THE FUTURE THROUGH THE PAST: THE USE OF ANALOG SITES FOR DESIGN CRITERIA AND LONG-TERM PERFORMANCE ASSESSMENT OF EVAPOTRANSPIRATION LANDFILL COVERS

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ABSTRACT

There is growing support for using evapotranspiration (ET) covers for closure of low-level waste (LLW) and other types of waste disposal sites, particularly in the lower latitude arid regions of the western United States. At the Nevada Test Site (NTS), monolayer ET covers are the baseline technology for closure of LLW and mixed LLW cells. To better predict the long-term performance of monolayer ET covers, as well as to identify design criteria that will potentially improve their performance, the properties of, and processes occurring on, analog sites for ET covers on the NTS are being studied. The project is funded through the Subsurface Contaminants Focus Area of the U.S. Department of Energy.

Four analog sites on the NTS have been selected to predict performance of ET covers over a 1,000-year compliance period. Two sites are relatively recently disturbed (within the last 50 years) and have been selected to evaluate processes and changes on ET covers for the early period after active cover maintenance is discontinued. Two other sites, late to mid-Holocene in age, are intended as analogs for the end of the compliance period (1,000 years or more); both surfaces are abandoned alluvial/colluvial deposits. The history of the early post-institutional control analog sites are being evaluated by an archeologist to help determine when the sites were last disturbed or modified, and the mode of disturbance to help set baseline conditions. Similar to other "landforms," ET covers will evolve over time because of pedogenic, biotic, and climatic processes. Properties of analog sites that could affect ET water balance performance will be evaluated to help understand ET cover performance over time.

Results of analog site work and resultant modifications to design, monitoring, and maintenance of ET covers on the NTS will be compared with results of a similar study being conducted at Sandia National Laboratories (SNL), where ET cover closures are planned as well. The comparison will help to distinguish potential regional differences needed in ET cover design. Although both sites are at similar latitudes, the NTS is located in a transition zone between the Mojave and southern Great Basin deserts, whereas SNL is located in the northern Chihuahuan desert. Differences in vegetation and seasonality of precipitation between the sites are significant.

INTRODUCTION

Vegetated, monolayer evapotranspiration or "ET" covers are gaining acceptance at arid and semi-arid sites for waste site closure based on water-balance and related studies being conducted at the Nevada Test Site (NTS), Sandia National Laboratories (SNL) (1), Pacific Northwest Laboratories (PNL) at Hanford (2), and at more than a dozen sites across the United States through the U.S. Environmental Protection Agency's Alternative Cover Assessment Program (ACAP) (3). The principle behind this closure technology is soil evaporation and plant transpiration of water that infiltrates into a single layer of native soil that covers the waste. ET covers are a significant departure from traditional closure cover designs that feature geotechnical layers that restrict infiltration of water through either a capillary break or reduction of permeability, or both. Rather than attempting to restrict infiltration of water, the monolayer-ET cover allows water to infiltrate into the soil where natural processes then remove the water.

A vegetated ET cover, as well as any type of cover, cannot be viewed as a static feature. Covers will be subject to natural processes of change the same as any alluvial/colluvial landform, particularly after the period when institutional control ends. These changes, and their subsequent impact on long-term cover performance, are difficult to capture in performance modeling. To supplement traditional approaches of cover design and performance prediction, a series of "analog" sites has been identified to serve as predictive tools for how an ET cover may evolve over a 1,000-year compliance period on the NTS. By understanding how a cover will change over time, modifications can be made to ET cover design, maintenance, and monitoring in the near term that will improve its long-term performance. In addition to its contribution to site-specific waste site closure and Long-Term Stewardship issues at the NTS, this project will contribute to the "Long-Term Capping/Cover Strategy" being developed by the Subsurface Contaminants Focus Area of the U.S. Department of Energy Environmental Management's Office of Science and Technology Development.

