Remote Sensing Investigations at a Hazardous-Waste Landfill

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ABSTRACT: In 1976 state licensed landfilling of industrial chemicals was begun above an abandoned, underground coal mine in Illinois. Five years later organic chemical pollutants were discovered in a monitoring well, suggesting migration 100 to 1000 times faster than predicted by laboratory tests. Remote sensing contributed to the determination of the causes of faster-than-predicted pollutant migration at the hazardous-waste landfill.

Aerial and satellite imagery were employed to supplement field studies of local surface and groundwater hydrology, and to chronicle site history. Drainage impediments and depressions in the trench covers collected runoff, allowing rapid recharge of surface waters to some burial trenches. These features can be more effectively identified by photointerpretation than by conventional field reconnaissance. A ground-based, post-sunset survey of the trench covers that showed that a distinction between depressions which hold moisture at the surface from freely-draining depressions which permit rapid recharge to the burial trenches could be made using thermal infrared imagery.

BACKGROUND

FROM 1917 to 1954 the Superior No. 4 Mine operated as an underground coal mine with a shaft and coal cleaning operations just outside the southern village limits of Wilsonville, Macoupin County, Illinois (see Figure 1). In 1976 the Earthline Corporation applied for a permit from the Illinois Environmental Protection Agency (IEPA) to develop an industrial chemical waste landfill on a 160-acre site formerly used by the coal mine. SCA Services, Inc., formerly a national waste disposal firm, acquired the landfill later that year and received a permit to operate the landfill in November 1976 (Illinois Legislative Committee).

Waste disposal at the Earthline landfill was by the trench and fill method in three areas of the property. The trench and fill method consists of clearing land of trees and brush, excavating a trench, filling the trench with refuse, and covering the refuse with earth. Twenty-six trenches 50-feet wide, 250-feet long, and 10- to 15-feet deep were excavated and filled with 55-gallon steel drums, bulk containers, and plastic sacks of liquid and solid wastes. One trench (#24) had a 3-foot thick compacted clay liner in the bottom where a sand lens was found during excavation. The landfill design relied upon low permeability and clay mineral attenuation to isolate wastes from the surrounding ecosystem.

In April 1977 the U.S. Environmental Protection Agency asked the landfill operators to receive polychlorinated biphenyl (PCB)-contaminated soil from an illegal oil dump in Missouri. Newspaper accounts of PCB toxicity angered Wilsonville citizens and, following a near riot in Wilsonville, the Macoupin County States Attorney and the Village of Wilsonville petitioned the County Court for an injunction against burial of wastes the residents recognized as potentially hazardous to humans. The Illinois Attorney General and Macoupin County Farm Bureau later joined the litigation on behalf of the Village. Legal proceedings lasted one year, and in August 1978 the Macoupin County Circuit Court ruled that the landfilling should cease and the operator should remove all hazardous wastes from the site. The Appellate Court affirmed the lower court decision in September 1979, and the Illinois Supreme Court upheld the Appellate Court ruling in May 1981.

SCA Services, Inc. announced that they would drop further appeals and comply with the court order. Exhumation of wastes began in September 1982 and was estimated to cost 25 to 30 million dollars. As a consequence of this litigation, legislation now prohibits burial of liquid hazardous wastes and burial of wastes above a mine, and it allows municipalities to reject location of a hazardous waste disposal site within 1 ½ miles of municipal boundaries (Illinois Annotated Statutes).

FIG. 1. Map showing the location of Wilsonville and the Earthline Corporate hazardous-waste landfill site.

A separate issue from the court proceedings and exhumation order was the discovery of organic pollutants in one of 33 monitoring wells at the landfill site during routine sampling in February 1982. This suggested that pollutants had migrated about 50 feet in three years, and that migration rates were 100 to 1000 times faster than predicted by laboratory hydraulic conductivity tests of remolded soil samples. SCA Services, Inc. (later acquired by Waste Management, Inc.), U.S. Environmental Protection Agency (USEPA), Illinois Environmental Protection Agency (IEPA), and Illinois State Geological Survey (ISGS) began a cooperative research investigation into the cause of the rapid mi-

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gration of wastes at the Earthline landfill. This paper details a part of that study pertaining to the remote sensing studies.

Geology

The landfill is situated in the Springfield Till Plain of the Central Lowland Province which has undergone several episodes of glaciation and is covered by loess deposits (Leighton *et al.*, 1948). Drainage is well integrated and much of the region exhibits mature topography.

Figure 2 shows a geologic profile of the landfill site. The upper part of the profile consists chiefly of two loessial units—Peoria Loess (upper) and Roxana Silt (lower)—which in turn overlie the Vandalia Till Member of the Glasford Formation. The discontinuous Berry Clay Member consists of colluvial deposits of loess and till eroded from high areas and deposited in depressions and low-lying areas where the soil materials became "gleyed." Beneath the Illinoian-age Vandalia Till lies the pre-Illinoian till of the Banner Formation, which overlies Pennsylvanian-age bedrock of the Modesto Formation. About 300-feet below the surface is an underground coal mine developed in the Herrin (No. 6) Coal Member of the Carbondale Formation. The mine roof is the Brereton Limestone Member; the mine floor is an unnamed gray mudstone and clay.

