Waste Site Characterization through Digital Analysis of Historical Aerial Photographs

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Abstract

Historical aerial photographs have been used to provide a physical history and preliminary mapping information for characterizing a Department of Energy waste burial site at Los Alamos National Laboratory. The photographs were digitally scanned in order to perform on-screen computer change detection. The digital analysis of these photographs allowed disparate views of the waste site to be transformed so that they matched in scale, orientation, and extent. This was especially useful for oblique photographs of the waste site. The coregistered images were studied individually (and in comparison with each other) to identify features which were indicative of human activity at the site and to provide a physical history of natural and human induced changes. The coregistered images were imported to a geographic information system and geographically coded to a common coordinate system. The geographic information system was used to extract the boundaries of features such as suspected trenches and disturbed soil. This preliminary analysis forms a basis for planning and comparing the results from other remote sensing and geophysical surveys which will be used to improve the characterization of the waste site.

Introduction

The U.S. Department of Energy (DOE) faces the formidable task of cleaning up its facilities after 45 years of nuclear weapons development, testing, production, and stockpiling. Waste sites at these facilities include landfills, outfalls, and storage tanks. This paper focuses on the characterization of a waste burial site known as MDA-F (Material Disposal Area F) at the Los Alamos National Laboratory, located in north central New Mexico (Figure 1).

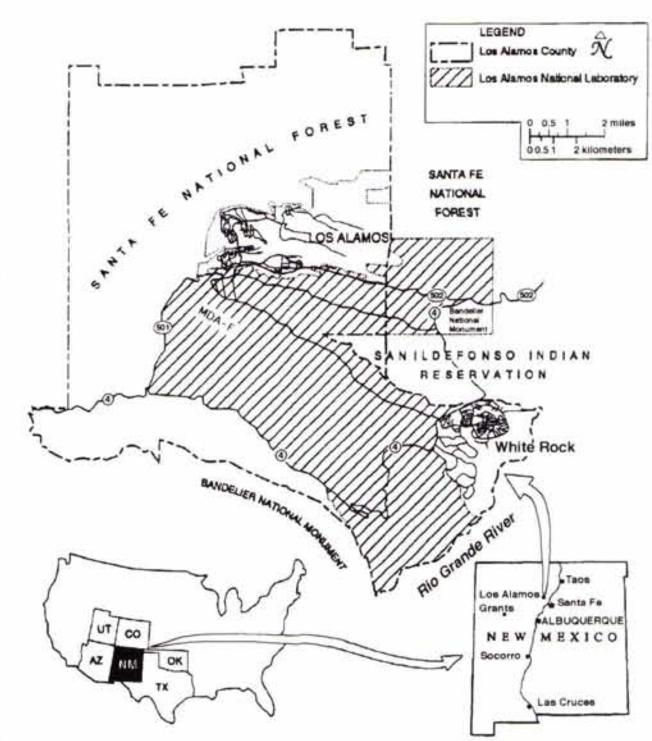

Figure 1. Location of the Los Alamos National Laboratory and MDA-F (adapted from Environmental Restoration Program, 1993).

Environmental restoration of trenches containing hazardous waste requires an initial characterization of the site. The required information includes the number of trenches in the area; their contents, surface location, and depth; and the physical history of the site from initial activity to the present. Historical information about trench boundaries and the nature of the burials may be lacking for older sites. Spatial technologies, such as remote sensing and geographic information systems, are being used to support the DOE Environmental Restoration effort (Albers *et al.*, 1993).

The use of remote sensing for waste site characterization and monitoring is receiving increased interest (Stohr and Lunetta, 1994). Remote sensing and geophysical surveys can provide information about a waste site's physical history, stability, and content (e.g., Stohr *et al.*, 1987; Zilioli *et al.*, 1992; Weil *et al.*, 1994). This information as well as information from field surveys can be efficiently organized within a geographic information system (GIS) for restoration planning and management (e.g., Korte *et al.*, 1989; Soby *et al.*, 1992; Runyon *et al.*, 1994). Historical aerial photographs are an inexpensive and rich source of remotely sensed data which can be utilized for characterizing hazardous waste sites (Erb *et al.*, 1981; Lyon, 1987; Sciacca, 1993). Digital analyses of these photographs enable the correction of differences in viewing geometry and provide for unique enhancements which would be more difficult with manual techniques. For example, Jackson and Gaston (1994) used digital image processing algorithms, such as the Normalized Difference Vegetation Index, to improve the interpretation of color and infrared aerial photos for environmental change assessment. Airola and Kosson (1989) used a digital analysis of historical aerial photographs to characterize a hazardous waste site. Their analysis included digitizing the photographs

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Figure 2. Overall view of MDA-F, circa 1987. The view is to the northeast. Note the two fenced areas, the soil and tuff mound, and the ponderosa pines that cover the site.

and geometrically transforming them so that they matched a common frame of reference.

