LA-UR- 96-1172

CONF-9607107--1

Title:

ENVIRONMENTAL WASTE SITE CHARACTERIZATION UTILIZING AERIAL PHOTOGRAPHS AND SATELLITE IMAGERY: THREE SITES IN NEW MEXICO, USA

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Submitted to:

XVIII ISPRS CONFERENCE, VIENNA, AUSTRIA

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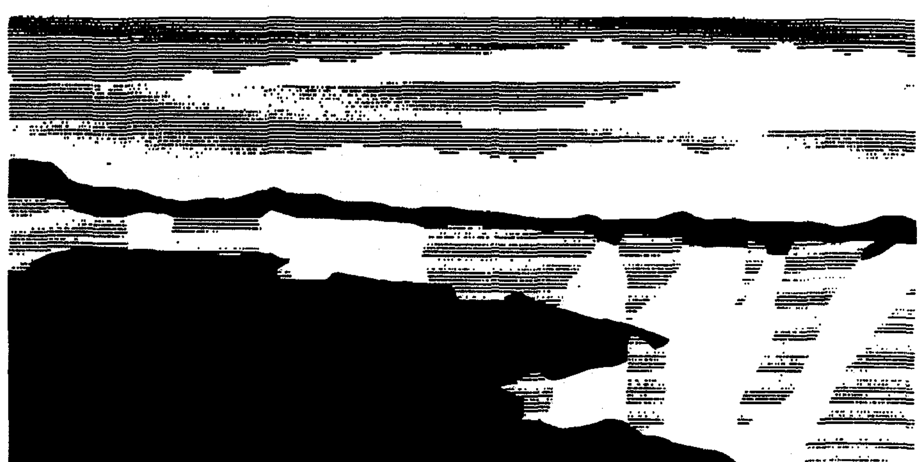

Los Alamos
NATIONAL LABORATORY

ENVIRONMENTAL WASTE SITE CHARACTERIZATION UTILIZING AERIAL PHOTOGRAPHS AND SATELLITE IMAGERY: THREE SITES IN NEW MEXICO, USA

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Commission VII, Working Group 1

KEY WORDS: Environment, Visualization, Imagery, Photogrammetry, Digitization, Change_Detection

ABSTRACT:

The proper handling and characterization of past hazardous waste sites is becoming more and more important as world population extends into areas previously deemed undesirable. Historical photographs, past records, current aerial satellite imagery can play an important role in characterizing these sites. These data provide clear insight into defining problem areas which can be surface sampled for further detail. Three such areas are discussed in this paper:

i. nuclear wastes buried in trenches at Los Alamos National Laboratory,
ii. surface dumping at one site at Los Alamos National Laboratory, and
iii. the historical development of a municipal landfill near Las Cruces, New Mexico.

1. INTRODUCTION

Los Alamos National Laboratory (Los Alamos), located in Northern New Mexico (Fig. 1), has been engaged in cleaning up many of its hazardous waste sites created during the last 50 years of weapons development. This effort has utilized a variety of techniques. Past records, current and historical aerial photographs, satellite and airborne remote sensing, as well as ground surveys have all played an important role. The effective combination of these data can provide clear insight into defining problem areas, as well as indicating where more detailed characterization information might be required. This paper specifically combines historical aerial photographs, airborne thermal and infrared data, and certain ground measurements to define the surface extent of pits, trenches , and surface contamination areas through time, both at Los Alamos and near the city of Las Cruces, New Mexico.

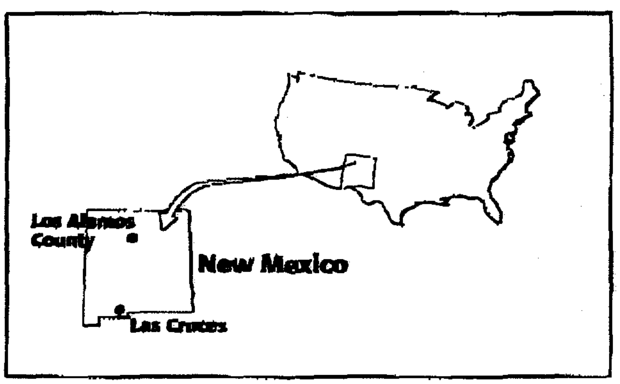

Fig. 1. Location of Los Alamos County and city of Las Cruces, New Mexico, USA

The waste sites evaluated at Los Alamos, known as Materials Disposal Areas F (MDA-F) and M (MDA-M), consist of hazardous waste buried in trenches and dumped on the surface. The locations of MDA-F and MDA-M are shown on Fig. 2, which displays the boundary of Los Alamos overlaid on a SPOT image. Los Alamos encloses about 43 square miles--the towns of Los Alamos and White Rock are shown in the image at the top and lower right respectively. The Rio Grande River crosses from the middle right to middle bottom of the image. The area has high relief, ranging from 7400 ft at the Los Alamos airport to about 6600 ft at White Rock. Los Alamos is located on the flanks of the Jemez Caldera, a volcano that last erupted over 1 million years ago.

