Land-Cover Monitoring with SPOT for Landfill Investigations

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ABSTRACT: As an extension of an airphoto-based inventory of active and inactive waste storage and disposal sites in a New York county, SPOT satellite images were evaluated to determine their capacity for monitoring land-cover changes that could be significant in landfill investigations. A panchromatic and a multispectral image of 25 1.5- by 1.5-km sites were displayed and minimally enhanced (contrast stretched and enlarged) on a digital image processing system, where the imaged test sites were compared visually to the most recent 1:24,000-scale U.S. Geological Survey topographic maps. Significant changes – disturbed, reclaimed, and developed land; recently exposed soil; ponded water; and new or removed structures – were interpreted and delineated, based only on the images and maps. Airphoto and field (helicopter) verification found the accuracy of SPOT interpretations to be approximately 95 percent. SPOT images are judged to be a cost-effective tool for county or regional monitoring programs.

INTRODUCTION

THE VALUE OF aircraft remote sensing for detecting, monitoring, and analyzing landfills has been well-documented and demonstrated operationally (Souto-Maior, 1973; Garofalo and Wobber, 1974; Philipson and Sangrey, 1977; Sangrey and Philipson, 1979; Erb *et al.*, 1981; Titus, 1982 and 1984; Lyon, 1987). It should be clear, however, that, while low and medium altitude remote sensing are extremely effective for site inventory and analysis, or for monitoring known sites, they are much less effective for monitoring large areas, such as counties or states. Where high-altitude aircraft photography could be expected to fill this gap, too little high-altitude coverage is available from government sources. Further, the recent re-direction of the National High Altitude Photography Program to acquiring medium-scale photography will likely increase the cost and decrease the availability of high-altitude coverage from private sources.

The application of images acquired by sensors from Earth-orbiting satellites would seem ideal for large-area monitoring. Toward this end, studies have shown that land-cover surveys can in fact be conducted with reasonable success with the 80-metre resolution images from the Landsat multispectral scanner and, especially, with the 30-metre resolution images from the Landsat thematic mapper (e.g., Middleton *et al.*, 1984; Toll 1985; Trolier and Philipson, 1986; Gregory and Moore, 1986). Following the 1986 launch of the French SPOT satellite, moreover, environmental monitoring can now be conducted with pointable sensors that acquire 10-metre panchromatic (0.51 to 0.73 μm) and 20-metre, three-band multispectral (0.50 to 0.59 μm, green; 0.61 to 0.68 μm, red; 0.79 to 0.89 μm, near-infrared) images (Courtois and Traizet, 1986). SPOT images should provide a wealth of land-use and land-cover detail, significant for landfill investigations (Andrews, 1984; Dolan *et al.*, 1984).

This study was conducted to test the suitability of SPOT satellite images for large-area monitoring of land-cover changes that could be significant in landfill investigations. The work was performed as an extension of a comprehensive airphoto-based inventory of active and inactive waste storage and disposal sites in Suffolk County, New York.

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METHODS AND MATERIALS

STUDY AREA AND TEST SITES

Suffolk County occupies the eastern two-thirds of Long Island, New York, an area of 2390 sq km. Being only some 25 km from the eastern boundary of New York City, the county has experienced rapid and continuing urbanization, with a population reaching a 1980 census total of over 1,284,000. Geologically, the county is dominated by glacial outwash plains, creating a region rich in sand and gravel resources (Soil Conservation Service, 1975). An ongoing airphoto–based inventory covering most of Suffolk County identified several hundred active and inactive waste storage and disposal sites. A representative sample of the sites was selected by the county and airphoto-inventory team for more detailed characterization. To take advantage of planned field investigations, these sites were chosen as test sites for the SPOT evaluation.

The test sites were located on the most recent 1:24,000-scale U.S. Geological Survey topographic maps (1967 or 1979), where they were delineated in 25 boxes, each 2.5 by 2.5 inches (6.35 by 6.35 cm). The corresponding ground area at each of the 25 test sites was thus approximately 1.5 by 1.5 km.

SPOT DATA AND ANALYSIS

The annotated maps were provided to two of the authors, experienced image interpreters, who had no familiarity with the county and no other background information. In addition, SPOT Image Corporation provided computer-compatible tapes (level 1B processing) for two SPOT scenes of the study area: one panchromatic scene, acquired 31 March 1986, and one multispectral scene, acquired 14 August 1986. Both scenes were centered at K629/J268 in the SPOT Grid Reference System of the United States.