Modern soil is developed in the Peoria Loess. Paleosols (ancient soil profiles) are developed in the Roxana (Farmdale Paleosol), Vandalia Till and Berry Clay (Sangamon Paleosol), and the Banner Formation (unnamed paleosol). The paleosols permit time-stratigraphic relationships to be determined and facilitate field identification of the units.

One unit, the Vandalia Till Member, is subdivided into its ablation zone and basal zone. The ablation zone is composed of materials left during glacial retreat; the basal zone is composed of glacial advance deposits. The basal zone can be further subdivided into weathered and unweathered basal till.

OBJECTIVES

The objectives of the remote sensing study were to

- Interpret satellite imagery for buried preglacial drainage which could influence regional groundwater movement;
- Examine historical aerial photography for changes in land use and drainage;
- Interpret medium-scale aerial photography of local geomorphic features (lineaments) relating to local groundwater movement and determine lineament association with polluted wells;
- Interpret large-scale aerial photography for depressions and features that inhibit runoff from trench covers; and
- Collect and interpret thermal infrared imagery, for distinction be-

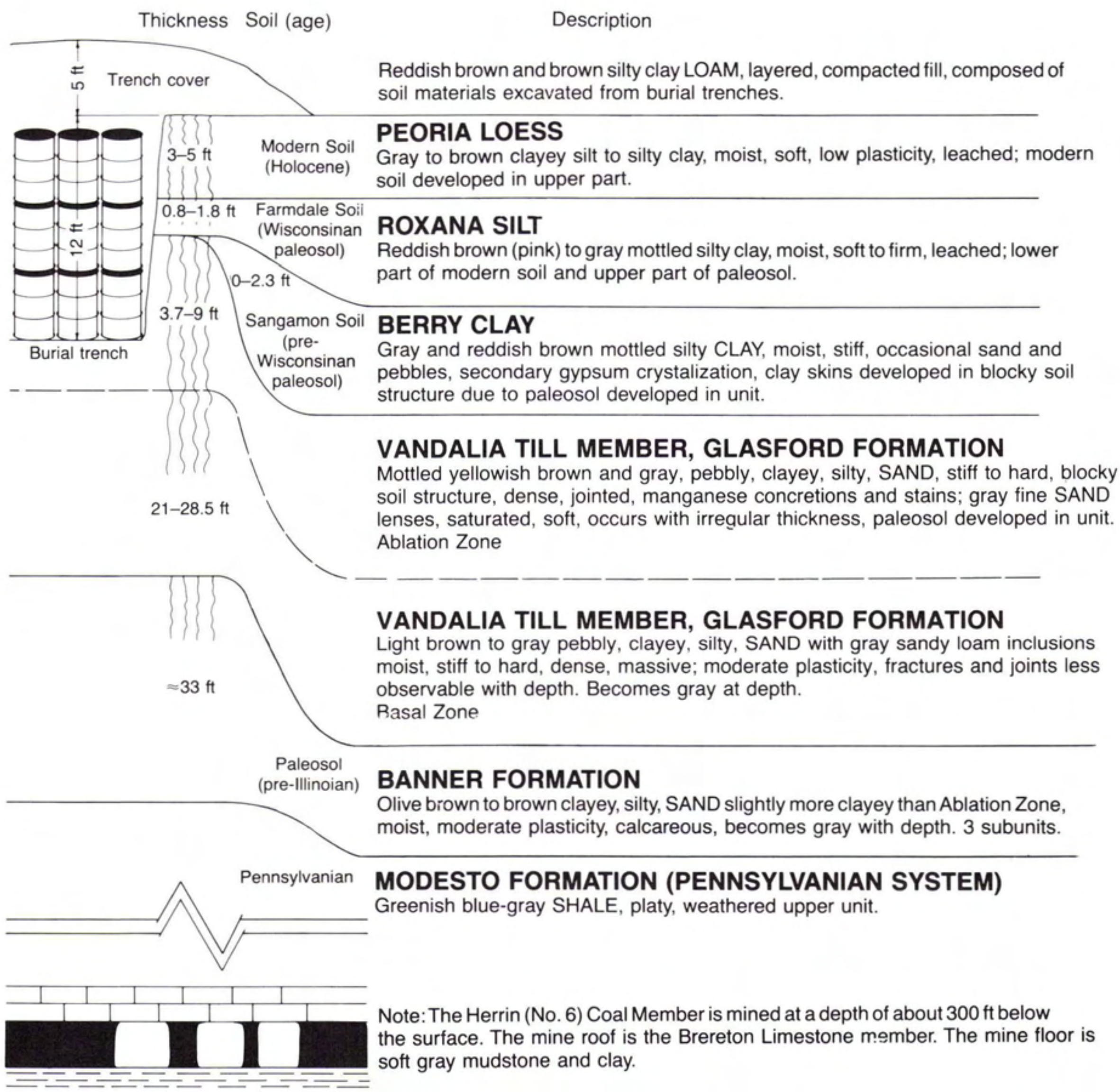

FIG. 2. Summary geologic profile of Earthline Corporation landfill.

