VEGETATED COVER SYSTEM FOR THE ENERGY*SOLUTIONS* CLIVE SITE: LITERATURE REVIEW, EVALUATION OF EXISTING DATA, AND FIELD STUDIES SUMMARY REPORT

Prepared for

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EXECUTIVE SUMMARY

Evapotranspiration (ET) covers are increasingly being employed as an alternative cover design for municipal solid waste and hazardous waste sites in arid and semiarid climates. Unlike conventional cover systems, which use materials with low permeability to limit movement of water into waste, ET cover systems minimize water percolation by storing and releasing water through evaporation from the soil surface and through transpiration from vegetation. The primary objective of ET cover systems is to use the water balance components of soil and vegetation to hold precipitation and release it through soil surface evaporation or transpiration without allowing water percolation into storage layers.

ET cover systems are desirable because they cost less to construct and maintain, and provide aesthetic benefits because they use native vegetation and materials. However, the ultimate goal of such systems is to prevent the movement or release of waste, and to prevent contamination of surface or groundwater. The use of ET cover systems for waste containment is relatively new. Since the amendment of the Resource Conservation and Recovery Act Subtitle D (40 Code of Federal Regulations § 258.60) in March 2004, ET cover systems and demonstration sites have been installed at hazardous and radioactive waste disposal facilities in the arid west: Hill Air Force Base (Utah), Monticello Mill Tailings (Utah), Los Alamos National Laboratory (New Mexico), Sandia National Laboratories (New Mexico), Sierra Blanca (Texas), Rocky Mountain Arsenal (Colorado), and the Hanford Site (Washington) (Rock et al. 2012). These facilities consist of research and demonstration ET cover systems and fully operational ET covers. In addition to these existing sites, ET cover systems have been proposed for the U.S. Ecology Nevada Site (Nevada), the Molycorp Tailings Facility (New Mexico), and Clean Harbors (Utah).

Energy*Solutions* is evaluating an ET cover system for its proposed Class A West embankment at the Clive Site, Utah. The ET cover system would use locally available soils and native vegetation and would be expected to naturally develop into a stable community that would endure for the 1,000-year life of the landfill cap. This type of cover design is expected to attract grazing and burrowing animals and to follow natural successional development to a climax natural biotic community, and could therefore increase the amount of bioturbation occurring on and around the cover relative to the existing conventional cover design. A literature review of published studies of operational and demonstration ET covers was conducted to identify regionally relevant design parameters and to identify site-specific data needs.

This report summarizes supporting literature on ET cover systems, and evaluates regionally relevant ET cover systems and demonstration sites that have published studies on the physical and biological processes that occur in different ET cover systems.

This report also includes a summary of the geology, climate, biogeography, and biological communities near the Clive Site; and the results of field studies conducted on and around the Clive Site to support the design of a site-specific ET cover design. The objective of field studies was to assess local ecological analogs to the Clive Site to identify the composition and density of biotic communities, assess bioturbation, and to assess soil characteristics and water and soil transport mechanisms.

Field studies were initiated on June 13, 2012, and completed on June 23, 2012. The results of field studies are as follows:

- <u>Vegetation</u>: Average plant species cover consisted of 14.3% black greasewood (*Sarcobatus vermiculatus*), 5.9% Sandberg bluegrass (*Poa secunda*), and approximately 3% cover each of shadscale saltbush (*Atriplex confertifolia*) and Mojave seablite (*Suaeda torreyana*). Fourwing saltbush (*Atriplex canescens*) and gray molly (*Bassia americana*) occurred in low densities with 1.6% and 1.3% cover, respectively. Ground cover was dominated by 79.2% average biological soil crust cover.

- Small Mammal Trapping: In all, 84 small mammals were captured during small mammal trapping, comprising 83 deer mice (*Peromyscus maniculatus*) and one kangaroo rat (*Dipodomys* sp.). Small mammals were concentrated in the northern portion of the study area, with exactly half (42/84 or 50%) of the total small mammal captures in Plots 12 and 13.
- Burrow Surveys: Burrows of deer mice, kangaroo rats, ground squirrels (*Spermophilus* spp.), and badgers (*Taxidea taxus*) were located in the study plots during the field studies.
- Ant Mound Surveys: Nineteen ant mounds were recorded and measured, with an average of 24 ant mounds per hectare. The average individual ant mound area estimate was approximately 1,900 square centimeters (cm^2), and the average ant mound volume estimate was 19,345 cm^3.
- Ant Mound Excavations: The average aboveground area and volume of the excavated ant mounds was 2,683 cm^2 and 28,348 cm^3, respectively. The belowground area of the excavated ant mounds was found to be sparsely distributed, with most of the ant nests within 0.6 meter (2 feet) of the surface.

Analyses of plant species cover, small mammal densities, animal burrow volumes, ant mound volumes, and soil chemistry and nutrition parameters identified several strong relationships between the variables. There were strong, positive relationships between total vegetation cover and mammal densities and burrow volumes. In contrast, there was no correlation between total vegetation cover and ant mound area or volume. There were also strong positive correlations between ant mound area and volume and cover of weedy species. This relationship was anecdotally observed in the 2010 study as well. There was a strong, negative correlation between ant mounds and soil silt, and somewhat strong negative correlations between animal densities and burrow volumes and soil clay content. High soil pH does not appear to be limiting for any of the native or weedy plant species that occurred in the plots. However, plant cover, particularly of shadscale saltbush, showed strong, negative correlations with high soil salinity.

The field study results point to several key design features for an ET cover system at the Clive Site:

- The plant species selected for the ET cover system should consist of native and desirable non-native, salt-tolerant shrubs and grasses.
- Although a vegetation community of sufficient diversity and density is desired to maximize transpiration from the soil, vegetation density was positively correlated with small mammal and burrowing activity. As such, bioturbation should be expected to increase with increasing vegetation cover.
- Small mammal activity should be expected to increase with a developing vegetation community that is established as part of an ET cover system. The field studies demonstrated that the density of small mammals and animal burrows increases with increasing vegetation cover.
- The presence of badgers and a large family of burrowing owls (*Athene cunicularia*) in the study plots indicates that the biota can potentially move large volumes of soil. A bioturbation barrier will be needed. Cover designs that maximize the depth of upper soil layers or that incorporate bioturbation barriers would also minimize penetration by ants into waste layers.
- Soil conditions on and near the Clive Site are typical of soils formed in arid environments. Soils were mostly silty clay loams with elevated pH and salinity and low organic matter. The soils collected in the study plot soils are not analogous to soils in the borrow units. For example, the following may be necessary: blending borrow soils to obtain the proper texture that allows for enough infiltration to support plants while avoiding deep infiltration and excessive runoff.

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INTRODUCTION

Energy*Solutions*' facilities at the Clive Site must meet regulatory requirements for containing waste and waste byproducts, prevent the infiltration of precipitation into final storage layers, and prevent the movement of waste into the surrounding environment. Waste products at the Clive Site are currently buried beneath an impermeable clay layer and capped with concrete riprap. Energy*Solutions* is evaluating an alternative ET cover system for its proposed Class A West embankment at the Clive Site, Utah. Permitting of an ET cover system will require that Energy*Solutions* provides scientifically rigorous data supporting the long-term functionality of such a system under expected and worst-case scenarios for the required 500–1,000-year functional life of the cap.

Evapotranspiration (ET) covers are increasingly being employed as an alternative cover design for municipal solid waste and hazardous waste sites in arid and semiarid climates. Unlike conventional cover systems, which use materials with low permeability to limit movement of water into waste, ET cover systems minimize water percolation by storing and releasing water through evaporation from the soil surface and through transpiration from vegetation. The primary objective of ET cover systems is to use the water balance components of soil and vegetation to hold precipitation and release it through soil surface evaporation or transpiration without allowing water percolation into storage layers.

ET cover systems are desirable because they cost less to construct and maintain, and provide aesthetic benefits because they use native vegetation and materials. However, the ultimate goal of such systems is to prevent the movement or release of waste, and to prevent contamination of surface or groundwater. The use of ET cover systems for waste containment is relatively new. Since the amendment of the Resource Conservation and Recovery Act Subtitle D (40 Code of Federal Regulations § 258.60) in March 2004, ET cover systems and demonstration sites have been installed at hazardous and radioactive waste disposal facilities in the arid west: Hill Air Force Base (Utah), Monticello Mill Tailings (Utah), Los Alamos National Laboratory (New Mexico), Sandia National Laboratories (New Mexico), Sierra Blanca (Texas), Rocky Mountain Arsenal (Colorado), and the Hanford Site (Washington) (Rock et al. 2012). These facilities consist of research and demonstration ET cover systems and fully operational ET covers. In addition to these existing sites, ET cover systems have been proposed for the U.S. Ecology Nevada Site (Nevada), the Molycorp Tailings Facility (New Mexico), and Clean Harbors (Utah).

Energy*Solutions* is evaluating an ET cover system for its proposed Class A West embankment at the Clive Site, Utah. The ET cover system would use locally available soils and native vegetation and would be expected to naturally develop into a stable community that would endure for the 1,000-year life of the landfill cap. This type of cover design is expected to attract grazing and burrowing animals and to follow natural successional development to a climax natural biotic community, and could therefore increase the amount of bioturbation occurring on and around the cover relative to the existing conventional cover design. A literature review of published studies of operational and demonstration ET covers was conducted to identify regionally relevant design parameters and to identify site-specific data needs.

ET cover systems are designed to store infiltrated water within a monolithic soil layer until it is removed by evaporation from the soil surface or through transpiration by vegetation. The proposed ET cover system would incorporate fine materials such as sand, silt, or clay to provide stability and protection from erosion, and to enhance ET relative to the existing design. The cover would incorporate some amount of coarse material to provide stability in the uppermost layers and to prevent burrowing animal access to waste or contaminated soils.

Small amounts of radiation may be absorbed by soils surrounding low-level radioactive waste. As such, soil turbation by plants and animals is a key consideration in the design of alternative cover systems, because bioturbation can transport buried waste to upper layers of the subsurface soil profile or to the soil surface. Studies of existing, traditional waste covers, and alternative cover systems indicate that ants, burrowing mammals, and deeply rooted plants are the primary biota of interest for movement and mixing of soils in arid ecosystems (Arthur et al. 1983; Arthur and Markham 1983; Cadwell et al. 1989; Smallwood et al. 1998; Mackay and Gaglio 1999; Hampton 2006). Ants and burrowing mammals provide constant mixing of the soil column, whereas plants can move buried wastes through root uptake and translocation of contaminants to various parts of the plant. Contaminants can also be transported by animal consumption of contaminated plants or by other means.

An ET cover system at the Clive Site would use locally available soils and native plant species that would be expected to naturally develop into a stable community that would endure for the life of the cap. Because alternative cover designs allow and potentially encourage plant growth to enhance ET and enhance stability, careful evaluation of the plant materials used for cap vegetation and the associated biotic community is required. This type of cover design is expected to attract grazing and burrowing animals, to follow natural successional development over the life of the cap, and could therefore increase the amount of bioturbation occurring on and around the cover relative to the current cover design.

In 2010, SWCA Environmental Consultants (SWCA) was contracted by Energy*Solutions* to assess soil bioturbation in biotic communities at and near the Clive Site. Five study plots were established: three on the Clive Site, and two off the Clive Site on lands administered by the Bureau of Land Management (BLM). These plots were selected to represent the range of existing biotic conditions at the Clive Site, and to represent potential biotic communities that could exist on the site a minimum of 1,000 years into the future. At each site, the following data were collected: ant diversity, nest size, and densities; plant species diversity, cover, and stem densities of grasses, forbs, shrubs, and trees in each vegetation association; and burrowing mammal diversity, burrow density, and estimates of soil excavation in each vegetation association. In addition to these data, site excavations were conducted at six locations on the Clive Site (Plots 3 and 4) to measure the maximum rooting depth and width of root masses of the dominant plant species at each site (SWCA 2010).

In March 2012, Energy*Solutions* retained SWCA to gather and summarize regional and site-specific data regarding the physical and biological processes that would occur in an alternative (ET) cover system. This report summarizes SWCA's review of supporting literature and existing vegetated cover systems and regional demonstration sites. Because the alternative cover performance timeframe is 500–1,000 years, climatic conditions significantly different than current climate in the region are not considered in this review.

Site-specific data from ecological analogs relevant to the Bonneville Basin and the Clive Site are also needed to support the design of an alternative cover system. This review includes a summary of additional data needed in support of a site-specific ET cover design. These data include site-specific scientific studies of local ecological analogs for climate, biotic communities, soils, bioturbation, and other water and soil transport mechanisms. Field studies to assess vegetation and animal diversity and densities, animal burrows and ant mounds, soils, and erosion mechanisms were conducted in June 2012.

Evapotranspiration Cover Systems

Final cover systems for waste landfills have relied on conventional designs that rely on a barrier layer to impede the downward percolation of precipitation and to minimize leaching of contaminants into groundwater (McGuire et al. 2009; Rock et al. 2012). Alternatively, ET cover systems are designed to take advantage of the ability of locally available soils and plants to store and release water through soil storage capacity and evaporation from the soil surface, and transpiration by vegetation (Hakonson 1997; Hauser et al. 2001; Dwyer 2003). ET cover systems are constructed of a uniform (monolithic) layer of soil, or monofill covers (Hauser 2009), or modified to provide a capillary break to impede the downward movement of water, or to provide layers that provide structural support or prevent burrowing by animals. There are numerous current publications that outline design requirements and considerations for ET cover systems (Hakonson et al. 1994; Gee et al. 1997, 1998; Benson et al. 2002; Albright et al. 2002, 2010; Hauser 2009; Environmental Protection Agency [EPA] 2011).

ET covers are increasingly being employed as an alternative cover design in arid and semiarid climates (Benson et al. 2005; EPA 2003). Because ET covers limit water percolation by storing water in upper soil layers and releasing it through soil surface evaporation and transpiration from vegetation (Albright et al. 2006; Albright et al. 2010; McGuire et al. 2009; EPA 2011), these systems do not function properly in humid environments (Albright and Benson 2005). Although the ET cover also functions to limit erosion and runoff, the primary objective of ET cover systems is to use the water balance components of soil and vegetation to hold precipitation and release it through soil surface evaporation or transpiration without allowing water percolation into storage layers (EPA 2011).

Predictive models have been widely used to assess the performance of alternative landfill cover systems (Benson et al. 2005; Fayer et al. 1992; Gee et al. 2005; Khire et al. 2000; Scanlon et al. 2005; Zornberg et al. 2003) and demonstration cover designs (Albright et al. 2004; Andraski 1997; Chadwick et al. 1999; Dwyer 2001; Gee et al. 2002; Melchior 1997; Ward and Gee 1997). The objective of numerical predictive models is to aid ET cover design by quantifying the performance and limitations of different cover designs under differing soil depths, impermeable layer components, vegetation composition, and climatic conditions. In general, predictive models are used to quantify percolation into an ET from the vadose zone for different cover designs under varying climatic conditions. Models do not replace data collection and experimental assessment of cover designs (Schwartz et al. 1990).

Need for an Evapotranspiration Cover System at the Clive Facility

Energy*Solutions*' facilities at the Clive Site must meet regulatory requirements for containing waste and waste byproducts, prevent the infiltration of precipitation into final storage layers, and prevent the movement of waste into the surrounding environment. The permitting and design of the Clive Site is regulated under 10 Code of Federal Regulations § 61.51(a) (Disposal site design for near-surface disposal), and Utah Administrative Code R649-9 (Waste Management and Disposal). To meet these requirements, an ET cover system must be designed such that there is long-term isolation of the waste and avoidance of continuing active maintenance after site closure. Waste products at the Clive Site are currently buried beneath an impermeable clay layer and capped with concrete riprap. Energy*Solutions* is evaluating an alternative ET cover system for its proposed Class A West embankment at the Clive Site, Utah.

Energy*Solutions* requires support on the following:

- The timing of establishment and the characteristics of the biological system(s) that will develop on a Clive Facility embankment with an ET cover
- Pertinent data to inform performance modeling (primarily hydrologic) of the embankment
- Potential design and construction recommendations to improve/enhance cover performance and stability

Evapotranspiration Cover Design Considerations

There have been two federal research programs to evaluate the performance of ET cover systems: 1) the Alternative Landfill Cover Demonstration (Dwyer 2003) and 2) the Alternative Cover Assessment Program (Benson et al. 2002; Albright and Benson 2005). These research programs have contributed to a set of design considerations and site specific data that should be compiled to inform site-specific design of an ET cover system.