The tapes were analyzed on the digital image processing system of the Remote Sensing Research Laboratory of the Agricultural Research Service, U.S. Department of Agriculture (International Imaging Systems model 75/system 600, with a host VAX 11/750 computer). The 25 test sites were located and subset from both scenes (only 22 sites were covered by the panchromatic scene).

Linear contrast stretching was applied to each subset image to improve its interpretability. Although each band of the multispectral images was stretched independently, these images

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 54, No. 2, February 1988, pp. 223–228.

0099-1112/88/5402–223$02.25/0

were analyzed as composites, corresponding to color-infrared photographs (green band displayed as blue, red band as green, and near-infrared band as red). No other enhancement besides enalarging was applied because the intent was to be able to relate the findings obtained using digital SPOT products to those that might be obtained using "standard" photographic products (which are routinely subjected to contrast stretching by SPOT Image Corporation).

For the actual site analysis, the images of each test site were displayed separately or together ("split screen"), and the features were compared visually to features on the topographic maps (i.e., 1986 images versus 1967 or 1979 maps). After examining all sites, a classification system was developed to uniformly characterize land-cover types that were observable and potentially significant in updating landfill inventories.

Sketch maps of each site were then compiled on overlays to the topographic maps, delineating changes within the 2.5- by 2.5-in. boxes in accordance with the classification system. Notably, a site analysis and draft sketch map could be completed in approximately ten minutes. The sketch maps, classification system, and site commentary were sent to the airphoto-inventory team for verification.

Verification of SPOT Interpretations

Each delineated unit of land-cover change on the SPOT-derived sketch maps was checked through (1) stereoscopic analysis of 1:24,000-scale panchromatic aerial photographs, acquired in 1984; (2) sightings from helicopter overflights made in April 1987; and (3) interpretation of small-format, low-oblique, color photographs, acquired during the helicopter overflights. Those areas interpreted as unchanged were also assessed, primarily with the 1984 aerial photographs.

RESULTS AND DISCUSSION

Classification System

The classification system applied in mapping land-cover changes that are observable with SPOT images and potentially significant in landfill investigations is recorded in Table 1. Disturbed land (C or E, in Table 1) or reclamation (V) provides the most direct evidence of possible waste disposal activity. New land developments (D) or specific new or removed structures (B, I, H, and R) may obscure earlier disposal activity (Erb *et al.*, 1981; Titus, 1982 and 1984), or their precise locations and times of occurrence, might relate to health problems (Vianna and Polan, 1984). New or removed ponds and wet areas (P and W) provide basic information regarding development in the area as well as possible sites of water contamination, even though leachate seeps are seldom large enough to be detectable with SPOT images.

Although a cursory examination showed that SPOT images could be used to *detect* many instances and types of waste disposal, no attempt was made to include landfills *per se* in the classification (*cf.*, Andrews, 1984). In addition, although the system should be transferable in whole or part to other geographic regions, it was designed for use in the urban-suburban environment of Long Island, New York. As field verification showed, however, at least one important category of land use was not included: recharge basins which are used to dispose of stormwater runoff and replenish the ground water supply. These basins are unlined regularly shaped open catchment areas, constructed in developed areas. Most are about 1.5 acres (0.6 ha.) in area and 3.5 metres deep, yet they range from 0.1 to over 30 acres (0.04 to 12.2 ha.), with depths to 14 metres (personal communication, Joseph Baier, Suffolk County Bureau of Water Resources). Although there were over 3000 such basins in Suffolk County in 1981, the authors who performed the SPOT mapping were not aware that this feature existed on Long Island.

SPOT Analysis

Input and output products for one of the most active test sites are shown in Plate 1. Included are the corresponding portions of a topographic map and SPOT images, and the derived sketch map which depicts change from the date of the map to the dates of the images. For improved interpretability, the multispectral image is shown at approximately one-half the scale of the panchromatic image and maps. It is interesting to observe in Plate 1 that significant change has occurred between 31 March 1986, the date of the panchromatic image, and 14 August 1986, the date of the multispectral image (e.g., box-shaped area labeled "D" near the bottom center).

