Multitemporal Analysis of Hazardous Waste Sites through the Use of a New Bi-Spectral Video Remote Sensing System and Standard Color-IR Photography*

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ABSTRACT: This study evaluated the utility of multispectral aerial video remote sensing data to map and monitor hazardous waste sites. The use of a video system offers several potential advantages over conventional photography for an operational monitoring program. These advantages include the immediate availability of multispectral data in either analog or digital form which can be acquired and stored efficiently and at low cost. Multitemporal comparison of airborne video data and conventional color infrared photography indicated that bi-spectral video data could be acquired and analyzed at sufficient resolution to accurately map a waste processing site near Phoenix, Arizona. Applying image processing and GIS techniques to the digitized video and photographic data permitted the effective generation of multitemporal land-cover maps that provided valuable information on the changing status of the site.

THE RAPID AND EFFICIENT ANALYSIS of the status of hazardous waste sites, waste dumps, and mining operations is of increasing concern in many regions of the country. Remote sensing technology coupled with the database and map generation capabilities of geographic information systems (GIS) affords a viable means of analyzing the changing conditions at these sites. In addition, the information derived from these data provide a means of assessing environmental compliance and can serve as evidence during litigation (Latin *et al.*, 1976). This study has utilized standard aerial color infrared photography, a new bi-spectral video acquisition system, and GIS software to evaluate changing conditions at a waste site near Phoenix, Arizona.

Investigations during the past two decades have demonstrated the value of aerial color and color infrared photography for analyzing and monitoring landfills and hazardous waste sites (Erb *et al.*, 1981; Evans and Mata, 1984; Garofalo and Wobber, 1974; Lyon, 1987; Shelton, 1984). More recently, high spatial resolution satellite sensors such as SPOT have been used on a regional scale to monitor landfills (Philipson *et al.*, 1988).

During this same period significant advances have been made in the application of both color and multi-band video remote sensing techniques (Everitt *et al.*, 1990; Meisner, 1986; Vlcek, 1983). In addition, the radiometric and photogrammetric accuracy of CCD video sensors has recently been investigated by Lenz and Fritsch (1990). Airborne video systems have been utilized in assessing and monitoring grassland and rangeland vegetation, agricultural crop conditions, forest pest management, soils, and water quality (Everitt *et al.*, 1986, 1989; Myhre *et al.*, 1990; Lee, 1990; Nixon *et al.*, 1985; Stutte and Stutte, 1990).

PROJECT OBJECTIVES

This study was an initial investigation of the utility of multispectral aerial video data to map and monitor hazardous waste sites. The use of a video system offers several potential advantages over conventional photography for an operational monitoring program. These advantages include the immediate availability of multispectral data in studies requiring an emergency response or rapid turn-around, the images can be acquired efficiently and at low cost and stored on an inexpensive medium (video tape), and when detailed analysis is warranted, the analog data can be converted to digital values and analyzed with standard image processing and GIS hardware and software. However, if video data are to become an effective tool in waste site analysis, then it must be demonstrated that they can be as effective as standard color or color infrared aerial photography.

To evaluate the applicability of the video data, we acquired and interpreted both a conventional color infrared aerial photograph and multispectral video data which were acquired approximately 2 1/2 years apart over a known waste processing site. Our objectives were to determine (1) the viability of the information derived from the video data for large scale mapping of hazardous waste sites and (2) the utility of advanced image analysis and GIS tools for mapping changes in land cover and conditions at the site between the photo mission and video image acquisition. By demonstrating the effectiveness of the video data, we can establish an additional remote sensing tool for environmental analysis.

STUDY AREA

The site investigated is a former waste processing facility located in Buckeye, Arizona, approximately 40 km west of Phoenix (Figure 1). The site covers an area approximately 390 m (north-south) by 270 m (east-west). It is currently inactive but had been used for waste storage and for waste container (drum) recycling. It is located in a predominately agricultural area (cotton) on essentially flat terrain and is partially covered by natural desert shrubs. Pertinent features that could be identified at the site included (1) waste containers, (2) buildings, (3) excavated or disturbed ground, (4) surface stains, and (5) changes in the areal extent of both bare or cleared ground and natural vegetation.

DESCRIPTION OF DATA

COLOR INFRARED AIR PHOTO

A standard color infrared aerial photograph, acquired by the U.S. Environmental Protection Agency (EPA) in March of 1988,

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was utilized in this study. The available photo print was at a scale of 1:840 and could be used to identify features less than 0.5 m in size.

