A Vegetation Map

of the

Valles Caldera National Preserve, New Mexico

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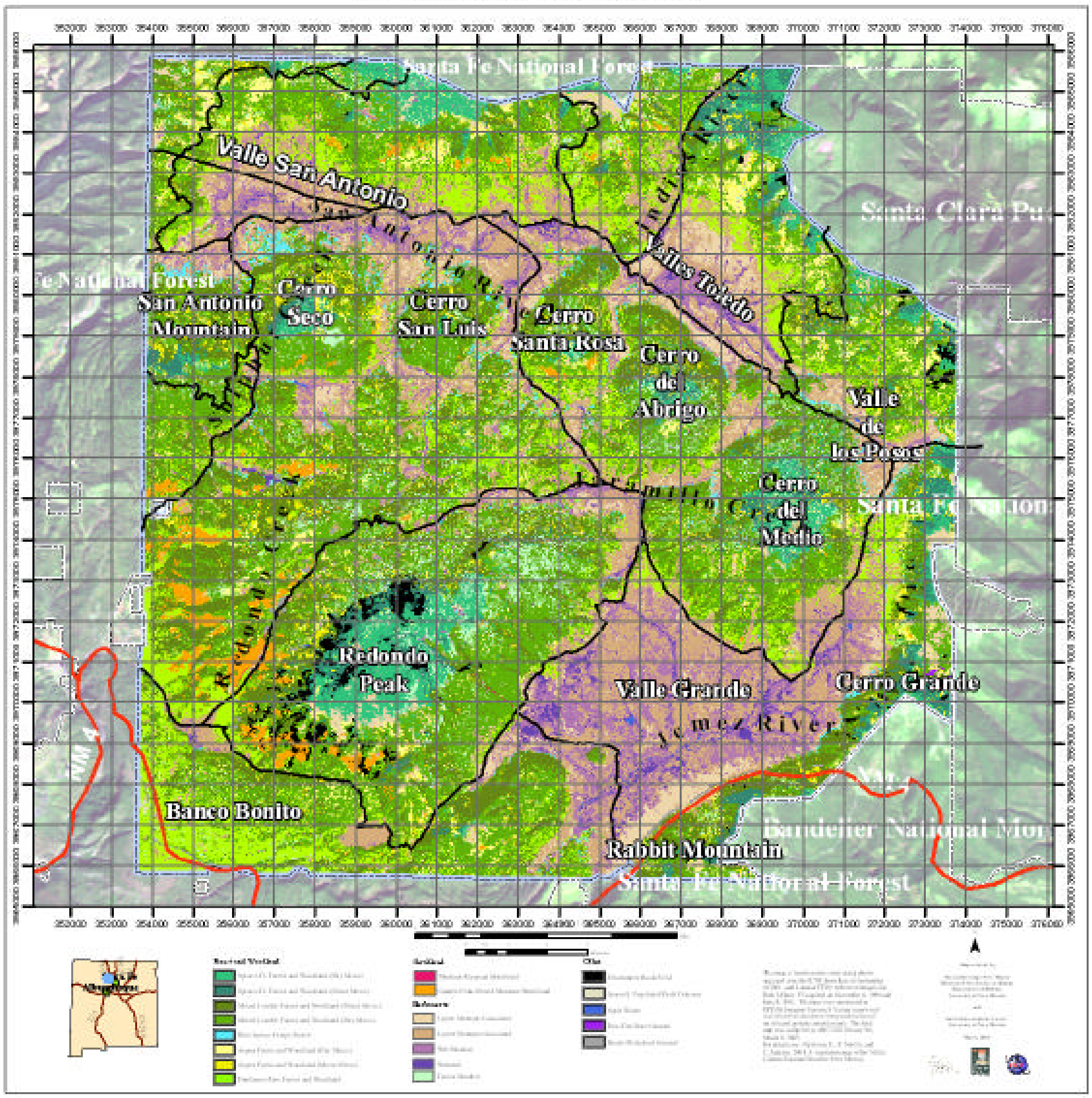

2005

A Vegetation Map of Valles Caldera National Preserve, New Mexico [1]

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2005

SUMMARY

To support the management and and sustainability of the ecosystems of the Valles Caldera National Preserve (VCNP), a map of current vegetation was developed. The map was based on aerial photography from 2000 and Landsat satellite imagery from 1999 and 2001, and was designed to serve natural resources management planning activities at an operational scale of 1:24,000. There are 20 map units distributed among forest, shrubland, grassland, and wetland ecosystems. Each map unit is defined in terms of a vegetation classification that was developed for the preserve based on 348 ground plots. An annotated legend is provided with details of vegetation composition, environment, and distribution of each unit in the preserve. Map sheets at 1:32,000 scale were produced, and a stand-alone geographic information system was constructed to house the digital version of the map. In addition, all supporting field data was compiled into a relational database for use by preserve managers.

Cerro La Jarra in Valle Grande of the Valles Caldera National Preserve (Photo: E. Muldavin)

[1] Final report submitted in July, 2005 in partial fulfillment of XXXXXX

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INTRODUCTION

The Valles Caldera National Preserve was established in 2000 to protect and manage nearly 89,000 acres (36,000 ha) of wildlands in northern New Mexico that are rich in natural resources and biodiversity. To support the management and sustainability of the preserve's ecosystems, a map of current vegetation was developed and is presented here. The mapping project was initiated in 2001 with a preliminary ecological assessment and vegetation survey to support the mapping process (Muldavin and Tonne 2003). In the first year, 101 vegetation plots were collected to quantitatively define the vegetation classification and to provide ground control for map development. At the same time, a digital ortho-rectified aerial photography and Landsat satellite imagery were processed and compiled into a geographic information system (GIS) in preparation for subsequent mapping. In 2002, an additional 273 plots were collected for a total of 374 ground control points. These were used in a mapping strategy that combined automated digital image classification of aerial photography/satellite imagery and direct image interpretation. The final map was designed to serve natural resources management planning activities at an operational scale of 1:24,000.

ACKNOWLEDGEMENTS

Funding was provided by a grant from the Valles Caldera National Preserve and the USGS Biological Resources Division, Fort Collins Science Center. Dedicated fieldwork on the part of Phil Tonne, Amanda Browder, Yvonne Chauvin, Jackie Smith, Paul Arbetan, Stacey Sekscienski, Elizabeth Milford, and Kyleb Wilde made the project possible. Rebecca Keeshen provided editorial assistance. Cover photo is of the Valle Grande from the preserve headquarters taken in August 2001.

STUDY AREA

The Valles Caldera National Preserve (VCNP) lies in north-central New Mexico in the heart of the Jemez Mountains (Figure 1). It is bounded primarily by Santa Fe National Forest lands with smaller units of Bandelier National Monument and Santa Clara Pueblo along its eastern flank. The preserve encompasses most of the original Baca Location No. 1 land grant except for the peripheral areas owned by the U.S. Forest Service (USFS), Bandelier NM, and Santa Clara Pueblo. The acreage is approximately 89,000 acres (36,000 ha). For more details on the history and landscape of the VCNP, see Muldavin and Tonne (2003).

