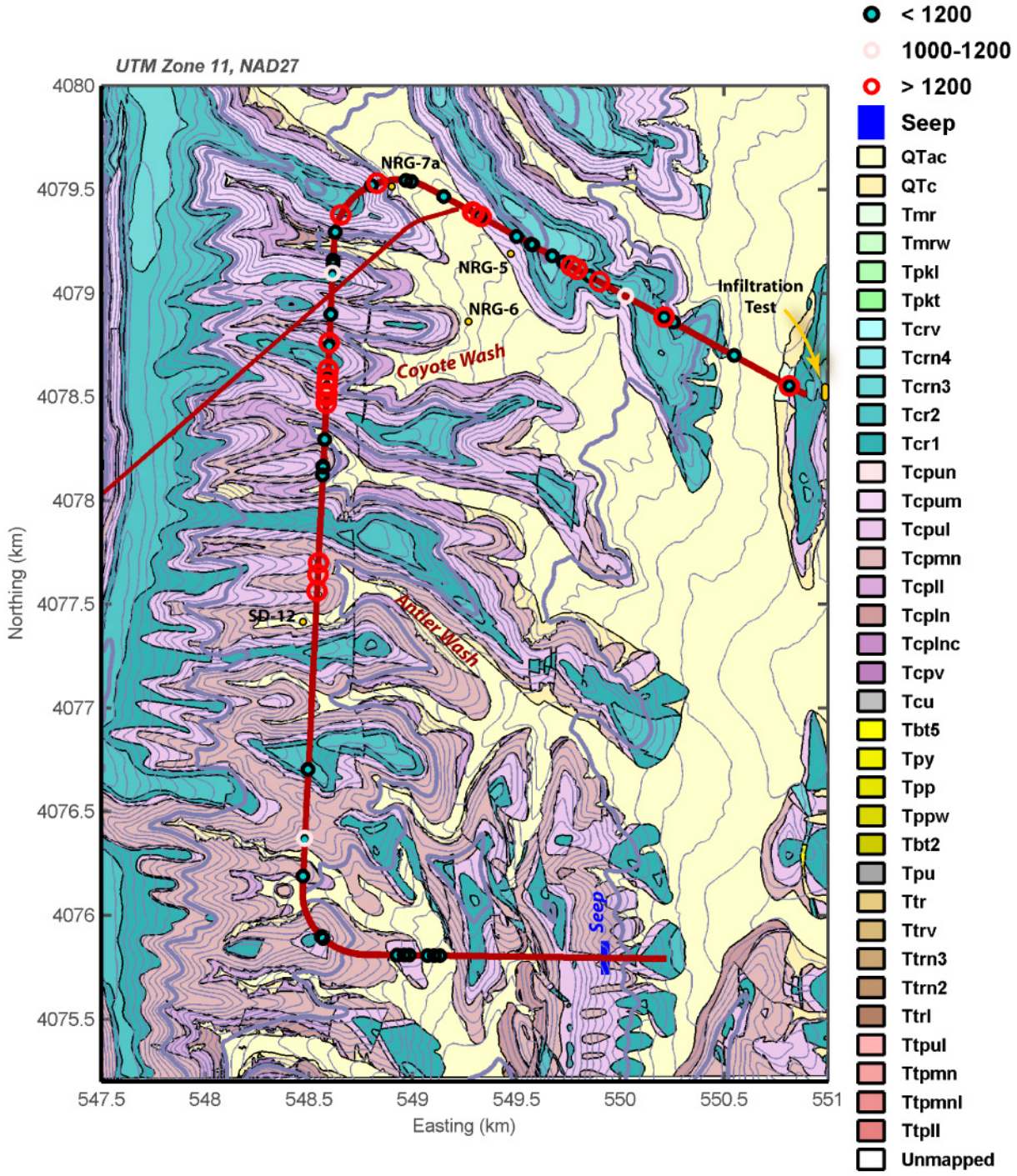

Figure 2–7. Location of field sites visited on 4/3/08. Contour interval is 10 m (heavy contours at 100-m intervals). Circles along ESF represent ratio of ^{36}Cl to Cl ($\times 10^{-15}$).