The objective of this study was to apply the technique of digital analysis of historical aerial photographs to derive preliminary characterization information about a DOE waste burial site. This preliminary information is needed as a base for the characterization of the site. This information will be augmented with other spatial data within a GIS to characterize the waste site further.

Study Area

The waste site at Los Alamos chosen for this study is known as Materials Disposal Area F (MDA-F). It is located in a relatively flat area near the northern edge of Two Mile Mesa on the Pajarito Plateau (Figure 2). The Pajarito Plateau lies on the eastern side of the Jemez mountains at an average elevation of 7,500 feet, and is comprised of a series of narrow mesas and canyons. The plateau is composed primarily of the Bandelier Tuff, a series of ash-flow deposits that were formed 1.1 to 1.5 million years ago. The tuff is soft and easily workable with power equipment. Soil cover on the mesa tops, as at MDA-F, is typically 3 to 4 feet deep. The disposal trenches were probably excavated through the soil and into the tuff.

Before the Los Alamos National Laboratory was established as part of the Manhattan Project in 1943, the mesas of this region were farmed by homesteaders. During World War II, the site was used for explosives testing and later for the burial of classified, obsolete materials (through 1952). These materials were buried in trenches which were then refilled. High explosive lenses were disposed of near this area by detonating them. A structure called the "timbered pit," which was used for explosives tests during World War II, is known to exist in this area. Specialized electrical components (spark gaps) containing cesium-137 were also disposed of in the area. It is possible that high explosives may have been buried. The exact location of the trench boundaries and whether additional materials were disposed of are not known. Therefore, it is important to identify and delineate the boundaries of trenches in the area so that samples can be taken close to the disposals without intercepting the waste itself.

The predominant vegetation in the area is ponderosa pine (Pinus ponderosa) and, in the areas formerly used for farming, a variety of grasses and forbs. The MDA-F site has been reclaimed by herbaceous vegetation and ponderosa pine, as shown in Figure 2. A large mound of soil and tuff is present in the center of the area believed to have been used for disposal. Some debris, mounds, and depressions can be found over the site. Fences were erected in 1981 around two areas suspected of containing disposal material (Environmental Restoration Program, 1993).

Archival Search and Photo Selection

Various local and national archives were searched for aerial photographs of MDA-F whose dates of acquisition bracketed and spanned the waste site's period of use. Many types of aerial photographs were found (Table 1), including vertical aerial survey frames with overlap in coverage (stereoscopic) and high and low obliques. The photographs were examined for the quality of characterization information they might yield by a digital analysis. Those which held the best potential for analysis by this technique were selected for digitization by scanning. Selection criteria included high contrast, amount of ground detail, physical condition of the photograph, and position of MDA-F relative to the center of the photograph. This last criterion was employed to reduce the amount of distortion which would have to be corrected. Aerial survey photographs typically have large amounts of overlap along a flight line and side lap between flight lines. Thus, several frames may contain the region of interest. Choosing the photograph that contains the target closest to the center, or principal point, reduces the inherent distortion effects due to view angle and terrain relief.

The most useful historical aerial photographs were from 1935, 1946, 1949, 1958, and 1972. These photos were chosen

Table 1. Chronological Listing of Documents Relating to Materials Disposal at Two Mile Mesa and Available Historical Aerial Photographs.

Date	Document or Photograph	Comments (survey organization)
1935	Photograph*	Vertical aerial survey photographs (B/W 1:40,000 scale) of Two Mile Mesa and surroundings (Soil Conservation Service).
1946, 15 May	Document	Notification of availability, until 1 June, of a pit for disposal purposes on Two Mile Mesa. Divisions and groups are urged to "clean house of obsolete, unusable, but classified material by use of this pit."
1946, 1 November	Photograph*	Low oblique aerial photograph (B/W) of MDA-F (Sandia Laboratory, Albuquerque New Mexico).
1947, 16 July	Document	Notification of availability of "special facilities" at Two Mile mesa for disposal of "scrap material" from this date for a period of two weeks.
1947, December	Photograph	Vertical aerial survey mosaic in the form of a photomap (B/W 1:12,000 scale) of the Los Alamos Scientific Laboratory (U. S. Atomic Energy Commission). Very poor physical quality and the ground is covered in snow.
1949	Photograph*	High oblique aerial photograph (B/W) of MDA-F. Exact date of acquisition and the survey organization are uknown.
1949, 2 & 3 August	Document	Job orders for creation of a "hole approximately 40 by 20 by 10 feet deep to bury material," which was to be refilled after use.
1949, 13 October	Photograph	High oblique aerial photograph (B/W) which contains MDA-F in the background (Los Alamos Science Lab).
1950, 21 & 24 February	Document	Job orders for creation of holes approximately 6 by 6 by 6 feet for burying material.
1950, 29 September	Document	Serial numbers of spark gaps to be disposed of, which contained cesium-137.
1951, 16 & 21 August	Document	Job orders for creation of a "hole 2 by 2 by 4 feet deep for disposal purposes," which is to be refilled after use.
1952, 27 March	Document	Serial numbers of spark gaps to be disposed of, which contained cesium-137.
1952, 22 July	Document	Serial numbers of spark gaps to be disposed of, which contained cesium-137.
1954, 28 May	Photograph	Vertical aerial survey photographs (B/W, 1:54,000 scale) of Two Mile Mesa and surroundings (U.S. Army).
1958, 22 November	Photograph*	Vertical aerial survey photographs (B/W, 1:4,900 scale) of MDA-F (U.S. Air Force).
1972, 25 June	Photograph*	Vertical aerial survey photographs (color IR, 1:24,000 scale) of Two Mile Mesa and surroundings. The survey organization is unknown.
1991, 30 September	Photograph*	Orthophotos (color, 1:1,200 scale) of Two Mile Mesa. New Mexico Central State Plane (NAD 83) coordinate tick marks are superimposed on the photograph (Los Alamos National Laboratory Environmental Restoration Project). Two orthophotos were needed to capture all of MDA-F.