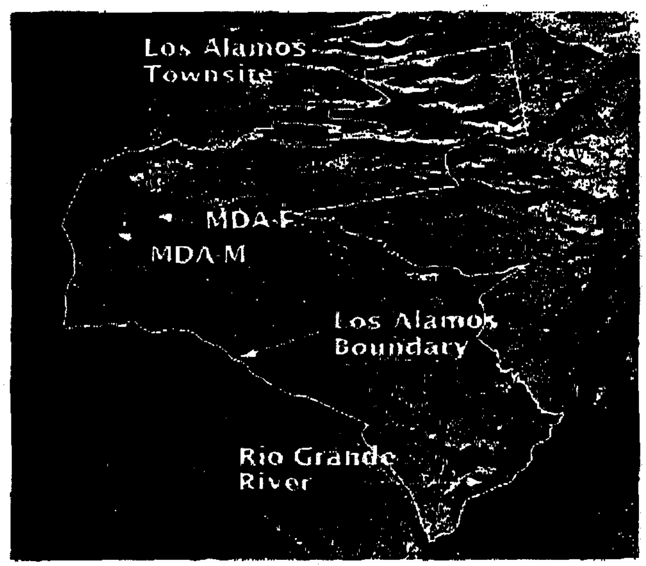

Fig. 2. Boundary of Los Alamos and waste site locations overlaid on SPOT image.

The mesas and plateaus are mostly tuffaceous, and the climate is quite dry.

Las Cruces, located in the southern part of New Mexico (Fig. 1), is also right next to the Rio Grande River. The landfill being studied as part of this paper is located southwest of the city (Fig. 3). This site is only a short elevation over the local water table. The landfill was closed in December of 1988 (backfilled in 1994) and there is concern about contaminant leakage into the Rio Grande. The immediate area varies from 3700 to 5000 ft in elevation and is also very arid.

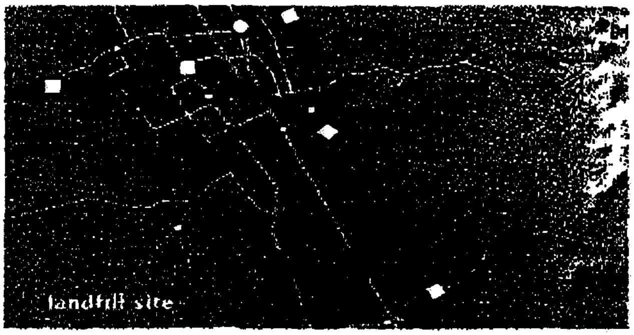

Fig. 3. Map of Las Cruces and the surrounding area.

2. LOS ALAMOS SITE MDA-F

The general area around MDA-F was used during World War II for the development of an implosion weapon, as part of the Manhattan Project activities. Waste disposal activities at MDA-F began in 1946, with the Laboratory Director ordering the construction of disposal pits for the burial of classified objects. It is believed that, in addition to classified objects, spark gaps containing ^{137}Cs, metal parts, tuballoy, primacord, and possibly small quantities of high explosives were buried at MDA-F. The number and location of these trenches and pits are unknown. Disposal continued through about 1952, although the number and location are unknown. The total depth of burial is also not known, but from the available records and interviews with participants, it is believed to be about 3 m. Since the exact location, number, and extent of the trench and pit boundaries are uncertain, it is important to identify and delineate the disposal boundaries in this area to aid in sampling and remediation activities.

Figure 4(a) shows a 1991 orthophoto of the MDA-F area, with boundaries of suspected trenches overlaid on the photo. Based on these boundaries, a magnetic survey area was defined as shown on Fig. 4(b), which is a photograph from the 1958 era. Note that the pits and trenches appear to extend beyond the fence lines shown in Fig. 4(a). Because it seemed that the pits and trenches did extend farther than originally thought, a study to evaluate historical photographs of the area was initiated.

2.1 The Historical Imagery of MDA-F

Historical aerial 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 collectively 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 images used are shown in Fig. 5(a)-(f). Note the clump of scrub oaks that are common to all images.

Fig. 4(a). 1991 orthophoto of MDA-F.

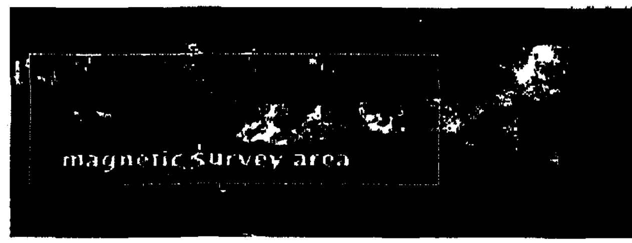

Fig. 4(b). 1958 matched photo of MDA-F.