Infiltration Experiment site

Stop 1 was at the Infiltration Experiment site above Alcove 1. DOE ran a long-term irrigation experiment, initiated on March 9, 1998, that induced seepage into Alcove 1 over a period of years. This experiment is documented in semiannual DOE progress reports starting from progress report 18. SNL uses the results of the experiment to estimate bedrock properties for the Mass Accounting System for Soil Infiltration and Flow (MASSIF) model. I wanted to see the site for myself to clarify the surficial characteristics of the site, in part because faulting has jumbled the surface lithology and I have not seen the site plotted on a geologic map to ascertain the unit cropping out. The field examination indicates that (i) the site is on a moderately steep hillslope (a slope of perhaps 30 percent); (ii) soil depth is variable between zero and perhaps 30 cm, with most areas likely less than 15 cm, based on a few small pits cleared and refilled during the visit; (iii) all shrubs and perhaps all plants were removed prior to the experiment; and (iv) the underlying unit appears to be one of the Tiva Canyon caprock layers, such as the Tcr1 or Tcr2 unit suggested by the Day et al. (1998) map, with nearby exposures of other units.

A potential for lateral subsurface flow exists at this location, because of the relatively permeable soil, steep slope, and high rates of applied water. I have found no description of either observations of or methods for observing lateral subsurface flow in the progress reports. From the field examination such flow may have been readily detectable, particularly in cooler periods of the year, because significant areas of exposed rock (contiguous segments of at least 10 to 20 percent of the width of the covered site) in exist immediately downslope of the experiment that would have created a visible seep if large quantities of water were diverted downslope rather than infiltrating.

There is a cleared exposure approximately 10 to 20 m away lower on the hill, to the south, that I visually interpreted as the Tcpul zone, which underlies the Tcp1 zone. Day et al. (1998) do not map this zone here. The bedrock at the Infiltration Experiment site appears more broken and irregular than at the cleared exposure. At this location, therefore, the Tcp1 zone may be similar in nature to the Tcpul zone. R. Fedors noted that there was abundant caliche in the fractures at the cleared exposure.

Bechtel SAIC Company, LLC (2006)[11] use the data from the seepage experiment to estimate saturated hydraulic conductivity of the upper bedrock unit, interpreting the high flux rates applied to the site as indicating an occasional unfilled fracture for this unit. The ITYM input dataset treats caprock units in general, including this subunit, as having extensive soil-filled joints at the surface. No attempt was made to investigate these conceptual models at the stop, because this would have involved more digging than there was time available for.

Mile High Mesa (G-2 and WT-24)

Stops 2 and 3 were at G-2 and WT-24, respectively, on Mile High Mesa. These were intended to be quick visual checks as to the nature of the rock cropping out and the soil characteristics. This area is within the unsaturated zone (UZ) model domain but not above the potential repository. Borehole G-2 has temperature data and borehole WT-24 has chloride data that have been used to estimate MAI, providing potential means for calibrating or verifying infiltration

[11] Bechtel SAIC Company, LLC. 2006. *Data Analysis for Infiltration Modeling: Bedrock Saturated Hydraulic Conductivity Calculation.* ANL-NBS-HS000054 REV 00, Bechtel SAIC Company, LLC. Las Vegas, NV.

models. The Tpcrn4 subunit of the Tiva Canyon caprock crops out at both of these boreholes, and is only found north of the little prow. In stable areas of Mile High Mesa (including much of the Tpcrn4), the Lundstrom et al. soil maps suggest that eolian deposits may cover Quaternary and Tertiary soils. The ITYM estimates suggest that MAI is near zero within these areas, whereas the Sandia National Laboratories (2007)[12] report does not show any unusual characteristics relative to other caprock units. Bodvarsson et al. (2003)[13] estimate zero MAI for G-2 using an analytic solution for temperature compared to the temperature measurements reported by Sass et al. (1988)[14]. My independent temperature estimates using the same analytical solution with an alternative interpretation of the thermal properties suggests that downward percolation fluxes may be fairly small in the top 300 m, perhaps gaining water through lateral flow at that depth.