Bi-Spectral Video Data

The bi-spectral video camera system employed was developed at the Arizona Remote Sensing Center and designed specifically to acquire data for use in both research and applications (Hutchinson *et al.*, 1990). The system consists of two bore-sighted cameras fitted with red (610 to 690 nm) and near-infrared (780 to 930 nm) bandpass filters, and a multiplexing unit which can generate three processed output products in real-time. These data products are (1) a composite simulated-color infrared output generated by mixing the red and near-infrared channels, (2) an output of alternate frames from each channel, and (3) an output of a vegetation index image derived from an analog ratio of the two channels [(NIR-Red + 0.5) / 2(NIR + Red)]. This is an electronic approximation to the classical normalized vegetation index [(NIR − RED) / (NIR + RED)]. The CCD video cameras produce an image which is 754 pixels (horizontal) by 488 pixels (vertical) (11.5-μm CCD elements). The exposure time is 1/60 second and the signal-to-noise is 50 dB peak signal to RMS noise.

The video data were acquired over the site in October of 1990. Mounted in a light aircraft, the mission was flown at approximately 305 m above ground level. At this flying height the cameras equipped with 12.5-mm lenses produced a ground pixel size 0.7 m by 0.7 m. The analog video data were digitized utilizing a frame-grabbing system, and four overlapping frames were needed to cover the waste site.

LAND-COVER ANALYSIS PROCEDURES

Land-Cover Classification

A site specific land-cover classification scheme was developed based upon the multilevel methods developed by the U.S. Geological Survey for remote sensing studies (Anderson *et al.*, 1976). The classification scheme was aimed at providing as much detail as possible for those land-cover classes pertinent to the evaluation of this site. Table 1 lists the eight classes used in the interpretation of the site. The three- and four-digit numbers following the site name follow the Anderson *et al.* (1976) classification strategy. The eight classes were identified and mapped based upon their characteristic size, shape, color, texture, and pattern.

Shrubs and brush were easily identified by their characteristic spectral response and texture. Most buildings on the site were made of aluminum and identifiable by their shape. Piles of debris and waste containers and drums were mapped on the basis of their distinctive color, shape, and pattern. Dumps (buried material) were mapped on the basis of their hummocky shape and texture while excavated ground showed clear signs of the movement of soil. The stained ground exhibited a distinctive darker color on the photo and video imagery with irregular size and shapes. Bare or cleared ground displayed the characteristic color and texture of the local soil.

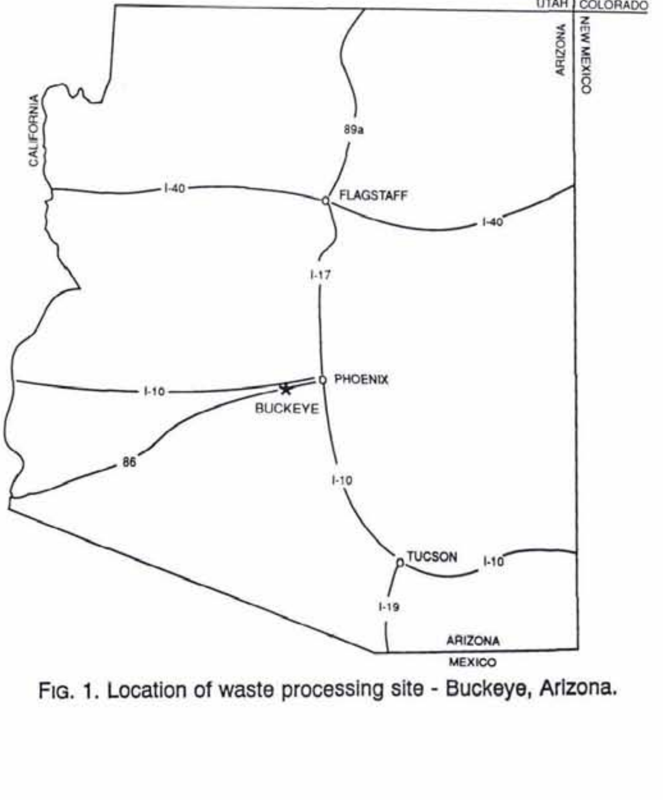

FIG. 1. Location of waste processing site - Buckeye, Arizona.