*A photograph from this survey was chosen for digital analysis. Overlapping frames were also chosen, when available, to facilitate manual stereoscopic viewing.

for analysis by digital techniques. Orthophoto coverage of the area was available from a more recent (1991) aerial survey of the Los Alamos area. Two orthophotos covered the MDA-F area. These orthophotos provided a base image for mapping of the waste site. The 1946 and 1949 oblique photos were the only ones available which were of good quality and contained sufficient detail of MDA-F during the period when the area was being used for disposal purposes. These acquisitions lacked overlapping pairs of photos. Preliminary comparisons with the vertical photos from the remaining dates pointed to a necessity for transforming the oblique photos so they could be more easily compared.

Digitization and Registration

A large-format drum scanner was used for digitizing the 1991 orthophotos, while a smaller flatbed scanner was used for the other photographs. Upper and lower brightness levels were adjusted for each scan to maximize the dynamic range of the output image. Gray-scale scans (8 bits per pixel) of the aerial photographs were done to facilitate comparisons of the more recent color photographs with the older black-and-white photographs. The larger scale 1991 orthophotos were scanned at 300 dpi while the smaller scale vertical and oblique photographs were scanned at 600 dpi optical resolution.

The scanned photographs were digitally transformed to match, or "register to," a base image of MDA-F so that comparisons could be performed more easily. The base image of MDA-F was created from scans of the two 1991 orthophotos that covered this area. The two scanned orthophotos were digitally mosaicked and trimmed. The result is a 1991 base image of MDA-F, shown in Figure 3a. The scale across an orthophoto is constant because it does not contain view angle and terrain relief distortions, making it ideal for mapping purposes. Transforming the historical aerial photographs to match the orthophoto mosaic helped to reduce the distortion effects in the vertical and oblique aerial photographs. All the digitized historical aerial photographs were transformed to match the 1991 base image of MDA-F. The results are shown in Figure 3. A normalized contrast enhancement was used for each image. This enhancement aided the on-screen interpretations of the images overall. Other enhancements, such as inversion, piece-wise linear, and logarithmic, were applied to enlargements of specific areas of the images to facilitate the interpretation of details within these individual regions.

Two computer codes were written to transform the scanned images so that they registered to the base image of MDA-F. A simple translation, rotation, and scaling (TRS) was applied to the vertical photos, while a more complicated two-dimensional projective transformation (2DPT) was used for the obliques. The TRS code trims, orients, and enlarges or reduces the size of the original image so that it matches the base image. Figure 4 shows such a transformation for the 1958 photograph. The 2DPT code treats the region of interest as if it were a plane viewed at an acute angle, and transforms the image to approximate an overhead view (Slama *et al.*, 1980). Figure 5 shows such a transformation for the 1946 photograph. These codes require the user to define control points, which are features common to the image to be transformed and the base image. The TRS process requires two control points and the 2DPT process requires four. Both of these transformations were programmed in the following manner. The output image was defined to be the same size as the base image in terms of the number of rows and columns of pixels. For each position in this output image, the