The site of G-2 is gently sloping, with variable soil depth. In some locations, bedrock is visible at or near the soil surface; in others, no sign of rock is visible. Where visible, the rock surface appeared similar to the caprock units such as Tcr2 and Tcrn3 exposed on Yucca Crest. The soil was fluffy, consistent with observations from Rock Valley that soil permeability varied by a factor of two over the year, with permeability larger in winter and spring, and smaller in autumn. R. Fedors describes the texture of the soil as desert varnish, referring to a hydro-resistant layer on a popcorn-shaped soil surface, which must be wetted for some time before it would transmit water. He also notes that the microtopography, especially the area between the knubbly points, may readily transmit water to areas with locally high infiltration capability (i.e., at a scale much smaller than the grid scale for ITYM or MASSIF).

No attempt was made to investigate soil depth. No obvious feature of the site was identified that suggests MAI should be lower than on Yucca Crest at G-2.

The site of WT-24 is in a narrower portion of the ridgetop, but otherwise has a similar slope and uppermost unit. The soil is thinner, in places with platy surface clasts forming an incomplete desert pavement or completely covering the soil. These characteristics would promote net infiltration, because water would readily enter the subsurface but evaporation would be greatly restricted by the surface clasts. The topmost rock is heavily weathered and features heavy desert varnish. Almost 1 m of rock was removed at the western edge of the drill pad, exposing a subunit that appears much less weathered. I was not able to tell if this unweathered subunit is Tcrn3 or simply an unweathered version of the Tcrn4. This subunit is visible over several meters, and few fractures were visible in the exposed stretch. R. Fedors noted that vertical fractures were spaced at intervals greater than 2 m, whereas the horizontal fractures were separated by 15 to 20 cm.

Drillhole Wash (NRG-5, NRG-6, NRG-7a)

Stops 4, 5, and 6 were at NRG-5, NRG-7a, and NRG-6, respectively, in Drillhole Wash. Estimated MAI is small at all of the locations using ITYM and according to both the USGS and SNL models. Shallow temperature observations are available for NRG-6 and NRG-7a but not

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[12] Sandia National Laboratories. 2007. *Simulation of Net Infiltration for Present-Day and Potential Future Climates.* ANL-NBS-HS-000032 REV-01. Sandia National Laboratories: Albuquerque, NM.
[13] Bodvarsson, G.S., E. Kwicklis, C. Shan, and Y.-S. Wu. 2003. Estimation of percolation flux from borehole temperature data at Yucca Mountain, Nevada. *Journal of Contaminant Hydrology 62–63*, 3–22.
[14] Sass, J.H., A.H. Lachenbruch, W.W. Dudley, Jr., S.S. Priest, and R.J. Munroe. 1988. *Temperature, thermal conductivity, and heat flow near Yucca Mountain, Nevada: Some tectonic and hydrologic implications*. Open-File Report 87-649. U.S. Geological Survey: Denver, CO.

NRG-5. Bodvarsson et al. (2003) estimates large percolation flux for both boreholes using the temperature observations, but notes that these boreholes are near faults that may be affecting temperature profiles because of gas flow. Bodvarsson et al. (2003) do not specify the faults affecting NRG-6 and NRG-7a; the Drillhole Wash fault is the closest major fault. The fault location is not well known, lying somewhere within the alluvium of Drillhole Wash. The fault is presumably closer than the distal side of Drillhole Wash, which is approximately 210 m from NRG-7a and 280 m from NRG-6.

