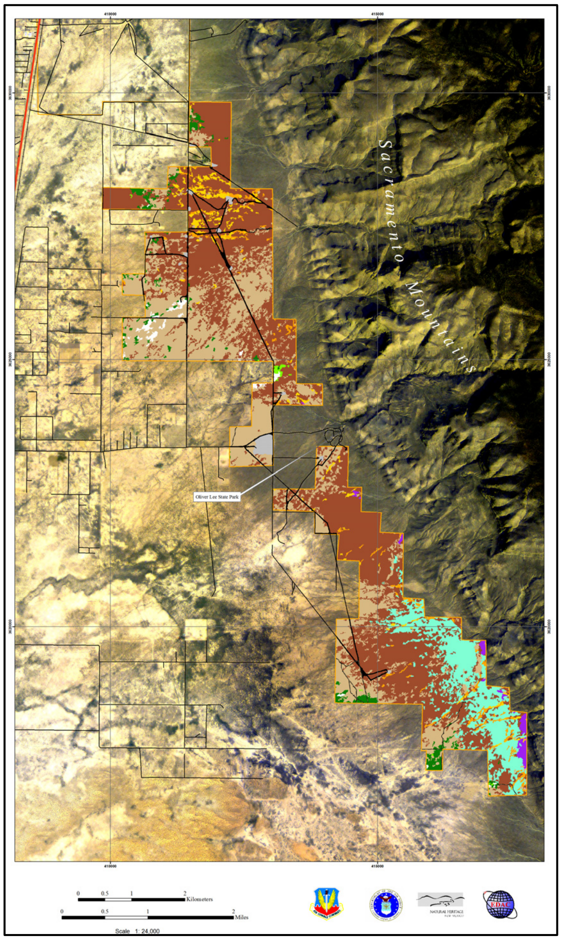

A Vegetation Survey and Map

of

Boles Wells Water System Annex

(Southern Portion)

Holloman Air Force Base, New Mexico

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A Vegetation Survey and Map of Boles Wells Water System Annex, Sothern Portion

Holloman Air Force Base, New Mexico[1]

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SUMMARY

A map of current vegetation of Boles Wells Water System Annex (BWWSA), southern portion (Douglas and San Andres wellfields) of Holloman Air Force Base was developed using aerial photography and satellite imagery. Following the guidelines of National Vegetation Classification, a vegetation classification was developed based on 55 field plots that were gathered as part of a vegetation survey in 2004-05. Ten plant associations among four alliances were described belonging primarily to the Chihuahuan Desert Scrub biome. The plot data was used in an automated supervised image classification to generate the initial map, followed by refinement with aerial photo interpretation and field verification. Eleven map were units defined with respect to primary and secondary component plant associations and inclusions, and final maps generated at 1:24,000 (the entire BWWSA) and 1:12,000 scales (separate Douglas and San Andres sheets). In addition, a search for noxious weeds was conducted as part of the vegetation survey and resulted in the discovery of small populations of African rue (*Peganum harmala*) and saltcedar (*Tamarix ramosissima*), plant species identified by the New Mexico Department of Agriculture as Class B and Class C noxious weeds, respectively. These maps complete the mapping of current vegetation on all Holloman Air Force Base lands. Periodic updating of the vegetation maps on a decadal basis is recommended to track trends in ecosystem change in the context of the military mission.

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INTRODUCTION

To aid in the management of natural vegetation communities in the Holloman Air Force Base (HAFB) Boles Wells Water System Annex (BWWSA), Natural Heritage New Mexico (NHNM) has conducted a vegetation survey and developed a detailed vegetation map for the southern portion of the BWWSA. Additionally, NHNM conducted a survey for noxious and invasive weeds and compiled a list of species found and their locations. The vegetation survey included the development of a comprehensive plant species list along with a classification of vegetation assemblages based on the National Vegetation Classification System (Grossman et al. 1998). The map was developed using available digital ortho-photography and ground checking, and is designed for use at the 1:24,000 scale, with a minimum mapping unit size of 0.10 ha. The species list and map form the foundation of a baseline inventory of plant resources within the BWWSA.

STUDY AREA

The Boles Wells Water System Annex (BWWSA) is located in south-central New Mexico within the Tularosa basin, and is approximately 16 km (10 mi) south of Alamogordo, NM. BWWSA encompasses a total of 2,802 ha (6,923 ac) and includes Boles Wells, Douglas, and San Andres wellfields (Figure 1). The southern portion of the BWWSA was our study area and includes the Douglas and San Andres wellfields (2,156 ha, 5,328 ac). Further official designations within these two fields are as follows: The Douglas Wellfield is divided into the San Andres, Douglas, and Frenchy fields, while the southern San Andres Wellfield is known as know as the Escondido field. For the purposes of this report, we will refer to the two geographically distinct Douglas and San Andres wellfields in the north and south, respectively.

The BWWSA serves as a potable water supply for the main base located approximately 20 km to the northwest. The western borders of the wellfields are privately owned with the exception of state and national park jurisdiction along the northern portion of the San Andres wellfield. The eastern borders of the wellfields are lands under the jurisdiction of the Bureau of Land Management and Lincoln National Forest (U.S. Forest Service). Oliver Lee Memorial State Park lies between the southern and northern boundaries of the Douglas and San Andres wellfields, respectively (Figure 1).

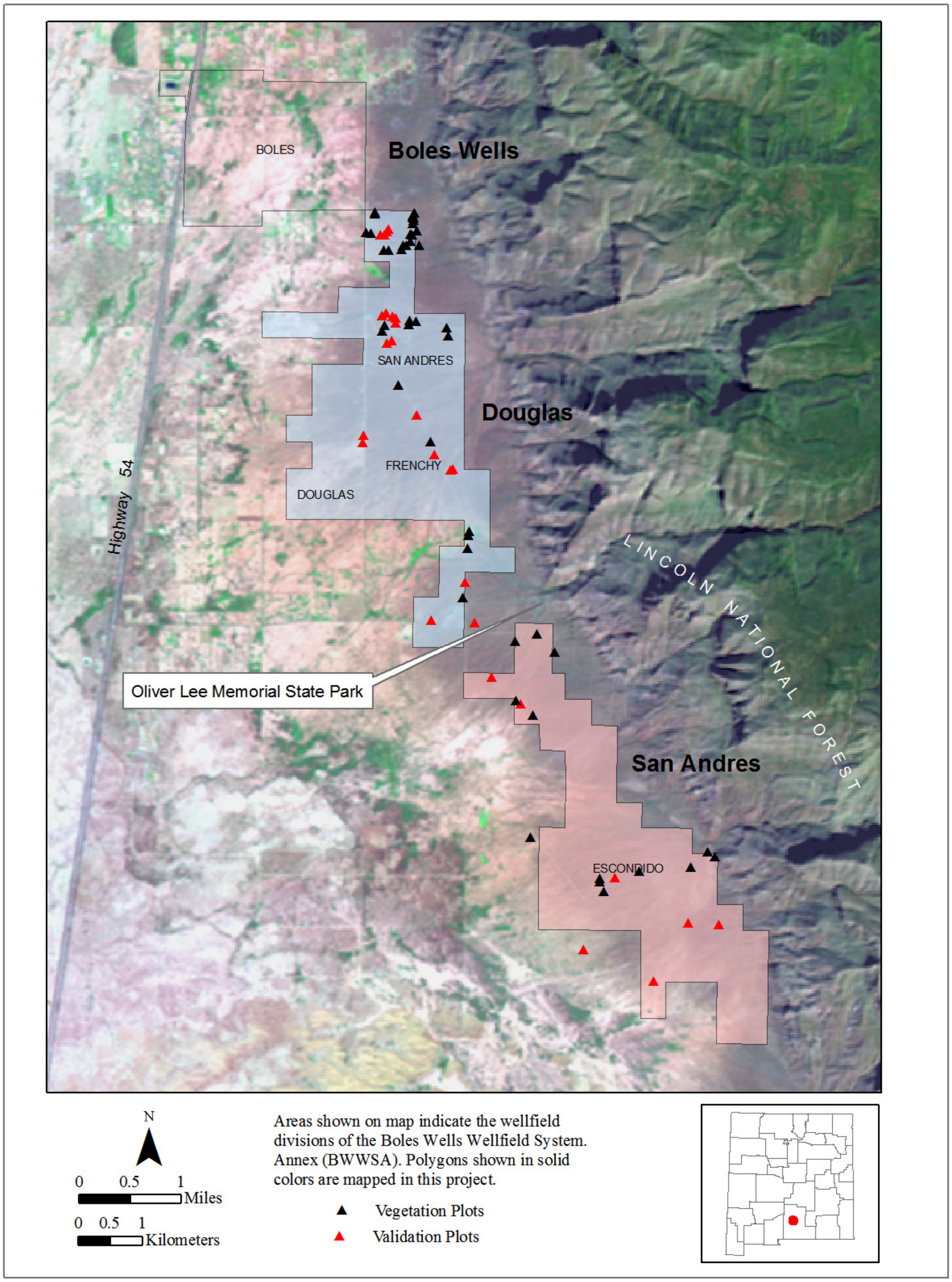

Figure 1. Boles Wells Wellfield System Annex (BWWSA), southern portion vegetation map study area.

