Remote Sensing Methods for Spill Detection and Tracking
Part I of II

Spill Research Fund Final Report

Project Manager: Jack Schooley

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REMOTE SENSING METHODS FOR SPILL DETECTION AND TRACKING:

FINAL REPORT[1]

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REMOTE SENSING METHODS FOR SPILL DETECTION AND TRACKING:

FINAL REPORT

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INTRODUCTION

Jeff Wasrud

This project had three objectives, as stated in the contract:

1. To provide end results which will assist the New Jersey Department of Environmental Protection (DEP) in applying remote sensing and geographic information system (GIS) technologies to monitoring, detection, and remediation of plumes and spills.

2. To provide valuable experience and training to the investigators so that they can apply the results to current environmental problems.

3. To evaluate and develop GIS and remote sensing technologies for detection and tracking of plumes, including:
   a. the movement of hazardous materials in the environment following accidental spills into the atmosphere, surface water, or ground water.
   b. the discharge of gases and particulates into the air, and suspended solids and heated waste water into the water from sewage treatment plants, manufacturing industries, and power generation stations.
   c. leachate movement in groundwater around hazardous waste sites.

-Attachment D, pages 2-3

This final report summarizes the work completed during this project. Each investigator, or team of investigators, has summarized the work completed, the results, and their conclusions in a chapter of this volume. The chapters are arranged according to the phenomena studied.

The search for a spill that occurred during a period of acquisition of remotely sensed data was completed during the third quarter. Although there were many spills in New Jersey, no match was found between a spill, that was of sufficient size and in the right geographic location, and an appropriate data source. Therefore, analysis of spills could not be accomplished. Hazardous landfills were analyzed in place of spills, as the techniques developed to analyze the impact of a landfill on the environment could be used to analyze the impacts of a spill.

The bibliography, as it has grown to over 650 articles, is included as a separate volume with this report. A Reflex database will be provided as a digital companion to this volume.

Remote sensing, like any tool, can be useful when fully understood and properly applied. This study will show some of the benefits and some of the difficulties associated with this tool. Remote sensing, as it is the collection of information from an object the researcher is not in contact with, is sometimes the only safe or convenient way to study a phenomenon. Detailed mapping of a hazardous landfill, for example, could prove to be unhealthy, or at the very least, uncomfortable.

Remotely sensed data are often available from many different dates over the course of many years. Some of the earliest large scale uses of remote sensing involved photography from captive balloons during the Civil War. Vertical aerial photography, very similar to what is used today, was in frequent use for agricultural and soil surveys by the 1930's. Historic aerial photography can be obtained through the EROS data center, the United States Geological Survey, the National Archives, state and local governments, and aerial survey firms. Multi-temporal remotely sensed data sets, such as those which can be created from several dates of photography, are especially valuable for tracking phenomena that are dynamic on a scale of weeks to months.

Space-borne sensors can also be valuable in studies such as this. Landsat MSS data, with a pixel size of roughly 60 by 80 meters, is often too coarse in spatial resolution for analysis of all but the largest landfills. However, the spectral and temporal resolution of Landsat MSS data, as well as Landsat TM and SPOT data, could be sufficient for the analysis of the impact of a landfill on the surrounding vegetation, if the area of impact is large enough[3].

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[3] A feature must occupy approximately four to sixteen pixels on a remotely sensed image before it can be identified as a unique feature. To determine that an landfill induced impact exists, this minimum classifiable area must be surrounded by a region of identical (or very nearly identical) land cover that can also be uniquely identified. Therefore, the area of unique land cover in a region of potential impact

One of the keys to understanding remotely sensed data is understanding the types of resolutions associated with remotely sensed data. There are four types of resolution -- spatial, spectral, radiometric, and temporal. Temporal resolution, which is the frequency of image acquisition, has been a limiting factor for many aspects of this study. Short-lived phenomenon, such as spills, are difficult to capture by a remote sensing system that is not dedicated to the study of these phenomenon. Spills are frequently imaged by ground based remote sensors, such as cameras, but these rarely provide the synoptic view afforded by an airborne platform. Helicopters would provide a quick response platform, but they are rarely equipped for vertical imaging. A camera through the porthole does provide remotely sensed data of an event, but this is an oblique view, and it is difficult to correct this type of image for the geometric distortions that occur in an oblique image.

Another problem related to temporal resolution is the season of acquisition of aerial photography. Photography acquired during leaf-off periods is less valuable for assessment of vegetation than photography acquired during the growing season. The impact on vegetation is frequently the only way to measure the total impact of an event with remotely sensed data, as vegetation is the only part of the environment that stands still. Unfortunately, much of the aerial photography for New Jersey has been acquired during leaf-off periods.

Spectral resolution, the number and width of the sensor's spectral bands, is another important factor to consider in remote sensing studies. Studies of atmospheric plumes would be greatly enhanced through the use of devices having many

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must be at least 12 x 12 pixels. Greater probability of detection occurs when this area becomes 48 x 48 pixels or larger. 12 x 12 pixels on a Landsat MSS scene is 720 x 960 meters, on Landsat TM it is 360 x 360 meters, on SPOT multispectral it is 240 x 240 meters, and SPOT panchromatic it is 120 x 120 meters. Therefore, selection of the remotely sensed data source to use is very case dependent, and the region of potential impact must be taken into consideration.

spectral bands in the visible portions of the spectrum. Studies of thermal plumes, especially from higher altitudes, would be enhanced by the use of sensors with more than one band in the thermal portion of the spectrum, as multiple thermal bands allow easy correction for atmospheric attenuation effects. Studies of vegetation are difficult without red, green, and near-infrared bands on the sensor, and these studies are enhanced if there is more than one band within one or more of these portions of the spectrum.

Radiometric resolution, most frequently associated with the range of digital numbers provided by a sensor, is another limiting factor. Studies of low reflectance phenomena, such as water-borne plumes, is complicated in images of low radiometric resolution. Enhancement techniques can improve the separability of these features, but image noise is also enhanced by these techniques. It is also difficult to uniquely identify these features if they are near the lower limits of detectability.

Spatial resolution, commonly expressed in terms of pixel size, is the type of resolution that is most commonly considered to be a limiting factor. However, increasing the spatial resolution of a system does not always enhance the usefulness of a system. Frequently, as spatial resolution increases, phenomenon that could be classified as a single feature are classified as two or more spectral features. For example, a SPOT panchromatic image of a runway airport will show runway markings, dark patches of burned rubber in the landing zone, and the "clean" concrete. Data with a larger pixel size will tend to show the runway as a homogeneous surface.