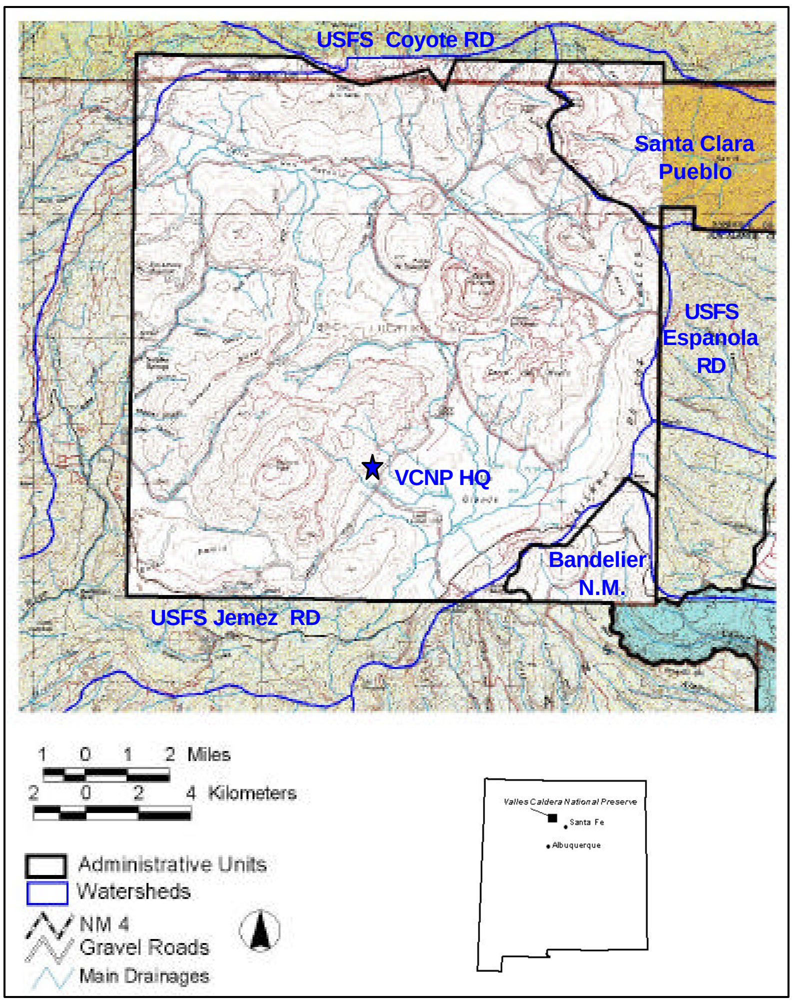

Figure 1. Valles Caldera National Preserve (VCNP) study area encompasses most of former Baca Location No. 1 (white) except for areas that were distributed to Bandelier National Monument, Santa Clara Pueblo, and the Coyote District of the Santa Fe National Forest.

MATERIALS AND METHODS

Vegetation Sampling and Classification

Over the course of two field seasons, 400 vegetation plots were collected to serve the purposes of vegetation classification and map development (a list of plots and locations is provided in Appendix A). The first year of sampling was focused on generating plots for developing the vegetation classification (see Muldavin and Tonne 2003). Hence, most 2001 plots were standard NHNM plots with complete floristic inventories and site characterization (100 plots). The second year was oriented towards maximizing the distribution of ground controls points to aid the mapping process. These ground control plots (XXX) contained only data sufficient to classify the plot to the plant association (dominant species and major site variables such as slope, aspect, and elevation). The details of plot data collection are provided in Muldavin and Tonne (2003).

Plots were distributed in such a way as to maximize the coverage of as many habitats as possible but within the logistical constraints of the preserve's rugged terrain (Figure 1). Using the digital ortho-rectified aerial photography in a GIS, polygons of homogeneous vegetation were identified and targeted for sampling if they were reasonably accessible by roads and trails and within a day's hike. Plots were most commonly located in "landscape clusters" whereby plots would be optimally distributed in such a way as to represent the local vegetation pattern and geomorphic configuration. For example, within a watershed patches of homogenous vegetation on north versus south slopes might be sampled along with that in the drainages or the ridgelines.

All vegetation and site data were entered into a Microsoft Access database and quality controlled through error checking computer routines and manual read-backs. A table of all plots, their plant association classification, and location is provided in Appendix A. An updated species list is provided in Appendix B. The databases along with complete records for all plots are provided in a Data Addendum on CD.

Muldavin and Tonne (2003) developed a preliminary vegetation classification for the preserve based on the 2001 data. This classification was updated by using the additional data from 2002 and reanalyzing the entire dataset using detrended correspondence analysis (DCA) and standard tabular comparison techniques (Mueller-Dombois and Ellenberg 1974). The updated vegetation classification is provided in Appendix C.

Map Development

The vegetation map was developed using a strategy that combined and automated digital image classification of aerial photography and satellite imagery along with direct analog image interpretation. Initially, the aerial photography and satellite imagery were processed and entered into a GIS along with ancillary spatial layers. Then a series of automated unsupervised and supervised classifications was conducted followed by fine-scale map refinement using direct image interpretation .

Aerial Photography Processing

As a first step in the mapping process, a digital ortho-rectified aerial photo image was constructed based on 267 natural-color aerial photographs over VCNP from June to September, 2001. These photographs were scanned into a digital image format with three bands (Band 1 displaying visible red reflectance, Band 2 displaying visible green reflectance, and Band 3 displaying visible blue reflectance) and at an 800-dpi pixel resolution. The ortho-rectification process combines the film geometry, camera geometry and ties it to the horizontal coordinate system and elevation through the solution of three co-linear equations. In this case the camera geometry was defined by the camera report that came with the project and tied to the film by the eight fiducial points located on each photo frame. Each frame was then tied to the ground by locating nine distinctly separated Ground Control Points (GCPs) on a one-meter spatial resolution panchromatic (black and white) USGS Digital Ortho-photo Quarter Quad (DOQQ) acquired over the area in 1996. Simultaneously, the elevation at the GCPs was also entered from the USGS ten-meter spatial resolution Digital Elevation Model (DEM). Using this process these photos were rectified to a 0.5-meter spatial resolution in a Universal Transverse Mercator projection, Zone 13, Clarke 1866 Spheroid, 1927 North American Datum.

The outcome was 267 ortho-rectified photos over the VCNP that were map-oriented and usable in a GIS, with each covering approximately 13 square kilometers (5 square miles). In order to display the whole study area as one image, the ortho-photos were then combined into one ortho-photo mosaic. To produce a seamless and uniform mosaic with minimum distortion several processing steps were required. To minimize radial illumination distortion (due to the ground directly underneath the camera reflecting the most back to the film causing a hot spot, and the edges reflecting back less making them darker), a contrast balance algorithm was applied to each photo. To minimize geometric distortion, the area used in each photo was limited to as close to the center as possible while still allowing overlap with the next photo. There can also be differences in solar illumination from photo to photo because each flight line is acquired at a different time, resulting in different intensity and shadowing. In this case, there were several months between some lines that not only also generated strong differences among photos due to differential cloud cover and shadows but also vegetation phenology changes (greenness differences). To compensate for this, the flight lines were matched by spectral histograms to minimize contrast, and then feathered together in the overlap zone. The feathering process was particularly good at reducing the contrast across the mosaic as a whole, but there can be ghosting of images in the overlap zone, particularly in places where the trees appear at different angles between photos.