Verification and Interpretation Accuracy

As described, all SPOT interpretations were verified with stereoscopic medium-scale aerial photographs, sightings from helicopter overflights, and small-format photographs acquired during the overflights. In reporting land-cover change, the SPOT interpreters mapped those parts of the 25 test sites that had

Table 1. Classification System Used for SPOT Mapping of Land-Cover Change for Landfill Investigations.

DISTURBED LAND
- C - Disturbed area, but not reclaimed (cf., "V") or being developed (cf., "D"); land surface may be vegetated or exposed but not recently exposed (cf., "E")
- E - Recently exposed soil
- V - Reclaimed area, possibly with vegetation

DEVELOPED LAND
- D - Area undergoing some type of development which generally includes structures
- B - Building(s), unspecified as to type; B′ - removed
- I - Industrial, commercial or other large building(s); I′ - removed
- H - Residential housing; H′ - removed
- R - Roadway or paved area (e.g., parking lot); R′ - removed
- P - Artificial pond; P- - removed

OTHER
- W - Water or wet spot
- D/E, C/E, D/C etc. - Combined mapping units (used for cartographic generalization)
- O - No significant change from topographic map

Table 2. Accuracy of SPOT-Interpreted Units of Land-Cover Change.

Class	No. Units Mapped	No. Units Correct	No. Units Incorrect	Confused Classes
C	25	25	0	
E	24	23	1	1-B
V	8	8	0	
D	11	11	0	
B	17	13	4	2-E, 2-P
I	23	22	1	1-P[1]
H	12	11	1	1-other[2]
R	3	3	0	
P,P′[3]	8	8	0	
W	4	4	0	
COMB[4]	17	17	0	
TOTALS:	152	145	7	(145/152 = .954)

[1]Interpretation based on multispectral imge only.
[2]Other: commercial lot containing sail boats.
[3]Includes recharge basins.
[4]Includes combined units of C/E, C/V, D/C, and D/E

