Use of Maps, Aerial Photographs, and other Remote Sensor Data for Practical Evaluations of Hazardous Waste Sites

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ABSTRACT: Aerial photographs and remote sensor data were used to identify and inventory hydrologic, soil, and vegetative conditions indicative of hazardous waste sites. Several papers and their results demonstrate the utility of these data and techniques for engineering applications. A combination of aerial photos, remote sensing, maps, and advanced evaluation techniques provided more information than traditional engineering techniques alone.

INTRODUCTION

NEW TECHNIQUES are required to augment traditional measurements used in analyses of hazardous waste sites. Maps, chemical sampling, and company documents only provide a portion of the data required for engineering analyses. There is a need for additional data and data of a different type than supplied by traditional measures. This has lead to application of historical maps, aerial photographs, and remote sensor data for management of hazardous waste sites (Lyon, 1982).

Interpretation of aerial photographs provided detail on historical and current conditions of waste sites. The resulting data were used to determine the presence or absence of landfills, as well as current and historic vegetative, soil, and hydrological indicators of hazardous conditions. Current aerial photographs or remote sensor data were valuable as additional data for planning of landfills, and monitoring of soil and water conditions of sites. Several applications follow which illustrate the value of these technologies for site evaluations.

FIG. 1. Piles of car batteries over-fill areas of Doane Lake, Oregon. The December 1983 View looks to the west.

HISTORICAL APPLICATIONS

Quantitative measurements and maps were made from historical aerial photographs (Lyon, 1982). These tools were then used for engineering evaluations of hydrologic, soil, and vegetative characteristics. From these products, it was possible to determine the location, extent, and chronology of change in landfills (Garofalo and Wobber, 1974; Erb *et al.*, 1981) Analysis of historical photographs and maps of sites in Oregon and Ohio provided details which could not be supplied by interviews with personnel or from company documentation.

The Doane Lake "super-fund" hazardous waste site of industrial northwest Portland, Oregon provided an example of the value of historical maps and photos for evaluation of landfills. Wastes were buried in the lake or marsh for more than 40 years, and now only an asphalt-covered surface is evident from the ground (Figure 1). Contributions to the lake included chemicals and waste from production of the herbicide 2,4-D, and creosote and chlorine. Sampling of surface and ground water adjacent to the site has indicated the presence of phenols, 2,4-D, lead, and other contaminants, including spent casings and pieces of lead cathodes from car batteries (Figure 1).

Analysis of an orthophoto map from 1975 (1:24,000 scale) and field visits from 1982 to 1985 provided few indicators of a large fill (Figure 3). 1:24,000 scale maps and historical aerial photos for 1951 (July 26) and 1970 (July 5) show the change in area of soil and vegetative cover on the site (Figures 2 and 3).

Both these photos represent the same season during different years. The 1:24,000-scale topographic maps were evaluated to determine the progression of filling the lake. Area measurements determined the approximate area of the lake filled with waste and other materials. The original area of the lake was approximately 8.7 Ha before 1951, with the filling beginning at the east end (Figure 2). In 1970 a map and photo showed additional fill and a diminished surface area measuring approximately 4.8 Ha (Fig. 3). By 1970, 55 percent of the lake east of the railroad bridge had been largely filled.

As an additional practical source of information, historical maps and aerial photo data were valuable because they could be used to reconstruct the chronology of change. Analysis of these old photos and maps also revealed several likely paths of water movement from the historic lake and channel system to the nearby Willamette River (Figures 2 and 3). Construction of a manufacturing plant on the site prevented further tracking of water movement. It is known, however, that buried waste movement is interfering with the quality of the manufactured product, and has forestalled expansion of the plant.

Very old historic maps can be an important source for analyzing landfills operating before regular acquisition of aerial photographs (<1936). Sites like Woburn, Massachusetts predate the Civil War as do many previously undetected disposal areas (Titus, 1981). To identify both location and variety of buried materials required analysis of U.S. Geological Survey (USGS) and other historical maps. Sanborn Fire Maps of Pelham, New York (Titus, 1983) document the historical location and contents of buildings in industrial areas. These maps have been compiled since the early 1800s as documentation for insurance purposes. Examination of maps compiled over a period of years successfully located buried materials for future clean-up (Titus, 1981).