Selection of a remotely sensed data source for a particular problem will be greatly influenced by the resolutions required for solving the problem. Each chapter author will relate how remote sensing data sources of various resolutions can solve the problems discussed in their chapter. Future acquisitions of remotely sensed data for the state of New Jersey should be influenced by these factors. New Jersey's environmental problems are severe enough to warrant a first-class program of mapping and remediation. Applying available remotely sensed data sets that were not acquired with these environmental problems in mind can produce valuable results. However, planning for the acquisition of remotely sensed data with forethought to plumes and spills can only enhance the utility of the remotely sensed data.

	Thematic Mapper (TM)	SPOT Multispectral	SPOT Panchromatic
Spatial Resolution	30 meters 120 meters (band 6)	20 meters	10 meters
Spectral Bands, Color Name, and Bandwidths in micrometers	Band 1 (blue-green) 0.45 - 0.52		
	Band 2 (green) 0.53 - 0.61	Band 1 (green) 0.50 - 0.59	Band 1 0.51 - 0.73 (approximates a B&W infrared photograph)
	Band 3 (red) 0.62 - 0.69	Band 2 (red) 0.61 -0.68	
	Band 4 (near-IR) 0.78 - 0.91	Band 3 (near-IR) 0.79 - 0.89	
	Band 5 (mid-IR) 1.57 - 1.78		
	Band 6 (thermal-IR) 10.42 - 11.66		
	Band 7 (mid-IR) 2.08 - 2.35		

Table I-1. Comparison of Landsat-TM and SPOT panchromatic data.

ATMOSPHERIC PLUMES

Jeff Wasrud

Introduction

This part of the project has focused on the detection of atmospheric plumes through the use of satellite scanner data. Several studies have shown the utility of air- or space-borne scanners for the detection of plumes. Before a plume can be detected with these sensors, certain conditions must exist. These include the following: illumination of the plume, preferably by sunlight; no clouds between the plume and the sensor; and a homogeneous background below the plume. The first two conditions are due to the passive nature of the sensors used in this study. These conditions are easily met. The third condition is not so easily fulfilled, nor is it as intuitively obvious a requirement as the other two.

Homogeneity of the area below the plume is critical for the automated discrimination of an atmospheric plume. Rarely does a plume totally obscure the region below the plume. Therefore, remotely sensed measurements of the plume, made from a platform above the plume, will include information from the features below the plume. This causes a mixed signal from the plume region, and prevents accurate classification of the plume. A plume can be visually detected over a non-homogenous area. This can be accomplished due to the a priori capabilities of the human interpreter. His job is made much easier when a homogeneous background exists. However, the total area of the plume could be much more than what the interpreter sees, as the plume will degrade until it appears similar to the "background" atmospheric haze.

Homogeneity, in this case, is not an absolute term. It is dependent on the sensor's spectral, spatial, and radiometric resolution. For example, Chung (1986) presents imagery of Korea, the Eastern seaboard, and the central portion of North

America, on which plumes are easily distinguished. All of these images were acquired from meteorological satellites, which have coarse spatial resolution and radiometric resolution less suitable for earth surface studies than satellites such as SPOT and Landsat. At this resolution, the Koreas appear quite homogeneous, as do the American images. The only readily distinguishable features are large water bodies, i.e. the Atlantic and Pacific Oceans, the Great Lakes, and the Mississippi and Missouri Rivers. The plumes discussed in Chung (1986) are very large plumes, i.e., the Mount Saint Helens eruption, dust storms that originated in the Chinese loessial plain, or very large forest fires. Meteorological satellites are well-suited for detection of this type of atmospheric plume, as the area under and around the plume appears homogeneous on the images from the meteorological satellite.

Literature Review

As the literature has shown the utility of remotely sensed data for the monitoring of atmospheric plumes, we have included parts of the atmospheric section of the first report submitted under this contract (Cary, 1987, pages 4-6).

> <u>Photography (Aerial and Laboratory)</u>
>
> Aerial color infrared photography was used by Hilton and Blais (1974) to estimate diffusion coefficients for a 12.6-mile-long plume from a Portland cement plant in Virginia. The visual interpretation techniques they used require vertical photography and a visible shadow of the smoke plume.
>
> A laboratory study by Nappo (1984) involved generation of a smoke plume in a wind tunnel. The plume was photographed by two cameras, one taking a four-minute exposure resulting in a time-averaged image, and the other taking exposures 1/60 second in length (i.e., near-instantaneous) every 15 seconds. The photographic negatives of time--averaged images were scanned with a microdensitometer to determine smoke particle concentration. These measurements were used to derive dispersion parameters, which were then used to estimate turbulence parameters.
>
> <u>Aircraft and Satellite Scanner Data</u>

Aircraft scanner data were used by Potter (1984) to estimate optical depth. The method was based on the fact that aerosol scattering varies with wavelength. From this, the idea was that regression of one channel against another would give a slope and intercept dependent on the mass of particulates in the air column.

Imagery from the green and red bands of the Earth Resources Technology Satellite (ERTS, now Landsat) was analyzed to determine the relationship between image brightness and the particulate concentration in a smoke plume from a smelter in Canada (Tempelmeyer and Ey, 1974). Walczewski (1984) cited studies by Walczewski (1976) and Dworak (1978) which also demonstrated the use of Landsat imagery for mapping aerosols emitted by industrial sources; the sites were at Crakow and Tarnow, Poland.

Landsat Thematic Mapper (TM) data were used to assess particulate concentrations by analysis of band-ratios (Carnahan et al., no date). The estimates of concentration were greatly influenced by whether underlying features were low or high in reflectance.

In another study, Carnahan et al. (forthcoming) looked at the atmosphere and the TM sensor together as one system. They calculated a line spread function (LSF) analogous to a point spread function, with a linear object instead of a point object (that is, their LSF was an indicator of spatial rather than spectral resolution). They found that the width of the line spread function of the atmosphere-TM system was broader when particulate concentration was greater.

Along similar lines, Kaufman (1984) used modulation transfer functions to show the effect of atmospheric scattering on apparent spatial resolution. The effect was such that, for targets larger than 200 meters, correcting for atmospheric effects would be more important than improving sensor resolution.

