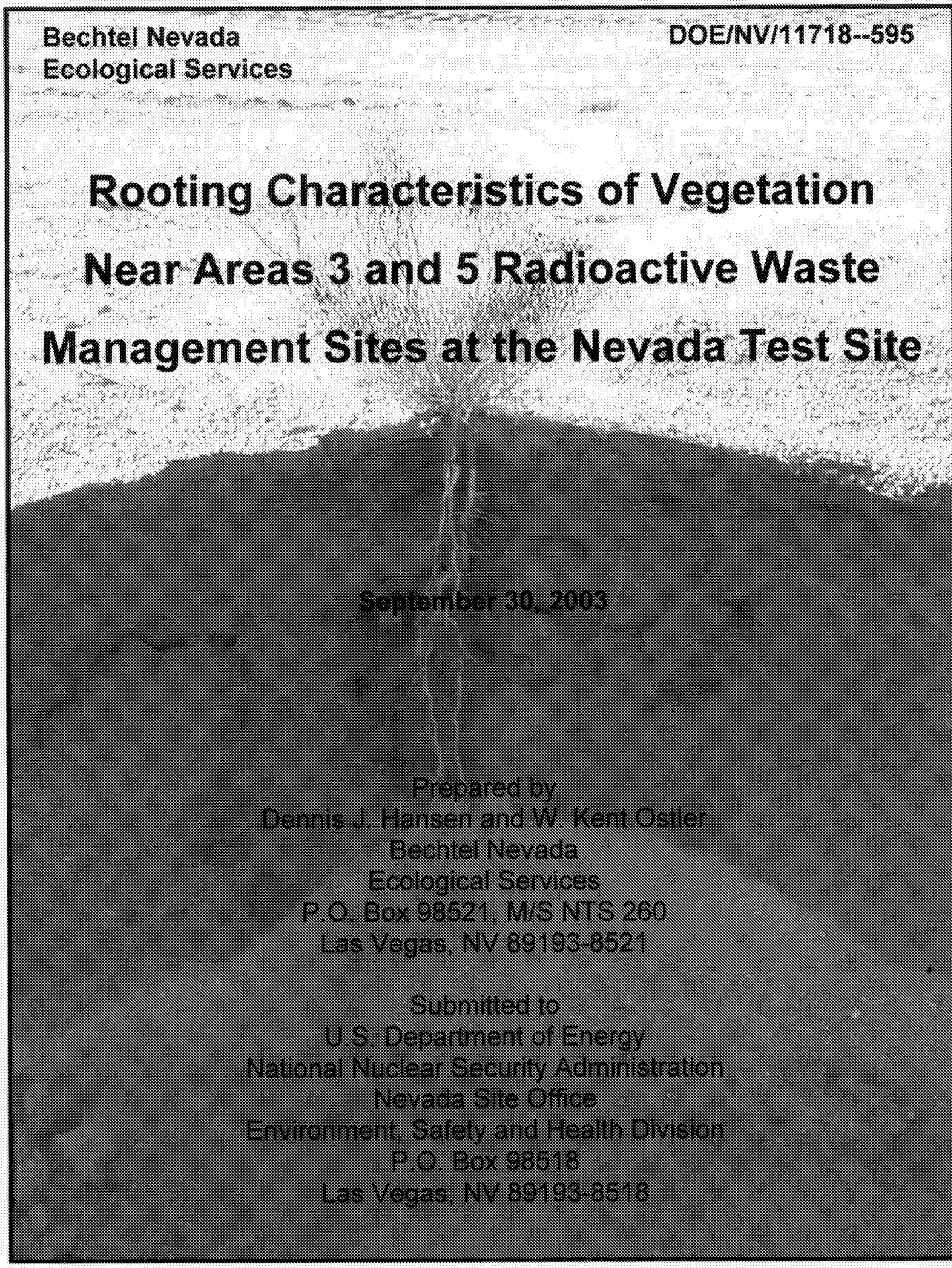

Bechtel Nevada
Ecological Services

DOE/NV/11718--595

Rooting Characteristics of Vegetation Near Areas 3 and 5 Radioactive Waste Management Sites at the Nevada Test Site

September 30, 2003

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Submitted to
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LIST OF ACRONYMS and ABBREVIATIONS

B.P.	before (the) present
CO_2	carbon dioxide
cm	centimeter(s)
cm^2	square centimeter(s)
DOE	U.S. Department of Energy
EG&G/EM	EG&G Energy Measurements, Inc.
ELU	Ecological Landform Unit
FACE	Free Air Carbon Enhancement Facility
ft	foot/feet
g	gram(s)
GCD	Greater Confinement Disposal
IBP	U.S. International Biological Program
in	inch(es)
kg	kilogram(s)
kg/ha	kilograms per hectare
km	kilometer(s)
km^2	square kilometer(s)
LLW	Low-level Radioactive Waste
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
m^3/ha	cubic meters per hectare
mi	mile(s)
mi^2	square mile(s)
mm	millimeter(s)
n	number
NAPP	Net Above-Ground Primary Production
NERP	National Environmental Research Park
NPP	Net Primary Production
NTS	Nevada Test Site
PA	Performance Assessment
PPT	Precipitation in millimeters from September to August
R^2	statistical measurement representing variance
RWMS	Radioactive Waste Management Site
Stdev	standard deviation
TRU	Transuranic
UCLA	University of California, Los Angeles

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EXECUTIVE SUMMARY

The U.S. Department of Energy emplaced high-specific-activity low-level radioactive wastes and limited quantities of classified transuranic wastes in Greater Confinement Disposal (GCD) boreholes from 1984 to 1989. The boreholes are located at the Area 5 Radioactive Waste Management Site (RWMS) on the Nevada Test Site (NTS) in southern Nevada. The boreholes were backfilled with native alluvium soil. The surface of these boreholes and trenches is expected to be colonized by native vegetation in the future. Considering the long-term performance of the disposal facilities, bioturbation (the disruption of buried wastes by biota) is considered a primary release mechanism for radionuclides disposed in GCD boreholes as well as trenches at both Areas 3 and 5 RWMSs. This report provides information about rooting characteristics of vegetation near Areas 3 and 5 RWMSs. Data from this report are being used to resolve uncertainties involving parameterization of performance assessment models used to characterize the biotic mixing of soils and radionuclide transport processes by biota.

The objectives of this study were to: (1) survey the prior ecological literature on the NTS and identify pertinent information about the vegetation, (2) conduct limited field studies to describe the current vegetation in the vicinity of Areas 3 and 5 RWMSs so as to correlate findings with more extensive vegetation data collected at Yucca Mountain and the NTS, (3) review prior performance assessment documents and evaluate model assumptions based on current ecological information, and (4) identify data deficiencies and make recommendations for correcting such deficiencies.

Biological research and reports describing the vegetation of the NTS were identified and reviewed in conjunction with other Bechtel Nevada efforts to update published reports on the ecology of the NTS. Descriptions of NTS vegetation and past climate were summarized from fossil packrat midden research based on climatic conditions on the NTS during the past 45,000 years. Reported findings suggested that annual temperatures may have been 6^0 C to 7^0 C cooler and precipitation 40 percent more than they are today. A possible return to these conditions formed the basis for future scenarios.

A recent classification of vegetation on the NTS provided access to detailed information about plant communities and ranges of individual plant species. The vegetation in the vicinity of Areas 3 and 5 RWMSs was described in the context of past plant communities and currently accepted classification of vegetation on the NTS. Descriptions of vegetation from these published sources were summarized.

Research on the root characteristics of vegetation on the NTS (including Mojave and Great Basin deserts) was described. Because of the natural variations in desert climates different patterns in rooting depth were identified. Differences in rooting exist because of genetic differences in plant life form (trees, shrubs, forbs, grasses) and seasonality (annuals vs. perennials). The principles of root development and growth were reviewed to explain why shrubs develop more roots near the surface than deep roots and why lateral root growth is favored over vertical root growth. The importance of climatic extremes and natural perturbations, such as fires, droughts, and diseases, was described.

Early NTS root studies were described and information summarized in tables, graphs, and narratives to document the findings of extensive ecological studies about shrub rooting patterns and statistical correlations between plant structures such as height, diameter, canopy cover, density, root depth, and biomass production of stems and roots.

As part of this study, BN biologists conducted field investigations at two sites near Area 5 RWMS and three sites near Area 3 RWMS to measure shrub structures by species for the purpose of correlating findings with those of early root studies. New image processing techniques were made available from the Strategic Environmental Research and Development Program (U.S. Department of Defense, U.S. Department of Energy, and U.S. Environmental Protection Agency) for 11 photo plots near Area 5 RWMS as part of technology transfer to evaluate shrub size classes and distribution of standing crop biomass from high-resolution, aerial, color-infrared photographs. Site conditions at the five study sites were summarized and presented in tables.

Estimates of annual production of the vegetation on the NTS were presented showing a strong correlation with precipitation received during the growing season. Estimates were made of net aboveground primary production (NAPP) for selected study sites based on mean annual precipitation. The findings estimate NAPP for multiple years at Rock Valley (1966 to 1968 and 1971 to 1976) and Yucca Mountain (1989 to 1993). Estimates of productivity for all species ranged from 0 (no production) in drought years to 682 kilograms/hectare during favorable years of precipitation.

Future scenarios were presented with likely patterns in development of vegetation based on current vegetation at the NTS and potential changes given the introduction from other areas of the world of exotic (non-native) annual plant species during the past century. Because of deep soils present at Areas 3 and 5 RWMSs, conclusions were made that these sites would develop as shrublands (i.e., shrub-dominated), not woodlands (i.e., tree-dominated), under cooler temperatures and increased precipitation as implied from evidence covering the past 20,000 years on the NTS. The strongest evidence in support of a grassland or shrubland comes from existing pinyon-juniper and sagebrush sites on the NTS where, historically, fires periodically remove taller vegetation on deeper soils that support sufficient fuel for carrying a fire through a plant community. No trees are found in the valley bottoms at higher precipitation and elevations on the NTS or on Nellis Air Force Ranges north of the NTS, mapped by BN scientists. Because of the permeable nature of the sandy loam soils on these sites, it is highly unlikely that ephemeral wetlands (i.e., only wet in the early part of the growing season) will ever develop on these sites even with substantial increases in precipitation. If cooler conditions returned, mesquite trees, found abundantly around large springs 16 to 32 kilometers [10 to 20 miles] south of the NTS, would not survive the winters; none is currently found on the NTS.

Measurements of the current vegetation were taken to describe vegetation properties such as plant structure and community composition in the vicinity of Areas 3 and 5 RWMSs. While little quantitative data exist for characterizing shrub roots in the vicinity of Areas 3 and 5 RWMSs, estimates of some root system parameters, such as root biomass and depth, can be made for some species at some sites (primarily Area 5 RWMS) for future modeling efforts. These estimates are based on statistical correlations of measured plant structures to other plant parts or parameters such as correlations of perennial and annual shoot biomass with root biomass, living volume (height x width x length) with shoot biomass, and plant height with maximum root depth. Historical and recent site observations of shrub rooting patterns document that root depth on the NTS rarely exceeds 2 meters deep, although a few very deep (8 meters) individual roots have been observed occasionally during construction of the waste trenches. Most of the roots are confined to the near surface horizons and diminish with depth as soil moisture and plant nutrients correspondingly decrease.

Data deficiencies include the lack of correlation factors (e.g., living volume-to-biomass conversion factors and root-to-shoot ratios) for selected plant species (e.g., white burrobush, green rabbitbush, spiny menadora, and budsage). Data on rooting characteristics of shrubs and trees at higher elevations of the NTS (e.g., big sagebrush, singleleaf pinyon, and Utah juniper) are also not available and projections of root distribution and biomass production are needed to characterize these species and plant communities if modeling efforts require these projections under future climatic changes.

Recommendations for reducing uncertainty in transport models suggest future research to obtain: (1) unknown correlation factors, (2) additional characterization of rooting profiles from trenches or pits near Areas 3 and 5 RWMSs, (3) possible excavation of mature shrubs that were transplanted into deeply disturbed soils on the NTS and may thus serve as analog studies, and (4) characterization of rooting depths of big sagebrush plants in pinyon-juniper/big sagebrush plant communities to facilitate an evaluation of future climates that are cooler and wetter than present conditions.

Findings developed in this study will assist future modeling efforts including those being conducted currently to evaluate the role of ants, termites, and burrowing animals.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) emplaced high-specific-activity low-level radioactive wastes (LLW) and limited quantities of classified transuranic (TRU) wastes in Greater Confinement Disposal (GCD) boreholes from 1984 to 1989. Nine of thirteen GCD boreholes were used to provide intermediate depth disposal. The boreholes are located at the Area 5 Radioactive Waste Management Site (RWMS) on the Nevada Test Site (NTS) in southern Nevada (Figure 1-1). The GCD boreholes measure approximately 3 meters (m) [10 feet (ft)] in diameter and 36 m (120 ft) deep. The bottom 15 m (50 ft) of each borehole were used for waste emplacement. The upper 21 m (70 ft) of each borehole consisted of native alluvium backfill. Additionally, trenches have been excavated to store radioactive wastes in Areas 3 and 5. The surface of these boreholes and trenches is expected to be colonized by native vegetation in the future. Considering the long-term performance of the disposal facilities, bioturbation (the disruption of buried wastes by biota) is considered a primary release mechanism for radionuclides disposed in GCD boreholes as well as trenches at both Areas 3 and 5 RWMSs. This report provides information about rooting characteristics of vegetation near Areas 3 and 5 RWMSs. Data from this report will be used to resolve uncertainties involving parameterization of models used to characterize the biotic mixing of soils and waste transport processes by biota.

A Performance Assessment (PA) has been prepared and evaluated by Sandia National Laboratories (Cochran et al., 2000). The focus of the evaluated PA was not to predict how the GCD system will actually perform, but rather to "provide simulations of a range of plausible outcomes, which are developed in a manner to provide confidence that the results of the analysis do not overestimate the ability of the GCD boreholes to protect human health" (Cochran et al., 2000). This approach allowed for the use of data that approximated the range of plausible values without having to use site-specific data, especially if the data were not readily available. Likewise, simplifying assumptions were made about biotic transport and in the LLW PAs.

Transport and exposure models were based on assumptions about vegetation, particularly rooting characteristics of shrubs and trees and their role in biotic transport of radionuclides. Because studies about NTS vegetation or site-specific information were sometimes difficult to identify, acquire in a timely fashion, or the data simply were not available in forms readily extractable, calculations were based on other information generally available in the public scientific literature. This information was frequently taken from studies remote from the NTS or Mojave Desert. Attempts were made to match pertinent data as closely as possible with NTS climate, vegetation, and site conditions; however, much of the data had to rely on ecological studies in other arid areas such as the Sonoran or Chihuahuan deserts. Since the completion of the draft GCD PA, additional information has become published about NTS vegetation and other pertinent vegetation studies. A three-year study describing the vegetation of the NTS was recently published (Ostler et al., 2000). Additionally, efforts were completed in 2001 to update NVO-167, *Ecology of the Nevada Test Site: A Narrative Summary and Annotated Bibliography* (O'Farrell and Emery, 1976), which describes the ecology of the NTS and provides abstracts of literature published about the NTS biota since 1976. This new report: DOE/NV/11718–594,

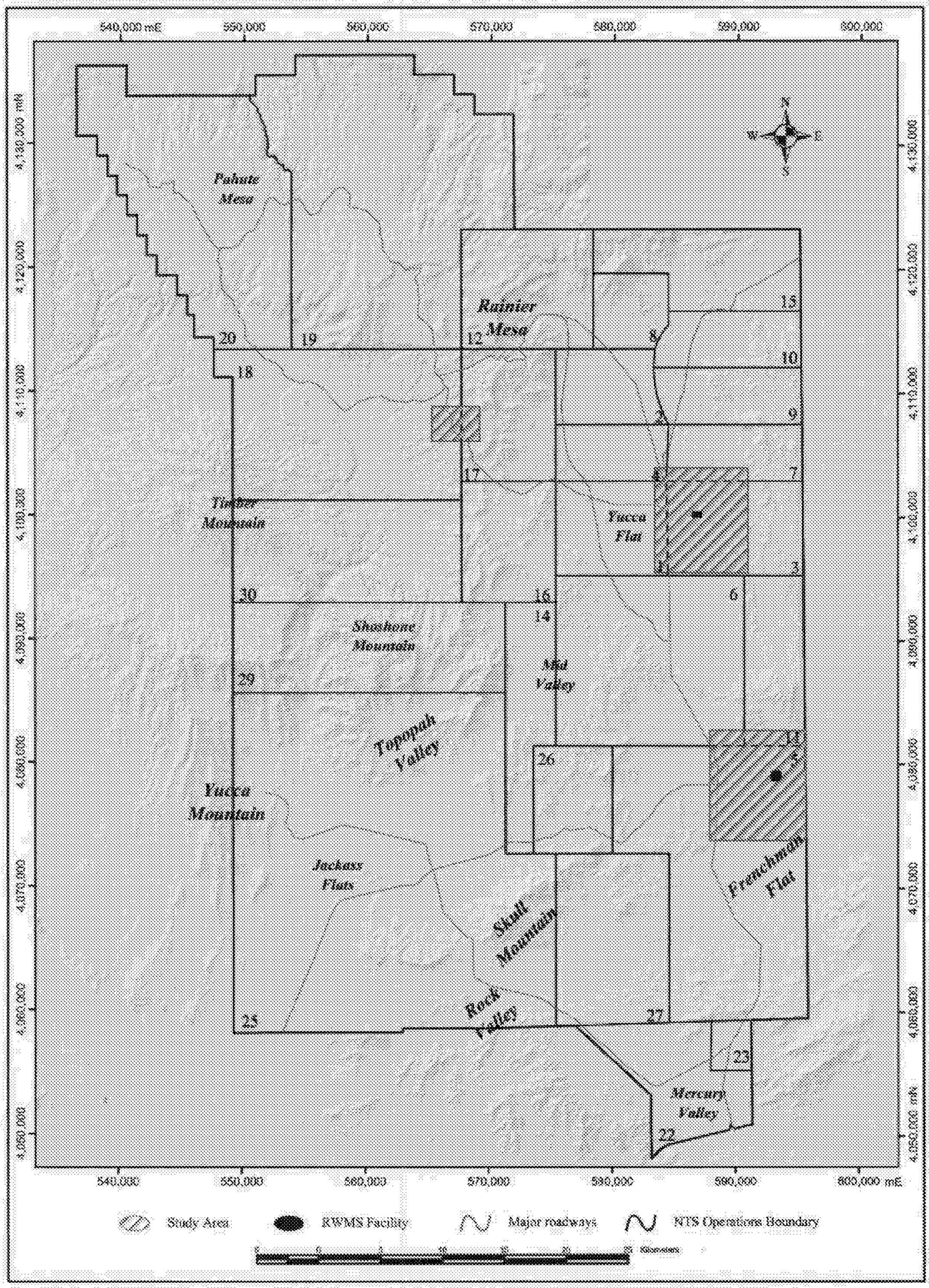

Figure 1-1. Major roads, topographic features and administrative areas on the Nevada Test Site

Ecology of the Nevada Test: An Annotated Bibliography (Wills and Ostler, 2001) identifies recent NTS-specific publications.

This study (i.e., the study described in this report) focuses on summarizing information about NTS vegetation from past studies in the vicinity of the Area 5 RWMS (including the GCD boreholes and trenches) and the Area 3 RWMS. It provides information about the current vegetation at these sites based on limited field studies, identifies vegetation data deficiencies, and attempts to describe plausible future vegetation scenarios that would likely develop at these sites under future climatic changes during the next 10,000 years. The field studies provide information about vegetation that can be used to evaluate the role of ants and termites in biotic mixing of soils and waste transport processes by biota (Hooten et al., 2001).

Section 3.0 provides a description of vegetation of the NTS including studies about changes in the climate and vegetation based on analysis of fossil packrat middens over the past 45,000 years, and historic reports documenting the vegetation of the NTS during the past five decades. Section 4.0 reviews the scientific literature for pertinent information about root development and early NTS root studies. Principles of root growth are described, including factors that limit and shape root growth in desert environments, particularly within the Mojave Desert. Section 5.0 reports the findings of field measurements of shrubs located near Areas 3 and 5 RWMSs. Descriptive statistics including mean, standard deviations, and maximum values for individual measurements are reported. Section 6.0 provides brief discussions of future scenarios which are based on changes in climate and vegetation. The types of changes in plant communities are discussed with emphasis on a return to a cooler and wetter climate as has occurred on the NTS in the past 25,000 years. Section 7.0 provides conclusions and summarizes the findings. This section provides mean values and ranges of values considered important for modeling and PAs in the future. Also discussed are data deficiencies and recommendations for correcting data deficiencies. Section 8.0 documents literature cited in this report. Section 9.0 provides an Appendix containing summary information about all of the plant associations found on the NTS in the vicinity of Areas 3 and 5 RWMSs and descriptions of root characteristics at various soil depths observed during construction of a new pit in Area 5 RWMS in August of 2001.

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2.0 PURPOSE AND SCOPE

2.1 Goals and Objectives

The purpose of this report is to provide information about the vegetation on the NTS that can be used to reduce uncertainty in the PA models by characterizing the biotic mixing of soils and radionuclide transport processes by biota at the Areas 3 and 5 RWMSs. The scope of the effort is limited to a preliminary review of NTS literature with the purpose of identifying useful data and data deficiencies. It also provides a limited amount of field work to help correlate vegetation in the vicinity of Areas 3 and 5 RWMSs with a recently published report (Ostler et al., 2000) that describes the vegetation of the NTS in detail. Data from limited field investigations will also be used by scientists of Neptune and Company, Inc., who are investigating the role of ants and termites in the biotic mixing of soils. Specific objectives include:

- Survey the prior ecological literature at the NTS and identify useful information about the vegetation (e.g., site-specific information on rooting characteristics) for parameterizing future PA models.
- Conduct limited field studies to describe the current vegetation in the vicinity of Areas 3 and 5 RWMSs and to help relate it to vegetation described in recent and past published reports.
- Review prior published reports for the PA of the GCD boreholes at the NTS and evaluate assumptions about the vegetation based on current ecological information and recently published reports.
- Describe data deficiencies where information that might be needed for future PA models.

2.2 Plant Parameters Used in PA Models

Vegetation colonizes most disturbed soils in time providing a biological cover that protects against water and wind erosion. Vegetation also redistributes water and nutrients, and provides energy in the form of fixed carbon that supports a complex web of life including animals and microorganisms. The vegetation is comprised of a diverse composition of plant species that vary in size and shape through time and space. This vegetation both influences and is influenced by other components of the environment. The future vegetation of any site is determined by a complex set of site conditions, including climate, soils, animals, pests/diseases, and man-induced perturbations as well as stochastic perturbations (e.g., fires and floods). In the Mojave and Great Basin deserts, where the NTS is located, these interactions are dynamic and are often shaped by major and minor climatic changes such as droughts, freezes, and local weather patterns. Often the best predictors of future vegetation are patterns of current vegetation in the area and an understanding of the interrelations of current and past vegetation with the environment.

Plant parameters that are particularly useful for modeling waste transport processes by biota are those that describe vegetation in three dimensions through time. Important parameters include:

- Vegetation patterns across the landscape and major forces shaping these patterns.
- Changes in vegetation patterns in the past and likely changes in the future.
- Species of plants and community structure that comprise vegetation patterns.
- Life history data that describe longevity and reproduction strategies for major species.
- Basic understanding of plant physiology (e.g., water requirements, plant nutrition and growth) of major species.
- Annual production of plant biomass and its persistence in the environment over time.
- Distribution of biomass above ground (e.g., canopy cover, height, and above-ground living volume) and below ground (e.g., rooting depth, lateral spread, species root interactions).
- Decomposition rates and the role of other organisms in the decomposition process (e.g., rabbits, rodents, insects, mites, fungi, nematodes, bacteria).

As with any biological study, a "complete" understanding of these parameters is seldom, if ever, achieved. However, it is possible to provide a substantial amount of information that is sufficient to parameterize models used to characterize the mixing of soils and waste transport processes by biota. Where specific data are unavailable, it is possible to draw from the scientific literature describing other studies and provide approximate values (e.g., the mean value and a range of likely values) that help us more accurately identify parameters of interest. Fortunately, the NTS vegetation is among the most studied in the Mojave and Great Basin deserts. Many ecological studies have been conducted on the NTS during the past several decades (O'Farrell and Emery, 1976; Wills and Ostler, 2001). Some of these studies have measured vegetation and environmental factors at multiple sites for more than a decade, which is rare in most desert areas where studies include a single year or at most two or three years of data collection. All of this research has made important contributions to understanding vegetation and natural cycles in arid land systems.

2.3 Approach and Methods

The approach used in this study to achieve the stated goals and objectives was to use as much site-specific data as possible rather than cataloging the range of potential data from locations far removed from the NTS. The latter data are often not plausible or may be misleading because of differing environmental conditions, germplasm, or being taken out of biological context. When site-specific data were not available, the most applicable data sets were used with a priority made for proximity to the NTS. Sound ecological principles and findings from the scientific literature are incorporated when appropriate, to better understand the ecology and biology of vegetation in Areas 3 and 5. It was also believed that collection of actual field data, even if limited, is often better than extensive speculation about specific parameters (i.e., what values might be). However, it is also recognized that collection of data about root distribution in desert soils is challenging, time-consuming, costly, and may not always remove uncertainty due to altered site conditions and restriction on time frames for study.

Research efforts were directed to obtain copies of publications from past NTS research, review them for pertinency, and summarize the data that relate to possible future PA model vegetation parameters. Outside literature surveys were also made to identify useful publications. Outside literature was also surveyed to update the work of O'Farrell and Emery (1976). It is believed that site-specific data provide information that best characterizes the vegetation in the vicinity of Areas 3 and 5 RWMSs. Emphasis was placed first on obtaining site-specific data in the Frenchman Flat (Area 5) and Yucca Flat (Area 3) areas of the NTS. Secondarily, emphasis was placed on obtaining data from other areas of the NTS. Thirdly, emphasis was placed on obtaining data from (listed in decreasing order of importance) the Mojave Desert, Great Basin Desert, and other arid and semiarid lands. The reason for placing priority on the NTS vegetation is that it shares a common regional climate, geology, and biota. Our approach recognizes that while data published about plants in other desert areas may share commonalities, they also have substantial differences due to different natural selection pressures.

Field investigations were limited to (1) sampling vegetation in the vicinity of RWMS 3 and 5 (within 2,000 m); and (2) observations of rooting depths in Area 5 RWMS excavated pits, old soil trenches, road cuts, and areas on the NTS where soil erosion had exposed roots. Field sampling consisted of site characterization as described by Ostler et al., (2000) and by sampling shrubs using the point-center quarter method (Bonham, 1989; Brower and Zar, 1977). Ten points were established along a 250 m linear transect (25 m between points) at each sampling location. Selection criteria of field sampling sites included:

- Sites that had no restrictions on foot traffic because of above-background levels of radionuclides.
- Sites that were readily accessible (i.e., close to roads to minimize off-road traffic).
- Sites that were located in plant associations recognized by Ostler et al., (2000) to be consistent with plant communities described for the NTS.
- Sites that appeared to have similar geology, landform, soils, and vegetation as occurs (or probably occurred, in the case of areas already cleared of vegetation) on the sites at Areas 3 and 5 RWMSs.

Evaluation of shrub canopy cover from digital scans of aerial photographs followed procedures described by Hansen and Ostler (2002).

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3.0 VEGETATION OF THE NTS

3.1 Vegetation Studies and Reports

Vegetation of the NTS has been widely studied in considerable detail. Much of this research is attributed to the fact that the NTS supported a nuclear testing program that funded a variety of ecological studies over a period of several decades. The NTS is also a recognized National Environmental Research Park (NERP) and was selected as one of several national sites for the U.S. International Biological Program, Desert Biome (IBP) to establish representative sites in the United States where the environment could be characterized and studied in detail over a period of years to establish a national baseline of ecological data. Because the NTS has been relatively protected against other land uses such as recreation, grazing, and farming, it remains a relatively pristine area, despite having severe disruption in the past due to nuclear testing (about 7 percent of the NTS or approximately1,375 square miles [mi^2] were disturbed [Ostler et al., 2000]). A variety of research is currently being conducted on the NTS through the DOE operations and NERP activities. This section of the report describes some of the pertinent vegetation research efforts on the NTS.

3.1.1 Early Climate and Vegetation

The history of vegetation at the NTS and woodlands in the southwestern deserts have been the focus of several publications (Van Devender, 1977; Van Devender and Spaulding, 1979; Spaulding, 1985; Spaulding and Graumlich, 1986; Van Devender 1987; and Van Devender et al., 1987). This work was based on radiocarbon-dated plant macro-fossil assemblages from ancient packrat (*Neotoma* spp.) middens (plant parts solidified by urine and feces). The purpose of these studies was to investigate changes in climate and vegetation during the past 45,000 years. A summary of their findings is shown in Table 3-1. The emphasis of these studies was regional climatic change as inferred by investigation of individual packrat sites. Less than a dozen sites were analyzed and most of these were miles from Frenchman and Yucca Flats.

It should be noted that fossil middens are restricted to steep rocky sites, often on south- or west-facing exposures. Such sites are usually considered ecotones (a transitional area between more stable plant communities). They yield relatively good information about the presence and absence of plant species within 30 m of the midden site. However, they are subject to analytical errors and limitations in interpretation as described by Spaulding (1985). Based on the ecology of packrats and an understanding of current vegetation of the NTS, care must be taken in extrapolating beyond the steep slopes to adjacent level sites on deeper soils. For example, trees like the Utah juniper and single needle pinyon pine are more commonly found in these steep rocky environments where water-harvesting from large rocks and protection from fires is common, while grasses and shrubs are found on deeper soils and flatter terrain where fossil middens are rare. These latter sites are often not represented because of a lack of fossil records.