The NRG-5 stop was a courtesy stop to allow the SNL researchers to view the deep cut for the drillpad, which exposes caliche along the bedrock surface, a network of filled fractures, and some of the typical rhythmically undulating soil cover. The NRG-5 drillpad cuts into a south by southwest facing hillslope. This unit is described as the upper lithophysal and middle nonlithophysal zones, undivided. According to Day et al. (1998): "Unit contains groundmass and lithophysal [sic] similar in character to the upper lithophysal zone (Tcpul) and grades to lithophysal-poor lower part (5–10 percent lithophysae) with groundmass similar in color and conchoidal fracturing characteristic of the crystal-poor middle nonlithophysal zone (map unit Tcpmn)." The NRG-5 drillpad is in the central to lower portion of the zone and does not exhibit lithophysae. R. Fedors noted that the horizontal and vertical spacing between the fractures was 10 to 20 cm. This spacing is consistent with exposures of the Tcpmn zone elsewhere around YM.

The NRG-6 and NRG-7a stops were intended to ascertain whether obvious surficial characteristics existed that would be consistent with elevated MAI fluxes. The NRG-6 borehole is completed in the nonlithophysal Tcpmn unit, which is densely fractured, and lies at the base of an east-dipping east/west trending ridge. The NRG-6 borehole has a gentle eastern aspect. This location is just south of the transition between distinctly mapped Tcpul and Tcpmn zones and the combined Tcpum zone. The drillpad obscures the original location; the borehole is mapped as lying within Qtac but the soil depth is reported as zero in the bore log. The borehole lies more than 15 m east of the nearest edge of the drillpad where rock is exposed. R. Fedors noted that horizontal fractures are separated by approximately 30 cm, with much larger spacing between vertical fractures, and noted that caliche is locally present in the fractures but does not predominantly fill the fractures. A small stream channel in several meters of fill exists within 60 m of the borehole, but this has a small catchment that may not provide significant infiltration. Aside from completion in the Tcpmn zone, no obvious hydrological features were identified that would provide unusual amounts of net infiltration at NRG-6.

The NRG-7a borehole is completed in the upper part of the Tcpll zone, at the base of a fairly steep hillslope facing to the northeast and exposing the Tcpum zone. The mapped contact between the Tcpll and Tcpum zones is within approximately 20 or 30 m of the borehole. It is possible that a combination of overland flow and interflow provides additional water for infiltration at the base of the Tcpum zone, which is described as similar to the densely fractured Tcpmn zone. No particular surficial features were observed that either strongly support or contradict this hypothesis. Note that indications of bomb-pulse chlorine-36 have been found in the ESF below the lower portion of the Tcpum exposed in a location almost directly upslope of NRG-7a (see Figure 1).

South ramp of the ESF

Unusually wet conditions during the winter of 2004-2005 yielded observed seeps from the fractures in the south ramp of the ESF primarily between ESF Centerline Stations 75+62 and 76+07, with a secondary seep at 77+52 (station length units of meters). The South Portal of the

ESF is at an approximate station of 78+77. The ESF approximately follows the ridgeline of an east-west trending ridge in the location of the seeps, perhaps lying a few meters to the south of the ridgeline, with an overburden of approximately 80 m. In the vicinity of the primary seeps, channel separation is approximately 100 m. The channel of the smaller southern watershed is approximately 27 m from the ridgeline and incised approximately 4 to 6 m relative to the ridgeline. The channel of the larger northern watershed is approximately 70 m from the ridgeline and incised approximately 12 to 15 m relative to the ridgeline. Both channels are incised into the Tcpmn zone.