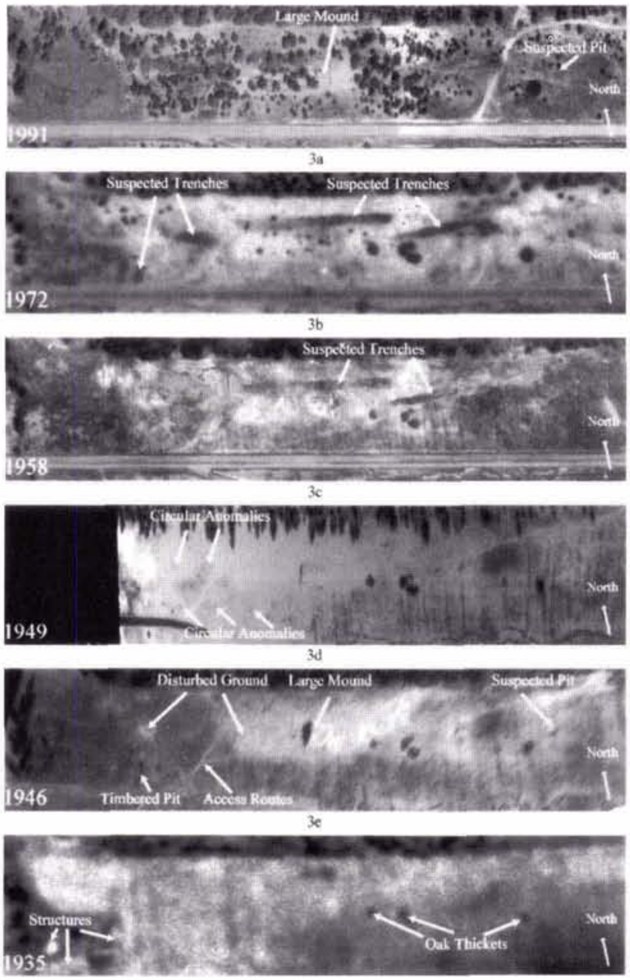

Figure 3. (a) The 1991 image. This image served as a base image for registering the 1958 aerial photograph, and it provided geographical coding information for all of the imagery used in this study. Note that the central portion is covered by ponderosa pine while the western and eastern portions have minimal cover. (b) The 1972 image. This image was created by using the TSR algorithm to transform a color infrared vertical aerial photograph of the area so that it registered to the 1958 base image. Four dark rectangular patches which indicate suspected disposal trenches can be seen. The patch on the southwest side just above the main road corresponds to the location of the timbered pit. Small ponderosa pines can be seen over the central portion of the image. (c) The 1958 image. This image was created by using the TSR algorithm to resample a vertical aerial photograph of the area so that it registered to the 1991 base image (see Figure 4). This image served as a base image for registering all the other historical imagery. Note the two long, dark rectangular patches just north of the large mound and the central oak thickets. The dark patches are probably vegetation growing on the refill over the disposal trenches. (d) The 1949 image. This image was created by using the 2DPT algorithm to resample an oblique image of the area so that it registered to the 1958 base image. The timbered pit is filled in and the road on the southwest side has been partially paved. Note the group of five circular anomalies in this image. The black area on the left was not visible in the oblique photograph. (e) The 1946 image. This image was created by using the 2DPT algorithm to resample an oblique image of the area so that it registered to the 1958 base image. This image clearly shows evidence of disposal activity. (f) The 1935 image. Features in this image are not sharp because of the small scale of the aerial photograph and limitations of the scanner used to digitize it. Vertical light and dark bands are probably furrows from farming of the mesa. This image predates Manhattan Project activity by 8 years. Note the oak thickets, which can be seen in all of the coregistered images of MDA-F.

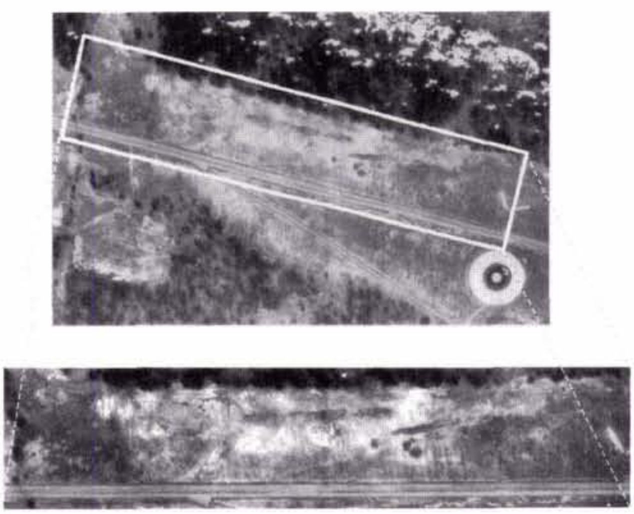

Figure 4. Illustration of the TSR process. The white rectangular outline superimposed on a 1958 aerial photograph of MDA-F defines the area of interest. This region is transformed by digital resampling so that it registers to the 1991 base image (see Figure 3a).