Table 3-1. NTS climate and vegetation based on analyses of packrat middens (data from Spaulding, 1985; and Van Devender et al., 1987)

Age/Epoch	*Conditions*	*Radiocarbon Age** *Years Before Present (1950)*	*Climate*	*Vegetation*
Middle Pleistocene (Wisconsin Glacial)	Expanding major continental ice-sheet	45,000 to 35,000 years Before Present (B.P.)	Annual precipitation was similar to present with increases of perhaps 10 to 20% above today's values. About 10% came as winter precipitation compared to about 25% at present. Temperatures were 1° to 2°C lower than present.	An open woodland of Utah Juniper (*Juniperus osteosperma*) and mountain mahogany (*Cercocarpus ledifolius*) with well-developed stands of sagebrush. *Pinus flexilus, Pinus monophylla, Quercus gambelii, Rhus trilobata*, and *Atriplex canescens* were absent.
Late Pleistocene (Wisconsin Glacial)	Continued expansion of continental ice-sheet	35,000 to 23,000 years B.P.	A progressive increase in effective moisture until 25,000 years B.P., then a gradual drying out. Average annual precipitation was about 10 to 25 % more than present and mean annual temperatures were at least 3°C lower than present.	Utah juniper, shadscale (*Atriplex confertifolia*) and rock spirea (*Petrophytum caespitosum*) were abundant. Pinyon pine (*Pinus monophylla*) was still unknown.
Late Pleistocene (Wisconsin Glacial)	Maximum extent of continental ice-sheet (full glacial at 18,000 years B.P.) and then gradual warming	23,000 to 10,000 years B.P.	Precipation was estimated to be 6^{0}C to 7^{0}C less than present. Average summer temperatures were 7^{0}C to 8^{0}C cooler. Winter precipitation was about 70% greater than present with a decrease in summer rainfall. The average annual precipitation did not exceed 40% more than present.	Xerophytic juniper-shadscale community begins a major biotic turnover to pinyon-juniper woodland. Shadscale was widespread. Frost-sensitive plants are missing or rare. Pinyon pine enters the area. Decreasing relative percentage of Great Basin steppe plants, including mountain mahogany.
Early Holocene	Receeding of continental ice-sheet	10,000 to 8,000 years B.P.	Climate transitional to current climate with slightly warmer and dryer climate.	Joshua tree (*Yucca brevifolia*) and creosote bush (8,100 yrs B.P.) enter the NTS. Plants characteristic of the Mojave Desert expand into the NTS and more mesic Great Basin shrubs decline. The end of the woodlands.
Middle and Late Holocene	Approximately current conditions	8,000 to 3,000 years B.P.	Current climate was established by 4,000 B.P. with brief cycles of wetter and drier (drought) than current conditions. Winter precipitation was slightly reduced. Summer and winter temperatures were slightly warmer.	Expansion of warm desert species, especially fourwing saltbush (*Atriplex canescens*) and white burrobush (*Hymenoclea salsola*). Juniper disappeared about 7,800 B.P. in Frenchman Flat. Creosote bush moved to its modern northern limits in the Mojave Desert about 5,000 years B.P.
Present to Next 500 Years	Possible chance of global warming	+ 500 years from Present	Increases in annual temperature of 2^{0}C to 3^{0}C and intensified rainfall on the NTS with increase from 50 to 100% in the summer and fall precipitation.	Increase in importance of annual exotic species and reduction of competing annual native species.
Next 10,000 Years	Similar to those of the last glacial age	+ 10,000 years from Present	Assumes that climates of last 45,000 years are approximate of climates that will occur in the next 10,000 years.	Slight shift toward drier shrubland communities and greater importance of annual species. Possible return of more mesic species if cooler climates return.

*Van Devender (1987) recognizes slightly different dates for epochs: Late Wisconsin, 22,000 - 1,000 yr B.P.; Early Holocene, 11,000 - ca. 8,900 yr B.P.; Middle Holocene, ca. 8,900 - ca. 4,000 yr B.P.; and Late Holocene, ca. 4,000 yrs B.P. to Present.

Statements from these studies about general climate-induced changes in regional vegetation (e.g, statements like "the region was dominated by Utah Juniper and shadscale") are meant to be interpreted rather loosely. For example, even though broad regional climatic changes may have resulted in broad regional vegetation changes, considerable variety and diversity was still present in the landscape, especially on the NTS that includes lowlands and uplands and a variety of soil types. This diversity in topography and soils resulted in a broad array of plant community types (e.g., there would have been mosaics of big sagebrush, blackbrush, and other plant communities) even under changing regional climatic conditions. Individual species grew according to their individual tolerances along environmental gradients rather than as discrete plant communities as pointed out by Van Devender and Spaulding (1979): "Simple vertical displacements are unrealistic because plant species respond differentially to climatic changes and not as community units, modern analog communities with composition similar to fossil assemblages in the middens are often difficult to find."

From these packrat midden studies, it can be concluded that one of the most important forces shaping the vegetation of the NTS over the past 45,000 years was the quantity of winter precipitation (and accompanying temperatures) which contributes about 75 percent of the current NTS precipitation. The remaining 25 percent of the precipitation on the NTS currently is in the form of intense summer convection storms, which compares with about 50 percent of annual precipitation in the Sonoran and Chihuahuan deserts. For this reason, one should use caution in comparing NTS vegetation cover, composition, and rooting characteristics with vegetation of the deserts further to the south, because of differences in the distribution of summer and fall precipitation. The distribution of precipitation and temperature thereby shape adapted vegetation to the prevailing climate and soils of localized areas. Conclusions reached through the analyses of packrat middens are merely brief glimpses through small windows in time into limited ecotones of the NTS. They are, however, significant contributions to our knowledge base that would otherwise be restricted to mere speculation.

3.1.2 Historical Vegetation

Vegetation of the NTS was first described in 1976 in the monumental work of Dr. Janice Beatley (1976). She provided the most detailed description of vegetation on the NTS during the period of 1962 to 1975. Her work began in 1959 and continued through 1975. It focused on collection of plants on the NTS for herbarium specimens. It also described plant communities based on field observations from 68 permanent study sites on the NTS. These sites were considered representative of the major types of vegetation and ecosystems on the NTS. In her book, data about vegetation included annual biomass produced from both annual and perennial vegetation, percent canopy cover by perennial plant species, and plant density. Environmental data included information about rainfall, temperature, soil texture, and soil moisture. Beatley recognized 23 plant associations in her book, but four of those (Ash-screwbean-Baccharis, mesquite, white fir, and Artemisia-Cercocarpus) occurred exclusively outside the NTS boundary (Table 3-2).

Table 3-2. Plant associations recognized by Beatley on the NTS in 1976.

MOJAVE DESERT REGION		
Bajadas		
	1.	*Larrea-Ambrosia*
	2.	*Larrea-Lycium-Grayia*
	3.	*Larrea-Atriplex*
Mountains		
	4.	Mountain
Arroyos		
	5.	Arroyo
Spring and Seepage Areas		
	6.	Ash-Screwbean-*Baccharis* (does not occur on the NTS)
	7.	*Atriplex* and *Atriplex-Haplopappus*
	8.	Mesquite (*Prosopis*) (does not occur on the NTS)
TRANSITION DESERT REGION		
Upper Bajada		
	9.	*Coleogyne*
	10.	*Larrea-Grayia-Lycium*
Lower Bajada		
	11.	*Grayia-Lycium*
	12.	*Lycium pallidum-Grayia*
	13.	*Lycium shockleyi-Atriplex*
GREAT BASIN DESERT REGION		
Atriplex		
	14.	*Atriplex confertifolia*
	15.	*Atriplex-Kochia**
	16.	*Atriplex-Ceratoides**
	17.	*Atriplex-Sarcobatus**
	18.	*Atriplex canescens**
Artemisia		
	19.	*Artemisia tridentata**
	20.	*Artemisia nova**
	21.	*Artemisia*-Pinyon-Juniper
	22.	*Artemisisa-Cercocarpus* (does not occur on the NTS)
White fir		
	23.	White fir (Abies concolor) (does not occur on the NTS)

* This mapping unit was not differentiated from other mapping units on Beatley's map

Descriptions of plant associations were provided in a narrative form, comparing similarities and differences between plant associations difficult. Much of this is reported in her publications on the ecology of the vegetation on the NTS (Beatley, 1974a; 1974b).

Sixty seven of Beatley's permanent plots were recently resampled (2000-2003) and rephotographed; results of that study are currently being prepared by the U.S. Geological Survey (Webb et. al., 2003). Data describing species density, height, canopy cover, and biomass index are described and compared with Beatley's data from 1963 and 1975. Climatically-driven changes in the vegetation over time (e.g., the drought in 1989) are described.

3.1.3 Ecology

In 1976, DOE published *Ecology of the Nevada Test Site: A Narrative Summary and Annotated Bibliography*, NVO-167 (O'Farrell and Emery, 1976). It included annotated summaries of all of the ecological papers and reports that had been published about the NTS. Much of that work had been done by the Nevada Applied Ecology Group between 1970 and 1976. Two key scientists, Van Romney and Arthur Wallace with the University of California Los Angeles (UCLA), contributed immensely to our knowledge of the vegetation of the NTS during this period. The focus of this program was on the impacts and distribution of radionuclides in the environment (Friesen, 1992). Much of their work investigated plant availability and uptake. They also looked at root distribution in the soils and described soil profiles over much of the southern basins of the NTS.

O'Farrell and Emery (1976) provided a summary of the general ecology of the NTS but also included several valuable appendices in NVO-167, such as complete lists for plant and animal species that occur on the NTS. They also provided an improved map of the vegetation associations and their distribution on the NTS that was derived from Beatley's early map. In 2001, this report has been updated and enlarged by Wills and Ostler (2001). This latter report provides a more comprehensive description of the ecology of the NTS and publications describing its biota.

3.1.4 Classification of Vegetation

In 2000, a comprehensive report on the classification of vegetation on the NTS was published (Ostler et al., 2000). This report was the result of field efforts from 1996 to1998 and sampling at over 1,500 locations or ecological landform units (ELU) on the NTS. Data from these sites were used in cluster analysis to determine which ELUs grouped together on the basis of vegetative similarity to one another. Assignment of ELUs to cluster groups (alliance and associations) was an iterative process. Based on this iterative clustering process, 10 alliances and 20 associations were recognized as occurring on the NTS. Alliances and associations were named after the dominant tree or shrub species based on relative abundance and according to Federal Geographic Data Committee and Ecological Society of America conventions (Grossman et al., 1998; Anderson et al., 1998). Results of the classification are shown in Table 3-3 and Figure 3-1.

Table 3-3. Vegetation ecoregions, alliances, and associations on the NTS.

Ecoregion	*Alliance*	*Association*
Mojave Desert	Lycium spp. Shrubland Alliance	Lycium shockleyi-Lycium pallidum Shrubland
	Larrea tridentata/Ambrosia dumosa Shrubland Alliance	Larrea tridentata/Ambrosia dumosa Shrubland
	Atriplex confertifolia-Ambrosia dumosa Shrubland Alliance	Atriplex confertifolia-Ambrosia dumosa Shrubland
Transition Zone	Hymenoclea-Lycium Shrubland Alliance	Lycium andersonii-Hymenoclea salsola Shrubland
		Hymenoclea salsola-Ephedra nevadensis Shrubland
	Ephedra nevadensis Shrubland Alliance	Menodora spinescens-Ephedra nevadensis Shrubland
		Krascheninnikovia lanata-Ephedra nevadensis Shrubland
		Eriogonum fasciculatum-Ephedra nevadensis Shrubland
		Ephedra nevadensis-Grayia spinosa Shrubland
	Coleogyne ramosissima Shrubland Alliance	Coleogyne ramosissima-Ephedra nevadensis Shrubland
Great Basin Desert	Atriplex spp. Shrubland Alliance	Atriplex confertifolia-Kochia americana Shrubland
		Atriplex canescens-Krascheninnikovia lanata Shrubland
	Chrysothamnus-Ericameria Shrubland Alliance	Chrysothamnus viscidiflorus-Ephedra nevadensis Shrubland
		Ericameria nauseosa-Ephedra nevadensis Shrubland
	Artemisia spp. Shrubland Alliance	Ephedra viridis-Artemisia tridentata Shrubland
		Artemisia tridentata-Chrysothamnus viscidiflorus Shrubland
		Artemisia nova-Chrysothamnus viscidiflorus Shrubland
		Artemisia nova-Artemisia tridentata Shrubland
	Pinus monophylla/Artemisia spp. Woodland Alliance	Pinus monophylla/Artemisia nova Woodland
		Pinus monophylla/Artemisia tridentata Woodland
Data from Ostler et al., 2000		

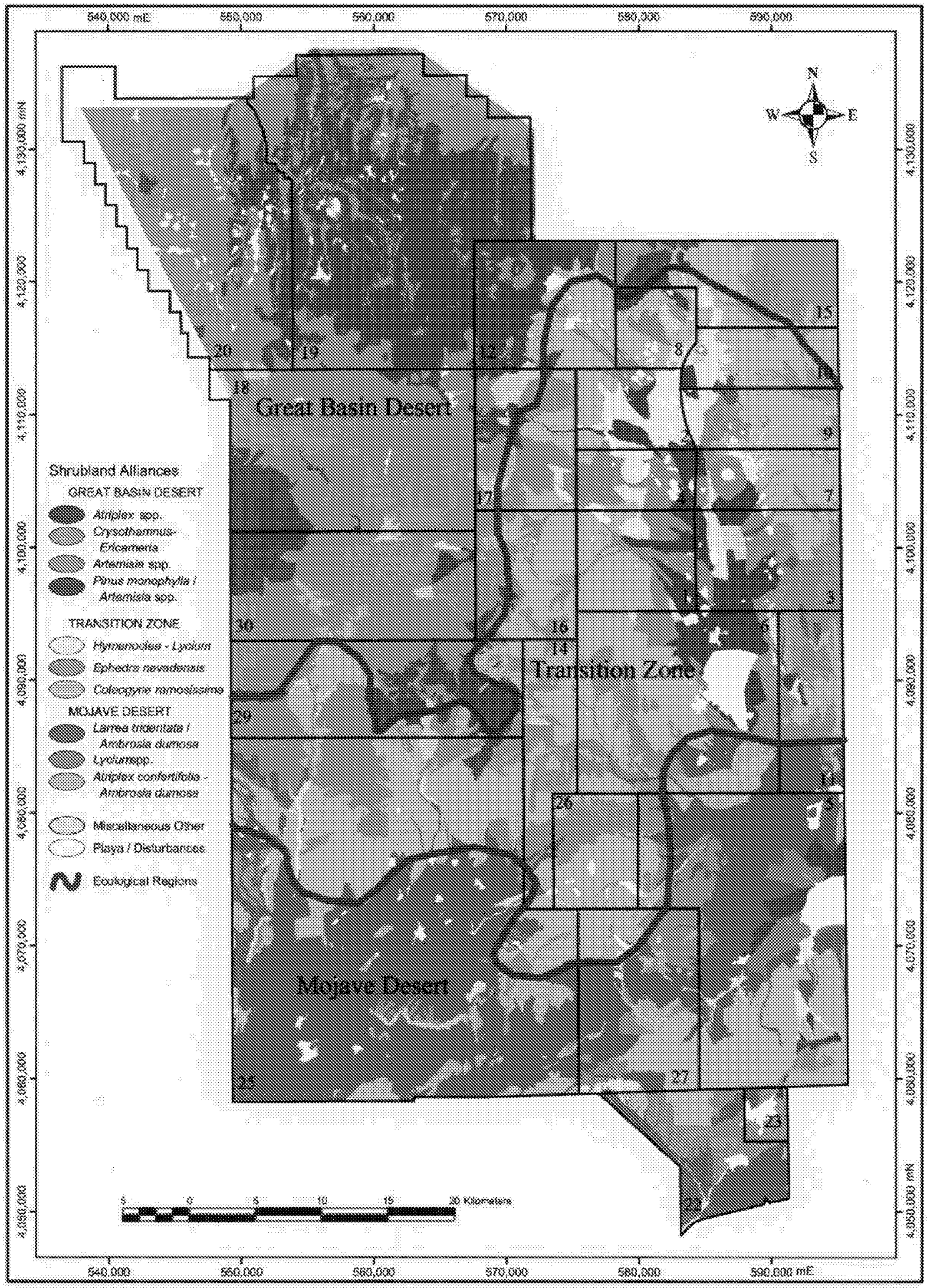

Figure 3-1. Distribution of Vegetation Types on the Nevada Test Site (Ostler et al., 2000)

In addition to maps of each vegetation association, the authors provided narrative descriptions for each of the associations recognized, including data on topography, surface soil textures, slope, common species, and relative cover of annuals.

3.1.5 Current Research on the NTS

Two groups are currently doing ecological research at the NTS. The first is a coalition of researchers from the University of Nevada Reno, University Nevada Las Vegas, and Desert Research Institute that is doing work on the impacts of increased carbon dioxide (CO_2) on desert ecosystems. Their study area is in the southern end of the Frenchman basin and includes several large research plots exposed to varying levels of increased CO_2. Their facility is known as the Nevada Desert Free Air Carbon Enhancement Facility (FACE). Numerous publications have been written and are currently being written from research done at this facility. The facility was initially established in 1998 and now has three years of data including biomass, litter production, root growth, and other vegetation parameters.

The second group is comprised of scientists and consultants of Neptune and Company, Inc. who are investigating insect activity (e.g., ants and termites) in the vicinity of Area 3 and Area 5 RWMS. They are also conducting limited investigations of rooting habits of selected plants. Hooten et. al., (2001). Their investigations are in support of Gold-Sims modeling efforts and documenting parameters for determining rates of bioturbation.

3.2 General Description of Vegetation on the NTS

3.2.1 Regional Climatic Setting

The NTS is located in Nye County in south central Nevada and encompasses approximately 3,561 square kilometers (km^2) (1,375 mi^2). Three large valleys dominate the southern two-thirds of the NTS: Yucca, Frenchman, and Jackass Flats (refer to Figure 1-1). Mountains, mesas, and hills enclose these valleys. The climate exhibits extremes in temperature, precipitation, and wind velocity, as well as great variability in these parameters from year to year and from site to site on the NTS. During years of high precipitation, surface water collects and forms shallow lakes in the closed basins of Yucca and Frenchman Flats. Jackass Flats is an open basin and drains to the southwest via Fortymile Wash. Mercury, Rock, Topopah, and Mid valleys are smaller basins and also have drainage outlets. Pahute Mesa, Timber, and Shoshone mountains dominate the northern, northwestern, and west central sections of the NTS. Elevation on the NTS ranges from a low of 820 m (2,688 ft) at the southeast corner of Jackass Flats to about 2,340 m (7,679 ft) on Rainier Mesa. Elevations at the base of mountains on the NTS are an average of 975 m (3,200 ft) in the south, 1,370 m (4,496 ft) in the central region, and 1,600 m (5,250 ft) in the northern part of the NTS. Mountains range from 1,400-1,800 m (4,593-5,906 ft) in the south and 2,100-2,300 m (6,890-7,546 ft) in the north. Associated with these elevation increases is the northern boundary of the Mojave Desert and the southern boundary of the Great Basin Desert within a broad east-west corridor of transition (Beatley, 1976).

NTS has a climate characteristic of high deserts with little precipitation, very hot summers, mild winters, and large diurnal temperature ranges. Monthly average temperatures on the NTS range from 7^0 C (45^0 F) in January to 32^0 C (90^0 F) in July (DOE, 1996). The average annual precipitation on the NTS ranges from 15 centimeters (cm) [6 inches (in)] at the lower elevations to 23 cm (9 in) at the higher elevations. About 60 to 75 percent of this precipitation occurs from September through March. Winter precipitation frequently occurs as snow, which persists in northern Yucca Flat and to the north. Higher mountains commonly are snow-covered much of the winter. Snow seldom persists for more than a few hours in the southern valleys. The climate history of the Mojave Desert Region from 1892 to 1996 is presented elsewhere by Hereford and Longpre (2000).

Beatley recognized two dominant ecoregions on the NTS, the Mojave and Great Basin Deserts as well as what she refers to as the "transition desert" which is the area between these two ecoregions. This transition is made up of rather unique vegetation associations that characterize this zone. The dominant plant association that typifies this zone is the Coleogyne ramosissima-Ephedra nevadensis Shrubland Alliance. In Ostler's analysis of vegetation on the NTS, ELUs containing blackbrush clustered together quite clearly showing the unique nature of this vegetation alliance (Ostler et al., 2000). The Mojave Desert vegetation associations occur generally in the southern portions of the NTS at elevations under 1,219 m (4,000 ft). The Great Basin vegetation associations occur in the northern two-thirds of the NTS and generally above 1,524 m (5,000 ft.)

3.2.2 Vegetation of Areas 3 and 5 RWMSs

This report focuses on the vegetation in the area surrounding the Areas 3 and 5 RWMSs. Beatley did have study plots in the general proximity to Areas 3 and 5 RWMSs that can help to understand the vegetation at these sites.

3.2.2.1 Area 5 RWMS

The closest Beatley plot to the Area 5 RWMS was Plot 28 which is approximately 1 kilometer (km) to the east over the border on the Nellis Air Force Range Complex. This site is classified by Beatley as a Larrea-Ambrosia association, which is the same as the area surrounding the RWMS and that would have existed at the RWMS prior to development. It is also the dominant vegetation association throughout much of Frenchman basin and the southern portions of the NTS. Beatley describes this vegetation association as "... occurring on soils that are deep, loose sands without a surface pavement..." Shrub cover on her study Plot 28 was 19.5 percent with creosote bush (*Larrea tridentata*) and Shockley goldenhead (*Acamptopappus shockleyi)* contributing most of the cover (7.2 percent and 5.4 percent, respectively). White bursage *(Ambrosia dumosa*) was the next most common shrub with 3.3 percent cover. These three species made up approximately 80 percent of the total cover. Root occurrence of both *A. dumosa* and *A. shockleyi* is generally rather shallow compared with root distribution in *L. tridentata*.

The description and distribution of this vegetation by Ostler et al., (2000) is included in Appendix 9.0 of this document. This is a large association and the only association found within the Larrea tridentata/Ambrosia dumosa Shrubland Alliance. There were 287 ELUs that were sampled and clustered within this association. It is one of the largest associations on the NTS, with over 61,000 hectares (152,500 acres) or 18 percent of the total area on the NTS. The dominant species in this alliance is creosote bush, which is the dominant shrub type within the Mojave Desert. On the NTS, white bursage (*Ambrosia dumosa*) is the most common co-dominant and actually has greater relative abundance than creosote bush (43 percent and 13 percent respectively); however, because of creosote's larger size the landscape appears to be dominated by this species. In other areas of the Mojave Desert, Anderson's wolfberry *(Lycium andersonii)*, spiny hopsage (*Grayia spinosa*), and shadscale saltbush may become co-dominants with creosote. Other associated species on the NTS include Nevada jointfir (*Ephedra nevadensis*), range ratany (*Krameria erecta*) and rabbitthorn (*Lycium pallidum*). This association ranges from low foothill slopes to valley bottoms but is most often found on piedmont slopes, the zone between the mountain base and valley bottom. It is also generally excluded from the zone around playas most likely because of unfavorable soil conditions. It occurs on a wide variety of slopes ranging from 1 to 42 degrees. Soil textures in this association generally range from sand to sandy loams and generally with no development of a caliche layer.

3.2.2.2 AREA 3 RWMS

Beatley had three study plots in the general area surrounding the Area 3 RWMS, but none in the immediate vicinity. This is in an area of transition between the Mojave and Great Basin Deserts and has high species diversity. Each of three study plots was classified as a different vegetation type. Beatley's Plot 50, which was approximately 4 km northwest of the Area 3 RWMS, was classified as a Grayia-Lycium Shrubland (association). This is different than what occurs in the area currently because of the heavy disturbance that has occurred in the Yucca Valley from testing; however, it is also different from that reported by Ostler et al., (2000) in that area. The dominant species reported by Beatley at Plot 50 were *Grayia spinosa* (17.3 percent cover), winterfat ([*Krashininnikovia*] *Ceratoides lanata)* (5.3 percent cover), and *Lycium andersonii* (4.7 percent cover). These three species made up almost 80 percent of the total cover for this study site in 1975 (34.9 percent). Total cover for this site in 1963 was only 25 percent. Beatley describes this vegetation association as covering "...large areas of the floors of closed basins ... where every night the lowlands are under the influence of cool or cold air accumulations." Beatley states that, "Total shrub cover in these communities, as measured, is from 32 to 37 percent; from 40 to 60 percent of this is attributable to the two dominant species *Grayia spinosa* and *Lycium andersonii*, which grow in close association in usually well-developed clumps. Average shrub height is 0.4 to 0.5 m. In many of the communities, especially those with silty soils, [*Krashininnikovia*] *Ceratoides lanata* is prominently represented...." She also listed other associated species as being *Acamptopappus shockleyi*, *Artemisia spinescens*, *Atriplex canescens*, *Chrysothamnus viscidiflorus* spp. *stenophyllus*, *Ephedra nevadensis,* and two species of *Tetradymia* (*T. axillaris* and *T. glabrata*). Dominant grasses included *Achnatherum hymenoides* and *Elymus elymoides*. Samples taken in the area of plot 50 in 1997 showed that *Atriplex canescens* was the dominant species with 41 percent of relative abundance, *[Krashininnikovia]*

Ceratoides lanata was second with 34 percent relative abundance. *Grayia spinosa* (10 percent), *Hymenoclea salsola* (6 percent), *Lycium andersonii* (5 percent), and *Artemisia spinescens* (2 percent) were other associated species. While cover and abundance are not directly comparable, they do show the relative importance of species and the change in dominance during the past 25 years. Cover was measured as a total of all perennial species and not by individual species in 1997. Those cover values ranged from 6.1 percent to 13.9 percent. The three ELUs that surround Plot 50 were all classified as Atriplex canescens-Krashininnikovia lanata shrubland. While Grayia and Lycium are still present, they are no longer the dominant species; however, *[Krashininnikovia] Ceratoides lanata* is still a dominant species.

A second plot (Plot 57) was located 3 km to the east of Area 3 RWMS along the upper bajadas of the western slopes of the Halfpint Range. Plot 57 was classified as a Larrea-Grayia-Lycium type. Total cover at this site was 25 percent in 1966 and increased to 26.8 percent in 1975. Dominant species in this plot as sampled by Beatley were *Grayia spinosa*, *Larrea tridentata*, and *Lycium andersonii*. Beatley states that other associated species include "*Ambrosia dumosa*, *Psorothamnus fremontii*, and *Krameria erecta*, all of which reach their northern limits in Yucca Flat". These are often replaced by "*Ceratoides lanata*, *Tetradymia axillaris*, *T. glabrata*, or *Artemisia spinescens*, all of which are better represented in other transition association or Great Basin Desert communities." Sampling from ELUs in 1998 in the area surrounding Plot 57 showed a diverse mix of species with no outstanding dominant species. *Krashininnikovia lanata* had the largest relative abundance with 14 percent while *Ephedra nevadensis* was a close second at 12 percent followed by *Acamptopappus shockleyi* at 10.8 percent. *Larrea tridentata* averaged 4.4 percent; *Grayia spinosa* was present averaging 4.8 percent while *Lycium andersonii* averaged 5.6 percent. Other species present in lesser amounts included *Hymenoclea salsola*, *Ambrosia dumosa*, and *Menodora spinescens*.

A third plot (Plot 58) was located in Area 3 approximately 5 km to the south of RWMS. Plot 58was classified as a Atriplex - Ceratoides type. The dominant species at this site was *Atriplex confertifolia* which averaged 7.8 percent cover in 1963 and 10.8 percent cover in 1975. *Ceratoides lanata* averaged 5.2 percent cover in 1963 and 7.9 percent cover in 1975. The third most common shrub was *Artemisia spinescens*, which averaged 2.9 percent cover in 1963 and 4.8 percent cover in 1975. Total cover for this plot was 17.5 percent in 1963 and increased to 25.6 percent in 1975. These three dominant species contributed approximately 91 percent in 1963 and 92 percent in 1975. Other less common species included *Grayia spinosa*, *Lycium andersonii*, and *Tetradymia axillaris*. ELUs that were sampled in 1997 surrounding Plot 58 showed this area as being classified as an *Atriplex confertifolia-Kochia americana* shrubland association. Beatley recognizes this association and describes it as being north of Yucca playa in the heaviest textured soil in the Yucca Flats area. This association intergrades with *Atriplex-Ceratoides* to the north and at slightly higher elevations. *Kochia americana* was the most abundant species averaging 52 percent relative abundance while *Atriplex confertifolia* averaged 40 percent. *Krashininnikovia lanata* (5 percent), *Artemisia spinescens* (2 percent), and *Atriplex canescens* (1 percent) were also present in these areas. Total perennial cover was low on these sites averaging 4.5 percent, which was very low compared to cover values in 1963 or 1975.

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4.0 PLANT ROOTING DEPTH

4.1 Applicable Literature

Studies and publications investigating the characteristics of plant roots have been the focus of numerous studies during the past several decades, especially those concerned about the PA for RWMSs at the NTS (Cochran et al., 2000; Shott et al., 2000). Several of these studies have focused on cataloging information from published reports about desert plants such as rooting depth, distribution, and biomass (Foxx et al., 1984a, 1984b; Winkel et al., 1995). While such efforts are useful to provide general descriptions about rooting characteristics (e.g., often extremes in values), caution has to be applied when attempting to generalize or extrapolate these findings to other areas with different plant ecotypes, soils, and climate. For example, the reader does not know the conditions under which the roots were grown. There is a tendency to assume that all roots grow to similar lengths, depths, or biomass. Information about means, variance, and other statistical information is usually lacking.

Of greater value to understanding root characteristics of plants near Areas 3 and 5 RWMSs are studies that report actual findings of detailed field studies (Wallace and Bamberg, 1972; Wallace and Romney, 1972; Wallace et al., 1974; Wallace et. al., 1980; Groeneveld and Crowley, 1988; and Reynolds and Fraley, 1989). These studies are frequently difficult to conduct because of the labor and precision required to excavate the root system. Such studies are also limited to some extent in that they describe vegetation that may not exist at the RWMS sites even though they may be in close proximity (e.g., at Rock Valley). However, they do describe vegetation that is grown under similar regional germplasm, soils, and climate. Caution still has to be exercised when interpreting the data to ensure that erroneous conclusions are not drawn.

Other types of information that are useful are those reports and publications that describe biological principles that help us better understand rooting processes and development (e.g., Rundel and Gibson, 1996). Examples of key principles that are useful for understanding rooting characteristics of plants on the NTS follows.

4.2 Principles of Root Development

Development of roots in arid land soils is the result of a complex interaction of plants, animals, climate, soils, perturbations, and other environmental factors. Despite the complexity of the root development process a few general observations can be made that help provide a better understanding of this process. Key principles include:

- Different plant species have different genetic potentials for root growth.
- Development of roots is an energy-requiring process that is limited by factors that limit plant growth.
- Roots are influenced by competition from other plants.

- Environmental extremes and perturbations may shape species survival and resulting rooting patterns.

- Herbivores have influence on plant community structure and development.

A discussion of these principles follows.

4.2.1 Genetic Differences

Differences in genetic composition of plants means that caution must be exercised when generalizing about characteristics measured for one species in one geographic area to another species in a different geographic area. An awareness of these genetic differences helps avoid erroneous conclusions and argues strongly for more site-specific data when greater precision and accuracy are needed for the purpose of better describing rooting characteristics of plants in the Areas 3 and 5 RWMSs of the NTS.

Natural selection pressures that shape the speciation of plants have been in existence for long periods of time, from thousands to millions of years. The creation of a new successful species is often based on genetic changes that permit a population of plants to differentiate themselves from other closely related species. This differentiation frequently involves differences in the way the population uses resources such as water and nutrients from the environment. The separation of two closely related groups of plants into species is often based on strategies that involve spatial or temporal differences such as where they are found and how they use resources in the environment. For example, on the NTS, species of the same genus usually are found occupying different niches (Ostler et al., 2000). The species of the genus *Yucca* (e.g., *Y. bacata*, *Y. brevifolia*, and *Y. schidigera*) or *Opuntia* (*O. basilaris, O. echinocarpa, O. erinacea, O. polyacantha*, and *O. puchella*) are found at different elevations with different mean precipitation. Species of the genus *Artemisia* (*A. nova, A. tridentata*, *A. ludoviviana*, and *A. spinescens*) are found on different soil types. Even exotic-introduced species of the same genus like *Bromus rubens* and *Bromus tectorum* or *Salsola kali* and *Salsola paulsenii* are found at different elevations and have slightly different moisture needs on the NTS.