DOE surveyed in a stake corresponding to the primary seepage point within the south ramp (verbal communication by Brian Dozier, SNL, during the visit). The stake location is N 36° 49.709 and W 116° 26.455 ±12 ft, at an elevation of 4007 ft, determined by Global Positioning System (GPS) during the visit. The stake appears to be located in an outcrop of the Tcpul zone, which extends upslope to the west. The Tcpul zone appears to be no more than a meter or two deep at the stake, based on observed contacts between lithophysal and nonlithophysal units on the side-slopes of the ridge to both the north and south of the ridgeline. The ridge top dips at the approximate bedding plane, judging from views from the channel. The Tcpul zone is mapped as disappearing downslope at some point, but the extent of Tcpul coverage immediately downslope of the stake was not ascertained. R. Fedors noted that Day et al. (1998) map the area as faulted, with the seep section slightly upthrown, so that the Tcpul disappears then reappears as one walks down the ridge eastward towards the south ramp portal. Note that essentially all of the rock between the primary seep location and the surface is the Tcpmn zone, aside from the thin layer of Tcpul.

Areas with Tcpmn exposed appear to have an irregular bedrock surface derived from bodily removal of bedrock along pre-existing fractures, with a plentitude of fractures, whereas areas with Tcpul tend to have a more regular surface visually consistent with *in situ* weathering, and with relatively few fractures. Often areas with Tcpmn exposed have a much greater soil rock fraction than areas with Tcpul, promoting deeper penetration of wetting pulses and reduced evaporation rates. The fine component of soil is similar between these zones because the fine component is predominantly eolian in origin over YM. These factors imply that areas with Tcpmn exposed are likely to have elevated MAI relative to areas with Tcpul exposed.

The nearest location with characteristics visually appearing to be consistent with an infiltration location lies approximately 1/2 to 2/3 of the way from the ridgetop to the southern channel. This location features a relatively planar catchment within the Tcpmn zone, with approximately 10 to 20 m extent consisting of visibly broken bedrock extending to the southern channel. Nowhere on the ridge did the soil show signs of active erosion, aside from the channel bottoms, implying that the soil is sufficiently permeable to essentially eliminate overland flow (although lack of erosion does not necessarily imply that interflow is inactive). The southern channel is the next closest feature; the channel bottom is only moderately fractured, with minimal trapped soil or pools, but the bedrock appears quite broken up on the hillsides within a few meters of the channel and the soil shows minimal signs of active erosion, implying that distributed infiltration may be active near the channel. The northern channel has similar characteristics as the southern channel, is bigger, but is twice as far from the ridgeline.

The southern hillslopes may be the most likely source for the seep waters because the lateral migration necessary for seeps to occur is approximately 20 m in approximately 80 m. The conceptualization of water movement being predominantly in the vertical in the shallow subsurface is best supported for this location. Infiltration in the northern hillslopes is less supported based on the doubled lateral distance necessary for water to travel and the reduced

vertical distance available for redistribution. It is possible that lateral redistribution updip and upslope occurred from areas of Tcpmn along the ridgetop; no especially promising location was identified within 10 to 20 m of the survey stake.

Antler Wash and Coyote Wash

The main drift of the ESF passes below Antler and Coyote Washes. A number of samples collected from the main drift showed ratios of chlorine-36 to chloride indicative of bomb-pulse waters below these washes (Figure 1). The ITYM, USGS, and SNL MAI model results suggest that MAI is not especially large in this area, implying that (if the observations are correct) (i) even a low level of MAI may find a rapid pathway to the repository horizon; (ii) lateral redistribution may occur over hundreds of meters from zones recognized as potentially yielding relatively large MAI; or (iii) surficial features near the bomb-pulse observations that are not captured in the models may promote higher-than-estimated levels of MAI. The field expedition made stops in both Antler Wash and Coyote Wash to examine the third option. In particular, the Tcpmn zone was considered as a potential source unit because it once again crops out above the locations where elevated fluxes are present in the ESF. Areas with elevated chlorine-36/chloride ratios to the north of these washes may be associated with smaller exposures in similar topographic positions, but may also be associated with caprock exposures. The Tcpmn unit is widely exposed in the area of the southern bend of the ESF; only one of the few samples from this portion of the ESF show a potential bomb-pulse signature (the white circle under Highway Ridge in Figure 1), but the value is not sufficiently large to represent an unambiguous bomb-pulse signal. Note that there are few sample locations in the southern half of the ESF that are well placed to observe infiltration from Tcpmn exposures (see Figure 1).