The resulting mosaic 0.5-m spatial resolution generated a very large digital file (approximately three gigabytes). While desirable for photo-interpretation, a file of this size is unwieldy and overly detailed for use in the follow-on automated classification process, and even simple processes such as displaying it in a viewer become cumbersome. Therefore, the mosaic was resampled down to a two-meter resolution, which reduced the size of the file by eight times and also helped to mute some of the remaining contrast problems. The two-meter mosaic was then subjected to a simple unsupervised, color-clustering image analysis in ERDAS Imagine software to create three functional group classes – forest, grassland, and wetland. These classes were then used as masks to create separate images used in subsequent image classifications (i.e., separate maps stratified by forest, grassland and wetlands).

Satellite Image Processing

To aid in the vegetation mapping process, two multi-spectral satellite Landsat Enhanced Thematic Mapper$^+$ (ETM$^+$) images were also used. The advantages and disadvantages of using Landsat imagery are almost the opposite of using air photos; ETM$^+$'s spatial resolution (30 meters) is much coarser than that of the air photo, but ETM$^+$'s spectral resolution covers the near and mid-infrared wavelengths which are important regions for differentiating vegetation and the underlying soil reflectance responses (Table 1). In addition, reflectance is much more uniform across the image that with ortho-mosaic photography. For the VCNP, two images were acquired from November 6, 1999 and June 4, 2001 to emphasize phenological differences across the seasons; for example, both deciduous (aspens and oaks) and coniferous (pines and firs) trees will be green in the June image, but only the conifers will be green in the November image. In addition, the years 1999 and 2001 bracket the Cerro Grande fire to help identify the fire damage.

Table 1. Landsat ETM+ band descriptions (Jensen, 2004).

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

Although the ETM$^+$ images were already geo-corrected, they were rectified again using the ortho-photo mosaic as a base to insure that the images overlayed directly onto the same sites in the ortho-photos; the ETM$^+$ images were also resampled to a 2 m spatial resolution. The images were projected into the same projection as the ortho-photos.

Band Ratioing

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. 1], the Normalized Difference Vegetation Index (NDVI) [Eq. 2], a moisture index [Eq. 3], and a canopy structure index [Eq. 4]. These were computed as follows:

NDSVI = ((Band 7 – Band 3) / (Band 7 + Band 3) + 1) * 100 (Eq. 1)

NDVI = ((Band 4 – Band 3) / (Band 4 + Band 3) + 1) * 100 (Eq. 2)

Moisture index = ((Band 5 – Band 7) / (Band 5 + Band 7) + 1) * 100 (Eq. 3)

Structure index = ((Band 4 – Band 5) / (Band 4 + Band 5) + 1) * 100 (Eq. 4)

Band ratios, in general, are designed to divide a reflectance peak against an absorption low for 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 around 0 and turns it into a positive integer value centered around 100. The NDSVI enhances the spectral differences of senescent vegetation (specifically grasses) that 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 ratioing a strong chlorophyll reflectance in the near-infrared wavelengths against chlorophyll absorption in the visible red wavelength (Jensen, 2000). The moisture index ratios relies on the relatively high reflectance values in the shorter wavelength part of the mid-infrared against strong absorption at the longer wavelength end of the mid-infrared by water molecules found in soil and vegetation (Jensen, 2000). The structure index enhances shadowing and leaf water content in plants (Jensen, 2000).

Texture Image

As noted above, the ortho-photos have limited spectral value due to image modifications in the creation of the ortho-mosaic, but they do provide valuable spatial detail. To analytically quantify this spatial detail a texture analysis conducted that 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). The variance image was computed as shown in Equation 5:

Variance image = S $((x – M)^2/(n-1))$ (Eq. 5)

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 (Leica, 2003). The lower the variance, the smoother the image is in the local area of the kernel, and vice versa, high variance represents roughness or boundaries.

Final Image Compilation

All of the source and derived layers were then compiled into a single image re-sampled to a two-m spatial resolution. This created a final image with 18 image bands, as listed in Table 2, and was necessary in order to make all of these bands available to the classification process.

Table 2. Image file setup for images used in classification.

Image Bands	Band Description
Band 1	Air Photo Visible Red Wavelengths
Band 2	Air Photo Visible Green Wavelengths
Band 3	Air Photo Visible Blue Wavelengths
Band 4	Air Photo Texture
Band 5	November 6 1999 Landsat Near-Infrared
Band 6	November 6 1999 Landsat Mid-Infrared
Band 7	November 6 1999 Landsat Mid-Infrared
Band 8	June 4 2001 Landsat Near-Infrared
Band 9	June 4 2001 Landsat Mid-Infrared
Band 10	June 4 2001 Landsat Mid-Infrared
Band 11	November 6 1999 NSVDI
Band 12	November 6 1999 NDVI
Band 13	November 6 1999 Moisture
Band 14	November 6 1999 Structure
Band 15	June 4 2001 NSVDI
Band 16	June 4 2001 NDVI
Band 17	June 4 2001 Moisture
Band 18	June 4 2001 Structure

Image Classification

The image classification procedure synthesizes satellite image data, field plot data, and ancillary data derived principally from GIS layers. A supervised classification strategy was adopted to create the vegetation map based on vegetation community types. This strategy develops spectral classes based on ground locations with known characteristics such as vegetation composition and landscape context.

In a supervised classification strategy, the field data are applied to the image data through an interactive process called "seeding." In the seeding process, a two-meter image pixel at the field plot location was selected and its spectral characteristics were used to gather other similar contiguous pixels to create a statistical model or "seed" of the field plot. The seeding algorithm (Eq. 6) searches around that point within user-defined parameters that contain a seed within: 1) a certain distance, 2) a certain area, and 3) a certain spectral distance defined as:

$$SD = \sqrt{\sum(\mu - X)^2} \quad (\textbf{\textit{Eq. 6}}),$$

where **SD** is the spectral distance between a new pixel and the mean of the current seed group pixels across all bands, m is the mean of the seed pixel group for each image band, and C is the spectral value of the new pixel for each band (Leica, 2003).

In an iterative process, we constructed the best seed models by adjusting the parameters and comparing the resulting pixel distributions against the terrain models and the original imagery. A seed was developed for each field plot using the plot GPS location and associated field information. The seed's maximum area was initially defined by the size of the vegetation community occurrence as determined in the field. The actual seed was then defined by increasing the spectral distance iteratively until the spectral signature collected within the seed generated a covariance matrix that could be inverted, a requirement for the maximum likelihood decision rule used later in the actual classification.

The seed shape and location were checked against field notes and maps, and by direct interpretation of the seed in the image on the screen, in conjunction with the terrain models. Each seed was saved in a signature file with its field plot number, mean values for each image band, variance, number of pixels that were used to create the seed, and minimum and maximum values.