Ecotypes of the same genus and species may harbor substantial genetic differences that translate into different abilities to adjust to different environmental conditions. For example, creosote bush (*Larrea tridentata*) exists as three distinct chromosomal races: diploids (two sets of chromosomes) in the Chihuahuan Desert, tetraploids (four sets of chromosomes) in the Sonoran Desert, and hexaploids (six sets of chromosomes) in the Mojave Desert. These races have different root-to-shoot ratios (tetraploids >diploids >hexaploids) (Walters and Freeman, 1983). Caution must be used when applying rooting information about one race to that of another race or geographic area. In other words, studies done in the Sonoran Desert on creosote bush may not apply to creosote bush from the Mojave Desert. Even within the same regional area, polyploidy (i.e., multiple sets of chromosomes) may exist and have significant differences in plant growth characteristics. For example, fourwing saltbush (*Atriplex canescens*) exists regionally as diploids, tetraploids, and hexaploids with measurable differences in mean area per leaf (0.228 square centimeter (cm^2), 0.427 cm^2, and 0.613 cm^2, respectively) (Senock et al., 1991).

4.2.2 Energetics of Root Growth

Plant growth is regulated by the plant's ability to secure the needed resources for growth. When resources are limited, growth is slowed or stopped completely. Among the resources needed for proper growth are sunlight (usually not limiting in the desert), favorable temperatures (not too hot or not too cold), water, nutrients, carbon dioxide in the air, and oxygen in the soil. Plants allocate fixed carbon from the photosynthetic leaves and stems in the form of sugars, protein, and other organic building blocks to various parts of the plant, including stems and roots that do not photosynthesize. Because below ground plant parts such as roots are energy-consuming, the plant's ability to allocate resources to these parts, without experiencing imbalances that result in stress or death to the plant, is limited. There is an energy-induced limit to rooting depth.

The distribution of biomass in a plant can often be expressed as a root-to-shoot ratio. The ratio is calculated by harvesting and drying the plant shoot and root and then dividing the root weight by the shoot weight. A plant with a root-to-shoot ratio of 1 has equal biomass as roots and shoots. A plant with a root-to-shoot ratio of 2 has approximately 2 times as much root biomass as shoot biomass. A plant with a root-to-shoot ratio of 0.5 has approximately ½ as much root biomass as shoot biomass. Most desert plants have root-to-shoot ratios of less than one, while most mesic (wetter) plants (e.g, meadow communities) have root-to-shoot ratios of greater than one. MacMahon and Schimpf (1981) reported that higher values of root-to-shoot were only found in the Great Basin Desert, but not in the Mojave Desert. Barbour (1973) reviewed several desert shrub studies (i.e., eight studies reporting root-to-shoot ratios) and concluded that root-to-shoot ratios varied over a wide range and that there was no "typical" value, but that in a majority of cases it was less than 1.0. Many plants in the desert have the ability to drop leaves during droughts or the dry period of the growing season and can favorably alter its root-to-shoot ratio. Therefore, the root-to-shoot ratio is not fixed and may change slightly from site to site and during the growing season.

Some shrubs on the NTS drop all their leaves as the soils dry out like Anderson's wolfberry *(Lycium andersonii)*. Other shrubs, like white burrobush *(Hymenoclea salsola),* gradually lose their leaves as the season progresses. While still other shrubs like creosote bush *(Larrea tridentata)* retain most of their leaves, but may drop older leaves under severe stress. Blackbrush *(Coleogyne ramosissima)* has the ability to maintain survival of the shrub without leaves for several years in severe droughts.

Still other shrubs like big sagebrush have dimorphic leaves, small-size leaves for unfavorable conditions or times of the year and a large-size leaf for more favorable conditions or times of the year (Miller and Shultz, 1987). Some plants, like Nevada jointfir *(Ephedra nevadensis)* and the cacti (e.g. *Opuntia* spp.), have lost their leaves completely and rely on photosynthetic stems to fix carbon.

When measured during the peak of the spring growing season, root-to-shoot ratios may provide meaningful data on root-to-shoot allocations for a species growing at a particular site. Root-to-shoot ratios have been measured at the NTS and Mojave Desert by species and provide us with useful information about standing crop biomass as roots and shoots (Barbour, 1973; Wallace, et al., 1974). Wallace and Bamberg (1972) analyzed eight perennial desert species and concluded that root biomass can be estimated for a population within a possible error of $\pm$ 10 to 20 percent. They reported that only about 15 percent of new photosynthate was stored in the root compared to about 85 percent that was stored in the stem based on ^{14}C isotope analyses over a five-month study. Walters and Freeman (1983) reported that roots contained less energy per milligram of dry weight than shoots, probably a result of the presence of large quantities of energy-rich chemicals (terpenoids) in the stems and leaves, which are components of herbivore (i.e., plant-eating animal) defense systems.

Descriptive and correlation statistics have been reported in the literature for shrub and root dimensions that also help better describe allocation patterns of fixed carbon to above-ground and below-ground parts. Such statistics are useful for establishing upper limits to values that describe plant dimensions such as height, diameter, living volume (height x $[\text{width}]^2$), and cover when the data are not known from direct measurement. Examples include biomass regression equations of dry weight with living volume for many species at the NTS (Romney et al., 1973). These above-ground dimensions are often statistically correlated with below-ground parts such as root depth, lateral spread, etc. For example, Foxx et al., (1984b) reports that rough estimates of root depth can be made from plant height measurements. They reported the ratios of the root depth to the shoot height (expressed as units of root depth-to-height ratio) to be 1.0 for trees, 1.2 for shrubs, 1.7 for forbs, and 2.0 for grasses. They also found that lateral root spread may be derived from root depth data (expressed as units of root depth-to-lateral spread ratio). They reported the root depth-to-lateral spread ratio to be less than 1.0 for shrubs and greater than 2.0 for forbs and grasses. The highest root depth-to-lateral spread ratios were for subshrubs; however, no values were provided).

Root depth is governed by the allocation of energy to the growing root. It is also governed by resources that are available for growth. Generally, roots do not grow into dry soil, or well into areas that have reduced nutrients or oxygen. Rooting depth is generally within the top two meters of soil depth. Soil nutrients have been shown to be concentrated near the surface of the soil, beneath shrubs and diminish exponentially with depth the same as root growth (Angerer et al., 1995). The greater presence of microorganism near the soil surface also helps recycle nutrients and retain new nutrients through mycorrhizal infections (i.e., beneficial fungil associated with plant roots) that are reported to decrease progressively with increasing soil depth (Handel et al., 1997). Deeper rooting is often restricted because of lack of oxygen (Lunt et al., 1973; Groeneveld and Crowley, 1988; Dobrowolski and Ewing, 1990) and increasing soil compaction (Bengough and Mullins, 1990). Lunt et al., (1973) reported the unusually high oxygen demands for creosote bush, big sagebrush, and explained their virtual exclusion from fine-textured, poorly drained soils. Lunt et al. (1973) suggested that tolerance to low soil oxygen may be a controlling factor for the distribution of desert species on various microsites (i.e., sites that have slightly different environmental conditions). Nelson et. al. (1990) reported that pythiaceous fungi become pathogenic as soil oxygen levels drop and can cause root rot in plants belonging to the *Chenopdiaceae* family. The wealth of evidence documenting physiological limitations in deep vertical rooting does not support the conclusions reached by Cochran et. al. (2000) that plants can extend roots downward as readily as laterally.

Once a plant becomes established in the soil, its roots extend downward in response to geotropic forces. As the roots mature, it is reported that hydrotropism (i.e., movement toward water) actually overrides geotropism (i.e., movement downward in response to gravity) in directing root growth (Senft, 1995). The surface soils (0 to 10 cm) are usually dry due to rapid evaporation from the surface after rain and only plants that extend roots deeper survive. As the plant matures, it creates organic matter by leaf drop and sloughing of roots. Roots absorb nutrients from greater depths and distances where they accumulate near the base of the shoot. Clumps of such shrubs have been termed "islands of fertility" (Muller, 1953; Garcia-Moya and McKell, 1970). DeLucia and Schlesinger (1991) reported that shrubs require high foliar N and P contents to support higher photosynthetic rates than trees and may rely on shallower root distribution where nutrients are more abundant to acquire these nutrients. Fitter (1994) concluded that the pattern of rooting is invariably correlated with resource concentrations down soil profiles (i.e., roots respond to resource patches by proliferation). Additionally, summer drying cycles may result in abscission of small roots. The deposition of organic matter and biological activity (microorganism, insects, and rodents) help increase infiltration of the soil and nutrient availability for future growth of the plant.

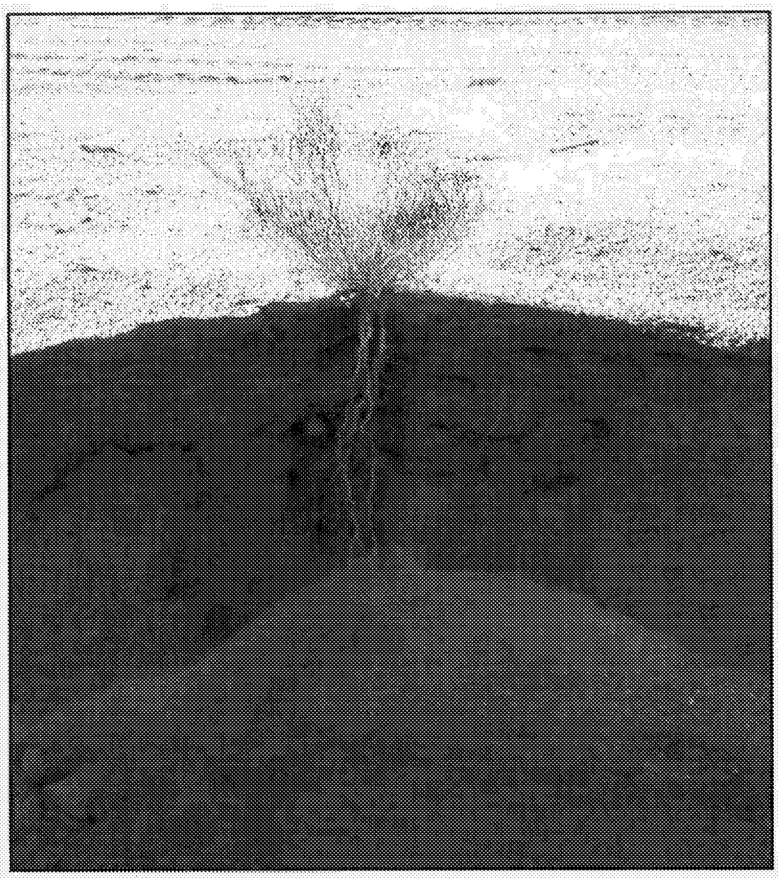

Figure 4-1. Soil moisture profile following 2.5 cm of rain (April 12, 2001). Note drier (lighter) soil directly beneath the plant.

Observations of rooting profiles (Figure 4-1) after a substantial rainfall event (2.54 cm of rain) in sandy soils in the Mojave Desert provide further evidence to explain why lateral root growth is favored over vertical root growth. Because roots extract most of the water in the immediate vicinity of the vertical root, a zone of depletion is created beneath and around the root resulting in lower soil moisture beneath the plant. New roots that extend beyond this water-depleted zone are able to obtain water needed for growth. When new roots enter soil where other roots (either its own or from other plants) are active, the soil no longer provides the needed moisture for growth, and subsequent root growth is retarded or ceases. This phenomenon encourages root growth into areas of higher soil moisture and fewer roots as is often the case with lateral root growth. When rain falls on a plant, the aerial shoots intercept moisture and some moisture is lost through evaporation, reducing soil moisture directly below the plant. If the rain falls intensely, the soil mound at the base of the plant, created by trapped wind-blown particles, usually directs runoff to the lateral sides of the plant. What moisture does enter the soil is usually soaked up by drier soil in the vicinity of the roots which have been extracting soil moisture. The end result is that many plants in the desert create an environment that directs higher moisture to the lateral sides of the plant, thereby encouraging more lateral growth than vertical growth. Creosote bush is reported to extend its relatively smooth vertical branches upward and outward to better direct falling rain to its drier base, thereby providing a competitive edge over other species (Whitford et al., 1996). In drier sites, shrubs were reported to be inverted cone shaped to facilitate shrub flow; in more mesic sites, shrubs were more hemispherically shaped to promote litter accumulation and increased retention of nutrients.

Root growth may also be restricted by soil layers that are cemented with calcium and silicate deposits. These hardpans, caliche, or petrocalcic horizons limit the penetration of roots. They may also retain soil moisture in the upper soil horizons above the hardened layers making it more available for plant growth. When such layers occur too close to the soil surface, the volume of soil available for plant growth may be substantially limited. Some species requiring deeper rooting, like creosote bush or white burrobush, may not be able to persist at these sites during severe drought and are replaced by more shallow-rooted plants like blackbrush, Femont's dalea, white bursage, or shadscale. These cemented layers are usually found on upland landforms (e.g., ballenas), somewhat protected by runoff and disturbance of soil by flooding and deposition. Such sites may also develop desert pavements, protective covering of closely-fitted clasts, that are underlain by soils rich in silts (Anderson et al.,1998). Very old surfaces (>10,000 to 1,000,000 years old) with well-developed pavements are usually devoid of shrub vegetation, except on the fringes of the area where runoff from the hardened and relatively inpenetrable surface benefits adjacent vegetation with increased soil moisture above that supplied by precipitation. Schlesinger and Jones (1984) reported the importance of overland flow to creosote and white bursage in areas where normal overland flows had been disrupted by construction of the Colorado River Aqueduct in 1936-1937. The blockage of overland flow resulted in reductions in density of 66 percent and 73 percent for creosote and whitebursage, respectively over control areas with a 23 percent reduction in biomass (71 kg/ha verus 92 kg/ha) for the total vegetation. Smith (1998) reported water stress of creosote bush to be greater the older the surface became. The least moisture-stressed vegetation was reported in shrubs growing in washes that had the deepest, coarsest textured soils.

Root growth is also restricted by the texture of the soil. Root growth is generally best in a loam type soil with equal parts of silt, sand, and clay because it provides good hydraulic conductivity to replenish water taken up by the roots (silts), good aeration needed for active uptake of nutrients (sands), and good nutrition resulting from high cation exchange potential (clays). Root penetration is reportedly best in silts. It is poor in sand and clays (Foxx et al., 1984a). Soil texture determines how permeable the soil is for intercepting precipitation, retaining soil moisture, and redistributing soil moisture once it is used by the plant. Finer-textured soils are usually higher in soluble salts in the desert, have reduced soil oxygen needed for plant growth, and create physical barriers that restrict root elongation. The soils in the vicinity of Area 5 RWMS were reported to consist of alluvium with an estimated composition of 20 percent gravel, 70 percent sand, and less than 8.5 percent silt/clay (primarily silt), and were classified as a gravelly sand/loamy sand (Cochran et al., 2000).

4.2.3 Root Competition

Distribution of plant roots within soils occupied by a plant community generally tends toward reductions in competition for water. In short, roots grow best into areas not occupied by other plants. Some species have genetic potential for deeper rooting, such as creosote bush and white burrobush, while others have restricted ability for deeper rooting, such as white bursage and shadscale. Brisson and Reynolds (1994) excavated root systems in a creosote bush community and described in detail the geometry of root systems they found. They concluded that when roots come in contact with other roots, they tend to grow away from them where resources are more plentiful. This was demonstrated by plotting root polygons that were found to be more non-overlapping than one would expect by models of unrestricted two-directional growth. They concluded that root systems show displacement in three dimensions away from competitive pressure.

Mahall and Callaway (1992) reported that creosote bush roots inhibited elongation of either creosote bush or white bursage roots in their vicinity, and that white bursage roots inhibited elongation of contacted roots on other white bursage roots only. They suggested that root-mediated allelopathy, in addition to competition for water, may play a role in maintaining distribution of roots to minimize root overlap in desert systems.

4.2.4 The Role of Environmental Extremes and Perturbations

Two of the most important factors influencing change in species composition of communities at the NTS are those of environmental extremes (e.g., droughts and freezes) and perturbations (e.g., fires and floods and pest damage) (Ostler et al., 2000). Climatic fluctuations create periods of drought that can exert significant changes to plant community composition. In the Frenchman Flat area of the NTS, prolonged drought in the late 1980s brought significant death of many shrubs near the playas where droughty soils around the playas contributed to zones where most of the shrubs died (e.g., fourwing saltbush, blackbrush, and creosote bush). Schultz and Ostler (1995) reported that the drought from 1987 to 1991 resulted in substantial die-off of shrubs at Yucca Mountain, Nevada, on the NTS. It resulted in a 46 percent reduction in low-elevation blackbrush crowns, 58 percent in creosote/bursage, and 57 percent reduction in creosote/boxthorn/hopsage. Indian ricegrass (*Achnathrum hymenoides*), desert needlegrass (*Achnathrum speciosa*), and shadscale (*Atriplex confertifolia*) were the species most affected by the drought; live plant crowns were reduced 3 percent, 43 percent, and 52 percent respectively. Late season freezes following a warm and early spring (e.g., April of 1995, personal observation of the authors) have also been observed to kill many shrubs near Frenchman Flat in Area 5. The importance of larger more dramatic shifts in environmental extremes operating over hundreds of years no doubt plays an important role in shaping plant communities and the rooting depths of surviving plants. Recovery of species at a site may require decades and perhaps hundreds of years. Turner (1990) reported declines in creosote bush of up to 90 percent during the first half of this century due to prolonged drought during 1936-1964 and reported little or no recruitment (i.e., new plant establishment) since. Surges in plant establishment are also rather infrequent and require periods of unusually high precipitation during certain periods for up to several years. These climatic extremes are probably more important than the mean climatic conditions in changing vegetation of the NTS.

The most common natural perturbations that affect plants at the NTS appear to be fires and floods. Fires are generally restricted to plant communities where fuels are high enough to carry a fire. Most frequently these communities are the blackbrush communities that tend to accumulate more fuel in the form of dead branches. They are also near steeper slopes where lightening strikes are more common. At higher elevations, the sagebrush and pinyon/juniper communities are shaped by fire. With the invasion of exotic grasses (*Bromus rubens* and *Bromus tectorum*), it is likely that fires will play an increasing role in influencing vegetation change at the NTS.

Once an area is burned, there is a loss of the dominant shrub species and an ecological release of secondary plant species that are more fire-resistant. For example, Nevada jointfir, white burrobush, and a variety of grasses are found flourishing on blackbrush sites that have been burned in Areas 3 and 5 of the NTS. At higher elevations, fires play an important role in selectively removing trees from deeper soils in the valleys where grasses and shrubs reestablish more readily from resprouting or from seedlings. Major flood damage is rarely observed on the NTS in recent history except in major drainages like Forty-Mile Canyon or on the playas; however, smaller channel runoff is important for maintaining some species of plants that require scouring and mixing of the soil for establishment. An example of a species that requires this perturbation is white burrobush, which has rather deep tap roots and frequently grows in disturbed channels (exceptions are notable in some areas).

4.2.5 The Influence of Herbivores

Because surface water is lacking over much of the NTS population, the numbers of large herbivores (i.e., antelope, sheep, and deer) are low. Even populations of horses on the NTS are declining (Townsend and Grossman, 2000). Changes in the vegetation due to herbivores are primarily from rabbits and from burrowing animals that turn the soil and create new niches for plant establishment. These changes are generally on a much smaller scale, although gophers have been observed to denude very sandy sites in Area 5 and other areas of the NTS (Hunter et al., 1980). Kitchen and Jorgensen (1999) concluded that winterfat is declining in the western United States due to recent colonization of ancient rodent burrow clusters by cheatgrass. Rodent

burrow clusters were thought to date to the Pleistocene/Holocene transition [14,000-10,000 years before present (B.P.)] and their presence sustained winterfat on these environments.
Insects perhaps have a larger influence on the vegetation than large animals (Parker et al., 1982), and it is reported by Johnson and Whitford (1975) that more than one half of the estimated annual primary production in the Chihuahuan Desert may be taken by insects (mainly termites). Manning and Barbour (1988) reported higher mortality of shrubs due to herbivory by grasshoppers in desert shrublands when root competition was high. Experiments with artificial seed clumps (buried, dispersed, and clumped) have demonstrated the efficiency of rodents and ants as seed predators (Inouye, 1986). In 24 hours, rodents found 100 percent of the groups of seed and took more than 80 percent of the individual seeds. Ants found about 85 percent of the surface groups and took about 45 percent of the seeds in these groups. The role of herbivores in influencing community structure and root characteristics is often underestimated or ignored. The importance of insects in deserts, with emphasis on the NTS, is the subject of a more detailed study by Neptune and Company, Inc. (Hooten et al., 2001).

4.3 Early NTS Root Studies

During the summer of 1967, specimens of several different shrub species were excavated in a sandy wash area of Rock Valley on the NTS in order to determine root and shoot biomass and investigate unique structural patterns which existed among prominent shrub species (Wallace and Romney, 1972). The information that follows was taken from their report and, despite the small number of plants excavated, makes an important contribution to our understanding of rooting characteristics of shrubs on the NTS. The area of their study is currently classified as a creosote bush/whitebursage shrubland by Ostler et al., (2000). It is the same classification as the plant community at Area 5 RWMS. The site was selected because it was not underlain by caliche hardpan, which was present on the adjacent bajadas of Rock Valley at varying depths from 10 to 70 cm. It was reported that this area provided the deepest roots with relatively uniform edaphic (soil factors) conditions, thus giving better opportunity for inherent differences in root structural patterns to occur. Table 4-1 shows the results of their findings. Of interest is the variation in root-to-shoot ratios within individuals of the same species. No plants were rooted deeper than 1 meter. Wallace and Romney (1972) concluded the following:

> Root excavation studies of specimens of prominent shrub species in Rock Valley disclosed structural systems ranging from massive tap (carrot shaped) root and secondary root systems to filamentous structured systems. The root biomass often exceeds the above-ground biomass. These root systems penetrate deeply into the hardpan layers. Shrubs generally grow much better in soils with unrestricted root penetration; however, since there is usually no close water table in this desert soil, the extent of root development is limited to the depth of the moisture zone from penetrating rainfall. An abundance of mycorrhizal fungi generally is associated with both living and dead roots. Roots of desert shrubs have the unique capacity to survive long periods of dormancy and high moisture stress which appears to be an adaptive mechanism since the same shrub specimens readily thrive when cultured under temperate and semi-tropical conditions.

Table 4-1 Root and top biomass of shrubs excavated in the Rock Valley wash area.

Shrub species	No.	Width cm	Height cm	Root Wt. grams (g)	Top Wt. g	Root/Shoot ratio
Acamptopappus shockleyi	1	30	25	51	54	0.94
Ephedra nevadensis	1	76	53	440	305	1.44
Krascheninnikovia lanata	1	36	36	47	94	0.50
	2	30	23	8	15	0.53
Ambrosia dumosa	1	28	20	19	16	1.19
	2	28	18	16	18	0.89
	3	61	36	643	168	3.83
	4	69	30	405	356	1.14
	5	69	30	337	265	1.27
	6	69	30	406	246	1.65
Grayia spinosa	1	84	64	360	594	0.61
	2	84	66	473	750	0.63
Krameria erecta	1	56	13	100	36	2.78
	2	46	13	45	27	1.67
Larrea tridentata	1	36	33	53	35	1.51
	2	86	66	364	379	0.96
	3	183	152	2586	1812	1.43
Lycium andersonii	1	76	33	923	362	2.54
	2	58	30	436	300	1.45
Lycium pallidum	1	36	18	64	16	4.00
	2	71	48	142	138	1.03

Source: Wallace and Romney, 1972

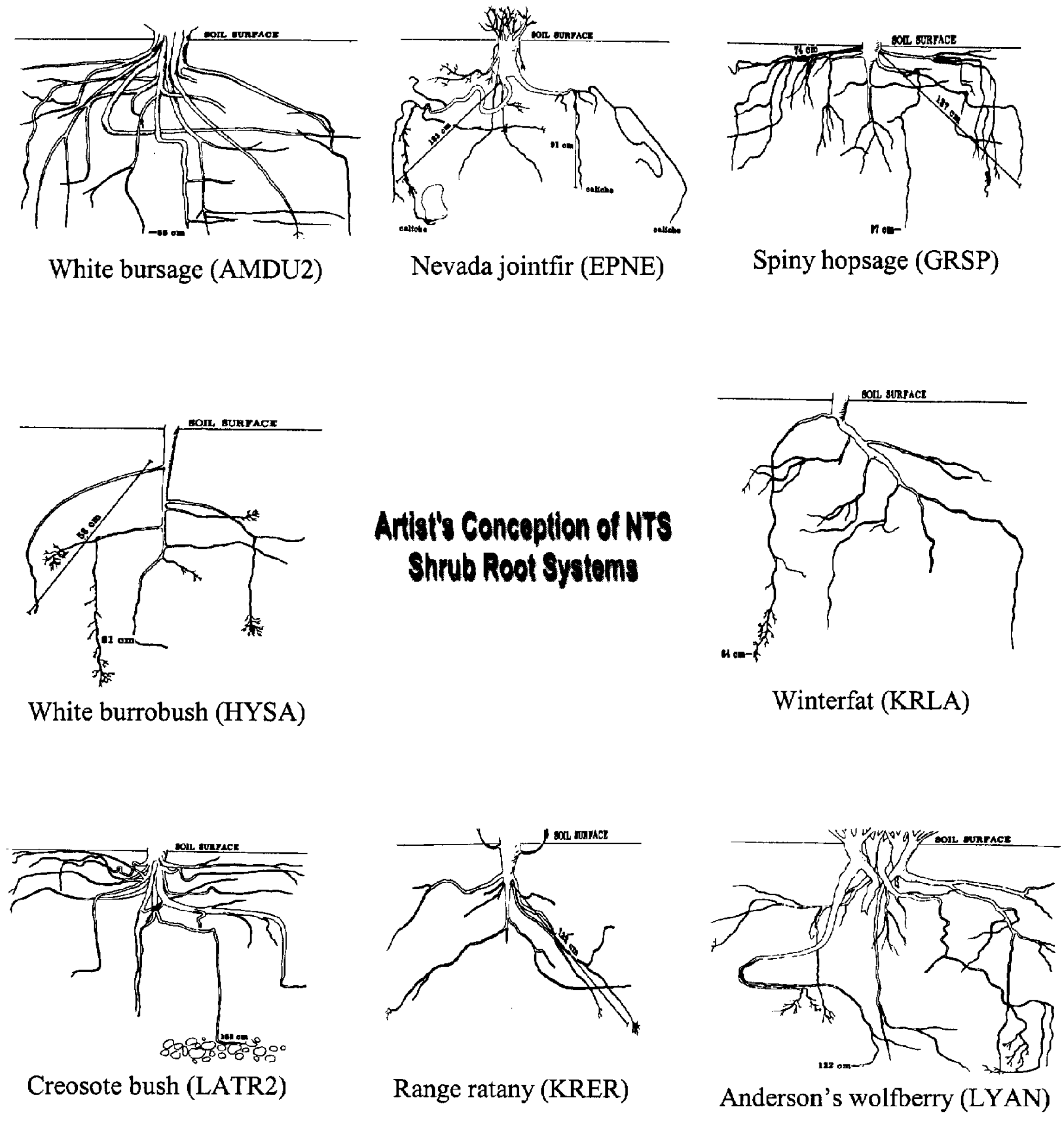

Figure 4-2. Sketches of shrub root systems at the NTS (Wallace and Romney, 1972).

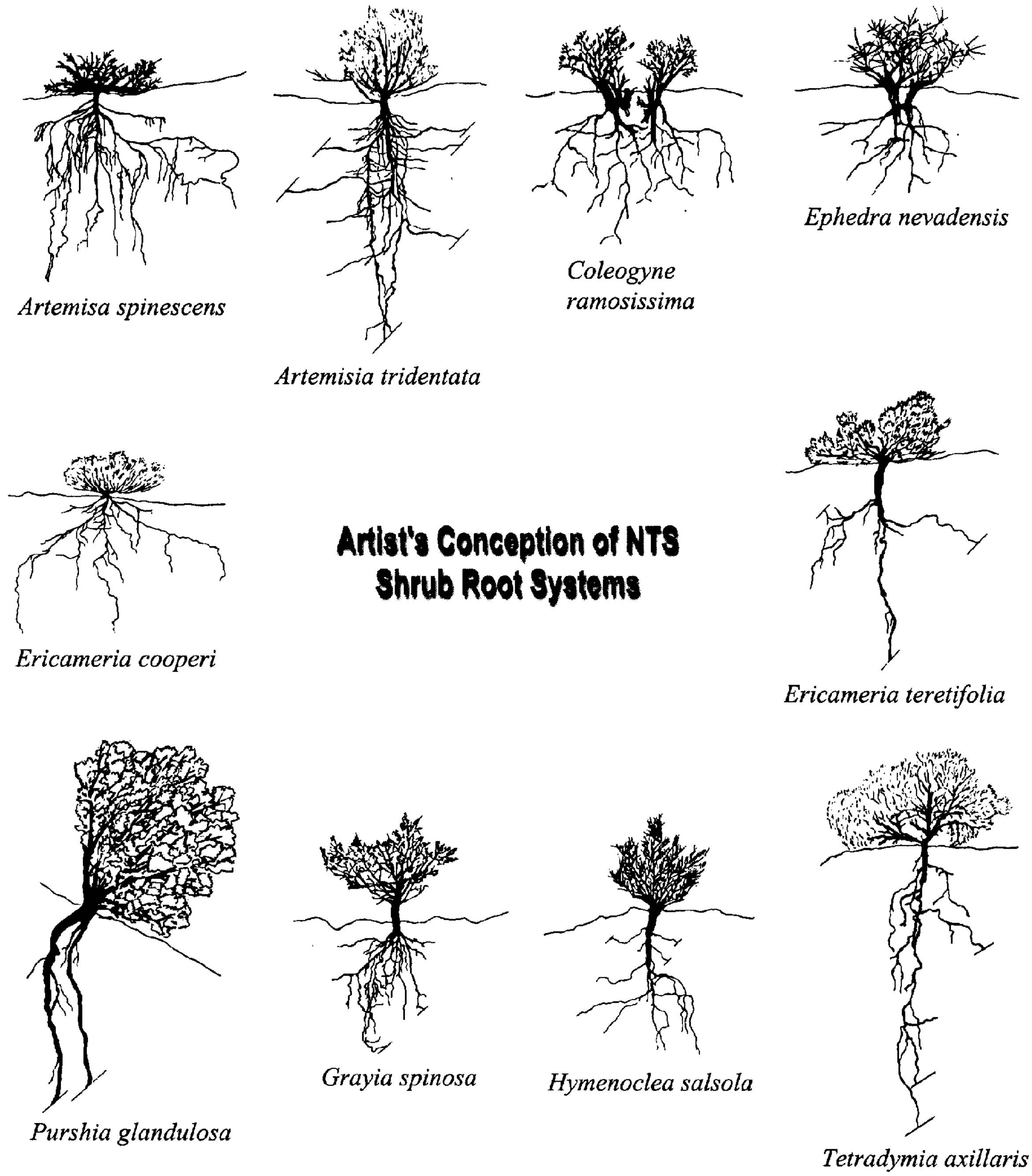

Figure 4-3. Sketches of Great Basin Desert shrub root systems at the NTS (Manning and Groeneveld, 1990).

