Practical Paper

The Use of Aerial Photographs in County Inventories of Waste-Disposal Sites

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ABSTRACT: Over the past 15 years, various studies have documented the value of remote sensing for inventorying and assessing waste-disposal sites. Most of these efforts have concentrated on specific sites. This paper reviews and illustrates a procedure that can be applied in performing comprehensive inventories of known and unknown, active and inactive, waste-disposal sites over county-size areas. The steps described include pre-survey activities, evaluation and acquisition of aerial photographs, development of the classification system, public information surveys, airphoto analysis, site geo-referencing, site prioritization and follow-up airphoto analysis, and implementation of a monitoring program. Although not a case-study report, the paper focuses on Suffolk County, N.Y., where multi-date, "historic" aerial photographs were analyzed in conjunction with field and citizen surveys to detect and categorize hundreds of previously unidentified sites for remedial action.

INTRODUCTION

IN THE UNITED STATES, the federal government is addressing the clean-up of several hundred known hazardous-waste landfills; however, state and local governments are faced with the challenge of finding thousands of active and inactive waste-disposal sites to determine the risk these sites pose to humans and the environment. This paper describes a procedure for applying multi-date, "historic" aerial photographs to inventory known and unknown waste-disposal sites over large areas. Being intended for use by counties, the procedure is based on over 15 years of experience in remote-sensing analyses of waste-disposal sites. Although illustrations will be drawn from a single, recent inventory in Suffolk County, Long Island, N.Y., the procedure is generalized and not developed or reported as a case study.

The application of remote sensing in detecting, monitoring, and analyzing waste-disposal sites is well documented (Souto-Maior, 1973; Garofalo and Wobber, 1974; Philipson and Sangrey, 1977; Sangrey and Philipson, 1979; Erb *et al.*, 1981; Titus, 1982; Titus, 1984; Lyon, 1982; Lyon, 1987; Redfield *et al.*, 1987; Stohr *et al.*, 1987; Philipson *et al.*, 1988; Airola and Kosson, 1989; Jones and Chidley, 1989). Special attention has been paid to the unique value of older, "historic" aerial photographs for (1) establishing the existence of a disposal site; (2) assessing the site's geology, soils, and changing drainage; and (3) objectively capturing the temporal record of the site's location, extent, possible contents, and both on-site and near-site land use and cover (Erb *et al.*, 1981). While most remote sensing analyses of disposal sites have concentrated on specific sites, Nelson *et al.* (1983) applied historic aerial photographs as part of a methodology to inventory, classify, and prioritize sites in one county in upstate New York. The procedure described here is similar to that of Nelson *et al.* (1983). Here, however, emphasis is placed on the remote sensing aspects of the effort. An earlier version of the procedure was presented by Barnaba *et al.* (1989).

PROCEDURE

The series of tasks that will be discussed is outlined in Table 1. Temporally overlapping, they range from pre-survey activities, through airphoto analysis of the highest priority sites, to inventory updating. In the case of Suffolk County, the inventory was conducted by a university laboratory as part of an extension effort, wherein university personnel worked closely with and trained county personnel, in addition to procuring aerial photographs and basic photo-analysis equipment for the county. It is desirable but not always possible for county personnel to conduct the inventory and updating in-house; it is essential that county personnel be intimately involved in the entire effort.

TABLE 1. TASKS TO BE PERFORMED IN COUNTYWIDE INVENTORY OF WASTE-DISPOSAL SITES.

A. Pre-survey activities
  1. Define scope and objectives
  2. Characterize survey area
  3. Design a working classification system
  4. Inventory available aerial photographs
  5. Consider new airphoto coverage
B. Evaluate and obtain airphotos/finalize classification system
C. Survey the public
D. Analyze airphotos—first stage
E. Geo-reference sites
F. Prioritize sites
G. Analyze airphotos—second stage
H. Implement a monitoring program

A. PRE-SURVEY ACTIVITIES

1. Define scope and objectives. At the outset, it is important to define clearly the scope and objectives of the survey program within the county's financial and time constraints. The principal (and ultimate) objective is normally to locate every known and unknown, active and inactive, waste-disposal site, and eliminate its potential risk. But what level of information and detail should the airphoto survey provide? This relates to (a) how site locations will be presented and (b) the extent to which the located sites will be categorized. For example, should the disposal-site boundaries be delineated or will site identification suffice? Over how many dates will each identified site be tracked? Should site locations be presented as annotations on contact or enlarged

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photographs, on topographic or tax maps, or on photo or map overlays? Alternatively, would recording the site or site boundaries as a digitizied data layer in a geographic information system be preferred? How many different classes of sites will the airphoto interpreter have to distinguish? Will one product of the airphoto analysis be recommended field sampling locations (e.g., for leachate), which would require characterizing the soil and hydrogeologic conditions as well as locating the site? Although the approach taken in the Suffolk County survey will be described, there are many possible variations.