General Design Considerations

The purpose of this literature review is to provide Energy*Solutions* with scientifically supported information on the current and historic biological systems that occur on and adjacent to the Clive Site, and to identify data needs to inform the design of an ET cover system. There are several studies of existing and demonstration cover systems in the arid Southwest (Albright et al. 2010; Dwyer 1998, 2003; Dwyer et al. 2000; McGuire et al. 2009; Rock et al. 2012; Warren et al. 1997; Waugh et al. 2008) that demonstrate a general set of site-specific data that would be required for the design an ET cover system and for subsequent modeling of preliminary cover designs or demonstration sites. The general parameters that should be assessed are climate, soils, vegetation, and animal activity. Site-specific data needs should consist of evaluating historic climate, geology, and plant and animal communities; assessment of on-site climate, soils, and biotic communities; and laboratory analyses of soil chemistry and nutrition (*sensu* Albright et al. 2010). The following sections outline the specific parameters that should be evaluated:

CLIMATE

The total water storage required for the uppermost soils layers is determined by the total annual precipitation relative to the growing season, temperature, and resulting total annual ET (EPA 2000; Hauser et al. 2001). The timing of precipitation should also be considered because high-volume precipitation events or spring snowmelt can demand large soil water storage capacity even though total annual precipitation is low.

- Precipitation: Annual average and extreme precipitation, seasonal time series of average precipitation, snowfall (average and extreme), snow depth (average and extreme)
- Temperature: Annual average and extreme temperature, seasonal time series of average temperature, heating degree days, cooling degree days, growing degree days
- Severe weather: Extended periods of drought, extended wet periods
- Shifts and trends: Long-term trends or shifts in seasonality of precipitation and temperature
- Past climate: Proxy records of past changes in climate, extended meteorological records or detect long-term shifts and trends in drought, wet periods, seasonality of precipitation, and temperature Tree ring records, pollen records, and packrat middens are examples of proxy records

- Global change projections: Models, future scenarios
- Other parameters: Solar radiation, humidity, wind speed and direction, micro-meteorology

SOIL COMPOSITION AND CHEMISTRY

Single-layer ET cover systems and capillary barrier systems have typically been constructed of silt or clay because of the high porosity and water-holding capacity of these find-grained soils (Rock et al. 2012). Soil bulk density and particle size are both determinants of water storage capacity, with high bulk density soils having low water storage capacity as well as limited plant growth (Chadwick et al. 1999; Hauser et al. 2001). The depth of monolithic or topsoil layers will depend on water storage capacity and structural concerns based on slope of embankments and likelihood of large volume precipitation events. ET cover systems have been constructed with soil layers 0.6–3.0 meters (m) (2–10 feet) thick.

- Soil types and distributions
- Geomorphic history geomorphology
- Drainage Patterns: Rilling, channel density, aeolian deposits, and channels
- Krotovinas: Animal burrows that have been filled with organic or mineral material from another horizon; evidence of animal burrows and root channels
- Soil Morphology: Samples collected at borrow location study sites only
- Soil Classification: Soil series descriptions and distributions of soil types
- Soil Profile: Soil horizonation, including presence/absence of calcium carbonate horizons (location and degree of calcite development; *sensu* Rettalack 1988)
- Soil physical properties
- Standard Soil Physical Properties: Texture or particle size (% sand, silt, and clay), gravel and cobble content, dry-weight bulk density (compaction), porosity, pH, electrical conductivity (salinity), cation exchange capacity (CEC), sodicity (sodium adsorption ratio (SAR) or exchangeable sodium percentage)
- Soil samples would be collected at the surface of ecological analogue study sites, and at the surface and at depth at borrow source study sites.

SOIL FERTILITY

Topsoil layers need sufficient fertility to support the survival and growth of a functioning vegetation community. Soils used for upper layers of the cover should be evaluated to determine if the pH, CEC, organic matter, nitrogen, phosphorus, potassium, and micronutrient content is sufficient to support the target vegetation. Although there are numerous soil amendments that can be used to improve soil fertility, organic matter content, and water holding capacity, the use of such amendments is expensive, and may require levels of maintenance that are not sustainable over the long term (Rock et al. 2012). Ideally, soil borrow materials will be of sufficient quality to support the establishment and succession of a native vegetation community. The soil fertility parameters that should be evaluated are macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur), micronutrients (manganese, iron, zinc, copper, molybdenum, chloride, and boron), and soil texture and organic matter content.

VEGETATION

Vegetation is established on the ET cover to promote transpiration of water from soil and to stabilize surface materials. ET cover systems should use native plant species that are well-adapted to local conditions, as well as a mixture of cool- and warm-season species (e.g., grasses and forbs) so that components of the vegetation community are physiologically active for the entire growing season (Dwyer et al. 1999).

To this end, the historic and current vegetation diversity of the region should be evaluated to identify appropriate species for revegetation, and expected patterns of succession from the installation of the target vegetation community to potential climax vegetation communities (Albright et al. 2010). The following vegetation community characteristics should be evaluated:

- Plant species richness
- Relative vegetation cover and density (number of plants per unit area) and spatial distributions (e.g., clumped, uniform, random)
- Vegetation structure and growth forms (e.g., grass, forb, shrub, tree)
- Species tolerances to disturbance, fire, grazing, disease, invasive species, drought
- Life histories of dominant plant species to identify season of growth (e.g., annual, perennial, evergreen, deciduous), and time to maturity and senescence
- Average and maximum rooting depths of dominant plant species

Transpiration indices have also been recommended as a method to assess potential ET by species and vegetation community. These measures are costly, and there are limited published leaf area indices (Albright et al. 2010).

BIOTURBATION

An ET cover system must also be designed to use the natural biotic community and physical characteristics of the site to enhance the performance of the cover system. That is, to minimize water infiltration and erosion, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity. Bioturbation is the mixing of underlying soils and geologic materials, and movement of these materials to the soil surface where they are exposed to the surrounding atmosphere (Smallwood et al. 1998). Animal burrowing contributes to soil formation, mixing, and erosion (Hole 1981; Smallwood et al. 1998), which, in combination with plant and fungal growth, transports materials from underlying rock to open air. The long-term stability of ET cover systems can be adversely affected by the loss or movement of soil caused by physical and biological processes. Physical processes consist of deflation (erosion) by wind or water, soil compaction, soil eluviation, and cryoturbation (sorting and heaving from freeze-thaw processes). Biological processes consist of bioturbation or biointrusion impacts from plant root growth and animal burrowing or other activities by animals. These processes can alter soil structure and soil evaporative potential, and can facilitate the movement of contaminants from storage layers to the soil surface, where further movement of contaminants occur by wind, water, or biotic activity.

Western harvester ants (*Pogonomyrmex occidentalis*) play a significant role in pedogenesis (soil development) (Carlson 1991; Green 1998; Mandel 1982; Salem 1968). This species moves large amounts of soil to the land surface during mound construction (Mandel 1982). Ants also increase soil fertility, porosity, water-holding capacity, and hydraulic conductivity during nest construction and subsequent movement of organic matter below ground (Green 1998; Wheeler 1986). The population size of a western harvester ant colony is estimated to be 400–9,000 individuals, with the average lifespan of a colony around 44 years (Keeler 1993). Mature mounds are cone-shaped, and average about 1 m (3.2 feet) in diameter and 35 cm (13.7 inches) in height (Scott 1951). Western harvester ant nest can be up 6 m (10.6 feet) deep. And, although western harvester ants clear the vegetation on and several meters around their nests, they secrete materials onto the mound to waterproof and stabilize its surface (Taber 1998; Wheeler 1963). Because of their large numbers and ubiquitous distributions, ants are a significant source of bioturbation and associated movements of hazardous wastes.

Examinations of ecological analog sites allow evaluation of soil turbation processes relevant to site-specific ET cover design. Key processes and soil components that could limit or enhance ET cover functioning need to be identified on a site-specific basis. The following should be evaluated for soil borrow sources and ecological analog locations: soil structure, soil composition, maximum potential rooting density and rooting depth of dominant plant species, animal burrowing densities and depths, and the potential vegetation that would be supported by a given soil type.

The following bioturbation parameters may be collected depending on the system being assessed:

- Habitat value of vegetation communities for grazing livestock and game animals
- Burrowing animal species composition and density
- Animal species burrow densities, depths, and soil volumes removed and replaced
- Soil sampling to determine how bioturbation affects soil properties
- Plant species areal cover: density relationships
- Plant species rooting densities and maximum rooting depths

Control layers that are designed to prevent penetration of waste layers are used in both conventional and ET cover systems (Rock et al. 2012). Control layers of rock or other coarse material can be used to prevent animal intrusion and exclude plant roots to some extent. These layers can also serve as capillary barriers that prevent the downward movement of water while excluding burrowing animals.

Regionally Relevant Evapotranspiration Cover Systems and Demonstration Sites for Hazardous Waste

The objective of ET cover systems is to store precipitation and release the water from the soil surface (evaporation) or from vegetation (transpiration). This "store and release" cover type requires that the potential ET of the area is greater than annual average precipitation. The Clive Site is well suited for this type of final cover design. The location of the Clive Site relative to other hazardous or radioactive waste sites in the arid southwest is shown in Figure 1.

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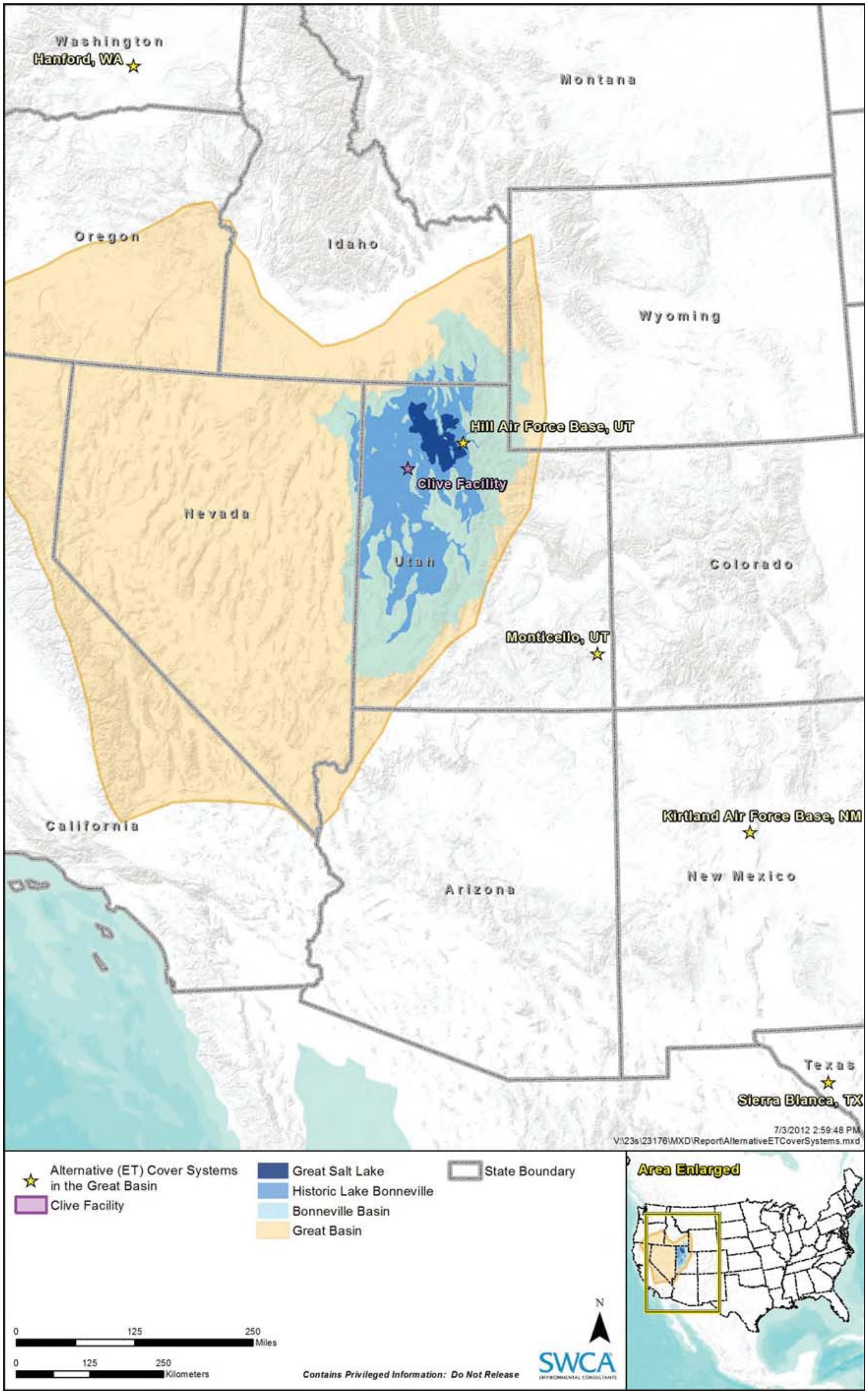

Figure 1. Location of the Clive Facility relative to other alternative (ET) cover systems for radioactive or hazardous waste in the Bonneville Basin, Great Basin, and arid west.

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SWCA conducted a literature review of recent and current ET cover systems and demonstration sites. The focus of the review was on the arid southwestern United States, with particular focus on systems in the Great Basin and other desert regions that are ecologically similar to the Clive Site. The location of the Clive Site in Utah's West Desert makes it comparable to other cold desert ecosystems, which are characterized by annual average precipitation of less than 400–500 millimeters (mm) (16–20 inches) and winter temperatures below freezing. On average, the Clive Site receives approximately 200 mm (8 inches) annual precipitation, and total annual ET would exceed total precipitation, even where precipitation occurs predominantly as snow in the winter when ET rates are very low. The low precipitation and high ET:precipitation ratio in the West Desert region of the Bonneville Basin and at other existing hazardous waste containment sites in the arid west, makes them well-suited for ET cover systems.

Numerous experimental and demonstration ET cover systems exist in the western United States (EPA 2011). Alternative cover systems for waste containment in arid and semiarid regions include monolithic ET covers, capillary barrier ET covers, and anisotropic barrier ET covers (Scanlon et al. 2005). These designs all use enhanced water storage in soil layers to reduce water percolation into waste (Albright et al. 2002; Scanlon et al. 2005). Review of the literature and other sources of data identify only a few research and demonstration sites for ET cover systems for hazardous or radioactive waste that possess meteorological, geological, and biological conditions similar to those at the Clive Site. These are Hill Air Force Base in Ogden, Utah; the Monticello uranium mill tailings disposal cell in Monticello, Utah; the Hanford Site in Richland, Washington; Sierra Blanco in northwestern Texas; and the Alternative Covers Assessment Program at Kirtland Air Force Base in Albuquerque, New Mexico. These sites also represent some of the most up-to-date research on alternative cover systems. There are numerous additional alternative cover systems in the arid southwest that could serve as important reference sites for the Clive Site, but many research and demonstration sites are outdated or obsolete (e.g., Andraski 1997), or there are limited or no published data available for the site. In addition, supporting information for the Clean Harbors proposed ET cover in Knolls, Utah, was evaluated, but the site is not described here because the project is not yet constructed, and the cover will not be vegetated. Several additional ET cover systems have been proposed or approved in the arid southwest, but have not been completed. These include the U.S. Ecology Nevada Site in Beatty, Nevada (approved), and the Idaho National Engineering Laboratory Superfund Site in Idaho Falls, Idaho (proposed) (Rock et al. 2012).

In general, operational, experimental, and demonstration ET cover systems have been successful in enhancing soil water storage, evaporation, and transpiration by cover vegetation once established. Successful establishment of cover vegetation has been shown to be a vital feature for enhancing water movement out of the cover and preventing drainage into underlying storage layers (Dwyer 2003; Scanlon et al. 2005). Initial vegetation establishment often requires supplemental irrigation that may contribute to initial drainage; however, nearly all of the sites examined showed that drainage ceased two or more years after construction (Scanlon et al. 2005). Capillary breaks have also been shown to prevent or minimize percolation into lower layers under most conditions (Hakonson 1997; Hauser et al. 2001; Dwyer 2003). Key considerations for design are the depth and density of soil layers. Other considerations, particularly biological composition and bioturbation, were not studied at most of the sites examined for this summary. Additional information on the potential biota of the proposed ET cover system is needed. The following pages summarize existing alternative cover systems that would be relevant to the physical and ecological conditions at the Clive Site.