The most widespread use of ET covers is in arid regions, where environmental processes that will modify the cover over time include the following:

- Erosion, aeolian deposition, and other surface modifications
- Pedogenic development
- Vegetation growth and succession
- Biointrusion from plants and animals
- Subsidence

There is often a tendency to view such processes individually; however, many are linked, or "coupled," to each other, sometimes with potentially competing impacts on the performance of the cover for containing or protecting waste. For example, work in the Mojave Desert National Preserve suggests that significant aeolian deposition of fine particles can occur, even on surfaces as young as 500 to 1,000 years old (4). This can have a beneficial impact of reducing infiltration and enhancing the cover performance. However, accumulation of these same fines could promote biointrusion by small mammals, normally a process viewed as having a detrimental impact on cover performance.

In addition, there is significant variation in these coupled processes in different deserts. A similar project is underway with analog sites near SNL in New Mexico. Although the NTS and SNL are along roughly the same latitude, the Mojave Desert, in which the NTS is located, is dominated by winter precipitation. By contrast, SNL is in the northern Chihuahuan Desert, which receives on average about double the average precipitation of the Mojave (Fig. 1), and can receive as much as half of its annual precipitation from summer "monsoon" storms (5).

The goal of the project is to understand the coupled processes that will affect vegetated, monolayer ET covers in these two desert regions, focusing on the 1,000-year performance period pursuant to DOE Order 435. Among the expected results are the identification of processes that potentially have the most significant impact on performance of the cover, positively or negatively, and the rates at which they will act upon the cover. Further, having identified these processes, the results will include an evaluation of whether design modifications or management activities, such as maintenance and monitoring during the period of institutional control, can enhance features or processes that improve cover performance over the long-term, or mitigate processes that could negatively impact the integrity of covers. Comparing results from the NTS and SNL (part of year 3 of the project) will help to better understand the range of design modifications, based on naturally occurring coupled processes, which could be considered to make these ET covers effective alternative covers over a range of arid and semi-arid environments.

ANALOG SITES ON THE NEVADA TEST SITE

Two areas on the NTS are used for shallow land disposal of low-level waste (LLW) and mixed LLW from approved generators across the United States: the Area 3 Radioactive Waste Management Site (RWMS) and the Area 5 RWMS. Although the results of this study are expected to be applicable to closures in both areas, as well as elsewhere in the Mojave Desert, there are subtle differences between the areas since the NTS is in a transition zone between the Mojave and Great Basin deserts (Fig. 2) (5). Because the U-3axbl monolayer ET cover (6) was recently constructed at the Area 3 RWMS and could serve as a baseline for comparison, the four analog sites were selected in this part of the NTS.

Analog sites were selected because of the following:

- They were composed of material similar to that used for ET cover construction in the area.
- Their degree of compaction was similar to that used when constructing covers.
- Surface gradients were low.
- There was good evidence the sites had been isolated from alluvial or colluvial deposition, sheet flow, and other similar deposition or erosion processes.
- There was means of determining or estimating when the surface was created or abandoned so that rates of feature developed could be determined.