Evaluation of aerial photographs from 1938 and 1958 has also been used to identify the extent of waste at the Love Canal

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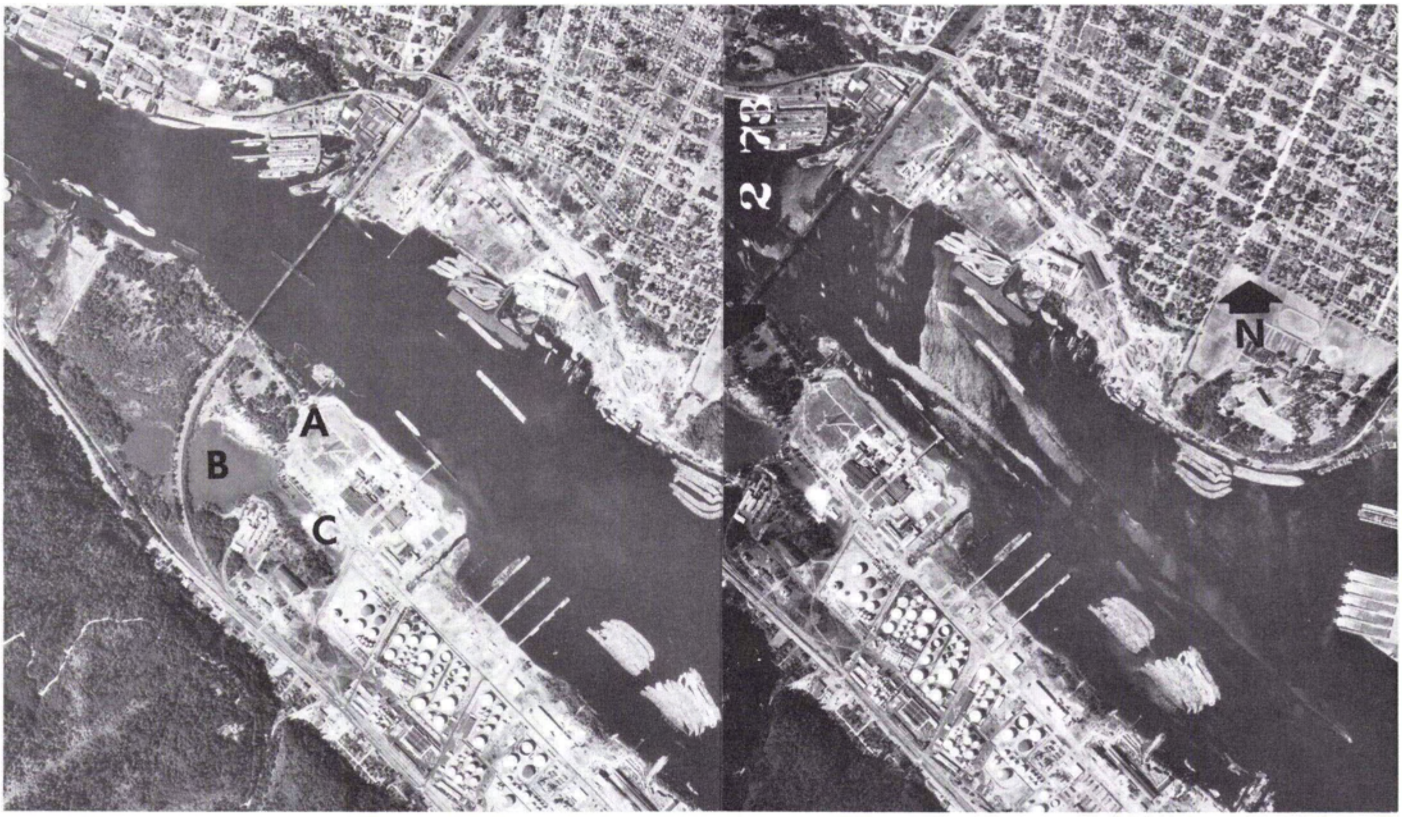

FIG. 2. 1951 aerial photograph of Doane Lake (original scale was 1:20,000). Note presence of drainage connecting the lake to the Willamette River (A), the lake east of the railroad bridge (B), and the bare area at the east end of the lake (C).

hazardous waste site (Erb *et al.*, 1981). The locations of the canal, school, playground, and homes constructed on the site were evident. Later coverage showed a canal covered by soil, and subsequent development of a school and homes on the site. The absence of vegetation on the covered canal in the 1970s was detected by the white tone of bare soil as interpreted from low altitude photos (Erb *et al.*, 1981; Lyon *et al.*, 1981). The low relative density of vegetation cover may be indicative of a "poisoned" site where few plants were able to grow.