The coregistered images were then imported to a GIS and geographically coded to a common coordinate system. The GIS was used to extract the boundaries of features such as suspected trenches and disturbed soil. The boundaries of disturbed ground, access routes, the main disposal trench, and three other suspected trenches were vectorized from the imagery by on-screen digitizing. These boundaries were overlaid on the most recent image of the site to display the historical characterization features within the context of how the site appears now. This preliminary analysis formed a basis for planning and comparing the results from other surveys of the site. The major trench found are shown on Fig. 6. Further details of this analysis can be found in Pope and others, 1995.

2.2 Infrared Data

Imagery from an airborne thermal infrared and multispectral survey, performed by EG&G/Remote Sensing Laboratory of Nellis AFB, was also made available for analysis. The imagery was geocoded and imported to the GIS. Various enhancements were calculated, including linear contrast stretches, edge enhancements, and principal components analysis. Information about trench locations and disturbed ground was extracted from the enhanced imagery. This information matched well with the analysis of the historical aerial photographs and the magnetic gradient survey.

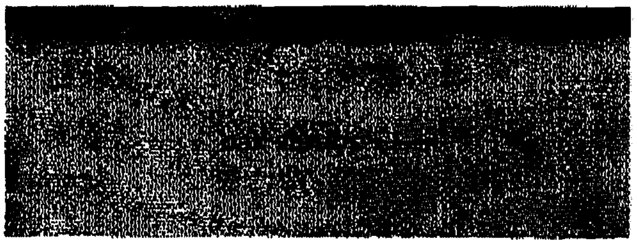

Fig. 5(a). 1935 image of MDA-F area.

Fig. 5(b). 1946 image of MDA-F area.

Fig. 5(c). 1949 image of MDA-F area.

Fig. 5(d). 1958 image of MDA-F area.

Fig. 5(e). 1972 image of MDA-F area.

Fig. 5(f). 1991 master image of MDA-F area.

Fig. 6. Suspected trenches and pits within the area of interest. Note the two large trenches. The one on the right wasn't suspected until the historical photography was done.

Fig. 7. Thermal imagery over MDA-F. The arrow note some particularly cooler and wetter locations, which partially correspond to pits and trenches.

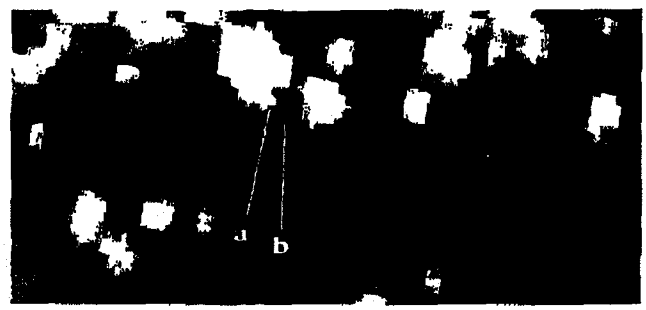

Fig. 8. Two transects across the easternmost pit, shown on thermal imagery.

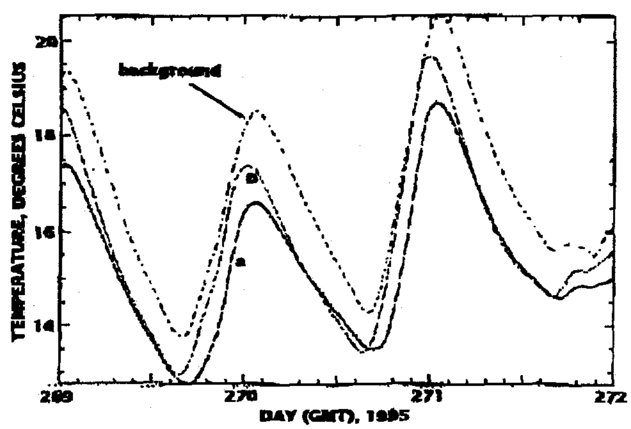

Fig. 9. Comparison of transect a and b temperatures with the background.

Figure 7 shows some of the thermal data over MDA-F. The cold and more moist spots are darker in this imagery. In order to verify that, two transects were established across the easternmost pit, as shown in Fig. 8. Both moisture and temperature measurements across these transects indicated differences from the surrounding area. In general the trenches were twice a wet as background and temperatures were lower. For example, Fig. 9 shows the lowering of temperatures at a 6 inch depth of burial in the middle of each trench compared to background.