HANFORD SITE/US DEPARTMENT OF ENERGY

Location: Richland, Washington	**Average Annual Precipitation:** 172 mm/year 1994–2002	
Type of Cover System: ET	**Position:** Above grade	
Design Target: < 0.5 mm/year water recharge for 1,000-year design life		
Date Constructed: 1994	**Status:** Experimental/full-scale operational project	
ET Layer Materials (upper-lower)	**Depth**	**Purpose**
Silt-loam soil with admix	1 m	ET/stability/H_2O storage
Silt-loam	1 m	ET/H_2O storage
Sand	0.15 m	Filter
Gravel	0.30 m	Filter
Basalt rock riprap	1.50 m	Barrier
Gravel	0.30 m	Drainage
Composite asphalt	0.15 m	Barrier
Top course	0.10 m	Barrier
Sandy soil	n/a	Fill
Materials source: Gee et al. 2002		
Monitoring/Research	**Results**	**Source**
ET	Met design target	Gee et al. 2002
Drainage/hydrology	Met design target	Gee et al. 2002
Erosion	No measurable erosion	Gee et al. 2002
Hydrologic modeling	Silt-loam layer H_2O storage exceeds 480-mm/year	Campbell et al. 1990; Gee et al. 1993b
Irrigated gravel side slope 10:1	Less drainage than expected	Sackschewsky et al. 1995; Ward and Gee 1997; U.S. Department of Energy 1999; Gee et al. 1993a, 2002
Irrigated basalt side slope 2:1	Less drainage than gravel	
Non-irrigated gravel side slope 10:1	Less drainage than expected	
Non-irrigated basalt side slope 2:1	Less drainage than gravel	
Vegetation composition	Sagebrush-rabbitbrush at 2 shrubs/m^2	Gee et al. 1996, 2002
Revegetation success	75% cover; 57%–97% revegetation species survival	Gee et al. 1996
1,000-year event (71 mm/8 hours)	Within design target	Gee et al. 1997, 2002
Max precipitation (480 mm/year)	Within design target	Gee et al. 1997, 2002

MONTICELLO URANIUM MILL TAILINGS DISPOSAL CELL/USDOE

Location: Monticello, Utah	**Average Annual Precipitation:** 390 mm/year	
Type of Cover System: ET	**Position:** Above grade	
Design Target: UMTRCA 200–1000-year design life; annual average percolation < 3.0 mm		
Date Constructed: 2000	**Status:** Operational (2012 CERLA review)	
ET Layer Materials (upper-lower)	**Depth**	**Purpose**
Gravel admix	20.0 cm	Stability, storage
Topsoil	41.0 cm	ET, storage
Fine-grained soil	41.0 cm	Storage, growth medium, frost protection
Cobbles filled with fine soil	30.5 cm	Animal intrusion barrier
Fine-grained soil	30.5 cm	Capillary barrier
Geotextile fabric	n/a	Enhance ET performance
Coarse sand	30.0–38.0 cm	Capillary barrier
HDPE geomembrane	n/a	Infiltration barrier
Compacted soil	60.0 cm	Radon/infiltration barrier
Materials source: Waugh 2002; Waugh et al. 2008		
Monitoring/Research	**Results**	**Source**
ET	Percolation < 3mm/year; 150 cm loam and clay designs had best performance	Waugh 2002; Waugh et al. 2008
Climate/edaphic factors	All percolation occurred during one exceptionally wet year	Waugh et al. 2008
Drainage/hydrology	Cumulative percolation 0.6 mm/year	Waugh et al. 2008
Water storage capacity	80%–90% of computed storage capacity based on soil water characteristic curves	Waugh 2002; Waugh et al. 2008
Soil hydraulic properties	Percolation was 100–1,000 times less than conventional cover systems	Waugh 2002; Waugh et al. 2008
Vegetation establishment	Success criteria of 40% not met until 2006	Sheader and Kastens 2008; Waugh et al. 2008
Vegetation density	Total of 28–142 shrubs/acre < target of 1,000 shrubs/acre	Waugh et al. 2008

HILL AIR FORCE BASE

Location: Ogden, Utah	**Average Annual Precipitation:** 436 mm/year	
Type of Cover System: ET	**Position:** Above grade	
Design Target: Lysimeter-based testing of five cover designs		
Date Constructed: ca. 1991	**Status:** Experimental	
ET Layer Materials (upper-lower)	**Depth***	**Purpose**
Vegetation	Native grasses/native grasses/native grasses and shrubs/none/native grasses	ET, stability
Gravel mulch	0.0cm/1cm/1cm/0.0cm/0.0cm	Erosion control
Sandy-loam at 1.86 g/cm compaction	0.9m/1.5m/1.5m/0.0m/1.2m	ET, stability, storage
Silt-loam with 15% pea gravel	0.0m/0.0m/0.0m/1.0m/0.0m	ET, erosion control, storage
Silt-loam	0.0m/0.0m/0.0m/1.0m/0.0m	ET, storage
Geotextile (GT)	None/GT/GT/GT/GT	Barrier
Sand	0.0m/0.0m/0.0m/0.15m/0.3m	Drainage
Gravel	0.0m/0.3m/0.3m/0.15m/0.0m	Barrier
Clay at 4% slope	0.0m/0.0m/0.0m/0.0m/0.6m	Lateral water diversion
* Depths listed for five cover types: Control (ET) cover/capillary barrier cover with grasses only/capillary barrier cover with grasses and shrubs/Hanford-type cover/modified RCRA cover; materials source.		
Monitoring/Research	**Results**	**Source**
ET	n/a	
Drainage/hydrology	41 cm/24.0cm/30.0cm/0.0cm/0.01cm	Warren et al. 1997
Erosion	n/a	
Biointrusion/bioturbation	n/a	
Drainage	All cover types had drainage possibly due to high soil density/low water holding capacity, limited plant root growth, and/or above-average snowfall and subsequent snowmelt	Warren et al. 1997

KIRTLAND AIR FORCE BASE/SANDIA NATIONAL LABORATORIES

Location: Albuquerque, New Mexico	**Average Annual Precipitation:** 220 mm/year
Type of Cover Systems: Capillary barrier/anisotropic/ET	**Position:** Above grade
Design Target: Testing of rates of annual percolation from traditional and alternative cover systems	
Date Constructed: 1995–1996	**Status:** Demonstration project

Capillary Barrier Materials (upper-lower)	**Depth**	**Purpose**
Topsoil	0.30 m	Growth medium, storage
Sand	0.15 m	Filter
Gravel	0.22 m	Drainage
Compacted native soil (fine)	0.45 m	Capillary barrier
Sand (coarse-grained)	0.30 m	Capillary barrier
Anisotropic Capillary Barrier Materials (upper-lower)	**Depth**	**Purpose**
Topsoil and pea gravel mixture	0.15 m	Stability, erosion control
Native soil (fine-grained)	0.60 m	Anisotropic capillary barrier
Fine sand	0.15 m	Wicking layer
Pea gravel (coarse-grained)	0.15 m	Anisotropic capillary barrier
ET Cover Materials (upper-lower)	**Depth**	**Purpose**
Topsoil with gravel veneer	0.15 m	Stability, erosion control
Native soil	0.90 m	ET barrier
Materials source: Dwyer 1997, Scanlon et al. 2005		

Monitoring/Research	**Results**	**Source**
Capillary barrier system	Average annual percolation of 0.87 mm; percolation higher than expected first year, slowed as vegetation developed.	Dwyer 1998, Dwyer et al. 2000; Scanlon et al. 2005
Anisotropic capillary barrier	Average annual percolation of 0.16 mm; percolation rate decreased as vegetation developed.	Dwyer 1998, Dwyer et al. 2000
ET cover system	Average annual percolation of 0.19 mm; percolation rate was lowest of the test systems by third year of testing; most effective at controlling infiltration. Drainage of 0.1-0.4 mm/year occurred only in the first 2 years of 5-year study.	Dwyer 1998, Dwyer et al. 2000; Scanlon et al. 2005
Vegetation cover	Drill-seeding with cool-season and warm-season native grasses was successful. Opportunistic shrubs (Atriplex spp.) also developed on the cover.	Scanlon et al. 2005
Hydrologic modeling	HELP/UNSAT-H (neither program was sufficiently accurate for regulatory settings).	Dwyer 2003; Scanlon et al. 2005

SIERRA BLANCA

Location: Chihuahuan Desert, Texas	**Average Annual Precipitation:** 311 mm/year	
Type of Cover System: GABET/CBET	**Position:** Above grade	
Design Target: Monitoring of prototype engineered covers for proposed low-level radioactive waste disposal site		
Date Constructed: 1997	**Status:** Experimental prototypes for proposed facility	
ET Layer Materials (upper-lower)	**Depth***	**Purpose**
Vegetation + mulch pad of 20-mm aspen shavings with biodegradable net	Five perennial warm-season bunchgrass species. Seedlings transplanted second year.	ET, stability
Sandy clay loam at 1.5 milligrams/m^3 bulk density with gravel (24% by weight)	0.3 m/0.3 m	ET, stability, erosion control, storage
Sandy clay loam at 1.8 mg/m^3 bulk density		ET, storage
Geosynthetic clay layer	1.3 m/none	resistive barrier
Sand	none/2.0 m	capillary barrier
Muddy gravel	none/ca. 2.3 m	not specified
Gravel	none/ca. 2.5 m	not specified
Sand	none/ca. 2.8 m	capillary barrier
* Depths listed for 2 cover types: geosynthetic clay layer overlying an asphalt barrier (GABET)/capillary barrier design (CBET)		
Monitoring/Research	**Results**	**Source**
ET	Vegetation was key in promoting rapid water storage and controlling water balance of both systems, particularly due to monsoonal precipitation during growing season.	Scanlon et al. 2005
Drainage/hydrology	0.4–0.5 mm/year estimated drainage due to irrigation (226–2,340 mm/year)	Scanlon et al. 2005
Erosion		Scanlon et al. 2005
Biointrusion/bioturbation	n/a	
Drainage	Capillary barriers increased water storage by a factor of 2.5 and prevented drainage.	Scanlon et al. 2005
Hydrologic modeling	Measured water balance was successfully reproduced by the models. Twenty-five-year models predicted drainage due to drainage events. Models were most sensitive to the presence/absence of vegetation and soil hydraulic parameters.	Scanlon et al. 2005

Geologic and Biogeographic History of the Clive Site

Energy*Solutions*' Clive Site is located in Tooele County, Utah, on the eastern edge of the Great Salt Lake Desert at ca. 40.690891˚ latitude -113.112073˚ longitude at approximately 1,307 meters (m) (4,288 feet) (in elevation (Figure 2). The Clive Site is nearly centrally located within the Bonneville Basin region of the Great Basin. The Clive Facility is located approximately 40 miles west of Great Salt Lake to the west of the Cedar Mountains and southwest of the Grassy Mountains. The facility is in a low elevation basin, with surrounding mountains rising to approximately 2,012 m (6,600 feet) and the highest elevations in the Deep Creek Mountains to the south rising to 3,658 m (12,000 feet).

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Figure 2. Location of the Clive Facility.

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The Bonneville Basin is the remains of ancient Lake Bonneville, a large closed-basin lake that inundated the Great Basin from approximately 32,000 to 14,000 years ago (Oviatt 1997). The Bonneville Basin occurs within the Basin and Range physiographic province (McNab and Avers 1994). The area is characterized by small, north-south-trending mountain ranges separated by valleys formed by alluvial erosion and sedimentation. The valleys are dominated by saltbush-desert scrub vegetation, playas, and salt flats. Elevation in the area ranges from approximately 1,200 to 2,400 m (4,000 to 8,000 feet).

The climate of the Bonneville Basin is semiarid with hot, dry summers and cold, dry winters. Average annual temperatures are from 7 degrees Celsius (°C) to 13°C (45 degrees Fahrenheit [°F] to 55°F) and the growing season ranges from 60 to 150 days (McNab and Avers 1994). The climate of Utah's West Desert is among the driest in the United States (Jewell and Nicoll 2011). Annual average precipitation is from 10.0 to 25.0 centimeters (cm) (4 to 10 inches), with most precipitation occurring in late winter and early spring (Knapp 1994, McNab and Avers 1994).

The topography of the West Desert of Utah, or Great Salt Lake Desert, is characterized by the aeolian formation of dunes. This pattern is present just south of Knolls, Utah, in the immediate vicinity of the Clive Site. The formation of dune features as a result of aeolian transport of fine materials or sand occurs in a pattern produced by predominant southwesterly winds, but wind direction can be highly variable (Jewell and Nicoll 2011).

Biotic Communities

Historic Flora

The historic vegetation communities of the lowlands of the Bonneville Basin were dominated by sagebrush and coniferous forest, and contained a species composition similar to the flora of montane areas of the basin today due to the colder and moister climate of the late Pleistocene/early Holocene (Rhode et al. 2005). The climate has been following a significant drying trend since the end of the Pleistocene, with the vegetation trending toward shrub-dominated stands of sagebrush (*Artemisia* spp.) and shadscale (*Atriplex* spp.). The vegetation communities that dominated throughout the Holocene were similar to the current vegetation: xerophilic shrub communities dominated by sagebrush, shadscale, black greasewood (*Sarcobatus vermiculatus*), and horsebrush (*Tetradymia* spp.) (Rhode et al. 2005).

Historic Fauna

A detailed record of historic small animal and plant occurrences in the Bonneville Basin has been identified from Homestead Cave on the southwestern edge of Great Salt Lake, which contains fossil-rich stratified layers of woodrat (*Neotoma* spp.) middens, owl pellets, and other remnants of animal occupation (Grayson 2000, 2006; Madsen 2000).

The fauna of the Bonneville Basin historically included bison (*Bison bison*), pronghorn (*Antilocapra americana*), desert bighorn sheep (*Ovis canadensis nelsoni*), mule deer (*Odocoileus hemionus*), and extensive populations of lagomorphs (rabbits and hares), and sage-grouse. Historic large predators included grizzly bear (*Ursus arctos*), gray wolf (*Canis lupus*), cougar (*Felis concolor*), and coyote (*Canis latrans*). Bison, grizzly bear, wolf, and bighorn sheep were extirpated following European colonization. There have been several reintroductions of large animals to the basin, such as desert bighorn sheep in the Deep Creek Mountain Range, elk (*Cervus canadensis*) in the Canyon Mountain Range, and bison to Antelope Island in Great Salt Lake.

The fauna associated with the open xerophilic shrublands that have dominated the landscape of the Bonneville Basin for the past 10,000 years are predominantly small mammals: cottontail rabbits (*Sylvilagus* spp.), pygmy rabbits (*Brachylagus idahoensis*), kangaroo rats (*Dipodomys* spp.), voles (*Microtus* spp.), pocket mice (*Perognathus* spp.), harvest mice (*Reithrodontomys* spp.), pocket gophers (*Geomys* and *Thomomys* spp.), woodrats (*Neotoma* spp.), and marmots (*Marmota* spp.; Grayson 1993, 1998; Madsen et al. 2001; Rhode et al. 2005).

The historic fauna of the Bonneville Basin included harvester ants (*Pogonomyrmex* spp.) and other ground-nesting insects, as well as dozens of species of burrowing reptiles. Based on the current distributions of reptiles in the region, the historic herpetofauna of the area likely comprised dozens of species of lizards, skinks, and snakes (Bosworth 2001). However, the historic distribution and abundance of reptiles in the Great Basin are not well understood (Mead et al. 1989).

Current Flora

Valley floors of the Bonneville Basin are typically dominated by big sagebrush (*Artemisia tridentata* spp.), saltbush (*Atriplex* spp.), and other xeric-adapted shrubs and grasses, with an ephemeral flora of perennial and annual forbs (Barbour and Billings 2000; Grayson 2006). Successional patterns in these xerophilic communities generally tend toward denser vegetation, from disturbed bare ground to grass-forb–dominated systems to saltbush and saltbush-greasewood–dominated shrublands.

The basins of the western desert of Utah are dominated by xerophilic shrub communities grading to sagebrush-grasslands and pinyon-juniper woodlands at increasing elevations. The 2010 bioturbation study (SWCA 2010) conducted at and near the Clive Site identified three primary vegetation communities on the Clive Site: 1) saltbush–gray molly (*Bassia americana*); 2) black greasewood; and 3) halogeton (*Halogeton glomeratus*)-disturbed (SWCA 2010).The vegetation at the Clive Site is dominated by sparsely distributed halophytic shrubs, with very limited distribution of grasses or forbs, except in disturbed sites where annual weeds dominate seasonally. Vegetation diversity at the elevational range of the Clive Facility is generally low, and ground cover is predominantly biological soil crust with one or two sparsely distributed xerophilic shrub species and limited grass and forb cover. A more detailed description of the existing vegetation at the Clive Site is given in the Field Studies Results sections below.

Current Fauna

The distribution of small mammals in the Bonneville Basin is complex due to the basin and range topography of the Great Basin region, which has created islands of low-lying habitats surrounded by mountain ranges and vice-versa (Brown 1971; Grayson 2006; Rickart 2001). The dry climate of the Great Basin has contributed to a wealth of fossil evidence of mammalian fauna of the region (Grayson 2006; Rhode and Madsen 1995).

There is limited historic evidence for the large mammal and ungulate distributions in the Great Basin (Grayson 2006). Long-distance seed dispersal was likely historically facilitated by now extinct large mammals (e.g., mastodons, mammoths, and other large herbivores). Present and near-future dispersal of seed would likely be limited to movements by small mammals and extant large herbivores (e.g., deer, elk, mountain sheep, horses, and pronghorn) (Grayson 2006).