The principal objective will normally define the level of information and detail to be provided, yet secondary objectives might have a major influence on how the project is conducted given the financial and time constraints. For example, in Suffolk County, one goal was to train county personnel and obtain basic photo-analysis equipment for the county in order that inventory updates could ultimately be done largely in-house.

2. *Characterize the survey area*. The area to be surveyed should be characterized with respect to its (a) development history (i.e., the nature and periods of development as they relate to the amount and types of waste disposal); (b) disposal practices (e.g., in mined areas or pits); and (c) physiographic setting (i.e., soils, geology, and hydrology). Information on the physiographic setting is always useful; however, it takes on crucial importance if leachate-sampling locations are to be recommended, given the relationship between migration of leachate and site hydrogeology (Sangrey and Philipson, 1979; Erb *et al.*, 1981).

To illustrate briefly, development in Suffolk County, an area of 2390 sq km, has been most intense since the end of World War II. Rapid and continuing urbanization has progressed from New York City, which is only some 25 km to the west. Because of this development pattern, the inventory was initially limited to the western two-thirds of the county. In general, there has been no heavy industrial development. The county is dominated by glacial outwash plains whose sand and gravel deposits offer particular susceptibility to groundwater contamination.

3. *Design a working classification system*. Although it is possible that certain types of waste disposal will either be unresolvable or uninterpretable on the available photographs, or that certain types of disposal may be unexpected or defined in finer detail during the survey, a "first approximation" of a waste-disposal site classification system should be devised. Because the aerial photographs to be used in the survey have not yet been obtained or, at least, they have not been analyzed, this working classification system normally reflects a compromise between the perceived needs of the county and the experience of the airphoto interpreter.

In Suffolk County, eight types of actual or potential waste-disposal sites were tentatively recognized: dumps, landfills, pits, lagoons, barrels and drums, mined land, disturbed land, and aboveground tanks (Table 2). The last, while not properly waste-disposal, was included by the county in recognition of the environmental risk that a spill or leak would pose.

4. *Inventory available aerial photographs*. Concurrent with Tasks A.2 and A.3, a systematic inventory of available airphoto coverage of the survey area should be performed. National, state, and local government sources as well as private sources should be queried to produce a detailed listing of the date (year, month), scale, film type, completeness (boundaries and gaps), total number of photographs, and cost of coverage, and if the coverage is stereoscopic. It is also important to ascertain if the photographs are accessible for preliminary evaluation (see Task B) and the time required to process a purchase order.

Being situated on Long Island, an area of dynamic growth and the home of two aerial survey companies, Suffolk County is fortunate to have been photographed on numerous occasions. At the time of the inventory, nine private and public sources were able to provide a total of 23 different dates of countywide coverage, 1930 through 1984; the majority were medium-scale, panchromatic.

TABLE 2. CLASSIFICATION SYSTEM USED FOR INVENTORYING WASTE-DISPOSAL SITES WITH MULTI-DATE, MEDIUM-SCALE, PANCHROMATIC AERIAL PHOTOGRAPHS, IN SUFFOLK COUNTY, N.Y.