TABLE 1. AERIAL PHOTOGRAPHY AND REMOTE SENSING IMAGERY USED FOR INVESTIGATION OF HAZARDOUS-WASTE LANDFILL

-Landsat, MSS, false color composite (FCC) (small scale)		
Record on 12 May 1977		
Image No. 20841-15403		
Scale: 1:250,000		
Remarks: image was enhanced by the GEOPIC (TM) process		
-Aerial Photography, U.S. Dept. of Agriculture (USDA) (medium scale)		
black and white, prints recorded on:		
11 Oct 1937	CK-4-22 to 25	1:20,000
7 July 1950	CK-2G-8 to 10	1:20,000
21 Sept 1968	CK-3JJ-5 to 7	1:40,000
-Aerial Photography, SCA Services, Inc. (large scale)		
black and white, prints recorded on:		
28 May 1982	43-102 to 115	1:3,000
-Thermal infrared imagery, Illinois State Geological Survey (close-range)		
Inframetric (brand name single channel scanner, video cassette recorded on:		
29 Aug 1983		
post-sunset, ground-based survey		

tween selected moisture-holding and freely draining depressions in trench covers.

Imagery used for the study are listed in Table 1.

REGIONAL GEOMORPHIC INTERPRETATIONS

Enhanced Landsat MSS imagery (see Table 1) was interpreted for spectral and geomorphic indications of preglacial drainage (which could influence the direction of pollutant migration) in the Upper Cahokia Creek watershed in which the Earthline landfill was located. Several features of the Cahokia Creek watershed are of interest, including tributaries of the upper watershed which enter only from the north, creating an unusual drainage pattern. The five tributaries are linear, and all are oriented north-south (see Figure 3). The wide tributary valleys suggested underfit modern streams developing over ancient drainage buried by episodes of continental glaciation.

Earlier work by Horberg (1950) described the topography of this eroded drift plain as reflecting major features of the bedrock surface. A bedrock topography map of the upper watershed and previous mapping by Fox (undated) confirm the presence of buried drainage beneath the modern drainage (see Figure 4). The coincidence of the modern and buried drainage valleys suggests that the deeper flow paths of the buried valleys will not interfere with the direction of the shallow groundwater flow paths. Groundwater studies by Herzog and Morse (1986) confirm that shallow flow paths at the Earthline landfill are predictable.

HISTORIC LAND USE AND LAND COVER

Impact of prior land use, excavations, or construction at a new waste disposal site can be quickly assessed by interpretation of historical aerial photography (Lyon, 1982; Erb *et al.*, 1981). Comparison of five decades of aerial photography of the land on which the landfill is located show several changes in land use and land cover. In the fall of 1937, the site (Figure 5) was dominated by an active underground coal-mining operation, including a shaft, processing plant, and railroad spur. Cropland lies to the south and east of the mining operation; the city of Wilsonville lies to the north. A reservoir in a forested valley adjoins the mine property to the west. A dwelling and outbuildings are observed on the southwest part of the property. The future northwest burial site was cropland, and southern burial sites were wood lots (see Figure 5).

Photography taken in the summer of 1950 (Figure 6) showed the mine to be active. A sizable coal-cleaning refuse (gob) pile occupied the area directly south of the mine buildings. The future northwest landfill area was apparently abandoned to scrub growth. The southern area remained as a wood lot.

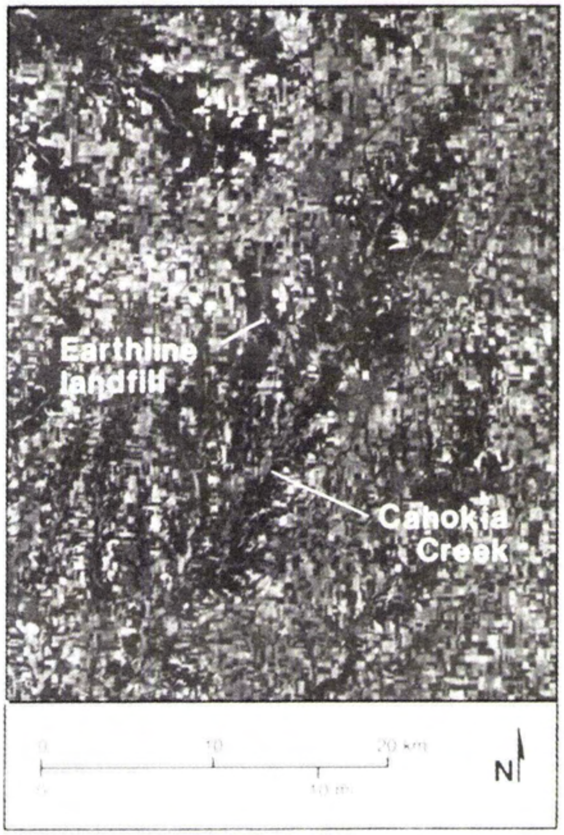

FIG. 3. Enhanced Landsat MSS image of the Upper Cahokia Creek Watershed recorded on 12 May 1977. Cahokia Creek trends flows to the southwest. All of the principal tributaries enter from the north and are oriented north-south in a parallel pattern. The modern drainage reflects the buried preglacial drainage.

By 1968, the mine buildings were removed and railroad grade abandoned. The gob pile dominates the site, as it does to this day. The northwest area supports young deciduous trees. The southern area remains wooded (see Figure 7).

The 1982 photography (Figure 8) was taken after operators ceased landfilling, but prior to exhumation of the buried wastes. New buildings supporting the disposal operation are seen in the northern part of the site. All of the burial sites are grass-covered clearings with gravel access roads. Water-holding rectangular pits are constructed near the burial sites. The study of historial aerial photography shows that

- The three burial sites were constructed in previously undeveloped portions of the property;
- Drainageways have not been altered prior to landfill development; and
- The coal cleaning refuse (gob) pile is the principal topographic alteration prior to landfilling at the site. Herzog and Morse (1986) show that the gob pile slightly increases the local hydraulic gradient.