Further analysis of the 1938 photos of the Love Canal area revealed crescentic-shaped dark and light toned areas indicative of abandoned channels, point bars and vegetation types (Erb *et al.*, 1981). The coarse-textured soils of point bars and abandoned channels provide a likely path for movement of leachate. Leachate from Love Canal has been found to move away from the site through storm sewers to Lake Erie (Jaffe and Hites, 1985). These storm sewers and abandoned channels are other potential areas of leachate movement, and they can be identified from photos for further evaluation.

Another use for remote sensor data is for monitoring hazardous waste disposal sites for early detection of problems. The contained dredge disposal facility and wetlands on Dickenson Island in Lake St. Clair, Michigan were mapped from color and color infrared (CIR) aerial photographs and Landsat satellite data (Lyon, 1979). Initially, these maps were used in a wetland management plan. In the future they will be used to evaluate change in vegetation community type and condition, which may be related to the contained disposal facility.

INDICATORS OF WASTE SITES

Analysis of photos for general soil textural and hydrological characteristics was useful for engineering projects. Many landfills occupy abandoned sand and gravel operations commonly located in glacial deposits, old alluvium, or floodplain areas. The coarse textured soils of these sites are poorly suited for landfills due to relatively higher rates of leachate movement (Erb *et al.*, 1981). The location of coarse textured soils adjacent to abandoned sites can be mapped from current and historical aerial photos, and the data can assist in selection of sites for monitoring the water quality adjacent to the site.

To locate areas where leachate may potentially move, it was important to interpret general soil type by photographic interpretation of color or grey-tone. Differences in color or tone indicated variation in the hydrological and textural characteristics of soils. Coarse textured soils appear lighter grey in tone on black-and-white photos, resulting from relatively rapid drainage of rainfall. Identification of lighter tones or coarse textured soils may indicate paths for movement of leachate and contaminants to the surface water (Way, 1982; Mintzer, 1983).

Wet areas of soil appeared as black or dark tones on black-and-white photographs. These dark tones were used as locators of lower areas composed of fine, textured soils that were conduits of runoff. Fine textured soils can be identified by evaluation of tone, and sites suitable for landfills can be mapped for further analyses.

Barren areas devoid of vegetation appear lighter in tone, indicating mineral soil. This tone is also characteristic of disturbed soil which can indicated a path for surface runoff. Figure 4 shows an abandoned landfill in Ohio where light tones indicate the path of surface runoff. Also, note the dark tone of plants as compared to areas without any plant cover (A).

Figure 5 shows a pond of leachate that was not evident from ground inspection (A). Conditions indicative of the movement of leachate included the pond, and low density of vegetation on the berm surrounding the landfall. Identification of these conditions was facilitated by the aerial view, revealing features which initially went unnoticed during field inspection.

Interpretation of the cross-sectional shape of gullies was also useful for identification of soil texture. Vertical or near-vertical