2.3 Summary

Digital analysis of aerial photos at Los Alamos allowed disparate views of a waste site to be transformed so that they matched in scale, orientation, and extent. Surface expression of old trenches can then be found more easily. Also, with additional data, such as infrared and ground based moisture and temperature, the outlines of the trenches begin to become even more apparent.

3. LOS ALAMOS SITE MDA-M

MDA-M was used as a surface dump at Los Alamos from 1948 until 1965. Debris at the site consist of material from the removal of the old buildings as well as construction debris. Inspection of photos from 1958 and 1974 determined that some tree removal had been performed and that changes in drainage patterns had occurred. This work also determined that the differences in the unimproved access road to the site were minimal and that no pits or trenches were detected.

3.1 Historical Imagery of MDA-M

Detailed analysis of historical photos for this site followed the same procedure as that used in the previous section except for two differences. First, the use of as many photos as possible (as opposed to the limited set in the previous example) greatly improved the temporal sampling available for determining the land use history of the site. Second, an Affine transformation was used in addition to the Translation, Rotation, and Scaling (TRS) code written for the MDA-F project (Pope et al., 1995). The Affine transformation provided an objective measure of the registration error for each image; a significant improvement over the subjective measure used for MDA-F. Only the basics of the method are described here as well as significant differences between this analysis and that of MDA-F.

Internal and external archives were searched for aerial photographs which bracketed and spanned the period of use of MDA-M for disposal purposes. The archives at Los Alamos were found to be sufficient, although other aerial photographs could be included in the analysis if greater temporal sampling between 1976 and the present time is desired. For example, a 1995 acquisition could capture the recently created improved access route into the area so that its position relative to historical features can be determined. For this analysis, photographs from 1935, 1947, 1948, 1951, 1958, 1960, 1964, 1972, 1974, 1976, 1986, and 1991 were used. For the sake of brevity, only a subset of those photos will be displayed in this paper.

These photographs were then scanned using a flatbed scanner capable of 1,200 dots per inch (dpi) optical resolution. The scanning resolution was varied so that the spatial resolution of the resulting image was as close to one foot per pixel as possible. Note that this means that photographs with an average scale greater than 1:14,400 do not allow a spatial resolution of 1 foot/pixel to be obtained due to the 1,200 dpi limiting resolution of the scanner. Photos with scales greater than 1:14,400 were scanned with this finest resolution.

Next, the historical images were transformed to match the scale, orientation, and extent of a base image. This base image was defined as the 1991 image because it was derived from an orthophotograph which is the most planimetrically accurate of all the photographs. Resampling the other images to match the master image reduces the amount of distortions due to the combined effects of viewing geometry and terrain relief. The 1991 base image was geocoded to New Mexico Central State Plane coordinates (NMCSP, NAD 1983) by using the tick marks on the orthophotograph as control points and an Affine transformation.

A two step approach was used to register the historical images to the 1991 base image. First, each image was resampled by the TSR method so that a good match was obtained between it and the base image. On-screen animation of this image and the base image still revealed significant misregistration errors. Therefore, another transformation algorithm was used to improve the match even further.

Several control points (three or more) were chosen between the TSR transformed image and the base image. These points were used to define an Affine transformation. An Affine transformation defines two scale changes, one rotation, and two translations. Thus, at least three control points are needed to determine these five transformation parameters. With three control points, the transformation is overdetermined by order one, and the parameters are found by the method of least squares. The root mean square (rms) error obtained by this solution provides an objective measure of the registration error of the resampled image relative to the registration accuracy of the base image. Of course, the use of more than three control points improves the statistics of the registration error estimate. On-screen animation of the TSR transformed image and the base image aided in determining control point selection. The results of registering the historical images to the 1991 base image are shown in Fig. 10(a)-(f). Nearest neighbor resampling was used to provide the greatest computation speed.

Fig. 10(a). 1935 image of MDA-M area.

Fig. 10(b). 1947 image of MDA-M area.

Fig. 10(c). 1951 image of MDA-M area.

Fig. 10(d). 1958 image of MDA-M area.

Fig. 10(e) 1974 image of MDA-M area.

Fig. 10(f). 1991 master image of MDA-M area.

The registered images shown in Fig. 10(a)-(f) were visually interpreted by viewing an on-screen animation of these images. This analysis allowed the following physical history of MDA-M to be derived. The 1935 image illustrates the fact that this area was an open space even before Los Alamos was created (Fig. 10(a)). Stereoscopic viewing of the 1935 stereo pair revealed many trails around this area which were most likely created by homesteaders who were in the region at this time.

There does not appear to be any indication of furrows in this open space, like those which were found in the MDA-F analysis. The relatively steep slope might have precluded farming of this open space.

The history of vegetation cover at the site is very interesting. There are at least four places in the 1935 image where the vegetation cover has stayed consistent through time up to 1991. Even more intriguing is the growth of the Ponderosa Pine in the northwest and southwest corners of MDA- M. A few of these trees can be detected in the 1958 image and the rest are readily detectable in the 1972 image.