LOCAL GEOMORPHIC INTERPRETATIONS

Aerial photointerpretation was employed in this study to investigate lineaments as indicators of pathways for potential groundwater movement and routes of pollutant migration. Lineaments have been used by other investigators to predict the groundwater movement through joints and fractures (Tator, 1960; Salomonson, 1983). Williams and Farvolden (1967) demonstrated how groundwater flows through joints and fractures of glacial till. Herzog and Morse (1986) confirmed this phenomenon at the Earthline Landfill.

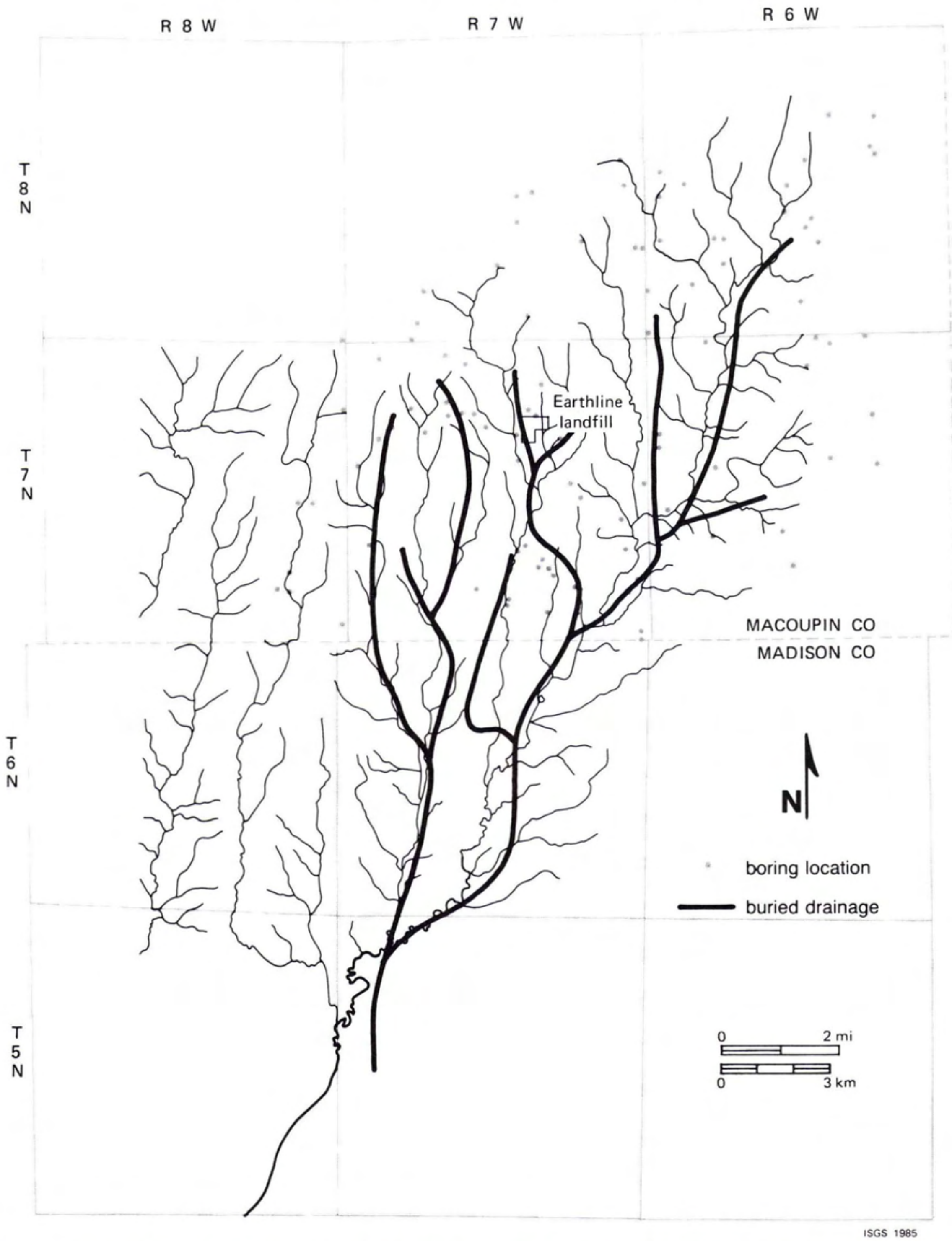

FIG. 4. Modern and buried drainage of Upper Cahokia Creek, Illinois. Modern drainage from U.S. Geological Survey topographic maps. Buried drainage taken from "Bedrock Topography of Madison County, Illinois" by John Fox.

The USDA aerial photographs (see Table 1) were interpreted for features relating to local groundwater movement near the landfill and are shown on the 7.5-minute topographic map (Figure 9). Particularly interesting is that in the area around the landfill property long, linear valleys drain to the southeast, i.e., joining tributaries from the west, whereas gulleys joining tributaries from the east are shorter and much less developed. This pattern suggests that the northwest-southeast gulleys are preferentially developed by linear features.

Short lineaments near the landfill site, defined by tonal patterns on the photos, could consistently be related to features found on the topographic map (see Figure 9). The lineaments that were not necessarily associated with drainage ways or obvious cultural features appear as light or dark linear tones on one date of photography but do not always appear on others. These tonal lineaments likely are artifacts of man-made activity rather than intrinsic properties of the natural regime.