Methodology

The types of plumes that are of interest to this study are relatively small in extent, and so require the use of larger scale imagery, such as Landsat TM or SPOT. On TM or SPOT imagery, the areas discussed in Chung (1986) would appear to be much more heterogeneous than they do on the meteorological satellite imagery, as Landsat and SPOT are designed to record detailed information about the earth's surface. Therefore, the degree of homogeneity needed for automated recognition of a plume with TM data is different from that needed with meteorological data. Broad, straight highways, parking lots, or grassy fields might provide the degree of homogeneity needed for plume detection. However, these background targets should be as homogeneous as possible, i.e., free of shrubs, trees, cars, and shadows. Areas that may contain these background targets were not examined for plumes for several reasons. First, they are difficult to find, and require detailed image analysis. Second, it is unlikely that there are these types of background targets that are close to an atmospheric emitter and are sufficiently homogeneous within the area of study. Therefore, plume detection was attempted over bodies of water. Water bodies are often very homogeneous targets, especially in the near- and mid-infrared portion of the spectrum. At these wavelengths, they are near-perfect absorbers, and are easily distinguished on the imagery.

Atmospheric plumes, especially particulate plumes, tend to reflect the most light in the visible portion of the spectrum. Generally, reflectance of particulates is at or near peak values in the blue portion of the spectrum. Therefore, TM band 1 (0.45 - 0.52 micrometers) is well-suited for the analysis of particulate plumes. A ratio technique has been shown useful to enhance plume discrimination (Carnahan, et al., 1985). This technique makes use of the reflectance properties of atmospheric plumes and water. The blue band is divided by an infrared band. The resulting ratio image will have high values when a plume is over a clear water body. The plume is highly reflective in the blue, and not as reflective in the IR, and clear water has low reflectance values in both bands. Plumes over water then show as bright features on a dark background, and would have a characteristic shape, i.e., emanating from a point, increasing in width and diffusing downwind.

This ratio technique was tried for the TM data acquired on 22 August 1985. The data encompass all of path 14 row 32, the southern two quarter scenes of path 14 row 31, and the northern two quarter scenes of path 14 row 33. The area examined is the state of New Jersey and its coastal waters, along with portions of Delaware, Pennsylvania, and New York. Each TM quarter scene was read onto the 3B15. The ERDAS program ALGEBRA was then used to generate the three ratios (band 1 over band 4, band 5, and band 7) for the quarter scene. The entire area was examined in 512 x 512 pixel subframes (approximately 9.5 x 9.5 miles). No features that could be considered to be atmospheric plumes were observed in the band 1/band 4 ratio data for this region. In areas especially suitable for plume detection, i.e., urban areas[1] with multiple water bodies nearby, or areas adjacent to known emitters, a more intensive approach was used. The image examination was extended to include band 1/band 4, band 1/band 5, and band 1/band 7. A false color composite was created using the three ratios to drive the red, green, and blue guns on the monitor[2]. Atmospheric plumes would appear to be light gray to white in color on this composite. However, no plumes were observed through the use of this technique. Histogram equalization (ERDAS program HISTOEQ) was used to enhance the image and aid in the detection of atmospheric plumes on both the single ratio and three-ratio images for the highly suspect 512 x 512 areas. Once again, no plumes were observed. Finally, cluster techniques (ERDAS program CLUSTER) were used on the single ratio and three ratio full and subset data sets. Generally, all three bands were clustered for a 512 x 512 area of suspected plumes. CLUSTER was used many times over many different areas with a range of cluster classes. The number of cluster classes varied from 10 to 255. The number of cluster classes for a particular 512 x 512 subset would be increased in direct proportion to the likelihood of plume detection. Areas surrounded by multiple water

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[1] Urban areas were assumed to be more likely than rural areas to have atmospheric emitters. Given this assumption, it can then be hypothesized that an urban area with a large water body nearby would be a suitable area for plume detection. An urban area with multiple water bodies nearby would be even more suitable, as different wind directions could still blow a plume over a water body.

[2] Usually, the 1/4 ratio was displayed as red, the 1/5 as green, and the 1/7 as blue. The bands can be displayed with whatever color is convenient. The colors displayed on the ratio image have no direct relationship with the color of the features being examined.

bodies and possessed of multiple emitters were subjected to the most intensive processing (greatest number of cluster classes). Generally, the number of cluster classes for the first attempt is the number of spectral classes the interpreter believes are present. As the ratio would increase the variation between plume and background, the other variables in CLUSTER were not manipulated. No plumes were observed with these techniques.

The north-eastern quarter of the path 14 row 32 TM scene, which includes the industrial heart of New Jersey, Manhattan, and the lake district of north-central New Jersey was extensively examined. The examination tested the hypothesis that ratio values would reflect general differences in air quality between the lake district (encompassing parts of Morris and Sussex counties) and the industrial/urban areas (Hudson, Essex, and Bergen counties, Manhattan, etc.) A land mask was created, using a supervised classification approach, in order to change the values for the land areas to zero and eliminate them from processing. The program MASK was then applied to bands 1, 4, 5, and 7 of the original data, and a new data set created. The new data set was ratioed, and the resulting data set clustered. This clustered data set (in GIS form) was colored using the palette option of the ERDAS program COLORMOD. No differences were noted between values for the lake district and the urban/industrial district.

There are several possible reasons for the lack of atmospheric plumes. One of the most likely reasons is the weather. The winds on this day were light (approximately 5 miles per hour) and variable. As there was no constant wind direction, plume development may have been retarded or severely localized. Emissions were probably occurring, but, if winds were variable, distinct plumes might not form. If they did form, the changing wind directions may have prevented them from developing to a size large enough to be detected by Thematic Mapper data.

In a further effort to find atmospheric plumes, the SPOT data acquired on 8 July 1986 for northeastern New Jersey, Manhattan, the Bronx, western Connecticut and western Long Island were analyzed. As the SPOT sensors do not have a "blue" band, the analysis was concentrated on the green portion of the spectrum. Analysis was performed in roughly the same manner as with the TM data, i.e., a green-IR ratio data set was created with the ERDAS program ALGEBRA. In an attempt to further automate the search for plumes, a land mask was created, using the ERDAS supervised classification approach, and applied to the data sets. The masked data were then ratioed, and were then colored with a "rainbow" scheme, i.e., ratio values were assigned, in ascending order, to red, orange, yellow, green, blue, indigo, and violet hues through the use of the ERDAS COLORMOD program. The resulting image contained patterns that appeared to be related to bathymetry or turbidity. These patterns had a local low ratio value in the center of the water body, and increasing ratio values approaching the shore zone. It is extremely unlikely that atmospheric plumes would follow such a pattern, especially given that two major water bodies (the Hudson River and Long Island Sound) that are roughly perpendicular to each other showed patterns that were aligned with the water body and not with any apparent wind direction.