The group traversed two ridges and the middle wash at the Antler Wash site, from N 36° 50.784' W 116° 27.386′ to borehole SD-12 (at approximately N 36° 50.597′ W 116° 27.432′). All three chlorine-36 observations lie within 100 m of the channel in the middle branch of Antler Wash; the northern and southern extremes lie below the ridgelines defining the middle branch. The southernmost observation is more than 250 m from the nearest outcrop of the Tiva Canyon caprock (e.g., Tcr1 or Tcr2), which are units where ITYM estimates large values of MAI. During the traverse, we observed typical Tcpmn surficial characteristics in most of the exposure; these characteristics include erratic bedrock elevations, plentiful soil clasts grading to talus in places, and minimal evidence for soil erosion. All aspects of the Tcpmn exposures appeared conducive to enhanced infiltration, with north-facing exposures especially conducive. The field observations support the hypothesis that the Tcpmn unit may be a potential source for near-vertical fast-pathway waters reaching the ESF near Antler Wash.

The group walked up the southern branch of Coyote Wash to approximately the intersection of the wash channel with the Sundance Fault. This stretch of wash features fairly steep sideslopes dominated by Tcpul exposures, Tcpmn exposed near the bottom of the slopes, and a wash channel on Tcpll (another zone with few fractures). Note that the bottom of the channel is mapped as Tcpmn upchannel from the intersection point, but I did not observe the upchannel reaches. The sideslopes featured plentiful shards and thin to nonexistent soil, implying that lateral flow may be important in this wash. It may be that the different chlorine-36 observations in the ESF below Coyote Wash arise from different sources, including (i) the exposure of caprock between the two branches of Coyote Wash; (ii) linear features in the upper part of the Tcpul mapped at Pavement 100; (iii) direct infiltration into the Sundance Fault; and (iv) localized infiltration into the Tcpmn, perhaps augmented by lateral flow down the hillslopes. The Coyote Wash site was not extensively investigated, but the group did notice that the vegetation was relatively lush in and near the wash channel.

Yucca Crest (G-3)

A quick stop was made at G-3, the southernmost borehole along Yucca Crest. Temperature observations reported by Sass et al. (1988) are available for this borehole; Bodvarsson et al. (2003) find that lower values of percolation flux are obtained at this borehole than estimated for other boreholes on the crest and implied by the ITYM and SNL infiltration maps. I wanted to check the surficial characteristics near the borehole to see if any obvious explanation was available justifying reduced MAI. In particular, I thought that perhaps the caprock was missing at this location south of the Day et al. (1998) central block map; at the time of the trip I was unaware of the south-central map by Dickerson and Drake (2004)[15] that clearly indicates the presence of caprock at the borehole.

It was obvious upon arrival that the caprock existed at this location. The soil appeared typical of similar locations elsewhere on the crest, perhaps shallower than elsewhere. R. Fedors noted that soil depths of 10 to 20 cm appeared representative of the area near and west of the road (i.e., the upper part of the crest ridge). R. Fedors also noted that large blocks covered approximately 50 percent of the area along the crest (which would tend to funnel water into the other area due to local overland flow), but he thought that this was typical of the top of the crest. Note that previous visits have identified soil depths of 30 to 50 cm in locations on the caprock that are topographically lower than the crestline. I identified no obvious feature of the site that suggests MAI should be lower than elsewhere. I got the qualitative impression that the bedrock may be less weathered or less fractured than I've seen elsewhere in the caprock, and perhaps had more caliche.

[15] Dickerson, R.P., and R.M. Drake, II. 2004. Geologic map of south-central Yucca Mountain, Nye County, Nevada. Miscellaneous Field Studies Map MF-2422, U.S. Geological Survey: Denver, CO.