As part of this investigation, additional monitoring wells were constructed at the landfill in order to determine the extent of pollutant migration. Of the five locations where monitoring wells were found to be contaminated, one occurred along a lineament between the southeast and southwest burial sites. Contaminated

FIG. 5. 1937 USDA aerial photograph with 1982 location of the Earthline Corporation hazardous-waste landfill site superimposed.

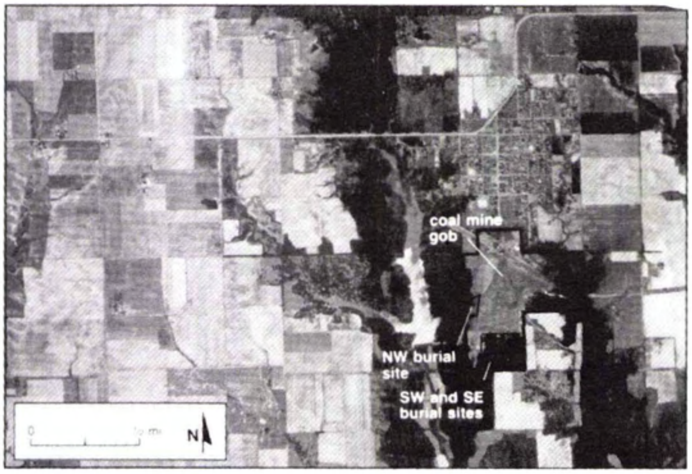

FIG. 6. 1950 USDA aerial photograph with superimposed location of the Earthline landfill site.

FIG. 7. 1968 USDA aerial photo of the location of the Earthline landfill site.

wells at two sites in the southwest corner of the landfill are very close to the lineaments. The contaminated wells in the northwest and southeast are isolated from nearby gulleys (and lineaments); hence, they likely became contaminated because of their proximity

FIG. 8. 1982 aerial photograph of the Earthline landfill site.

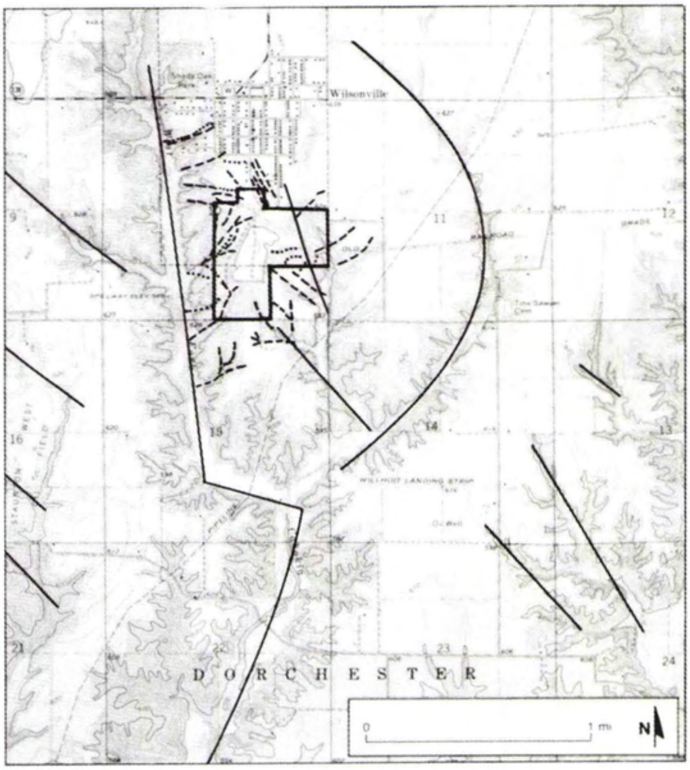

FIG. 9. Photolineaments transferred to a portion of the USGS Gillespie South Quadrangle. Solid lines show prominent linear features that coincide with valleys of tributaries entering West Fork from the northwest. Short dashed lines are tonal lineaments from 1950 photography; dotted lines are tonal lineaments from 1968 photography.

to the depressions developed in a trench cover (see Figure 10, 11, and 12).

TRENCH COVER INVESTIGATIONS

During the initial site visit an open hole was discovered in trench 24. This, coupled with the issue of long-term trench-cover stability, prompted a separate study of soil properties, and the contribution of the trench cover to the pollutant migration.