The current fauna of the West Desert region of the Bonneville Basin include pronghorn, several species of lagomorphs, and mule deer in the mountain ranges. Extant large predators are cougar, coyote, and bobcat. Game bird populations consist of greater sage-grouse (*Centrocercus urophasianus*), non-native chukar (*Alectoris chukar*), and Hungarian partridge (*Perdix perdix*). Resident and migratory bird species and small reptile species also occur throughout the basin.

Small mammal trapping conducted at and near the Clive Site in 2010 identified four small mammal species across five study plots (see maps 1 and 2 in SWCA 2010): deer mouse (*Peromyscus maniculatus)*, northern grasshopper mouse (*Onchomys leucogaster)*, Great Basin kangaroo rat (*Dipodomys microps*), and Ord's kangaroo rat (*Dipodomys ordii*). Trapping conducted in 2010 on the three study plots on the Clive Site resulted in only seven total captures of deer mice (SWCA 2010). Mammal burrow surveys also indicated that badgers, ground squirrels, and voles are present at or near the Clive Site (SWCA 2010).

Ant diversity and mound distribution studies were also conducted at and near the Clive Site in 2010. In all, 1,628 ant specimens were collected across the five 2010 study plots. All but four ant specimens were western harvester ants; the remaining four specimens were *Lasius* species (possibly *L. niger*). Western harvester ants are widely distributed throughout most of Utah and other western states (Cole 1942). This species produces large, conical mounds whose basal area is presumably roughly proportional to the depth and subterranean area of the nest and quantity of soil excavated.

Climate

Historic Climate

The historic climate of the Bonneville Basin has been shaped by the decline of Lake Bonneville, with the climate of the region warming and drying with dropping lake levels starting approximately 15,000 years ago (Atwood 1994). Rapid warming and drying of the climate approximately 12,000 years ago caused the lake level to fall rapidly, and resulted in the desert climate of the region that persists today.

Current Climate

Meteorological Solutions (2012) summarized 19 years of meteorological data collected at the Energy*Solutions* monitoring station at Clive, Utah. The current climate of the region is classified as desert, which is characterized by precipitation levels that are less than half of the potential ET in a given year (Donn 1975). The area has cold winters and hot summers, with most of total annual precipitation falling from April through July during summer storms, and the remainder falling as isolated rain and limited winter snow (Meteorological Solutions 2012). Average daily temperatures range from lows of -2.5°C (27.5°F) in December to highs of 26.4°C (79.5°F) in July. Average annual precipitation is 218.4 millimeters (mm) (8.6 inches). Total average annual ET for the 19-year dataset was 1,338.6 mm (52.7 inches).

The greatest total precipitation for the period of study was 108.6 mm (4.3 inches) in May 2011, with a maximum daily precipitation event of 29.5 mm (1.2 inches; Meteorological Solutions 2012).

Potential Future Climate

Climate change is expected to significantly affect the Great Basin region within this century (Chambers 2008). Climate scenarios over the next ca. 1,000 years will likely be a continuation of the regional warming trend, but conditions will vary locally within the Great Basin. Recent trends have shown an increase in minimum temperatures and a 6%–16% increase in precipitation across most of the Great Basin (Chambers 2008). Temperatures in the Western United States are expected to increase approximately 2°C –5°C (3.6°F–9°F) in the next century (Cubashi et al. 2001). Associated increases in fire frequencies in the warmest regions of the Great Basin should also be expected, particularly in association with increasing cover of invasive annual grasses (cheatgrass [*Bromus tectorum*]; Smith et al. 2005; Ziska et al. 2005), and increasing variability in springtime precipitation that may contribute to fuel loading in some years and drought in others (Westerling et al. 2006).

Near-future climate warming is expected to increase the mean temperature of the coldest months, which may facilitate the northward migration of more southern desert species, particularly creosote bush (*Larrea tridentata*), and associated reductions in the ranges of more cold-adapted dominants such as sagebrush (Grayson 2006). Another potential scenario would predict the expansion of woodlands into desert shrub and sagebrush habitats (Wagner et al. 2003).

Under near-future climate scenarios (within the next several hundred to thousand years), the natural vegetation of the West Desert region of the Bonneville Basin would be expected to succeed to invasive grasslands, salt desert scrub, and greasewood shrubland communities. This assumes that current trends toward a hotter, drier climate will continue (Chambers 2008). A wetter future climate would result in the expansion of conifer woodland communities such as pinyon-juniper woodlands, although the very basic and saline conditions of the valley floor soils would exclude many higher elevation species.

2012 FIELD STUDIES OF ECOLOGICAL ANALOGS TO THE CLIVE SITE

The diversity and bioturbation data collected at the Clive Site in 2010 provides baseline data on the existing biological community at the Clive Site as well as estimates of species diversity, densities, and bioturbation potential. Because the objectives of the 2010 studies (SWCA 2010) were to assess potential future conditions over geologic time periods, data were collected across a wide range of ecological conditions and elevations, and most of the study plots possess different biotic communities than those that currently exist on the Clive Facility. These data are not applicable as ecological analogs to the Clive Facility within a 1,000-year time frame. However, Plot 3 (2010) was located on the Clive Site, and much of the data collected at that plot can be used as part of the ecological analog data to demonstrate current conditions and to evaluate how an ET cover system would perform under different successional scenarios.

Examination of ecologically analogous sites to the Clive Facility was needed. In June 2012, a set of ecological analog study sites (study plots) was selected at and near the Clive Site. These sites were selected based on having similar soils and elevational ranges that exist on the Clive Facility, and to provide a detailed assessment of the native vegetation and animal communities that could exist at the Clive Facility. Field study plots were also chosen to capture conditions at on-site soil borrow sources. These ecological analog study sites were also selected to provide data on the distribution and density of burrowing animals (ants and mammals) in different vegetation communities, and estimates of the density, depth, and volume of potential bioturbation that could occur on the cap. In June 2012, SWCA collected site-specific climate, soils, and geologic data to support the design of an ET cover system at the Clive Site, Utah. Field studies included examination of soils, vegetation diversity, areal cover and density, animal diversity, and burrow and ant mound densities and dimensions at eight ecological analog locations (2012 study plots) on and near the Clive Facility.

Objectives

The objective of the 2012 field studies was to provide a scientific basis for the design of an alternative cover system to meet Energy*Solutions*' permitting requirements under the EPA and the State of Utah. To achieve this objective, SWCA examined study plots that are ecologically analogous to the conditions that would exist on an alternative cover system at the Clive Facility. In addition to limited 2010 data (SWCA 2010), additional study plots were needed to examine the potential biotic communities that could exist within the elevational range of the cap, the biotic communities currently associated with borrowed soils and other borrow source materials, and the biotic communities associated with reclaimed sites with similar ecological conditions.

Methods

Study Plot Selection

Field study plots were selected to be ecologically analogous to the Clive Site, with similar soils, elevations, and with locally adapted, native biotic communities. Field study plots were also chosen to capture conditions at potential soil borrow sources and at any existing reclaimed sites near the Clive Facility.

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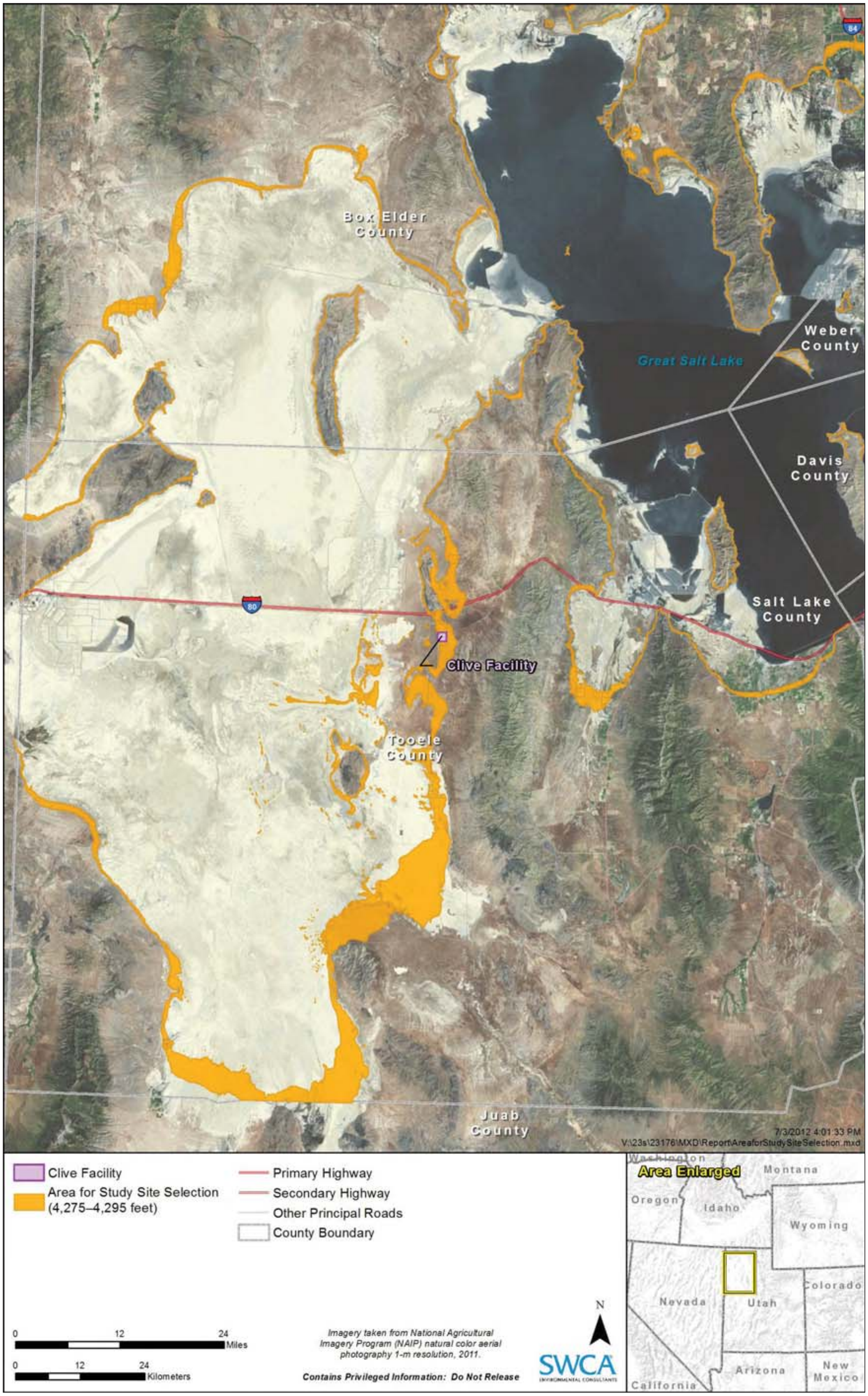

Figure 3. Range of potential ecological analog study sites at and near the Clive Site within an elevational range of 1,303–1,309 m (4,275–4,295 feet) in elevation.

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The Clive Facility occurs in Tooele County, Utah, on the eastern edge of the Great Salt Lake Desert at ca. 40.690891˚ latitude -113.112073˚ longitude at approximately 1,307 m (4,288 feet) (in elevation (see Figure 1). A target elevational range for ecological analog study sites was chosen as 1,303–1,309 m (4,275–4,295 feet) to capture the vegetation, soils, and biota that would be associated with the cap. Figure 3 shows the relatively limited distribution of this elevational range in the Bonneville Basin. The area for study plot selection was also limited to the Clive Site and BLM-administered lands.

Eight study plots and one soil borrow site were selected based on the following criteria: ecological relevance, soil or fill borrow source, and disturbance or reclamation history. All study plots are within the elevational range of the Clive Facility (1,303–1,309 m [1,275–4,295 feet] in elevation). The study plots were distributed so that all potential vegetation types within the target elevation range were captured, and to include variations in aspect and slope. Three study plots were positioned on isolated hills, comprising one on an east-facing aspect, one on a west-facing aspect, and one on a south-facing aspect. One study plot, in the immediate vicinity of Plot 3 (2010), was placed on the Clive Site in a soil borrow site to assess ant mound size and depth. No rock or gravel borrow sites were selected, because none fell within the study area elevational range or possessed relevant ecological conditions. Figure 4 shows the distribution of the five 2010 study plots (Plots 1–5) relative to the distribution of the eight 2012 study plots (Plots 6–13). Only Plot 3 from the 2010 field studies falls within the target elevation range for the Clive Facility.

Because the soils that will be used in the alternative cover system must be able to support the desired native vegetation and meet ET and erosion-resistance requirements for the cover, the vegetation and soil conditions at on-site soil borrow sites were examined as part of field studies. Soil samples were collected at study and borrow sites for analysis of soil physical and chemical properties in order to quantify soil fertility, stability, evaporation potential, and bioturbation potential. SWCA acquired a research permit to conduct these studies on BLM lands, and consulted with Energy*Solutions* on selection of on-site borrow sources and associated excavations

One study plot was on the Clive Facility and seven plots were on BLM-administered lands. At each study plot, a 31.6 × 31.6–m (0.10 hectare or 1,000 m^2) plot was established using three 50-m tapes. Each plot is oriented with each side aligned with the cardinal directions (north-south-east west). The 2012 study plot sizes were 1/10th the size of the 2010 study plots, but the sample size was larger (eight plots) within one community type, and sampling for all parameters (vegetation, mammals, burrows, ant mounds) was more intensive within each sample plot compared to the 2010 sampling effort.

A 0.10-hectare field study plot was established at each study plot. The center of each study plot was recorded using a Trimble GPS. Each 31.6 × 31.6–m plot was oriented in a north-south direction. Vegetation and small mammal sampling, and burrow and ant mound quantification were conducted following the sampling methods employed for 2010 bioturbation studies for the Clive Site (SWCA 2010). Soil samples were collected from each study plot and from the soil borrow site. The following ecological parameters were measured at each study plot:

- Vegetation diversity, cover, and density
- Small mammal diversity and abundance (live trapping)
- Animal burrow density and soil volumes
- Ant mound area, volume, and density
- Soil erosion, channeling, and aeolian transport

Photographs were taken at each study plot to show representative vegetation conditions, burrows and ant mounds, and evidence of surface erosion or soil transport. The following sections describe the specific methods used, results, discussion of key findings, and a set of recommendations based on the results of the field studies.

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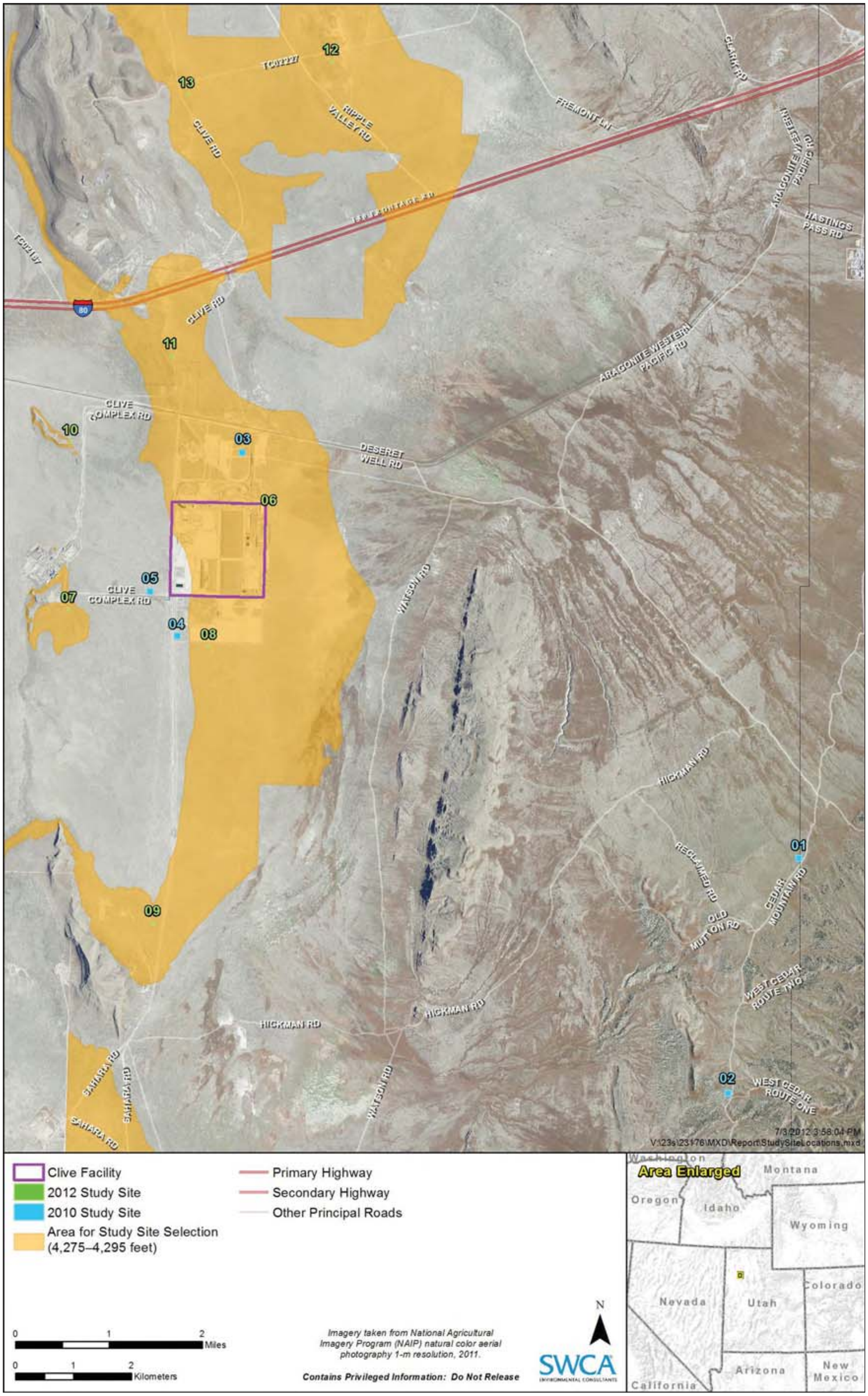

Figure 4. The distribution of 2010 Plots 1–5 and 2012 Plots 6–13 within the study area for the Clive Facility.