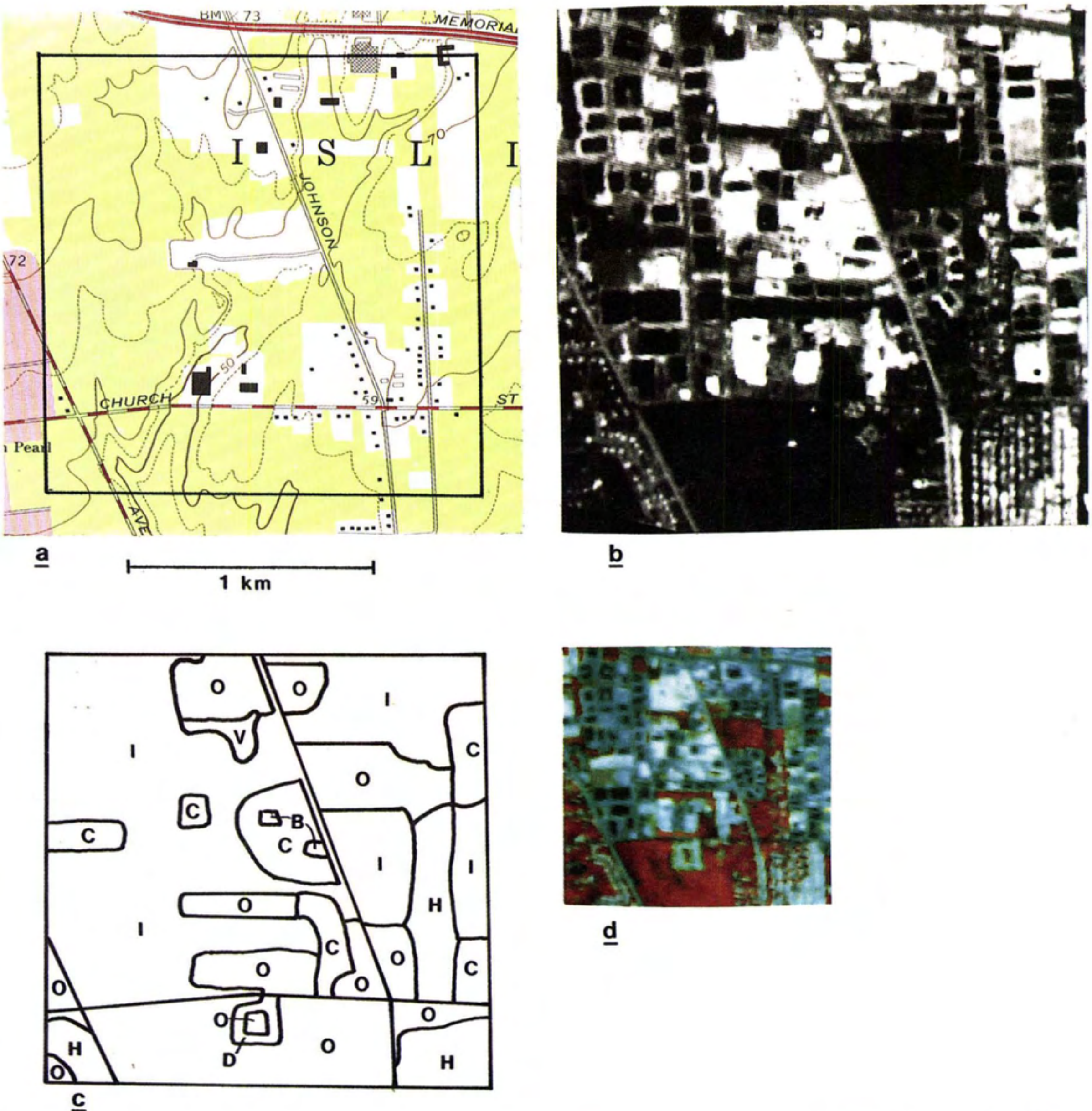

PLATE 1. Typical test site shown on (a) U.S. Geological Survey topographic map (1967, 1:24,000 scale), (b) panchromatic SPOT image (31 March 1986), (c) sketch map depicting SPOT-interpreted, land-cover changes from 1967 to 1986, and (d) multispectral SPOT image (14 August 1986). © SPOT image Copyright 1986 CNES.

changed with 152 delineated units (Table 2). These units were found to be 95.4 percent correct. In addition, judging mostly from the 1984 aerial photographs, those parts of the test sites that were interpreted as unchanged were also found to have been interpreted correctly.

One interpretation error occurred more than once, and it is thought to be the only serious error: confusing a structure with exposed soil in a recently disturbed area or in a recharge basin where the vegetation has been removed (B in Table 2). Although more care in interpretation should have overcome this confusion, the error is relatively easy to make when rooftops and exposed soil appear equally bright and when pixels lend their square shape to soil exposures. In Figure 1, for example, corresponding portions of a 1984 aerial photograph and 1986 SPOT image show a large school building ("n") which did not appear on the topographic map (1967). This building was interpreted as recently exposed soil, an example of which does appear in the SPOT image ("e") but not on the aerial photograph. In this case the SPOT interpreters were influenced by the existence of another school which did appear on the topographic map ("s" in Figure 1).

With regard to those cases where the exposed soil was associated with a recharge basin (two cases of B that were actually P, Table 2), it has been noted that the SPOT interpreters were unaware that recharge basins existed in the county. Although more care would likely have avoided the error made in interpreting these occurrences of exposed soil as structures, only an awareness of the basins might have prevented the error made in interpreting the basins as ponds or removed ponds. By design, the basins should allow collected runoff to drain within a day or so. In reality, the basins may be wet or retain water for much longer periods, and they may be vegetated or exposed, or both.