The purpose of a trench cover is to minimize water infiltration

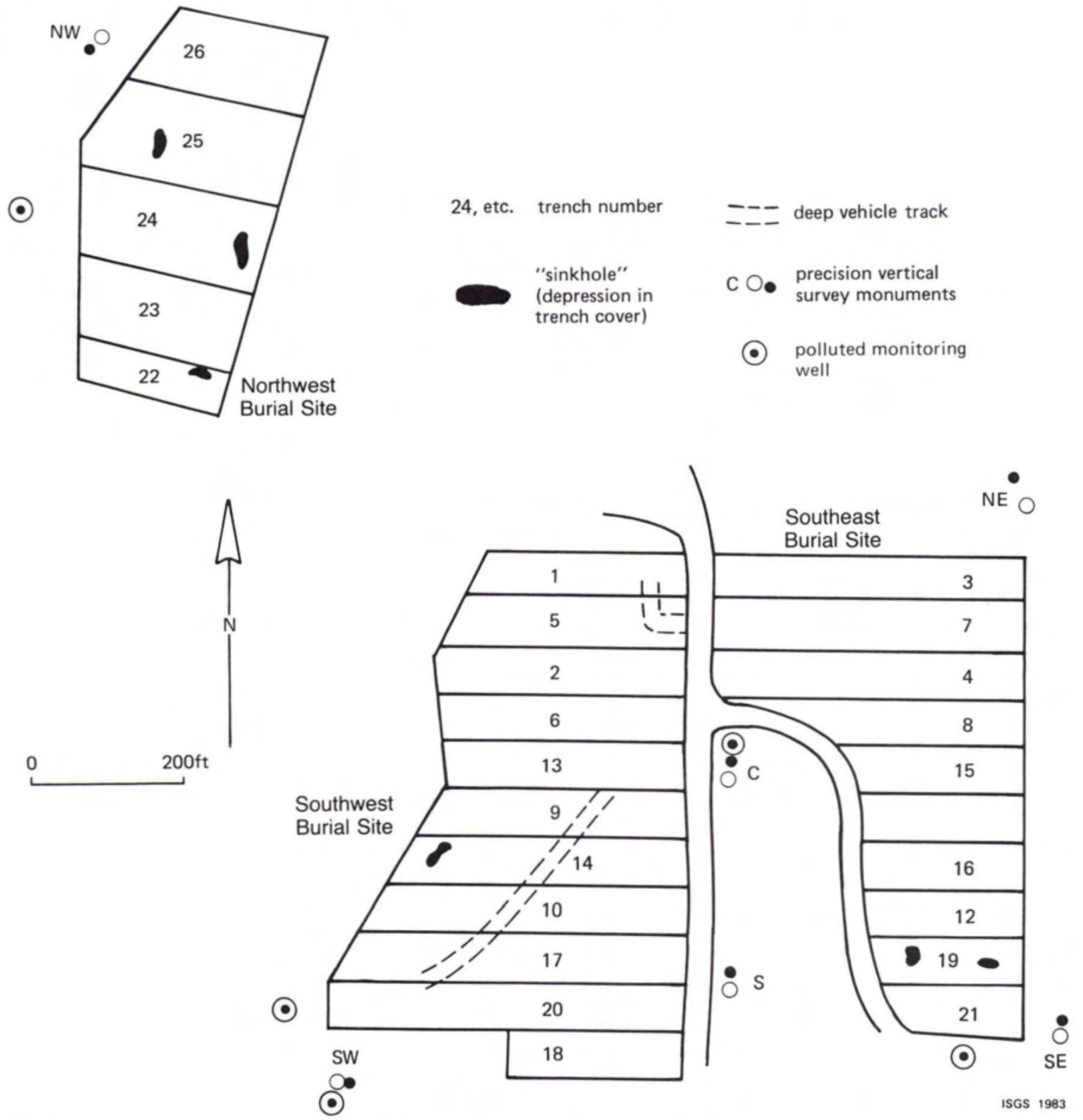

FIG. 10. Sketch map showing trench-cover depressions found 11 August 1982 during a ground survey of the Earthline landfill.

into burial trenches by directing surface runoff away from the burial area. Original plans for the trench covers indicated that the cover would be mounded to shed water after a rainstorm, thereby minimizing infiltration of water through the cover into the trench. If less water flows into the trench, then less contaminated leachate flows from the trench wastes into the surrounding groundwater regime.

However, photointerpretation and field and laboratory studies reveal differences between design plans for trench covers and the covers as constructed. [Note: The trench covers were never completed as designed owing to a court order which stopped construction activity of the site.] The actual construction included erosion control dikes and roadways that were constructed along segments of the perimeter of the mounds. Field observations show that water ponded behind some of the dikes and roads, conflicting with the original intent of the design.

In addition, depressions developed in trench covers after construction. Initial field reconnaissance in July 1982 found an open hole in trench cover 24 at the northwest burial site, prompting a determination of the contribution of depressions in the covers to pollutant migration.

Surface hydrology and runoff direction of the landfill were determined by stereoscopic study of large-scale aerial photography. This study found several instances where the access roads impounded surface runoff over the covers, thereby allowing water to infiltrate into the burial trenches. The inferences made by photointerpretation were substantiated at excavations made at the east end of trench 20 in the southwest burial area where a large impoundment was delineated. At this location the trench cover and *in situ* soils were wet and, unlike sidewalls at other locations, began to slump into the excavation, prompting the hasty relocation of a large portable steel canopy used to cover the working area.

The first inventory of trench cover depressions identified six depressions during a field reconnaissance. The perspective and vertical exaggeration of stereoscopic vertical photography enabled the identification of 22 additional depressions. Interpretation of the large-scale photography proved difficult because visual cues (tone, texture, optical slant, and impression of a closed contour) for disturbed ground are different and more variable than for undisturbed surfaces.