Their study found no uniquely different root structural system among the species examined that seemed to occur in shrubs and trees common to temperate climate ecosystems, although they mentioned that spiny hopsage (*Grayia spinosa*) and range ratany (*Krameria erecta*) generally tended to develop root systems having many small roots and root hairs, irrespective of the presence or absence of underlying caliche hardpan. Figures 4-2 and 4-3 show an artist's conception (illustrations from Wallace and Romney, 1972 and Manning and Groeneveld, 1990) of typical root systems of key shrub species found on the NTS. Noteworthy was the absence of small auxiliary roots in roots excavated by Wallace and Romney (1972). Smaller roots were observed only on young plants and near the tips of large feeder roots. Manning and Groeneveld (1990) noted deeper rooting depths with plants favoring taproot-type root systems such as desert bitterbrush (*Purshia glandulosa*), white burrobush (*Hymenoclea salsola*), and needleleaf rabbitbrush (*Ericameria teretifolia*).

In 1972, additional field excavations were made in the Rock Valley on the NTS (Wallace et al., 1980). Root systems of 53 individual plants representing nine species were excavated. Distribution of root biomass by soil depth is shown in Table 4-2. Virtually all of the roots systems were distributed in the top 50 cm of soil. Means for root biomass of the nine species by soil depth were 39 percent (0-10 cm deep), 31 percent (10-20 cm deep), 16 percent (20-30 cm), and 9 percent (30-40 cm). (**Note:** Five percent of the total was unaccounted for because of rounding errors.) They concluded that the shallow rooting is related to the sparsity of precipitation (mean annual precipitation is about 10 cm) and with the presence of a caliche layer at 30 to 50 cm. They reported that Shockley goldenhead and range ratany were more shallow rooted than other species (more than 85 percent of their roots in the top 20 cm), wolfberry species were more uniformly distributed throughout the root zone than most species, and winter annual plants were more shallow than perennial plants (Table 4-3). Mean root biomass for all annual plants sampled from Frenchman Flat by soil depth were: 42 percent (0-15 cm), 8 percent (5-10 cm), 19 percent (10-20 cm), and 31 percent (20-30 cm) using the assumption that winter annuals occupy approximately 20 percent of the area (considered "realistic" by Wallace et al., 1980).

In 1973, Romney et al. (1973) characterized the aboveground biomass of shrubs and soil profiles of 79 sites located in five NTS areas: Mercury Valley, Frenchman Flat, Rock Valley, Jackass Flats, and Yucca Flat. Biomass regression equations were developed for key plants (Table 4-4). These equations are useful for estimating shoot biomass from the volume (length x width x height) expressed in cubic meters (m^3).

In 1974, 113 shrubs of 10 species of perennial shrubs were excavated at Rock Valley on the NTS (Wallace et al., 1974). Equations were developed to estimate root biomass from stem biomass as shown in Table 4-5. Standing biomass was reported to be approximately 1,618 kg/ha of roots and 1,520 kg/ha of stems for a combined root-shoot-ratio of approximately 1.06. Root-to-shoot ratios were generally higher for larger plants than for smaller plants. They reported that a minimum of 16 samples per species were required to achieve a precision of 10 to 15 percent of the mean root biomass values based on calculated standard deviations of measured biomass.

Table 4-2. Distribution by depth of roots of perennial plant species collected from Rock Valley.*
(values are percent of total root system)

Depth cm	*A. shockleyi* (3)	*L. tridenta* (3)	*L. andersonii* (5)	*L. pallidum* (6)	*E. nevadensis* (7)	*A. dumosa* (8)	*K. erecta* (8)	*A. canescens* (6)	*A. confertifolia* (7)
					Large roots (above 2 mm)				
0-10	45.7 ± 9.4	24.4 ± 0.8	25.9 ± 5.4	27.5 ± 4.5	38.4 ± 5.3	24.8 ± 2.4	39.9 ± 3.3	39.8 ± 5.0	39.7 ± 6.1
10-20	25.3 ± 7.5	25.4 ± 1.0	15.5 ± 3.6	28.3 ± 4.8	19.7 ± 3.6	25.7 ± 2.2	20.1 ± 5.2	14.9 ± 2.2	16.1 ± 1.5
20-30	5.2 ± 2.9	12.6 ± 1.9	15.1 ± 2.6	9.8 ± 2.0	11.2 ± 2.0	10.4 ± 1.7	2.1 ± 2.1	10.6 ± 2.5	6.7 ± 1.5
30-40	0.8 ± 0.8	7.0 ± 1.6	9.2 ± 2.0	5.4 ± 0.4	5.2 ± 1.8	4.0 ± 1.6	2.0 ± 2.0	4.9 ± 1.8	2.8 ± 0.6
40-50	0.0	3.1 ± 2.2	8.7 ± 3.8	3.5 ± 1.6	1.0 ± 0.4	1.7 ± 1.2	0.0	6.0 ± 2.0	1.4 ± 0.6
Over 50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4 ± 1.4	1.2 ± 1.2
Percent of Total	**77.0**	**75.4**	**74.5**	**74.4**	**75.4**	**75.6**	**64.0**	**67.0**	**67.9**
					Small roots (2 mm or less)				
0-10	5.9 ± 1.6	2.1 ± 0.7	2.2 ± 0.8	2.9 ± 1.1	1.6 ± 1.0	2.9 ± 0.7	16.3 ± 7.7	3.4 ± 1.1	6.1 ± 1.1
10-20	8.5 ± 6.1	8.3 ± 2.6	8.2 ± 2.0	10.5 ± 3.4	5.7 ± 1.1	9.9 ± 1.9	14.3 ± 3.3	10.7 ± 2.6	10.0 ± 3.0
20-30	7.1 ± 6.4	7.2 ± 1.7	7.3 ± 1.7	6.5 ± 2.5	10.6 ± 3.3	6.4 ± 1.6	2.9 ± 2.9	8.4 ± 1.4	7.4 ± 1.6
30-40	1.5 ± 1.5	4.1 ± 1.5	4.6 ± 1.2	3.2 ± 0.9	5.4 ± 2.2	4.4 ± 0.8	2.5 ± 2.5	4.9 ± 1.4	5.6 ± 1.5
40-50	0.0	2.9 ± 1.8	3.1 ± 0.7	2.6 ± 1.1	1.1 ± 0.5	1.4 ± 0.9	0.0	4.5 ± 1.2	2.4 ± 0.9
Over 50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1 ± 0.7	0.6 ± 0.6
Percent of Total	**23.0**	**24.6**	**25.5**	**25.7**	**24.6**	**24.4**	**36.0**	**33.0**	**32.1**

* Data from Wallace et al., 1980.
± is the standard error of the mean.
Numbers in parentheses under species are number of plants in sample.
mm = millimeter(s)

Table 4-3. Depth distribution of roots from annual plants at Frenchman Flat*.

Depth	*Root Material*	*Liberal Estimate 100% of area, kg/ha*	*"Realistic" Estimate 20% of area, kg/ha*
Above ground	litter	367	-
0-5 cm depth			
	large roots	-	-
	small roots	-	-
	fine roots	-	-
	fine roots in organic debris	181	36
	Percent of Total:	**42**	**42**
5-10 cm depth			
	large roots	-	-
	small roots	-	-
	fine roots	5	1
	fine roots in organic debris	31	5
	Percent of Total:	**8**	**8**
10-20 cm depth		-	-
	large roots	-	-
	small roots	109	22
	fine roots	53	11
	fine roots in organic debris	82	16
	Percent of Total:	**19**	**19**
20-30 cm depth			
	large roots	-	-
	small roots	-	-
	fine roots	25	5
	fine roots in organic debris	104	21
	Percent of Total:	**30**	**31**
	Totals (kg/ha):	**590**	**118**

* Source: Wallace et al., 1980

** Estimates of winter annuals root biomass were made using two assumptions:
(1) Biomass is uniformly distributed over the area (probably overestimates)
(2) Winter annuals occupy 20% of the area (considered "realistic")

Table 4-4. Relationship of living shrub volume to dry weight*.

Scientific Name	*Common Name*	n	r	Conversion Factor (CF) W = CF*V	F-value
Acamptopappus shockleyi (ACSH)	**Shockley goldenhead**	43	0.90	2.79300	171.3
Ambrosia dumosa (AMDU2)	**white bursage**	62	0.92	2.23757	318.0
Artemisia spinescens (ARSP5)	**budsage**	10	0.97	4.01357	139.2
Atriplex canescens (ATCAC)	**fourwing saltbush**	20	0.91	2.56917	82.9
Atriplex confertifolia (ATCO)	**shadscale saltbush**	28	0.98	4.86397	609.7
Chrysothamnus vicidiflorus (CHVI)	**green rabbitbrush**	0	*NA*	*NA*	*NA*
Ephedra nevadensis (EPNE)	**Nevada jointfir**	7	0.92	1.45191	26.9
Grayia spinosa (GRSP)	**spiny hopsage**	53	0.82	2.00176	105.3
Hymenoclea salsola (HYSA)	**white burrobrush**	0	*NA*	*NA*	*NA*
Krameria erecta (KRER)	**range ratany**	34	0.78	1.93778	51.3
Krascheninnikovia lanata (KRLA)	**winterfat**	56	0.91	3.04614	274.8
Larrea tridentata (LATR2)	**creosote bush**	41	0.90	1.53936	170.6
Lycium andersonii (LYAN)	**Anderson's wolfberry**	56	0.83	1.97537	118.1
Menodora spinescens (MESP2)	**spiny menadora**	12	0.88	8.19228	33.0

Regressions are of the form: W(kg) = a V (m^3) - b, where b = 0. All F-values are statistically significant at the 1% level.
W = weight of above ground standing crop in kilograms (kg); V = living volume in m^3 = Height X longest width X shortest width
NA: data not available because of an uncommon shrub, or structural configuration was not suitable for dimensional analyses

* Source: Romney et al., 1973.

Table 4-5. Relationship of root and shoot weights of shrubs on the NTS*.

Scientific Name	*Common Name*	n	r	*Standard Deviation (%)*	*Standard Error of Mean (%)*	Conversion Factor (R)** $Root_{(g)} = b\ stem_{(g)} + a$
Acamptopappus shockleyi (ACSH)	**Shockley goldenhead**	8	0.948	8.9	2.16	R = (0.45 stem + 1.23) 1.15
Ambrosia dumosa (AMDU2)	**white bursage**	25	0.926	9.5	1.90	R = (1.15 stem - 13.95) 1.15
Artemisia spinescens (ARSP5)	**budsage**	**NA**	**NA**	**NA**	**NA**	**NA**
Atriplex canescens (ATCAC)	**fourwing saltbush**	11	0.903	7.9	2.36	R = (0.42 stem + 20.30) 1.15
Atriplex confertifolia (ATCO)	**shadscale saltbush**	14	0.989	9.5	2.54	R = (0.29 stem + 9.30) 1.15
Chrysothamnus vicidiflorus (CHVI)	**green rabbitbrush**	**NA**	**NA**	**NA**	**NA**	**NA**
Ephedra nevadensis (EPNE)	**Nevada jointfir**	11	0.891	11.6	3.49	R = (0.85 stem - 26.20) 1.15
Grayia spinosa (GRSP)	**spiny hopsage**	5	0.943	11.3	5.05	R = (0.60 stem + 2.38) 1.15
Hymenoclea salsola (HYSA)	**white burrobrush**	**NA**	**NA**	**NA**	**NA**	**NA**
Krameria erecta (KRER)	**range ratany**	2	0.722	9.5	3.87	R = (0.35 stem + 55.20) 1.15
Krascheninnikovia lanata (KRLA)	**winterfat**	**NA**	**NA**	**NA**	**NA**	**NA**
Larrea tridentata (LATR2)	**creosote bush**	13	0.981	12.3	3.40	R = (1.37 stem - 87.10) 1.15
Lycium andersonii (LYAN)	**Anderson's wolfberry**	10	0.959	10.3	3.26	R = (0.82 stem - 23.00) 1.15
Menodora spinescens (MESP2)	**spiny menadora**	**NA**	**NA**	**NA**	**NA**	**NA**

Based on values for all plants sampled, the mean percent of the total plant biomass that was root biomass was approximately 45%.

* Source: Wallace et al., 1974.

*** The constant 1.15 corrects for fine roots not recovered that represent about 15% of the total root weight.*

NA: data not available

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5.0 FIELD INVESTIGATIONS

Field surveys and photo interpretation studies were conducted in 2001 and 2002 by Bechtel Nevada biologists. The goal was to characterize plant community composition of vegetation and aboveground biomass adjacent to Areas 3 and 5 RWMSs. Sites were first selected using 1:4280 scale aerial photographs and then visited in the field to collect data. Site parameters were recorded, vegetation measured, and living volume estimates made from individual measurements of plant height, width, and length. Estimates of shrub density and cover were also calculated using the point-centered quarter method (Bonham, 1989). To confirm canopy cover estimates, new image analysis techniques were used (Hansen and Ostler, 2002) to provide more accurate measurements of plant cover and individual shrubs. Ground plots were selected that measured 100 meters x 100 meters in size (an area of 1 hectare). Within these plots each shrub was digitally measured to obtain shrub length, width, and area. Methods are described in Section 2.3.

Field surveys were conducted at six selected sites in the vicinity of Area 3 and Area 5 RWMSs (Figures 5-1 and 5-2) and two sites in Area 17 and 18. Site selection criteria included:

- Sites that were relatively undisturbed with homogeneous vegetation.
- Plant communities that represented the major vegetation associations within 3 km of the Areas 3 and 5 RWMSs.
- Sites that appeared to have the same or similar soils and land forms as occur in Areas 3 and 5 RWMSs.
- Sites in the vicinity of Areas 3 and 5 RWMSs that might have higher and lower values of plant biomass for the purpose of establishing a likely range of potential biomass values.
- Sites within vegetation types thought to occur under future scenarios such as those dominated by big sagebrush on relatively deep soils.

Based on field surveys conducted in 2001 and 2002, information was collected from eight plant communities. Two plant communities (sites) were sampled near the Area 5 RWMS; Site 1 is approximately 220 m north of Area 5 RWMS and Site 2 is approximately 1.2 km east-southeast of Area 5 RWMS. The plant communities represent vegetation typical for the area. Soils sampled at Site 1 were older, sandier, and less rocky than Site 2, where larger rocks were prevalent and runoff channels caused mixed layers..

Three relatively undisturbed plant communities were sampled near Area 3 RWMS. Sites 3, 4, and 5 are approximately 1.9 km northeast, 1.5 km northwest, and 1.9 km northwest of Area 3 RWMS, respectively. Site 6 is located 200 m west of Site 1 and was selected to replaced Site 1, which was destroyed in 2001 during construction of the new Area 5 RWMS disposal pit.

Sites 7 and 8 are located in big sagebrush communities in Areas 17 and 18; they are believed to be representative of plant communities that are wetter and cooler than plant communities located in Areas 3 and 5.

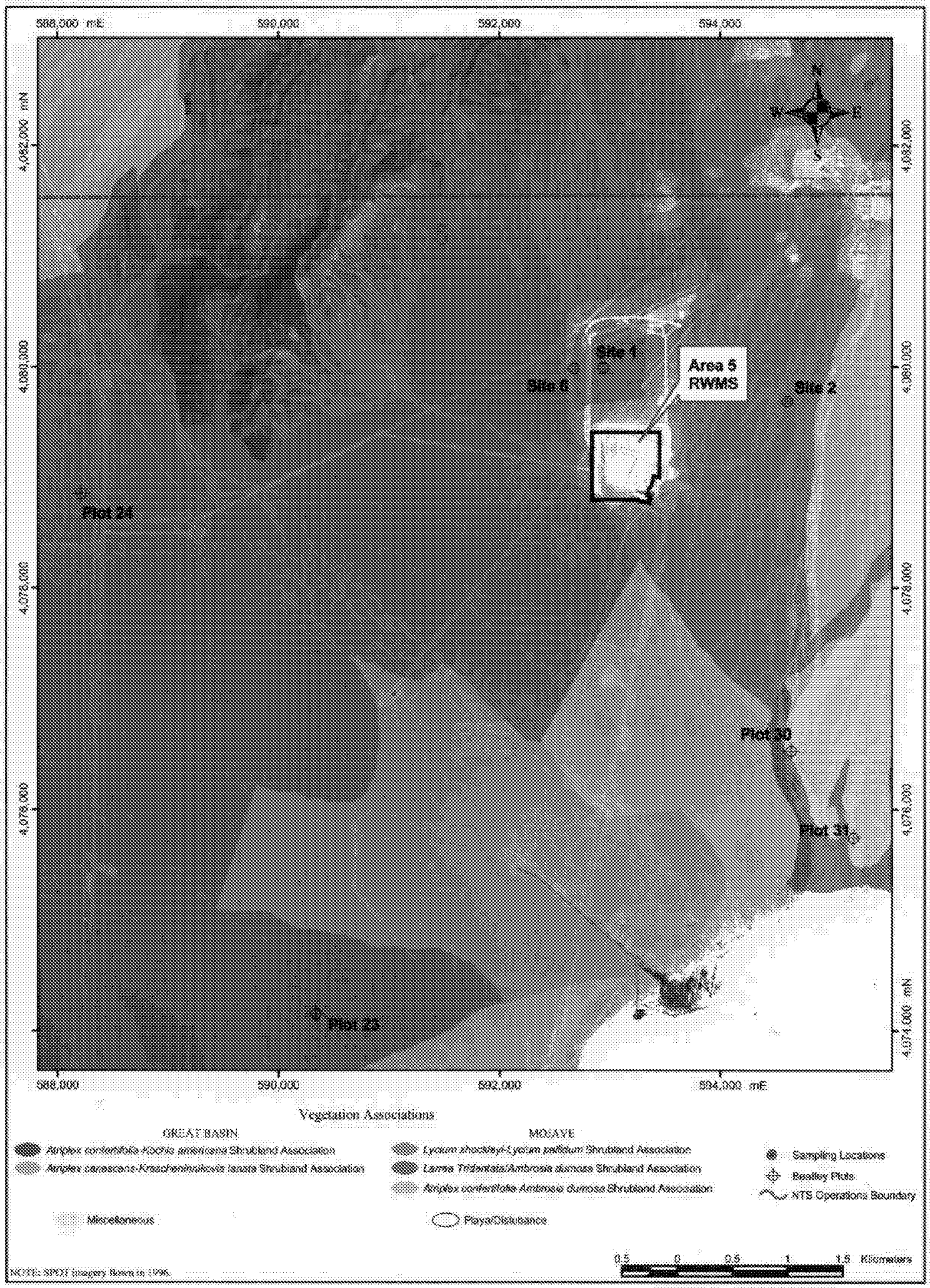


Figure 5-1. Location of Field Sampling Sites in the Vicinity of Area 5 RWMS

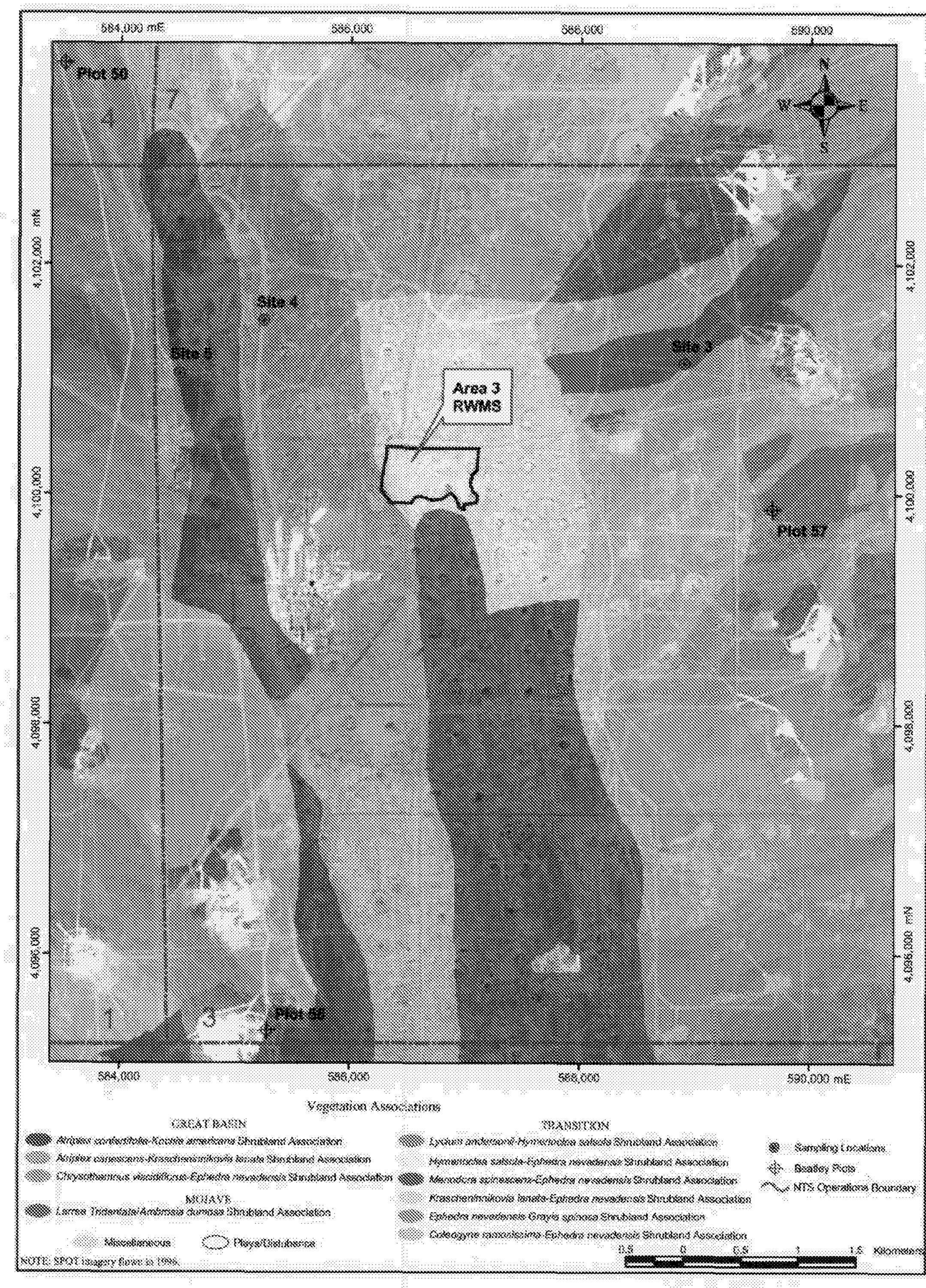


Figure 5-2. Location of Field Sampling Sites in the Vicinity of Area 3 RWMS

5.1 Image Analysis Measurements of Area 5 RWMS Historic Aerial Photographs

Digitally-scanned images of historic color infrared photographs of the Area 5 RWMS site taken by EG&G in 1988 were used to estimate shrub canopy cover. While similar scale photographs were available of Area 3 RWMS, the vegetation at Area 3 RWMS had been removed previously leaving only weedy annuals with extremely low vegetation cover. The negative scale of the photos covering Area 5 RWMS was 1:4280 (i.e., 1 inch on the photograph equals 4,280 inches on the ground). Canopy cover of shrubs was identified by adjusting image intensity values of individual pixels until only plant cover was delineated using Image Pro® Plus Version 4.1 software (Hansen and Ostler, 2002). Canopy cover of shrubs was then separated into four size classes:

Class		*Area*		
Class 1 =	0.05	to	3 m^2 per shrub
Class 2 =	3	to	6 m^2 per shrub
Class 3 =	6	to	10 m^2 per shrub
Class 4 =	10	to	70 m^2 per shrub

The field cover classes were useful to help establish estimates of shrub diameter, height, and living volume that could then be used to estimate shrub shoot biomass. Using the shrub shoot biomass and root-to-shoot ratio, it was possible to estimate root biomass and root depth from published statistical correlation equations and conversion factors. For example, Foxx et al., (1984b) reported that plant height can give a rough estimate of root penetration depth and that shrubs had a root depth-to-height ratio of 1.2, and a root depth-to-lateral spread ratio of less than 1.0.

To determine the variability of shrub cover and sizes of plants in the vicinity of Area 5 RWMS, eleven 1-hectare photo plots were sampled and shrub sizes measured on each shrub in the plant community over 0.05 square meter (m^2) in area (Figures 5-3 and 5-4).

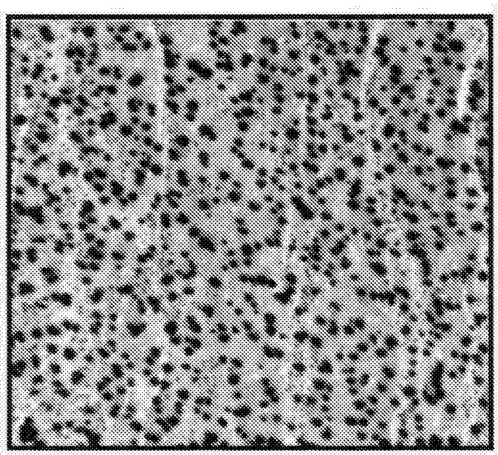


Figure 5-3. Example of aerial photograph showing shrub silhouettes at Photo Plot B2.

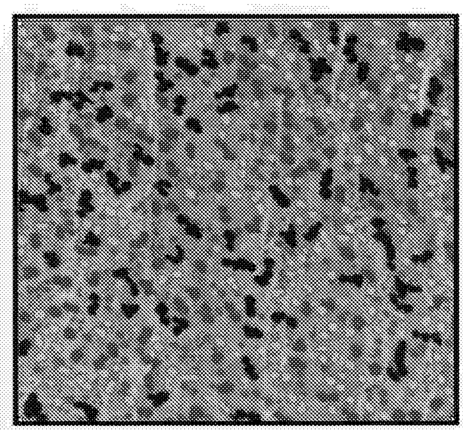


Figure 5-4. Example of shrub silhouettes color-coded by size class at Photo Plot B2.

Plots extended north and west of Area 5 RWMS (Photo Plots A1, A2, A3, B1, B2), north (C1, C2), approximately 600 m, and to the northeast of RWMS 5 (D1, D2, D3, D4) approximately 1,250 m. Measured values for 9,149 objects are shown in Table 5-1. The relationship between mean diameter and mean area of NTS shrubs was shown to be approximated by the polynomial equation $Y = -.0160 + 0.3236X + 0.707X^2$, where Y = mean area in square meters and X = mean diameter in meters ($R^2 = .996$) (n = 9,149).

The distribution of shrub sizes near Area 5 RWMS is shown in Figure 5-5. An interpretation of this chart suggests that there are subtle gradients in the size of shrubs that occur across the landscape. These changes in shrub sizes are probably due to soil differences. For example, Photo Plot C1 and D4 occur on soils that are relatively young and along stream channels where soil mixing favors many smaller shrubs. Older soil surfaces occur on Photo Plots, A3, B1, and B2. They have fewer, smaller shrubs and generally have more annual plants. These subtle soil differences appear to create major differences in the plant community structure.

Using the calculated means of the cover classes described above and the conversion factors for root depth per plant height (factor=1.2) described by Foxx et al., (1984b), approximations of root depths and percentages of the shrub cover in various size classes are shown in Table 5-2.

Table 5-2. Shrub measurements and estimates of rooting depth at Area 5 RWMS.

Class Size	*Percent of Total Cover*	*Mean Diameter per plant (m)*	*Mean Area per plant (m^2)*	*Mean Height (m)*	*Maximum Root Depth (m)*
1	26%	0.98	3.07	0.62	0.75
2	28%	2.24	7.04	1.33	1.60
3	25%	3.06	9.60	1.79	2.15
4	21%	4.25	13.34	2.46	2.95

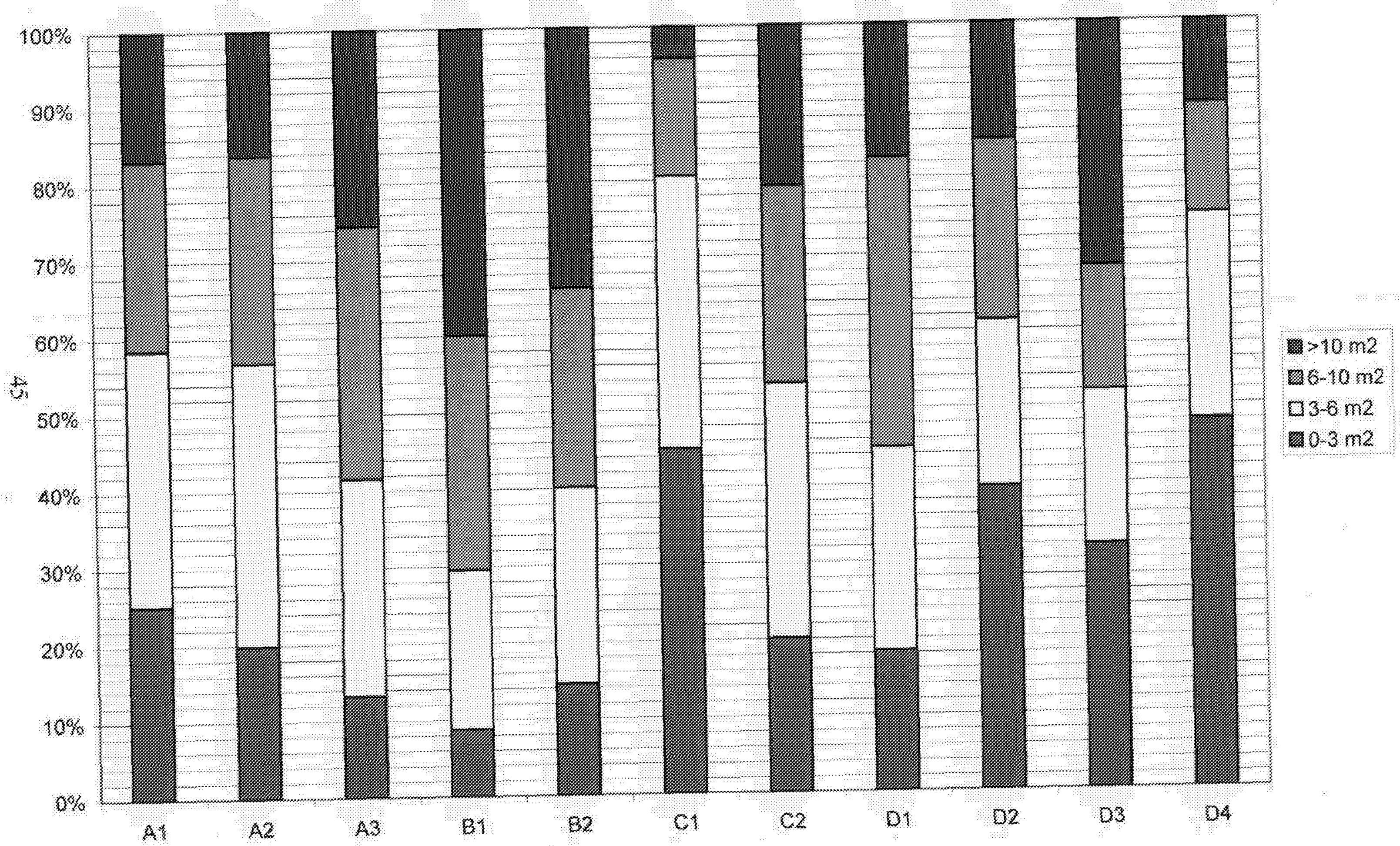
Estimates of plant height were made by regression analysis of measured mean shrub diameter (longest width x shortest width/2) on measured shrub height collected at Area 5 RWMS (Figure 5-6).