Mapping Procedures and Results

Previous applied research has illustrated the advantages of combining image processing and GIS technologies for land-cover mapping utilizing multispectral video and photographic data (Marsh *et al.*, 1990). In the previous study, we combined the image processing capabilities of ERDAS* and the GIS mapping and analysis proficiency of ARC/INFO to effectively map agricultural land-use patterns. In this study, we again wanted to demonstrate the capabilities of these techniques to facilitate land-cover mapping. This was especially important to fulfill our objective of producing multitemporal change maps of the site.

Thus, procedures were developed to convert both the analog color infrared photo and the video frames into a common digital format for geometric registration of the two data sets and subsequent interpretation and analysis. To achieve this objective we utilized two systems – MicroImages' MIPS package (Version 2.70) and the U.S. Army Construction Engineering Research Laboratory's GRASS package. These image processing and GIS packages allowed us to scan the airphoto to convert it to a digital (raster) format as well as to enter the previously grabbed digital video frames. The image data could then be interpreted in a raster format and analyzed and mapped in vector format.

Pre-Processing and Geometric Registration

The air photo was scanned using the MIPS software at a resolution that provided a 0.11-m pixel. A three-band image (red, green, and blue) is created from the original color infrared photograph. Given the initial pixel size of 0.7 m for the video data, we selected a common pixel size of 0.5 m. Therefore, the digitized air photo was resampled to a 0.5-m pixel and then geometrically rectified using nine ground control points and a second-

*Trade names are included for the benefit of the reader and do not imply an endorsement to the product by the University of Arizona.

TABLE 1. WASTE SITE LAND-COVER CLASSIFICATION SCHEME

Vegetation
1. Shrubs and Brushland (320)
Industrial Land
2. Buildings (131)
3. Debris (132)
4. Waste Containers and Drums (1321)
Open Land
5. Dumps (1921)
6. Excavated Ground (1922)
7. Bare or Cleared Ground (1923)
8. Stained Ground (1924)

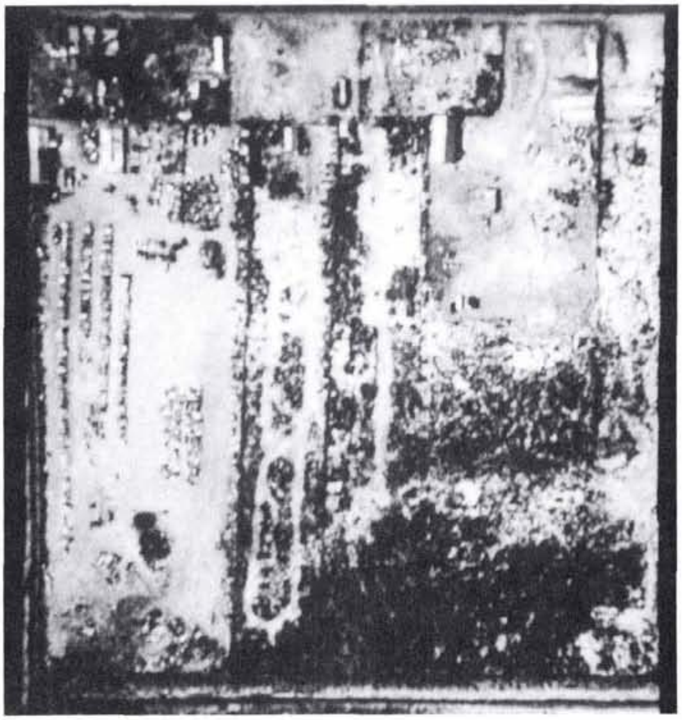

FIG. 2. Digitized color infrared photograph of the Buckeye site.

order polynomial fit to the 1:24,000-scale topographic basemap (Figure 2). The resulting UTM registration had a root-mean-square (RMS) error of less than one pixel (0.5 m). The original red and near-infrared bands from the video data were also resampled to a 0.5-m pixel and, using common ground control features, registered to the air photo (RMS < 1 pixel) (Figure 3).

TABLE 2. LAND-COVER MAPPING RESULTS

Land-Cover Class	1988 Photo	1990 Video
Shrubs and Brush	35.6%	34.2%
Buildings	1.3%	1.0%
Debris	2.9%	1.8%
Waste Containers	1.2%	0%
Dumps	0%	1.2%
Excavated Ground	0.6%	0%
Stained Ground	1.0%	2.2%
Bare Ground	57.4%	59.5%
	100.0%	100.0%

Interpretation and Classification

The two images were then interpreted following the classification scheme given in Table 1. Comparison of the original air photo print and the corresponding resampled digital image, as well as a visit to the site in 1990, indicated that equivalent land-cover classes could be accurately mapped on the digital air photo as well as on the video images. The interpretation was done interactively by viewing the displayed air photo and video images and utilizing the feature mapping capabilities of MIPS. Contiguous structures such as buildings, debris, stained ground, excavated areas, and dumps were mapped and classified using the cursor to draw the outlines of these features just as one would perform this task manually.