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Vegetation Study Methods

VEGETATION COMMUNITY DISTRIBUTION

The distribution of land cover and vegetation community types was mapped using the Southwest Regional Gap Analysis Project (SWReGAP) database.

SPECIES COMPOSITION METHODS

In each study plot, five 30-m transects were established at 6, 12, 18, 24, and 30 m along the south edge of the plot (Figure 5). Six 1-m^2 quadrats were sampled on the west side of each transect at 5, 10, 15, 20, 25, and 30 m, for a total of 30 quadrats per plot (30 m^2 or 3% of each 1,000-m^2 plot area). At each quadrat location, each plant was identified to species and listed on the datasheet.

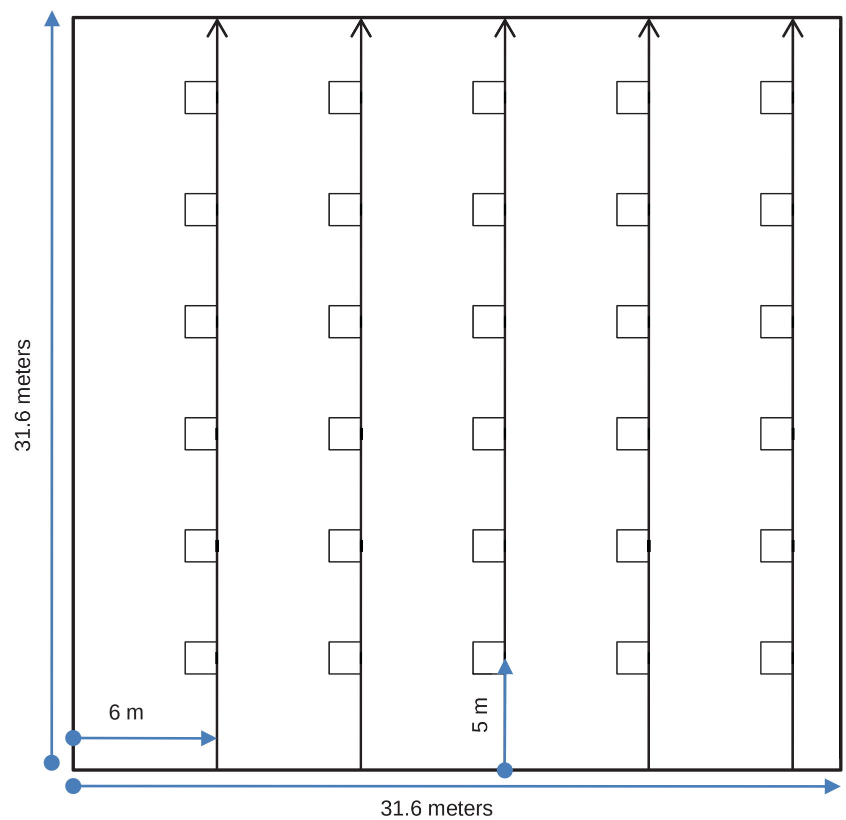

Figure 5. Study plot design showing vegetation sampling transects and quadrat locations.

COVER ESTIMATION METHODS

The areal percentage cover of each plant species, biological soil crust, litter, rock, and bare ground within each quadrat was visually estimated and recorded.

DENSITY ESTIMATION METHODS

The number of individual stems of each plant species within each quadrat was recorded.

A copy of the vegetation datasheet is provided in Appendix A.

Animal Bioturbation Study Methods

The objective of small mammal trapping was to identify the distribution and density of small mammals associated with each study plot. Animal burrow surveys were conducted to estimate the density, depth, and soil volumes that can be displaced by the native biota. Ant mound surveys were also conducted to provide estimates of the density of ant mounds and the volume of soil displaced by ant colonies in each study plot.

SMALL MAMMAL TRAPPING METHODS

Each 0.1-hectare plot was subdivided into nine 10.5 × 10.5–m subplots. One large trap (approximately 8 × 8 × 23 cm) was placed at each trapping station and one extra-large trap (approximately 10 × 10 × 40 cm) was placed at every other station, for a total of 14 traps per plot. Figure 6 shows the trapping station design and layout of the nine large and five extra-large traps installed at each plot.

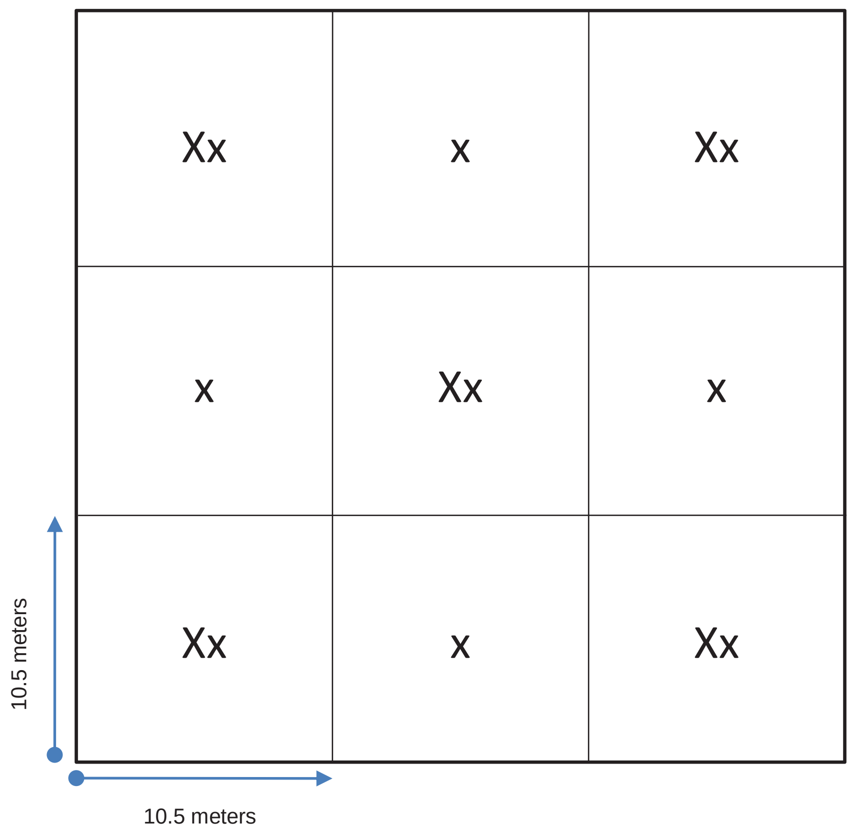

Figure 6. Small mammal trapping station layout, where X represents extra-large traps and x represents large traps.

Mammal traps were placed on-site prior to baiting and setting the traps in order to accustom animals to the presence of the traps. Traps were baited with four-grain horse feed rolled in molasses and set in the evening. Cotton balls were also placed in the traps to be used as bedding and insulation by trapped animals in order to prevent hypothermia. The traps were checked around sunrise the following morning, and any captured animals were identified to species, marked, and released. The purpose of marking captured animals was to prevent overestimation of small mammal densities. Representative photographs of captured small mammal species and other observations of animal activities were also recorded at each plot location.

A copy of the small mammal trapping datasheet is provided in Appendix B.

MAMMAL BURROW SURVEY METHODS

Mammal burrow surveys at the eight study plots were conducted on June 13, 16, 22, and 23, 2012. To ensure 100% survey coverage, each 0.10-hectare plot was surveyed by walking transects approximately 3 m (10 feet) apart. The universal transverse mercator (UTM) location of each individual burrow or groupings of burrows was recorded using a handheld global positioning system (GPS) unit for individual burrows or a group of similar burrows. Burrows were identified to species level when possible; however, in many cases, burrows were assigned a likely "group" of burrowers (i.e., mouse/vole/rat). Considering the large number of deer mice captured during trapping efforts, it is possible that burrows in this particular category are deer mice burrows. Soil excavations (digging locations with no burrow entrance) were not recorded.

A copy of the burrow survey datasheet is provided in Appendix C.

ANT MOUND SURVEY METHODS

Ant mound surveys of the eight study plots were conducted on June 13, 16, 22, and 23, 2012. To ensure 100% survey coverage, each 0.10-hectare plot was surveyed by walking transects approximately 3 m (10 feet) apart. The UTM location of each ant mound was recorded using a handheld GPS unit. The following information was collected for each ant mound in the study plots:

- Date, observer, plot number, and UTM coordinates
- Height, width, and length of the mound
- A photograph of the mound
- The orientation of the mound entrance (e.g., north, south, north-northeast)

No ant specimens were collected for identification to species, because it is assumed that all ants in the study area are western harvester ants (*Pogonomyrmex occidentalis*). This assumption was made based on the results of the 2010 ant mound surveys, which identified over 99.7% of 1,624 ant specimens as western harvester ants (SWCA 2010). In addition, the four ants that were identified to *Lasius* species in 2010 were collected from Plot 1, a grassland vegetation community at a considerably higher elevation than the Clive Facility. The western harvester ant is widely distributed in Utah and other western states, and frequently occurs in flat areas that have been recently disturbed by human activities (Allred 1982). These habitat conditions are descriptive of the entire study area and are representative of the habitat conditions that would exist on the cap.

Western harvester ant mounds are generally conical in shape. However, because ant mounds are usually irregular cone shapes, the formula for the volume of a cone does not provide an accurate estimate. Formulas for an ellipsoid and elliptic paraboloid have also been used to estimate the three-dimensional characteristics and volume of ant mounds (Porter et al. 1992; Vogt et al. 2004). Although these formulas provided more accurate volume estimations, they did not account for the irregular shape of ant mounds and overestimated volume, especially with increasing ant mound size. A recently published study of fire ant (*Solenopsis invicta*) mound volume identified the formula for an oblique cone or hyperboloid as a more accurate estimator (Vogt 2007). Vogt's (2007) volume formula provides a better estimator because it accounts for the eccentric base and oblique cone shape of ant mounds. Both published studies of ant mound architecture (Porter et al. 1992; Vogt et al. 2004; Vogt 2007) and field observations in the Bonneville Basin demonstrate that the surface area and volume of western harvester ant mounds are generally oblique cones with eccentric bases, as described in Vogt (2007).

The surface area occupied by ant mounds was estimated using the area of an ellipse (or eccentric base), given as $A = \pi \times a \times b$, where a is the radius of the long (major) axis and b is the radius of the short (minor) axis ($\pi = 3.14159265359$). The approximate soil volume occupied by ant mounds was estimated using Vogt's formula: $1/3 \times \pi \times (a/2) \times (b/2) \times c$ (Vogt 2007), where a is the radius of long axis (x), b is the radius of short axis, and c is the radius of height (vertical) axis.

A copy of the ant mound survey datasheet is provided in Appendix D.

ANT MOUND EXCAVATION METHODS

The objective of ant mound excavations was to estimate the relationship between above and belowground nest volumes in native vegetation and soils on and near the Clive Facility. Ant mound excavations were conducted on the Clive Site using an excavator and hand tools, as needed.

OTHER BURROWING ANIMAL OBSERVATIONS

Incidental occurrences of burrowing animals are also an important consideration in assessing the bioturbation potential in study plots near the Clive Facility. The presence of mammals, birds, or insects in or anywhere near the study plots was noted during all field activities. Animal occurrences were captured in photographs where feasible.

Soils

The objectives of the soil field studies and analyses were to characterize existing soil properties. From both an engineering and reclamation perspective, understanding soil properties such as physical characteristics, chemical parameters, and capacity as a growth medium are integral to reclamation success.

SOIL MAPPING AND CLASSIFICATION

The objective of evaluating soil type distributions and classifications was to understand the relationship between soil properties in the study plots, and the vegetation, biophysical components, and chemical processes the vegetated cover system seeks to replicate. General information regarding parent material, soil formation, and characteristics complied by Natural Resources Conservation Service (formerly Soil Conservation Service) are available at the soil map unit and series level for the Clive site. However, very limited site-specific data are available that describe organic matter content, macronutrients, micronutrients, and other parameters that must be considered by Energy*Solutions* for the establishment and long-term development of an ecologically functioning vegetation community on the cap.

SOIL EROSION

In addition to collecting soil samples, SWCA mapped the location of wind and water erosion features at each study plot. Identifying the presence and relative abundance of these features is important because local climatic and weather conditions, soil characteristics, and wind speed and direction patterns are conducive to moving sediment by wind and water. Excessive erosion at the study plots could be of concern to Energy*Solutions* during the vegetation establishment period because loose topsoil on the ET cover would have no physical or biological structures to keep it in place.

SOIL SAMPLING

Soil sampling methods followed the recommended soil sampling protocol from Utah State University (USU) Analytical Laboratories in Logan, Utah. At each study plot, SWCA gathered soil subsamples at five locations. Soil subsample locations were randomly selected along five transects within the study plots using a random number generator. The number generated (range of 0–32) represents the distance in meters from the southern boundary to the northern boundary of the plot (Figure 7). Subsample locations were characteristic of conditions within the study plot. All subsamples were taken at a depth of 0–30 cm (0–12 inches) using a 5-cm (2-inch) soil auger, as per the recommended sampling protocol. The five soil subsamples were combined to create one composite sample. The soil samples were stored in resealable plastic bags and labeled with the study plot number, date, and time of collection.

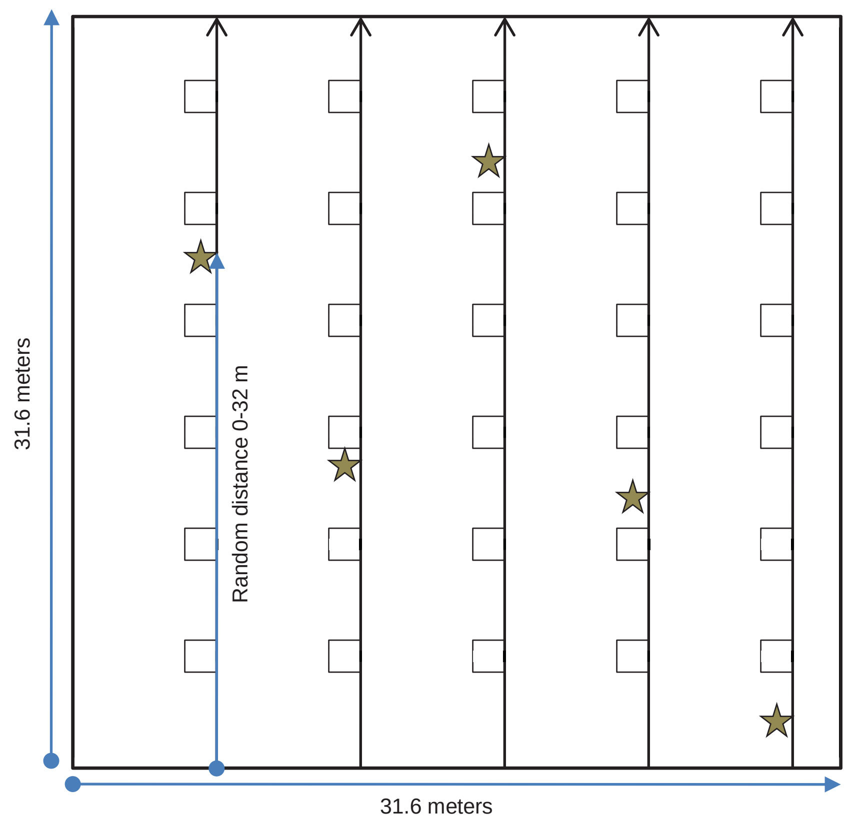

Figure 7. Example random soil sample distribution relative to vegetation transects in study plots.