The correlation equation was $Y = 7.09367 + 0.563088X$ ($R^2 = 86.5\%$, n = 80). In all likelihood, this approach probably overestimates mean root depth for this reason: Plant diameter at the higher values was generally less than plant diameter in actual measurements that were made at the site because only the very tallest leaders and widest leaders were measured. Additionally, the larger shrub class sizes are occasionally a coalescing of two or more shrubs into one canopy area.

Table 5-1. Vegetation parameters in selected photo plots around Area 5 RWMS.

AREA	Class	# Objects	% Objects	Mean Area m2	Total Area m2	% Area	Mean Diam. m	Mean Canopy Cover per plant (%)	Mean Area per plant (m2)	Mean Diam. m	Canopy Cover (%)
A1									**2.74**	**1.57**	**17.61%**
A1	1	477	65.34%	1.06	503.59	25.18%	1.01	0.00929%			
A1	2	162	22.19%	4.12	667.24	33.36%	2.20	0.03626%			
A1	3	66	9.04%	7.48	493.47	24.67%	3.06	0.06582%			
A1	4	25	3.42%	13.43	335.73	16.79%	4.31	0.11822%			
A2									**2.95**	**1.60**	**16.13%**
A2	1	373	60.06%	0.98	363.81	19.86%	0.94	0.00859%			
A2	2	158	25.44%	4.28	676.56	36.92%	2.21	0.03770%			
A2	3	67	10.79%	7.39	494.86	27.01%	2.99	0.06502%			
A2	4	23	3.70%	12.92	297.07	16.21%	4.00	0.11371%			
A3									**3.19**	**1.59**	**23.05%**
A3	1	489	59.42%	0.71	347.68	13.25%	0.76	0.00625%			
A3	2	167	20.29%	4.45	742.51	28.29%	2.25	0.03905%			
A3	3	116	14.09%	7.44	863.13	32.89%	3.01	0.06536%			
A3	4	51	6.20%	13.16	671.35	25.58%	4.07	0.11563%			
B1									**4.71**	**2.00**	**26.66%**
B1	1	310	47.40%	0.87	269.88	8.77%	0.86	0.00754%			
B1	2	145	22.17%	4.41	639.45	20.78%	2.23	0.03821%			
B1	3	122	18.65%	7.70	939.75	30.54%	3.04	0.06674%			
B1	4	77	11.77%	15.95	1,228.43	39.92%	4.53	0.13822%			
B2									**3.28**	**1.60**	**24.09%**
B2	1	519	61.28%	0.78	403.11	14.50%	0.79	0.00673%			
B2	2	167	19.72%	4.27	712.98	25.64%	2.20	0.03699%			
B2	3	94	11.10%	7.69	722.51	25.98%	3.10	0.06659%			
B2	4	67	7.91%	14.06	942.33	33.89%	4.24	0.12185%			
C1									**2.40**	**1.62**	**10.75%**
C1	1	348	73.57%	1.47	511.88	45.02%	1.32	0.01391%			
C1	2	98	20.72%	4.12	403.71	35.51%	2.25	0.03896%			
C1	3	24	5.07%	7.25	174.07	15.31%	3.06	0.06859%			
C1	4	3	0.63%	15.78	47.34	4.16%	4.34	0.14923%			
C2									**3.93**	**2.02**	**17.29%**
C2	1	235	50.54%	1.56	367.53	20.11%	1.33	0.01479%			
C2	2	137	29.46%	4.43	607.29	33.23%	2.29	0.04192%			
C2	3	63	13.55%	7.46	470.05	25.72%	3.06	0.07056%			
C2	4	30	6.45%	12.76	382.91	20.95%	4.04	0.12071%			
D1									**4.11**	**2.06**	**20.08%**
D1	1	212	48.96%	1.53	325.16	18.26%	1.34	0.01729%			
D1	2	109	25.17%	4.34	472.73	26.55%	2.23	0.04890%			
D1	3	87	20.09%	7.74	673.14	37.80%	3.07	0.08724%			
D1	4	25	5.77%	12.39	309.68	17.39%	3.96	0.13967%			
D2									**1.39**	**1.03**	**24.15%**
D2	1	1339	86.89%	0.63	846.91	39.54%	0.77	0.00713%			
D2	2	112	7.27%	4.15	464.99	21.71%	2.25	0.04681%			
D2	3	67	4.35%	7.52	503.64	23.51%	3.07	0.08476%			
D2	4	23	1.49%	14.19	326.45	15.24%	4.18	0.16004%			
D3									**1.90**	**1.19**	**25.18%**
D3	1	982	83.57%	0.73	712.04	31.89%	0.84	0.00818%			
D3	2	104	8.85%	4.30	447.57	20.04%	2.25	0.04853%			
D3	3	46	3.91%	7.88	362.37	16.23%	3.06	0.08883%			
D3	4	43	3.66%	16.53	711.00	31.84%	4.58	0.18644%			
D4									**1.26**	**1.02**	**19.38%**
D4	1	1229	88.61%	0.68	836.79	48.00%	0.81	0.00757%			
D4	2	112	8.07%	4.17	466.72	26.77%	2.29	0.04632%			
D4	3	33	2.38%	7.56	249.64	14.32%	3.09	0.08409%			
D4	4	13	0.94%	14.61	189.99	10.90%	4.46	0.16245%			

Figure 5-5. Shrub sizes in photo plots at Area 5 RWMS (West to East).



However, these calculations provide a different approach in calculating root depth biomass and provide a more accurate estimate of what percentage of the total canopy cover is distributed into different sizes that are known to have varying root depths.

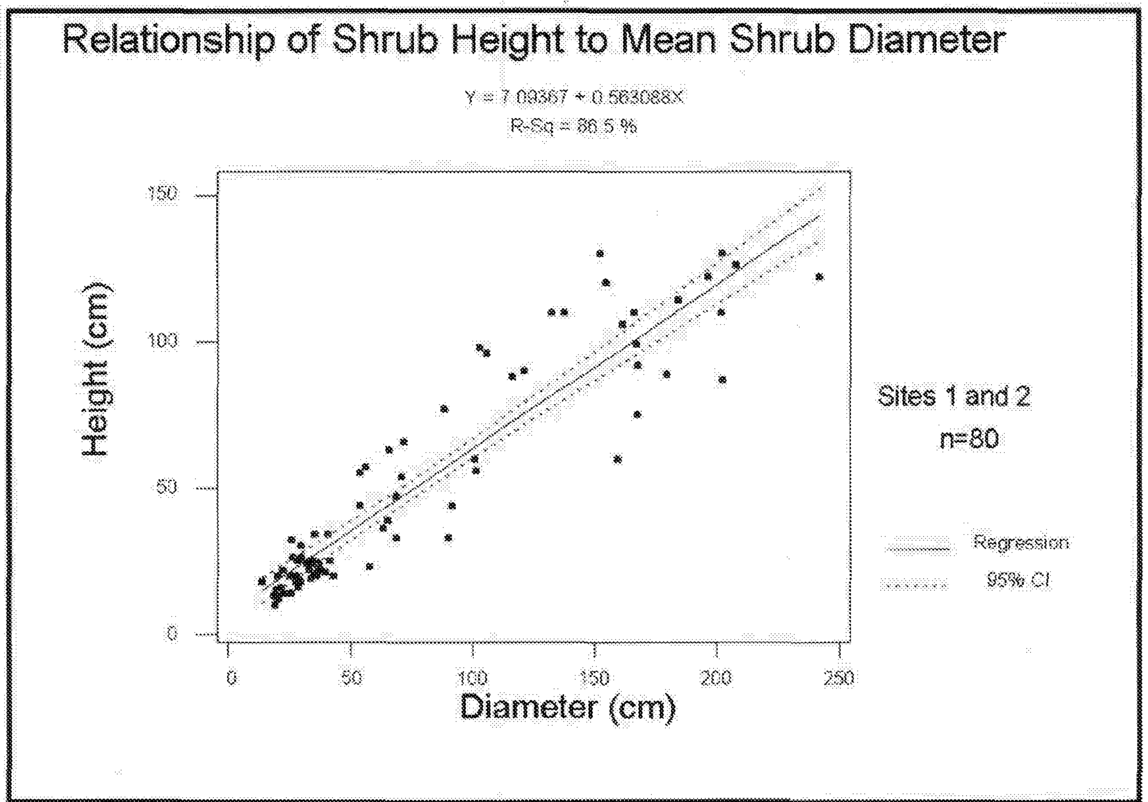


Figure 5-6. Correlation of mean shrub diameter and shrub height at Area 5 RWMS.

5.2 Field Measurements of Shrubs near Area 3 and 5 RWMS

Analyses of field data from Sites 1 thru 8 provided detailed descriptions of vegetation (size, structure, canopy cover, and density) at these sites as well as information about site characteristics (geology, landforms, soil, desert pavement, cryptogamic crusts, and rodent burrows) and relative abundance of herbaceous vegetation. These data were used to describe community structure and variability of selected parameters. Means, number of plants sampled (*n*), and standard deviations (*Stdev*) in measurements are provided in tables. Standard error of the means can be calculated by the following formula:

$$\text{Standard error of the mean} = \pm \frac{Stdev}{\sqrt{n}}$$

5.2.1 Site 1 Near Area 5 RWMS

Site 1, shown in Figure 5-7, is located about 600 m north of Area 5 RWMS. Table 5-3 shows the characteristics of shrubs found in this community. Table 5-4 shows the estimates of shoot and root biomass for vegetation at Site 1. This site best represents conditions for vegetation growth at Area 5 RWMS (undisturbed areas) currently and for the next several hundred years once the site is revegetated naturally. It is located on a sandy loam soil and desert pavement of a mean size less than 5 cm in diameter covering about 80 percent of the soil surface.

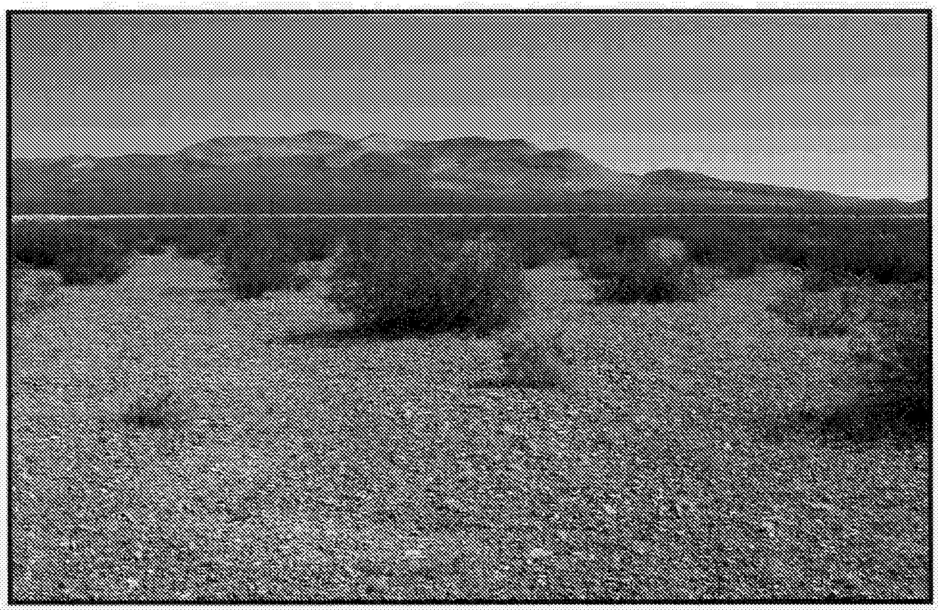


Figure 5-7. Site 1 north of Area 5 RWMS located in a creosote bush-white bursage plant community (April 12, 2001).

The coarse soils drain precipitation quickly and appear to restrict growth of shallow-rooted shrub species (found primarily in the wash channels) which constitute less than 40 percent of the site shrubs in relative abundance, but contribute only 1.6 percent of the root biomass. This condition may also explain why the site has a high number and biomass production of shallow-rooted herbaceous species that probably flourish during the winter and early spring when soil moisture is higher and then complete their life cycle or go dormant by summer. Grasses, in order of importance (i.e., relative abundance), included: foxtail brome (*Bromus rubens*), sixweeks fescue (*Vulpia octoflora*), Indian ricegrass (*Acnatherum hymenoides*), and low woolygrass (*Erioneuron pulchellum*). Forbs (herbaceous plants), listed in order of importance, included: little deserttrumpet (*Eriogonum trichopes*), shaggyfruit pepperweed (*Lepidium lasiocarpum*), bashful four o'clock (*Mirabillis pudica*), globemallow (*Sphaeralcea ambigua*), smooth desertdandelion (*Malacothrix glabrata*), milkvetch (*Astragalus lentiginosus*), bristly fiddleneck (*Amsinckia tessellata*), birdsnest buckwheat (*Eriogonum nidularium*), whitemargin sandmat (*Chamaesyce albomarginata*), prickly Russian thistle (*Salsola kali* ssp *tagus*), small wire-lettuce,

Table 5-3. Characteristics of shrubs in plant communities at Site 1 near Area 5 RWMS.

Site:	1	***Elevation:***	972 m
Location:	600 m north of Area 5 RWMS	***Slope/Aspect:***	$1^0/180^0$
NTS Grid:	215 (X 20)	***Soil Texture:***	Sandy loam
UTM:	592937 E, 4079992 N	***Rodent Activity:***	Low
Date:	6/4/2001	***Desert Pavement Size:***	Fine < 2.5 cm
Time:	9:00 AM	***Percent Rock Cover:***	80%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	none
Landform:	Piedmont Slope, fan piedmont	***Annual Productivity:***	high
Geology:	Qa		

Common Name / ***Species (National Plant Code)***	***n***	***Rel. Density***	***No./ha***	***Abundance***		***Height cm***	***Width1 cm***	***Width2 cm***	***Area m2***	***Volume m3***
creosote bush	24	60%	860	60%	***Mean:***	96.5	160.4	131.8	2.277	2.373
Larrea tridentata (LATR2)					***Stdev:***	22.45	53.28	48.69	1.273	1.588
Shockley goldenhead	9	23%	323	20%	***Mean:***	20.4	34.3	26.3	0.093	0.020
Acamptopappus shockleyi (ACSH)					***Stdev:***	5.13	10.45	7.95	0.043	0.011
white bursage	3	8%	108	8%	***Mean:***	21.7	35.3	28.0	0.099	0.021
Ambrosia dumosa (AMDU2)					***Stdev:***	3.79	4.16	8.00	0.031	0.004
Anderson's wolfberry	2	5%	72	8%	***Mean:***	41.5	72.0	84.5	0.621	0.263
Lycium andersonii (LYAN)					***Stdev:***	3.54	8.49	28.99	0.280	0.138
range ratany	1	3%	36	2%	***Mean:***	33.0	98.0	82.0	0.804	0.265
Krameria erecta (KRER)					***Stdev:***	*NA***	*NA***	*NA***	*NA***	*NA***
winterfat	1	3%	36	2%	***Mean:***	32.0	28.0	23.0	0.064	0.021
Krascheninnikovia lanata (KRLA)					***Stdev:***	*NA***	*NA***	*NA***	*NA***	*NA***
Total Shrub Density*:	1,433	plants/hectare			***Total Shrub Mean:***	67.9	113.4	93.9	1.447	1.450
Total Percent Shrub Cover:	21.0%	canopy cover			***Total Shrub Stdev:***	39.91	72.47	61.98	1.428	1.674
Total Shrub Living Volume:	2,079	m^3/ha								

*Density = $1/d^2$, d = mean distance
**NA = not applicable as there was only one individual in sample

Table 5-4. Estimates of shoot and root biomass for vegetation at Site 1 near Area 5 RWMS.

Site: 1
Location: 600 m north of Area 5 RWMS
NTS Grid: 215 (x 20)
UTM: 592937 E, 4079992 N

Common Name Species (National Plant Code)	Relative Density	No./ha	Mean Height per plant (cm)	Volume per plant (m3)	Vol./Biomass Factor*	Stem Biomass per plant (kg)	Root/Shoot Ratio**	Root Biomass per plant (kg)	Total Stem Biomass (kg/ha)	Total Root Biomass (kg/ha)	% of Total Root Biomass	Max. Depth** Below Ground per plant (cm)
creosote bush *Larrea tridentata (LATR2)*	60%	860	96.5	2.373	1.53936	3.65290	1.24	4.530	3,141	3,895	98.4%	115.8
Shockley goldenhead *Acamptopappus shockleyi (ACSH)*	23%	323	20.4	0.020	2.79300	0.05586	0.56	0.031	18	10	0.3%	24.48
white bursage *Ambrosia dumosa (AMDU2)*	8%	108	21.7	0.021	2.23757	0.04699	1.16	0.055	5	6	0.1%	26.04
Anderson's wolfberry *Lycium andersonii (LYAN)*	5%	72	41.5	0.263	1.97537	0.51863	0.83	0.430	37	31	0.8%	49.8
range ratany *Krameria erecta (KRER)*	3%	36	33.0	0.265	1.93778	0.51388	0.79	0.406	18	15	0.4%	39.6
winterfat *Krascheninnikovia lanata (KRLA)*	3%	36	32.0	0.021	3.04614	0.06277	0.90	0.056	2	2	0.1%	38.4
								Total for All Species:	**3,223**	**3,959**	**100.0%**	

*Conversion Factors from Romney et al. 1973
**Conversion Factors from Wallace et al 1974
***Conversion Factors from Foxx et al 1984b

(*Stephanomeria exigua* ssp *exigua*), and wooly desert marigold (*Baileya multiradiata*). Evidence of rodent activity (e.g., burrows and signs of digging) was low. Total shrub canopy cover was approximately 21 percent with approximately 1,433 plants per hectare of shrub density. Mean height of all shrub species was 67.9 cm (96.5 cm for creosote bush), with a mean length and width of 113.4 cm and 93.9 cm, respectively. Mean living volume was 1.45 m^3 per shrub. Total root biomass was estimated at 3,959 kg/ha primarily from creosote bush (98.4 percent). Maximum rooting depth per shrub was estimated at an average of 115.8 cm.

5.2.2 Site 2 Near Area 5 RWMS

Site 2, shown in Figure 5-8, is located about 1.2 km northeast of Area 5 RWMS. It is located on loamy sand soils and has larger rocks and more evidence of runoff channels than at Site 1. Desert pavement of a mean clast size less than 5 cm in diameter covers about 60 percent of the surface.

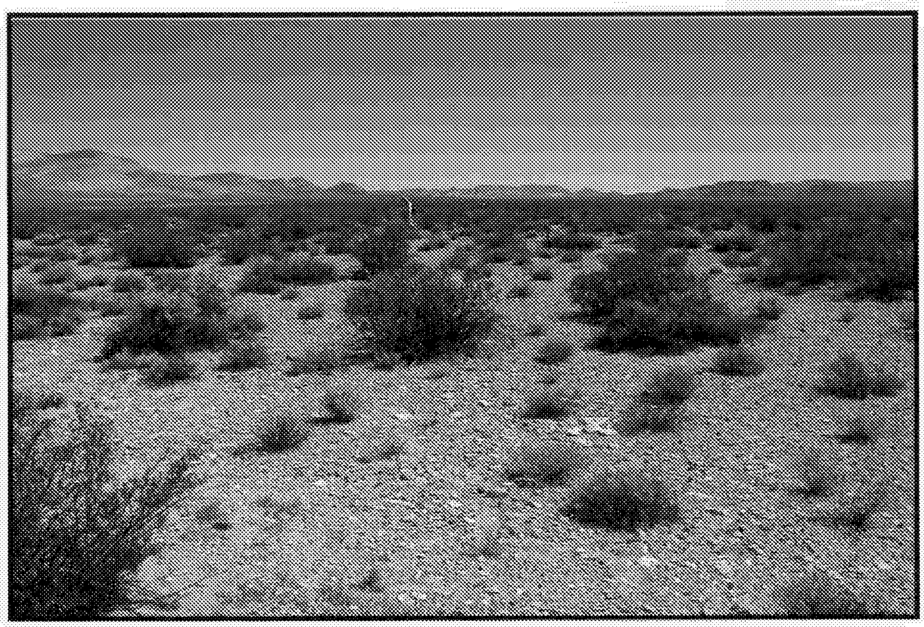


Figure 5-8. Site 2 northeast of Area 5 RWMS located in a creosote bush-white bursage plant community (June 4, 2001).

Based on shrub height and cover, this site appears drier than Site 1. Finer-textured soils help maintain a greater plant species diversity and abundance of shallow-rooted shrubs that persist in droughts. Creosote bush represents only about 13 percent relative density, but about 90 percent of the root biomass. Table 5-5 shows the characteristics of shrubs found in this community. Table 5-6 shows the estimates of shoot and root biomass for vegetation at Site 2.

Table 5-5. Characteristics of shrubs in plant communities at Site 2 near Area 5 RWMS.

Site:	2	***Elevation:***	988 m
Location:	1.25 km northeast of Area 5 RWMS	***Slope/Aspect:***	$1^{o}/180^{o}$
NTS Grid:	215 (Y 19)	***Soil Texture:***	Loamy sand
UTM:	594605 E, 4079688 N	***Rodent Activity:***	Low
Date:	6/4/2001	***Desert Pavement Size:***	Fine < 2.5 cm
Time:	10:00 AM	***Percent Rock Cover:***	60%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	none
Landform:	Piedmont Slope, fan piedmont	***Annual Productivity:***	very low
Geology:	Qa		

Common Name Species (National Plant Code)	n	Rel. Density	No./ha	Abundance		Height cm	Width1 cm	Width2 cm	Area m2	Volume m3
white bursage					**Mean:**	21.11	33.63	26.05	0.097	0.024
Ambrosia dumosa (AMDU2)	19	48%	2,267	46%	**Stdev:**	6.57	13.40	9.39	0.081	0.031
Shockley goldenhead					**Mean:**	21.56	35.67	31.00	0.123	0.027
Acamptopappus shockleyi (ACSH)	9	23%	1,074	18%	**Stdev:**	2.70	12.44	13.57	0.092	0.021
creosote bush					**Mean:**	79.60	148.00	123.00	2.182	2.261
Larrea tridentata (LATR2)	5	13%	597	14%	**Stdev:**	31.98	63.40	74.73	2.212	2.918
range ratany					**Mean:**	21.50	52.00	35.50	0.243	0.076
Krameria erecta (KRER)	2	5%	239	6%	**Stdev:**	16.26	42.43	27.58	0.294	0.103
Anderson's wolfberry					**Mean:**	36.00	46.50	50.00	0.272	0.119
Lycium andersonii (LYAN)	2	5%	239	4%	**Stdev:**	15.56	23.33	33.94	0.274	0.141
winterfat					**Mean:**	44.00	64.00	44.00	0.282	0.124
Krascheninnikovia lanata (KRLA)	1	3%	119	4%	**Stdev:**	*NA***	*NA***	*NA***	*NA***	*NA***
Nevada jointfir					**Mean:**	34.00	45.00	25.00	0.113	0.038
Ephedra nevadensis (EPNE)	1	3%	119	4%	**Stdev:**	*NA***	*NA***	*NA***	*NA***	*NA***
spiny hopsage					**Mean:**	57.00	57.00	55.00	0.314	0.179
Grayia spinosa (GRSP)	1	3%	119	4%	**Stdev:**	*NA***	*NA***	*NA***	*NA***	*NA***
Total Shrub Density*:	4,773	plants/hectare			***Total Shrub Mean:***	31.08	51.58	42.10	0.390	0.319
Total Percent Shrub Cover:	18.6%	canopy cover			***Total Shrub Stdev:***	23.20	44.74	41.36	0.992	1.195
Total Shrub Living Volume:	1,520	m^3/ha								

*Density = $1/d^2$, d = mean distance
**NA = not applicable as there was only one individual in sample

Table 5-6. Estimates of shoot and root biomass for vegetation at Site 2 near Area 5 RWMS.

Site: 2
Location: 1.25 km northeast of Area 5 RWMS
NTS Grid: 215 (Y 19)
UTM: 594605 E, 4078745 N

Common Name / Species (National Plant Code)	Rel. Density	No./ha	Mean Height per plant (cm)	Volume m3	Vol./Biomass Factor*	Stem Biomass per plant (kg)	Root/Shoot Ratio**	Root Biomass per plant (kg)	Total Stem Biomass (kg/ha)	Total Root Biomass (kg/ha)	% of Total Root Biomass	Max. Depth** Below Ground per plant (cm)
white bursage *Ambrosia dumosa (AMDU2)*	48%	2,267	21.11	0.024	2.23757	0.05446	1.16	0.063	123	143	5.0%	25.3
Shockley goldenhead *Acamptopappus shockleyi (ACSH)*	23%	1,074	21.56	0.027	2.793	0.07598	0.56	0.043	82	46	1.6%	25.9
creosote bush *Larrea tridentata (LATR2)*	13%	597	79.60	2.261	1.53936	3.48001	1.24	4.315	2,078	2,576	89.4%	95.5
range ratany *Krameria erecta (KRER)*	5%	239	21.50	0.076	1.93778	0.14761	0.79	0.117	35	28	1.0%	25.8
Anderson's wolfberry *Lycium andersonii (LYAN)*	5% 5%	239	36.00	0.119	0.51863	0.06188	0.83	0.051	15	12	0.4%	43.2
winterfat *Krascheninnikovia lanata (KRLA)*	3%	119	44.00	0.124	3.04614	0.37743	0.9	0.340	45	40	1.4%	52.8
Nevada jointfir *Ephedra nevadensis (EPNE)*	3%	119	34.00	0.038	1.45191	0.05554	0.84	0.047	7	6	0.2%	40.8
spiny hopsage *Grayia spinosa (GRSP)*	3%	119	57.00	0.179	2.00176	0.35770	0.72	0.258	43	31	1.1%	68.4
							Total for All Species:		**2,427**	**2,882**	**100.00%**	

*Conversion Factors from Romney et al., 1973
**Conversion Factors from Wallace et al., 1974
***Conversion Factors from Foxx et al., 1984b

Several runoff channels provide soil mixing, making soils younger than at Site 1. Grasses, listed in order of importance, include: sixweeks fescue (*Vulpia octoflora*), foxtail brome (*Bromus rubens*), and Indian ricegrass (*Acnatherum hymenoides*). Forbs, listed in order of importance, include: bristly fiddleneck (*Amsinckia tessellata*), globemallow (*Sphaeralcea ambigua*), prickly Russian thistle (*Salsola kali* ssp *tagus*), and red triangles (*Centrostegia thurberi*). Evidence of rodent activity is low at this site. Total shrub canopy cover was 18.6 percent with approximately 4,773 plants per hectare of shrub density. Mean height of all shrub species was 31.1 cm (79.6 cm for creosote bush), with a mean length of 51.6 cm and width of 42 cm, respectively. Mean living volume was 1.20 m^3 per shrub. Total root biomass was estimated at 2,882 kg/ha primarily from creosote bush (89.4 percent). The mean maximum rooting depth was estimated at 95.5 cm. Interspecific competition for soil moisture between the fewer deep-rooted species and the many shallow-rooted species probably reduces the mean shrub-rooting depth.

5.2.3 Site 3 Near Area 3 RWMS

Site 3, shown in Figure 5-9, is located about 1.9 km northeast of Area 3 RWMS. It is located on a sandy loam soil and desert pavement development that covers about 70 percent of the surface. It has a rather uneven microtopography. Evidence of rodent activity is low at this site.

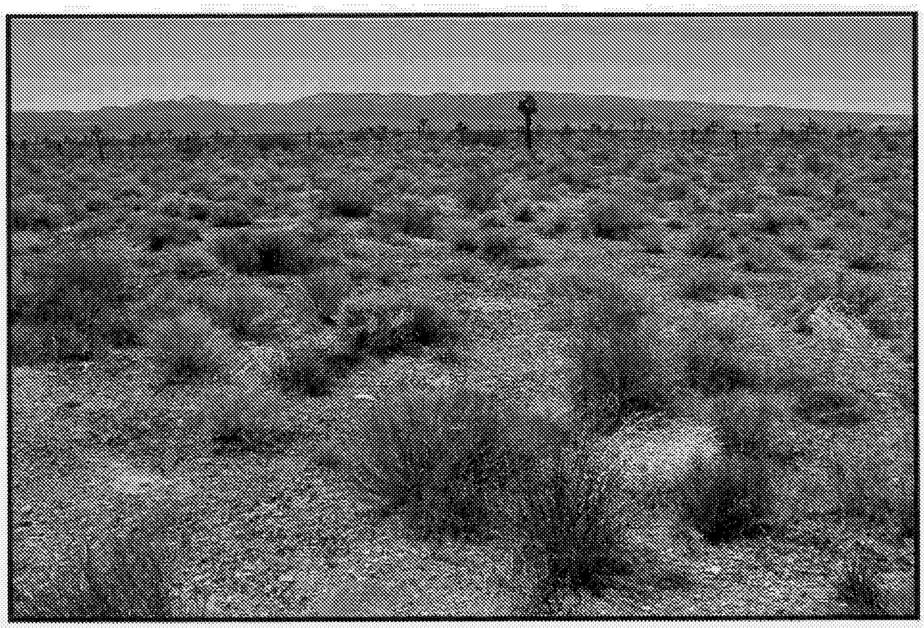


Figure 5-9. Site 3 northeast of Area 3 RWMS located in a white burrobush - green rabbitbrush plant community (June 4, 2001).

Table 5-7 shows the characteristics of shrubs found in this community. Table 5-8 shows the estimates of shoot and root biomass for vegetation at Site 3.

Table 5-7. Characteristics of shrubs in plant communities at Site 3 near Area 3 RWMS.