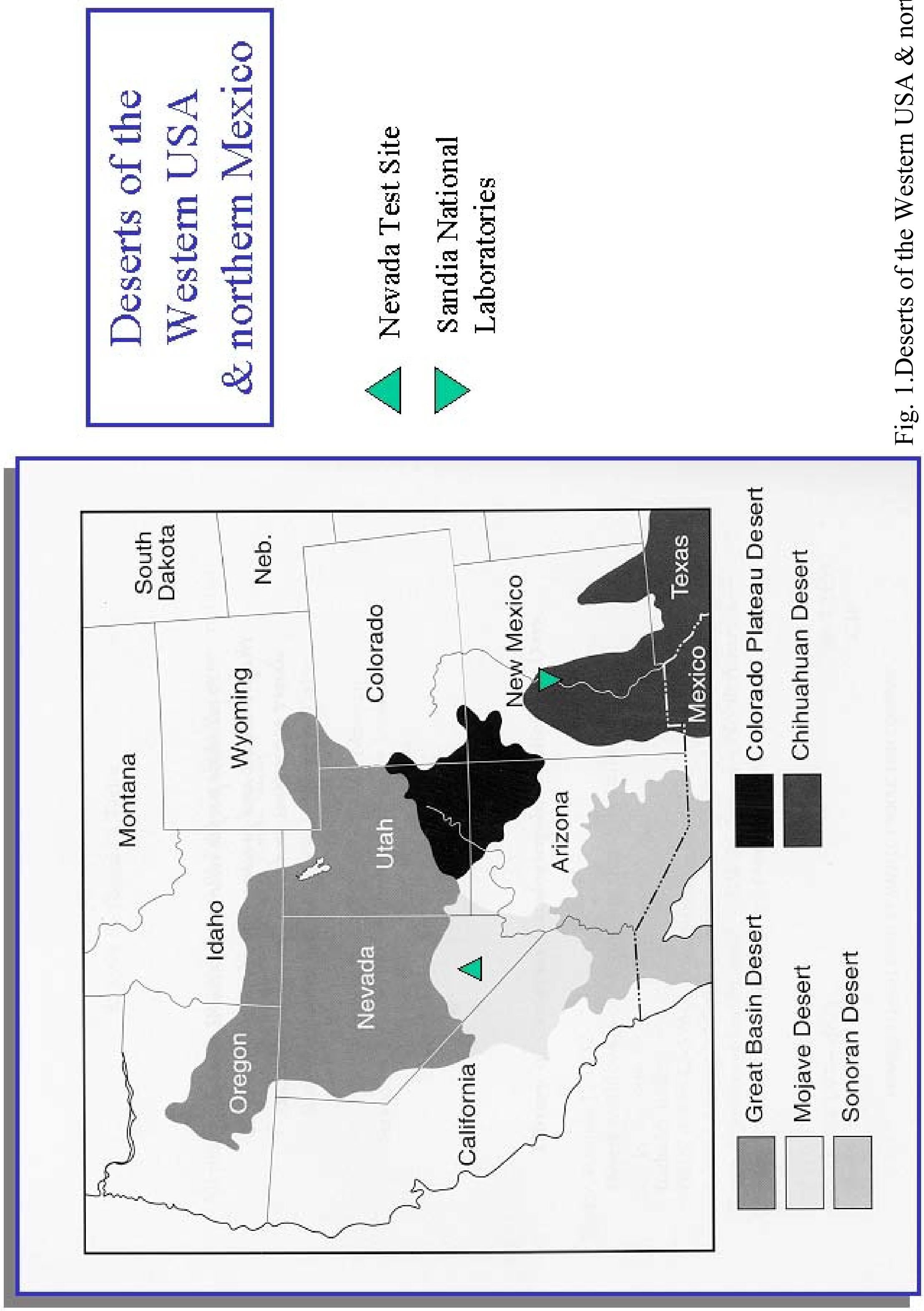

Fig. 1.Deserts of the Western USA & northern Mexico

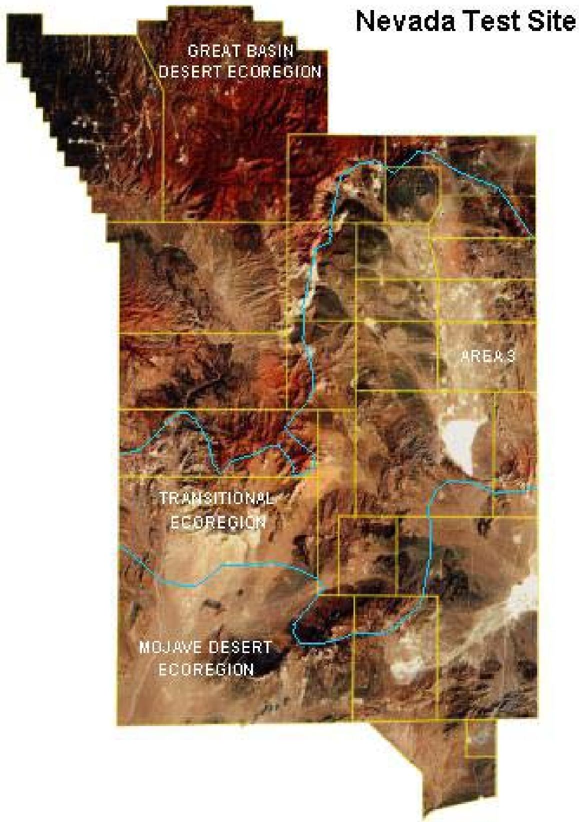

Fig. 2. Ecoregions of the Nevada Test Site.