Class	Description and Identifying Features
Dump	Open desposits of solid wastes in unordered accumulation; no regard for aesthetics; no maintenance.
Landfill	Includes all degrees of landfilling where solid wastes are deposited and covered by soil (i.e., uncontrolled, sanitary, and secured); similar to dumps in some respects, except landfills exhibit ridges or mounds of soil cover on the active face, with heavy-machinery marks revealing the process of covering and compaction.
Pit	Deep, open hole in the ground; natural or constructed; used for liquid wastes; may appear similar to a lagoon, but there is no raised containment edge, and the area covered is usually smaller.
Lagoon	An engineered approach to liquid-waste disposal; leaching pools and trenches constructed with bermed edges usually wide enough to accommodate a transporting vehicle.
Barrels/ Drums	Stacks or piles of barrel-like containers are present; barrels and drums are normally identifiable only when they occur in quantities, in the open.
Mined Land	Sites where mining for sand and/or gravel has occurred; easily observed by the high reflectance of the exposed soil and the cavity from excavated material.
Disturbed Land	Land surface appears disrupted or dissimilar to its surroundings for reasons that cannot be observed at the date of the photograph examined; further evaluation is needed to confirm, drop, or re-classify the site; includes salvage yards where tanks, stains, seeps, or other indicators of potential problems are observed.
Above-ground Tanks	Closed tanks or silos other than barrels; used for storage of various liquids, such as crude oil, refined petroleum products, or chemicals (included in the inventory classification because of the danger of spills or leaks); easily identified when spaced upright, in open, or by shadow if small; may be difficult to detect when near or attached to buildings, when tightly clustered, or when positioned horizontally.

5. *Consider new airphoto coverage*. The decision will need to be made about whether to fly new airphoto coverage. While primarily an economic decision, survey-related considerations will include the most recent date of appropriate, available airphoto coverage; the level of waste-disposal activity since the most recent coverage; and the amount and reliability of alternative information on waste-disposal activities since the most recent coverage.

B. EVALUATE AND OBTAIN AIRPHOTOS/FINALIZE CLASSIFICATION SYSTEM

Selection of the specific sets (i.e., dates) of airphoto coverage that will be used in the survey is based on an analysis of those factors listed in Task A.4 and on a visual assessment of the photographic quality; it is done in concert with a test of the waste-disposal classification system outlined tentatively in Task A.3. The test is meant to (a) confirm or refine the full range of photographic requirements needed to recognize the desired classes, and (b) finalize the classes. If the actual photographs of a particularly important date are inaccessible, a photo-index and sample coverage should be obtained before investing in countywide coverage.

Although the strategy of selecting dates of coverage might vary somewhat with the objectives and scope defined in Task

A.1, economic reasons suggest that the initial acquisition should be limited to the minimum number of dates needed to capture the most critical periods of development (Task A.2). As will be described in Task G, additional dates of coverage might be obtained later. For the average user, the photographs should be obtained as contact prints, the least expensive product.

Of the 23 dates of airphoto coverage of Suffolk County, only three were judged necessary for the initial acquisition: 1947, 1962, and 1972. The end points of this time period were defined, first, by the development that began in 1945 and, second, by the county laws and policing that went into effect in 1975. Specific dates of coverage were selected after visiting federal, state, and county offices to preview their photographs and, in some cases, to borrow sample coverage. The primary concern was photographic quality, but it was valuable to test the classification system with the actual photographs. No change was made to the original list of waste-disposal classes (Table 2). That the three chosen sets of coverage were of uniform scale (approximately 1:20,000) was a significant factor in their selection. Although leaf-off conditions would have been desirable in all cases, the year rather than the month was the overriding factor.

C. Survey the Public

A variety of secondary sources can provide information (or misinformation) about known and possible waste-disposal sites (Nelson *et al.*, 1983). One source which should always be utilized is a public information survey, or "call-in/write-in campaign," if for no other reason than to keep citizens of the county informed of actions that may affect them. The essential elements of such a survey are public advertisements requesting anyone with information about waste disposal sites—especially, clandestine or inactive sites—to convey this information, openly or anonymously, to a central coordinator.

For the Suffolk County inventory, the public information survey was conducted by the Cornell Cooperative Extension Association of Suffolk County. Requests for information were made through articles in regional and local newspapers, radio announcements, and letters to government officials and citizen organizations. Insofar as possible, those responding by telephone were queried from a prepared questionnaire. It is interesting to note that only 24 responses were received in the Suffolk County survey; by comparison, some 100 to 200 were received in similar surveys in other New York counties.

D. Analyze Airphotos—First Stage

At this stage, the objectives of the airphoto analysis are to (a) "flag" the locations of waste-disposal sites on the photographs, (b) classify the sites, and (c) describe the site and disposal activities over the periods of observation. Handling the different sets of photographs and interpretations need not be a bookkeeping problem. In Suffolk County, for example, the three sets of airphoto coverage were separated by date, divided into flight strips, then assembled according to 1:24,000-scale, U.S. Geological Survey topographic maps. In this way, all dates of coverage for each map could be examined at one time, beginning with the earliest date.