In addition to those samples obtained from the study plots, SWCA gathered soil samples from three ant mound excavation sites at depths of 0.3 m and 1.1 m (1.0 and 3.5 feet), one ant mound excavation site at a depth of 0.2 m (0.5 feet), and a soil borrow site at depths consistent with the bottom of Borrow Unit 4 and top of Borrow Unit 3 on the Clive Site.

Field study data were compiled into an Excel workbook for databasing and summary analyses. Soil samples were submitted to USU Analytical Laboratories for analyses of soil physical and chemical parameters. The soil parameters that were analyzed are listed in Table 1, including a description of each parameter and its effect on vegetation growth and survival.

Table 1. Clive Site Soil Parameters

Parameter	Description	Effect on Vegetation
Soil texture	Proportion of particles of various sizes in the soil	Determines nutrient, water, and air supply ability of soils.
pH	Ratio of hydrogen to hydroxyl ions resulting in acidic, neutral, or alkaline conditions	Although the hydrogen ion in high concentrations may be toxic and may directly affect plants, the availability of some essential nutrients is affected by pH.
Salinity ECe	Measure of soil salinity and indicative of an aqueous solution to carry an electric current	Plants may be affected physically and chemically by excess salts. Reclamation in soils with high salinity should avoid salt-sensitive plants. Salinity can be defined in terms of suitable plant species for a reclamation site.
SAR	Comparative concentrations of Na^{+} (sodium ion), Ca^{2+} (calcium ion), and Mg^{2+} (magnesium ion) in soil solutions	Soils that are high in Na+ relative to other salts may cause plants to have difficulty absorbing water. This typically occurs when the SAR rises above 12–15. (Ecosystem Restoration 2004)
Phosphorous, potassium, nitrate-nitrogen, sulfate-sulfur	Macronutrients	Essential elements used by plants in relatively large amounts that are important constituents for growth. Concentrations of these elements determine the need for the type and amount of soil amendments.
Zinc, iron, copper, and manganese	Micronutrients	Essential elements used by plants in relatively small amounts that are important constituents for growth.
Organic matter	The percentage of recognizable organic material and humus in the soil	Organic matter influences physical (open and loose) and chemical (source of nutrient elements) properties of soil, which affect plant growth.
Metals (cadmium, chromium, nickel, and lead)	Heavy metals	Essential elements that are essential for healthy plant growth but that may be toxic to plants at high levels.

CORRELATION ANALYSES

To assess the relationships between biotic and abiotic features of the ecological analog study sites, Pearson's correlation analyses were performed to identify relationships among the variables that were assessed during field studies: vegetation cover and density; small mammal distributions and densities; burrow volumes; ant mound area, volume, and densities; and soil structure and chemistry. The Pearson product-moment correlation coefficient (Rodgers and Nicewander 1988) is a widely used measure of the degree of correlation, or linear dependence, between two variables. The relationship between two variables, X and Y, is given geometrically, with Y plotted as a function of X with a resulting slope value between +1.0 and -1.0 (Rodgers and Nicewander 1988). The Pearson product-moment correlation coefficient, often given as r, represents a slope ranging from -1.0, which is a perfect negative relationship where Y decreases linearly with increasing values of X, to 1.0, which is a perfect positive relationship between X and Y. A coefficient of 0 indicates that there is no linear relationship between the variables.

Correlation coefficients, or *r* values, between -0.5 to -1.0 and +0.5 to 1.0 are generally considered indicative of a strong linear association between two variables (Cohen 1988). All correlation analyses were performed in MS Excel (Microsoft Office 2010).

ORDINATION ANALYSES

Ordination analyses were also performed to assess trends in the distribution of vegetation community features (species cover, ground cover, and total cover) with small mammals, other burrowing animals, ants, and abiotic site features. All ordination analyses were performed in PC-Ord Version 5.0 (MjM Software Corporation 2007).

Results

Field studies were initiated on June 13, 2012, and completed on June 23, 2012. The locations of the eight analog study sites were determined in the field to confirm the spatial distributions of vegetation cover types and to ensure that the entire plot is contained within a distinct vegetation community. Small mammal trapping was initiated immediately due to the two-week window for field studies. Burrow and ant mound surveys were conducted concurrently with mammal trapping or after trapping was completed. Vegetation and soil sampling were conducted concurrently during the second week of field studies.

Vegetation Sampling Results

Vegetation sampling was performed from June 19 to 21, 2012. In each field plot, five 31.6-m-long transects were oriented south to north every 6 m (6 m, 12 m, 18 m, 24 m, and 30 m) from the southwestern corner of the plot. On each transect, six 1-m^2 sampling quadrats were sampled at 5, 10, 15, 20, 25, and 30 m for a total of 30 sample quadrats per plot (30 m^2 or 3% of each 1,000-m^2 plot area). Figure 8 shows the typical mix of black greasewood and saltbush vegetation on and near the Clive Site.

Figure 8. Typical vegetation community near the Clive Site: a mosaic of black greasewood and shadscale saltbush dominated by biological soil crust.

Ten plant species were identified in the eight 2012 field plots. Vegetation cover was sparse in all of the plots. Biological soil crusts are a dominant feature of vegetation communities throughout the Great Salt Lake Basin, and were the dominant ground cover in all eight sample plots.

VEGETATION COMMUNITY DISTRIBUTION RESULTS

Vegetation communities in the study area consist of three cover types: 1) Inter-Mountain Basins Greasewood Flat; 2) Inter-Mountain Basins Mixed Salt Desert Scrub; and 2) Developed/Disturbed land cover. Figure 9 shows the distribution of the study sites relative to these land cover types. The dominant vegetation and other features of these cover types are described following the map.

The vegetation in the study area is generally sparse, and comprises a matrix of greasewood-dominated to desert scrub-dominated habitats. Although the SWReGAP database includes Invasive Annual Grassland in the study area, this vegetation type was not found in the study area during the field studies. The locations of Invasive Annual Grassland and Inter-Mountain Basins Playa (shown in Figure 9) were actually dunes of windblown soil and sand that are similar in color to grassland and playa communities in the area, but that occur at higher and lower elevations than the Clive Facility, respectively.

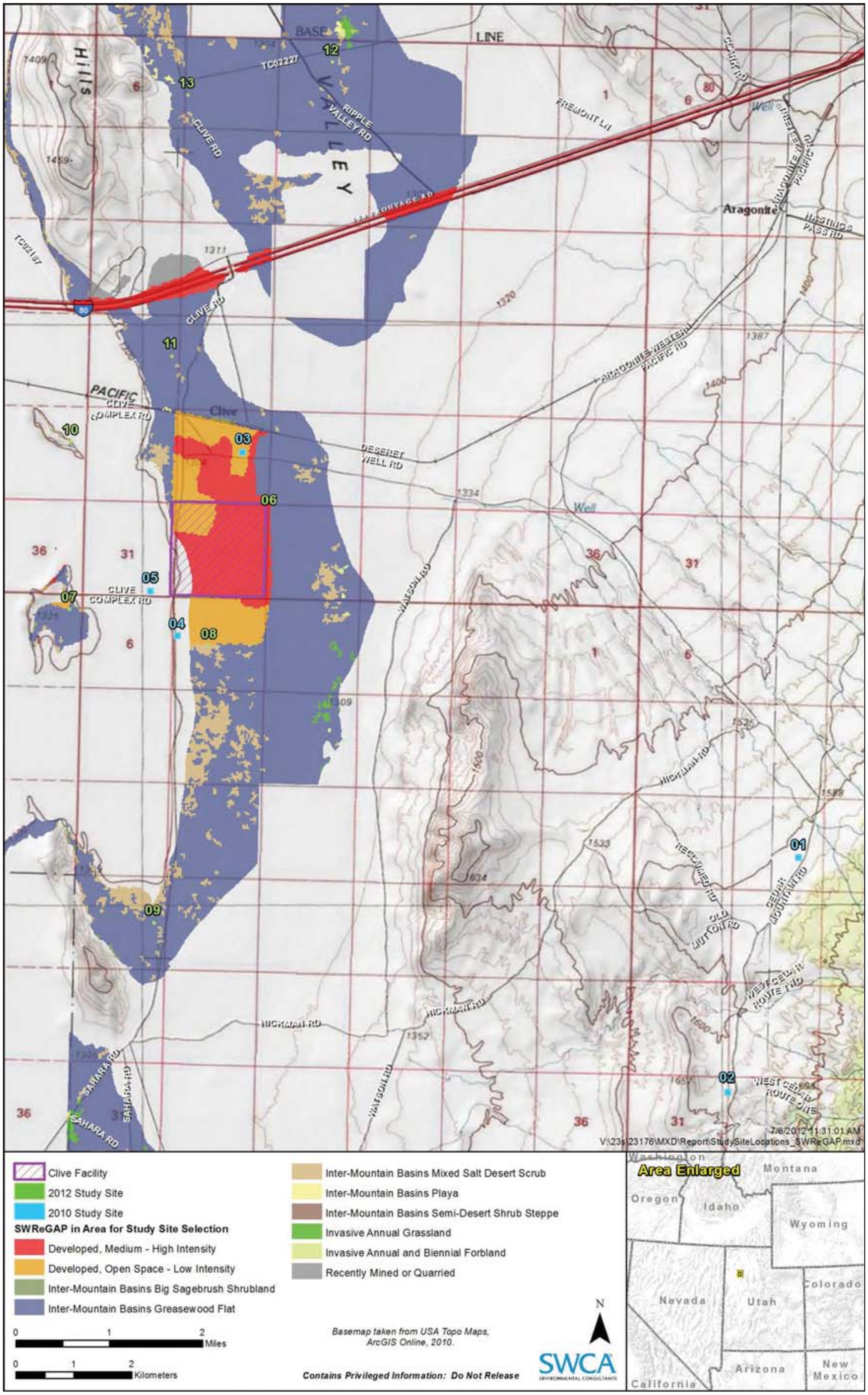

Figure 9. SWReGAP vegetation community distributions near the Clive Facility.

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LAND COVER DESCRIPTIONS

Inter-Mountain Basins Greasewood Flat

This vegetation community usually occurs near drainages on flats and stream terraces, but in the western Bonneville Basin, it occurs in association with sparsely vegetated playas. This association typically has saline soils, a shallow water table, and remains dry for most growing seasons. The vegetation consists of open to moderately dense shrublands dominated or co-dominated by black greasewood. Other shrub and forb species that are present in the study area are shadscale saltbush (*Atriplex confertifolia*), fourwing saltbush (*Atriplex canescens*), Mojave seablite (*Suaeda torreyana*), gray molly, and bug sage (*Picrothamnus desertorum*). Non-native invasive species associated with this community include fivehorn smotherweed (*Bassia hyssopifolia*), herb sophia (*Descurania sophia*), halogeton, and clasping pepperweed (*Lepidium perfoliatum*). Groundcover is dominated by biological soil crust, with limited cover of rock/cobble, litter, and bare ground.

Inter-Mountain Basins Mixed Salt Desert Scrub

The vegetation of this ecological system is characterized by open to moderately dense shrubland composed of one or more *Atriplex* species. Shrub, forb, and graminoid species present in the study area consist of shadscale saltbush, fourwing saltbush, Mojave seablite, gray molly, and sandberg bluegrass (*Poa secunda*). Halogeton can also occur as a dominant forb in this community type. Groundcover was dominated by biological soil crust with limited cover of litter and bare ground.

Developed/Disturbed

Developed and disturbed conditions predominate on the Clive Site, with small areas of greasewood and salt desert scrub vegetation intermixed with roads and facilities to the north and east. Impervious surfaces are limited to access roads and parking areas associated with the Clive Facility.

SPECIES COMPOSITION, COVER, AND DENSITY RESULTS

The species and cover composition of each plot, and the percentage cover and density of each is summarized in Table 2. Biological soil crust was the dominant cover in all study plots.

Table 2. Vegetation Species Distributions, Percentage Cover, and Densities for the 2012 Study Plots and 2010 Study Plot 3

Species or Cover Type	Plot 3 (2010)		Plot 6		Plot 7		Plot 8		Plot 9		Plot 10		Plot 11		Plot 12		Plot 13	
	% Cover	Density	% Cover	Density	% Cover	Density	% Cover	Density	% Cover	Density	% Cover	Density	% Cover	Density	% Cover	Density	% Cover	Density
Fourwing saltbush *Atriplex canescens*	–	–	0.7	1.0	–	–	–	–	–	–	–	–	3.5	7.5	–	–	–	–
Shadscale saltbush *Atriplex confertifolia*	1.3	1.4	1.3	16.2	1.5	3.2	5.1	6.8	1.6	3.9	2.3	1.0	2.3	14.7	17.3	1.7	2.1	2.9
Gray molly *Bassia americana*	0.9	1.2	0.8	1.0	0.9	2.1	1.3	2.6	2.3	2.0	1.3	1.0	3.8	6.4	1.2	1.3	1.7	4.3
Fivehorn smotherweed *Bassia hyssopifolia*	0.6	0.7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Burningbush *Bassia scoparia*	0.1	1.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Herb Sophia *Descurainia sophia*	–	–	–	–	0.5	3.0	–	–	–	–	–	–	–	–	–	–	–	–
Halogeton *Halogeton glomeratus*	1.1	12.3	–	–	0.5	3.0	0.5	3.0	0.6	19.6	0.7	6.7	–	–	0.5	1.0	–	–
Clasping pepperweed *Lepidium perfoliatum*	–	–	–	–	1.6	28.3	–	–	–	–	–	–	–	–	–	–	–	–
Bug sage *Picrothamnus desertorum*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.3	1.0	–	–
Sandberg bluegrass *Poa secunda*	–	–	–	–	–	–	–	–	–	–	5.9	40.4	–	–	–		–	–
Black greasewood *Sarcobatus vermiculatus*	11.5	0.7	16.6	1.0	19.0	1.3	–	–	–	–	–	–	–	–	18.4	0.6	17.7	2.4
Mojave seablite *Suaeda torreyana*	3.0	0.7	1.3	4.4	3.4	1.8	7.4	2.7	4.8	1.7	2.0	1.0	0.8	1.4	0.8	1.0	1.2	1.0
Bare ground	3.1	–	3.8	–	2.8	–	2.3	–	1.2	–	59.5	–	5.5	–	1.3	–	0.0	–
Biological soil crust	85.3	–	85.0	–	80.0	–	87.1	–	84.8	–	25.4	–	83.0	–	80.8	–	84.0	–
Litter	6.0	–	3.4	–	9.0	–	6.9	–	13.1	–	11.9	–	9.5	–	7.4	–	8.9	–
Cobble	–	–	–	–	7.5	–	–	–	–	–	–	–		–	5.0	–		–

A summary of average plant species cover, plant density per square meter, and ground cover types is given in Table 3. The average total vegetation cover was 2.9%, consisting of 8.6 total plant stems per square meter. Average total shrub cover was 4.2% for 3.0 shrubs per square meter. Average plant species cover consisted of 14.3% black greasewood, 5.9% Sandberg bluegrass, and approximately 3% cover each of shadscale saltbush and Mojave seablite. Fourwing saltbush and gray molly occurred in low densities with 1.6% and 1.3% cover, respectively. Ground cover was dominated by 79.2% average biological soil crust cover. Summary tables of average plant species cover for each plot are given in Appendix E.

Table 3. Average Plant Species Cover and Density, and Average Ground Cover for All Plots

Species or Cover Type	Average Cover (%)	Average Plant Density (plants per square meter)
Black greasewood *Sarcobatus vermiculatus*	14.3	0.9
Sandberg bluegrass *Poa secunda*	5.9	40.4
Shadscale saltbush *Atriplex confertifolia*	3.2	7.3
Mojave seablite *Suaeda torreyana*	2.8	2.2
Fourwing saltbush *Atriplex canescens*	1.8	3.6
Gray molly *Bassia americana*	1.6	2.9
Clasping pepperweed *Lepidium perfoliatum*	1.6	28.3
Bug sage *Picrothamnus desertorum*	1.3	1.0
Halogeton *Halogeton glomeratus*	1.0	12.3
Fivehorn smotherweed *Bassia hyssopifolia*	0.6	0.7
Herb Sophia *Descurainia sophia*	0.5	3.0
Burningbush *Bassia scoparia*	0.1	1.0
Average	**2.9**	**8.6**
Biological soil crust	79.2	–
Litter	7.9	–
Bare ground	7.8	–
Cobble	6.7	–

Bioturbation

SMALL MAMMAL TRAPPING RESULTS

Small mammal trapping was conducted from June 13 through June 23, 2012. Mammal traps are usually placed on-site for 48–72 hours before baiting and setting them; this helps accustom animals to the presence of the traps. However, because of a short trapping window of 14 days for eight plot locations, some of the traps were left on-site for only 1–48 hours prior to baiting. The traps on Plots 7, 8, and 9 were baited within 1 hour of placement. Traps on Plot 6 were left in place without bait for 48 hours prior to baiting. The traps at Plots 10, 11, 12, and 13 were left in place for 48 hours prior to baiting. The traps on Plots 6 through 9 were baited from June 15 to June 17 before dusk and checked the following mornings. The traps on Plots 10 through 13 were baited from June 17 to June 22 and checked the following mornings. The new moon occurred on June 19, 2012, so moonlight during trapping was minimal.