The BWWSA lies at the base of the foothills of the Sacramento Mountains, and is representative of areas that provide mountain-front recharge to the Tularosa Basin. Elevations range from 1,244 m (4,081 ft) to 1,353 m (4,439 ft) in the Douglas wellfield and 1,251 m (4,104 ft) to 1,446 m (4,744 ft) in the San Andres wellfield. The landscape is characterized by a north to south trending alluvial piedmont (bajada) that runs along the mountain front and is composed of ancient coalesced alluvial fans that had their origins in the mountain front canyons. The majority the Douglas wellfield lies along the lower bajada, whereas the San Andres wellfield lies higher within the mid to upper slopes of the piedmont and captures a small area of the adjacent foothills. The bajada is deeply dissected by westward-facing drainageways or arroyos that carry the current runoff from the adjacent mountain canyons. The lower, western edge of the bajada gives way to an alluvial apron leading to the Tularosa basin bottom.

With respect to soils, the bajada has been mapped primarily as the Nickel-Tencee association (Figure 2). These are shallow, gravelly soils (3.2–4.1 cm; 8–10.5 in) formed from the mixed alluvium composed of sedimentary and igneous rocks from the adjacent mountains (Soil Survey Staff 2006). The Nickel soils comprise 50% of the unit and dominate the summit platform of the bajadas. These soils lack a strong caliche (petrocalcic horizon) and are hence classified as loamy-skeletal, mixed, thermic Typic Calciorthids. In contrast, the Tencee soils, which make up 35% of the unit, differ in having a restrictive barrier of petrocalcic horizons at 3.2–11.8 cm (8–30 in) in depth and are classified as loamy-skeletal, carbonatic, thermic, shallow Typic Paleorthids. Tencee soils are on side slopes of fans and upper parts of older fans.

The fan apron and alluvial flats of the western edge of the study area are mapped as Mimbres-Prelo and Mimbres-Tome Associations. These are finer-textured soils that lack caliche layers. The Prelo and Mimbres soils are classified as fine-silty, mixed, superactive, thermic Typic Haplocambids and Tome soils as fine-silty, mixed, superactive, thermic Typic Haplocambids. Both Prelo and Tome soils are on the distal edges of the alluvial fans, while Mimbres is associated with fan fringes and bottom lands.

At the other end of the spectrum, the foothills that bound the upper alluvial fan piedmont are mapped as Rock outcrop-Lozier complex. Lozier soils are shallow and gravelly, and formed in loamy residuum over limestone bedrock (loamy-skeletal, carbonatic, thermic Lithic Haplocalcids). They are intermixed with up to 50% limestone rock outcrop.

Based on weather station records from Alamogordo, the climate of BWWSA is typical of the northern Chihuahuan Desert (Table 1). Winters are cold and reach extremes of -25.5 ºC (-14 ºF) while summers can be exceptionally hot (43.3 ºC; 110 ºF). Consistent with the desert conditions, the overall precipitation is low (Table 2). The majority of the precipitation falls in the summer (70% or 8.01 in/20.34 cm) as part of the "Southwest Monsoon" rainy season, while the remainder comes in the winter as a combination of rain and snow. Periodic severe droughts are common where little or no precipitation will occur within a season or even across years.

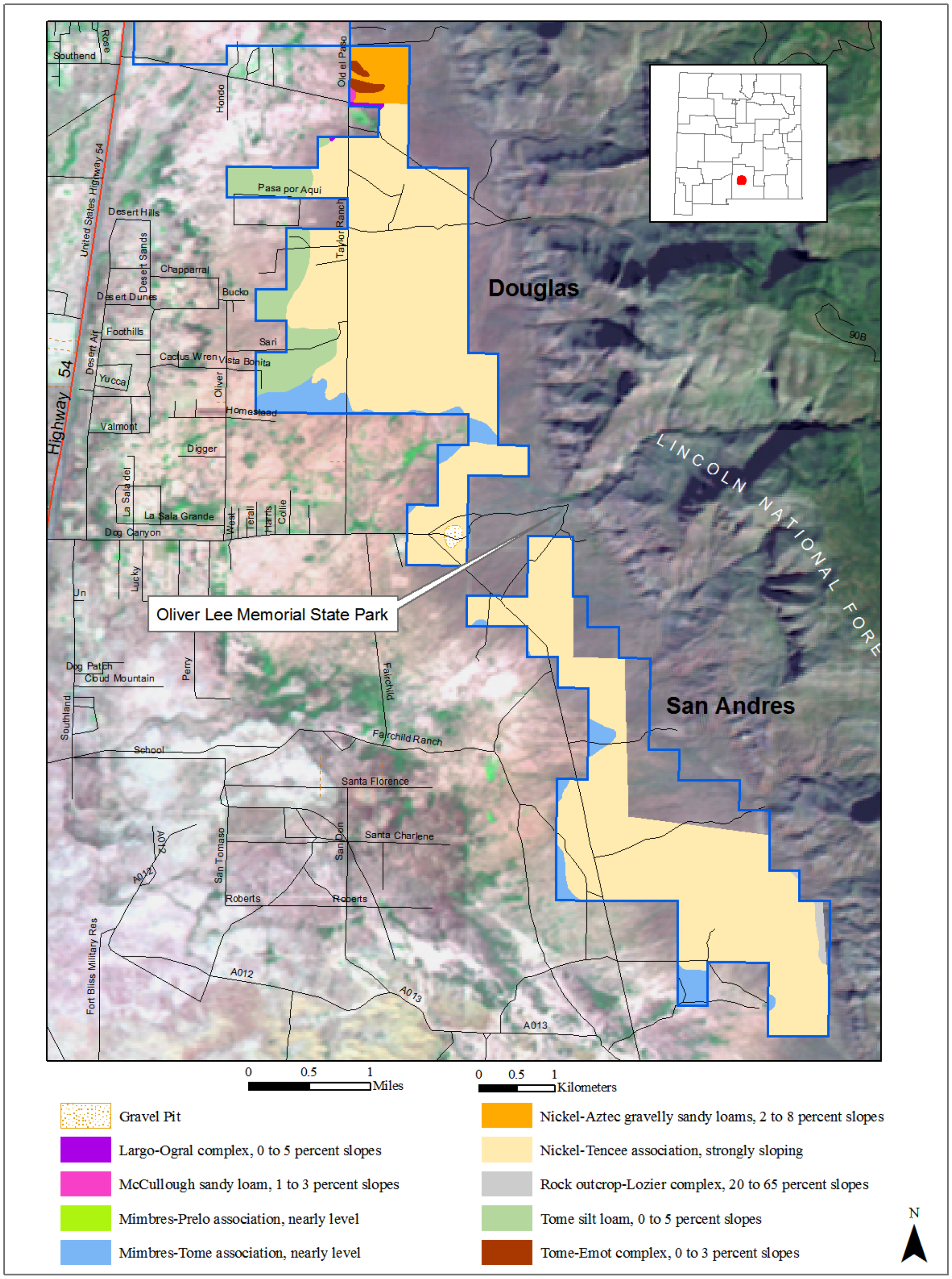

Figure 2. Soils of the Boles Wells Wellfield System Annex (BWWSA), southern portion study area (source: Soil Survey Geographic (SSURGO) database 2006).