Statistics gathered in the seeding process were used to perform a supervised classification. Supervised classifications are based on a maximum likelihood decision rule containing a Bayesian classifier that uses probabilities to weight the classification towards particular classes. In this study, the probabilities were unknown, so the maximum likelihood equation (Eq. 7) for each of the classes is given as:

$$D = [0.5\ln(cov_c)]-[0.5(X-M_c)^T * (cov_c^{-1})*(X-M_c)] \quad (\textbf{\textit{Eq.7}}),$$

where **D** is the weighted distance, $\mathbf{cov_c}$ is the covariance matrix for a particular class, C is the measurement vector of the pixel, $M_{\mathbf{c}}$ is the mean vector of the class and $^{\mathbf{T}}$ is the matrix transpose function (Leica, 2003). Each pixel is then assigned to the class with the lowest weighted distance. This technique assumes the statistical signatures have a normal distribution.

This decision rule is considered the most accurate, because it not only uses a spectral distance (as the minimum distance decision rule), but it also takes into account the variance of each of the signatures. The variance is important when comparing a pixel to a signature representing, for example, a grassland community, which might be fairly homogeneous, to a forest class, which is more heterogeneous.

To locate problems, informal accuracy checking was used based on field data, air photos, personal knowledge of a site and other ancillary data. If a distribution problem with a seed was detected, the seed was rechecked to insure it was properly modeling the vegetation type and landscape. This preliminary map had as many map classes as seeds used to develop it.

Final Map Units

Once the image was classified, the seed classes representing the various plant associations of the preserve were grouped into operational map units based on two criteria. Either they were grouped ecologically into map units that were appropriate for land management at the target scale of 1:24,000, or they were grouped because they were spatially or spectrally so similar that they were not differentiable with confidence at the target scale. Hence, most map units were represented by sets of plant associations that are separated into primary components (dominant plant associations comprising the majority of a map unit), secondary components (other plant associations with significant coverage), and potential inclusions (plant associations estimated to have less than 10% coverage within the unit). Map unit descriptions were then developed describing the composition and distribution of each unit (see Appendix C for a list of plant associations used in the map unit descriptions).

Fine-scale Image Interpretation

Mapping in areas of high relief and with a complex vegetation mosaic such as that at VCNP can pose significant mapping problems, particularly in areas of deep shadows and narrow linear features (e.g., narrow bands of wetland and riparian vegetation). In addition, while the supervised approach was suitable for analyzing large homogeneous patches of relatively uniform spectral response, the two-meter resolution of the imagery often led to small patches and a rather heterogeneous classification pattern driven by small differences in spectral response, e.g., individual trees or shrubs might be classified as one thing while the intervening grassland matrix might be classified as another. Therefore, using the supervised classification as a foundation, the map was refined using direct image interpretation of the aerial photos supported by the various special analysis layers and ancillary information such as ground-based mapping and photos.

As a first step, a filtering process was applied to create a minimum map unit polygon size of 0.36 m^2 (approximately 3 pixels by 3 pixels or 6 m x 6 m). The procedure eliminates the "speckle" created by spatially solitary delineations. The eliminated areas were then filled with the majority MU found in the surrounding cells. While the specified minimum map unit size was 5,000 m^2 (0.5 ha), the higher resolution was maintained at the request of the VCNP land management staff.

Of particular issue was the distribution of aspen among mixed conifer and spruce-fir forests. To increase the accuracy of the aspen distribution, a stepwise multiple regression model between image layers and percent aspen cover from ground plots was developed. The resulting equation had a R^2 of 0.605, and was used to create a total aspen coverage image with values representing percentage cover of aspen within each pixel. Similarly, a complementary conifer image was created. These layers were used to complement the aerial photo interpretation-driven refinement of aspen distribution.

The determination of dry-mesic versus moist-mesic vegetation communities was done through a combination of image interpretation and the application of a solar irradiance-terrain model based on the 30-meter DEM. Using the DEM, a solar irradiance model was developed by integrating an hourly time-step model of solar irradiance per pixel of the DEM for each month in watts/meter/hour and then averaging each month to create an annual average model (Fu and Rich, 2000). The higher the value the warmer, and presumably drier, the site. In addition, a topographic curvature image was created using the second derivative of the DEM. This generates positive values for convex features such as hills or ridges and negative ones for concave features such as drainages and valleys. For our purposes, this model represents where water was being shed off ridges and upper slopes versus being accumulated in draws and hollows. Since the curvature and the solar irradiance models had very different dynamic ranges, in order to use them together they were rescaled as relative values ranging from 0 to 255 (histogram stretched to an eight-bit image). They were then averaged together to represent a general term of moisture availability. In the resulting combined model a threshold between dry and most mesic sites was empirically determined based on ground data and aerial photo interpretation and applied as a classifier of dry mesic versus moist mesic forest communities.

Finally, a stream accumulation image was derived from the DEM. The stream accumulation approach evaluates each pixel's elevation and finds how many pixels drain into it, if any. The larger the resulting image's pixel value the more of a watershed that drains into the pixel. The stream accumulation image was used to identify where montane riparian corridors existed and then these were integrated into the image.

No attempt was made to classify buildings, pavement, concrete, or lawns due to the heterogeneity of reflecting surfaces. Roads in vector format were placed directly onto the map to provide for their classification.

The final map along with a plot location and ancillary data layers necessary for output of the vegetation map was incorporated into an ArcGis project file and delivered directly to VCNP. It was also copied to the accompanying Data Addendum CD.

VALLES CALDERA NATIONAL PRESERVE VEGETATION MAP

The final version of Valles Caldera Vegetation Map was produced as a single map sheet at 1:32,000 scale to accompany this report. A reduced version of the map is shown in Figure 2. There are 20 map units as outlined in Table 3 with their associated aerial coverage. For each map unit, the primary and secondary component plant associations are listed along with inclusions (see Appendix C for the vegetation classification and a list of plant associations for the preserve). Primary components are those plant associations 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 the dominants. Inclusions are associations that occupy less than 10% of the area. An annotated legend with detailed map units descriptions follows. The descriptions are grouped by Forest and Woodland, Shrubland (montane shrublands and riparian shrublands), and Herbaceous vegetation (grasslands and herbaceous wetlands). Cover definitions criteria are provided for each map unit, along with information on distribution within the preserve.

Table 3. Map units of the Valles Caldera National Preserve Vegetation Map (2005).