Two images, acquired with the Biovision color-infrared video camera, of the Salem nuclear power plant's cooling tower plume were also processed in an attempt to see if computer enhancement and classification would aid in plume discrimination. The images are less than optimal, for several reasons. First, the images are not vertical images, but are obliques. One is a low oblique (horizon does not appear in the image), the other is a high oblique (horizon does appear). Oblique images are difficult to work with, as scale changes radically within the image. Second, no homogeneous background is present. The low oblique image includes the power plant facilities. The high oblique does include a part of the Delaware River (a relatively homogeneous surface), but vignetting problems are very apparent in the image, causing the river to appear heterogeneous. Third, the data did not include any information from the blue portion of the spectrum. As stated previously, atmospheric particulates tend to have highest reflectances in the blue portion of the spectrum. Fourth, the extreme brightness of the plume, in relation to its background, caused a halo effect in the vicinity of the plume.

Computer processing was performed on the image in an attempt to enhance the plume. The techniques tried were ratio analysis (the two visible bands divided by the infrared), principal component analysis, and texture analysis of the first principal component. These techniques were tried on the raw data, on "smoothed" data (3 x 3 and 5 x 5 low pass filter), and on data that were warped 90 degrees and then filtered. No single enhancement, or combination of enhancements, provided more information about the plume than the raw data did. An additional processing step was the clustering of an eight band data set, consisting of the smoothed data, the ratio data, and the principal component data. No changes in information content were noted. The texture data were then added to the cluster results, and a cluster then performed on the new data set. Once again, no additional information was gained.

In order to make the plume more obvious, several image processing techniques were attempted using the ERDAS program WFM. The image was displayed, and then an inverse logarithmic function applied to it. The green and red bands (blue and green guns on the monitor) were then manually manipulated. The resulting transformation was an inverse logarithmic function for digital numbers (DNs) from zero to approximately 180, a linearly increasing function for DNs from 180 to 240, and a horizontal function for DNs 240-255. The plume then appears as a solid, cyan colored object on a dark background. This processing step, although it does change the color of the plume to something quite exotic, did not reveal any information about the plume that was not obvious in the original image. The image can be manipulated with WFM in such a manner as to make the plume appear larger. However, this is probably not a valid technique because 1) as the image is manipulated, areas obviously outside the region impacted by the plume also begin to appear in the same colors and 2) the increase in apparent size may be due to the plume locally saturating the sensor and causing some "bleeding" into the regions adjacent to the plume.

Conclusions and Recommendations

Further studies in remote sensing of atmospheric plumes could be undertaken at Cook College. Cook College is equipped with several devices that should make basic research into the feasibility of various remote sensors for atmospheric work possible. Chief among these is a steel tower, approximately sixty feet in height, that is equipped with instruments for recording wind speed and direction. The tower is surrounded by a grass plot, a paved roadway, and greenhouses. This siting arrangement would permit the study of plumes over a variety of surfaces. Cook College also has a plume generator, capable of producing plumes of various gasses and particulates, that has been used for training in visual analysis of plumes. If a color video camera, that can complement the color-infrared video camera the center already has, is obtained, the College will then have the capacity to acquire remotely sensed data, in four distinct spectral bands, of controlled atmospheric plumes from a platform situated above the plume. In addition, if a spectrometer can be obtained, spectra of various atmospheric contaminants could be documented in order to provide a reference for future work. No reference has been found that documents the reflective properties of atmospheric contaminants in a manner that would be useful with remotely sensed data of the type used in this study. Such a reference would be crucial to further work in remote sensing of atmospheric contaminants.

The literature has shown remote sensing to be a useful technique in the discrimination and measurement of atmospheric plumes. The results of this study show the importance of the four types of resolution --spatial, spectral, radiometric, and temporal-- in remote sensing of atmospheric plumes. That the TM data could not be used to discriminate a plume is probably due to the temporal problems, as there were poor weather conditions for the formation of plumes on the date the TM data were acquired. The SPOT and video data were less than ideal due to their spectral resolution. Any operational system for the remote sensing of atmospheric plumes must have the capacity to overcome these difficulties. Such a system should be available on demand, be possessed of a spectral and radiometric resolution sufficient to identify most of the pollutants of interest to the DEP (both presently and in the future), and have a spatial resolution small enough to identify plumes of interest, but large enough to prevent otherwise homogeneous targets from appearing heterogeneous. Such a system might be as simple as a multi-camera unit mounted in a very small platform, such as an ultralight manned aircraft or a radio controlled model airplane. It could be as complex as the Airborne Imaging Spectrometer, which would be carried in a multi-engined aircraft, or the STARS system, which may be carried on Landsat-6. Ground based systems, if synoptic coverage is not required, could also be of value to DEP.

LANDFILLS

Teuvo M. Airola and Jeff Wasrud

Introduction

The release of toxic materials into the environment poses a significant environmental quality problem. Accidental spills and purposeful releases of hazardous materials have occurred at terrestrial and oceanic sites. While these spill events have been monitored and remediated whenever possible, we have not found a real-time recording of an actual event in New Jersey. Consequently remotely sensed data of a spill have not been available for further evaluation and processing.

The lack of remotely sensed data concurrent with a terrestrial hazardous waste spill event lead to the decision to focus on existing hazardous waste sites in New Jersey. The rational was that leachate moving from such a site would enter the surface water, the ground water, or both. In turn, the uptake of water contaminated by hazardous materials might have an impact on vegetation growing on or adjacent to such a site. Through this mechanism, it might be possible to monitor the indirect impact of such a site on the environment using plants as indicators. Therefore, although the release of contaminants from a waste site is not instantaneous, as in a spill, the methods discussed below could be applied in a spill condition.

A primary goal of this component of the project was to evaluate the use of a wide range of remotely sensed data for the monitoring of three hazardous waste sites. The research was designed to provide an evaluation of satellite digital data, scanned conventional aerial photography, and color infrared video data acquired using a light aircraft as a platform.