Table 1. Seasonal temperature summary for Alamogordo, NM for the years 1914-2005 (source: Western Regional Climate Center www.wrcc.dri.edu).

	Monthly Average Temperature					
	Max.		Min.		Mean	
	°F	°C	°F	°C	°F	°C
Annual	76.4	24.6	47.0	8.3	61.7	16.5
Winter	58.3	14.6	30.4	-0.8	44.3	6.8
Spring	77.2	25.1	46.1	7.8	61.6	16.4
Summer	93.8	34.3	64.6	18.1	79.2	26.2
Fall	76.5	24.7		8.4	61.8	16.5

Table 2. Seasonal precipitation summary for Alamogordo, NM for the years 1914-2005. (source: Western Regional Climate Center www.wrcc.dri.edu).

	Monthly Average Precipitation							
	Mean		High			Low		
	in	cm	in	cm	Year	in	cm	Year
Annual	11.40	29.08	21.87	55.50	1941	4.85	1.20	1952
Winter	2.01	5.10	7.64	19.40	1992	0.11	0.27	1919
Spring	1.39	3.53	5.66	14.37	1941	0	0	1972
Summer	4.78	12.14	9.53	24.20	1914	1.37	3.47	1956
Fall	3.23	8.2	9.89	2.51	1985	0.10	0.25	1917

Vegetation

With respect to the general vegetation of BWWSA, the site sits within Chihuahuan Desert Scrub as defined by Brown, Reichenbacher, and Franson (1998) and mapped by Brown and Lowe (1980). Accordingly, the scrub vegetation is dominated by creosotebush (*Larrea tridentata*), honey mesquite (*Prosopis glandulosa*), mariola (*Parthenium incanum*), and ocotillo (*Fouquieria splendens*). The upper elevations of the site lie at the cusp with Chihuahuan Semi-desert Grasslands and hence support more grassland elements such as black grama (*Bouteloua eriopoda*) and bush muhly (*Muhlenbergia porteri*).

MATERIALS AND METHODS

Sampling

Field data were collected initially from August 11-13, 2004 and then revisited on September 9, 2005 for a validation of the draft map. A series of quantitative plots and mapping points were established in homogeneous stands of vegetation and were used to classify the various plant associations found across the study area (Figure 1). Plots were standard NHNM plots that were usually 400 m^2 and square, with other sizes occasionally used to fit the structure of a community, especially along drainages where vegetation stands conform to the channel shape. A list of all vascular plant species, stratified by lifeform (tree, shrub, subshrub, grass and forb layers) was compiled for each plot and aerial cover determined for each species using a modified Domin-Krajina Scale (Table 3). In addition, several site attributes were recorded including percent slope, aspect, slope shape, surface rock type, and ground cover (percent rock, gravel, bare soil and litter), along with narratives on species composition and site conditions. Besides the 55 vegetation plots, 27 abbreviated mapping points were collected where only the dominants and their abundance were recorded. All plot locations were established with handheld Garmin GPS units and determined from a raw running average of one minute or more. Accuracy is estimated to be +/- 10 m or less. All vegetation and site data were entered into a Microsoft Access 2000 database and quality controlled through error checking computer routines and manual read-backs. The database is provided on an accompanying Data Addendum CD.

In addition to the survey to create a vegetation map, a noxious weed survey of the southern wellfields was conducted at well sites, along roads, and within vegetation plots. Voucher collections of invasive species were taken and identifications later confirmed using materials at the herbarium of the Museum of Southwestern Biology at the University of New Mexico.

Vegetation Analysis

The vegetation plots were classified into plant associations according to the National Vegetation Classification (Grossman et al. 1998) as modified for use in New Mexico (Table 4). In general, each plot was classified into an Alliance based on dominant or indicator species, and then to a particular Plant Association (PA) based on codominance and/or other groups of differential species. Phases of associations were assigned as necessary to further define the character of the plant community. Since the National Vegetation Classification (NVC) is intended to be part of a universal international system, it, by design, lacks regional categories such as “Chihuahuan Desert Scrub” or “Chihuahuan Desert Grassland,” which are part of regional and state classifications such as Brown et al. (1998), Dick-Peddie et al. (1993) or the U.S. Fish and Wildlife Gap Analysis Project classification for New Mexico (Thompson et al. 1996). These regional “biomes” or “zones” are essentially floristically based and can be very useful for general analysis and planning. They conceptually reflect regional knowledge of broad vegetation types and serve as effective categories for communication among scientists, managers and the public in the Southwest. Recently, a new national classification of "ecological systems" has been developed by NatureServe to help addresses these regional entities (NatureServe 2003). Accordingly, NHNM has also attempted to incorporate the regional concepts of vegetation in the development of a comprehensive state classification. The state system keeps the alliance and association levels of the national classification but attempts to integrate regional formation and biome concepts from the above authors plus the NHNM wetland classification of Muldavin et al. (2000).

The plant associations are the fundamental unit of the classification. Ecologists use the concept of plant association to help describe and recognize patterns in the way vegetation occurs in the landscape. By grouping land areas based on the ability to support similar associations, general management observations and recommendations can be made for each grouping. In the past 30 years, resource managers have found that the classification of vegetation into plant associations has provided insight and the ability to predict vegetation changes in response to various disturbance processes. In addition, plant associations are used to define map unit components in the mapping process, providing the information linkage between vegetation spatial distribution and its ecology.

Table 3. Modified Domin-Krajina vegetation cover scale from Mueller-Dombois and Ellenberg (1974). Cover Class is the scalar value assigned in the field; Percent Canopy Cover is the range of cover the class represents; m^2/ 400 m^2 is the actual area represented by the cover class within the 400 m^2 plot; and Midpoint % Cover is the midpoint canopy cover value used in data analysis.

Cover Class	Percent Canopy Cover	m^2 /400 m^2	Midpoint % Cover
+0	[Undefined]	[Outside plot]	[0.001]
+	< .05	<0.04 m	0.01
1	< 0.1	≥ 0.04 & < 0.5	0.05
2	< 1	≥ 0.5 & < 4	0.5
3	1 – 4	≥ 5 & < 20	2.5
4	5 – 10	≥ 20 & < 40	7.5
5	10 - 25	≥ 40 & <100	17.5
6	25 - 33	≥ 100 & <132	29.0
7	33 - 50	≥ 132 & <200	41.5
8	50 - 75	≥ 200 & <300	62.5
9	> 75	≥ 300 m	87.5

Table 4. NHNM state vegetation classification hierarchy.

Level	Definition	Example
I	Formation type: growth form and structure of vegetation	Grassland
II	Primarily climate zones within formations	Xerophytic Grassland
III	Biomes or Ecological Systems	Chihuahuan Desert Scrub
IV	Regional floristically and environmentally related Alliance Groups	Chihuahuan Broadleaf Evergreen Desert Scrub
V	Alliance. A group of plant associations characterized by a common dominant(s) and/or diagnostic species	*Larrea tridentata* Shrubland Alliance
VI	Plant Association: fundamental unit of vegetation characterized by a set of dominant and/or diagnostic species from any stratum	*Larrea tridentata/Muhlenbergia porteri* Shrubland

Map Development

Image Acquisition and Processing

Two different sets of imagery were used in the vegetation mapping – digital aerial photographs (USGS DOQs) and satellite imagery (Landsat). The two data sets have contrasting advantages and disadvantages with the DOQs having a one-meter spatial resolution as opposed to Landsat's spatial resolution of 30 m. On the other handm, Landsat's spectral resolution covers the near and mid-infrared wavelengths, important regions for differentiating vegetation and the underlying soil reflectance responses, while the DOQs roughly divide the spectrum from the visible green to near unfra-red wavelengths (Table 5).