Unit No.	Map Unit	Ha	Acres	%
1 & 2	**Spruce-Fir Forest**	**2835**	**7005**	**7.89**
1	Spruce-Fir Forest and Woodland (Dry Mesic)	1742	4304	4.85
2	Spruce-Fir Forest and Woodland (Moist Mesic)	1093	2701	3.04
4, 5 & 7	**Mixed Conifer Forest and Woodland**	**14798**	**36566**	**40.41**
4	Mixed Conifer Forest and Woodland (Dry Mesic)	8834	21829	24.59
5	Mixed Conifer Forest and Woodland (Moist Mesic)	5651	13963	15.73
7	Blue Spruce Fringe Forest	313	774	0.87
10 & 11	**Aspen Forest and Woodland**	**2065**	**5103**	**5.75**
10	Aspen Forest and Woodland (DryMesic)	1297	3204	3.61
11	Aspen Forest and Woodland (Moist Mesic)	768	1899	2.14
13	**Ponderosa Pine Forest**	**3739**	**9241**	**10.41**
14	**Gambel Oak-Mixed Montane Shrubland**	**584**	**1443**	**1.63**
16, 17 & 3	**Montane Grassland**	**8035**	**19858**	**22.37**
16	Upper Montane Grassland	1996	4933	5.56
17	Lower Montane Grassland	5111	12631	14.23
3	Forest Meadow	928	2294	2.58
19 & 20	**Wetlands and Wet Meadows**	**2773**	**6853**	**7.72**
19	Wet Meadow	2360	5832	6.57
20	Wetland	413	1021	1.15
21	**Montane Riparian Shrubland**	**6**	**14**	**0.02**
24	**Sparsely Vegetated Rock Outcrop**	**64**	**159**	**0.18**
25	**Felsenmeer Rock Field**	**370**	**915**	**1.03**
26	**Roads-Disturbed Ground**	**622**	**1536**	**1.73**
27	**Open Water**	**23**	**56**	**0.06**
28	**Post-Fire Bare Ground**	**7**	**17**	**0.02**
	Total	**35922**	**88765**	**100.00**

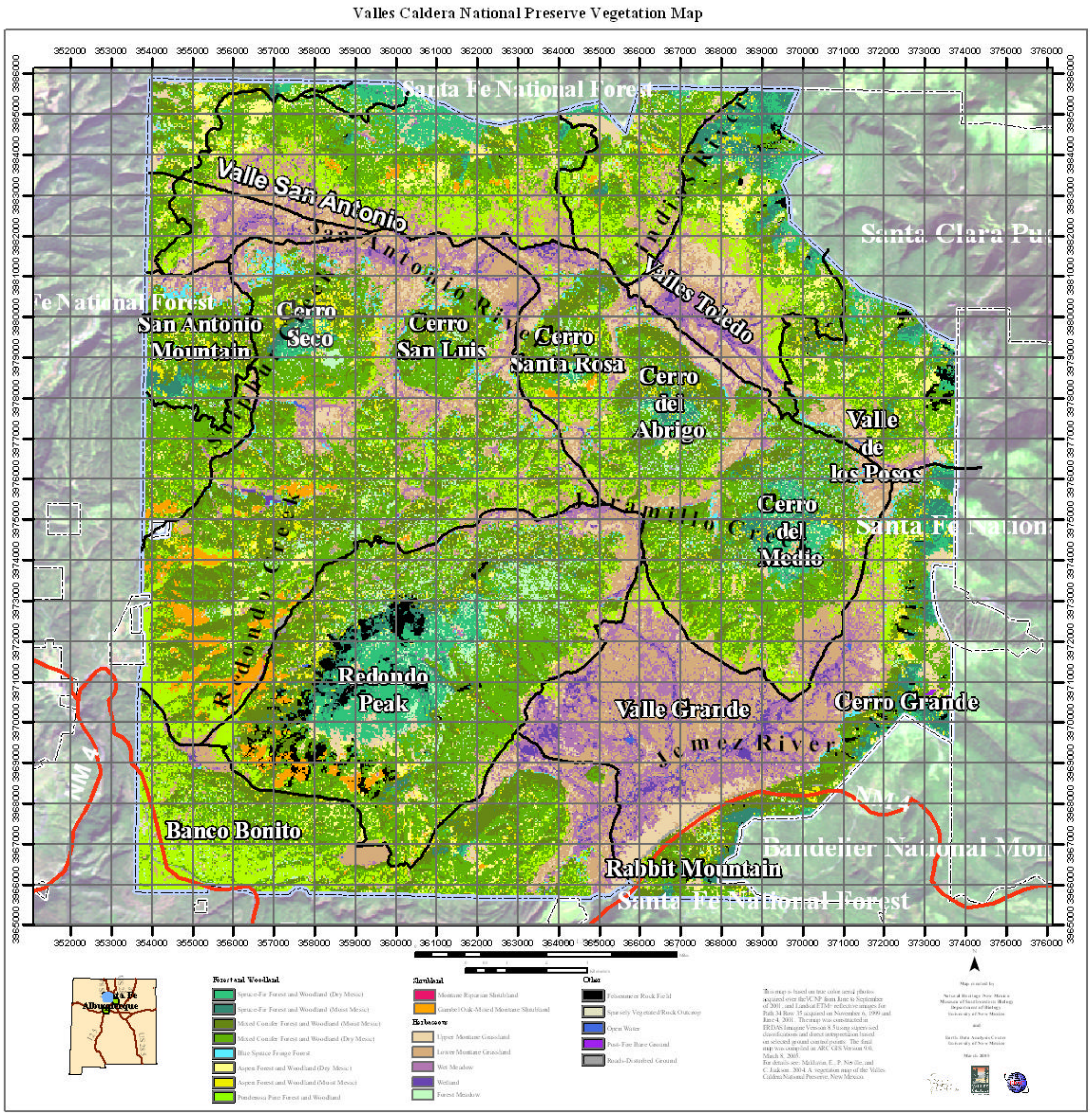

Figure 2. Vegetation map of Valles Caldera National Preserve, New Mexico (June 16, 2005).

ANNOTATED LEGEND

Forests and Woodlands

Vegetation dominated by trees over 5 m tall.

Rocky Mountain Spruce-Fir Forest

High-elevation conifer forests dominated by Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*). Other conifers may be present but clearly subordinate or successional (not reproducing). Aspens (*Populus tremuloides*) are also common to abundant successional trees.

Spruce-Fir Forest and Woodland (Dry Mesic)	**1**
Ha: 1,742	**Acres:** 4,304
Primary Components: Corkbark fir /Whortleberry Engelmann Spruce/Whortleberry Corkbark Fir/Moss Forest Engelmann's Spruce/Moss	
Secondary Components: Engelmann Spruce-Rocky Mountain Maple Engelmann Spruce/Common Juniper Engelmann Spruce/Parry's Danthonia Engelmann Spruce/Parry's Thurber Fescue	
Inclusions: Limber Pine/Common Juniper Quaking Aspen/Whortleberry	
Summary: Elevations typically range from 9,500 to 11,250 ft (2,900 to 3,430 m). Stands occur on cold, mid to upper slopes and ridges on northerly aspects; lower slopes to ridges on southerly aspects. Shrubs and subshrubs typically dominate, but on the coldest sites most vascular vegetation is replaced by soil mosses. Grassy understories occasionally occur adjacent to upper montane grasslands.	

Figure 3. Subalpine Fir/Whortleberry Forest along the San Antonio Rim at 10,000 ft (plot: 01VC055; photo: P. Tonne)

Spruce-Fir Forest and Woodland (Moist Mesic)	**2**	
Ha: 1,093	**Acres:** 2,701	
Primary Components: Corkbark Fir/Sprucefir Fleabane Engelmann Spruce/Sprucefir Fleabane Engelmann Spruce-Rocky Mountain Maple		
Secondary Components: Engelmann Spruce/Dryspike Sedge Engelmann Spruce/Fringed Brome		
Inclusions: Subalpine Fir/Whortleberry Engelmann's Spruce/Whortleberry Quaking Aspen/Sprucefir Fleabane		
Summary: Elevations typically range is from 9,000 to 10,500 ft (2,750 to 3,200 m). Stands occur on cold, mid to lower slopes on northerly aspects, and occasionally in lower slope coves of southerly aspects. The understory is dominated by herbs and can be diverse and luxuriant in cover. With the exception of Rocky Mountain maple, shrubs and subshrubs are typically poorly represented. Grassy understories occasionally occur adjacent to upper montane grasslands		

Figure 4. Engelmann Spruce/Sprucefir Fleabane Forest along the rim northwest of Canada Bonita at about 9,300 ft (Plot: 01VC093; photo: E. Muldavin).