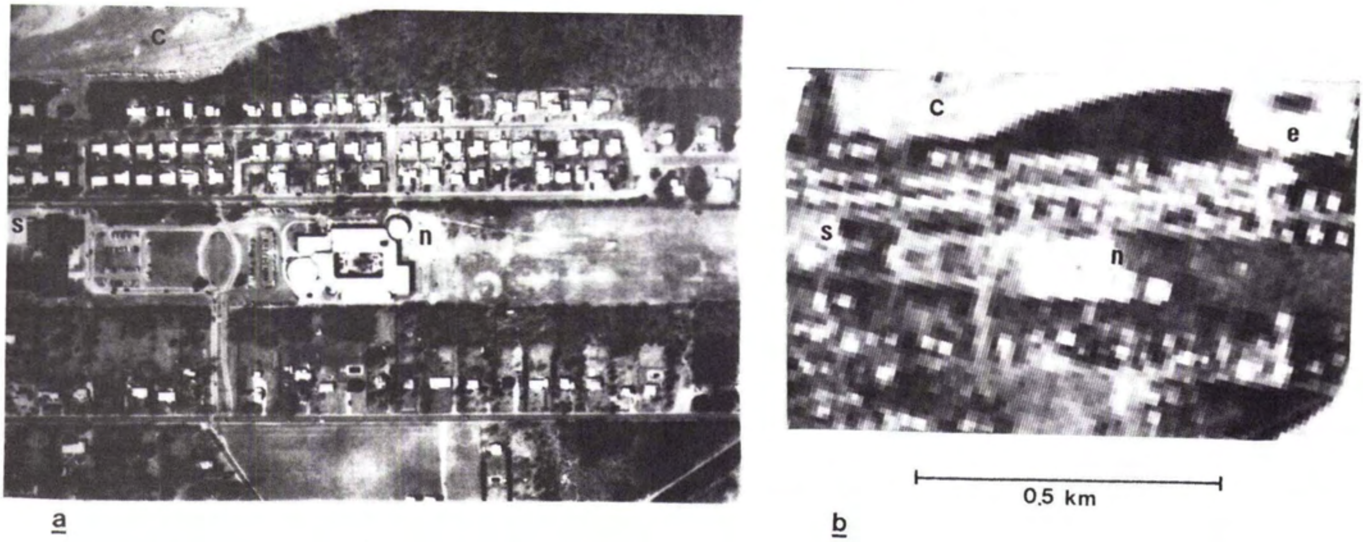

FIG. 1. School buildings ("s" and "n") and disturbed land ("c") on (a) panchromatic aerial photograph (1984, original at 1:24,000 scale) and (b) panchromatic SPOT image (1986), and recently exposed soil ("e") on SPOT image, only.