Airphoto analysis can be performed with a zoom, mirror, or lens stereoscope, the last being most convenient. The Suffolk County survey made use of a two- or four-power lens stereoscope. When a site is detected on any date of coverage, the site should be highlighted by a red-penciled arrow or circle directly on the photograph, and the other dates of coverage of the site should be examined. Based on analysis of all dates of coverage, each detected site is then assigned a letter-number code; the letter(s) signifying the class(es) of waste-disposal site (e.g., "L"-landfill; "MLB"-mined land converted to landfill with barrels) and the number indicating the specific site on the specific topographic map (Figure 1). Pertinent information about the site should be recorded on a data sheet for each date of coverage. General site description, location, approximate size of site, photo identification numbers, topographic map, and any special observations should all be included (Figure 2). Data sheets are referenced by the name of the topographic map. Field verification at this point, while potentially useful, is not deemed essential.

At least three aspects of the actual photo classification are significant: (a) class assignments should be based on the "best-fit"—not all classifications will be clear-cut; (b) sites observed to have more than one type of disposal activity on a single date should be labeled with more than one letter code; and (c) if a site is observed to evolve through different classes, the site is usually labeled by its most recent phase; however, in some cases, labeling with more than one class may be more appropriate.

Information derived through the public survey is incorporated in the airphoto analysis at this stage. This includes information on the history or contents of sites that have already been identified as well as any information on undetected sites—i.e., location, history, or contents. Undetected sites that can be verified on the photographs should be added to the inventory.

The first-stage airphoto analysis of the western two-thirds of Suffolk County identified 656 new sites: 168 dumps, 52 landfills, 22 lagoons, 45 pits, 142 mined areas, 140 disturbances, 17 barrels/drums, and 70 aboveground tank yards. All work was performed by a single, experienced airphoto interpreter, who examined some 1200 photographs. No attempt was made to identify the 99 sites that had already been inventoried in the county by New York State. Of the 24 sites reported by the public information survey, two had been undetected by the airphoto interpreter, 16 had already been observed, and six either were out of the survey area or lacked sufficient information for determining their location.

E. Geo-Reference Sites

Sites identified on the aerial photographs must be geographically referenced. This is done to facilitate field verification and to allow the sites to be related accurately and efficiently to environmental phenomena that they might impact or imperil (e.g., aquifers, residential land use, unique habitats, or wetlands). Geo-referencing normally involves transferring the photo-derived information to a map base or geographic information system (usually by means of a map base). The transfer process can be accomplished in several ways, with or without the aid of a photogrammetric instrument. Similarly, several alternative map bases might be chosen, including an orthophotograph. The accuracy of recording photo-derived sites on maps will be governed by the scale, accuracy, and detail of the base map; the quality, scale, and tilt of the photography; the nature and amount of terrain relief; and the inherent accuracy of the transfer method. In general, the selection of a particular transfer process and map base will be guided by the available equipment, the costs and time for data transfer, and the expected use of the data. Notably, this task need not be performed by the airphoto interpreter.

For the Suffolk inventory, the decision was made to geographically reference a *general* point location for each site, rather than the site boundaries; the annotated photographs themselves would constitute the primary source of information on site location and site boundaries. The 1:24,000-scale topographic maps were chosen as the map base due to their ease of handling, accessibility, compatibility with the scale of inventory photographs, and familiarity to multiple users. Only 17 maps were required to cover the survey area. The location of each site was transferred visually from the photographs to the corresponding topographic map, without the aid of any optical transfer device. A stick-on, colored, "signal" dot, 6 mm in diameter, was used to designate the approximate site location