Site:	3	***Elevation:***	1,250 m
Location:	1.9 km northeast of Area 3 RWMS	***Slope/Aspect:***	3 °/200 °
NTS Grid:	203 (U 32)	***Soil Texture:***	Sandy loam
UTM:	588894 E, 4101133 N	***Rodent Activity:***	Low
Date:	6/4/2001	***Desert Pavement Size:***	Fine < 2.5 cm
Time:	12:53 PM	***Percent Rock Cover:***	70%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	High
Landform:	Piedmont Slope, fan piedmont	***Annual Productivity:***	Very low
Geology:	Qa		

Common Name Species (National Plant Code)	n	Rel. Density	No./ha	Abundance		Height cm	Width1 cm	Width2 cm	Area m2	Volume m3
green rabbitbrush	12	30%	3,459	28%	***Mean:***	26.8	43.8	32.3	0.152	0.047
Chrysothamnus vicidiflorus (CHVI)					***Stdev:***	9.24	13.84	9.80	0.087	0.043
Nevada jointfir	5	13%	1,441	12%	***Mean:***	44.6	77.4	66.4	0.659	0.389
Ephedra nevadensis (EPNE)					***Stdev:***	19.22	43.75	41.43	0.686	0.487
budsage	5	13%	1,441	10%	***Mean:***	16.2	26.6	16.2	0.046	0.008
Artemisia spinescens (ARSP5)					***Stdev:***	4.66	7.86	6.18	0.026	0.005
Shockley goldenhead	4	10%	1,153	8%	***Mean:***	20.8	35.8	23.3	0.106	0.030
Acamptopappus shockleyi (ACSH)					***Stdev:***	10.53	20.95	14.84	0.112	0.041
white burrobrush	3	8%	865	6%	***Mean:***	37.3	53.0	37.7	0.214	0.090
Hymenoclea salsola (HYSA)					***Stdev:***	10.07	16.52	16.86	0.156	0.086
shadscale saltbush	3	8%	865	12%	***Mean:***	25.3	37.7	27.0	0.138	0.057
Atriplex confertifolia (ATCO)					***Stdev:***	18.58	25.38	21.70	0.178	0.088
spiny hopsage	2	5%	577	6%	***Mean:***	24.5	27.0	19.5	0.053	0.013
Grayia spinosa (GRSP)					***Stdev:***	16.26	1.41	0.71	0.005	0.007
Anderson's wolfberry	2	5%	577	4%	***Mean:***	40.0	57.5	51.5	0.298	0.116
Lycium andersonii (LYAN)					***Stdev:***	11.31	7.78	3.54	0.060	0.010
spiny menadora	2	5%	577	10%	***Mean:***	15.0	44.0	48.5	0.272	0.056
Menadora spinescens (MESP2)					***Stdev:***	9.90	31.11	37.48	0.316	0.074
creosote bush	1	3%	288	2%	***Mean:***	150.0	206.0	217.0	4.470	6.705
Larrea tridentata (LATR2)					***Stdev:***	NA**	NA**	NA**	NA**	NA**
winterfat	1	3%	288	2%	***Mean:***	55.0	54.0	50.0	0.270	0.149
Krascheninnikovia lanata (KRLA)					***Stdev:***	NA**	NA**	NA**	NA**	NA**
Total Shrub Density*:	11,531	plants/hectare			***Total Shrub Mean:***	31.5	49.5	39.9	0.320	0.258
Total Percent Shrub Cover:	36.9%	canopy cover			***Total Shrub Stdev:***	24.06	35.09	36.87	0.737	1.064
Total Shrub Living Volume:	2,978	m^3/ha								

*Density = $1/d^2$, d = mean distance
**NA = not applicable as there was only one individual in sample

Table 5-8. Estimates of shoot and root biomass for vegetation at Site 3 near Area 3 RWMS.

Site: 3
Location: 1.9 km northeast of Area 3 RWMS
NTS Grid: 203 (U 32)
UTM: 588894 E, 4101133 N

Common Name Species (National Plant Code)	Rel. Density	No./ha	Mean Height per plant (cm)	Volume m3	Vol./Biomass Factor*	Stem Biomass per plant (kg)	Root/Shoot Ratio**	Root Biomass per plant (kg)	Total Stem Biomass (kg/ha)	Total Root Biomass (kg/ha)	% of Total Root Biomass	Max. Depth** Below Ground per plant (cm)
green rabbitbrush *Chrysothamnus viscidiflorus (CHVI)*	30%	3,459	26.8	0.047	*NA*	*NA*	**0.53**	*NA*	*NA*	*NA*	*NA*	32.2
Nevada jointfir *Ephedra nevadensis (EPNE)*	13%	1,441	44.6	0.389	1.45191	0.56417	0.84	0.474	813	683	*NA*	53.5
budsage *Artemisia spinescens (ARSP5)*	13%	1,441	16.2	0.008	4.01357	0.03222	*NA*	*NA*	46	*NA*	*NA*	19.4
Shockley goldenhead *Acamptopappus shockleyi (ACSH)*	10%	1,153	20.8	0.030	2.79300	0.08488	0.56	0.048	98	55	*NA*	24.9
white burrobrush *Hymenoclea salsola (HYSA)*	8%	865	37.3	0.090	*NA*	*NA*	**0.70**	*NA*	*NA*	*NA*	*NA*	44.8
shadscale saltbush *Atriplex confertifolia (ATCO)*	8%	865	25.3	0.057	4.86397	0.27511	0.44	0.121	238	105	*NA*	30.4
spiny hopsage *Greyia spinosa (GRSP)*	5%	577	24.5	0.013	2.00176	0.02509	0.72	0.018	14	10	*NA*	29.4
Anderson's wolfberry *Lycium andersonii (LYAN)*	5%	577	40.0	0.116	1.97537	0.22832	0.83	0.190	132	109	*NA*	48.0
spiny menadora *Menadora spinescens (MESP2)*	5%	577	15.0	0.056	8.19228	0.46193	*NA*	*NA*	267	*NA*	*NA*	18.0
creosote bush *Larrea tridentata (LATR2)*	3%	288	150.0	6.705	1.53936	10.32187	1.24	12.799	2973	3686	*NA*	180.0
winterfat *Krascheninnikovia lanata (KRLA)*	3%	288	55.0	0.149	3.04614	0.45235	0.90	0.407	130	117	*NA*	66.0
							Total for All Species:		*NA*	*NA*		

*Conversion Factors from Romney et al., 1973
**Conversion Factors from Wallace et al., 1974, Bold values from Winkle et al., 1995.
***Conversion Factors from Foxx et al., 1984b

This site is not typical of conditions at Area 3 RWMS because it receives additional precipitation (closer to the mountains), and receives more surface flow from storm runoff. Soils are older, shallower, and likely more fertile. It represents a site with extremely high productivity which might serve as an analog site to Area 3 RWMS under a future climate with increased moisture. This site is located on a sandy loam soil with fine desert pavement (<2.5 cm in diameter) covering 70 percent of the area. It appears to be one of the more fertile sites and, based on the abundance of biotic crusts (nitrogen-fixing algae) and the presence of Joshua trees, it appears to have the highest biomass and precipitation of all the five lowland sites sampled. The dominant shrub species are green rabbitbrush, Nevada jointfir, and budsage.

Grasses, listed in order of importance, include: foxtail brome (*Bromus rubens*), bottlebrush squirreltail (*Elymus elymoides* ssp *elymoids*), and Indian ricegrass (*Acnatherum hymenoides*). Forbs, listed in order of importance, include: globemallow (*Sphaeralcea ambigua*), red triangles (*Centrostegia thurberi*), spiny polygala (*Polygala subspinosa*), bristly fiddleneck (*Amsinckia tessellata*), flatcrown buckwheat (*Eriogonum deflexum*), prickly Russian thistle (*Salsola kali* ssp *tagus*), Native American pipeweed (*Eriogonum inflatum*), bashful four o'clock (*Mirabillis pudica*), and smooth desertdandelion (*Malacothrix glabrata*). Evidence of rodent activity was low. Total shrub canopy cover was approximately 36.9 percent, the highest of the five sites, with approximately 11,531 plant per hectare of shrub density. Mean height of all shrub species was 31.5 cm (150 cm for creosote bush), with a mean length of 49.5 and width of 39.9 cm, respectively. Mean living volume was 0.258 m^3. Total root biomass could not be estimated because living volume-to-biomass conversion factors for green rabbitbrush and white burrobush and root/shoot ratios for budsage and spiny menodora were not known. The mean maximum rooting depth was estimated at 180 cm.

5.2.4 Site 4 Near Area 3 RWMS

Site 4, shown in Figure 5-10, is located about 1.5 km northwest of Area 3 RWMS. It is located on sandy loam soil and desert pavement development covers only about 15 percent of the surface. This site supports strong evidence of previous disturbance (e.g., abundance of prickly Russian thistle and occasional scrape marks in the soil) and partial recovery. Evidence of rodent burrowing is moderate at this site. This site most closely resembles the vegetation type of Area 3 RWMS, although in a disturbed condition (no undisturbed areas exist near Area 3 RWMS). Table 5-9 shows the characteristics of shrubs found in this community. Table 5-10 shows the estimates of shoot and root biomass for vegetation at Site 4. This site is dominated by Anderson's wolfberry, budsage, white burrobush, and Nevada jointfir. Grasses, listed in order of importance, include: cheatgrass (Bromus tectorum), Indian ricegrass (*Acnatherum hymenoides*), and foxtail brome (*Bromus rubens*). Forbs, listed in order of importance, include: prickly Russian thistle (*Salsola kali* ssp *tagus*), Nevada buckwheat (*Eriogonum deflexum var. nevadense*), redstem stork's bill (*Erodium cicutarium*), red triangles (*Centrostegia thurberi*), tumblemustard (*Sisymbrium altissimum*), annual psathyrotes (*Psathyrotes annua*), bashful four o'clock (*Mirabillis pudica*), milkvetch (*Astragalus lentiginosus*), blazingstar (*Mentzelia* sp.), bristly fiddleneck (*Amsinckia tessellata*), hoary aster (*Machaeranthera canescens* ssp.

Table 5-9. Characteristics of shrubs in plant communities at Site 4 near Area 3 RWMS.

Site:	4	***Elevation:***	1,234 m
Location:	1.55 km northwest of Area 3 RWMS	***Slope/Aspect:***	$1^{0}/90^{0}$
NTS Grid:	187 (S 32)	***Soil Texture:***	Sandy loam
UTM:	585245 E, 4101509 N	***Rodent Activity:***	Moderate
Date:	6/4/2001	***Desert Pavement Size:***	Fine < 2.5 cm
Time:	1:55 PM	***Percent Rock Cover:***	15%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	None
Landform:	Basin Floor, alluvial flat/plain	***Annual Productivity:***	High
Geology:	Qa		

Common Name / ***Species (National Plant Code)***	***n***	***Rel. Density***	***No./ha***	***Abundance***		***Height*** ***cm***	***Width1*** ***cm***	***Width2*** ***cm***	***Area*** ***m2***	***Volume*** ***m3***
Anderson's wolfberry	18	45%	389	46%	***Mean:***	46.8	76.3	59.1	0.506	0.268
Lycium andersonii (LYAN)					***Stdev:***	13.00	28.70	30.59	0.427	0.260
budsage	12	30%	259	26%	***Mean:***	25.4	44.6	29.8	0.135	0.035
Artemisia spinescens (ARSP5)					***Stdev:***	6.39	13.22	6.78	0.056	0.015
white burrobrush	3	8%	65	8%	***Mean:***	58.7	90.7	69.3	0.632	0.384
Hymenoclea salsola (HYSA)					***Stdev:***	16.50	22.14	14.01	0.203	0.213
Nevada jointfir	3	8%	65	8%	***Mean:***	48.7	69.7	57.3	0.420	0.214
Ephedra nevadensis (EPNE)					***Stdev:***	6.51	21.55	15.31	0.220	0.133
winterfat	2	5%	43	8%	***Mean:***	51.5	72.0	55.0	0.399	0.209
Krascheninnikovia lanata (KRLA)					***Stdev:***	4.95	2.83	19.80	0.158	0.101
spiny hopsage	1	3%	22	2%	***Mean:***	54.0	99.0	44.0	0.436	0.235
Grayia spinosa (GRSP)					***Stdev:***	NA**	NA**	NA**	NA**	NA**
shadscale saltbush	1	3%	22	2%	***Mean:***	48.0	82.0	74.0	0.607	0.291
Atriplex confertifolia (ATCO)					***Stdev:***	NA**	NA**	NA**	NA**	NA**
Total Shrub Density*:	864	plants/hectare			***Total Shrub Mean:***	41.9	67.9	50.7	0.393	0.199
Total Percent Shrub Cover:	3.4%	canopy cover			***Total Shrub Stdev:***	15.20	26.98	25.79	0.343	0.215
Total Shrub Living Volume:	172	m^3/ha								

*Density = $1/d^2$, d = mean distance

**NA = not applicable as there was only one individual in sample

Table 5-10. Estimates of shoot and root biomass for vegetation at Site 4 near Area 3 RWMS.

Site: 4
Location: 1.55 km northwest of Area 3 RWMS
NTS Grid: 187 (S 32)
UTM: 585245 E, 4101509 N

Common Name Species (National Plant Code)	Rel. Density	No./ha	Mean Height per plant (cm)	Volume m3	Vol./Biomass Factor*	Stem Biomass per plant (kg)	Root/Shoot Ratio**	Root Biomass per plant (kg)	Total Stem Biomass (kg/ha)	Total Root Biomass (kg/ha)	% of Total Root Biomass	Max. Depth** Below Ground per plant (cm)
Anderson's wolfberry *Lycium andersonii (LYAN)*	45%	389	46.8	0.268	0.51863	0.13876	0.83	0.115	54	45	NA	56.1
budsage *Artemisia spinescens (ARSP5)*	30%	259	25.4	0.035	4.01357	0.13888	NA	NA	36	NA	NA	30.5
white burrobrush *Hymenoclea salsola (HYSA)*	8%	65	58.7	0.384	NA	NA	0.70	NA	NA	NA	NA	70.4
Nevada jointfir *Ephedra nevadensis (EPNE)*	8%	65	48.7	0.214	1.45191	0.31041	0.84	0.261	20	17	NA	58.4
winterfat *Krascheninnikovia lanata (KRLA)*	5%	43	51.5	0.209	3.04614	0.63754	0.90	0.574	28	25	NA	61.8
spiny hopsage *Grayia spinosa (GRSP)*	3%	22	54.0	0.235	2.00176	0.47086	0.72	0.339	10	7	NA	64.8
shadscale saltbush *Atriplex confertifolia (ATCO)*	3%	22	48.0	0.291	4.86397	1.41670	0.44	0.623	31	13	NA	57.6
								Total for All Species:	NA	NA		

*Conversion Factors from Romney et al., 1973
**Conversion Factors from Wallace et al., 1974.
***Conversion Factors from Foxx et al., 1984b

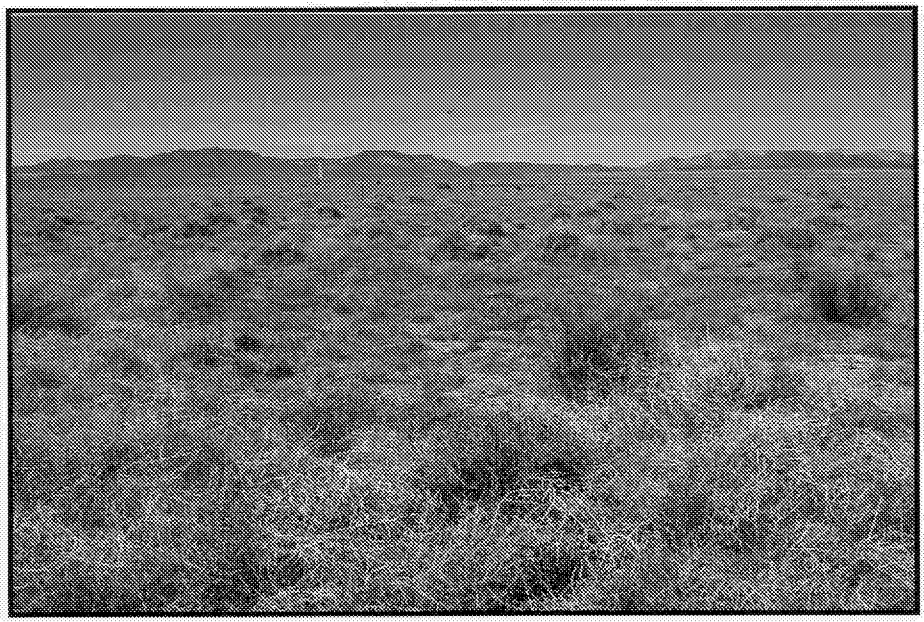


Figure 5-10. Site 4 northwest of Area 3 RWMS located in a disturbed mixed-shrub plant community (June 4, 2001).

canescens), globemallow (*Sphaeralcea ambigua*), halogeton (*Halogeton glomeratus*), whitemargin sandmat (*Chamaesyce albomarginata*), and smooth desertdandelion (*Malacothrix glabrata*). Evidence of rodent activity was moderate.

Total shrub canopy cover was approximately 3.4 percent with approximately 864 plants per hectare of shrub density. Mean height of all shrub species was 41.9 cm, with a mean length of 67.9 and width of 50.7 cm, respectively. Mean living volume was 1.45 m^3 per shrub. Total root biomass could not be calculated because the living volume-to-biomass factor for white burrobush and the root-to-shoot ratio for budsage were not known. Production at this site was estimated to be the least of the five sites sampled, due to edaphic (soil-related factors) and climatic conditions prevailing at this site. The mean maximum rooting depth was estimated at 64.8 cm.

5.2.5 Site 5 Near Area 3 RWMS

Site 5, shown in Figure 5-11, is located about 1.9 km northwest of Area 3 RWMS. It is located on a silty loam soil and desert pavement covering about 75 percent of the surface with interlocking clasts and crunchy surface when walked on. Vegetation is found between large areas of desert pavement. This site is relatively undisturbed, but is atypical of Area 3 RWMS in that it has a very old soil and soil conditions that limit shrub production. However, it does represent the best estimate of an undisturbed site with similar climatic conditions as the RWMS.

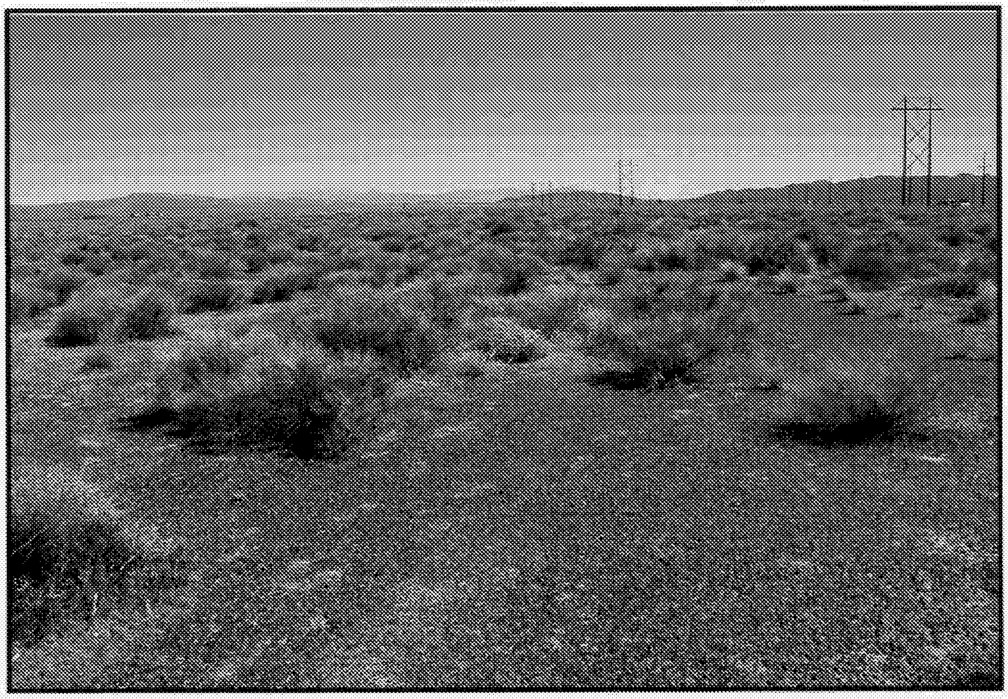


Figure 5-11. Site 5 northwest of Area 3 RWMS located in an Anderson wolfberry-white burrobush plant community (June 4, 2001).

Table 5-11 shows the characteristics of shrubs found in this community. Table 5-12 shows the estimates of shoot and root biomass for vegetation at Site 5. Dominant shrubs were white burrobush, shadscale saltbush, fourwing saltbush, and Nevada jointfir. Grasses, listed in order of importance, include: Indian ricegrass (*Acnatherum hymenoides*), foxtail brome (*Bromus rubens*), bottlebrush squirreltail (*Elymus elymoides* ssp *elymoids*), and cheatgrass (Bromus tectorum). Forbs, listed in order of importance, include: bristly fiddleneck (*Amsinckia tessellata*), prickly Russian thistle (*Salsola kali* ssp *tagus*), Nevada buckwheat (*Eriogonum deflexum var. nevadense*), pincushion flower (*Chaenactis fremontii*), devil's spineflower (*Chorizanthe rigida*), milkvetch (*Astragalus lentiginosus*), bashful four o'clock (*Mirabillis pudica*), tumblemustard (*Sisymbrium altissimum*), annual psathyrotes (*Psathyrotes annua*), globemallow (*Sphaeralcea ambigua*), and halogeton (*Halogeton glomeratus*).

Evidence of rodent activity is low at this site with few burrows or evidence of burrowing. Total canopy cover was approximately 6.9 percent, with approximately 1,687 plants per hectare of shrub density. Mean height of all shrub species was 48.2 cm with a mean length and width of 64.9 and 52.6 cm, respectively. Mean living volume was 0.245 m^3 per shrub. Total root biomass was not calculated because the living volume-to-biomass conversion factor for white burrobush was not known, but was estimated to be relatively low compared to Sites 1, 2, and 3.

Table 5-11. Characteristics of shrubs in plant communities at Site 5 near Area 3 RWMS.

Site:	5	***Elevation:***	1,239 m
Location:	1.95 km northwest of Area 3 RWMS	***Slope/Aspect:***	$1^{0}/80^{0}$
NTS Grid:	187 (RS 32)	***Soil Texture:***	Silty loam
UTM:	584512 E, 4101046 N	***Rodent Activity:***	Low
Date:	6/4/2001	***Desert Pavement Size:***	Fine < 2.5 cm
Time:	2:50 PM	***Percent Rock Cover:***	75%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	None
Landform:	Basin Floor, alluvial flat/plain	***Annual Productivity:***	Moderately low
Geology:	Qa		

Common Name Species (National Plant Code)	n	Rel. Density	No./ha	Abundance		Height cm	Width1 cm	Width2 cm	Area m2	Volume m3
white burrobrush *Hymenoclea salsola (HYSA)*	13	33%	548	28%	***Mean:*** ***Stdev:***	60.0 15.74	87.1 33.97	76.3 28.66	0.752 0.498	0.508 0.393
shadscale saltbush *Atriplex confertifolia (ATCO)*	9	23%	379	22%	***Mean:*** ***Stdev:***	31.8 6.04	45.7 12.43	33.9 7.64	0.161 0.067	0.052 0.024
fourwing saltbush *Atriplex canescens (ATCAC)*	7	18%	295	24%	***Mean:*** ***Stdev:***	50.86 18.63	48.43 19.76	37.14 18.86	0.207 0.146	0.124 0.110
Nevada jointfir *Ephedra nevadensis (EPNE)*	6	15%	253	14%	***Mean:*** ***Stdev:***	49.0 10.83	71.3 19.68	54.7 13.91	0.398 0.170	0.209 0.130
Anderson's wolfberry *Lycium andersonii (LYAN)*	3	8%	126	6%	***Mean:*** ***Stdev:***	41.0 4.58	61.0 27.22	46.3 11.24	0.295 0.191	0.123 0.082
winterfat *Krascheninnikovia lanata (KRLA)*	1	3%	42	4%	***Mean:*** ***Stdev:***	33.0 NA**	34.0 NA**	27.0 NA**	0.092 NA**	0.030 NA**
spiny hopsage *Grayia spinosa (GRSP)*	1	3%	42	2%	***Mean:*** ***Stdev:***	57.0 NA**	68.0 NA**	51.0 NA**	0.347 NA**	0.198 NA**
Total Shrub Density*:	1,687	plants/hectare			***Total Shrub Mean:***	48.2	64.9	52.6	0.410	0.245
Total Percent Shrub Cover:	6.9%	canopy cover			***Total Shrub Stdev:***	16.59	29.41	26.12	0.388	0.298
Total Shrub Living Volume:	413	m^3/ha								

*Density = $1/d^2$, d = mean distance
**NA = not applicable as there was only one individual in sample

Table 5-12. Estimates of shoot and root biomass for vegetation at Site 5 near Area 3 RWMS.

Site: 5
Location: 1.95 km northwest of Area 3 RWMS
NTS Grid: 187 (RS 32)
UTM: 584512 E, 4101046 N

Common Name Species (National Plant Code)	Rel. Density	No./ha	Mean Height per plant (cm)	Volume m3	Vol./Biomass Factor*	Stem Biomass per plant (kg)	Root/Shoot Ratio**	Root Biomass per plant (kg)	Total Stem Biomass (kg/ha)	Total Root Biomass (kg/ha)	% of Total Root Biomass	Max. Depth** Below Ground per plant (cm)
white burrobrush *Hymenoclea salsola (HYSA)*	33%	548	60.0	0.508	*NA*	*NA*	0.70	*NA*	*NA*	*NA*	*NA*	72
shadscale saltbush *Atriplex confertifolia (ATCO)*	23%	379	31.8	0.052	4.85637	0.25114	0.44	0.110	95	42	*NA*	38
fourwing saltbush *Atriplex canescens (ATCAC)*	18%	295	50.86	0.124	2.56917	0.31846	0.67	0.213	94	63	*NA*	61
Nevada jointfir *Ephedra nevadensis (EPNE)*	15%	253	49.0	0.209	1.45191	0.30348	0.84	0.255	77	64	*NA*	59
Anderson's wolfberry *Lycium andersonii (LYAN)*	8%	126	41.0	0.123	1.97537	0.24230	0.83	0.201	31	25	*NA*	49
winterfat *Krascheninnikovia lanata (KRLA)*	3%	42	33.0	0.030	3.04614	0.09228	0.90	0.083	4	4	*NA*	40
spiny hopsage *Grayia spinosa (GRSP)*	3%	42	57.0	0.198	2.00176	0.39570	0.72	0.285	17	12	*NA*	68
							Total for All Species:		*NA*	*NA*		

*Conversion Factors from Romney et al., 1973
**Conversion Factors from Wallace et al., 1974.
***Conversion Factors from Foxx et al., 1984b

5.2.6 Site 6 Near Area 5 RWMS

Site 6, shown in Figure 5-12, is located about 200 m west and 340 m south of Site 1. This site was selected as a replacement site for Site 1, which was destroyed during the excavation of a new disposal pit (Pit 8) at Area 5 RWMS. Vegetation at this new site is similar to that of Site 1, but has shrubs with greater cover and greater living volume. This site appears to be located on soils that are similar to those at Site 1. It is located on a sandy loam soil and desert pavement of a mean size less than 5 cm in diameter, covering about 80 percent of the soil surface.

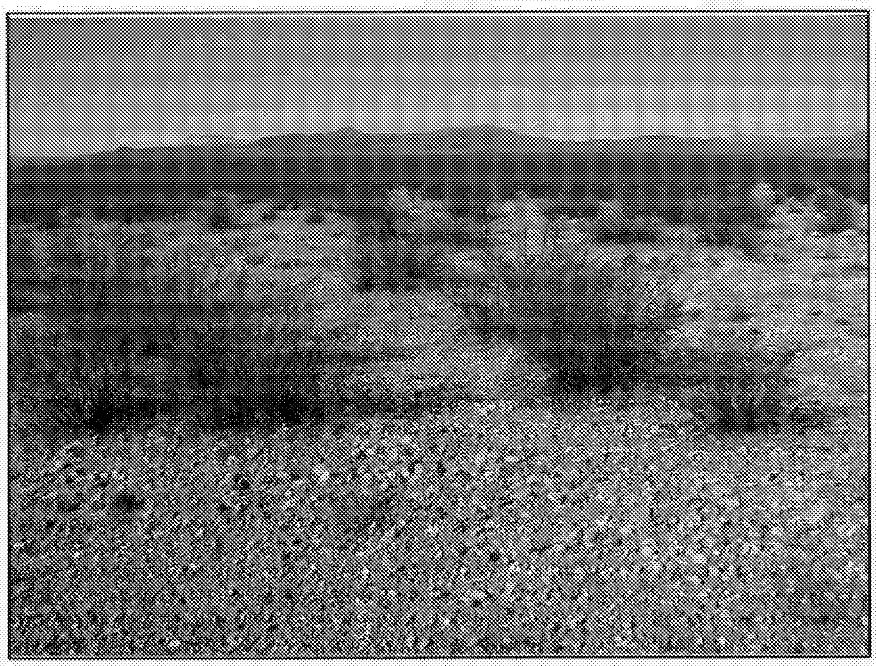


Figure 5-12. Site 6 west of Area 5 RWMS located in a creosote bush-white bursage plant community (April 4, 2002).

The coarse soils drain precipitation quickly and appear to restrict growth of shallow-rooted shrub species (found primarily in the wash channel) which constitute less than 8 percent of the site shrubs in relative abundance, but contribute only 0.1 percent of the root biomass. This may also explain why the site has a high number and biomass product of shallow-rooted herbaceous species that probably flourish during the winter and early spring when soil moisture is higher and then complete their life cycle and go dormant by the summer. Table 5-13 shows the characteristics of shrubs found in this community. Table 5-14 shows the estimates of shoot and root biomass for vegetation at Site 6.

Dominant shrubs were creosote bush, Shockley goldenhead, and white bursage. Grasses, in order of importance, include: low woolygrass (*Erioneuron pulchellum*), foxtail brome (*Bromus rubens*), Indian ricegrass (*Acnatherum hymenoides*), and sixweeks fescue (*Vulpia octoflora*). Forbs (herbaceous plants), in order of importance, include: little deserttrumpet

Table 5-13. Characteristics of shrubs in plant communities at Site 6 near Area 5 RWMS.

Site:	6	***Elevation:***	972 m
Location:	200 m west of Site 1 at Area 5 RWMS	***Slope/Aspect:***	$1^{0}/180^{0}$
NTS Grid:	215 (X 20)	***Soil Texture:***	Sandy loam
UTM:	592738 E, 4079652 N	***Rodent Activity:***	Moderate
Date:	4/2/2002	***Desert Pavement Size:***	Fine < 5 cm
Time:	1:45 PM	***Percent Rock Cover:***	80%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	Occasional
Landform:	Piedmont slope, fan piedmont	***Annual Productivity:***	Moderate
Geology:	Qa		

Common Name ***Species (National Plant Code)***	***n***	***Rel. Density***	***No./ha***	***Abundance***		***Height*** ***cm***	***Width1*** ***cm***	***Width2*** ***cm***	***Area*** ***m2***	***Volume*** ***m3***
Creosote bush	36	90%	860	92%	***Mean:***	90.0	125.5	114.8	1.690	1.860
Larrea tridentata (LATR2)					***Stdev:***	35.5	53.9	52.5	1.296	2.001
Shockley goldenhead	2	5%	323	4%	***Mean:***	18.5	14.0	16.0	0.030	0.005
Acamptopappus shockleyi (ACSH)					***Stdev:***	5.0	12.7	11.3	0.036	0.005
White bursage	2	5%	108	4%	***Mean:***	18.0	11.5	14.0	0.020	0.003
Ambrosia dumosa (AMDU2)					***Stdev:***	2.8	2.1	1.4	0.005	0.001
Total Shrub Density*:	2,107	plants/hectare			***Total Shrub Mean:***	82.9	114.2	104.8	1.520	1.680
Total Percent Shrub Cover:	32.0%	canopy cover			***Total Shrub Stdev:***	40.1	61.0	58.3	1.328	1.978
Total Shrub Living Volume:	3,540	m^3/ha								

*Density = $1/d^2$, d = mean distance

Table 5-14. Estimates of shoot and root biomass for vegetation at Site 6 near Area 5 RWMS.