The more automated feature mapping capabilities of MIPS also permitted mapping the widely distributed and non-contiguous land-cover classes. In particular, the vegetation and bare ground-cover classes could be mapped utilizing the equivalent of an interactive classifier (boxcar). By selecting two or more prototype pixels from the display, the software calculates the largest and smallest pixel values in the composite multispectral data and identifies all pixels that fall within that range. By interactively adjusting the prototype pixels, a land-cover classification that included even individual trees and shrubs could be easily

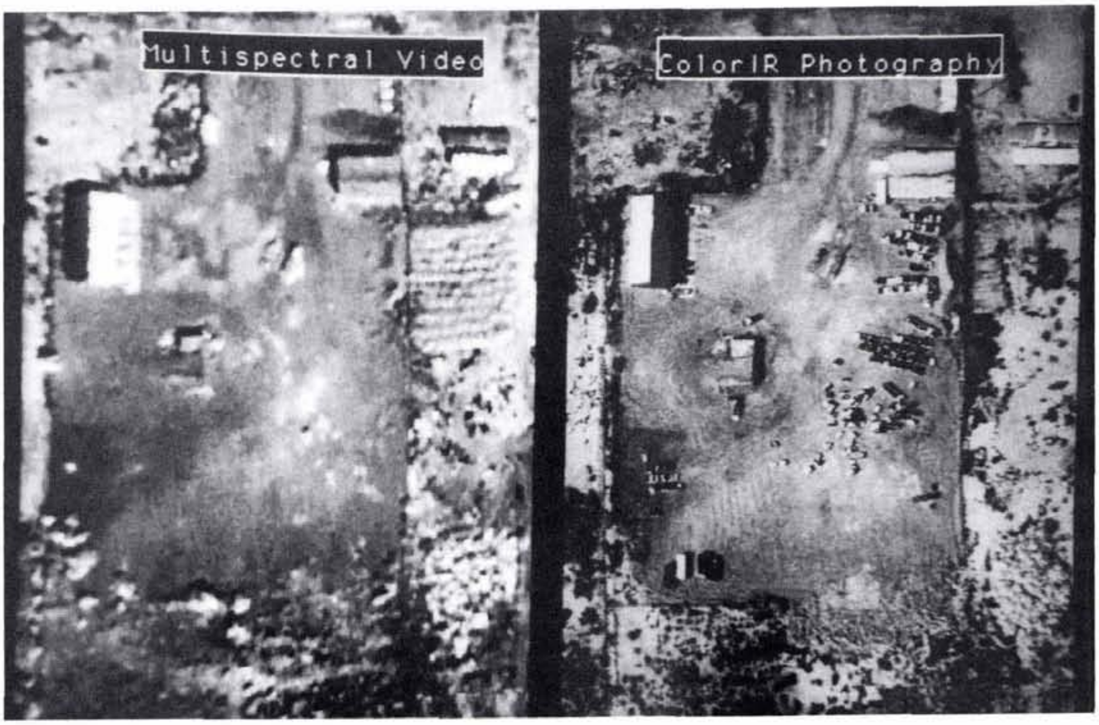

FIG. 3. Comparison of the digitized CIR photograph and video image of the site.

created. These classes were sufficiently spectrally homogeneous to permit a "supervised" classification. However, we found that, when dealing with image data at such high spatial resolution, most of the features are too spectrally heterogenous to permit viable automated classification.

The resulting land-cover classifications of the 1988 air photo and the 1990 video image are displayed in Figures 4 and 5. To facilitate interpretation of the two classification maps, the data sets were transferred to the GRASS system and filtered with a 3 by 3 majority filter. This filter serves to "clean-up" the classification by assigning individual pixels within the filter to the predominate class determined in the nine-pixel array. Table 2 provides the percent of the total area classified in the two data sets after filtering.

Multitemporal Analysis

Our ability to successfully map and classify the land cover at the site in 1988 and 1990 permitted more detailed evaluation of this change. During the 2 1/2-year period between air photo and video data acquisition, efforts at remediation included the removal of waste containers and the clearing of debris. Approximately 30 percent of the area land-cover classification changed. To document these changes, a series of maps were created in vector format utilizing the MIPS software.