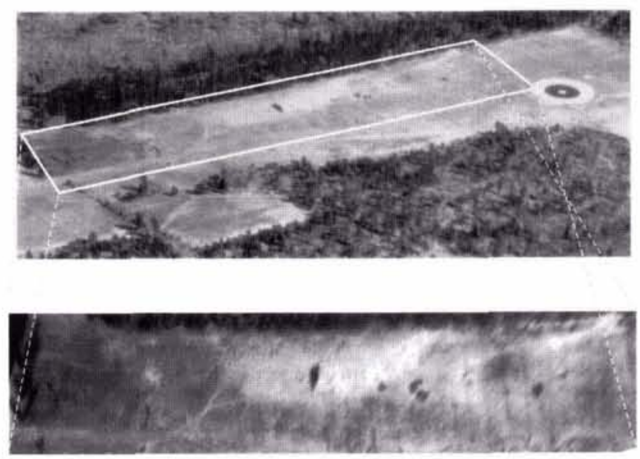

Figure 5. Illustration of the 2DPT process. The white rectangular outline superimposed on a 1946 oblique photograph defines the area of interest. This region is transformed by digital resampling so that it registers to the 1958 base image (see Figure 3c). The result is an overhead-like view of the area.

TABLE 2. REGISTRATION ERRORS RELATIVE TO THE 1991 AND 1958 BASE IMAGES.

Image	Registration error relative to the 1958 base image [m]	Registration error relative to the 1991 base image [m]*	Comments on registration errors relative to the 1958 base image
1972	2.0	3.0	Error overall is 2.0 m.
1958	N/A	1.0	Errors in the west, central, and northeast portions are 0.5, 1.0, and greater than 2.0 m, respectively (relative to the 1991 base image).
1949	2.0	3.0	Errors in the central and east portions are 2.0 and greater than 3 m, respectively.
1946	1.5	2.5	Error in the central portion is 1.5 m and greater than 2.0 m in the southwest and northeast portions.
1935	2.0	3.0	Error overall is 2.0 m.

*The registration error of an image relative to the 1991 base image was estimated by adding the registration error of the image relative to the 1958 base image and the registration error of the 1958 base image relative to the 1991 base image, i.e., 1.0 m.

inverse transformation equation was used to calculate the associated position in the input image. The gray-scale value in the input image closest to this calculated position (i.e., nearest-neighbor resampling) was placed in the output image.

The transformation of the oblique photographs in this study was critical to gaining an understanding of the physical condition of the site during its use for disposal purposes. As mentioned previously, no other aerial photographs of value were found for this area during the 1945 to 1952 time frame. A photomosaic map of Los Alamos, dated December 1947, was available, but it had very poor physical quality, and the ground was covered with snow when the survey was performed (Table 1). Transforming the obliques with the 2DPT code offered overhead-like views of the site, making comparisons with the other aerial photographs much easier.

It was often difficult to identify features common to the 1991 base image and the historical images because of changes in the area over time, such as the ponderosa pine growth over the site and the lack of sharply defined objects. The identification of common features in the oblique aerial photographs was made even more difficult by large differences in view angle. This problem was solved by registering the 1958 photograph to the 1991 base image, and using the result as an intermediate base image (Figure 3c). The 1958 photograph was chosen because it has the largest scale, and therefore greatest detail, of the historical photographs (Table 1). Also, the principal point for this photo was very close to the central area of MDA-F, which ensured that relief distortion was minimal. It was easier to transform the other historical photographs to match the 1958 base image because common features were more obvious. The disadvantage of this process is that registration error in the 1958 image carries over when the other transformed images are compared to the 1991 base image.

Difficulties in defining control points required several iterations of a transformation process for a particular image in order to obtain satisfactory results. For example, the initial transformation of an oblique photo was done by finding four features which were contained in this image and the 1958 base image. These features might not be optimal control points (i.e., near areas of high relief) but they were easily identified even though there were extreme differences in view angle between the photos. The oblique photo was then transformed with the 2DPT algorithm by using these control points. The result was a more overhead-like view of the area. This aided in identifying features which could serve as more accurate control points (i.e., not near areas of high relief and positioned closer to the central portion of MDA-F). These features could then be more easily identified on the original oblique image and a new set of control points could be defined. The process was repeated until no improvement in registration could be detected between the 1958 base image and the transformed photo. Control points that gave the best registration results for the central portion of the image, where the burial trenches are most likely located, were used to create the coregistered imagery in Figure 3.

Registration errors were estimated by on-screen flickering of base and corrected images and measuring the shifts in the positions of common features. Because the error varied across any image studied, a single value was chosen as representative of the error in the central portion. The registration errors of the transformed historical imagery relative to the 1958 and 1991 base images are given in Table 2.

Physical History of MDA-F

The digitized and transformed historical aerial photographs are shown in Figures 3a through 3f. The transformations described resampled the digitized photographs so that they matched in scale, orientation, and extent. These images were studied on an individual basis and animated or "flickered" on-screen to view changes in the site through time. A physical history for MDA-F was derived from these coregistered images.