Rocky Mountain Aspen Forest and Woodlands

Broadleaf forests dominated by aspen (*Populus tremuloides*) that occur between 8,600 to 10,200 ft (2,630 to 3,110 m). Conifers can be common, particularly as reproduction in the understory, but do not exceed 25% of canopy cover. Stands are typically considered successional to high-elevation mixed conifer or spruce-fir forests following fire, but clonal aspen forests can be long-lived and occupy a site for long periods, particularly with repeated burning.

Aspen Forest and Woodland (Dry Mesic) **10**	
Ha: 1,297 **Acres:** 3,204	
Primary Components: Quaking Aspen/Whortleberry Quaking Aspen/Thurber Fescue	
Secondary Components: Quaking Aspen / Fringed Brome	
Inclusions: Gambel Oak-New Mexico Locust/Meadow-rue Engelmann Spruce/Whortleberry	
Summary: Elevations typically range from 8,600 to 10,200 ft (2,630 to 3,110 m). Stands occur on cold, mid to upper slopes and ridges on northerly aspects; lower slopes to ridges on southerly aspects. Shrubs and subshrubs typically dominate, but on the coldest sites soil mosses replace most vascular vegetation. Grassy understories occasionally occur adjacent to upper montane grasslands.	Figure 5. Quaking Aspen/Thurber Fescue along the Valle San Antonio rim at about 10,000 ft (plot: 01VC015; photo: Y. Chauvin).

<table>
<tr><td colspan="2">Aspen Forest and Woodland
(Moist Mesic)</td><td>11</td><td rowspan="6">

Figure 6. Quaking Aspen/Fendler's Meadow-rue Woodland along Pajarito Rim at about 9,100 ft (plot: 01VC071; photo: P. Tonne).</td></tr>
<tr><td>Ha: 768</td><td colspan="2">Acres: 1,899</td></tr>
<tr><td colspan="3">Primary Components:
Quaking Aspen/Fendler's Meadow-rue
Quaking Aspen/Sprucefir Fleabane</td></tr>
<tr><td colspan="3">Secondary Components:
Quaking Aspen /Fringed Brome</td></tr>
<tr><td colspan="3">Inclusions:
Gambel Oak-New Mexico Locust/Meadow-rue
Engelmann Spruce/ Sprucefir Fleabane</td></tr>
<tr><td colspan="3">Summary: Elevations typically range from 8,700 to 9,500 ft (2,650 to 2,900 m). Stands occur on mid to lower slopes on northerly aspects, and occasionally in lower slope canyon bottoms and coves of southerly aspects. The understory is dominated by herbs and can be diverse and luxuriant in cover. With the exception Rocky Mountain maple, shrubs and subshrubs are typically poorly represented. Grassy understories occasionally occur adjacent to montane grasslands.</td></tr>
</table>

Rocky Mountain Mixed Conifer Forest

Forests of mid elevations (8,500 to 10,000 ft; 2,600 to 3,050 m) codominated by a combination of firs and pines: Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), blue spruce (*Picea pungens*), southwestern white pine (*Pinus strobiformis*), limber pine (*Pinus flexilis*), and ponderosa pine (*Pinus ponderosa*). Ponderosa is typically successional and not reproducing. Aspens are also common to abundant successional trees. Blue spruce can form nearly pure stands on the margins of valle grasslands (map unit 7). Engelmann spruce and corkbark fir are absent or clearly subordinate (< 25% of the conifer canopy cover).

Mixed Conifer Forest and Woodland (Dry Mesic)	**4**
Ha: 8,834	**Acres:** 21,829
Primary Components: White Fir-Douglas-fir/Oregongrape Abies concolor/Carex rossii White fir-Douglas-fir/Common Juniper Picea pungens/Juniperus communis	
Secondary Components: Douglas-fir/Fringed Brome White Fir- Douglas-fir/Bigtooth Maple White Fir-Douglas-fir/Thurber Fescue	
Inclusions: White Fir-Douglas-Fir/Gambel Oak White Fir-Douglas-fir/Whortleberry Quaking Aspen/Thurber Fescue	
Summary: Elevations typically range from 8,300 to 10,000 ft (2,540 to 3,050 m). Stands occur on mid to upper slopes and ridges on northerly aspects; lower slopes to ridges on southerly aspects. Shrubs and subshrubs typically dominate, but grassy understories occasionally occur adjacent to upper montane grasslands.	

Figure 7. White Fir-Douglas-fir/Oregongrape Forest along Redondo Border in upper Freelove Canyon at about 9,400 ft (plot: 01VC029; photo: E. Muldavin).

Mixed Conifer Forest and Woodland (Moist Mesic)	**5**
Ha: 5,651	**Acres:** 13,963

Primary Components:
White Fir/Sprucefir Fleabane Forest
White Fir- Douglas-fir/Fendler's meadow-rue
White Fir- Douglas-fir/Bigtooth Maple
White Fir/Dryspike Sedge
Blue Spruce/Dryspike Sedge Forest White Fir-

Secondary Components:
White Fir/Cliffbush
White Fir-Douglas-Fir/Gambel Oak
White Fir-Douglas-fir/Fringed Brome
Douglas-fir/Whortleleaf Snowberry

Inclusions:
White Fir-Douglas-fir/Thurber Fescue
Quaking Aspen/Fendler's meadow-rue

Summary: Elevations typically range is from 8,600 to 9,800 ft (2,630 to 2,990 m). Stands occur on mid to lower slopes on northerly aspects, and occasionally in lower slope canyon bottoms and coves of southerly aspects. The understory is dominated by herbs and can be diverse and luxuriant in cover. With the exception of Gambel oak and Rocky Mountain maple, shrubs and subshrubs are typically poorly represented. Grassy understories occasionally occur adjacent to lower montane grasslands

Figure 8. White Fir- Douglas-fir/Bigtooth Maple Forest along Redondo Border and upper Deer Canyon at about 9,550 ft (plot: 01VC018; photo: Y. Chauvin).

Blue Spruce Fringe Forest	**7**
Ha: 313	**Acres:** 774

Primary Components:
Blue Spruce/Dryspike Sedge Forest
Blue Spruce/Sprucefir Fleabane

Secondary Components:
Blue Spruce/Common Juniper

Inclusions:
White Fir/Sprucefir Fleabane Forest
White Fir- Douglas-fir/Fendler's meadow-rue
Ponderosa Pine/Parry's Danthonia

Summary: Elevations range is from 8,400 to 9,000 ft (2,550 to 2,750 m). Nearly pure blue spruce stands that occur as narrow belts (fringes) on northerly aspects between valle grasslands and mixed conifer forests of the mountain slopes. The understory is dominated by herbs and can be diverse and luxuriant in cover. With the exception of common juniper, shrubs and subshrubs are poorly represented. Grassy understories with similar compositions to adjacent valle grasslands can also occur.