The air photos used specifically were color-infrared (CIR) digital orthophoto quadrangles originally acquired under the United States-Mexico Transboundary Aerial Photography and Mapping Initiative. The project area had been flown at two distinctively different dates (February 1, 2003 and March 23, 2003) creating photographs of highly contrasting radiometry for the western half versus the eastern half mainly from different phenology. Due to this, the two sets of flightlines could not be mosaicked without creating a noticeable impact on the classification. In order to compensate for this, the histogram for each air photo band (green, red, NIR) of each half was separately matched to the Landsat band representing the same wavelengths from a scene acquired July 2, 2002 which covered the entire project area. This made the radiometry of the two halves much more similar and these modified DOQs were then mosaicked together into one image. This mosaic was resampled to two-meter spatial resolution as the detail provided by the finer spatial resolution data was considered unnecessary for resolving plant communities, whereas the savings in disk space and processing time was considerable.

Table 5. Thematic Mapper Landsat band descriptions.

Landsat Band	Wavelength (μms)	Surface Response
1	Visible Blue (0.45-0.52)	Absorption by most materials except saline or sandy soils
2	Visible Green (0.52-0.6)	Minor green vegetation reflectance peak
3	Visible Red (0.63-0.69)	Green vegetation absorption, but senescent vegetation reflectance and iron-stained soils reflect in these wavelengths
4	Near-Infrared (0.76-0.9)	Green vegetation reflectance peak
5	Mid-Infrared (1.55-1.75)	Woody vegetation has less reflectance than herbaceous vegetation due to shadowing
7	Mid-Infrared (2.08-2.35)	Hydrated vegetation, wet soil and clayey soils have strong absorption features in these wavelengths

Two Landsat images were acquired over BWWSA - the July 2, 2002 scene mentioned above and a September 20, 2002 scene. These were used to emphasize the phenological differences across the seasons. For example, warm-season grasses will be senescent in early July but green in late summer (September 20, 2002), whereas there would be very little difference in creosotebush green-up between the two times. Although these images were already geo-corrected, they were rectified again using the ortho-photo mosaic as a base to insure that the images overlaid directly onto the same sites in the ortho-photos; the Landsat images were also resampled to a 2 m spatial resolution in order to match the spatial resolution of the resampled ortho-mosaic.

Although the CIR air photos have limited spectral value, the ortho-photos provide valuable spatial detail. To quantify this spatial detail we created a texture image which enhances the amount of spectral change between neighboring image cells. In this case, a texture image was derived by averaging variance images representing three different scales or kernel sizes (3x3 cells - 36 m^2, 5x5 cells – 100 m^2, and 7x7 cells – 196 m^2). A variance image is an image of the variances, or the squares of the standard deviations in the values of the ortho-photos (Eq. 1), where **x** is the value of a particular pixel, **M** is the mean value for the moving window kernel, and **n** is the kernel size.

$$\text{Variance image} = \Sigma \left((x - M)^2/(n-1)\right) \qquad \text{(Eq. 1)}$$

In addition to the spectral bands, several vegetation indices were computed to enhance various vegetation or ecosystem characteristics. The four indices used were the Normalized Difference Senescent Vegetation Index (NDSVI) [Eq. 2], the Normalized Difference Vegetation Index (NDVI) [Eq. 3], a moisture index [Eq. 4], and a canopy structure index [Eq. 5].

$$\text{NDSVI} = ((\text{Band 7} - \text{Band 3}) / (\text{Band 7} + \text{Band 3}) + 1) * 100 \qquad \text{(Eq. 2)}$$

$$\text{NDVI} = ((\text{Band 4} - \text{Band 3}) / (\text{Band 4} + \text{Band 3}) + 1) * 100 \qquad \text{(Eq. 3)}$$

$$\text{Moisture index} = ((\text{Band 5} - \text{Band 7}) / (\text{Band 5} + \text{Band 7}) + 1) * 100 \qquad \text{(Eq. 4)}$$

$$\text{Structure index} = ((\text{Band 4} - \text{Band 5}) / (\text{Band 4} + \text{Band 5}) + 1) * 100 \qquad \text{(Eq. 5)}$$

Band ratios, in general, work by contrasting reflectance peak highs against absorption lows to generate unique surface features. Due to the potential differences between image data ranges, the difference between bands is normalized against the total data range of the image bands. The adding of “1” and multiplying by “100” in each equation takes the original result, which would be a positive or negative fractional value centered on 0, and converts it into a positive integer value centered on 100. The NDSVI enhances the spectral differences of senescent vegetation (specifically grasses), which have a relatively low reflectance response in the red wavelengths and a high reflectance in the mid-infrared wavelengths. The NDVI emphasizes vigorous green plant growth by contrasting strong chlorophyll reflectance in the near-infrared wavelengths against chlorophyll absorption in the visible red wavelength. The moisture index contrasts relatively high reflectance values in the shorter wavelength section of the mid-infrared against strong absorption at the longer wavelength end of the mid-infrared by water molecules found in soil and vegetation. The structure index enhances more shadowing and some innate water response in plants. The final image used in image classification was created combining all of these separate images into one image file with 20 image bands (Table 6).

Image Classification

To construct the vegetation map, a “supervised” image classification procedure was used based on ground-cover characterization. For each vegetation plot representing a given plant association (seed), the image spectral characteristics (signatures) in the immediate area of a plot were collected. The seeds for each plant association are considered together and a maximum-likelihood classification algorithm used to classify the entire image into its component plant associations. Hence, the selection of plots to construct the spectral

Table 6. Sources for each band in image classification file.

Image Band	Band Description
1	Air Photo Visible Blue Wavelengths
2	Air Photo Visible Green Wavelengths
3	Air Photo Visible Red Wavelengths
4	July 2 2002 Landsat Near-Infrared
5	July 2 2002 Landsat Mid-Infrared
6	July 2 2002 Landsat Mid-Infrared
7	September 20 2002 Landsat Near-Infrared
8	September 20 2002 Landsat Mid-Infrared
9	September 20 2002 Landsat Mid-Infrared
10	Visible Green Texture
11	Visible Red Texture
12	Near-Infrared Texture
13	July 2 2002 NSVDI
14	July 2 2002 NDVI
15	July 2 2002 Moisture
16	July 2 2002 Structure
17	September 20 2002 NSVDI
18	September 20 2002 NDVI
19	September 20 2002 Moisture
20	September 20 2002 Structure

signatures is critical in the classification process. Vegetation plots that were considered transitional among plant associations and those with irregular spectral characteristics were not used. A total of 25 plots were used in this initial seeding process. Eight additional seeds from the draft map validation field visit were used to modify the map based on the second field trip to the study area.

RESULTS

Noxious Weed Survey

African rue (*Peganum harmala*) and saltcedar (*Tamarix ramosissima*) are plant species targeted by the New Mexico Department of Agriculture as noxious weeds and found within the wellfield study area. The African rue and saltcedar are Class B and Class C weeds, respectively. Class B weeds are typically geographically limited to portions of the state where infestations are severe. State regulations require management plans designed to contain the infestation and stop any further spread of this African species (Figure 3). Class C species are considered widespread throughout the state; control of further infestations is to be determined at a local level. Additionally, Lehmann's lovegrass (*Eragrostis lehmanniana*) an introduced, African invasive species, was found at several of the wellsites. Although not listed as a noxious weed, the long-term impact to Chihuahuan Desert natural biodiversity is unknown. Similarly, *Cynodon dactylon* (Bermudagrass), while not listed yet in New Mexico, is listed in four other states as either noxious or invasive (Utah, California, Arkansas, and Kentucky). We identified nine sites where these invasive species were found. The invasives were typically found in highly disturbed sites such as the wellheads themselves or along roads (Figure 4). While we found no invasive species within our vegetation plots, further vehicular disturbances into undisturbed sites may potentially lead to further spread of these invasives.

Figure 3 African rue (*Peganum harmala*), a noxious weed of concern in Boles Wells Well System Annex, southern portion.