Captured mammals were identified to species and released. Mouse species were marked with nail polish before release; however, kangaroo rats did not tolerate the marking process. Additionally, during the course of trapping, it became apparent that some mice were chewing off nail polish markings or pulling out marked fur, making recapture information difficult to obtain. For these reasons, the recapture estimates may be underestimated, and the total small mammals captured may be overestimated for some plots.

Table 4. Summary of Small Mammal Species and Number Captured (number of recaptures) for 2012 Study Plots and 2010 Study Plot 3

Study Plot	Deer Mice (*Peromyscus maniculatus*)	Kangaroo Rats (*Dipodomys* species)
Plot 3 (2010)	2 (1)	0
Plot 6	11 (3)	0
Plot 7	6 (0)	0
Plot 8	0	0
Plot 9	13 (3)	–
Plot 10	4 (2)	0
Plot 11	22 (6)	0
Plot 12	47 (13)	1
Plot 13	12 (4)	0

In all, 115 captures (including 31 recaptures) or a total of 84 individuals were trapped during small mammal trapping. Small mammals were concentrated in the northern portion of the study area (Plots 11, 12, and 13; see Figure 4). In all, 83 deer mice and one kangaroo rat were captured. Exactly half (42/84 or 50%) of these captures occurred on Plots 12 and 13.

The kangaroo rat captured on Plot 12 (Figure 10) was most likely Ord's kangaroo rat (*D. ordii*) based on measurements taken in the field, but that species can be very difficult to distinguish from the chisel-toothed kangaroo rat (*D. microps*; personal communication between George Oliver, UDWR and Amanda Christensen, SWCA, June 25, 2012).

Figure 10. Kangaroo rat captured at Plot 12.

Several mice died either in the traps or shortly after being released, presumably due to shock or hypothermia. Two mice died during trapping on Plot 12, and one mouse was unintentionally left in a trap on Plot 11. This occurred because only one mouse exited the trap when it was checked on the morning of June 22, and the second mouse in the trap was not detected. The trap was shut and replaced on-site.

MAMMAL BURROW SURVEY RESULTS

Mammal burrow surveys were conducted on June 13, 16, 22, and 23, 2012. The geographic location of each burrow was recorded using a handheld GPS unit. Burrows were mapped as either individual burrows or as groups of similar burrows. No burrows were found on Plots 6, 8, 9, 10, or 13.

Burrows were identified to species level when possible; however, in many cases, burrows were assigned a likely "group" of burrowers (i.e., mouse/vole/rat). Considering the large number of deer mice captured during trapping efforts, it is highly probable that most of the mouse/vole/rat burrows were made by deer mice. Soil excavations (digging locations with no burrow entrance) were not recorded. Table 5 displays the number of burrows for all plots by burrow type. Burrows only occurred on Plots 7, 11, and 12. Coyote burrows/dens were observed near survey plots, but none fell within plot boundaries.

Table 5. Summary of Mammal Burrow Survey Results by Species for 2012 Study Plots and 2010 Study Plot 3 (average soil displacement per burrow in parentheses (liters)

Study Plot	**Mouse (*Peromyscus* spp.)**	**Kangaroo rat (*Dipodomys* species)**	**Ground squirrel *(Spermophilus sp.)***	**Badger *(Taxidea taxus)***
Plot 3 (2010)	–	–	–	–
Plot 6	0	0	0	0
Plot 7	1 (0.0L)*	1 (0.25L)	0	1 (13.5L)
Plot 8	0	0	0	0
Plot 9	0	0	0	0
Plot 10	0	0	0	0
Plot 11	0	0	1 (45.5L)	0
Plot 12	9 (6.2L)†	6 (18.2L)‡	0	3 (26.0L)
Plot 13	0	0	0	0

* 5 burrow entrances in complex; no soil displacement.

†9 total burrow entrances in plot.

‡30 total burrow entrances in plot.

After each burrow location was documented, the volume of soil that had been brought to the surface was measured. To do this, the obviously mounded or disturbed soil around a burrow entrance was collected and measured in liters.

The locations of two soil excavations (without burrow entrances; Figure 11) were also recorded on Plot 11, but soil volumes were not measured.

Figure 11. Soil excavation.

ANT MOUND SURVEY RESULTS

Nineteen ant mounds were recorded and measured in Plots 6–13, with an average of 2.4 ant mounds per 1/10th hectare plot (Table 6). This is a very similar estimate to the results of the 2010 ant mound surveys, which found an average density of 2–33 mounds per hectare (SWCA 2010). Table 6 summarizes the total mounds per plot, total mound area (cm^2) per plot, and total aboveground volume (cm^3) per plot. A very large active ant mound occurred in Plot 7 (Figure 12). Well-developed biological soil crust is also visible surrounding the ant mound.

Table 6. Ant Mound Surface Area and Density for 2012 Study Plots and 2010 Study Plot 3

Study Plot	Total Number of Mounds per 1,000-m^2 Plot	Total Mound Area (cm²) per 1,000-m^2 Plot	Total Aboveground Volume (cm^3) per Plot
Plot 3 (2010*)	3.3	9,500.0	25,268.3
Plot 6	3	11,815.9	47,881.1
Plot 7	4	25,612.6	144,686.3
Plot 8	2	13,160.1	52,264.5
Plot 9	2	7,747.2	16,320.4
Plot 10	4	15,473.9	77,217.7
Plot 11	1	5,103.9	10,888.4
Plot 12	1	1,540.6	3,286.6
Plot 13	2	6,209.0	18,881.4
Average per plot	2.4	4,561.2	46,428.3

* The values given for Plot 3 (SWCA 2010) are averages due to the larger plot size and sample size.

Based on the measurements recorded for ant mounds in the study plots, the average ant mound density and area in the study area is 24 mounds covering 456.1 m^2, respectively, *per hectare* (10,000 m^2). The average area of each harvester ant mound was 1,900.5 cm^2. Based on the ant mound dimensions measures and volume estimates, the average aboveground volume of harvester ant mounds per hectare is approximately 0.5 m^3. Belowground ant mound volume estimates are discussed in the next section.

Figure 12. Large ant mound in Plot 7.

ANT MOUND EXCAVATION RESULTS

Presumably, the aboveground area and volume of each ant mound is proportional to the depth and belowground volume of the nest, but that relationship has not been clearly established for *P. occidentalis* mounds in the particular soil types present on the study plots. Four ant mound locations were selected north of the Clive Facility near soil borrow Units 3 and 4. The aboveground height, long axis, and short axis (cm) of each ant mound was measured. An excavator removed soil along a straight line starting at the outside edge of the ant mound and then excavated three to four additional sections toward the center of the ant mound. The average aboveground area and volume of the excavated ant mounds was 2,683 cm^2 and 28,348 cm^3, respectively. The average ant mound area estimate from Plots 3–13 was approximately 1,900 cm^2, and the average ant mound volume estimate was 19,345 cm^3. The belowground area of the excavated ant mounds was found to be sparsely distributed, with most of the ant nest within 0.6 m (2.0 feet) of the surface. Some scattered chambers occurred in deeper soil layers, but were very difficult to locate using a large excavator and hand tools. Figure 13 shows one of the excavated ant mound locations, with evidence of large chambers near the surface of the soil and rapidly decreasing root densities and ant structures as soil depths approach the condensed clay layer that is typical of the soils on the Clive Site (SWCA 2010).

Figure 13. Ant mound excavation showing some large ant chambers near the soil surface with very little root biomass or evidence of ant activity at or below the condensed clay layer at approximately 0.6 m (2 feet) below the soil surface.

OTHER BURROWING ANIMAL OBSERVATIONS

Animals observed during field surveys included pronghorn, black-tailed jackrabbits (*Lepus californicus*), badgers (*Taxidea taxus*; Figure 14), and burrowing owls (*Athene cunicularia*; Figure 15). The presence of the badgers and jackrabbits in the study area indicates the potential for large volume soil bioturbation within the existing vegetation communities and soil types.

Figure 14. Badger (*Taxidea taxus*) photographed near Plot 12 (Photograph: Thomas Sharp, SWCA, June 2012).

Figure 15. Seven burrowing owl (*Athene cunicularia*) fledglings in burrow immediately south of the Clive Facility (Photograph: Thomas Sharp, SWCA, June 2012).

Soils

Soil sampling was conducted concurrently with vegetation sampling. Using the recommended soil sampling protocol from USU Analytical Laboratories in Logan, Utah, SWCA gathered soil subsamples at five locations within each of the eight study plots on the Clive Site. Soil sampling occurred from June 19 to 21, 2012. Subsample locations were characteristic of conditions within the study plot. All subsamples were taken at a depth of 0–30 cm (0–12 inches) using a 5-cm (2-inch) soil auger, as per the recommended sampling protocol. The five soil subsamples were combined to create one composite sample. SWCA stored the soil in a resealable plastic bag and labeled it with the appropriate study plot information, date, and time. Seventeen soil samples were sent to the USU Analytical Laboratories on June, 22, 2012.

SOIL MAPPING AND CLASSIFICATION

Soil Map Units

The study plots fall within three soil maps units (Figure 16), which delineate broad areas with distinctive soils, relief, and drainage (U.S. Department of Agriculture 2000). These map units are useful in describing conditions over large areas and suitability for land uses, and characterize the general conditions found at the eastern extent of the Great Basin. Table 7 describes similar elevation, climate, and vegetation characteristics in the soil map units present near the Clive Site.

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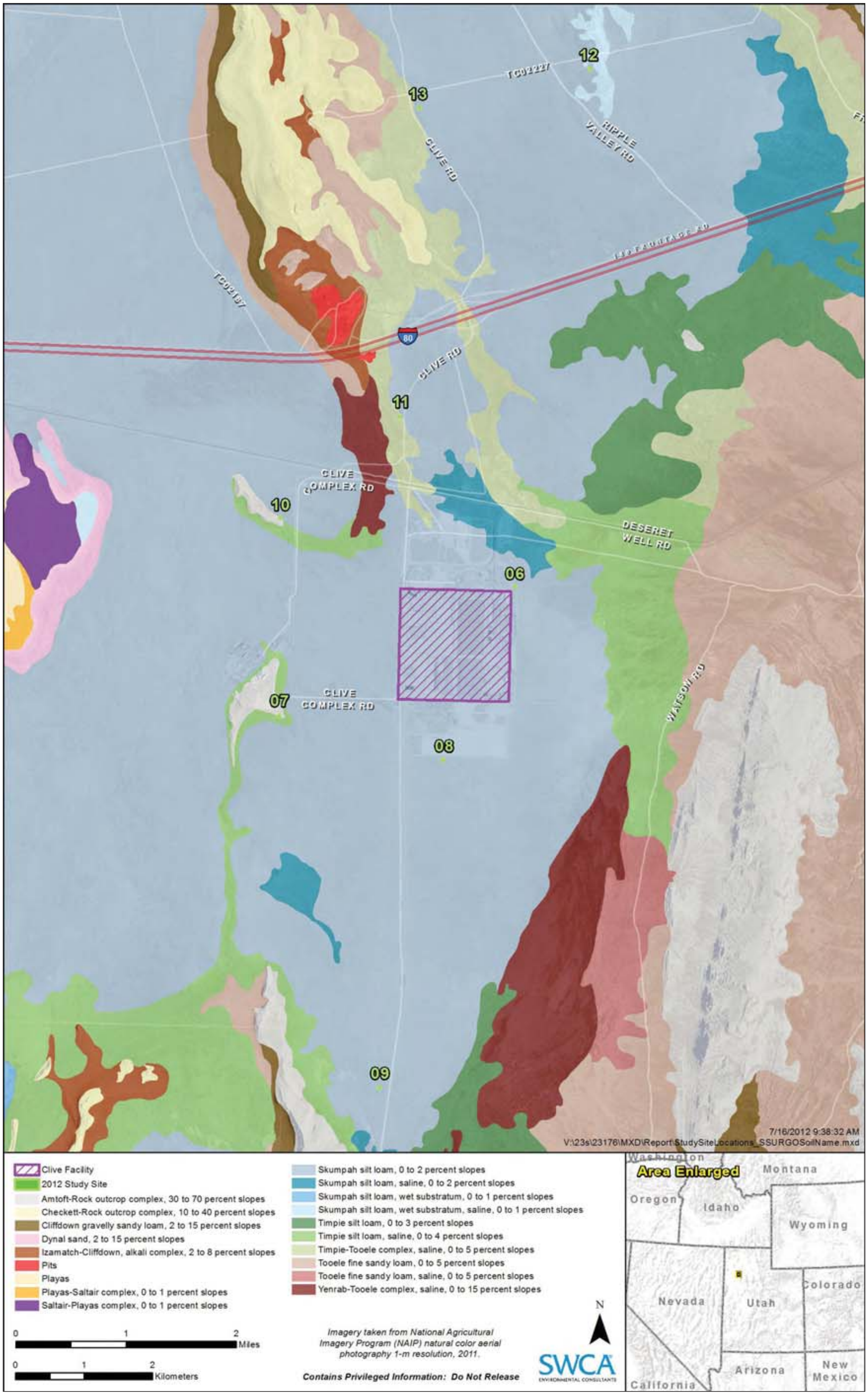

Figure 16. Soil map units.

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Table 7. Clive Site Soil Map Unit Characteristics

Soil Map Units	Elevation (feet)	Precipitation (inches)	Slope (%)	Mean Annual Air Temperature (°F)	Average Frost-Free Period (days)	Native Vegetation	Land Use
Skumpah-Yenrab-Dynal	4,200–5,050	6–8	0–15	45–52	120–160	Shadscale, greasewood, bottlebrush squirreltail (*Elymus elymoides*), Indian ricegrass (*Acnatherum hymenoides*), and fourwing saltbush	Rangeland and wildlife habitat; controlling grazing is necessary to maintain forage production.
Tooele-Cliffdown-Timpie	4,200–6,000	6–8	0–15	45–52	120–160	Shadscale, greasewood, Indian ricegrass, horsebrush (*Tetradymia* spp.), and bottlebrush squirretail	Rangeland, wildlife habitat, and irrigated alfalfa hay; controlling grazing is necessary to maintain forage production.
Amtoft-Rock Oucrop-Checkett	4,250–7,000	8–12	30–70	45–49	100–140	Black sagebrush, Utah juniper (*Juniperus osteosperma*), bluebunch wheatgrass (*Pseudoroegneria spicata*), Indian ricegrass, and Salina wildrye (*Leymus salinus*)	Rangeland and wildlife habitat; controlling grazing is necessary to maintain forage production.

Source: U.S. Department of Agriculture (2000)

Soil Series

Soil series descriptions provide more detailed and localized information concerning soil formation and drainage. The study plots are located across three soils series: Amtoft, Skumpah, and Timpie-Tooele Complex. As described in Table 8, these soils series were formed under different conditions but have similar drainage characteristics. The distribution of the 40 soil samples (5 per plot) within each soil series is also identified in Table 8. Most of the study plots occurred on the Skumpah soil series.

Table 8. Soil Series Characteristics near the Clive Site

Soil Series		Soil formation	Drainage	Number of Soil Samples
Amtoft-rock outcrop		Residuum and colluviums derived from calcareous sedimentary rocks	Well drained and somewhat excessively drained	5
Skumpah silt loam		Alluvium and lacustrine sediments derived from mixed rock sources	Very deep, well drained, moderately slowly permeable soils on lake terraces	30
Timpie-Tooele Complex	Timpie series	Alluvium and lacustrine sediments derived dominantly from limestone and quartzite	Very deep, well drained, moderately slowly permeable soils on lake terraces and fan remnants	5
	Tooele Series	Aeolian material, lacustrine sediments, and alluvium derived from mixed rock sources	Very deep, well drained, moderately rapidly permeable soils on lake terraces and fan remnants	

Source: U.S. Department of Agriculture (2000)

Soil Parameters

Site characteristic data that quantify landscape-level processes are available from NRCS for the three soils series. Those relevant to the design of an alternative cover system for the Clive Site are wind erodibility index (tons/acre/year), depth to restrictive layer (cm), depth to water table (cm), drainage class (well drained to poorly drained), pH, and range production value (pounds/acre/year). Table 9 lists the soil parameters and range of ratings or values for the three soil series present near the Clive Site.