Figure 9. Blue Spruce Fringe Forest along Sulphur Creek on the west side of the preserve (photo: E. Muldavin).

Rocky Mountain Ponderosa Pine Forest and Woodland

Conifer forests dominated by ponderosa pine (*Pinus ponderosa*) occupy the lower elevations of the forest zone between valle grasslands and mixed conifer forests. Other conifers can be present but clearly subordinate in the canopy (< 25% of the tree canopy).

Ponderosa Pine Forest and Woodland	**13**
Ha: 3,739	**Acres:** 9,241
Primary Components: Ponderosa Pine/Arizona Fescue Ponderosa Pine-Gambel Oak	
Secondary Components: Ponderosa Pine/Parry's Danthonia Ponderosa Pine/Common Juniper	
Inclusions: Ponderosa Pine/Trumpet Gooseberry/Sun Sedge Pinyon Pine-Gambel Oak	
Summary: Elevations typically range from 8,100 to 9,300 ft (2,450 to 2,840 m). On southerly aspects stands extend out into valle grasslands or high montane grasslands as "woodland savanna." In contrast, at upper elevations and on northerly slopes stands are commonly successional to mixed conifer forest. Understories range from shrub to grass dominated. Small inclusions of pinyon pine woodland occur on southerly slopes on the west side of the preserve.	

Figure 10. Ponderosa Pine/Arizona Fescue Forest located along the lower slope of the Valle San Antonio rim (plot: 01VC032; photo: E. Muldavin).

Shrublands

Vegetation dominated by shrubs up to 5 m tall.

Rocky Mountain Montane Shrubland

Shrublands dominated by Gambel oak (*Quercus gambelii)* and New Mexico locust (*Robinia neomexicana*) that are less than 5 m tall. Trees are usually scattered and occupy less than 10% cover. Stands are typically considered successional to lower-elevation ponderosa and mixed conifer fir forests following fire, but clonal Gambel oak shrublands can be long-lived and occupy a site for long periods, particularly with repeated burning.

Gambel Oak-Mixed Montane Shrubland	**14**
Ha: 584	**Acres:** 1,443
Primary Components: Gambel Oak-New Mexico Locust/Meadow-rue Gambel Oak/Kentucky Bluegrass	
Secondary Components: Gambel Oak/Rockspirea Gambel Oak/Sun Sedge	
Inclusions: Rock Outcrop White Fir-Douglas-Fir/Gambel Oak	
Summary: Elevations typically range from 8,300 to 9,400 ft (2,540 to 2,870 m). Shrublands dominated by Gambel oak and New Mexico locust that typically occur on southerly aspects of mid to lower mountain slopes and in canyons, often on rocky sites. Understories range from shrub to grass dominated.	

Figure 11. Gambel Oak/Kentucky Bluegrass Woodland in Alamo Canyon at about 8,760 ft (plot: 01VC026; photo: Y. Chauvin).

Rocky Mountain Montane Riparian Shrubland

Riparian shrublands dominated by thinleaf alder (*Alnus tenuifolia*) that occur along perennial mountain streams. Blue spruce may also be a significant component forming open riparian woodland. Other conifers are typically absent or minor.

<table>
<tr><td colspan="2">Montane Riparian Shrublands</td><td>21</td><td rowspan="6">

Figure 12. Thinleaf Alder/Fendler Waterleaf Montane Riparian Shrubland along La Jara Creek at about 9,420 ft (plot: 01VC010; photo: Y. Chauvin).</td></tr>
<tr><td>Ha: 6</td><td colspan="2">Acres: 14</td></tr>
<tr><td colspan="3">Primary Components:
Thinleaf Alder/Fendler Waterleaf
Thinleaf Alder Montypic stand</td></tr>
<tr><td colspan="3">Secondary Components:
Blue Spruce/Thinleaf Alder/Fendler Waterleaf
Bog Birch/Water Sedge/Stiff Clubmoss</td></tr>
<tr><td colspan="3">Inclusions:
Northwest Territory Sedge-Smallwing Sedge
Woolly Sedge-Common Spikerush</td></tr>
<tr><td colspan="3">Summary: Broadleaf riparian shrublands that occur along perennial mountain streams and fen (bogs) margins. Elevations typically range from 8,300 to 9,400 ft (2,540 to 2,870 m). Streamside communities that are dominated by thinleaf alder and occasional blue spruces. Understories are forb-rich and luxuriant, and typically have numerous obligate wetland species. The fen complex in Alamo Canyon supports a unique bog birch community that is part of this unit.</td></tr>
</table>

Herbaceous Vegetation

Vegetation dominated by graminoids and forbs; trees or shrubs have less than 10% canopy cover.

Rocky Mountain Montane Grasslands

Grasslands dominated by upland bunch grasses. Scattered conifers and aspens can occur on sites that have had low fire incidence or as remnants following fire or logging.

Upper Montane Grasslands	**16**
Ha: 1,996	**Acres:** 4,933
Primary Components: Parry's Danthonia-Thurber's Fescue Thurber's fescue-Kentucky Bluegrass	
Secondary Components: Festuca thurberi-Stipa lettermannii Parry's Danthonia-Arizona Fescue	
Inclusions: Arizona Fescue-Mountain Muhly Arizona Fescue-Pine Dropseed Arizona Fescue-Blue Grama	
Summary: Elevations typically range from 8,400 to 10,500 ft (2,560 to 2,870 m). At lower elevations, these grasslands are found along the upper alluvial fan piedmonts of valles, and occasionally in the valley floor. At the highest elevations they occupy south-facing slopes and ridges.	

Figure 13. Parry's Danthonia-Thurber Fescue Upper Montane Grassland on the Valle Grande east piedmont at about 8,680 ft (plot: 01VC012; photo: Y. Chauvin).

Lower Montane Grasslands	**17**
Ha: 5,111	**Acres:** 12,631
Primary Components: Arizona Fescue-Pine Dropseed Grassland Arizona Fescue -Kentucky Bluegrass	
Secondary Components: Arizona Fescue-Blue Grama Grassland Arizona Fescue-Mountain Muhly Pine Dropseed-Mountain Muhly Pine Dropseed-Prairie Junegrass	
Inclusions: Parry's Danthonia-Thurber's Fescue Thurber's fescue-Kentucky Bluegrass	
Summary: Elevations typically range from 8,400 to 9,000 ft (2,560 to 2,750 m). These grasslands are found along the alluvial fan piedmont slopes extending into the valle bottoms, often below a band of Upper Montane Grasslands (Map Unit 16). They occasionally occur on mountain foot slopes or in isolated mountain valleys. Shrubs such as wooly cinquefoil can be common, but not abundant.	

Figure 14. Arizona Fescue-Mountain Muhly Lower Montane Grassland in the Valle Grande east piedmont at about 8,550 ft (plot: 01VC014; photo: Y. Chauvin).