Literature Review[1]

A variety of remote sensing techniques have been used to identify, evaluate, and monitor landfills and hazardous waste disposal sites. At the site level, instruments such as "ground-penetrating" radars, metal detectors, hand held magnetometers and measurements of electrical resistivity and seismic refraction have been used to locate and identify buried objects and to characterize the extent and nature of potential ground water contamination (Chichowicz et al., 1981; Straight, 1983).

The overall monitoring of landfills and hazardous waste disposal sites has relied extensively on the use of aerial photography and both satellite and aircraft scanner data. Landsat multispectral (MSS) data have been used to map regional geologic features that might influence potential groundwater movement near a hazardous waste landfill (Stohr et al., 1985). The relatively coarse spatial resolution (i.e. 80 meters) of MSS data has precluded its use for monitoring the specific characteristics of these sites. SPOT panchromatic and multispectral data, having a spatial resolution of 10 meters and 20 meters respectively, have been used to detect land-cover changes related to landfill operations (Philipson, W. R. et al., 1988).

High resolution aircraft scanner data and conventional aerial photography have been used to characterize the surface features of these sites and to detect the movement of leachate. Thermal scanner data have also been used to detect leachate that is thermally anomalous. Sangrey and Philipson (1979) provide a detailed review of the key elements that must be considered in selecting the appropriate scanner, aerial camera, and filters and film combinations to maximize the detection of landfill leachate contamination.

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[1] This material was taken from: Airola, T.M. and D. Kosson, <u>Evaluation of a Hazardous Waste Site Using the Digital Analysis of Historic Aerial Photography</u>, 1988, which was submitted to the Journal of the Water Pollution Control Federation.

The methodology for the inventory of hazardous waste disposal sites using historic aerial photography is well developed (Nelson et al., 1983). Aerial photography has been used to document present site conditions, reconstruct the physical history of the site over time, and provide insights into spatial relationships between physical factors present at the site. Aerial photography has also been incorporated into a larger geographic information system approach (Page, 1983). Color, color infrared, and black and white infrared photography have been used to identify hydrological and soil conditions, possible leachate movement, and the effects of toxic materials on vegetation at hazardous waste sites (Lyon, 1987). The existence of multiple dates of aerial photography for a site allows the assessment of changes over time, changes in adjacent land use patterns, and potential changes in the physical environment (Erb et al., 1981).

Methodology

Site Selection

Following a number of discussions with individuals from NJ DEP, EPA - Region II, and the University, three sites were selected on the basis of several factors. Chief among these were: availability of data (both remotely sensed data and "ground-truth" data); spatial extent of the landfill; and the potential impact of the site on the surrounding surface water, ground water, and vegetation. The three hazardous waste sites selected for further study were:

(1) Kin-Buc landfill, located in Edison Township, Middlesex County;

(2) Lone Pine landfill, located in Freehold Township, Monmouth County; and

(3) the Vineland Chemical Company, Inc. site, located in Vineland, Cumberland County.

Data Availability

Satellite data from the Landsat Thematic Mapper (TM) instrument were obtained for the entire state of New Jersey through the cooperation of NJ DEP and the State Planning Commission. The data were acquired by the satellite on August 22, 1985, a nearly cloudless day, and the three 180 km by 180 km scenes provide coverage of the entire state. SPOT data, acquired on July 8, 1986, were obtained through a joint effort of the Remote Sensing Center and NJ DEP. The three scenes acquired provided only limited coverage of the coastal sections of northern and central New Jersey.[2] Both multispectral and panchromatic data for each SPOT scene were acquired[3].

Following selection of the study sites, historic aerial photographic coverage of the sites was made available through the cooperation of the Office of Environmental Analysis (OEA). Photography available for the study sites is indicated by date and film type in Table III-1.

In order to evaluate the use of other remotely sensed data for monitoring the potential environmental impact of sites such as these, satellite digital data and high spatial resolution color-IR video data were obtained for some of the sites. The TM data that provided coverage of the Vineland Chemical site were extracted from the computer compatible tape and downloaded for further analysis using an ERDAS image processing system. On June 8, 1988, color IR video data were acquired for the Vineland Chemical site using the Remote Sensing Center's Biovision camera system flown in a light aircraft.

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[2] SPOT's scene format is 60 km by 60 km.

[3] Table I-1 provides a comparison of both the spectral and spatial characteristics of the TM and SPOT digital data.

Date	Vineland Chemical	Kin-Buc Landfill	Lone Pine Landfill
1940	None	B&W, 10 April	B&W, 10 April
1947	None	B&W, 2 July	None
1951	B&W, 27 March	None	B&W, 6 April
1958	None	B&W, 20 November	None
1961	None	B&W, 20 April	None
1962	B&W, 22 March	None	B&W, 13 January
1972	CIR, 25 March	None	CIR, 25 March
1977	CIR, 12 September	CIR, 26 August	None
1986	CIR, 21 March	CIR, 27 March	CIR, 23 March

B&W--Black and White Photography CIR--Color Infrared Photography

Table III - 1. Available photography[4], by date and film type.

[4] We would like to thank the OEA and Ken Sass for locating the photography and loaning it to us.

Aerial Photography

Historic aerial photography has been used extensively for reconstructing the site history of hazardous waste sites and monitoring changes over time. Most of this analysis has required trained photo interpreters and the optical/physical transfer of information from available imagery to a suitable map base. This process is both difficult and time consuming. The optical/physical production of images and maps at the variety of scales that might be desired for analysis and field work is expensive if not impossible. The conversion of historic aerial photographs to a digital format for analysis and processing using image processing techniques provides a number of distinct advantages:

(1) the ability to enhance contrast, within selected portions of an image, to aid in visual interpretation;

(2) the ability to perform an image to image registration, thus allowing images acquired at different times, flight line orientations, and scales to be superimposed and simultaneously displayed;

(3) the ability to geometrically correct the images to a desired coordinate system so that distances and area measurements can be made;

(4) the ability to produce scaled hardcopy of a site once geocorrection has taken place; and

(5) as a result of these procedures, the ability to locate features of interest within a hazardous waste site that may have been buried under debris and/or fill and that are consequently no longer visible at the site.