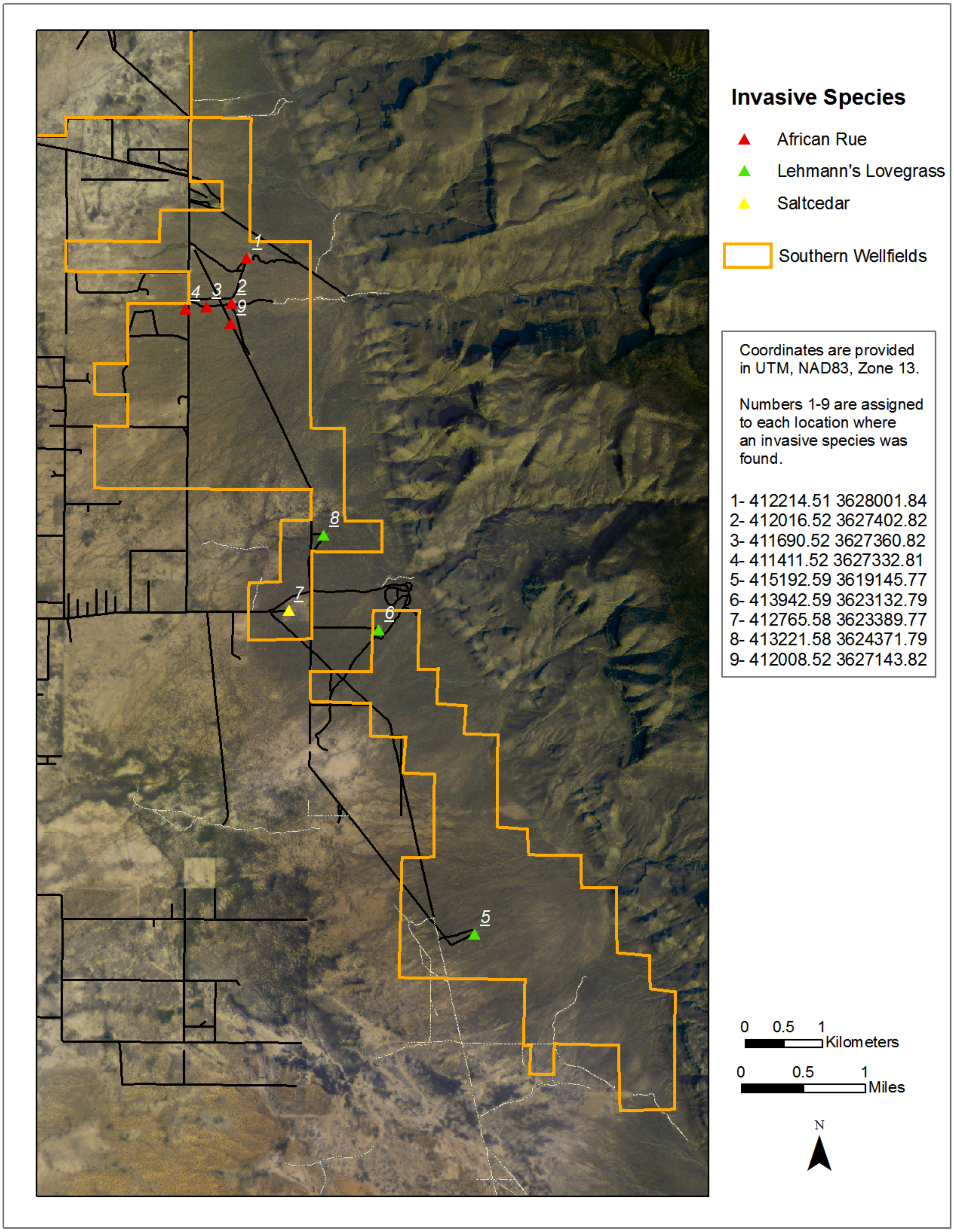

Figure 4. Invasive species locations within the BWWSA, southern portion.

Vegetation Classification

Ten plant associations (PA) among four alliances were identified for the southern portion of BWWSA (Table 7). The vegetation is dominated by Chihuahuan Desert Scrub primarily represented by the *Larrea tridentata* (creosotebush) Shrubland Alliance along with *Fouquieria splendens* (ocotillo) and *Parthenium incanum* (mariola) shrublands. The *Larrea* communities are generally distributed along a topographic gradient with the *Larrea tridentata-Flourensia cernua*/Sparse Shrubland and *Larrea tridentata/Muhlenbergia porteri* Shrubland association occurring near the foot of the alluvial fan piedmont bajada, and, in some areas, extending out into the basin floor. In the *Larrea tridentata-Flourensia cernua*/Sparse PA the canopy approaches 40% cover with *Larrea* and *Flourensia cernua* (tarbush) as codominants. The understory is typically very sparse, with only a few scatted forbs or grasses. In contrast, the *Larrea tridentata/Muhlenbergia porteri* PA has a grassy ground cover dominated by *M. porteri* where cover averages 30% but reach as high as 50%, filling in the inter-shrub spaces.

Further upslope onto the mid portion of the bajada, the *Larrea tridentata/*Sparse Shrubland tends to dominate, with or without *Prosopis glandulosa* (honey mesquite) as a co-dominant. While typically shrub canopies are typically about 40% cover, they can range as high as 60%. Grasses and forbs are few or absent and either exposed soils or gravel desert pavements occupy the inter-shrub spaces. Interspersed with this association is *Larrea tridentata-Parthenium incanum* Shrubland which is more diverse and characterized by the subshrub *Parthenium incanum* (mariola) distributed in the spaces between the *Larrea* along with *Gutierrezia sarothrae* (broom snakeweed), and various admixtures of cacti, particularly *Opuntia* (*O. engelmannii, O. macrocentra,* and *O. leptocaulis*). The *Larrea tridentata-Parthenium incanum* PA is typically found on rockier sites and becomes more prevalent near the top of the bajada where it is found in a complex mosaic with the *Larrea tridentata-Fouquieria splendens* and *Fouquieria splendens-Parthenium incanum* associations. These associations can be quite diverse, particularly with respect to cacti, and the area of the upper bajada and lower mountain footslopes form what is locally referred to as a "cactus belt" (Figure 5). Besides the *Opuntia*, other cacti include *Echinocereus dasyacanthus, Echinocereus stramineus, Echinocactus horizonthalonius, Escobaria* spp., and *Mammillaria grahamii*. Along with the tall *Fouquieria splendens* (ocotillo), conspicuous *Yucca torreyi* (Torrey's yucca) dot the landscape and tend to define the limits of the cactus belt.

Figure 5. The "cactus belt" along the upper bajada of the San Andres wellfield.

Table 7. Vegetation classification hierarchy for Boles Wells Water System Annex, Southern Portion, Holloman Air Force Base, New Mexico. The lowest level is the plant association (see Table 4), but there are two lower-level phases indicated. The plant association scientific name is provided, followed by the common name; "Confid" refers to the status of the plant association where: 1 = established type represented by five or more plots; 2= provisional represented by 3-5 plots; and 3 = new represented by one to two plots; " Plots" are the number of plots in the dataset for that association.