Forest Meadow	**3**
Ha: 1,996	**Acres:** 4,933
Primary Components: Thurber Fescue-Kentucky Bluegrass Kentucky Bluegrass/Common Dandelion	
Secondary Components: Parry Danthonia-Kentucky Bluegrass Arizona Fescue-Kentucky Bluegrass	
Inclusions: Thurber Fescue-Parry's Danthonia	
Summary: Elevations typically range from 8,900 to 10,500 ft (2,560 to 3,175 m). Grasslands associated with post-burn and post-logging high-elevation forests. Scattered remnant trees are common. Most common on mountaintops and ridgelines.	

Figure 15. Forest Meadow is commonly associated with post-logging clearings such as this one along Redondo Border (photo:E. Muldavin).

Rocky Mountain Wet Meadows and Wetlands

Herbaceous vegetation of valley bottoms and swales dominated by grasses, rushes and sedges, many of which are either facultative or obligate wetland species.

Montane Wet Meadow	**19**
Ha: 2,360	**Acres:** 5,832
Primary Components: Tufted Hairgrass/Woolly Cinquefoil Baltic Rush-Kentucky Bluegrass Baltic Rush-Tufted Hairgrass Grassland Kentucky Bluegrass- Common Dandelion	
Secondary Components: Tufted Hairgrass-Smallwing Sedge Baltic Rush-Kentucky Bluegrass Pine Dropseed-Baltic Rush	
Inclusions: Arizona Fescue -Kentucky Bluegrass Northwest Territory Sedge-Smallwing Sedge	
Summary: Elevations typically range fro m 8,400 to 9,000 ft (2,560 to 2,740 m). Herbaceous vegetation dominated by a combination of facultative wetland and upland species. Stands most commonly occur on valley bottom surfaces that are not part of the active floodplain (terraces and lower alluvial slopes). They can extend up drainage ways and in springy areas of the surrounding valle alluvial piedmont slopes.	

Figure 16. Pine Dropseed-Baltic Rush Wet Meadow in the Valle Toledo at 8,600 ft (plot: 01VC006; photo:P. Tonne).
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<table>
<tr><td colspan="2">Montane Wetland</td><td>20</td><td rowspan="6">

Figure 17. Northwest Territory Sedge-Smallwing Sedge Wetland in the Valle Toledo at 8,610 ft (plot: 01VC033; photo: P. Tonne).</td></tr>
<tr><td>Ha: 413</td><td colspan="2">Acres: 1,021</td></tr>
<tr><td colspan="3">Primary Components:
Northwest Territory Sedge-Smallwing Sedge
Woolly Sedge-Common Spikerush</td></tr>
<tr><td colspan="3">Secondary Components:
Northwest Territory Sedge-Longstyle Rush
Water Sedge-Northwest Territory Sedge
Tufted Hairgrass-Northwest Territory Sedge
Kentucky Bluegrass- Common Dandelion</td></tr>
<tr><td colspan="3">Inclusions:
Tufted Hairgrass/Woolly Cinquefoil
Baltic Rush-Kentucky Bluegrass
Baltic Rush-Tufted Hairgrass Grassland
Narrowleaf Burreed Herbaceous Alliance</td></tr>
<tr><td colspan="3">Summary: Elevations typically range from 8,100 to 8,700 ft (2,450 to 2,640 m). Herbaceous vegetation dominated by obligate and facultative wetland species. Stands occur along valley bottom drainage ways that are part of the active floodplain. They can extend up drainage ways and into springy areas of the surrounding valle terraces alluvial piedmont slopes. The unit also includes small inclusions of aquatic vegetation (narrowleaf burreed plant association).</td></tr>
</table>

Miscellaneous Map Units

Rock Outcrop		**24**
Ha: 64	**Acres:** 159	
Primary Components: Sparsely Vegetated Rock Outcrop		
Secondary Components:		
Inclusions: Felsenmeer Rock Field Roads-Disturbed Ground		
Summary: Volcanic rock outcrops commonly composed of rhyolite or andesite are scattered on the slopes of the domes and the caldera rim		

Figure 18. Rock Outcrop along the Valle San Antonio rim at about 9,000 ft (plot: 01VC070; photo: E.. Muldavin)

Felsenmeer Rock Field		**25**
Ha: 370	**Acres:** 915	
Primary Components: Felsenmeer		
Secondary Components:		
Inclusions: Sparsely Vegetated Rock Outcrop Roads-Disturbed Ground		
Summary: talus slopes composed volcanic cobles and boulders that are typically un-vegetated		

Figure 19. Felsenmeer on Redondito forming essentially non-vegetated talus slopes (photo: E. Muldavin).

DISCUSSION

We consider the vegetation map of the Valles Caldera National Preserve presented here to be the most accurate and highest resolution map produced to date. While a formal, quantitative accuracy assessment was not generated at this time, several informal field validation trips were conducted to insure that the general patterns of vegetation distribution matched well with the map at the target user scale of 1:24,000 and the specified minimum map unit delineation size of 0.5 ha (keeping in mind the national USGS/NPS standard of 80% accuracy). Accordingly, although the map as delivered in its digital format is at a minimum map unit size of 36 m^2, we caution against ascribing high confidence to the patches smaller than the 0.5 ha of original target minimum map unit size (USGS/NPS specifications). For uses at the finer resolution, we recommend follow-on site-level mapping at 1:6,000 scale.

Overall, the map should serve general natural resources management uses well in the realms of grazing, forestry, wetlands protection, and wildlife and biodiversity conservation. Furthermore, since the map is available in a digital form within a GIS, timely updates can be performed as new information becomes available, either at the local site level or across the preserve as a whole, making the map a living document serving the adaptive management needs of the preserve.

REFERENCES

Leica, 2003. ERDAS Imagine 8.7. Service Pack 2. Leica Geosystems GIS and Mapping , LLC.

Muldavin. E. and P. Tonne. 2003. A Vegetation Survey and Preliminary Ecological Assessment of Valles Caldera National Preserve, New Mexico. Natural Heritage New Mexico final report to Valles Caldera National Preserve, New Mexico. 73p + App.

APPENDIX A.

List of Vegetation Plots

List of all plots collected for the development of the Valles Caldera National Preserve Vegetation Map. Plot Id refers to plot number in the VCNP vegetation map database. Type refers to plot type where OMP = observation Mapping point (dominant species only), STP = standard NMNHP vegetation plot (all species in $400m^2$ square quadrat), and RP = releve plot (expanded standard plot to include complete stand species list). Plant Association according to the NHNM state vegetation classification. Phase is a variant of the association. PA No. refers to the unique database plant association number. Easting and northing coordinates are given in the NAD 27 datum (the spatial distribution of the plots is shown in Figure 1 of the text). In addition, an Argos shapefile was produced that matches the tables, which can be found on the accompanying CD data disk.

APPENDIX B

Plant Species List

Lists of plant species recorded as part of the Valles Caldera National Preserve Vegetation Map field survey from 2001 through 2003. 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. Some species may occur in two or more strata. Plants symbol refers to the code form the PLANTS database (USDA-NRCS, 2002). The NHNM code is the respective code in the database provided in the Data Addendum CD. N refers to the number of occurrences in the database.

Table A-1. VCNP vegetation map plant species list ordered by lifeform strata and scientific name.

APPENDIX C

Valles Caldera National Preserve Vegetation Classification