The photography was made available to the Department of Environmental Resources (DER) one day a week, during business hours. The photography was scanned using the Eikonix Charge-coupled Device (CCD) and the ERDAS program called CAPTURE. By scanning the photography into a digital format, CAPTURE permitted the Department of Environmental Resources to recall the imagery and use the image processing capabilities of ERDAS to enhance the imagery. CAPTURE was a first generation program, which has since been improved upon with the development of the ERDAS program ESCAN. The software and hardware configuration at the time of the scanning had several problems which were overcome, but not without compromises. The greatest problem to be overcome was the time needed for scanning. A three color scan, at 2048 x 2048 pixels, could require 6 hours for set up, testing, and scanning. On one occasion, due to problems beyond our control, one scan required a full two days to complete[5]. Because of the time limitation, the color infrared photography was scanned at 2048 x 2048 pixels, which produced a larger than optimum pixel size[6]. To scan at the full resolution of the Eikonix (4096 x 6400) would have required up to 30 hours per three color photograph, given the equipment in use at that time.

After the photography was scanned, the various dates were rectified to each other. The general procedure was to take the oldest photograph and use this as a "base map", and rectify all other photography to its coordinate system[7]. The base photograph and the photograph to be rectified were displayed on adjacent ERDAS systems. The ERDAS program CURSES was then used to determine the coordinates of control points that were visible on both images. Control points had to be taken from 512 x 512 sub-areas of the images, as this was the maximum resolution of the display. A reduced image (greater than 512 pixels in length or width) does not allow accurate determination of the coordinates of a control point, as a pixel on

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[5] Most of these problems have since been rectified with the addition of a normalizer board to the Eikonix, and with the use of a much higher-powered light source.

[6] The color infrared photography was NHAP (National High Altitude Photography program) photography. Its scale of 1:58 000 is generally at a much smaller scale than other types of aerial photography.

[7] If a newer photograph is at a considerably larger scale than the oldest photograph, the large scale photograph should be used as the base photograph. This will prevent the loss of detail that would occur if the large scale photograph is resampled to a smaller scale.

the screen represents two or more pixels on the scanned photograph. Extreme care was taken to ensure that the control points were exactly the same. The target error was 0.5 pixel Root Mean Square Error (RMS)[8]. This target could be reached if careful analysis, based on the shape of the control point target and its spectral properties, was performed.

The 512 x 512 sub-areas must be chosen from several different areas of the photograph. Aerial photographs are not maps, and contain several types of geometric distortions. Many of these distortions increase as a function of distance from the center of the photograph. Ideally, 512 x 512 areas would be chosen from the center, from the edges, and from the corners of the photograph. In practice, it was often difficult to find good control points from all of these areas.

When ten or more control point coordinates had been identified, they were put into a file with the ERDAS control point editor program GCP. The coordinate file was then used as input to the ERDAS program COORD2, which calculates the transformation matrix to be used to rectify the image. COORD2 also prompts the user for the maximum RMS error allowable. As the program was calculating, errors associated with each control point were determined, and displayed on the screen or on the printer. If the first (or subsequent) attempts did not meet the user-specified RMS, the control point that contributes the most to the RMS was discarded, and the program began again with the reduced set. If the RMS target could not be reached when the control points were reduced to two, the program stopped[9].

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[8] An error of 1.0 RMS, although not ideal, would be acceptable for most purposes.

[9] An image that is rectified on the basis of two control points would be of dubious value, as the correction would only be one dimensional. A minimum of three is needed to form a two dimensional correction, but best results are obtained with ten or more. The upper limit would be based on diminishing returns, which would vary on a case by case basis.

The list of bad control points was very useful in rechecking the coordinates on the original image. Often RMS error could be reduced by going back to the image and reselecting control points. After the transformation matrix had been computed to the accuracy deemed adequate to the user, the image was then transformed through the use of the ERDAS program RECTIFY. A total discussion of image rectification is beyond the scope of this report, however, certain important points should be mentioned.

Image rectification is simply the changing of the coordinate system of an image to another coordinate system. Generally, image rectification is used to transform the image into a standard geographic coordinate system such as Universal Transverse Mercator (UTM), state plane or latitude and longitude. Image rectification can be easily visualized with two sheets of graph paper, upon which numbers have been written within each square. Overlaying the two, with the principal axes offset by some rotation, produces a situation similar to that which exists prior to rectification. If one wanted to rectify the upper sheet of graph paper to the lower sheet's "coordinate system", one could use a blank sheet of graph paper, oriented to the lower sheet, to transfer the "pixel" values to the blank graph paper. This would be a very simple rectification exercise. However, it often happens that a pixel on the upper sheet does not fall entirely within the boundary of a pixel on the base coordinate system. A decision has to be made as to what value to assign this border pixel. Several algorithms have been developed to make this decision. RECTIFY allows the user to choose from three of the most popular- Bilinear Interpolation, Cubic Convolution, and Nearest Neighbor. The first two were not used in this study, and should not be used in any similar study. Bilinear Interpolation and Cubic Convolution, use an averaging algorithm. Areas of change- "edges" in the image- will be smoothed. For instance, in an area of rapid spectral change, such as the border between a water body and land, a ring will be created around the water body on the output image. When it is necessary to prevent this from happening, as was the case in this study, the Nearest Neighbor algorithm should be used. The Nearest Neighbor approach assigns the value for the output pixel based on the value for the input pixel whose center is closest to that of the center of the output pixel. The Nearest Neighbor algorithm preserves, as much as possible, the radiometric fidelity of the image.

After an image has been rectified, it was then displayed along with the base image using the ERDAS program READ. READ is commonly used to display a single data set on the monitor. However, if one carefully selects the parameters within read, two or three monochrome images can be displayed on the screen. READ would be run once for each image to be displayed. Each image would be displayed using a different color gun assignment; data values, and not function memory values, would be chosen as the values to drive the color gun intensity; and, naturally, one would NOT blank the screen between the display of the base image and the rectified image. Typically, the images were displayed with a magnification of one, i.e., a 512 x 512 sub-area was displayed from the base image and the rectified image. The coordinates for the center point of the area to be displayed were selected. The coordinates were used for both images, as the rectified image should now have the same coordinate system as the base image. When the analyst views this image, the features common to both images should be in perfect alignment. If not, the entire rectification procedure would be begun anew, with particular emphasis being placed on careful consideration of the control points.