In addition, two sites (Sites 1 and 3) were selected to evaluate processes and conditions of the surfaces at what would be analogous to the end of the 1,000-year compliance period for a low-level radioactive waste ET cover. In contrast, Sites 2 and 4 were selected to evaluate similar phenomena that could occur or have developed on covers within a few decades of the end of institutional controls. The following is a brief description of the four analog sites:

- **Site 1** is a low-elevation, late to mid-Holocene surface that is cut by the Yucca Fault. This site was selected because it is a rare area of undisturbed ground in the otherwise heavily disturbed basin floor of Yucca Flat. It is also within an area of widespread aeolian deposition of silt and fine sand particles, locally referred to as the "sand box," stretching north from the Yucca Playa at the southern end of the basin. The craters from underground nuclear testing in Area 3, some now used as waste disposal pits at the Area 3 RWMS, are also located in the sand box.

  Whereas surface soils in this area are dominantly fine-grained, larger clasts are present and an early-stage desert pavement is forming at the site. It is unlikely, however, that a desert pavement of high clast density will ever develop at this site because the small quantity of larger clasts in the shallow subsurface. However, a "source limited" pavement is under development (source limited because larger clasts make up a relatively small percentage of the native material) and may be representative of the type of surface that could evolve over time on covers in the "sand box" if native materials are used. It is hypothesized that past and continuing burrowing by small mammals has brought the larger clasts to the surface.

Where burrowing is occurring today, fine-grained mounds up to a meter across are present, often surrounded by coarser clasts. In some cases, plants are preferentially growing at the boundary between the fine-grained mounds and the coarser material. In other situations, dieback of a shrub (Mormon tea, at this site) occurred in the center of the mound. In some parts of the Mojave Desert/Lower Colorado River Desert such features are ubiquitous on the landscape and are regionally referred to as "sleeping circles" or "stone circles." Perennial plants at the site include hollyleaf bursage (*Ambrosia ilicifolia*), Mormon tea (*Ephedra nevadensis*), creosote bush (*Larrea tridentata*), hopsage (*Grayia spinosa*), winterfat (*Kraschenimikovia lanata*), goldenbush (*Haplopappus sp.*), groundthorn (*Menadora spinescens*), green rabbitbush (*Chrysothamnus greenia*), four-winged saltbush (*Atriplex canescens*), and Indian ricegrass (*Achnatherum hymenoides*). Three exotic annuals that have become common in the northern Mojave Desert are also present. They are halogeton (*Halogeton glomeratus*), Russian thistle (*Salsola iberica*) and cheat grass (*Bromus sp.*).

- **Site 2** is located just south of the Area 3 RWMS and was "disturbed" as part of the underground nuclear testing program as equipment was "skidded" between different ground zero sites. It was last disturbed in 1973. Site 2 was selected to evaluate coupled environmental processes after an early post-institutional control period, for a cover of fine-grained material like that used in the construction of the U-3axbl ET cover. A thin layer of pebbles, assumed placed on the surface during construction to help stabilize it, overlies fine-grained aeolian material. Polygonal cracks are ubiquitous across the surface. The cracks probably formed because of two processes. The first is ground motion created during underground nuclear testing. The second process occurs after the periodic ponding of water in low-lying areas of Yucca Flat, particularly following winter convective storms. The "mudcracks," which may form preferentially along stress lines from ground motion, develop as the wetted surface soils desiccate from evaporation following the ponding events. The polygons are up to a meter across. Today there is probably slight preferential drainage into these cracks given that plants in the area are often rooted there. Native plants are limited at analog site 2, but include Indian ricegrass (*Achnatherum hymenoides*), *Eriogonum* sp., skeleton weed (*Eriogonum deflexum)*, and four-winged saltbush (*Atriplex canescens*) More common than natives are exotics such as cheat grass and halogeton (7).