Discriminating between depressions that pond water at the

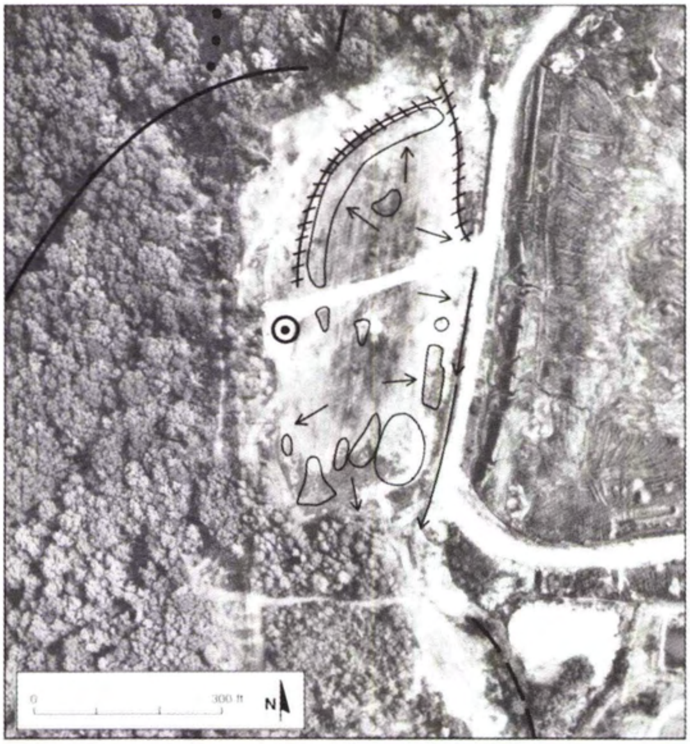

FIG. 11. Northwest burial site in center of photo; coal-cleaning tailings (gob) to right. Depressions on Earthline landfill cover are marked with circles. Hatchures are on crest of erosion control dike. Arrows show direction of drainage of the cover. Polluted wells lie at west end of burial site (encircled dot). Bold lines, dashes, and dots show lineaments from Figure 9.

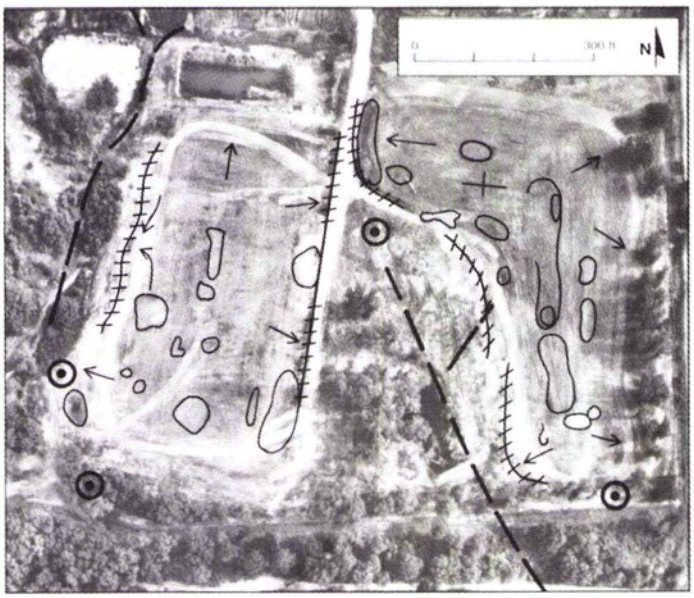

FIG. 12. Southwest and southeast burial site (north is to the top). Depression on Earthline landfill cover are marked with circles. Hatchured lines are erosion control dikes. Arrows show direction of surface drainage from the disturbed landfill covers. White crosses along perimeter of property are ground control stations. Polluted wells are indicated by encircled dots. Dashed lines show lineaments from Figure 9.

surface and depressions that allow drainage into the trenches is problematic with panchromatic photography; however, this distinction could be made with increased certainty with the aid of thermal infrared imagery. Selected depressions were studied in a post-sunset (about 2000 local time) ground thermography survey on 29 August 1983—three days after a rainstorm. An Inframetrics (brand name) thermal infrared scanner sensitive to radiation in the 8 to 14-μm wavelength band (±0.1°C) and a video recorder were used to measure thermal characteristics of depressions in the trench cover. The thermal IR survey was made three days after a rainstorm in order to allow water to drain from freely draining depressions, yet ensure that moisture-retaining depressions had not dried out. Interpretation of thermography shows a contrast in thermal emittance varying according to moisture-holding characteristics of depressions. Depressions that retained moisture were muddy and appeared as dark (cool) spots in the thermography, in contrast to the lighter, better-drained ground around them (see Figure 13).

Freely draining depressions were dry, radiating about 1 to 2° above the surrounding ground. Because the freely draining depressions did not contrast well thermally with their surroundings, they were located by landmarks and a careful search (see Figures 14 and 15). The dry soil in the depressions apparently has a relatively low thermal inertia, meaning that it gives up or takes up heat readily.

The thermal infrared survey proved useful for distinguishing between moisture-retaining depressions and freely draining depressions—due largely to the timing of the survey, i.e., post-sunset, three days after a rainstorm. The delay had allowed freely draining depressions to shed the rainwater, while moisture was retained in the soil of the trench cover overall. Thermography

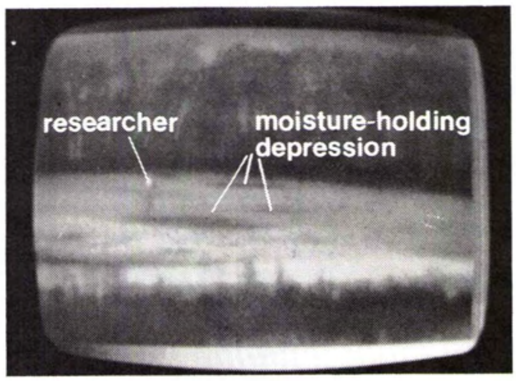

FIG. 13. Post-sunset thermograph of northwest burial site looking west from atop gob pile. Light area (warm) is trench cover with darker (cooler) moisture-holding depressions. Researcher stands left of center. Dark background is treas.