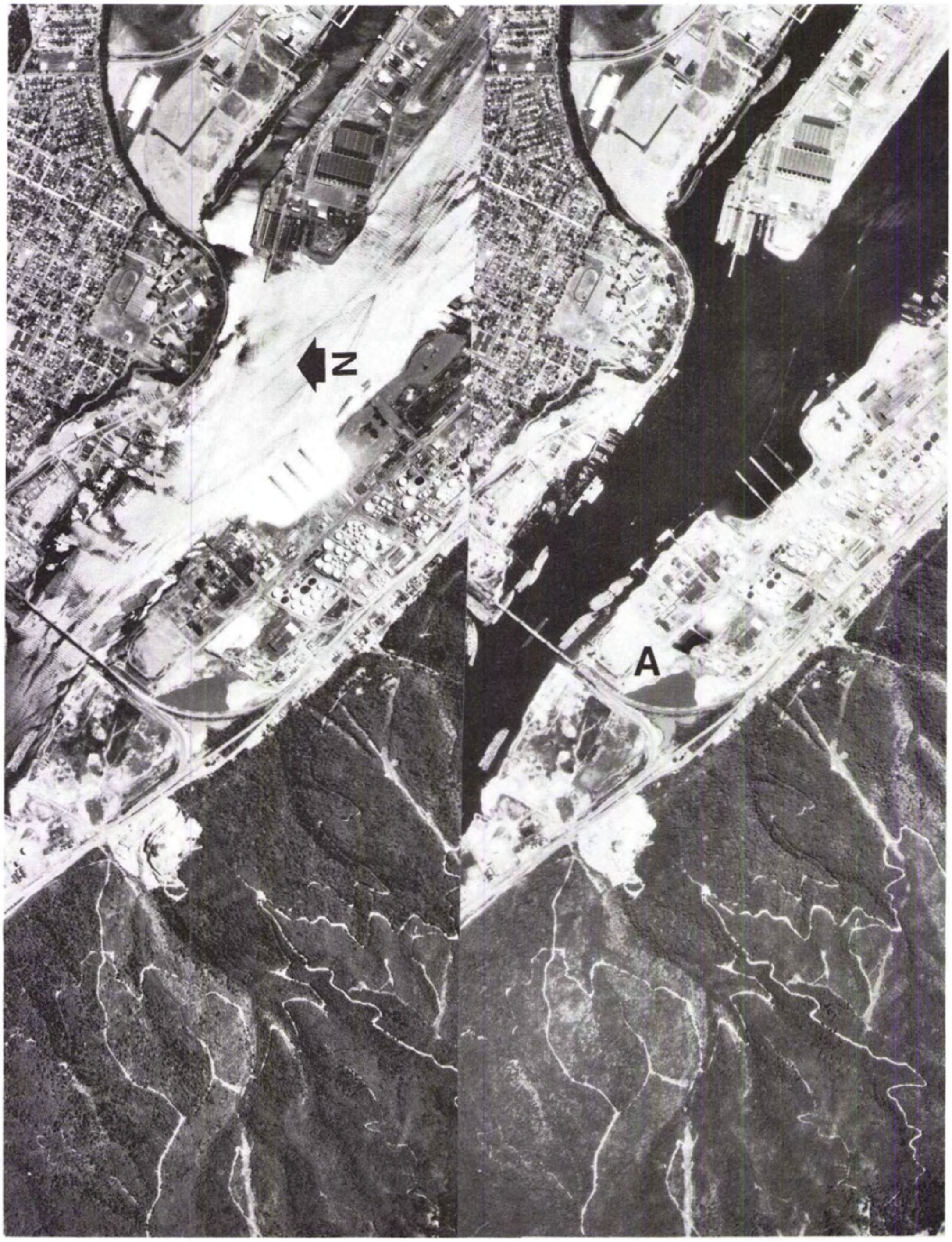

FIG. 3. 1970 aerial photograph of Doane Lake (original scale was 1:20,000). Note the filled area (A), the change in vegetation from the 1951 photos, and the increase in number of roads and buildings.

gullies sides are indicative of fine-textured, cohesive soil materials. V-shaped gully cross-sections indicate sandy soils. Attention to gully shape helped to identify general texture of soils, and shape can be reliably interpreted as an indicator of texture (Way, 1982; Mintzer, 1983).

PLANTS AS INDICATORS

Individual plants or groups of plants may respond in several ways to the presence of hazardous waste. They may decrease in size, vigor, density, or number of species, or the variety of species may be different from undisturbed sites (Lyon *et al.*, 1981; Lyon *et al.*, 1986). Individual plant species and groups of species also respond to altered hydrological conditions and the presence of toxic materials. Examination of photos for these vegetative conditions can indicate where unusual hydrological and soil conditions exist.

In particular, several vegetative conditions are indicative of problems and can be interpreted from aerial photographs or remote sensor data (Lyon *et al.*, 1981). These include identification of (1) barren soil areas, (2) decreased number of plants, (3) decreased vigor of plants, (4) absence of characteristic plant species, (5) presence of dead trees or shrubs, (6) early "fall colors" or senescence in plants, and (7) presence of plant species adapted to grow on sites with toxic materials.