- **Site 3** is an abandoned late Holocene alluvial/distal fan surface on the east side of Yucca Flat (Fig. 3). Although shallow, intermittent channels bound the area today, the presence of mature Joshua trees (*Yucca brevifolia*) indicates that the surface has been abandoned with respect to runoff in the area. This site, as well as Site 1, was selected to represent analog conditions at the end of the compliance period for a monolayer ET cover. Native plants include those present at Site 1, plus Joshua tree (*Yucca brevifolia*) and desert trumpet (*Eriogonum inflatum*).

Although mature shrubs are present on the surface, burrowing by small mammals continues, often resulting in small mounds with larger clasts atop finer-grained material. Burrowing also continues beneath and on the margins of larger shrubs. A feature that indicates the extent of turnover of soil from bioturbation is the presence on the surface of clasts with carbonate rinds. These rinds form in the subsurface, and are usually eroded or dissolved away if exposed on the surface for any significant length of time.

- **Site 4** is the easternmost of the analog sites, and was an equipment storage and staging area for underground nuclear tests conducted in 1971 and 1972 (Fig. 3). It is believed to have been abandoned for about 30 years. Engineering records indicate that the area was graded flat, and then brought to near grade with the adjacent power line access road using fine-grained construction material from a nearby source. A thin, pea gravel cover (approximately 0.64 cm thick) was also placed on the surface to help stabilize it, particularly if it became wet.

  Successful natural recruitment of shrubs has occurred during the last 30 years. Plants present at the site include those at Site 1 as well as wolfberry (*Lycium andersonii),* which are found in local areas where infiltration is higher. Burrowing is extensive around the bases of larger shrubs, so much so that mounds up to a meter high have formed around some of the shrubs. However, also evident at the site is some early shrub dieback, particularly where bioturbation has been extensive, and may be the beginning of the development of sleeping circles discussed under analog site 1.

  Shallow pits dug into the surface indicate that aeolian deposition has already been quite extensive. Although an Av horizon has not developed, the amount of fine sand and silt just below the surface is sufficient to hold up surface clasts on a cut face of a pit without the clasts collapsing into the pit. Some of the aeolian material is probably locally derived from winnowing of fine-grained material from nearby or immediately adjacent disturbed surfaces, but some could also be a result of longer-range transport of material from the Yucca Playa and other aeolian material sources to the south. In general, although this site is relatively young compared to the late Holocene Site 3, the types of coupled processes occurring and the plant species present are quite similar.

POTENTIAL COUPLED PROCESSES IMPORTANT FOR ET COVER PERFORMANCE AND DESIGN

Although year 2 of the project will focus on quantifying properties and processes of surface and subsurface soils, bioturbation, and vegetation, among other factors, some processes are already emerging as having important implications for the long-term performance and the near-term design of evapotranspiration covers. In addition, some of the hypotheses — for example, potential benefits of small mammal bioturbation — are different from what are often perceived positive and negative impacts of natural processes.

Fig. 3. Analog sites 3 and 4 on the Nevada Test Site. Although analog site 3 (left) is a late Holocene surface and analog site 4 (right) is a surface abandoned less than 30 years ago, the types of coupled environmental processes occurring at the sites and the vegetation established are quite similar.

Emerging hypotheses and recommendations for ET covers include the following:

- Bioturbation by small mammals begins almost immediately after abandonment of surfaces (akin to the end of institutional control on a monolayer ET cover), as observed on the analog sites selected to predict ET cover conditions shortly after the end of maintenance. Such bioturbation may have both positive and negative effects on the hydrologic performance of a cover. A hypothesized positive effect is to promote establishment of native shrubs. Burrowing brings larger stone clasts to the surface and appears to create a more favorable environment for establishment of native shrubs, which are effective transpiration agents for ET covers.

  Accumulation of coarser clasts from bioturbation may be an early stage in the development of a desert pavement. Mid-stage desert pavements have been noted for the stability they add to surfaces in arid regions and research is underway on a separate project to mimic the formation of desert pavements for stabilizing disturbed surfaces in deserts.