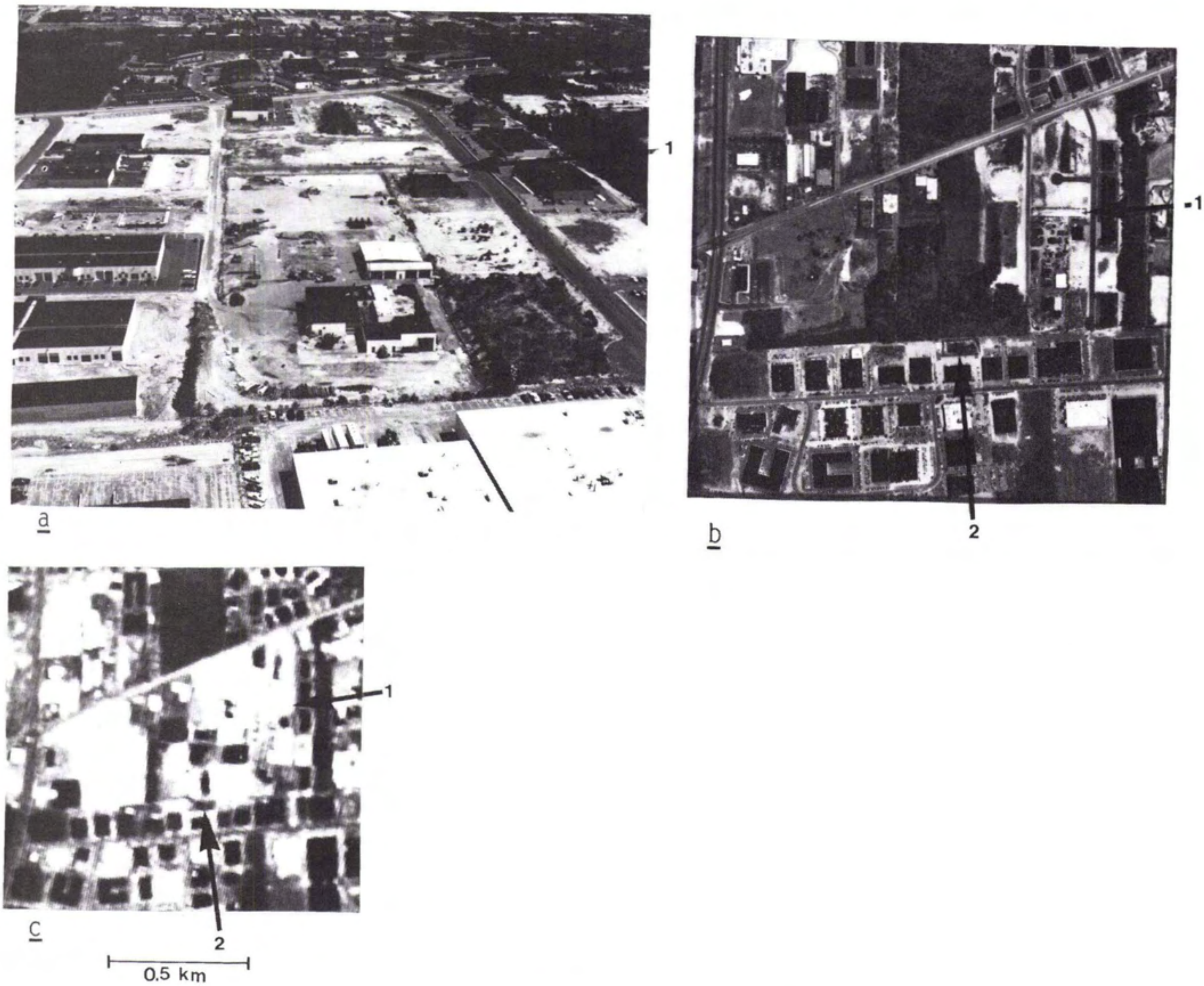

FIG. 2. Aquifer recharge basins (1 and 2) on (a) black-and-white copy of a color oblique helicopter-acquired photograph (1987), (b) panchromatic aerial photograph (1984, original at 1:24,000 scale), and (c) panchromatic SPOT image (1986). (Basin 2 is not covered by the oblique photograph.)

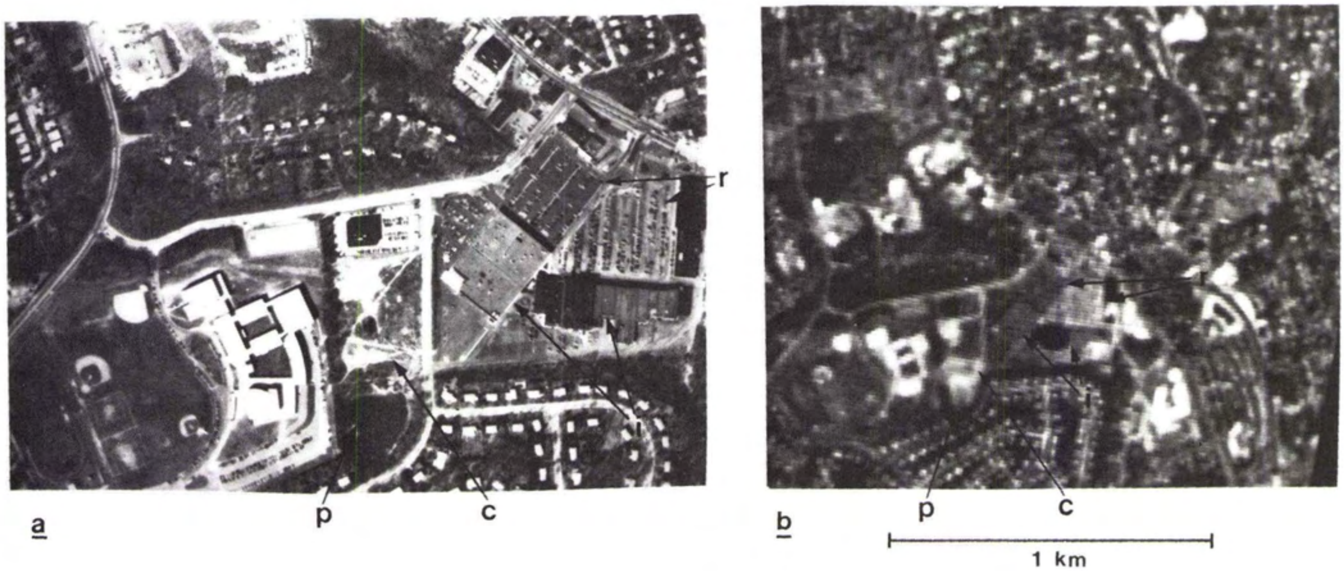

FIG. 3. Aquifer recharge basin ("p"), disturbed land ("c"), parking lots ("r"), and large buildings ("i") on (a) panchromatic aerial photograph (1984, original at 1:24,000 scale) and (b) panchromatic SPOT image (1986). (Basin is filled in aerial photograph and drained in SPOT image.) © SPOT image Copyright 1986 CNES.