The road into the area was not created until some time between 1948 and 1951. The width of this road does not appear to change significantly from 1951 to 1991. The appearance of this road coincides with the first appearance of surface debris at the site in 1951.

Drainage patterns across the area are clearly visible in the 1947 image, possibly due to heavy vegetation cover within the drainage and/or high contrast due to shadowing effects. The changes in drainage across the area due to creation of the berm are clearly visible in the 1958 image. There does not appear to be any significant change in sediment deposition and transport between 1951 and 1991.

As previously mentioned, surface disposal appears to have started some time between 1948 and 1951. The dark features apparent in the 1948 image do not seem to correspond well with the three mounds of debris clearly detectable in all the images after 1948. They do appear to correspond well with dark patches of ground evident in the 1947 image and may also correspond to the drainage pattern of this image. This combined with the fact that the road is not apparent in the 1948 image leads to the conclusion that these dark features must be regions of heavy forest cover. In general, the poor quality of the 1948 photograph made interpretations difficult.

Surface disposal at the site is indicated in these images by generally darker, elongated features which have a mottled appearance and contain smaller and brighter pieces of material. The dark appearance of the debris could be due to the coloration of the material as well as the forest cover which develops on top of the mounds over time. This is similar to the signature of the disposal trenches determined from the analysis of MDA-F.

Three large mounds of debris are visible in the 1951 image. These areas change only slightly between 1951 and 1954, due to deposition of debris on the western end of the first and second mounds. A much brighter material is deposited on the northwestern portion of the first mound between 1951 and 1954. Of special note is the fact that these mounds do not change significantly between 1954 and 1991, which suggests that the majority of the surface disposal was performed between 1948 and 1954. Also, the berm around the site can be seen in the images from 1951 up to 1991.

Finally, stereoscopic viewing of the 1951 and 1958 photographs reveals significant movement of soil and material in several places within the bermed area. There is a small region of cleared ground and mounded material on the northwestern edge of the second mound in the 1951 image. This area is covered in debris in the 1954 image. There is a similar region of cleared ground and mounded material on the southeastern edge of the second mound. This occurs around a cluster of vegetation which is apparent in the 1951 image, but even more so in the 1958 image. This region persists from 1951 up until 1991.

Several types of features were extracted from the registered historical images. These features were extracted by on-screen digitization of the boundaries of these features as determined by visual inspection of the images and stereoscopic viewing. The 1947, 1951, and 1958 images were used to derive these features because they are indicative of the major changes which have occurred at the site and they have good contrast and detail.

The drainage patterns evident in the 1947 and 1958 images were traced. The top of the berm was traced from the 1958 image. The boundaries of the three mounds of debris were extracted from the 1951 and 1958 images. This allows the positions of the historical features to be compared within the context of how the site appears presently (excluding the recent addition of the improved access road to the area).

Changes in the drainage patterns across the area are readily apparent. The creation of the berm has restricted runoff from the northwestern portion of the site to travel close to the berm in a west to east fashion where it eventually spills into the southern tributary of Pajarito Canyon. Heavy erosion within the bermed area is only apparent in the south central portion.

Changes in the extent of the three debris mounds is also apparent in Fig. 10(a)-(f). The increase in surface disposal is clearly evident on the northwestern portions of the first and second mounds. Uncertainty in locating the edges of these mounds leads to areas where the boundary of the mound as derived from the 1951 image extends farther out than the boundary as derived from the 1958 image. It is also apparent that a large portion of the eastern end of the site is covered in debris. The berm may extend around the eastern end of the site, but it was not readily apparent in the images nor through stereoscopic viewing.

3.2 Summary

The digital analysis of historical aerial photographs of MDA-M has enabled a characterization of the site to be derived. Changes in the drainage pattern across the area due to creation of the berm was clearly evident. The change in extent of surface disposal could be seen. The stability in the coverage of debris could be seen from 1954 up until 1991. The analysis indicated that most of the disposal work was performed between 1948 and 1954. The analysis was not able to provide evidence for varying layers at the site, however three mounds of debris appeared to be present at the site with varying degrees of piling. The addition of photographs between 1951 and 1954 would aid in determining how the mounds were created; however, no photographic acquisitions are known to exist during this period.

4. LAS CRUCES LANDFILL

The landfill in Las Cruces, Doña Ana County came into existence before the EPA's strict standards of sanitary landfills. Aerial photographs dated as early as 1955 shows evidence of unregulated dumping. Since the landfill is so old, it does not have a liner and is most likely leaching contaminants into the groundwater beneath it.