In general, "clean" abandoned sites free of hazardous waste

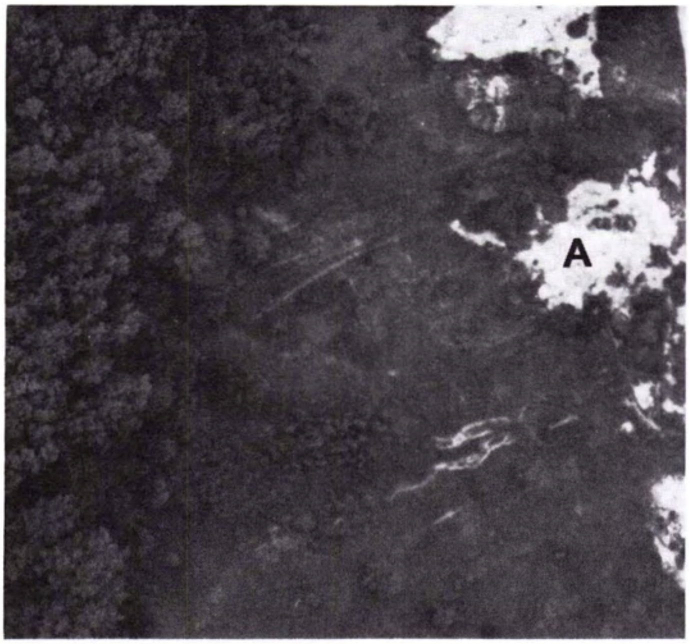

FIG. 4. Low altitude aerial photos of a closed landfill in Ohio (September 1984, original scale, ~ 1:1,000). White toned areas are bare of vegetation and are locations of surface runoff.

FIG. 5. Low altitude aerial photo of an open landfill in Ohio (September 1984, original scale, ~ 1:1,500). Note location of a pond formed of runoff from the pit (A).

are covered with plants in a few years. The "succession" or replacement of barren soil areas with shrubs and eventually with other woody plants is known to occur on most sites in humid regions. Plant species are adapted to exploit a variety of soil and hydrologic conditions, and "weedy" species rapidly populate sites with bare soil. With time weedy species are replaced with woody shrubs. Shrubs, in turn, will be replaced by tree species where the dominant regional land cover is forest.

Departures from the local sequence of vegetation succession and the resulting absence of vegetation or lower relative abundance of plants on a give site are suspect. An abandoned site which is currently and historically in "weedy or barren" cover has not experienced the sequence of weed, shrub, and forest cover. Commonly, a human-induced problem interrupts the progression and creates an anomolous vegetative condition (Figure 5). These sites can be identified from aerial photos and later evaluated by on-site inspection.

In areas of high concentration of waste (such as inorganic compounds), the number of species and the extent of vegetative cover may often decline. The plants that are present may be only species that tolerate high relative concentrations of inorganic toxins. In high and medium concentration areas, plants often die or exhibit "fall colors" earlier in the season as compared to normal sites. Plants may also appear yellow or chloretic (without chlorophyll) at different times of the growing season, depending on concentration of contaminant and plant species.

Plants also respond to high relative concentrations of nutrients including nitrogen, phosphorus, and potassium compounds. Color infrared aerial photographs (CIR) can be used to identify vigorously growing vegetation on sites with higher concentrations of these nutrients or availability of water. High nutrient or water seepage areas can often be interpreted as the relatively bright magenta or red in color of vigorously growing vegetation. In particular, CIR has been valuable for locating wastes that are plant nutrients, or nutrients from failed septic systems (Titus, 1983). The grass grows vigorously with higher concentration of nutrients and water, and these areas can be detected and inspected on the ground.

Vegetation can provide an indicator of movement of mercury and PCB contaminated leachate from the site. Any dead or diseased plants and absence of vegetation can be identified on black-and-white, color, or color infrared aerial photos and further evaluated with traditional methods. Analysis of aerial photos and further evaluated with traditional methods. Analysis of aerial photos using this "vegetative indicator" approach can help assist the monitoring of waste sites. The use of vegetation as an additional long-term monitoring approach has been valuable where adjacent, high value resources are of concern to the public and the cost is justifiable (Ruth *et al.*, 1980; Siegal and Welby, 1981).