Classification Hierarchy	Confid.	Plots
I. Upland		
II. Shrubland		
III. Xerophytic Shrubland		
IV. Chihuahuan Desert Scrub		
V. Chihuahuan Broadleaf Deciduous Desert Scrub		
VI. *Fouquieria splendens* Shrubland Alliance (Ocotillo Shrubland Alliance)		
Fouquieria splendens-Parthenium incanum Shrubland (Ocotillo-Mariola Shrubland)	1	1
V. Chihuahuan Broadleaf Evergreen Desert Scrub		
VI. *Larrea tridentata* Shrubland Alliance (Creosotebush Shrubland Alliance)		
Larrea tridentata/Muhlenbergia porteri Shrubland (Creosotebush/Bush Muhly Shrubland)	1	2
Larrea tridentata/Sparse Shrubland; *Prosopis glandulosa* Phase (Creosotebush/Sparse Undergrowth Shrubland; Honey Mesquite Phase)	1	15
Larrea tridentata/Sparse Shrubland (Creosotebush/Sparse Undergrowth Shrubland)	1	5
Larrea tridentata-Flourensia cernua/Sparse Shrubland (Creosotebush-Tarbush/Sparse Undergrowth Shrubland)	1	1
Larrea tridentata-Fouquieria splendens Shrubland (Creosotebush-Ocotillo Shrubland)	2	2
Larrea tridentata-Parthenium incanum Shrubland; *Prosopis glandulosa* Phase (Creosotebush-Mariola Shrubland Honey Mesquite Phase)	1	7
Larrea tridentata-Parthenium incanum Shrubland (Creosotebush-Mariola Shrubland)	1	5
Larrea tridentata-Parthenium incanum Shrubland; *Gutierrezia sarothrae* Phase (Creosotebush-Mariola Shrubland; Snakeweed Phase) 1, 1		
V. Chihuahuan Microphyllous Desert Scrub		
VI. *Parthenium incanum* Shrubland Alliance (Mariola Shrubland Alliance)		
Parthenium incanum/Viguiera stenoloba Shrubland (Mariola/Skeletonleaf Goldeneye Shrubland)	1	1
I. Riparian/Wetlands		
II. Scrub-Shrub Wetland		
III. Broad-Leaved Deciduous Scrub-Shrub Wetland		
IV. Broad-leaved Deciduous Scrub-Shrub Wetland, Intermittently Flooded		
V. Lowland Broad-leaved Deciduous Shrub Wetland, Intermittently Flooded		
VI. *Chilopsis linearis* Shrubland Alliance (Desert Willow Shrubland Alliance)		
Chilopsis linearis/Fallugia paradoxa Shrubland (Desert Willow/Apacheplume Shrubland)	1	1
VI. *Viguiera stenoloba* Shrubland Alliance (Skeletonleaf Goldeneye Shrubland Alliance)		
Viguiera stenoloba-Porophyllum scoparium Shrubland (Skeletonleaf Goldeneye-TransPecos Poreleaf Shrubland)	3	2

The bajadas are cut throughout by large arroyos and small on-fan drainages. These support "arroyo riparian" communities such as the *Chilopsis linearis/Fallugia paradoxa* Shrubland, *Viguiera stenoloba-Porophyllum scoparium* Shrubland, *Parthenium incanum/Viguiera stenoloba* Shrubland. These too can be highly diverse, particularly in the shrub layer. Beside the dominants (*Chilopsis linearis* or desert willow, *Viguiera stenoloba* or skeletonleaf Goldeneye, *Porophyllum scoparium* or Trans-Pecos poreleaf), the arroyos can harbor *Aloysia wrightii* (Wright's beebrush), *Atriplex canescens* (fourwing saltbush), *Brickellia laciniata* (split leaf brickellbush), *Rhus microphylla* (littleleaf sumac), *Condalia warnockii* (Warnock's snakewood), *Flourensia cernua*, and *Prosopis glandulosa*. Along with the many shrubs are admixtures of some 20 forb and grass species. The complex structure and diversity of these communities adds significant heterogeneity to the landscape beyond what their limited aerial coverage would suggest. Furthermore, the relatively mesic environments and vertical structural complexity likely provide key habitat for wildlife, particularly birds.

Vegetation Map

Using the vegetation classification as a foundation, we have developed a vegetation map containing 11 mapping units (Table 8). The map has been produced as a single sheet at the original target scale of 1:24,000 that covers both the Douglas and San Andres wellfields (Map Sheet 1), and as two sheets at 1:12,000 covering each wellfield separately (Map Sheets 2 & 3. respectively). While the map can be projected at finer scales in a GIS, we would caution against application at finer scales because of the limits posed by multiple processing steps. which that include spatial integration of satellite imagery and aerial photography, geometric correction of images, and original resolution differences. More importantly, even though the minimum map delineation is small at 0.1 ha, the focus should remain on the large-patch pattern in any interpretation (>0.5 ha).

Map unit descriptions for each map follow. For each unit, the primary and secondary components are listed along with inclusions. Primary components are those plant associations listed in Table 7 that together comprise the majority of the unit. Secondary components are minor associations that can occupy at least 10% of the unit, but are not dominants. Inclusions are associations that occupy less than 10% of the area. Plant associations are also ordered by their importance within component groups.

Table 8. Vegetation map units for the Boles Wells Water System Annex (Southern Portion) Vegetation Map.

Map Unit #	Map Unit Name	Hectares	Acres	%
1	Sparse Creosotebush Shrubland	618.9	1529.4	28.6
2	Sparse Creosotebush Shrubland with Mesquite Phase	1067.4	2637.5	49.4
3	Creosotebush/Mariola Shrubland	40.4	99.8	1.9
4	Roads	68.9	170.3	3.2
5	Creosotebush-Ocotillo Shrubland	214.2	529.2	9.9
6	Creosotebush-Tarbush Shrubland	3.9	9.6	0.2
7	Ocotillo/Mariola Shrubland	17.3	42.7	0.8
8	Creosotebush/Bush Muhly Shrubland	51.0	126.1	2.4
9	Arroyo Riparian	42.7	105.4	2.0
10	Non Vegetated	16.5	40.7	0.8
11	Disturbance	20.5	50.6	0.9
	Total	2161.6	5341.4	100

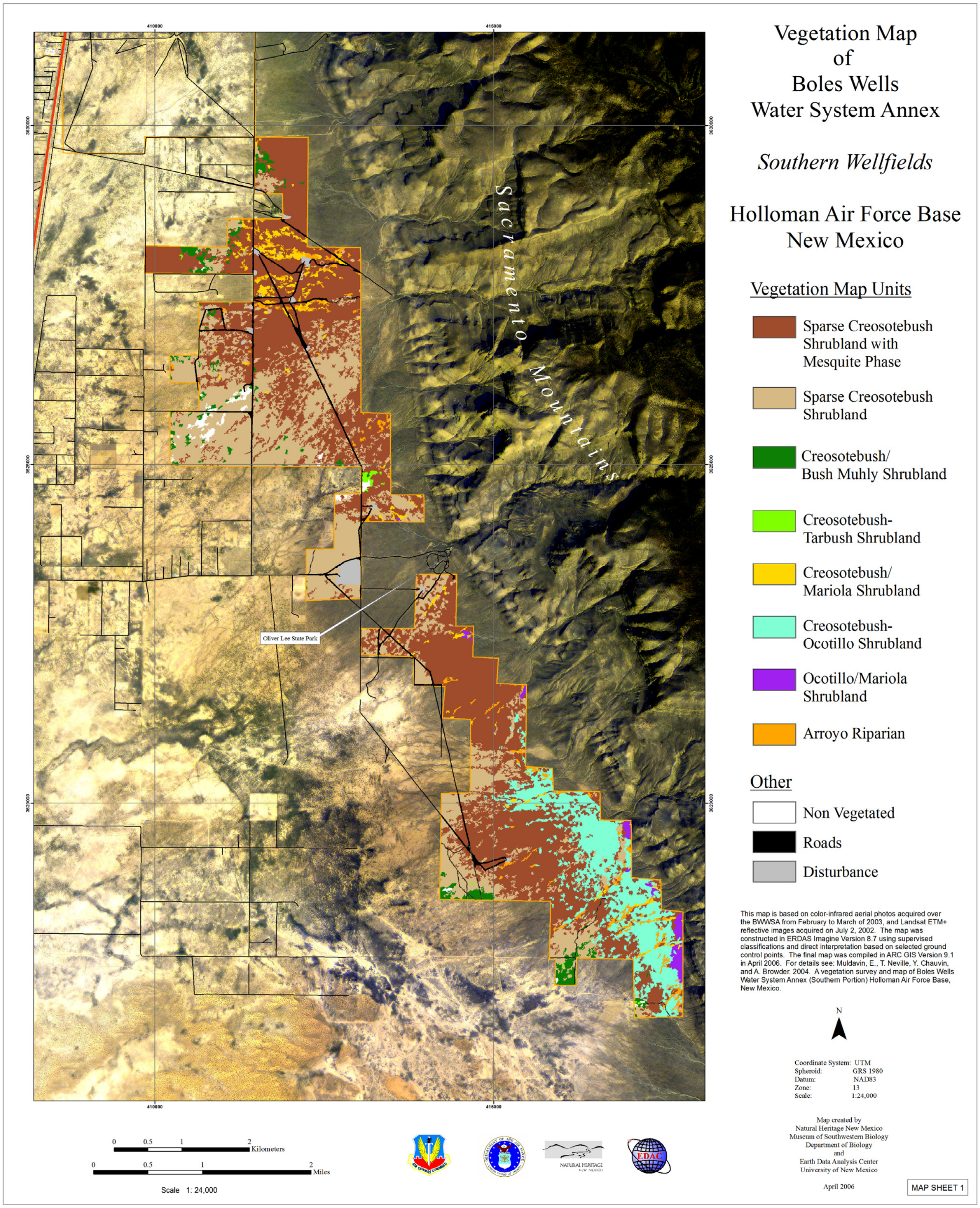

Figure 6. Vegetation Map of Boles Wells Water System Annex (Southern Portion).