Large changes in the site can be seen by comparing the 1935 and 1946 images (Figures 3f and 3e). The 1935 image captures the mesa when it was being farmed. Structures and furrows can be seen in this image. Magnified stereoscopic viewing of overlapping photos from the 1935 survey was used as an aid to interpret this digital image (Figure 3f) because of the coarse spatial resolution incurred by the small scale of the original photo and the 600 dpi digitization limit of the scanner. The structures appear to be cabins, corrals, pens, and small garden plots of a homestead. Three scrub oak thickets (Quercus gambelii) are also visible. These thickets are present in every image studied and serve as good reference features. The 1946 image shows areas of disturbed soil, a large mound, two open pits, and unimproved roads. The aerial photograph from which this image was derived was taken on 1 November 1946, just after disposal activity was documented to have started on 15 May 1946 (Table 1). Thus, this image provides excellent indications of early disposal activity.

Minor changes in the site can be seen by comparing the 1946 and 1949 images (Figures 3d and 3e). The timbered pit has been filled in, probably after being filled with waste material (Table 1). The areas of disturbed soil, the large mound, and unimproved roads can still be seen. The main road has been partially paved from the west. Five circular anomalies just west of the large mound were found in the 1949 image. Comparison with the 1946 image reveals that these features are also present in this image, although the contrast is not as good due to the poor quality of the original photograph.

The 1958 image (Figure 3c) was taken more than six years after the date of the last documented disposal at MDA-F (Table 1). The large mound can still be seen, as well as areas of disturbed soil common to both the 1949 and 1946 images. Access roads into the area are clearly visible as well-defined tire ruts. The most interesting features are several dark rectangles. The dark appearance of these rectangles is probably due to vegetation growing on the refill over the disposal

Table 3. Total Location Error of Features Derived from the Geographically Coded Imagery of the MDA-F.

Date	Location error relative to New Mexico Central State Plane (NAD 83) coordinates [m]*
1991	0.79
1972	3.8
1958	1.8
1949	3.8
1946	3.3
1935	3.8

*These values were calculated by adding the location error of the 1991 image relative to the New Mexico Central State Plane coordinate system, i.e., 0.79 m, to the values from the third column of Table 2.

trenches. It is interesting to note that the appearance of this vegetation indicates growth and not stress over these waste sites. Vegetation stress, not growth, is mentioned most often in the literature as an indication of the presence of hazardous waste sites. Growth of vegetation as an indicator of hazardous waste is often associated with organic liquid waste such as raw sewage. In this case, the indication of a waste site is more like the anomalous vegetation signatures used to identify archaeological sites. The causes for this growth are likely associated with increased moisture content within the loose refill material. The highly geometrical shape of these features is strong evidence that they were man-made.

Two of these dark rectangles are clearly visible on the 1958 image. However, the 1972 image (Figure 3b) has better contrast and shows these features as well as two more on the western side. One of these dark rectangles corresponds to the timbered pit. The other three are suspected trench boundaries. The suspected trench north of the timbered pit could also be identified in the 1958 image by on-screen animation of the 1958 and 1972 images. Small, young ponderosa pine can be seen over the central portion of the 1972 image.

The 1991 image (Figure 3f) shows the greatest change of the site over time. Ponderosa pines cover much of the area, making it difficult or impossible to see the suspected trenches and other features which were easily identified on the imagery derived from the historical aerial photographs. The ponderosa pines seem to cover only the portion of the site that was most disturbed. There is minimal ponderosa pine cover on the western and eastern sides of Figure 3a. The soil disturbance may have removed herbaceous vegetation that would compete with establishment of the ponderosa pine. The growth of the pine may also have been aided by the lack of severe drought during the past 15 to 20 years (Personal communications with Dr. Craig Allen, Bandelier National Monument, and Laurence W. Creamer, LANL, 1994). This image serves as an excellent reference for field checking of the features observed in the other imagery, as well as providing location information for roads, fences, and utility poles in the area.

Image Geographic Coding and Digitization of Feature Boundaries

The coregistered images of MDA-F were used to extract characterization information in the form of feature boundaries such as suspected trenches, access roads, and disturbed soil. These feature boundaries were extracted by on-screen digitization, whereby a cursor was used to trace their outlines from the imagery. This process was done by using a GIS. The GIS can be used to recall and combine this characterization information for mapping of the site. The GIS processing is based on the fact that all the layers of information are spatially defined within a common coordinate system.

The 1991 image was geographically coded to the New Mexico Central State Plane (NAD 83) coordinate system to facilitate mapping of the characterization feature boundaries. This coordinate system is the standard for the Los Alamos National Laboratory Environmental Restoration Project. Coordinate tick marks on the original orthophotos from which the 1991 image was formed were used to geographically code the image. An affine approximation was used to interpolate coordinate values across the image. The other images were geographically coded simply by copying this coding information from the 1991 base image. This was possible because the other images had been coregistered to the 1958 image which had been registered to the 1991 image.