CURRENT APPLICATIONS

Interpretation of remote sensor data and aerial photos can yield a variety of hydrological and soils data for identification of potential landfill sites. The applications include (1) location of sites with clay-like soils, (2) evaluation of local drainage, (3) identification of sites with low gradient slopes, (4) assistance in the location of diversion structures, and (5) exclusion of poorly suited sites from further evaluation, including wetlands, coarse-textured soils, floodplains, erosion-prone soils, permafrost areas, and critical habitat for biota.

A program to collect aerial photographs and remote sensor data over active sites can be helpful for hazardous waste site management. Periodic photography provides a record of position and burial of materials over time. This record can assist in recovery of materials, or facilitate evaluation of undesirable chemical reactions or settlement of soils. After closure, acquisition and interpretation of low altitude aerial photos can be used to monitor site conditions.

HOW TO OBTAIN DATA

Aerial photos can be acquired in several ways. The higher cost approach is to obtain coverage by an aerial photography firm. The photography is useful for production of engineering maps (scales of 1:2,400 to 1:4,800), and this may justify the cost as most engineering jobs require large scale aerial photos.

A relatively low cost approach is to employ 35-mm or video cameras to photograph waste sites from a rented aircraft. Another cost-efficient method is to obtain a camera mount to acquire vertical or oblique coverage (Figures 4 and 5). These 35-mm or video systems are valuable, low cost, and quantitative approaches for acquisition of data (McCarthy et al., 1982; Lyon and Drobney, 1984). In addition, these systems can be rapidly deployed to photograph sites as required.

Existing aerial photographs can be ordered from archives. When requesting available coverage, it is best to indicate the latitude and longitude of the site. It is also helpful to include the quadrangle or other appropriate map of the site.

Aerial photographs are flown and archived by several groups.

U. S. Geological Survey photographs are archived by the EROS Data Center, Sioux Falls, South Dakota. Photos can also be viewed and ordered at regional centers, including Menlo Park, California, Denver, Colorado, and Rolla, Missouri. Department of Agriculture photographs are archived by the Agricultural Stabilization and Conservation Service (Aerial Photography Field Office, P.O. Box 30010, Salt Lake City, UT 84130).

Historical maps of the United States are available through the National Cartographic Information Center (NCIC), USGS, Reston, VA 22090. To obtain aerial photographs before 1941, contact the Cartographic and Architectural Branch, National Archives and Records Service, Washington, DC 20408.

Canadian aerial photos can be obtained from the National Air Photo Library, Surveys and Mapping Building, 615 Booth St., Ottawa, Canada, K1A 0E9. Remote sensor data can be obtained from the Canada Centre for Remote Sensing, 717 Belfast Rd., Ottawa, Canada, K1A 0Y7.

Aerial photos of specific hazardous waste sites may be obtained from the U.S. Environmental Protection Agency (EPA, Remote Sensing Branch, P.O. Box 15027, Las Vegas, NV 89114, or EPA Interpretation Center, P.O. Box 1575, Vint Hill Farms Station, Warrenton, VA 22186). This coverage can be obtained only through the Freedom of Information Act, and the NCIC is the disbursing agent.

Aerial photography companies often archive their historical photos. These firms can be found in the Yellow Pages and through professional directories or lists of sustaining members in *Photogrammetric Engineering and Remote Sensing*.

CONCLUSIONS

Hazardous waste sites present difficult problems for inventory and management. Several technologies have identified technologies which supply quantitative data in a rapid and comprehensive manner. Historical and current data can be provided by interpretation of aerial photographs and remote sensor data. Measurements were used to establish both the change in size and characteristics of landfills over time. Siting, monitoring, closure, and rehabilitation of abandoned hazardous waste sites were facilitated by use of these data.

Identification of soil, hydrological, and vegetative conditions of sites are valuable uses of aerial photos, remote sensor data, and maps. Managers can potentially save money and help maximize use of human resources by using a combination of traditional measurements, maps, and aerial photo or remote sensor technologies.

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