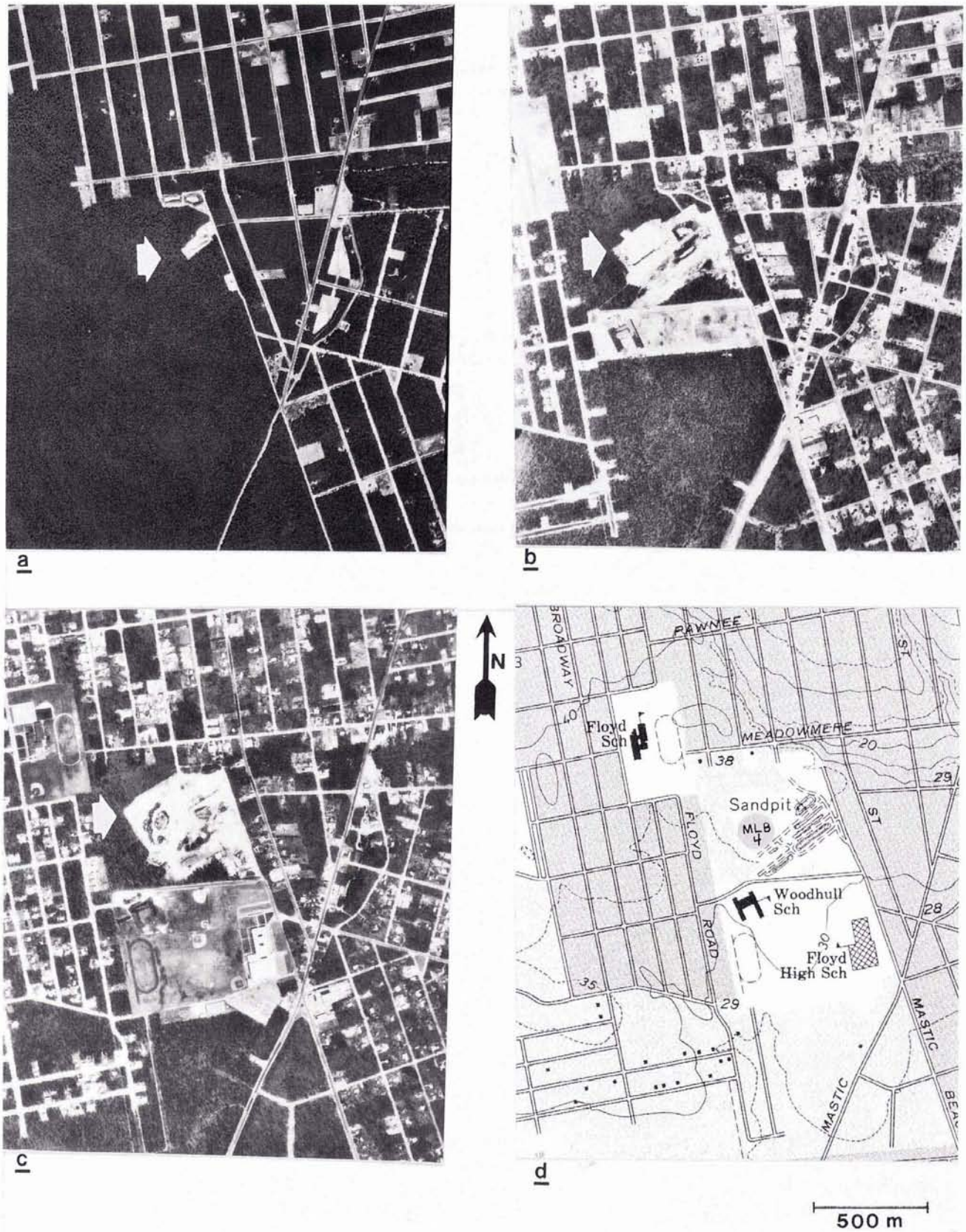


FIG. 1. Aerial photographs document changes in a waste-disposal site. A sand mining operation in 1947 (a) was converted to a landfill with barrels by 1962 (b), and landfilling expanded through at least 1972 (c). Photos are at scale of annotated 1967 topographic map (d).