Typical recharge basins are shown in Figure 2 in enlarged portions of a 1987 oblique aerial photograph, a 1984 vertical aerial photograph, and a 1986 SPOT panchromatic image. One recharge basin is also labeled in Figure 3, which shows the basin filled with water in the panchromatic aerial photograph (1984) and drained in the panchromatic SPOT image (1986). For comparison, typical occurrences of disturbed land ("c"), parking lots ("r") and large buildings ("i") are also labeled in Figure 3.

METHODOLOGY AND COST-EFFECTIVENESS

Clearly, SPOT satellite sensors can provide the detail required for monitoring significant land-cover changes in landfill investigations. Because the sensors can periodically image county-size areas – 60 by 60 km or up to 80 by 60 km with off-nadir viewing – SPOT images are compatible with the needs of a county or regional monitoring program. SPOT images could be acquired and analyzed as frequently as is judged necessary for the particular county or region; SPOT interpretations could guide field investigations; and, for completeness and improved identifications, comprehensive inventory updates could be performed occasionally with stereoscopic medium-scale aerial photographs.

The remaining consideration is the cost-effectiveness of SPOT images, a topic that cannot be examined without considering alternative methodologies for image analysis (Philipson, 1986). To make full use of the SPOT data, whether analyzing single images or performing image-to-image comparisons (e.g., change detection), they should be analyzed as computer-compatible tapes on an interactive digital image processing system. It is likely, however, that most of the requirements of a land-cover monitoring program for landfill investigations can be fulfilled adequately through visual analysis of photographic SPOT products. The "standard" photographic products, available at scales as large as 1:100,000, are substantially lower in price than the digital tapes. Furthermore, optical equipment needed for their analysis is far less expensive than digital equipment. A digital approach would normally be warranted only if the image processing system were already available to the monitoring agency, if the system were to be used for other applications, or if the monitoring agency wished to do more than simply monitor change and thereby chose to invest in a geographic information system with an image processing capability.

As to whether the panchromatic or multispectral images would be more valuable, the study produced no surprises. The higher resolution panchromatic images conveyed more information on most land-cover changes considered; however, the multispectral images were especially useful for interpreting the presence or absence of vegetation and water or wetness. For monitoring, panchromatic images should be treated as the principal tool, while multispectral images should be examined on a less-regular basis.

Two points of qualification should be emphasized. First, standard SPOT photographic products were not available for this study. Although the level of processing applied to the digital images was minimized in order to maintain comparability with photographic analysis, a true test of the standard photographic products would be desirable. Second, fee structures for satellite image data change. The imposition of an acquisition charge or any appreciable increase in image cost would necessitate a re-evaluation of SPOT's cost-effectiveness.

CONCLUSION

Visual analysis of computer-displayed SPOT satellite images of 25 1.5- by 1.5-km test sites has demonstrated that the images are capable of reliably detecting land-cover changes that are potentially significant in landfill investigations – disturbed, reclaimed, and developed land; recently exposed soil; ponded water; and new or removed structures. At present costs, the images are judged to be a cost-effective tool for county or regional monitoring. The satellite images could be acquired and systematically analyzed for change on a regular basis, with more comprehensive airphoto inventories being conducted less frequently. While interactive analysis of the images on a digital image processing system may extract more information, visual analysis of standard photographic products is likely to be adequate for the purpose. In addition, although the higher resolution panchromatic images would be the principal tool of a monitoring program, the multispectral images convey important information on vegetation and water or wetness and should be examined periodically.

ACKNOWLEDGMENTS

The authors are grateful to the Suffolk County Department of Health Services, for their technical and financial support; the Suffolk County Police Department, for providing the helicopter, pilot, and photographer for field verifications; and SPOT Image Corporation, for providing the satellite images. In addition, the authors thank William Teng, for his many helpful suggestions, and Galen Hart and William Philpot, for their thoughtful reviews.

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(Received 8 August 1987; revised and accepted 21 October 1987)

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