Map Unit Descriptions

Sparse Creosotebush Shrubland	**1**
Acres: 1529.4	**Ha:** 618.9
Primary Components: Creosotebush/Sparse PA, Typic Phase	
Secondary Components: Creosotebush/Sparse PA, Mesquite Phase	
Inclusions: Creosotebush/Bush Muhly PA Creosotebush-Tarbush PA	
Distribution: A major shrubland unit within both Douglas and San Andres wellfields, but particularly common on the lower bajada of Douglas. Nickel is the most common soil.	

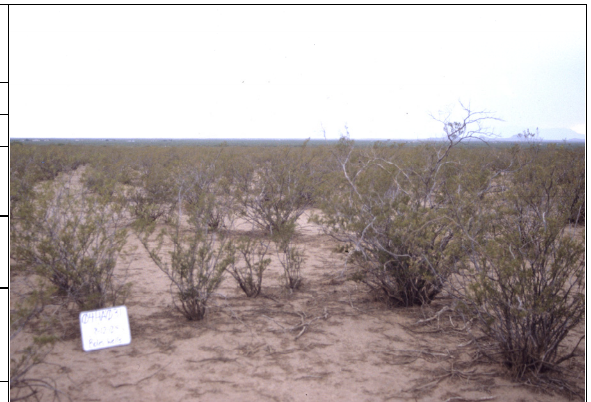

Figure 7. Plot 04HA031 facing west. Note the exposed soil in the inter-shrub spaces and little or no herbaceous cover.

Sparse Creosotebush Shrubland with Mesquite	**2**
Acres: 2637.4	**Ha:** 1067.3
Primary Components: Creosotebush/Sparse PA, Mesquite Phase	
Secondary Components:	
Inclusions: Creosotebush/Sparse PA Creosotebush/Mariola PA	
Distribution: The most widespread shrubland unit within the wellfield found primarily from mid to upper bajada. Nickel and Tencee are the common soils.	

Figure 8. Plot 04HA011 facing East-northeast. Note scattered honey mesquite, gravelly soil surface, and low herbaceous cover.

Creosotebush/Mariola Shrubland **3**

Acres: 99.8 | **Ha:** 40.4

Primary Components:
Creosotebush/Mariola PA

Secondary Components:

Inclusions:
Creosotebush/Sparse PA, Mesquite Phase
Desert willow/Apache plume PA

Distribution: Narrowly distributed unit found on upland alluvial fan terraces along arroyos, particularly in northern portion of Douglas wellfield. Often found within a complex mosaic with Creosotebush/Sparse PA, Mesquite Phase mostly on Tencee soils.

Figure 9. Plot 04HA002 facing southwest. The unit is often associated with small on-fan drainages along the bajada.

Creosotebush-Ocotillo Shrubland **5**

Acres: 529.2 | **Ha:** 214.2

Primary Components:
Creosotebush-Ocotillo PA

Secondary Components:
Creosotebush/Sparse PA, Mesquite Phase

Inclusions: Ocotillo/Mariola PA
Creosotebush/Mariola PA

Distribution: Found primarily in the south portion of the San Andres wellfield, this shrubland unit occurs on upper bajada slopes on Tencee soils.

Figure 10. Plot 04HA025 facing southwest near the top of the bajada in the San Andres wellfield.

Creosotebush-Tarbush Shrubland	**6**	
Acres: 9.6	**Ha:** 3.9	
Primary Components: Creosotebush-Tarbush PA		
Secondary Components:		
Inclusions: Creosotebush/Bush Muhly PA		
Distribution: Small patches of this shrubland unit are scattered in depressions at the margins of the lower bajada onto the alluvial plain. A minor component within the wellfield that is associated with Mimbres soils.		

Figure 11. Plot 04HA043 facing south. Inter-shrub spaces are sparse and the soils are fine textured.

Ocotillo/Mariola Shrubland	**7**
Acres: 42.7	**Ha:** 17.3
Primary Components: Ocotillo/Mariola PA	
Secondary Components:	
Inclusions: Creosotebush-Ocotillo PA	
Distribution: A mixed sub-shrub and succulent unit that occurs on steep, colluvial sideslopes. A minor component found within the far southeastern portion of the San Andres wellfield. Restricted to the Lozier soils and rock outcrops.	

Figure 12. Plot 04HA038 facing southeast on rocky limestone hillslope in the southeastern portion of the San Andres wellfield.

Creosotebush/Bush Muhly Shrubland	**8**
Acres: 126.1	**Ha:** 51.0

Primary Components:
Creosotebush/Bush Muhly PA

Secondary Components:
Creosotebush/Sparse PA, Typic Phase

Inclusions:
Creosotebush-Tarbush PA

Distribution: The shrubland unit is found within the alluvial plain at the westerly margins within the wellfield boundaries. Stands typically occur on Prelo or Tome soils, and occasionally on Mimbres.

Figure 13. Plot 04HA022 facing southeast. Note the inter-shrub spaces are dominated by grasses, usually bush muhly.

Arroyo Riparian	**9**
Acres: 105.4	**Ha:** 42.6

Primary Components:
Desert willow/Apache plume PA

Secondary Components:

Inclusions: Creosotebush/Mariola PA

Distribution: In southwesterly drainages that are sparsely vegetated with arroyo riparian species including desert willow and apache plume.

Figure 14. Plot 04HA019 facing west and downstream within an on-fan arroyo.

Discussion

The vegetation map presented here of the southern portion of the Wells Water System Annex completes the mapping of vegetation for Holloman Air Force Base that began in 1995 with the mapping of the main base and the Boles Wells northern portion (Muldavin et al. 1997). These maps present the best picture to date of the current vegetation composition and pattern for installation lands and are intended to serve the environmental planning needs for the base over the next decade or so. However, vegetation is dynamic, and updates will periodically be needed to keep pace with the changes. Furthermore, mapping technologies are always improving, enhancing our capability to map with greater detail, accuracy, and speed. Accordingly, we would recommend remapping on a decadal basis to track trends of vegetation change in keeping with the military mission of ecosystem management of lands under their stewardship.

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APPENDIX A – BWWSA (SOUTHERN PORTION) PLANT SPECIES LIST

Table A-1. Plant species list for the Boles Well Water System (Southern Portion) vegetation map project. The list includes only those species found in vegetation plots and as part of the noxious weed survey. "LF" refers to lifeform strata: 1 = trees; 2 = tall shrubs (>0.5 m); 2.5 = dwarf shrubs (<0.5 m); 3 = grasses and grass-like plants (graminoids); and 4 = forbs. "Plants symbol" refers to the code from the PLANTS database (USDA-NRCS, 2006). The "NHNM acronym" is the respective code in the database provided in the Data Addendum CD. "Obs" refers to the number of occurrences in the database. "D" refers to duration: P = perennial; A = annual; and B = biennial. "O" refers to origin: native (N); Introduced (I); or Unknown (U). "N" indicates the status of the species as a noxious weed, e.g., Class B or C, according to the New Mexico Department of Agriculture, or as invasive as indicated in the PLANTS database.