Contamination of groundwater and nearby surface water is a serious problem, especially for unlined and abandoned landfills. When rain filters through a landfill it leaches out water soluble dyes, metal compounds, and other toxic materials. This material seeps from the bottom of the unlined landfill into the local watershed. Ground water contamination is only one side effect of unlined landfills. Since the landfill area is covered with dirt, organic wastes decompose anaerobically. Such underground decomposition of waste produces many toxic and volatile gases such as hydrogen sulfide and methane gas.

4.1 Historical Imagery of Las Cruces Landfill

Figure 11 depicts the general terrain of the survey area. This graphic is a 1:250,000 Digital Elevation Model (DEM) merged with a georeferenced polygon vector representing the Rio Grande River. The white lines comprise a vector file of all roads in the Las Cruces area. The vectors were created using TNTmips (a commercial image processing software package) and the DEM was acquired from the USGS WEB site. The final DEM in Fig. 11 was created by merging an east and west DEM through a mosaic interpolation process inherent to TNTmips.

Digital analysis of historical photography acquired from the Earth Data Analysis Center (EDAC) provided a preliminary characterization through change detection. Changes were mapped from 1947 through 1994. Biomass change mapping of coregistered, multidate, color infrared imagery helped reveal changes in biomass and plant vigor over time, a common anomaly found in and around waste areas. The change in plant health and abundance, either for the better or worse is a strong indicator of leachates and nonsource point pollution. Map based information such as soil, hydrology, and topography were fused with existing imagery to help assess potential contaminant routes from the site toward ground water areas and the Rio Grande.

Landfills can be easily identified and characterized on aerial photographs. Several multidate, aerial photographs covering the Las Cruces landfill and surrounding area were collected (Fig. 12(a)-(c) show examples). The coverage time line ranges from December of 1947 to April of 1994. The images were scanned at 600 dpi and included the site area which extends east to the Rio Grande, 0.25 miles beyond the western edge of the site, 0.5 miles beyond the northern edge, and 1 mile south of the southern most boundary. The resolutions varied from 1:20,000 to 1:40,000 ft.

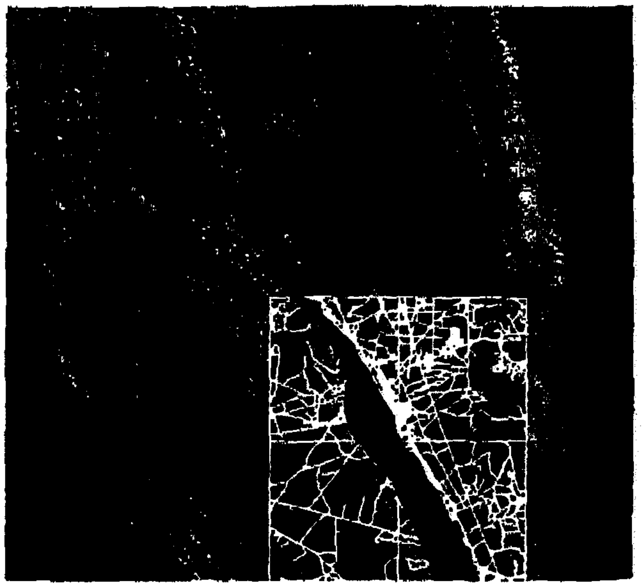

Fig. 11. Digital elevation model of Doña Ana County at 1:250,000 scale.

Fig. 12 (a) 1980 image of Las Cruces landfill.

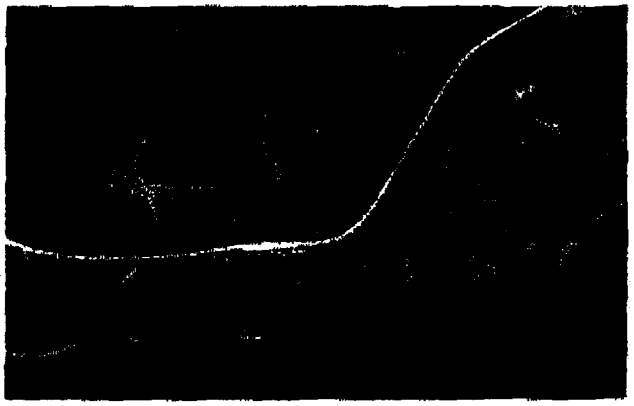

Fig. 12(b) 1989 image of Las Cruces landfill.

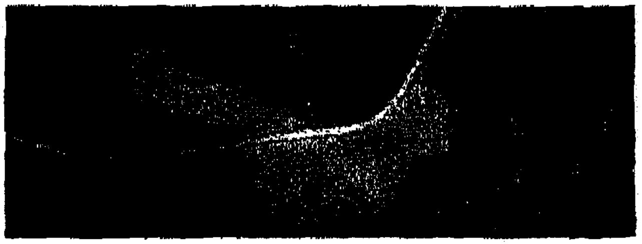

Fig. 12(c) 1994 image of Las Cruces landfill.