Table 9. Soil Parameters Available for Soil Series near the Clive Site

Parameter	Rating or Value Range
Wind Erodibility Index (tons/acre/year)	48–86
Depth to restrictive layer (cm)	>200
Depth to water table (cm)	>200
Drainage class	Well drained
pH	Strongly alkaline (8.5–8.8)
Range production (pounds/acre/year)	500–850

Source: NRCS SSURGO data

SOIL SAMPLING RESULTS

Seventeen composite samples were hand delivered to the USU Analytical Laboratories for analysis. After coordination with the USU Analytical Laboratories, SWCA requested that a suite of parameters be analyzed.

Soil Analyses

Table 10 lists the results of analytical tests performed by the USU Analytical Laboratories on the soil samples taken from study plots and potential soil borrow sources on the Clive Site.

Table 10. Soil Analysis Results

Parameter	Unit	Study Plot/Borrow Unit / Ant Mound Excavation Number																
		Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Unit 4	Unit 3	Ex 1-0.5	Ex 2-1.0	Ex 2-3.5	Ex 3 1.0	Ex 3-3.5	Ex 4-1.0	Ex 4-3.5
		Texture																
		Silty Clay Loam	Clay Loam	Silty Clay Loam	Silty Clay Loam	Loam	Silty Clay Loam	Silt Loam	Silty Clay	Silty Clay	Sand	Silt Loam	Silt Loam	Silty Clay	Clay Loam	Silty Clay	Silty Clay Loam	Silty Clay
>2mm	%	2.22	13.3	0.66	0.48	2.88	1.94	0.63	1.67	10.1	13.5	4.3	17.9	10.9	2.94	8.14	7.2	7.65
Sand	%	13	26	15	20	27	19	23	9	0	91	28	20	0	21	4	16	12
Silt	%	49	39	51	51	47	48	51	53	61	0	51	54	47	50	50	56	47
Clay	%	38	35	34	29	26	33	26	38	39	9	21	26	53	29	46	28	41
pH	n/a	8.3	8.2	8.3	8.3	8.2	8.2	8.4	8.1	8.3	8.0	7.6	8.4	8.0	8.4	7.9	8.0	7.9
Salinity ECe	dS/m	16.0	16.4	10.8	10.90	6.02	6.78	3.34	12.70	55.60	11.10	17.7	15.90	29.40	25.90	12.60	24.00	29.00
Phosphorous	mg/kg	11.6	8.5	7.4	5.40	6.80	5.60	8.60	6.90	3.90	4.40	37	4.90	6.70	2.90	6.90	3.50	5.60
Potassium	mg/kg	899	811	899	899	804	899	680	899	548	167	899	899	667	776	805	128	899
Nitrate-Nitrogen	mg/kg	9.47	8.78	10.90	9.95	9.18	8.58	11.00	12.60	5.89	3.12	19.20	1.58	4.51	3.88	7.48	4.87	5.08
Zinc	mg/kg	0.20	0.14	0.09	0.09	0.05	0.09	0.08	0.14	0.12	0.01	0.13	0.05	0.13	0.03	0.23	0.04	0.10
Iron	mg/kg	2.34	3.28	2.34	2.55	2.33	2.70	1.88	2.67	7.19	5.68	1.69	2.28	2.92	2.60	2.92	2.25	1.82
Copper	mg/kg	0.50	0.50	0.40	0.39	0.04	0.44	0.33	0.53	0.75	0.06	0.35	0.40	1.15	0.43	1.30	0.39	0.81
Manganese	mg/kg	2.75	2.59	2.25	2.28	2.11	1.91	2.04	2.52	1.11	1.56	5.76	0.94	0.96	0.80	0.91	0.82	0.95
Sulfate-Sulfur	mg/kg	154	136	107	80	18	126	11	105	623	13	78	146	388	157	463	188	277
Organic Matter	%	2.7	1.8	2.6	2.9	1.2	1.70	1.9	1.9	1.7	1.2	2.1	1.2	0.8	2.0	1.0	1.2	1.2
SAR	n/a	72.2	92.7	68.8	81.9	37.8	40.2	28.9	67.3	176.0	24.6	131.0	62.3	88.5	110.0	94.7	98.4	73.9

Soil Texture

Soil texture in the study plots ranges from silty clay loam to loam. Soils from all plots contain relatively similar proportions of sand, silt, and clay with the exception of Plot 13, which contains only 9% sand.

Soil pH, Salinity, and Sodium Adsorption Ratio

The results for pH show high alkalinity with a range of 8.0–8.4 across the study plots and soil borrow site. Salinity ranges from 3.3 to 55.6 decisiemens per meter (dS/m), which is weakly saline to very strongly saline, respectively. Qualitative descriptions for salinity such as strong or weak are relative measures. When considering the pH of the soil and the potential for reclamation, it is generally understood that certain plants have salinity and pH thresholds that make them more or less successful in establishing under saline conditions. The Sodium Absorption Ratio is a comparison of the concentrations of sodium (Na+), calcium (Ca2+) and magnesium (Mg2+) ions in soil solution. Results range from 24.6 to 176 milliequivalents (meq)/L and are as such considered sodic soils. These soils do not contain equal amounts of neutral soluble salts and can have a detrimental effect on plants due to sodium toxicity (Brady 1974).

Macronutrients

The amount of phosphorous, potassium, and nitrate-nitrogen in the study plot soils is generally consistent across the eight plots. Phosphorous ranges from 5.4 to 11.6 milligrams/kilogram (mg/kg). Potassium ranges from 680 to 899 mg/kg. Nitrate-nitrogen ranges from 8.58 to 12.60 mg/kg. Whether or not these values reflect high, medium, or low levels of macronutrients requires additional research, but it is assumed that these essential elements are not readily available to plants given high pH and other physical and chemical conditions.

Micronutrients

The amount of zinc, iron, copper, manganese, and sulfate-sulfur in the study plot soils is generally consistent across the eight plots. Zinc ranges from 0.05 to 0.2 mg/kg. Iron ranges from 1.88 to 3.28 mg/kg. Copper ranges from 0.04 to 0.53 mg/kg. Manganese ranges from 1.91 to 2.75 mg/kg. Sulfate-Sulfur ranges from 11 to 154 mg/kg. Study plots 10 and 12 comprise loam and silt loam, respectively, and consistently have micronutrients at the low end of these ranges.

Organic Mater

Organic matter in the study plots ranges from 1.2% to 2.9%. Soils in arid lands typically have low amounts of organic matter (Perry and Perry 1989). Identifying "healthy" soil based on organic matter percentage requires additional research.

Metals

Cadmium and chromium are generally undetectable in the study plots with the exception of Plots 6, 11, and 13, which have 0.005 mg/kg, 0.002 mg/kg, and 0.001 mg/kg, respectively. Nickel and lead are found in all soil samples in relatively consistent amounts.

Missing Soil Analyses

As of the finalization of this report, SWCA had still not received the analysis results for three soil parameters; CEC; sand sieve analysis; and water soluble elements.

Cation Exchange Capacity

CEC is an estimate of the rate at which nutrient cations are stored and released. It is a function of positive and negative charges of cations. CEC is related to soil texture because clays and organics typically have a negative charge that bonds with positive cations such as calcium, magnesium, potassium, sodium, and hydrogen. Low CEC values can mean that soils lack the ability to hold applied nutrients. High CEC values can mean the soil lacks airspaces, resulting in anaerobic conditions.

Sand Sieve Analysis

This test classifies soils based on course grain size. It is more commonly used for engineering purposes to determine Atterberg limits (e.g., liquid limit, plastic limit, and shrinkage limit) than to assess plant growth medium suitability.

Water Soluble Elements

Water soluble elements (saturation paste) is a measure of bioavailable nutrients. For plants to use certain nutrients (e.g., potassium), these elements must be in a readily available (i.e., water soluble) form. This analysis measures the amount of water-soluble elements in the soil, including nitrate-N, potassium, and sulfur.

The results of these analyses will be incorporated into the soils data analyses here and provided to Energy*Solutions* as soon as they are made available to SWCA.

SOIL EROSION RESULTS

In general, there was limited evidence of wind and water erosion on the study plots. Wind erosion, where evident, appears to be associated with breaks in the biological soil crusts (e.g., animal trials). In addition to soil stabilization, biological soil crusts provide nitrogen fixation, increase nutrient availability, and improve vascular plant establishment (Pendleton et al. 2007). There was little to no evidence of water erosion (e.g. rilling) even on those study plots (e.g., Plot 13) with a discernible slope. In general, all soil types are susceptible to erosion regardless of proportion of particle size. The elevated position of an ET cap relative to the surrounding landscape is likely to increase the susceptibility of surface soils to wind erosion. The use of gravel, application of spray-on soil adhesives, and inoculation of soil with crust-forming soil algae and mycorrhizal fungi are potential strategies for reducing soil erosion.

SOIL EXCAVATION RESULTS

In addition to those samples obtained from the study plots, SWCA gathered soil samples from three ant mound excavation sites at depths of 0.3 m and 1.1 m (1.0 and 3.5 feet), one ant mound excavation site at a depth of 0.2 m (0.5 feet), and a borrow area at depths consistent with the bottom of Borrow Unit 4 and top of Borrow Unit 3 on the Clive Site. Table 11 compares the soil analysis results for the soil excavations from Borrow Unit 4 and ant mound excavation sites with the soil samples from the eight study plots. There are some dissimilarities between the soil features of these locations.

Table 11. Summary of Soil Analysis Results from the Ecological Analogue Study Sites (Plots 6–13) and Soil Borrow Locations at the Clive Site (Unit 4 and Adjacent Topsoil Excavations)

Soil Parameter	Units	Ecological Analogue Soils (Plots 6–13)			Borrow Soils (Unit 4 and on-site excavations)		
		Range	Mean	Standard Deviation	Range	Mean	Standard Deviation
Particle size >2mm	%	0.48–13.3	2.97	4.26	2.94–17.9	8.64	4.59
Sand	%	9.0–27.0	19.00	6.35	0.0–28.0	12.63	10.46
Silt	%	39–53	48.63	4.34	47–61	52.00	4.78
Clay	%	26–38	32.38	4.87	21–53	35.38	11.07
pH	n/a	8.1–8.4	8.25	0.09	7.6–8.4	8.06	0.28
Salinity (ECE)	dS/m	3.34–16.4	10.37	4.71	12.6–55.6	26.26	13.37
Phosphorus (PO_4)	mg/kg	5.4–11.6	7.60	1.99	2.9–37.0	8.93	11.44
Potassium	mg/kg	680–899	848.75	79.76	126–899	702.63	263.74
Nitrogen (NO_3)	mg/kg	8.58–12.6	10.06	1.36	1.58–19.2	6.56	5.38
Zinc	mg/kg	0.05–0.20	0.11	0.05	0.03–0.23	0.10	0.07
Iron	mg/kg	1.88–3.28	2.51	0.40	1.69–7.19	2.96	1.77
Copper	mg/kg	0.04–0.53	0.39	0.16	0.35–1.30	0.70	0.37
Manganese	mg/kg	1.91–2.75	2.31	0.29	0.80–5.76	1.53	1.71
Sulfur (SO_4)	mg/kg	11.2–154.0	92.14	52.72	77.7–623	289.96	186.89
Organic matter	%	1.2–2.9	2.09	0.58	0.8–2.1	1.40	0.48
SAR	n/a	28.9–92.7	61.23	22.89	62.3–176	104.35	35.76

Soil Texture

Borrow Units 4 and 3 at the borrow source location have very different soil textures when compared to the study plots. Borrow Unit 4 is silty clay with no sand particles, and Borrow Unit 3 is 91% sand.

Soil pH, Salinity, and Sodium Adsorption Ratio

Soil pH in Borrow Units 4 and 3 are 8.3 and 8.0, respectively, and within the range of the study plots. Salinity and SAR in Borrow Unit 4 significantly exceed the range of values found in the study plots. Salinity and SAR in Borrow Unit 3 are within the range of values found in the study plots.

Macronutrients

All three macronutrients are consistently lower than the levels of these essential elements found in the study plots.

Micronutrients

Borrow Unit 4 has comparable zinc, high iron, high copper, low manganese, and high sulfate-sulfur when compared to the study plots. Borrow Unit 3 has low zinc, high iron, low copper, low manganese, and comparable sulfate-sulfur when compared to the study plots.

Organic Mater

Organic matter content falls within the range found in the study plots.

Metals

Cadmium, chromium, and nickel are undetectable in Borrow Units 4 and 3. Lead in Borrow Unit 4 is within the range found in the study plots. Lead is considerable lower in Borrow Unit 3 relative to the study plots.

CORRELATION ANALYSES

The Pearson product-moment correlation coefficient (*r*) was used to assess relationships between biotic and abiotic variables that were assessed in each plot: plant species cover, small mammal densities, animal burrow volumes, ant mound volumes, and soil chemistry and nutrition parameters. Strong relationships that were identified between variables are described here:

- There were strong, positive relationships between total vegetation cover and mammal densities and burrow volumes, with *r* ranging from 0.62 (deer mouse density) to 0.84 (badger burrow volume). Total badger and deer mouse burrow volumes were particularly strongly correlated with shadscale saltbush cover (r = 0.95 and 0.97, respectively).
- In contrast, there was no correlation between total vegetation cover and ant mound area or volume.
- There were strong, positive correlations between ant mound area and volume and cover of weedy species (r = 0.77). This relationship was anecdotally observed in the 2010 study as well.
- There was a strong, negative correlation between ant mounds and soil silt content (r = -0.83), and somewhat strong, negative correlations between animal densities and burrow volumes and soil clay content (r = 0.53).
- There are strong, positive correlations between ant mound surface area and soil salinity (ECE; r = 0.60), iron (r = 0.65), and SAR (r = 0.59).
- High soil pH does not appear to be limiting for any of the native or weedy plant species that occurred in the plots. However, plant cover, particularly of shadscale saltbush, showed strong, negative correlations with high soil salinity (ECE), potassium, iron, sulfur, and SAR (r = -0.64, -0.81, -0.68, -0.63, and -0.59, respectively).

ORDINATION ANALYSES

Because of the small data set and large numbers of variables, ordination analyses did not clearly identify trends in the distribution of plant species with mammals, ants, or soils. The ordination axes that resulted did not sufficiently separate the plots so that trends in habitat-bioturbation distributions could be identified.

Recommendations

Vegetation

The plant species selected for the ET cover system should consist of native and desirable non-native, salt-tolerant shrubs and grasses. Localized native species will be best adapted to the high pH and highly saline and toxic contents of the local soils. Although a vegetation community of sufficient diversity and density is desired to maximize transpiration from the soil, vegetation density was positively correlated with small mammal and burrowing activity. As such, bioturbation should be expected to increase with increasing vegetation cover.

Bioturbation

Because kangaroo rats did not tolerate the marking process and markings were wearing off or being chewed off the deer mice, total recaptures are likely underestimated, and the resulting total small mammal captures may be overestimated for some plots. However, the species distributions and densities identified during field studies are an approximate estimate of total small mammal densities and associated bioturbation potential in the study plots. Overall, small mammal activity is to be expected in any native vegetation community that is established as part of an ET cover system at the Clive Facility. As stated above, the density of small mammals and animal burrows should be expected to increase with increasing vegetation cover.

The levels of animal activity that were observed in and near the plots, including the documented presence of badgers and a large family of burrowing owls, indicate that bioturbation that could move large volumes of soil is to be expected in any native vegetation community in the area. A bioturbation barrier will likely be needed that is designed to exclude large and small burrowing mammals (i.e., mice, rats, hares, badgers). Designs that maximize the depth of upper soil layers or that incorporate bioturbation barriers would help to prevent penetration by ants into waste layers.

Soils

The soil analyses performed on the soil samples taken from the eight study plots confirm that conditions are typical of soils formed in arid environments. There is a range in soil texture, with most being silty clay loams, elevated pH and salinity, and low organic matter. Even when considering these constraining conditions, recreating them within the root zone of the ET Cap in order to support a native vegetation community may be challenging given the difference between the study plot soils and those taken from the Borrow Units. For example, blending borrow soils to obtain the proper texture that allows for enough infiltration to support plants while avoiding deep infiltration and excessive runoff is likely necessary. Buffering the amount of sodium found in the borrow soils with and amendments, e.g. gypsum, or leaching it below the root zone may also be necessary given the high SAR values of Borrow Unit 4. Soil amendments or fertilizer may also be necessary since borrow soils have less macronutrients than the study plots. However, additional analysis is needed to determine the appropriate application rates since overfertilization could result in establishment of non-native or invasive species. Finally while the soil analyses are sufficient to characterize study plot soils and provide baseline conditions, additional investigation is need to prescribe suitable types and amendments and qualities to create suitable conditions for native plant establishment on the ET Cap. Also, soils may need to be treated to minimize disturbance at the biogeochemical level. Inoculation with crust forming soil algae and mycorrhizal fungi can serve a variety of functions from soil stabilization, to moisture regulation to nitrogen fixation to nutrient mobilization.

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