These maps depict change from 1988 to 1990 that includes (1) disturbed areas (debris, bare ground, and excavated ground) that became vegetated (Figure 6); (2) areas classified as debris, vegetation, and waste containers that became bare ground (Figure 7); (3) areas classified as debris, vegetation, bare, ground or waste containers that became stained ground (Figure 8); and (4) vegetation, bare ground, and excavations that became dumps (Figure 9). Table 3 provides the percent of total area and the

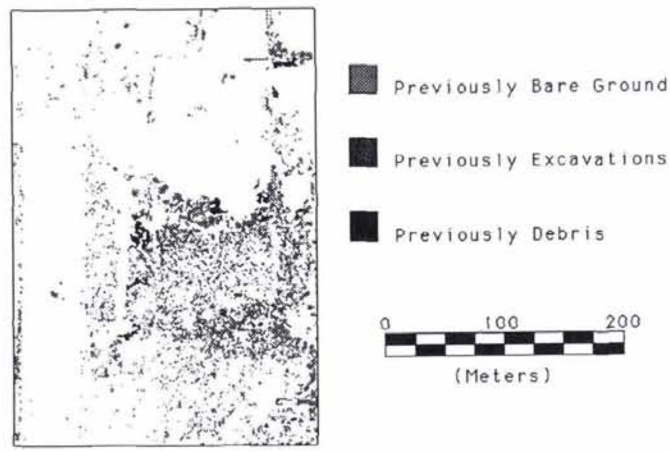

FIG. 6. Change map - to vegetation.

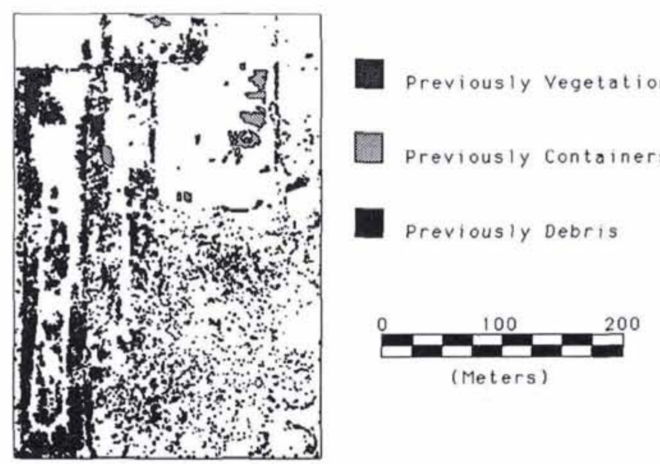

FIG. 7. Change map - to bare ground.

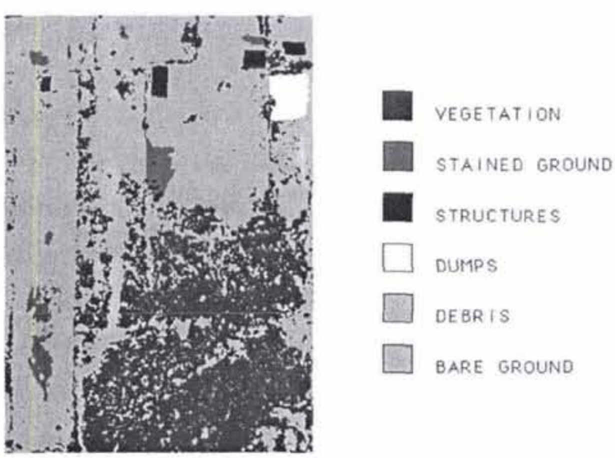

FIG. 4. 1990 land-cover classification map.

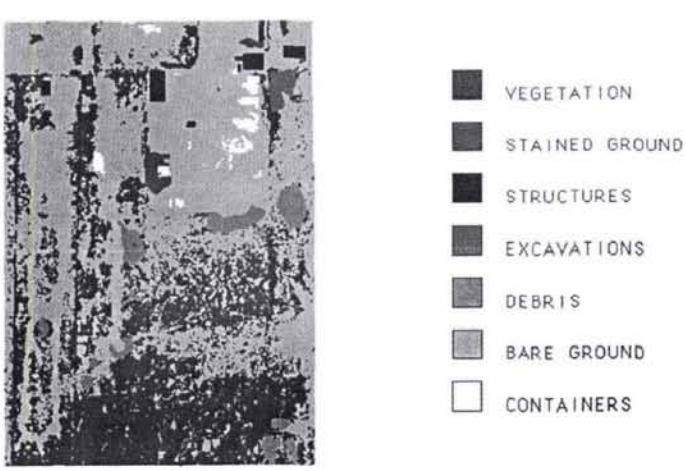

FIG. 5. 1988 land-cover classification map.