When all the photographs had been rectified to a common coordinate system, they were combined into one data set using the ERDAS program SUBSET. The analyst began the SUBSET program by supplying the name of the first input data set. Typically, this was the oldest image. When prompted for the size of the output data set, the analyst would remember that the data sets were now all the same size in the X and Y directions, and that the output image would have as many bands as the total number of dates of photography.

The resulting data set was quite large and difficult to deal with. Perhaps the most difficult problem was understanding the image. Typically, an image was displayed from the multitemporal data set, with each of the monitor's color guns (red, green, and blue) being used to display a different year's photography. When an analyst who is used to seeing red, green, and blue representing spectral information was confronted with those same colors representing temporal information, the analyst was typically confused for some period of time. Extreme care must be taken in the analysis of this data set.

SPOT data

The Lone Pine landfill was also examined through the use of SPOT data. SPOT panchromatic data have sufficient spatial resolution (10 meters) to distinguish certain gross characteristics of the landfill, but lack the spectral resolution required to analyze vegetation and other phenomena. The SPOT multispectral resolution data are from three spectral bands (the green, red, and near-infrared), but have 20 meter spatial resolution. In order to utilize the information contained in best of both data sets, the two sets were combined using the Intensity-Hue-Saturation (IHS) transformation. The IHS transform is a complex technique. A full and lucid explanation of it is not readily available in the literature. The following is a brief description of the IHS transform and an explanation of how it can be implemented it on an ERDAS system.

Remotely sensed data are generally displayed on a red-green-blue (RGB) monitor. The resulting image can be considered to be a projection in RGB space.

RGB space can be described as a three dimensional cartesian coordinate system. IHS space is also three dimensional, but is a polar coordinate system[10]. A graphic example of IHS space is the color wheel, frequently used in cartographic production and in the printing trade. The color wheel generally is a set of plates, similar to Munsell color plates, suspended from a central axis. The intensity, hue, and saturation changes as distance from the center point (measured linearly and angularly) increases.

To use IHS transformation with the SPOT data sets, several preliminary steps were necessary. First the multispectral data were registered to the panchromatic data, much in the same way as different dates of photography are registered. The program RECTIFY was then used to resample the multispectral data to the 10 meter resolution of the panchromatic data. The ERDAS program ALGEBRA was then used to perform IHS transformation on the multispectral data set that was resampled to 10 meters[11]. The result of this transformation was a three band data set, where the first band was intensity, the second was hue, and the third was saturation. The panchromatic band was then substituted for the intensity component, using the ERDAS program SUBSET. The panchromatic file was used as input to SUBSET, and the output was the first band of the IHS transformed file. As an IHS-transformed file could not be properly displayed on an RGB monitor, the file had to be transformed back into RGB space[12]. The resulting image approximates a 10 meter three band data set.

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[10] The human eye works not in RGB space, but in IHS space.

[11] The reader should refer to the ALGEBRA section of the ERDAS manual for details on the many variables needed to implement the IHS transformation.

[12] Once again, the reader is referred to the ERDAS manual for the specifics.

Biovision Video Data

The recent development of a standard video camera system modified to record spectral information in the IR portion of the spectrum can permit the cost effective acquisition of real time data of a spill event or acquisition of data over any site of interest. As a preliminary test of this concept, the Remote Sensing Center's Biovision color IR video camera system was flown over the Vineland Chemical Company site on June 8, 1988.

The Biovision system consists of a color video camera that had been modified to be sensitive to the near infrared portion of the spectrum. The camera produced a standard NTSC format output signal, within which three spectral bands were recorded:

(1) channel 1 - 0.5-0.6 micrometers (green);

(2) channel 2 - 0.6-0.7 micrometers (red); and

(3) channel 3 - 0.7-1.1 micrometers (near infrared).

The specific channels corresponded to those used in the multispectral scanner (MSS) with the exception of channel 3 which spanned the band width of the MSS bands 3 and 4. The ability to collect information in the near IR portion of the spectrum was particularly useful in monitoring vegetation stress, as living, actively photosynthesizing plants are strongly reflective in the IR portion of the spectrum.

Recording and processing of color IR video data using a digital approach required the development of specific software and a number of steps:

(1) testing of the Biovision camera and portable VCR system;

(2) actual data collection over the Vineland Chemical Company site using a light aircraft as a platform;

(3) conversion of the video data from analogue to digital format; and

(4) reformatting the data for compatibility with the ERDAS image processing system.

Following testing of the system, which consisted of the camera, a portable VCR, and portable color monitor, the system was flown over the Vineland Chemical Company site on June 8, 1988. The overflight was scheduled for early afternoon to minimize ground shadows and data were recorded at nominal altitudes of 1000, 2000, and 3000 feet. Conversion of the analogue data to a digital format was accomplished using a Truevision TARGA32 graphics board. Although present portable VCR technology resulted in a degraded signal (ie. the 512 line format of the camera system was recorded as approximately 240 lines) which reduces the spatial resolution of the image, the spectral properties of the image remained. TARGA32 board permitted the playback of the video data through a RGB monitor and the "grabbing" of a video frame of interest. Through this process, frames of interest were converted from analogue format to a digital format. The resulting TARGA files consisted of 512 by 482 8-bit pixels in each of four bands, the fourth representing an overlay graphics channel. TARGA format differs from ERDAS format with respect to the coordinate system used to reference the location of each pixel in the image and the header information that is appended to the file. Software was written by Remote Sensing Center personnel to convert TARGA files to ERDAS format to permit the digital analysis of the data. A copy of this software will be made available to the DEP.

TM Satellite Data

TM digital data providing coverage of the Vineland Chemical Company, Inc. site was used to produce both simulated color and color IR images using an ERDAS image processing system and a Lasergraphics film recorder (see Figures III-1 and 2). Figure III-1 is a simulated true color 512 by 512 pixel image providing coverage of the site and the surrounding area. The major features that can be observed are:

(1) the Maurice River, which flows from north to south through the image to where it enters the northern portion of Union Lake;

(2) Route 55, a multi-lane limited access highway, adjacent to the Maurice River;

(3) the city of Vineland, which extends across the image to the east and exhibits a characteristic gridiron street pattern;

(4) the Blackwater Branch stream corridor, which enters the Maurice River just south of the first interchange visible on Route 55; and

(5) the Vineland Chemical Company site, which is barely visible as a bright area along Blackwater Branch east of the first north-south road intersection.