- Shrubs and perennial herbs observed in proximity to concentrations of stone clasts on the surface include hollyleaf bursage (*Ambrosia ilicifolia*), Mormon tea (*Ephedra nevadensis*), creosote (*Larrea tridentate*), hopsage (*Grayia spinosa*), winterfat (*Ceratoides lanata*), goldenbush (*Happlopassus*), groundthorn (*Menadora spinescens*), green rabbitbush (*Chrysothamnus greenia*), and four-winged saltbrush (*Atriplex canescens*). Of these shrubs, only the latter two were observed having been recently reestablished on disturbed, fine-grained surfaces (i.e., lacking coarser clasts on the surface).

- Once established on a surface, shrubs seem to promote further bioturbation in their vicinity. This may be in part because the shrubs provide shelter for small mammals. Infiltration may be enhanced near these shrubs because of the lower soil bulk density from bioturbation; this could be a negative feedback for the hydrologic performance of ET covers. However, the higher infiltration rate may be balanced by deeper root penetration in the same area, resulting in greater transpiration potential by shrubs.

- Positive effects may occur during precipitation events because of locally enhanced infiltration through coarse clasts, and during evaporation on soil surfaces with a mix of fine and coarser clasts on the surface. During precipitation events, rainfall or snowmelt on coarser clasts may concentrate infiltration in small gaps between coarser clasts or on the edges of areas of coarser clasts. This "concentration of runoff" may be small, but it may be enough to support a shrub that could not otherwise survive in finer-grained soils accumulated between areas of coarser clasts. Furthermore, during evaporation, water may be maintained for slightly longer periods beneath coarser clasts, maintaining soil moisture longer in the part of the soil profile that would be most important for the establishment of seedlings. Tests of this last hypothesis may be aided by ongoing research by the Desert Research Institute at the Yuma Proving Grounds in Arizona to examine soil moisture profiles beneath desert pavements.

- Many surfaces, particularly those recently disturbed, have a high concentration of exotic annual plants that may inhibit establishment of native plants that are important for the long-term transpiration performance of the cover. These exotics include Russian thistle, halogeton, and cheatgrass (*Bromus sp*.). These plants become locally established on older sites in bioturbated zones and other areas where fines are present; however, in such cases, the native plants appear to remain competitive. For example, Indian ricegrass, which can be a dominant native perennial grass in this region, remains on older analog sites with a mixed clast size surface, as well as on similar younger surfaces even if the previously mentioned exotic plants are locally established.

- Older analog sites lack a well-developed Av horizon unless they are at least as old as mid-Holocene. However, there is a concentration of clay- and silt-sized particles in the uppermost soil horizons that could help to hold water longer for seedling establishment, as well as reducing the depth of infiltration into the cover (8). Aeolian deposition is an ongoing process in Yucca Flat from resuspension of soil particles from the Yucca Flat playa on the south end of the basin. Features designed into ET covers such as increased surface roughness (e.g., incorporating mixed clast mantles on covers or mimicking features such as bar and swale topography of alluvial fans) may help to accelerate the development of aeolian deposition and aid in the development of an ET effective surface.

NEXT STEPS IN EVALUATION OF ANALOG SITES

Although many of the processes occurring on covers and the analog sites truly are coupled, the focus of upcoming work will be on describing soil morphology and hydraulic properties at the analog sites for comparison with existing ET covers in the region. Specifically, this will include the following:

- Describing the soil morphology from soil pits or trenches, including evidence of Av horizon development or textural contrast that increases water-holding capacity of soils; and preferential pathways for infiltration including rooting features.

- Measuring water retention properties of soils at various surface environments, and in the shallow subsurface where the root mass of vegetation is concentrated.

- Determining bulk density of soils to compare against engineering criteria typically used for cover construction.

- Measuring infiltration and initial runoff abstraction. Infiltration will be measured in various microenvironments on the surfaces such as where desert pavement has begun to develop, and in areas of dense bioturbation.

- Measuring bulk electrical conductivity using electromagnetic induction to look for evidence of higher water content or lower salinity. Salinity profiles could be a proxy for the typical depth of infiltration that occurs at the analog sites.

- Evaluating the depth of bioturbation by small mammals and evaluating the effects on the hydraulic properties of soils in areas where such bioturbation is concentrated.

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