These multidate images were trimmed and exported as raw data files. These images were fed to a transformation process so they could be registered to a base image. In this study, the 1994 photo served as the master image. All the photos were vertical, requiring only rotation, scaling, and translation to match the master image. A program called MOTIFSHO was used to coregister, warp , and animate the site images. The coregistration and animation of multidate imagery provide an accurate time line analysis or change mapping of the site. As a direct result of the animation, a vector map was created which reveals the annual growth of the site from 1955 through June of 1994. Figure 13 illustrates that growth.

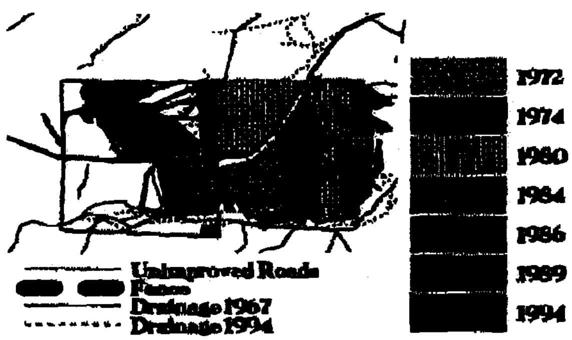

Fig. 13. Vector map created from animation of multidate imagery.

Identifying and tracking the transformed features of the landfill not only provided estimates of annual growth, but also provided clues to significant changes concerning topography. Some transformations are significant enough to change the behavior of the watershed. These modified areas are shown in Figs. 12(a)-(c).

4.2 Drainage Evaluation

The drainage texture ranges from fine to a medium texture at the landfill site. This implies that the soils and rocks in this area have poor internal drainage and high surface runoff. Another indicator of poor internal drainage is the gully shape found throughout the site photos. The gullies are generally "U" shaped suggesting the soil is silty or loamy.

The flow of surface water runoff from the site appears to originate from the freshly graded portions of the site, down average to steep embankments to a primary channel and eventually to the Rio Grande and it's adjacent plains. Natural drainage from the site to the Rio Grande has increased slightly due to :

1.) removal of vegetation around the site reducing consumptive water loss,
2.) soil disturbance, leaving exposed bare rock or impermeable soil (high potential runoff), and
3.) some increased bank slopes.

The Mesilla Valley water table is 10-25 feet below land surface and has a south dipping gradient at approximately 4.5 feet per mile. This gradient forces the direction of water flow to the south. See Fig. 14 for water gradient contours. In general, the ground-water in this region occurs under confined conditions, because clay has reduced the vertical permeability.

Ground-water moves southeastward beneath the West Mesa area, eventually converging with the water in the southern Mesilla Valley. Ground-water discharge occurs throughout both areas as drain flow to the river and evapotranspiration. Large surface-water irrigation allotments increase ground-water recharge, which improves the shallow ground-water quality neighboring these areas. Shallow ground-water discharges to drains which flow into the Rio Grande.

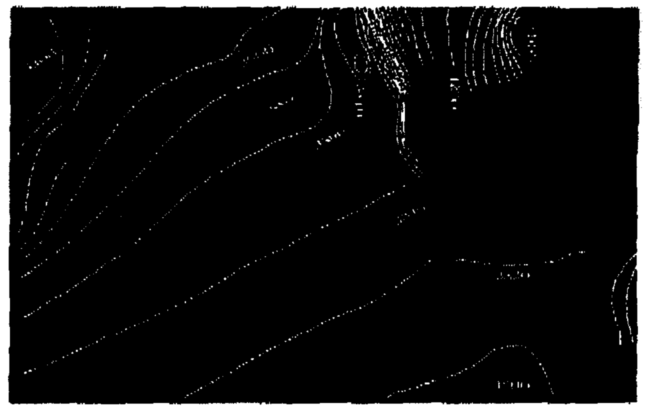

Fig. 14. Water gradient contours.

We have found from the water quality study done in the southern Mesilla Valley that there are perhaps several factors contributing to the high levels of dissolved- solids in water samples. We wanted to determine whether the landfill could be the source. Our objective was to determine if poor water quality could be related to changes in vegetation vigor. The method would be to algebraically manipulate color infrared imagery to show changes in vegetation health.

4.3 Biomass Evaluation

We had a limited amount of color infrared aerial photography, removing our ability to map changes over the entire operating period of the site. A decision was made to look at imagery collected a short time after the peak dumping or growth period of the landfills life cycle. This peak period occurred during 1980. We chose coverage shortly after that, 1984 and 1986. Choosing coverage during this period would ensure that if any migration of contaminants had occurred, it would have had time to spread to nearby vegetation. Growth of the site had continued for these years as well, but was overall in general decline.