SITE DATA SHEET

Topo:
Site: M4, L4, B4

AIRPHOTO INVENTORY OF POTENTIAL HAZARDOUS WASTE DISPOSAL AREAS
in SUFFOLK COUNTY, NEW YORK

	Year: 1947	Year: 1962	Year: 1972
Site Type:	Mined Area	Mined Area - Landfill	Landfill - Barrels/Drums
Size:	4 1/2 Acres	19 Acres	24 Acres
Description:	Active sand mining - two sections; pit surrounded by scrubby woodlands; sparsely developed residentially.	Sand mining continued - not as intense as in '47; landfilling detectable -- including detectable wastes and barrels within pit, two trenches, soil mounds for cover material, and a pile of loose dark material (for disposal?) along the top.	'72 shows a highway maintanence center adjacent to pit; site appears to be mainly used as a landfill; wastes detectable in bottom of largest excavation in huge pile with well trafficked access encircling it; other wastes intensively deposited.
Photo:	ASA - 4D - 148	2023 - 27 - 404	2398 - 28 - 734
Other:			

Location: Town _____ City _____ Street _____

Field Visit: No _____ Yes _____ If yes, date of visit _____

FIG. 2. Typical data sheet with information reported for site shown in Figure 1.

on the map. Each dot was labeled with the letter-number code, described in Task D, and the dots were covered with transparent adhesive tape (Figure 1). To supplement the information on the 1:24,000-scale maps, all site locations were also transferred to a 1:63,360-scale county highway map. Here, color-penciled dots defined site locations, with the color signifying the class of waste-disposal activity.

F. Prioritize Sites

Presented with a large number of waste-disposal sites for which remedial action might be required, the county must adopt some approach to prioritizing the sites. Various schemes have been used or proposed (e.g., Silka and Swearingen, 1978; Klee and Flanders, 1980; LeGrand, 1980; Caldwell *et al.*, 1981; Nelson *et al.*, 1983). In many instances, sites having high and low priority are readily singled out without the benefit of a broader analysis. In the Suffolk inventory, for example, the 17 sites observed to have barrels and drums were considered highest priority (Table 2). Other candidates for more immediate, in-depth analysis were dumps and landfills located either in medium to high-density residential areas or in association with schools. In contrast, mined land, disturbed land, and aboveground tanks were arbitrarily ranked lowest priority.

G. Airphoto Analysis—Second Stage

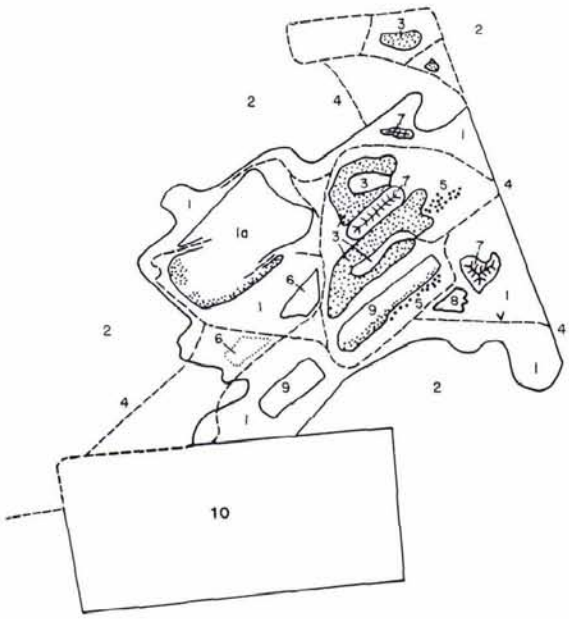
Typically, the most cost-effective, yet accurate, field programs begin with comprehensive airphoto analyses which draw on all available background information. Once site prioritization is complete, the airphoto interpreter can begin detailed study of at least the higher priority sites. This will likely follow acquisition of additional airphotos—existing years of coverage that were not obtained originally. Normally, it will also involve field verifications, which, to some extent, can be performed utilizing light aircraft.

Decisions required at this time should have been made during Task A.1. They relate to how the photo-derived data should be presented (e.g., as map or photo overlays; as a GIS data layer) and to "how far" the airphoto interpretations should go. For example, should the analysis be limited to providing a detailed account of changes in and near the site, or should the interpreter try to assess the potential for surface and groundwater contamination, recommending field sampling points for leachate or methane gas. Obviously, the information and detail that can be derived are governed by the photographs and study area, by the time and fiscal constraints, and, ultimately, by the ability of the interpreter (Erb *et al.*, 1981).