LF	Species name	Common name	Family	Plants symbol	NHNM Acronym	Obs	D	O	N
1	Chilopsis linearis	desert willow	Bignoniaceae	CHLI2	CHILIN	1	P	N	
2	Aloysia wrightii	Wright's beebrush	Verbenaceae	ALWR	ALOWRI	7	P	N	
2	Atriplex canescens	fourwing saltbush	Chenopodiaceae	ATCA2	ATRCAN	2	P	N	
2	Brickellia laciniata	splitleaf brickellbush	Asteraceae	BRLA	BRILAC	4	P	N	
2	Condalia warnockii	Warnock's snakewood	Rhamnaceae	COWA	CONWAR	1	P	N	
2	Dasylirion wheeleri	common sotol	Agavaceae	DAWH2	DASWHE	3	P	N	
2	Ephedra trifurca	longleaf jointfir	Ephedraceae	EPTR	EPHTRI	2	P	N	
2	Fallugia paradoxa	Apache plume	Rosaceae	FAPA	FALPAR	3	P	N	
2	Flourensia cernua	tarbush	Asteraceae	FLCE	FLOCER	21	P	N	
2	Fouquieria splendens	ocotillo	Fouquieriaceae	FOSP2	FOUSPL	3	P	N	
2	Larrea tridentata	creosotebush	Zygophyllaceae	LATR2	LARTRI	45	P	N	
2	Opuntia engelmannii	cactus apple	Cactaceae	OPEN3	OPUENG	7	P	N	
2	Opuntia imbricata	tree cholla	Cactaceae	OPIM	OPUIMB	3	P	N	
2	Opuntia leptocaulis	Christmas cactus	Cactaceae	OPLE	OPULEP	10	P	N	
2	Porophyllum scoparium	TransPecos poreleaf	Asteraceae	POSC6	PORSCO	5	P	N	
2	Prosopis glandulosa	honey mesquite	Fabaceae	PRGL2	PROGLA	42	P	N	
2	Rhus microphylla	littleleaf sumac	Anacardiaceae	RHMI3	RHUMIC	1	P	N	
2	Tamarix ramosissima	saltcedar	Tamaricaceae	TARA	TAMRAM	1	P	I	C
2	Viguiera stenoloba	skeletonleaf goldeneye	Asteraceae	VIST	VIGSTE	9	P	N	
2	Yucca torreyi	Torrey's yucca	Agavaceae	YUTO	YUCTOR	14	P	N	
2.5	Dalea formosa	featherplume	Fabaceae	DAFO	DALFOR	2	P	N	
2.5	Echinocactus horizonthalonius	devilshead	Cactaceae	ECHO	ECHHOR	2	P	N	
2.5	Echinocereus coccineus	scarlet hedgehog cactus	Cactaceae	ECCO5	ECHCOC	6	P	N	
2.5	Echinocereus dasyacanthus	rainbow cactus	Cactaceae	ECDA	ECHDAS	6	P	N	
2.5	Echinocereus stramineus	strawberry hedgehog cactus	Cactaceae	ECST2	ECHSTR	3	P	N	
2.5	Echinocereus triglochidiatus	kingcup cactus	Cactaceae	ECTR	ECHTRI	2	P	N	
2.5	Ephedra torreyana	Torrey's jointfir	Ephedraceae	EPTO	EPHTOR	1	P	N	
2.5	Escobaria spp.	beehive cactus	Cactaceae	ESCOB	ESCOBA	1	P	N	
2.5	Gutierrezia sarothrae	broom snakeweed	Asteraceae	GUSA2	GUTSAR	9	P	N	
2.5	Mammillaria grahamii	Graham's nipple cactus	Cactaceae	MAGR9	MAMGRA	1	P	N	
2.5	Mammillaria grahamii var. grahamii	Graham's nipple cactus	Cactaceae	MAGRG4	MAMGRAG	1	P	N	

LF	Species name	Common name	Family	Plants symbol	NHNM Acronym	Obs	D	O	N
2.5	Menodora scabra	rough menodora	Oleaceae	MESC	MENSCA	7	P	N	
2.5	Opuntia macrocentra	purple pricklypear	Cactaceae	OPMA8	OPUMAC	17	P	N	
2.5	Opuntia phaeacantha	tulip pricklypear	Cactaceae	OPPH	OPUPHA	11	P	N	
2.5	Parthenium incanum	mariola	Asteraceae	PAIN2	PARINC	34	P	N	
2.5	Thymophylla acerosa	pricklyleaf dogweed	Asteraceae	THAC	THYACE	2	P	N	
3	Aristida purpurea var. nealleyi	Nealley's threeawn	Poaceae	ARPUN	ARIPURN	2	P	N	
3	Bothriochloa barbinodis	cane bluestem	Poaceae	BOBA3	BOTBAR	1	P	N	
3	Bouteloua curtipendula	sideoats grama	Poaceae	BOCU	BOUCUR	3	P	N	
3	Bouteloua eriopoda	black grama	Poaceae	BOER4	BOUERI	4	P	N	
3	Bouteloua gracilis	blue grama	Poaceae	BOGR2	BOUGRA	1	P	N	
3	Cynodon dactylon	bermudagrass	Poaceae	CYDA	CYNDAC	1	P	I	
3	Dasyochloa pulchella	fluffgrass	Poaceae	DAPU7	DASPUL	2	P	N	I
3	Elymus elymoides	bottlebrush squirreltail	Poaceae	ELEL5	ELYELY	1	P	N	
3	Eragrostis lehmanniana	Lehmann's lovegrass	Poaceae	ERLE	ERALEH	3	P	I	I
3	Erioneuron pilosum	hairy woollygrass	Poaceae	ERPI5	ERIPIL	1	P	N	
3	Muhlenbergia porteri	bush muhly	Poaceae	MUPO2	MUHPOR	12	P	N	
3	Muhlenbergia setifolia	curlyleaf muhly	Poaceae	MUSE	MUHSET	1	P	N	
3	Panicum hallii	Hall's panicgrass	Poaceae	PAHA	PANHAL	1	P	N	
3	Setaria leucopila	streambed bristlegrass	Poaceae	SELE6	SETLEU	1	P	N	
3	Sporobolus cryptandrus	sand dropseed	Poaceae	SPCR	SPOCRY	1	P	N	
3	Trichloris crinita	false Rhodes grass	Poaceae	TRCR9	TRICRI	1	P	N	
3	Tridens muticus	slim tridens	Poaceae	TRMU	TRIMUT	2	P	N	
4	Acourtia nana	desert holly	Asteraceae	ACNA2	ACONAN	2	P	N	
4	Amsonia longiflora	tubular bluestar	Apocynaceae	AMLO	AMSLON	1	P	N	
4	Argythamnia neomexicana	New Mexico silverbush	Euphorbiaceae	ARNE2	ARGNEO	1	A	N	
4	Astrolepis cochisensis	Cochise scaly cloakfern	Pteridaceae	ASCO42	ASTCOC	1	P	N	
4	Bahia absinthifolia	hairyseed bahia	Asteraceae	BAAB	BAHABS	3	P	N	
4	Cevallia sinuata	stinging serpent	Loasaceae	CESI	CEVSIN	2	P	N	
4	Chaetopappa ericoides	rose heath	Asteraceae	CHER2	CHAERI	1	P	N	
4	Eriogonum havardii	Havard's buckwheat	Polygonaceae	ERHA	ERIHAV	1	P	N	
4	Hibiscus denudatus	paleface	Malvaceae	HIDE	HIBDEN	2	P	N	
4	Lepidium spp.	pepperweed	Brassicaceae	LEPID	LEPIDI	6	A		
4	Lesquerella purpurea	rose bladderpod	Brassicaceae	LEPU2	LESPUR	1	P	N	
4	Oenothera brachycarpa	shortfruit eveningprimrose	Onagraceae	OEBR	OENBRA	1	P	N	
4	Peganum harmala	African rue	Zygophyllaceae	PEHA	PEGHAR	5	P	I	B
4	Senna bauhinioides	twinleaf senna	Fabaceae	SEBA3	SENBAU	1	P	N	
4	Stephanomeria pauciflora	brownplume wirelettuce	Asteraceae	STPA4	STEPAU	3	P	N	
4	Talinum aurantiacum	orange flameflower	Portulacaceae	TAAU	TALAUR	1	P	N	
4	Thymophylla pentachaeta	fiveneedle pricklyleaf	Asteraceae	THPE4	THYPEN	3	P	N	
4	Zephyranthes longifolia	copper zephyrlilly	Liliaceae	ZELO	ZEPLON	1	P	N	