The location error of the tick marks on the 1991, 1: 1,200-scale orthophotos used is 0.49 m (Personal communication, Gregory L. Cole, LANL, 1994) The RMS error in geographically coding the 1991 image was 0.30 m. An estimate for the location error of features derived from the 1991 image was calculated as the sum of these errors, or 0.79 m Adding this value to the registration errors for each image relative to the 1991 image (Table 2) yields an estimate of the location error of features derived from each image. These values are given in Table 3. Even though these values are high compared to the accuracy obtained from more formal orthorectification transformations, such as those used to obtain the 0.49-metre accuracy of the 1991 orthophotos, it was decided that the results were accurate enough to derive preliminary characterization information about the waste site.

The 1991 image was used to extract the locations of current features in the area. Features digitized from this image were the main road, unimproved roads, utility poles, and fences. This information was anticipated to be an aid in determining where the historical features lie relative to more recent features. A circular anomaly was also digitized from this image. This feature also appears to be an open pit on the eastern side of the 1946 image (Figure 3e). However, the registration error on the eastern side of this image was greater than 3 m (Table 2). The feature was tracked through time by on-screen flickering of the registered images so that it could be identified on the 1991 image. Because the location accuracy of this image is better than that of the 1946 image (Table 3), extracting the boundary of this feature from the 1991 image should be more accurate. Unfortunately, this could not be done with the other features identified in the historical imagery because changes over time have either eliminated these features (such as some of the roads), or they are obscured by the ponderosa pines (such as the suspected trench boundaries).

Features were also extracted from the coregistered and geographically coded historical imagery (Table 4). These features were identified in the analysis of the physical history of MDA-F as being significant to the characterization of the site. Both the 1972 and the 1958 images were used to identify the boundaries of three suspected trenches so that the variation between the two could be studied. The boundary of the timbered pit was extracted from the 1946 image and the 1972 image.

MDA-F Characterization

Feature boundaries digitized from the coregistered, geographically coded images are summarized in Plate 1, where boundaries are combined by using the GIS to overlay them on the 1991 base image. This shows the spatial relationship of these historical features within the context of how the site appears today. A summary of these results is also presented in Table 4.

A long, rectangular suspected trench boundary lay within a large area of disturbed soil in the center of Plate 1. The dimensions of this suspected trench were 122 m long by

Table 4. Features Extracted from the Coregistered and Geographically Coded Imagery of the MDA-F

Image	Features extracted	Comments
1991	Main road, utility poles, fences, unimproved roads, and a pit.	The pit was identified in the 1946 image. Flickering the 1946 and 1991 images located the pit in the 1991 image.
1972	Three suspected trenches and the timbered pit.	The trenches and timbered pit were identified as dark rectangles in the imagery.
1958	Three suspected trenches and the base of the large mound.	The trenches were identified as dark rectangles in the imagery.
1949	Two circular anomalies.	The low contrast and large location error of this image precluded the extraction of other features.
1946	Unimproved roads, disturbed soil, three circular anomalies, and the timbered pit.	The good contrast, ground detail, and acquisition date provided significant information.
1935	Homesteading structures.	These structures are cabins, pens, and garden plots.

11 m wide. The large mound lay within this area and was close to this suspected trench. Access roads branched into the large area of disturbed soil and passed through or close to other areas of disturbed soil. All of the suspected trenches lay close to these routes or near disturbed soil. The suspected trench boundaries derived from the 1972 and 1958 images were very similar. The only discrepancy was in the length of the eastern-most trench, which appeared slightly longer in the 1972 image.

The large circular anomalies lay close to the access roads and the timbered pit. The average radius of these anomalies was 2.7 m. They were spaced regularly with an average separation of 34 m vertically and 29 m horizontally. The boundaries of the timbered pit extracted from the 1946 and 1972 images matched the suspected location. This pit was originally used for explosives experiments, but might have been used for materials disposal before being filled in. The systematic arrangement of the circular anomalies and their proximity to the timbered pit suggested that these features may also have been created when the area was used for experimental work.

The fence boundary associated with the central suspected trench matched the boundary extracted from the 1958 image. However, it encompassed only about one third of the entire length of the trench. The southern fence boundary did not encompass any of the other features, although a circular anomaly and an area of disturbed soil were in close proximity.

The presence of the suspected trenches, pits, disturbed soil, large mound, and access roads were strong indications of disposal activity. The imagery suggested that disposal activity was confined to the central portion of the area defined by the 1991 base image. Evidence for disposal activity in this area was provided by the coregistered and geographically coded imagery of MDA-F.