For the Suffolk inventory, 33 sites were selected for more detailed characterization using the original three dates of photographic coverage and up to three additional dates of coverage (e.g., Figure 3). (If it was clear from the original photographs that no change had occurred at a particular site, no interim dates of photography were obtained.) Significant changes in the location and nature of the sites and their surroundings were delineated and transferred to acetate overlays on enlarged (1:4,800-scale) portions of the most recent (1984) aerial photographs. The transfer was accomplished visually or with the aid of a stereoscopic Zoom Transfer Scope™, depending on the nature of the information transferred. Field checking was done (in 1987) by overflying the sites in a police helicopter, from which color, oblique photographs of the sites were acquired with a small-format camera (Figure 4). Once the data sheets were updated and summary reports on site changes written, all pertinent material was collected in a separate file for each site.

H. Implement a Monitoring Program

Although attention will be focused on field investigations and remedial actions at the sites identified in the inventory, there will be no end to waste disposal, legal and possibly illegal. A monitoring program is therefore needed to accomplish three objectives: (1) surveillance, (2) periodic updating of inventory information on known sites, and (3) periodic search for, and



Key:
1. Extent of property involved in sand & gravel mining; 1a. Active portion of sandpit, including access ramp; waste deposits detectable at stippled area
2. Woodland
3. Former sandpits used for solid waste disposal; waste deposits at stippled area
4. Access roads (dashed lines) a complex, well trafficked network
5. Barrels/drums (dots)
6. Former sandpits or shallow trenches like 9; faintly detectable
7. Mounds of uniform material, probably for cover
8. Black material, soil stains
9. Shallow trenches; waste deposits at stippled area
10. School property

FIG. 3. Detailed airphoto analysis of one date of coverage of site shown in Figure 1 (see Figure 1b.).

characterization of, new sites. Generally, the first objective is referred to as "regulatory monitoring," the last objective is "inventory," and the second objective can be regulatory monitoring or inventory, depending on the circumstances. Although the optimum program will vary with the available personnel and resources, current technology, and the nature of the county and waste disposal therein, several alternatives are outlined in Table 3. Suffolk County has considered the application of satellite data (Philipson *et al.*, 1988) and is considering the merits of video from low-altitude aircraft.

CONCLUSION

As described, state and local governments in the United States are faced with the challenge of finding and assessing the risk of thousands of waste-disposal sites. The remote sensing procedure described in this paper is an effective approach to performing comprehensive inventories of known and unknown, active and inactive, waste-disposal sites over county-size areas.

It is significant that, because of the number and nature of waste-disposal site changes observed during the one-year survey of the western two-thirds of Suffolk County, the inventory was subsequently extended to the remainder of the county. Moreover, a countywide inventory update with more recent coverage was completed, and site locations in priority areas are being transferred to property tax maps to facilitate follow-up action.

TABLE 3. COMPARISON OF APPROPRIATE REMOTE SENSING SYSTEMS AND APPROACHES FOR COUNTY MONITORING OF WASTE DISPOSAL AND STORAGE SITES

SYSTEM/ APPROACH	ADVANTAGES	DISADVANTAGES
Aircraft-based		
Use airphotos acquired by other agencies	Accurate, proven approach; relatively low cost	Lack of flexibility; nature and schedule of data may not be optimum or adequate
Visual sighting from low altitude aircraft, with auxiliary, hand-held, small-format, or video camera	Flexible; relatively low cost operation, though good video equipment is costly; good for analyzing known or easily identified sites; useful for regulatory monitoring	Limited value for county inventory because areawide coverage is not collected (limited *a priori* information on where to photograph for permanent record)
Direct contract with aerial survey firm	Reasonably flexible; should be able to obtain desired coverage	Relatively costly
Implementation of in-house capability for flying aerial photography	Flexible; obtain desired type of coverage when needed; fly site and, possibly, countywide coverage (need 9-in. format for latter)	Requires camera equipment (preferably better than 35mm), scheduling aircraft with wing mount or camera port, arranging for film processing, etc.
Fly or contract for "other" sensors (e.g., thermal or geophysical sensors)	May be valuable for special site investigation	Generally, more costly than aerial photography and fewer contractors
Satellite-based		
Landsat thematic mapper or SPOT	Data can be acquired regularly; all or nearly all of county may be covered in a single scene or less	Data are of limited but definite value for monitoring; cost is high; relatively costly equipment needed if computer-based image analysis is to be conducted

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FIG. 4. More recent coverage of site shown in Figure 1, including (a) a portion of a 1984 panchromatic, vertical photograph and (b) a black-and-white copy of a 1987 color, oblique photograph.

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