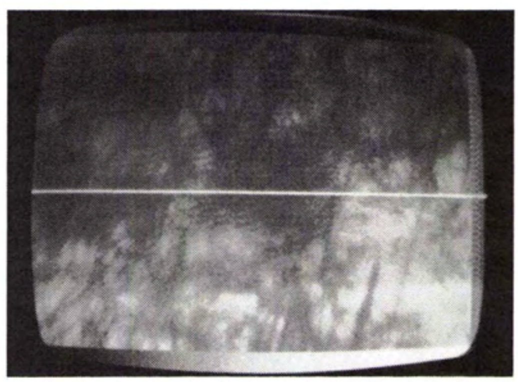

FIG. 14. Close-range, post-sunset thermograph of freely draining depression in trench 19, southwest burial site. Light areas are relatively warm (higher rediance); dark areas are relatively cool (lower radiance). Weeds appear relatively cooler (dark) than bare soil (light). The edge of the depression is near the center of the thermograph. White horizontal line is scan line.

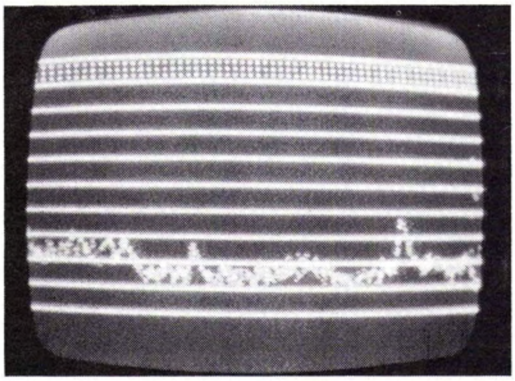

FIG. 15. Graph of emitted (thermal) radiance along scan line of thermograph of trench 19 shown in Figure 14. The 1°C increments show the freely draining depression (left) to be about 1°C warmer than the surrounding trench cover (right).

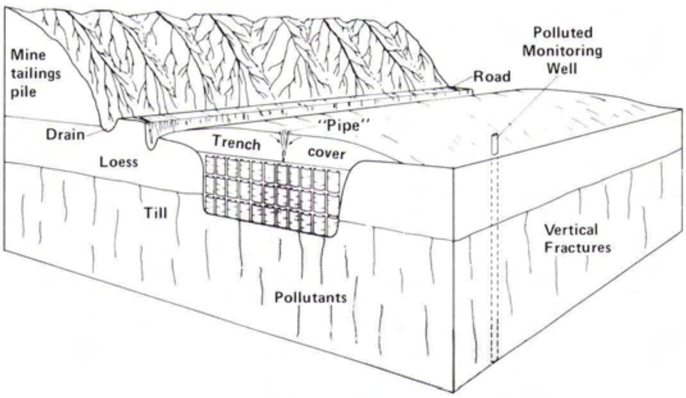

FIG. 16. Failure mechanism of trench cover at Earthline landfill. Rainwater directly recharges burial trench through an open hole (caused by piping of dispersive soil) in the trench cover. Liquid pollutants are flushed into the glacial till and migrate to monitoring well (from Stohr *et al.* (1985)).

at another time of day would show different thermal relationships.

Soil tests reveal that some soils used in construction of the trench covers were highly erodible (dispersive) (Stohr *et al.*, 1985). Internal erosion of the trench covers; observation of incomplete or eroded backfill between waste containers (Stohr *et al.*, 1985); and proximity of depressions to monitoring wells strongly suggest that the depressions in the trench cover significantly contributed to the flushing of buried wastes into the jointed and fractured till beneath the trenches (see Figure 16).

CONCLUSIONS

Photointerpretation of satellite imagery was useful method for identifying buried drainage and extrapolating bedrock topography from boring logs and surrounding maps. However, pollutant migration of waste from burial trenches did not necessarily follow photo-lineaments interpreted from aerial photographs.

A study of historical aerial photography shows that areas of waste burial were previously undisturbed. The principal change at the site, construction of a coal cleaning refuse (gob) pile, was found by related studies to have a minor influence on groundwater movement. The faster-than-predicted pollutant migration from burial trenches could not be due to land use prior to landfilling.

The impediments to surface drainage and depressions developed in the trench cover were readily found by stereoscopic photointerpretation. Access roads caused water to pond over and infiltrate the burial areas. Depressions in the cover collected runoff, some of which rapidly recharge the burial areas. Depressions and ponding significantly contributed to the rapid migration of buried contaminants into the groundwater regime. Both drainage impediments and depressions can be easily identified by photointerpretation with more certainty and probably more economically than by conventional field reconnaissance, observation, and surveying.

A ground-based thermographic infrared imagery survey distinguished freely draining depressions which permit water to enter burial trenches from water-retaining depressions which hold precipitation near the surface. This distinction is thought to be a transient phenomenon which occurred at this site survey a few days after a rainstorm event. The combination of aerial photointerpretation and thermography offers a valuable tool that would allow identification of potentially harmful depressions in trench covers.

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