Site: 6
Location: 500 meters west of Site 1 at Area 5 RWMS
NTS Grid: 215 (x 20)
UTM: 592738 E, 407965 N

Common Name Species (National Plant Code)	Relative Density	No./ha	Mean Height per plant (cm)	Volume per plant (m3)	Vol./Biomass Factor*	Stem Biomass per plant (kg)	Root/Shoot Ratio**	Root Biomass per plant (kg)	Total Stem Biomass (kg/ha)	Total Root Biomass (kg/ha)	% of Total Root Biomass	Max. Depth** Below Ground per plant (cm)
creosote bush *Larrea tridentata (LATR2)*	90%	860	90.0	1.860	1.53936	2.86321	1.24	3.550	2,462	3,053	99.9%	108
Shockley goldenhead *Acamptopappus shockleyi (ACSH)*	5%	323	18.5	0.005	2.79300	0.01397	0.56	0.008	5	3	0.1%	22.2
white bursage *Ambrosia dumosa (AMDU2)*	3%	108	18.0	0.003	2.23757	0.00671	1.16	0.008	1	1	0.0%	21.6
								Total for All Species:	**2,468**	**3,057**	**100.0%**	

*Conversion Factors from Romney et al. 1973
**Conversion Factors from Wallace et al 1974
***Conversion Factors from Foxx et al 1984b

(*Eriogonum trichopes*), shaggyfruit pepperweed (*Lepidium lasiocarpum*), bristly fiddleneck (*Amsinckia tessellata*), globemallow (*Sphaeralcea ambigua*), and shredding suncup (*Camissonia boothii* ssp. *condensata*). Because of the low precipitation at this site it is possible that other annual forbs were not visible, but the seed may have been present. Evidence of rodent activity (e.g., burrows and signs of digging) was moderate. Total shrub canopy cover was approximately 32 percent with approximately 2,107 shrubs per hectare of shrub density. Mean height of all shrubs was 82.9 cm (90.0 cm for creosote bush), with a mean length and width of 114.2 cm and 104.8 cm respectively. Mean living volume was 1.68 m^3 per shrub. Total root biomass was estimated at 3,057 kg/ha primarily from creosote bush (99.9 percent). The mean maximum rooting depth was estimated at 108 cm.

5.2.7 Site 7 North of Horse Wash in Area 17

Site 7, shown in Figure 5-13, is located east of the Pahute Mesa Road in Area 17-18, just north of Horse Wash in the Eleana Mountain Range. It is located on a sandy loam soil derived from weathering rock (tuff) with a desert pavement of fine (less than 5 cm in diameter) clasts covering approximately 90 percent of the soil surface. Table 5-15 shows the characteristics of shrubs found in this community. This site is located on a piedmont slope, (fan piedmont) (Ostler et al. 2000) with hills and on either side. The adjacent hillsides have Utah juniper (*Juniperus osteosperma*) and pinyon pine *(pinus monophylla*) trees encroaching into the valley floor. Located on the north side of the rocky outcrops of the valley are pack rat middens used to characterize past climatic conditions on the Nevada Test Site (Spaulding 1985). 02)

Figure 5-13 Site 7 north of Horse Wash in Area 17 in a basin big sagebrush-green rabbitbrush shrubland plant community (April 2, 2002).

Table 5-15. Characteristics of shrubs in plant communities at Site 7 in Area 17.

Site:	7	***Elevation:***	1,768 m
Location:	Major canyon north of Horse Wash	***Slope/Aspect:***	$3^{0}/250^{0}$
NTS Grid:	120 (G 36)	***Soil Texture:***	Sandy loam
UTM:	568069 E, 4108253 N	***Rodent Activity:***	Low
Date:	4/2/2002	***Desert Pavement Size:***	Fine < 5 cm
Time:	9:20 AM	***Percent Rock Cover:***	90%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	Occasional
Landform:	Piedmont slope, fan piedmont	***Annual Productivity:***	Low
Geology:			

Common Name Species (National Plant Code)	***n***	***Rel. Density***	***No./ha***	***Abundance***		***Height cm***	***Width1 cm***	***Width2 cm***	***Area m2***	***Volume m3***
Big sagebrush *Artemisia tridentata (ARTRT)*	28	70%	12,811	74%	***Mean:***	43.0	56.4	43.5	0.313	0.173
					Stdev:	15.5	29.3	26.9	0.375	0.261
Green rabbitbush *Chrysothamnus viscidiflorus (CHVI)*	12	30%	2,078	26%	***Mean:***	29.6	41.3	28.2	0.129	0.040
					Stdev:	8.9	15.1	11.5	0.086	0.028
Total Shrub Density*:	17,123	plants/hectare			***Total Shrub Mean:***	39.0	51.8	38.9	0.258	0.133
Total Percent Shrub Cover:	44.7%	canopy cover			***Total Shrub Stdev:***	15.1	26.6	24.3	0.327	0.226
Total Shrub Living Volume:	2,303	m^3/ha								

*Density = $1/d^2$, d = mean distance

The site was selected because it is representative of climatic conditions that are currently cooler and wetter than RWMS 5 and may be typical of future site conditions at the Area 5 RWMS if weather patterns become cooler and wetter than present.

Basin big sagebrush (*Artemisia tridentata*) and green rabbitbrush (*Chrysothamnus viscidiflorus*) are the two dominant shrub species at this site. Basin big sagebrush represents approximately 70 percent of all of the shrubs on site while green rabbitbrush represents about 30 percent. Grasses listed in order of importance include: bottlebrush squirreltail (*Elymus elymoides* ssp. *elymoids*), desert needlegrass *(Achnatherum speciosa)*, Indian ricegrass (*Achnatherum hymenoides*), and cheatgrass (*Bromus tectorum*). Forbs, listed in order of importance, include: desert woolstar (*Eriastrum eremicum*), heartleaf twistflower (*Streptanthus cordatus* var. *cordatus*), lupine (*Lupinus* possibly *flavoculatus*?), cushion buckwheat (*Eriogonum ovalifolium* var. *ovalifolium*), wirelettuce (*Stephanomeria* possibly *exigua* ssp. *exigua*), Nevada goldeneye (*Heliomeris multiflora* var. *nevadensis*), and clustered broomrape (Orobanche fasciculata).

Evidence of rodent activity is low at this site with occasional evidence of biological crusts. Evidence of horse use was high. Total shrub canopy cover was 44.7 percent with approximately 17,313 plants per hectare of shrub density. Mean height of all shrub species was 39 cm (43 cm for basin big sagebrush), with a mean length of 51.8 cm and width of 38.9 cm, respectively. Mean living volume was 0.133 m^3 per shrub.

No estimates of shoot and root biomass for vegetation are presented because the root-to-shoot ratios for the dominant species are not known. Total root biomass was not measured or estimated because data were not collected or not available from previous historical samplings for this plant community. Maximum rooting depth was not measured or estimated.

5.2.8 Site 8 North of Horse Wash in Area 18

Site 8, shown in Figure 5-14, is located east of the Pahute Mesa Road in Area 18, just north of Horse Wash in the Eleana Mountain Range. It is located on a sandy soil derived from weathering rock (tuff). Desert pavement was comprised of fine-textured (less than 5 cm in diameter) rock clasts and covered approximately 15 percent of the soil surface. This site is located on a piedmont slope, (fan piedmont) (Ostler et al. 2000) with hills and on either side. The adjacent hillsides are predominantly covered with blackbrush (*Coleogyne ramosissima*) and black sagebrush (*Artemisia nova*), but have an occasional Utah juniper (*Juniperus osteosperma*) or pinyon pine *(pinus monophylla)* tree encroaching into the valley floor. The site was selected because it is representative of climatic conditions that are currently cooler and wetter than Area 5 RWMS and may be typical of future site conditions at the Area 5 RWMS, if weather patterns become cooler and wetter than present. The soils on this site are deep and sandy. Because of its lower elevation and drier soils, this site would be slightly drier and hotter than Site 7.

Table 5-16 shows the characteristics of shrubs found in this community. Nevada smokebush *(Psorothamnus polydenius),* Nevada jointfir *(Ephedra nevadensis)* and fourwing saltbush (*Atriplex canescens*) are the three dominant shrub species at this site based on percentage of abundance. Nevada smokebush represents approximately 40 percent of all of the shrubs while Nevada jointfir and fourwing saltbush represent about 28 percent and 22 percent respectively.

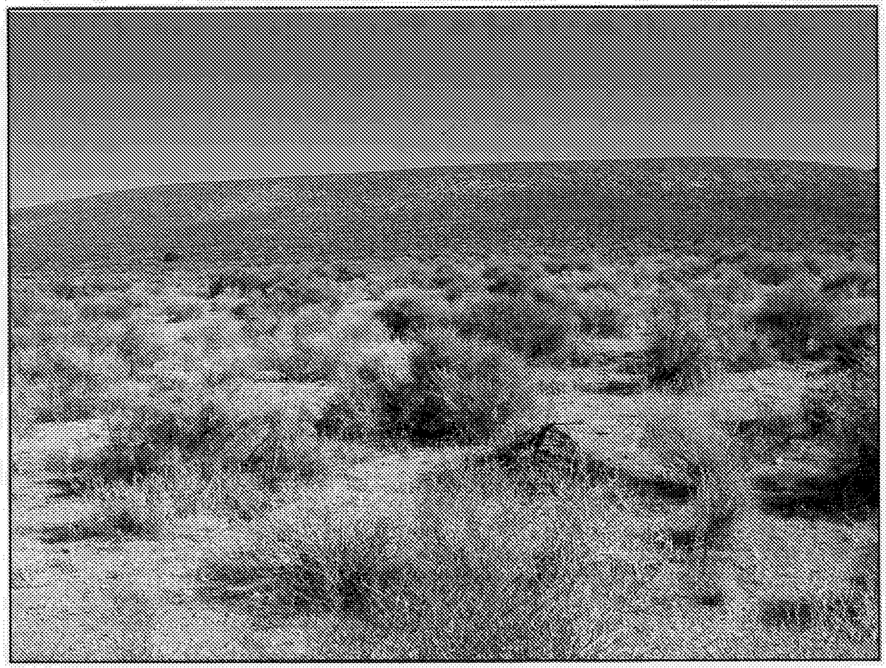


Figure 5-14 Site 8 north of Horse Wash in Area 18 in a Nevada jointfir - spiny hopsage shrubland plant community (May 30, 2002).

Grasses listed in order of importance include: cheatgrass (*Bromus tectorum*), Indian ricegrass (*Achnatherum hymenoides*), desert needlegrass *(Achnatherum speciosa*), and red brome (*Bromus rubens*). Forbs, listed in order of importance, include: Nevada goldeneye (*Heliomeris multiflora* var. *nevadensis*), desert woolstar (*Eriastrum eremicum*), heartleaf twistflower (*Streptanthus cordatus* var. *cordatus*), lupine (*Lupinus* possibly *flavoculatus*?), cushion buckwheat (*Eriogonum ovalifolium* var. *ovalifolium*), globemallow (Sphaeralcea ambigua), wirelettuce (*Stephanomeria* possibly *exigua* ssp. *exigua*), and wooly desert marigold (*Baileya multiradiata*). A cactus occasionally present was staghorn cholla (*Opuntia echinocarpa* var. *echinocarpa*).

Evidence of horse use was high at this site while evidence of rodent activity was low. No biological soil crusts were observed at the site. Total shrub canopy cover was 58.4 percent with approximately 3,375 plants per hectare of shrub density. Mean height of all shrub species was 74.6 cm (65.6 cm for Nevada smokebush), with a mean length of 129.2 cm and width of 105.5 cm, respectively. Mean living volume was 2.535 m^3 per shrub.

Total root biomass was not measured or estimated because data were not collected or not available from previous historical samplings for this plant community. Maximum rooting depth was not measured or estimated.

Table 5-16. Characteristics of shrubs in plant communities at Site 8 in Area 18.

Site:	8	***Elevation:***	1,749 m
Location:	Small canyon north of Horse Wash	***Slope/Aspect:***	$2^0/225^0$
NTS Grid:	120 (G 35)	***Soil Texture:***	Sandy
UTM:	566314 E, 4106753 N	***Rodent Activity:***	Low
Date:	5/30/2002	***Desert Pavement Size:***	Fine < 5 cm
Time:	9:00 AM	***Percent Rock Cover:***	15%
Collectors:	W. Kent Ostler & Dennis Hansen	***Cryptogamic Crust:***	None
Landform:	Piedmont slope, fan piedmont	***Annual Productivity:***	Moderate
Geology:			

Common Name ***Species (National Plant Code)***	***n***	***Rel. Density***	***No./ha***	***Abundance***		***Height cm***	***Width1 cm***	***Width2 cm***	***Area m2***	***Volume m3***
Fourwing saltbush	10	25%	843	22%	***Mean:***	74.6	97.0	84.5	0.980	0.805
Atriplex canescens (ATCA)					***Stdev:***	18.8	42.7	46.5	0.923	0.761
Green rabbitbush	2	5%	169	4%	***Mean:***	54.0	67.5	53.0	0.369	0.193
Chrysothamnus viscidiflorus (CHVI)					***Stdev:***	7.1	14.8	15.6	0.184	0.073
Nevada jointfir	11	28%	928	28%	***Mean:***	92.8	193.5	150.5	3.501	3.690
Ephedra nevadensis (EPNE)					***Stdev:***	22.0	81.1	87.4	3.342	4.148
Money buckwheat	2	5%	169	4%	***Mean:***	63.0	67.5	60.0	0.415	0.260
Eriogonum numulare (ERNU4)					***Stdev:***	1.4	9.2	22.6	0.208	0.125
Nevada smokebush	15	38%	1,266	40%	***Mean:***	65.6	119.9	99.5	1.289	0.887
Psorothamnus polydenius (PSPO)					***Stdev:***	9.3	36.2	35.6	0.676	0.524
Big sagebrush	0	0%	0	2%						
Artemisia tridentata (ARTRT)										
Total Shrub Density*:	3,375	plants/hectare			***Total Shrub Mean:***	74.6	129.2	105.5	1.730	1.571
Total Percent Shrub Cover:	58.4%	canopy cover			***Total Shrub Stdev:***	19.8	66.6	62.3	2.125	2.535
Total Shrub Living Volume:	5,304	m^3/ha								

*Density = $1/d^2$, d = mean distance

5.3 Estimates of Annual Production on the NTS

An important component in understanding and assessing the rate of soil biotic transport is biomass or annual productivity of plants at these locations. Several variables of biomass are of interest in this evaluation but perhaps the most important variable is net primary production (NPP). This is defined as the amount of new biomass produced in a system annually. This term can be further divided into net above-ground primary production (NAPP) and net below ground primary production. The latter variable is often very difficult to measure; therefore, few references exist where these data have been measured and reported even though it may exceed that for above-ground primary production on a global basis (Begon et al., 1990).

Multiple-year field measurements of NAPP have occurred on the NTS at Rock Valley from 1966 to 1968 and 1971 to 1976, and at Yucca Mountain from 1989 to 1993. Both of these areas were classified as the plant association, *Larrea tridentata - Ambrosia dumosa* shrubland which is the association that is also found at the Area 5 RWMS. Soil parameters and precipitation values may vary slightly among those sites, but the data are valuable in providing a baseline for comparisons and demonstrating the variability that exists on a temporal and spatial basis. Wallace and Romney gathered the earlier NAPP data (1966-1968) at Rock Valley as reported in Wallace and Romney (1972). The latter data were gathered by ecologists from UCLA working under the Desert Biome of the U.S. International Biological Program and conducting validation data for the Mojave Desert ecosystem (Rundle and Gibson, 1996). Data at Rock Valley were collected by species to provide species-level data that can be used in models. They also gathered data on plant association species composition reported on a spatial (association) level.

One of the factors that is particularly important to consider and that becomes evident in multi-year data is the variability that exists from year to year. NAPP of shrubs at Rock Valley varied from a low of 183 kg/ha in 1971 to a high of 682 kg/ha in 1973 (Table 5-17). Turner and Randall (1989) showed that NAPP of shrubs was highly correlated r = 0.95) with the precipitation of the hydrologic year (September to August) (Figure 5-15). They derived a formula that predicted NAPP from precipitation for the Mojave Desert at the NTS:

$$\text{NAPP} = - 8.35 + 3.1\ (\text{PPT})$$

where NAPP is represented in kg/ha and PPT is the precipitation in millimeters (mm) occurring from September to August during that growing year. This equation intersects the x-axis (PPT) at approximately the 25-mm level which corresponds to empirical evidence reported by Beatley (1974a) for annual plant germination and growth, and predicts that there can be years when there is essentially no NAPP, which was observed in data reported at Yucca Mountain during the drought of 1988 to1990. This often results in the death of less adaptive species or the loss of living above-ground biomass, which was observed at Yucca Mountain (Schultz and Ostler, 1995).

Table 5-17. Estimated net above-ground primary production (NAPP) by perennials during the spring growing season in Rock Valley and associated hydrologic year precipitation (September to August). Data taken from Rundel and Gibson (1996).

Year	NAPP (kg/ha)	Hydrologic Year Precipitation (mm)
1966	490	161
1967	310	148
1968	430	152
1971	183	100
1971	206	75
1973	682	250
1974	220	98
1975	210	113
1976	380	146

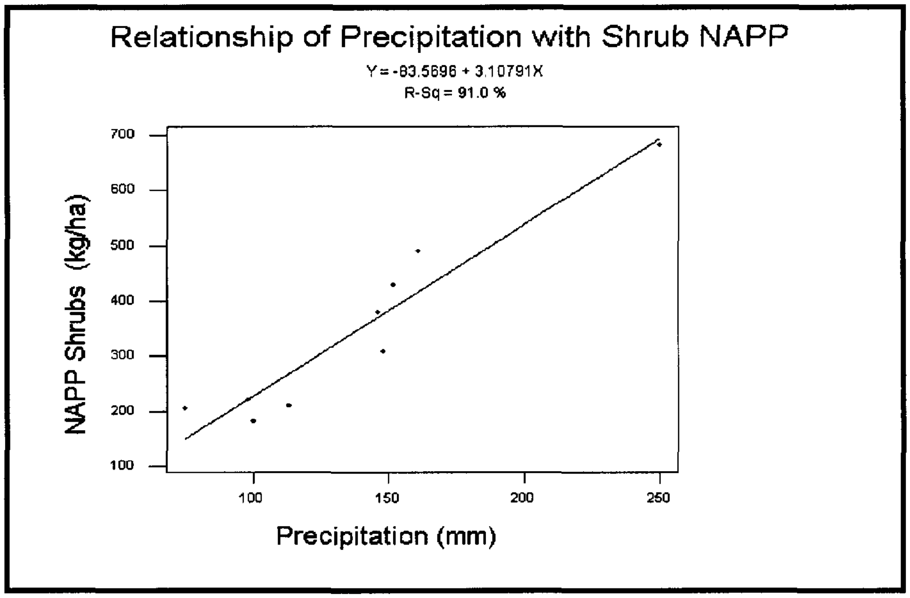


Figure 5-15. Relationship of precipitation (September to August) and NAPP at Rock Valley from 1966 to 1976 (Turner and Randall, 1989)

Field sampling of NAPP was also taken at Yucca Mountain in Area 25 and just west of the NTS border on U.S. Bureau of Land Management property from 1989 to 1993. NAPP was taken by life form (shrubs, perennial grasses/forbs, annuals) rather than by species. Also, sampling occurred at only one time (estimated period of peak biomass on a stand basis) at these sites so data reported are likely to underestimate NAPP compared to Rock Valley data where individual species were sampled when they reached their individual peaks. Four different vegetation types were recognized and sampled at Yucca Mountain (Hessing et al., 1996). Two of these would be classified within the Larrea tridentata - Ambrosia dumosa shrubland; however, the density of shrubs within these two types varied tremendously (60.2 and 129.3 per 100 m^2). This difference in density did not impact total NAPP between the sites, but it did influence shrub NAPP (Figures 5-15 and 5-16).

Analysis of NAPP from Yucca Mountain also shows the strong correlation (R^2 =0.986) between NAPP and growing season precipitation (September to August) (Figure 5-14). A similar correlation using shrub NAPP also shows a positive relationship with precipitation although the variability is greater (R^2 = 0.818) (Figure 5-17).

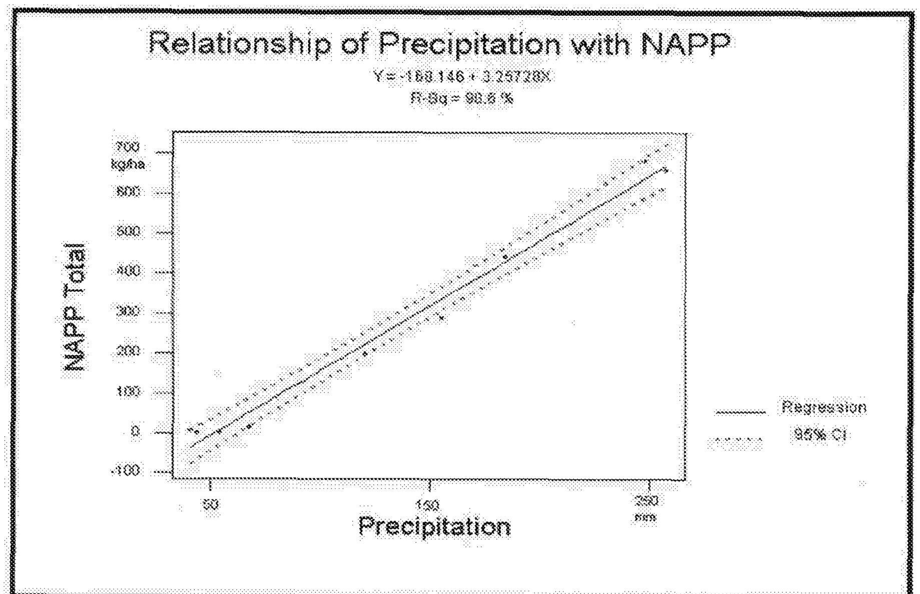


Figure 5-16. Relationship of growing season precipitation (September to August) and NAPP of all species at Yucca Mountain from 1989 through 1993.

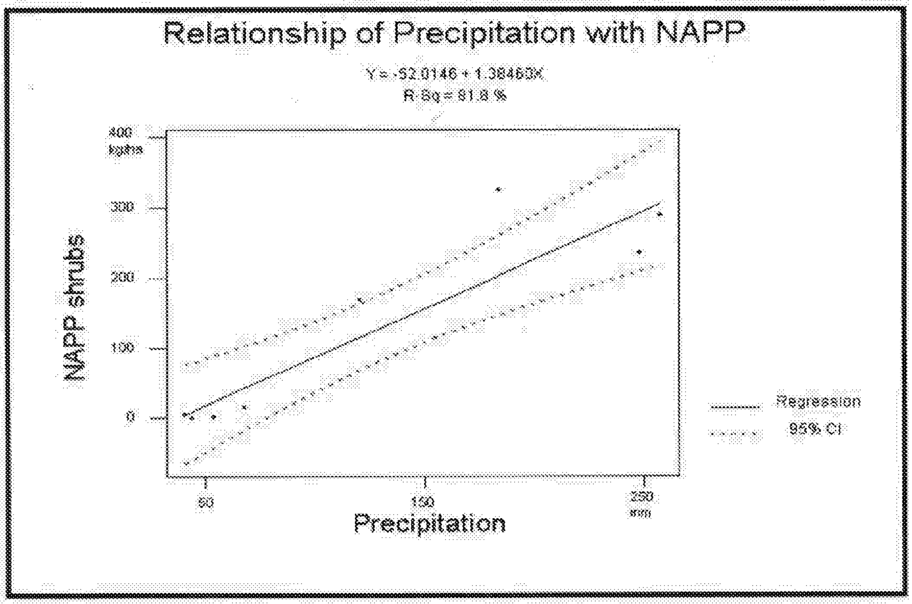


Figure 5-17. Relationship of growing season precipitation (September to August) and NAPP of shrubs at Yucca Mountain from 1989 to 1993.

A comparison of the Rock Valley shrub NAPP (Table 5-16) with the Yucca Mountain shrub NAPP (Table 5-18) shows that sampling techniques at Yucca Mountain yielded shrub NAPP values that were roughly 40 percent of the Rock Valley values at comparable precipitation levels. This difference could be caused by a number of factors including different sampling methodologies, inherent site differences, or even residual impacts of the 1988 to 1990 drought.

The data from Yucca Mountain provide information on the relationship of shrub density and NAPP of shrubs. Figure 5-18 shows the regressions of precipitation for the two different vegetation types at Yucca Mountain. The Larrea-Ambrosia type (A) had a shrub density of 1.29 plants/m^2 while the Larrea-Lycium-Grayia type (B) had a shrub density of 0.60 plants/m^2. At a given level of precipitation, the Larrea -Ambrosia type averaged about twice as much shrub NAPP as that of the Larrea-Lycium-Grayia type. Thus, shrub density may be an important variable when estimating woody biomass at the landscape level.

Table 5-18. Estimated NAPP in two vegetation types at Yucca Mountain and associated hydrologic year precipitation (September to August). LLG=Larrea-Lycium-Grayia vegetation type, LA=Larrea-Ambrosia vegetation type.

Vegetation type	Year	Total NAPP (kg/ha)	Shrub NAPP (kg/ha)	Hydrologic Year Precipitation (mm)
LLG	1989	1.9	1.9	54.0
LLG	1990	14.8	14.7	67.7
LLG	1991	290.4	114.1	155.7
LLG	1992	684.6	235.5	248.6
LLG	1993	660.7	289.4	258.0
LA	1989	0.9	0.9	44.0
LA	1990	9.1	5.5	41.0
LA	1991	201.7	168.9	120.4
LA	1992	445.0	325.8	184.1

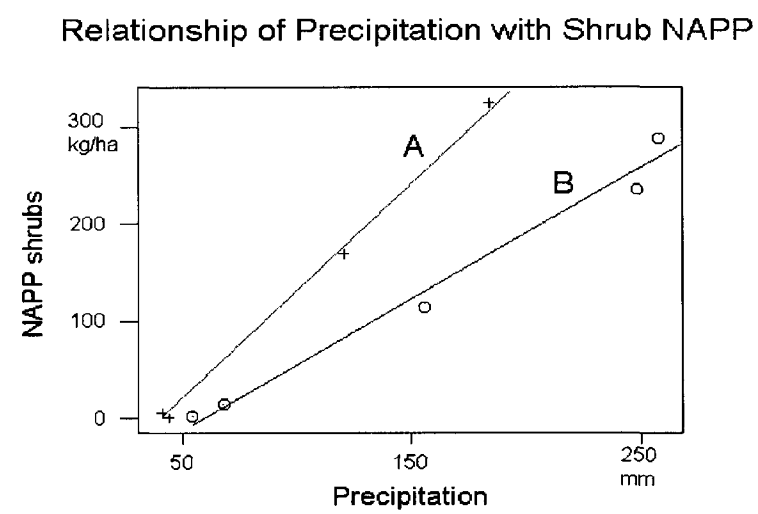


Figure 5-18. Relationship of precipitation (September to August) and Shrub NAPP for the Larrea-ambrosia vegetation type (A) and the Larrea-Lycium-Grayia vegetation type (B) at Yucca Mountain. $R^2 = 0.998$ for A and $R^2 = 0.982$ for B.

The NAPP of annual species is a parameter that may be important for ants and their abundance at the RWMSs because ants are such effective harvesters of seed produced by these species. Like shrubs, the NAPP of annuals is highly correlated to precipitation at the NTS (Rundel and Gibson, 1996). Figure 5-19 shows the relationship of growing season precipitation (September -March) with NAPP of annuals. The data are used in developing the correlation of precipitation and NAPP of annuals from studies at Rock Valley from 1966 to 1976 (Rundel and Gibson, 1996) and at Yucca Mountain from 1989 to 1994 (Hessing et al., 1996) in vegetation types that are similar to vegetation at area 5 RWMS. NAPP of annuals ranged from no production during the drought years of 1989 to 1990 to a high of 688 kg/ha in 1973 when the Rock Valley site received 218 mm of precipitation from September 1972 to March 1973.

The allocation of NAPP in annuals to shoot, root, and reproductive tissue has been studied during a six-year period from 1971 to 1976 (Rundel and Gibson, 1996). Unlike shrubs where over 50 percent of NAPP is below ground, annuals contribute on an average only 6.6 percent with root/shoot ratios of 0.06 to 0.09 (Table 5-19), which is similar to other studies of desert annuals in the southwestern U.S. (Bell et al., 1979; Forseth and Ehleringer, 1982). Approximately 44 percent of the biomass of annuals is allocated to reproduction, which is equally split between flowers and fruits. The fruits and seeds are particularly important to ants and other insects.

Table 5-19. Percentages for biomass of winter annuals at Rock Valley allocated to various plant parts (from Rundel and Gibson, 1996).

Year	Leaves	Stems	Flowers	Fruits	Roots
1971	26.6	27.3	19.7	20.1	6.3
1972	27.9	19.8	25.5	19.8	7.0
1973	19.8	34.2	11.6	28.0	6.4
1974	36.4	20.3	28.7	19.2	5.4
1975	25.9	20.6	17.7	17.7	8.1
1975	22.3	24.5	19.0	27.5	6.7
Mean	**24.8**	**24.5**	**22.0**	**22.1**	**6.6**
Standard Deviation	**3.1**	**5.6**	**6.5**	**4.5**	**0.9**

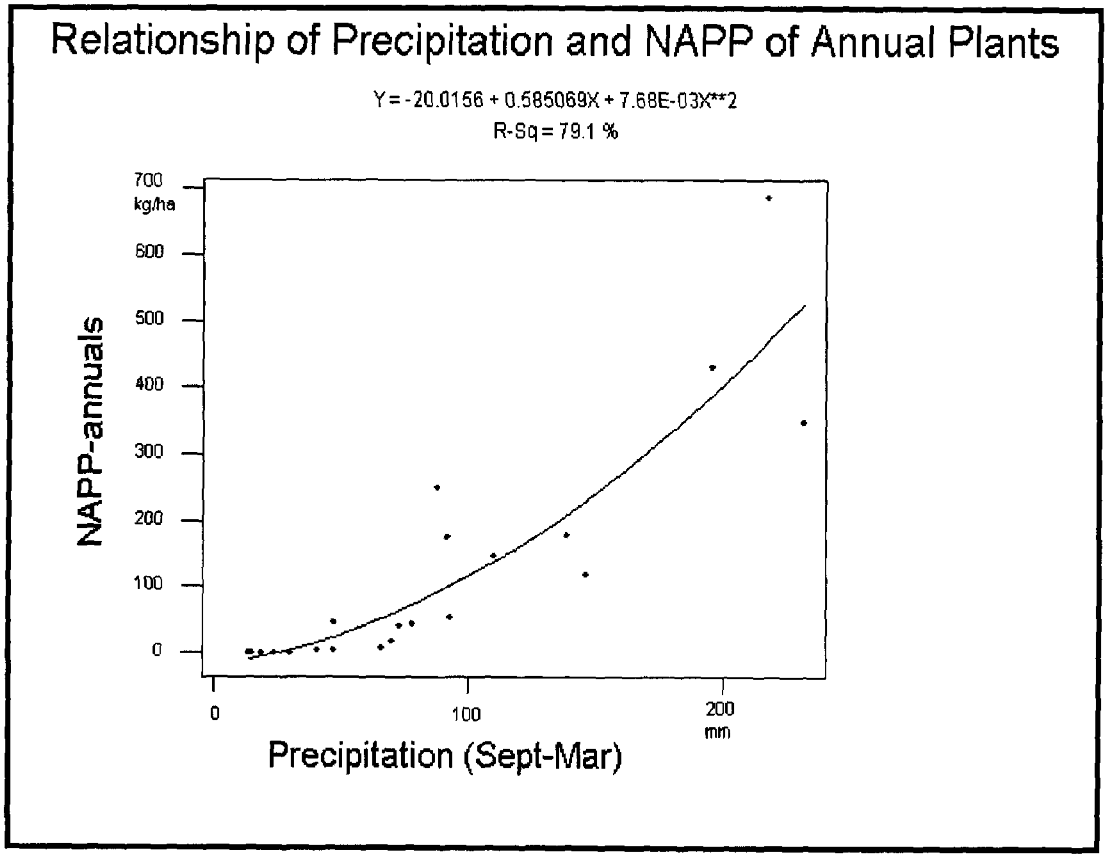


Figure 5-19. Relationship of growing season precipitation (September to March) with NAPP of winter annuals on the NTS. Data is from Rock Valley (1966 to 1976) and from Yucca Mountain (1989 to 1994).