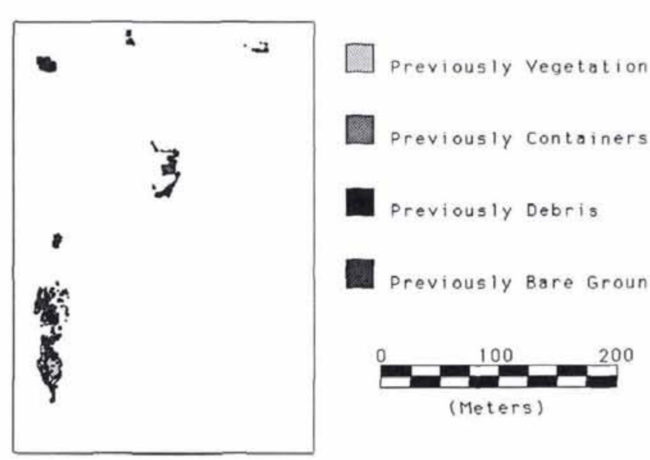

FIG. 8. Change map - to stained ground.

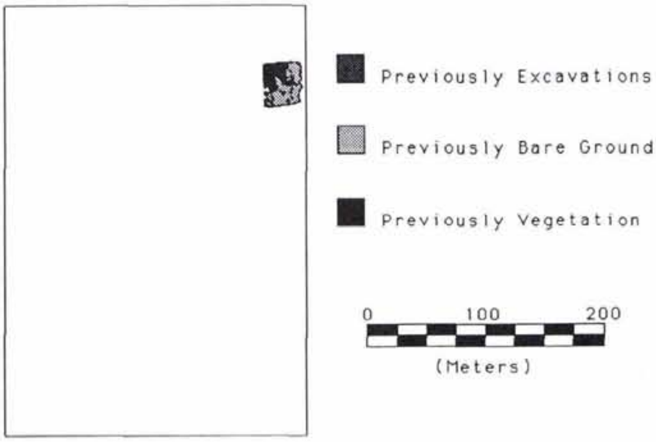

FIG. 9. Change map - to dumps.

TABLE 3. IMPORTANT LAND-COVER CLASS CHANGES

Class Change		Percent of Total Area	Percent of Changed Ground
1988 Photo	1990 Video		
Debris	Vegetation	0.7	2.2
Bare	Vegetation	10.6	35.6
Excavated	Vegetation	0.2	0.5
Debris	Cleared	0.8	2.6
Vegetation	Cleared	12.2	40.9
Containers	Cleared	1.1	3.8
Debris	Stain	0.2	0.3
Vegetation	Stain	0.5	1.5
Bare	Stain	1.0	3.3
Containers	Stain	0.2	0.3
Vegetation	Dumps	0.2	0.5
Bare	Dumps	0.7	2.3
Excavations	Dumps	0.4	1.3
Other Changes		1.1	4.9
Unchanged		70.1	—
		100.0%	100.0%

percent of changed ground that each of these land-cover changes represent.

Though the actual total area for many of these changes is small, their importance in understanding what actually transpired during remediation efforts and the current hazards posed by the site may be very significant. As an example, an area mapped as excavated and bare ground in 1988 was mapped as a dump in 1990. Certainly, what might have been buried in this area would be of environmental concern.

CONCLUSIONS

Based upon these initial results and the logistical advantages of utilizing airborne video data, further evaluation and utilization of these remote sensing data for hazardous waste site analysis is warranted. The spatial resolution of the video data, when flown at an appropriate flying height, was sufficient to permit the accurate mapping of the waste site. Analyzing the data in digital form permitted geometric registration and interactive classification of the raster images. Comparison with a standard color infrared aerial photograph revealed that equivalent information could be derived from both media.

Application of image processing and GIS techniques proved to be an effective means of analyzing the multitemporal data set. Though interactive mapping of land cover proved effective in this study, manual interpretation and subsequent digitization of the photo map into a GIS remains a viable and effective option of analysis. Change maps generated from the multitemporal land-cover classifications of the site proved to be an effective means of identifying small, yet potentially hazardous, conditions. The digital map database can now serve as the baseline for monitoring the site in the coming years.

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