Conclusion

This project has demonstrated the usefulness of digital analysis of historical aerial photographs for characterizing a DOE

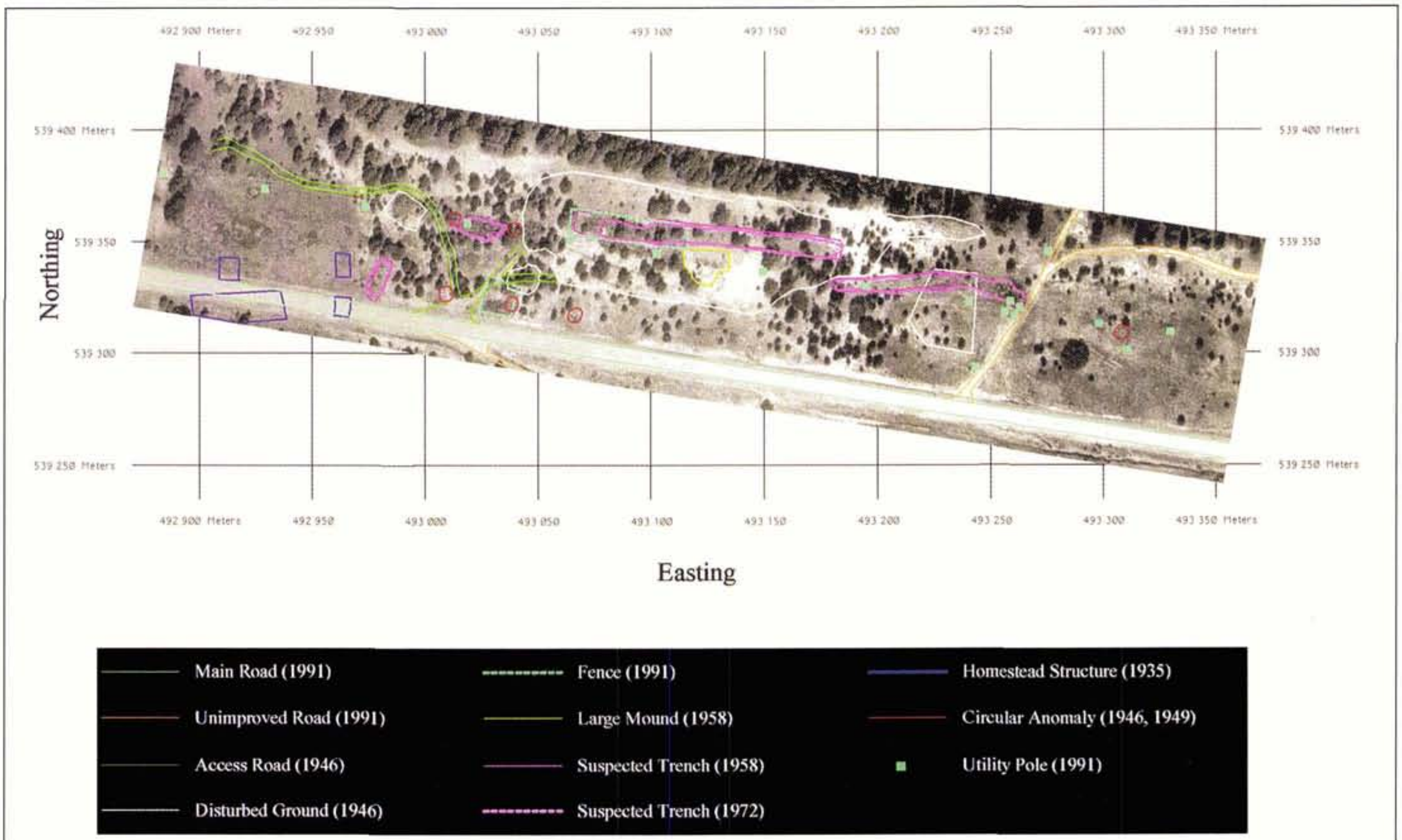

Plate 1. The 1991 image overlaid with the feature boundaries digitized from the coregistered imagery of MDA-F.

waste burial site. Historical aerial photographs with varying scales, orientations, and views of the waste site were transformed so that they matched a base image of the region of interest. The 2D projective transformation allowed the oblique photographs to be resampled so that overhead-like views of the site were created. These images of the waste site provided characterization information for the period of greatest activity, when no vertical aerial photographs of value existed. Coregistered images were easily compared by on-screen flickering. Digitized orthophotos provided geographical coding information for an area that contains few sharply defined man-made features. Feature boundaries were digitized from the coregistered and geographically coded imagery. The geographic coding and digitization work was performed by using a GIS. The GIS enabled these features to be combined with each other and the orthophoto mosaic of the area so that their locations could be displayed within the site as it appears currently. Lengths were easily measured on the geographically coded imagery by using tools available in the GIS. The information will help plan restoration efforts at the site.

This work provided information on the location of trench boundaries for an inactive landfill that may contain hazardous waste. Further work will integrate spatial data from other remote sensing and geophysical surveys of this waste site. Additional information may include high-resolution magnetometry and thermal, radiological, and multispectral surveys.

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