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6.0 FUTURE SCENARIOS

Projections of likely future conditions at the NTS are based on principles of uniformitarianism. It is anchored on an understanding of what past climatic conditions may have been, what they are currently, and likely conditions that may occur in the future. Upon reviewing evidence from ancient packrat middens from the NTS and southern Nevada, Spaulding (1985) concluded that increased atmospheric carbon dioxide within the next 500 years probably will result in a 2^0 to 3^0 C increase in annual temperature and intensified rainfall in the NTS region. Current climatological models indicate that, within the next 10,000 years, climatic conditions may be similar to those of the last glacial age with a cooler and wetter climate.

6.1 Continuation of Current Conditions

Assuming climatic conditions stay the same as currently, we can predict slight changes in the vegetation at the NTS due to the introduction of exotic annual species that are likely to continue to displace annual forbs, grasses, and some shrubs. It is highly unlikely that this trend of increasing biomass and distribution of invasive species will reverse itself given the rather significant die off of native shrubs and increase in invasive species that have taken place in the western United States during the past several decades (McArthur et al., 1990). The implication of this trend is that shrub rooting depths may diminish slightly as shrubs with deeper roots are displaced by shallow-rooted invasive annual grasses. Litter from the invasive species may provide fuel in wet years that permit fires to periodically remove shrubs. With increases in CO_2 it is possible that these annual grasses may respond with greater biomass production than shrubs, thereby, exacerbating this trend.

6.2 Hotter and Drier Future Conditions

In the event that future conditions become hotter and drier than current conditions, it can be predicted that vegetation will become more typical of sandy sites at lower elevations on the NTS where creosote bush continues to dominate. Shrub canopy cover and density will likely decline slightly as less soil moisture is available for plant production. In the event that summer moisture declines more than currently, abundance of shallow-rooted annual species will become more important during the winter and early spring. Rooting depth will be slightly more shallow for larger shrubs, primarily because episodic droughts will selectively remove some plants or their roots, leaving shallower-rooted plants (with less root density) followed by periods of recovering root growth during more favorable climatic cycles.

Introduced invasive annual species will continue to displace a few of the more shallow-rooted shrubs, except perhaps along minor drainage channels where collection of runoff may increase deeper soil moisture and thereby favor persistence of species like the fourwing saltbush and white burrobush. This scenario would most likely result from global warming and may be of shorter duration (thousands of years). Spaulding (1985) indicates that longer-term (tens of thousands of years) trends are expected to a return of glacial conditions.

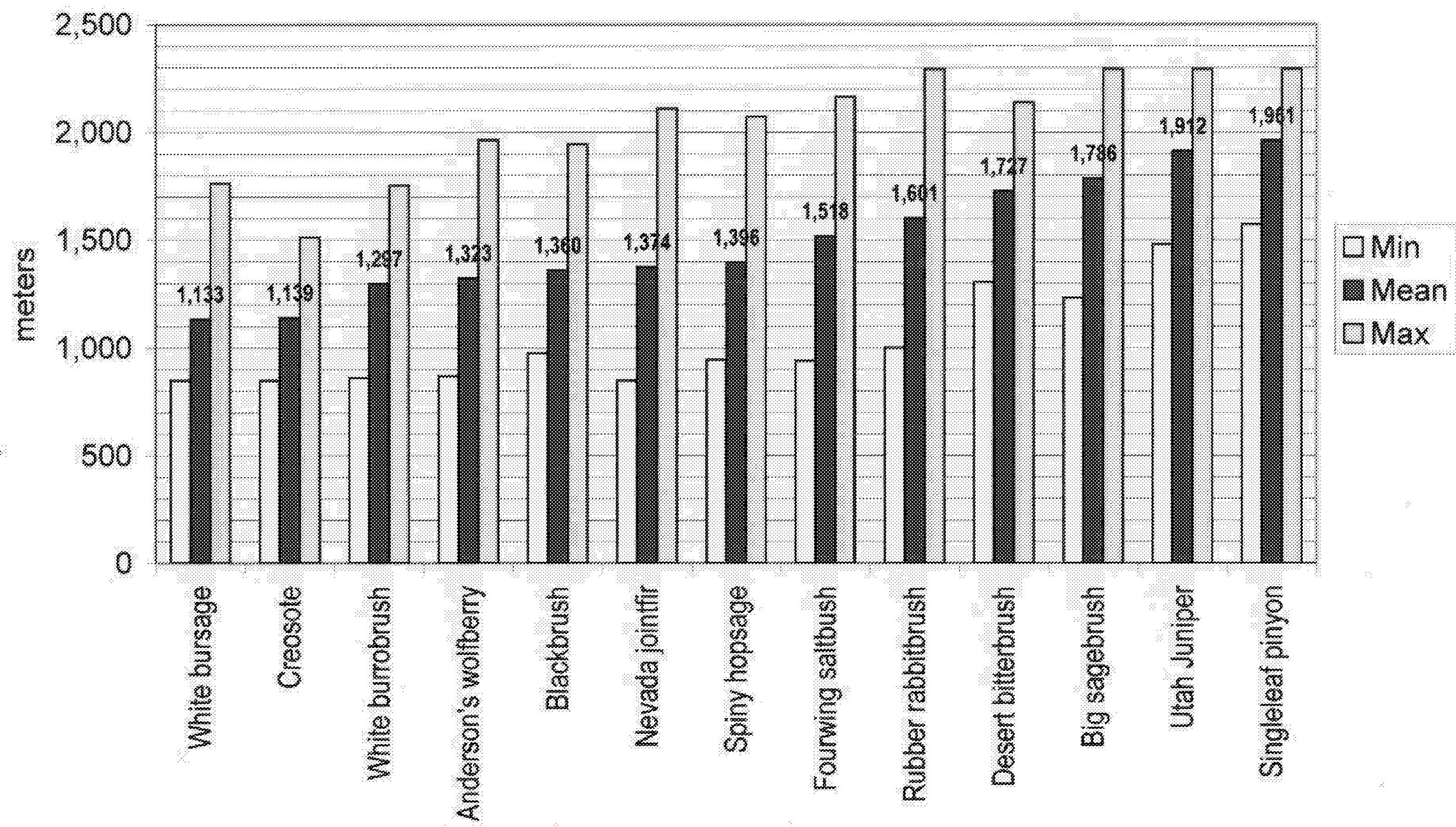
6.3 Cooler and Wetter Future Conditions

Under the scenario that the NTS site conditions would become cooler and wetter than current conditions, the decrease in mean temperature is expected to be no more than about 6^0 C, based on estimates of temperature and precipitation at the NTS during the past 23,000 years as described by Spaulding (1985). Precipitation is estimated to be no more than 40 percent greater than current values, with most of the precipitation occurring in the winter months. Using these climatic conditions, it is possible to project the changes in vegetation that would likely occur.

Individual species of shrubs and trees on the NTS are distributed along elevation and precipitation gradients (Figure 6-1, data taken from Bechtel Nevada's Ecosystem Geographic Information System database [Ostler et al., 2000]). At the lower end of the precipitation gradient on the NTS is creosote bush/white bursage shrubland, which is at the northern-most boundary of the Mojave Desert at the Areas 3 and 5 RWMSs. It has a current mean annual precipitation of approximately 17 cm (Ostler et al., 2000). At the upper-most end of the NTS precipitation gradient is the pinyon-juniper/big sagebrush shrubland plant community (association). A 40 percent increase in current mean annual precipitation (17cm) would result in a mean annual precipitation of approximately 24 cm. This correlates with the plant associations of big sagebrush-green rabbitbrush shrubland (at middle elevations) or a black sagebrush-green rabbitbrush shrubland (at middle elevations), not plants of the pinyon-juniper/big sagebrush shrubland plant communities (at high elevations) with a mean annual precipitation of 28 cm.

Based on the deeper soils that would result at the Areas 3 and 5 RWMSs, it is likely that vegetation under this scenario would be a shrubland consisting of mixed shrubs dominated by big sagebrush. It is possible that the steeper, rockier slopes to the north of the Area 5 RWMS would be occupied by trees such as Utah Juniper and perhaps some pinyon; however, fires and drought usually remove these tree species from deeper soils, even under higher mean annual precipitation rates. Figure 6-2 shows typical pinon-juniper-big sagebrush plant communities currently on the NTS. It should be noted that trees rarely occupy the bottomlands of the valley. These deeper soils usually are occupied by sagebrush and rabbitbrush. As annual precipitation increases, there is a trend for such sites to be colonized as grasslands because soil moisture is high enough to maintain grasses that promote the spread of fires, which selectively remove woody vegetation. Sagebrush, a plant whose seeds are dispersed by wind, usually reestablishes more quickly than the pinyon or juniper, whose seeds are dispersed by animals, thereby resulting in a gradient in the valley bottoms of grasslands along the channels to shrublands, to trees along the steeper (Figure 6-3), and often rocky outcrops where lack of soil moisture diminishes the fuel loading and allows the survival of most trees.

Figure 6-1 Mean Elevation of Shrubs and Trees on the NTS



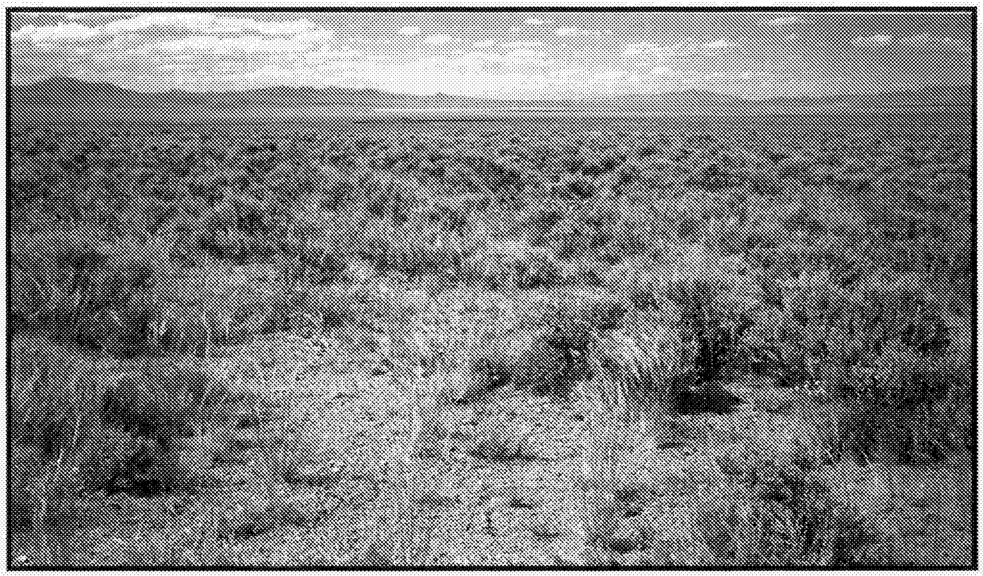


Figure 6-2. Big sagebrush community on the NTS typical of what would likely establish on the Areas 3 and 5 RWMSs under increased precipitation and cooler climate (photo of Kawich Valley, northern NTS, looking north).

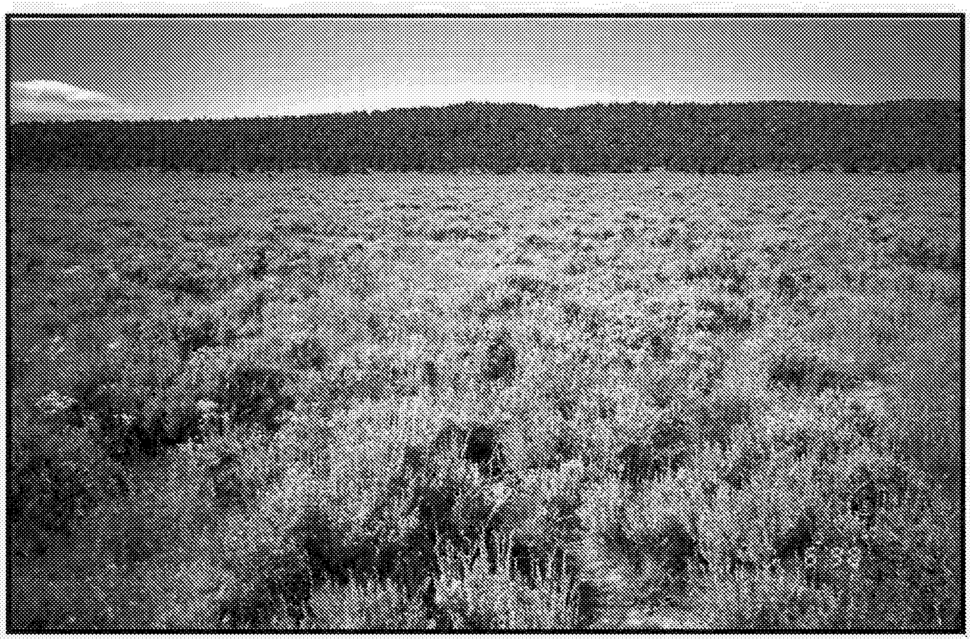


Figure 6-3. Big sagebrush community on the NTS with singleleaf pinyon on the steeper side slopes and big sagebrush and grasses in the valley bottom (photo of Pahute Mesa, northern NTS, looking west).

Information about vegetation of the NTS (Ostler et al., 2000) suggests that under a cooler and wetter scenario vegetation of the Areas 3 and 5 RWMSs would not support trees such as juniper or singleleaf pinyon. This conclusion is different than a conclusion reached by Cochran et al., (2000). If a decrease in temperature were less than 6^0 C and increase in precipitation were less than 40 percent, it is possible that other shrub communities would develop such as Nevada jointfir, spiny hopsage, or fourwing saltbush rather than creosote bush. These communities are dominated by low-growing shrubs and have little or no contribution by tree species. Rocky shallow soils usually develop as black sagebrush (*Artemisia nova*) plant communities. Such sites are not typical of the deeper soils at the Areas 3 and 5 RWMSs; however, black sagebrush plant communities may develop on older, undisturbed soils to the northwest and northeast of the Area 3 RWMS under this scenario.

This study did not attempt to characterize the biomass production or root distribution of plants in the sagebrush plant communities. Root biomass would likely be higher than the creosote bush that currently occupies the Area 5 RWMS, but lower than exists at current sagebrush sites that have developed on the NTS. This is because most sagebrush plants occur on soils with more loamy textures than those at Area 5 RWMS. A soil predominantly comprised of sands or sandy loams has poorer water- and nutrient-holding capacities that loamier soils developing under wetter climatic conditions. Reports of the rooting depth of big sagebrush on the NTS have not been located.

6.4 Ephemeral Wetlands

According to Cochran et al., (2000), under a cooler and wetter climatic scenario, subsidence within the wastes may create shallow surface depressions that may become colonized by woody vegetation (with deeper roots) like tamarisk or mesquite trees (although mesquite tress are not cold tolerant). However, this assumption is not supported by conditions at any of the 25 wetland sites on the NTS currently (Hansen et al., 1997) or by observations at hundreds of subsidence craters in Frenchman and Yucca flats visited in the process of classifying NTS vegetation (Ostler et al., 2000). Only on the playas do depressions in the soil colonize with such woody species, because the soils of these areas are fine textured (clays and silts) and runoff across the playa collects in the low-lying areas and creates high soil moisture needed to maintain such vegetation. Most sites with such woody vegetation are on Frenchman Lake or Yucca Lake. A few other old excavations that had an abundance of drilling fluids (clay muds) in their bottoms have one or two tamarisk plants, but these are the exception rather than the rule. Most subsidence craters are vegetated with annual exotics like Russian thistles (*Salsola* spp.) or tumblemustard (*Sisymbrium altissimum*). Other areas like Cambric Ditch southeast of Area 5 RWMS was used to convey pumped ground water over the surface for many years and these areas developed a vegetative cover of cattails and tamarisk. Because nearly all of the subsidence craters on Yucca Flat remain free of any woody vegetation and the fact that fill soils above the GCD boreholes are sandy in texture and do not retain soil moisture, it is not likely that Cochran's scenario would ever be realistic even under two to three times the mean current annual precipitation, and not just a forty percent increase.

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7.0 CONCLUSIONS

7.1 Plant Parameters Important for Modeling and Performance Assessments

Current measurements are available to describe the above-ground characteristics of vegetation in plant communities near Areas 3 and 5 RWMSs such as plant structure (e.g., height, diameter, cover, density) and plant community composition (e.g., species composition). However, no quantitative data on below ground root systems of shrubs have been collected. Estimates of some root system parameters can be made for some species at some sites for future modeling efforts. These estimates are based mostly on data collected from other locations at the NTS and from conversion factors established by statistical correlation of stem and root relationships collected in past NTS studies. Because data from other locations on the NTS did not provide conversion factors for all species encountered at Areas 3 and 5 RWMSs, some calculations could not be made. Data are more complete for the Area 5 RWMS. To the extent possible, data have been provided in summary tables. A summary of important parameters of vegetation for the Areas 3 and 5 RWMSs that may be needed for modeling biotic mixing of soils and waste transport process by biota are shown in Table 7-1

Table 7-1. Important characteristics of vegetation at the RWMSs

Parameter	***Area 5 RWMS***	***Area 3 RWMS***
Canopy cover	18.6% to **21.0%**	3.4 to **6.9** to 36.0%
Shrub density	**1,433** to 4,773 plants/hectare	864 to **1,687** to 11,531 plants/hectare
Total shrub shoot biomass	2,427 to **3,223 kg/ha**	N/A
Total shrub root biomass	2,882 to **3,959 kg/ha**	N/A
Total above-ground biomass for annuals	0 to 688 kg/ha	N/A
Total below ground biomass for annuals	0 to 45 kg/ha	N/A
Estimated maximum rooting depth	95.5 to **115.8 cm**	70.4 to **72.0** to 180 cm
Net above-ground primary production for shrubs	183 kg/ha to 682 kg/ha	N/A
Net below ground primary production for shrubs	183 to 1,3641 kg/ha*	N/A
Mean Net above-ground primary production	**347** kg/ha (at 138-mm precipitation)	N/A

Bold values represent the more likely value of the range based on similarity to the RWMS
N/A = Data not available because of unknown conversion factors for a few species.
* 1-2 times above-ground primary production based on isotope studies.

Total shrub biomass at plant communities closest to the Area 5 RWMS is comprised primarily of creosote bush (98.4 percent). This biomass is further distributed into four different size classes of plants (refer back to Table 5-1). About 26 percent of the creosote bush shrubs have a mean area of 3.07 m^2 and an estimated maximum root depth of 75 cm. Another 28 percent of the shrubs have a mean area of 7.04 m^2 and an estimated maximum root depth of 160 cm. A third-size class has about 25 percent of the shrubs with a mean area of 9.6 m^2 and an estimated maximum root depth of 215 cm. The largest size class has about 21 percent of the shrubs with a mean area of 13.34 m^2 and an estimated maximum root depth of 295 cm. Maximum rooting depths were based on a conversion factor of 1.2 as reported by Foxx et al. (1984b). It should be noted that these "maximum" values should probably be interpreted as extrapolated mean rooting depths based on observations of numerous shrub species by many authors. These values are within the range presented by Cochran et al. (2000, Table 7-2). A few individual shrubs have been observed to extend roots up to 8 m deep (e.g., Raytheon Services Nevada 1991), although such observations are rare. All of the roots observed during recent examination of pit walls in 2001 were within the top 2 m.

Table 7-2. Statistical parameters for maximum root length data sets (cm).

Parameter	*Annual*	*Perennial*	*Shrub*	*Tree*
number	23	196	67	59
mean	39	106	227	436
Stdev	49	95	172	566
minimum	2	2	35	20
maximum	162	823	914	3,000

(Data from Cochran et al., 2000)

Distribution of shrub roots by depth is generally considered by modelers to be an exponential relationship (Shott et al., 2000; Cochran et at., 2000). Figure 7-1 shows the distribution of shrub roots with depth as reported by Wallace et al. (1980). These data were for a total of 53 individuals (9 species) from Rock Valley on the NTS. Because this site has a caliche layer at about 1 m in depth, it is possible that the data do not accurately portray rooting distribution at greater depths as would occur at Areas 3 and 5 RWMSs. However, they do represent the only data on distribution of root biomass with depth available for the NTS.

Recent studies of plant communities, site characteristics, and correlation of species distribution along precipitation and elevation gradients on the NTS (Ostler et al., 2000) suggest that future climatic scenarios that are wetter and cooler at Areas 3 and 5 RWMSs would not support woodland development with tree species on these deeper soils, but would probably favor development of shrublands like big sagebrush with shallower rooting systems.

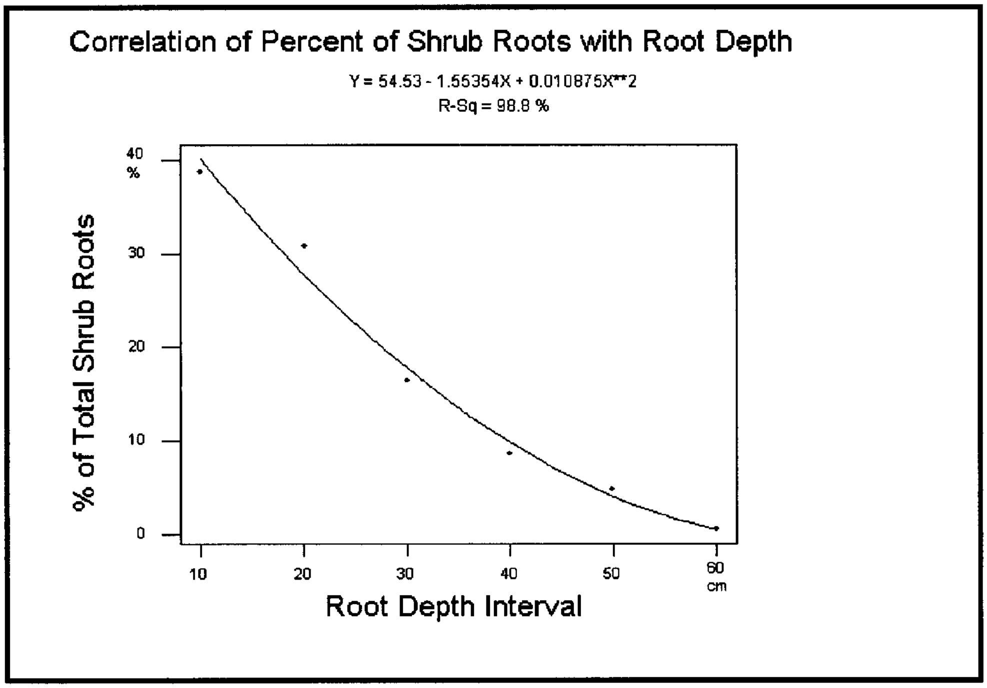

Figure 7-1. Correlation of percent of shrub roots with root depth (Wallace et al., 1980).

7.2 Data Deficiencies

A literature survey of historical research conducted on the NTS identified numerous studies that describe root characteristics of shrubs and annuals forbs (herbaceous plants) on the NTS. While most of the research was centered at the Rock Valley site west of Mercury, Nevada on the NTS, a few studies were conducted in Frenchman and Yucca flats. Information about rooting depth, standing biomass of roots and shoots, and root-to-shoot ratios were published for most of the plant species found at Areas 3 and 5 RWMSs.

No detailed descriptions of root distributions were found in geological and hydrological surveys of these areas and only passing comments were included when soil pits were described. No excavations were apparently made in these areas to determine root distributions, although such data may be estimated or inferred from correlation data developed for the same species at other locations on the NTS. Conversion factors were not reported for a few species in the vicinity of Areas 3 and 5 RWMSs making it impossible, without additional field work, to estimate root biomass for some species.

This study did not focus on characteristics of vegetation at higher elevations on the NTS such as big sagebrush, singleleaf pinyon, and Utah juniper. Root characteristics of these species may be important if further evaluation needs to be made for future climatic scenarios in which there is a change in the vegetation in response to climatic conditions that are cooler and wetter. The emphasis of the study was on rooting characteristics of vegetation in the vicinity of the GCD boreholes and trenches in Area 5 RWMS and also on vegetation in the vicinity of Area 3 RWMS.

7.3 Recommendations

To help reduce uncertainty from transport models, future research efforts could focus on obtaining living volume-to-biomass conversion factors and root-to-shoot ratios for selected species (e.g., white burrobush, green rabbitbrush, spiny menodora, and budsage). These measurements should be made in the spring when plant production is maximum. The data should be relatively easy to obtain unless the year has subnormal precipitation where NAPP is severely restricted. Also needed is a better estimate of NAPP for shrub species and its contribution to root biomass. However, such information is often not easy to obtain because of the logistics of excavating, separating, and weighting biomass. Annual fluctuations in climatic cycles may also hamper efforts to obtain meaningful data (e.g., in years of drought, annual production may not occur). Additionally, efforts should be directed to determine more precisely rooting distribution from soil pits excavated in plant communities near Areas 3 and 5 RWMSs. Limited field observations were made in August of 2001 as a new disposal pit at the Area 5 RWMS was constructed. Documentation of those observations is found in Appendix 9B. Any future excavations should be coordinated to obtain additional observations about patterns and depth of shrub roots.

An alternative method for confirming (or approximating) shrub rooting patterns on disturbed sites is to excavate transplanted shrubs growing on old revegetation test plots established by UCLA and others. These sites were ripped, leveled, backfilled (in some cases), and planted with transplanted shrubs to determine if, and how, they would grow and how long they would persist on the NTS. These sites are now several decades old and have large shrubs (i.e., tall shoots and deep roots) growing on them. A few sites exist in the vicinity of Areas 3 and 5 RWMSs. These sites may serve as analogs for waste disposal sites and may have similar root growth and patterns of root distribution. Individual shrubs are mature in size and have roots that have grown for decades. They are well spaced, thereby minimizing problems associated with distinguishing between roots of adjacent plants. Roots of individual plants could be carefully dug up using a backhoe and hand tools to determine maximum rooting depth. On sites overlaying prior disposal wastes containing radionuclides, it might also be possible to use selected radioisotope tracers to determine rooting depth without disturbing the underlying wastes. Effort is needed to identify potential sites, characterize them (e.g., plant size and species), and select those that would best serve as analog sites. Plant persistence is rather short (three to four decades) and has not had thousands of years to develop; therefore, rooting depth may not be at maximum depth as it would under long, wet climatic cycles. However, the rooting growth patterns would approximate those that the climate would support over shorter climate cycles experienced during the past three to

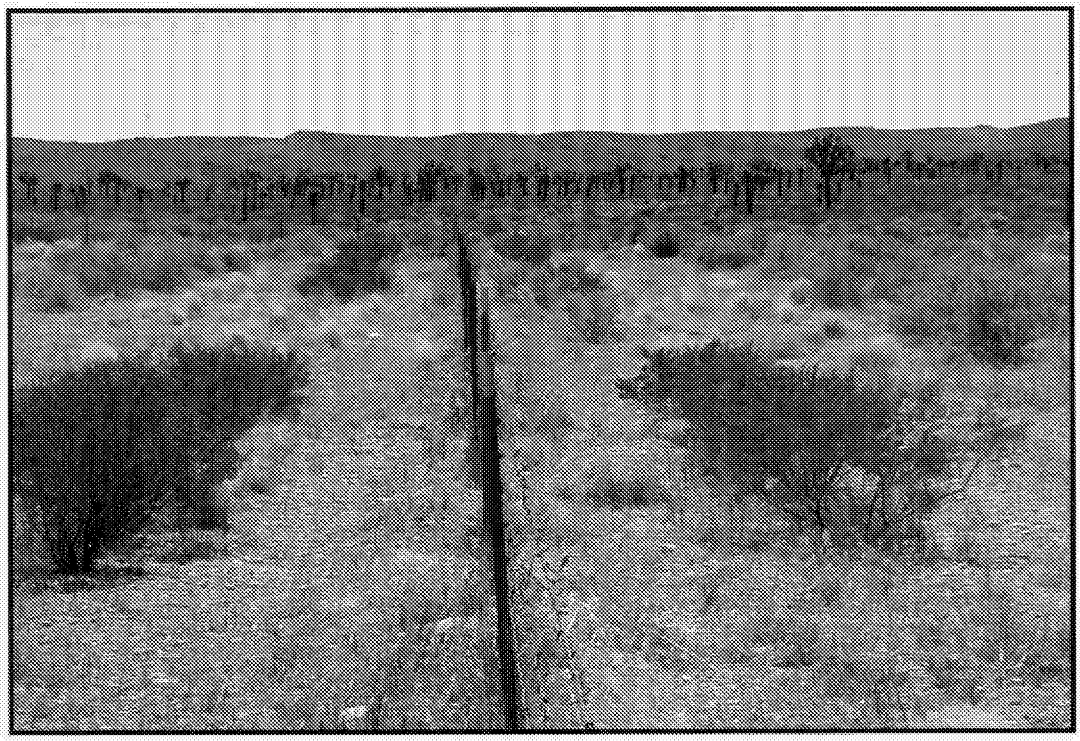

Figure 7-2 Example of six year old revegetation test plot on disturbed soil in Plutonium Valley near Area 3 RWMS.

the past three to four decades. This time period is long enough to be representative of average or slightly above average precipitation and short-term droughts on the NTS and Mojave Desert (Hereford and Longpre, 2000).

Characterization of rooting of shrubs, especially big sagebrush, in pinyon-juniper/big sagebrush plant communities with deep soils on the NTS would help provide data upon which to model future climatic scenarios that are wetter and colder than exist at these sites now. No data have been identified about root distribution of big sagebrush on the NTS. A limited amount of data is available for sites in the Great Basin Desert to the north of the NTS, but these sites are usually characterized by loamy soils that are not comparable to those found on the NTS which are much more sandy in texture. Plant measurements needed include plant height, diameter, percent canopy cover, living volume, biomass, root-to-shoot ratios, and maximum rooting depth. These values would not be needed unless future climatic scenarios are to be evaluated. Alternatively, values for other NTS shrubs such as creosote bush could be used to approximate those values for big sagebrush. Such values would probably underestimate rooting depth, but would be more realistic and closer to actual values for big sagebrush than would the use of values reported for trees species such as singleleaf pinyon or Utah juniper reported by others (e.g., Foxx et al., 1984a, 1984b) in areas distant from the NTS (e.g., southern Texas and New Mexico).

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