Two 1:58,00 scale, color infrared (CIR) images were scanned. The scanning process yielded 3 files per image, a red, green, and blue intensity image. These two CIR images were studied very carefully for signs of vegetation decay. Then each pair of bands were subtracted. Subtraction is primarily a way to discover differences between images. Subtracting one image from another effectively removes from the difference image all features that do not change, while highlighting those that do. It is very important when subtracting vegetation images they must be very close in acquisition date, acquisition geometry, and illumination. If these parameters are not consistent there will be entirely too much variation in pixel value, and the subtraction will produce false changes in the resultant image.

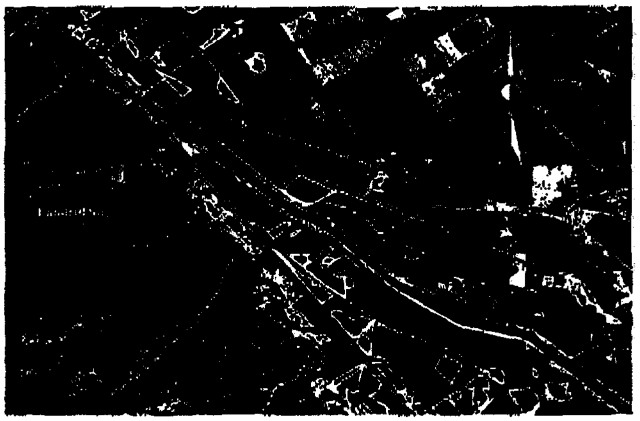

Fig. 15. Image difference between 1984 and 1986. Color IR images of the Las Cruces landfill. White blocky polygons delineate areas of vegetation stress. Image scale is 1:58,000 ft.

The change image was examined to detect areas of vegetation which showed initial stress, areas of advanced stress, and areas of dead or defoliated vegetation. All three levels of decay were delineated into polygons shown on Fig. 15.

Once there was evidence of vegetation stress, it could be merged with hydrography vectors of the area. The merged vectors would reveal trends in vegetation stress and local water flow in and around the landfill site. Figure 16 shows hydrology and vegetation stress vectors merged. The vectors show that south and east from the landfill there are several areas of stressed vegetation. The stressed vegetation shows a migration tendency southward along the west side of the Santo Tomas Drain. This migration coincides with the shallow ground-water discharge patterns, which discharge to drains and ultimately flows into the Rio Grande. Further details of this study can be found in Lewis and Van Eeckhout, 1996.

4.4 Summary

A good preliminary characterization and analysis has been completed with the outcome being the Las Cruces Municipal Landfill is potentially a threat to the local water table. Monitoring wells for leachate and drinking water should be established. A total of 6 would be adequate, one of each kind located on the southeast, south, and northwest faces. Several wells south along the Santo Tomas Drain would also be beneficial. Soil samples should be taken over a uniform area surrounding and including the site. Future characterization work would include sub-surface characterization using variograms or Kriging models for subsurface contamination (plume detection/migration). A 3-D model should be created for combining the surface and sub-surface data.

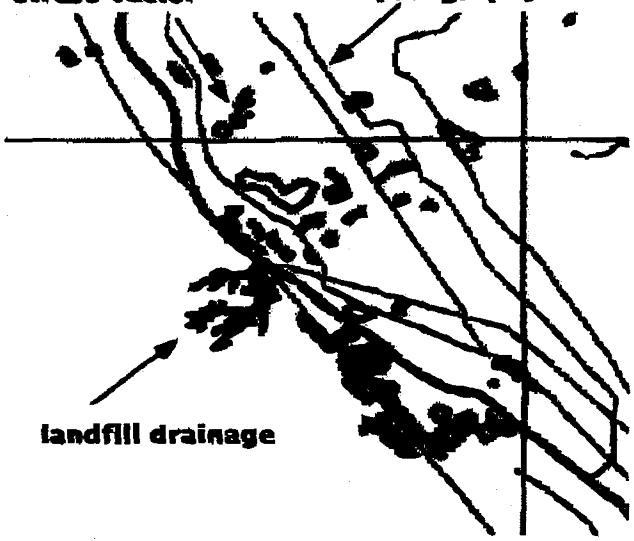

Fig. 16. Hydrography vector merged with vegetation stress vector. Landfill drainage is also shown.

5. ACKNOWLEDGMENTS

Special thanks go to Ray Brewer, Larry Creamer, Eddie Tafoya, all of Los Alamos National Lab. The assistance of Lee Balick, from the Bechtel Remote Sensing Lab, for infrared images is also gratefully acknowledged. For the Las Cruces portion, the assistance of Narendra Gunaji, Sr. Associate of Gunaji-Klement & Assc., Las Cruces was crucial. Funding for this work has been provided by the Los Alamos environmental restoration program and internal Los Alamos National Laboratory funds.

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