Figure III-2 represents a simulated color IR image of the same 512 by 512 pixel image as Figure III-1. The vegetation in the scene is characteristically represented by red tones. Both the forested areas adjacent to the Maurice River and Blackwater Branch are clearly visible in the image, but the band of dead vegetation on either side of Blackwater Branch extending downstream below the Vineland Chemical Company site towards the Maurice River is not discernable. Although the TM data provides synoptic coverage of the site and the confluence of Blackwater Branch and the Maurice River, the spatial resolution of the data (30 meters) is insufficient to detect the band of dead vegetation adjacent to Blackwater Branch. The extraction of training sites within the known area of disturbance failed to produce a unique signature which would isolate this area from similar vegetation to the north and south.

Kin-Buc

The two earliest dates of photography used for Kin-Buc were 1940 and 1947. Detailed observation of the photography revealed massive changes during the war years. Chief among these was the total removal of the wetland forest in this region. Small shacks, warehouses, and low-income housing made up the majority of structures in the region.

The next set of photographs was taken in 1958, apparently as part of the New Jersey Turnpike construction, as they are oriented with the Turnpike and not in a North-South direction. This was a problem during image registration, but not an insurmountable one. One problem prevented the successful registration of the 1958 and later photography to the 1940-47 photography, and that was the massive denudation, paving, and development of this region. If it were not for the presence of the Raritan river in the photography, it would have been difficult to recognize that the photographs were of the same site. Between 1947 and 1958, the existing vegetation was removed, most roads were eliminated, all housing was demolished, and a totally new landscape was created. No unambiguous control points could be found to tie the 1958 to the 1947 photography. Attempts were made using the intersection of dirt roads, stream intersections, mosquito control canals, and other uncertain control points. The results were unsatisfactory, as Root Mean Square (RMS) errors were on the order of five, and the resulting image was uninterpretable. Visual comparison was also quite difficult, as the radical changes destroyed any landmarks that could be used to orient the interpreter. After several attempts to rectify the 1958 photography to the 1940 photography, it was decided to have two base photographs- the 1940 for the 1940 and 1947 photography, and the 1958 photography for all subsequent dates. This was an unfortunate situation, and is an interesting statement on the rate of development in central New Jersey.

<u>Lone Pine</u>

No problems, such as the ones affecting the Kin-Buc imagery, existed with the Lone Pine landfill photography. The road network, although not dense, was stable throughout the time period encompassed by the photography. The photography was easily matched for the various dates.

Vineland

Through the cooperation of the Office of Environmental Analysis, historic aerial photographic coverage of the Vineland Chemical Company site was made available for conversion into a digital format using the Remote Sensing Center's Eikonix CCD camera. Using this system, digital files were created and stored online for further analysis. In order to evaluate changes at the Vineland Chemical site over time, digital images for 1951, 1962, and 1977 were co-registered to one another using ground control points (GCPs) visible in each image. The 1951 photograph was used because it is the earliest date available and the 1962 photograph was used because it is from the same time of the year. The 1977 photograph was used to have a leaf-on condition for investigating vegetation stress. Registration of the 1951 image to the 1962 image was accomplished using a set of 15 GCPs. After computing the transformation matrix, 7 pairs of GCPs remained using a root mean-square (RMS) threshold of 1.0. Following the creation of a new file having the 1951 data as channel 1 and the 1962 data as channel 2, the 1977 image was then rectified to the 1962 image. Although 12 matching GCPs were identified in each image, the transformation matrix used only 4 sets of points to calculate a set of coefficients meeting the desired 1.0 RMS threshold. Much of this problem was related to the difficulty of identifying unambiguous GCPs in the images, as significant changes in land use occurred over the period 1962 through 1977.

In addition to these photographs, the 1986 color IR photograph providing coverage of the site was also converted to digital format. Figure III-3 represents a 2048 by 2048 pixel color IR subset image of the site for this date. The image, which unfortunately is quite dark, provides coverage of the site and the alignment of Route 55 which was under construction at that time. Additional processing of the image also allowed identification of dead or dying vegetation along Blackwater

Branch below the Vineland Chemical Company site. Because of the low contrast in the digital image, additional image processing of the data was not undertaken.

During a series of overflights of the Vineland Chemical Company site, color IR video data were acquired at altitudes of 3000, 2000, and 1000 feet in order to provide both an overview of the entire site and more detailed spatial information. The Biovision camera system was hand held in an approximate vertical position to reduce geometric distortion of the resulting images. The flight lines were made parallel to Wheat Road which resulted in bisecting the site. The force of wind resistance on the camera system produced a rotation of the camera body which resulted in images that are rotated approximately 45 degrees from a north-south orientation.

Figure III-11 is a video frame acquired at 3000 feet over the site. Visible within the image is the complex of Vineland Chemical Company buildings, waste holding ponds, and the packing house adjacent to the site which fronts on Mill Road. The apparent contrast of the image is low as a consequence of the highly reflective bare soil surrounding the site and the auto iris feature of the camera system which automatically reduces the amount of light entering the camera when focused on a bright scene. Figure III-12 represent the same video frame which has been processed to enhance contrast in the vegetated portion of the image. The reflectance properties of the vegetation adjacent to Blackwater Branch are clearly different than that of the vegetation upstream and at some distance from the stream channel. Low reflectance in the IR portion of the spectrum would be consistent with stressed, dying, or dead vegetation.

Results

<u>Vineland Chemical</u>

The Vineland Chemical Company, Inc. has carried out the manufacture of herbicides at its present location from the mid 1950's. The company occupies a site approximately 20 acres in size that is located adjacent to the Blackwater Branch, a tributary of the Maurice River, on Wheat Road in Vineland, New Jersey. It is alleged, that prior to 1977, that the improper storage of arsenic salts at the site lead to contamination of ground and surface water (NJDEP, 1986). Research funded by NJDEP was undertaken to characterize the levels of contamination in both water and sediments taken from both above, at, and below the plant. The results indicate that downstream of the plant that both the water and bottom sediments are substantially contaminated with arsenic (Faust et al., 1987).

The presence of arsenic contamination of the Blackwater Branch provides an opportunity to investigate the linkage between the movement of a pollutant into a surface water body and its potential impact on the adjacent plant communities. Although Blackwater Branch is relatively small in size (ie. 1-3 meters across), the hypothesis was formulated that arsenic contamination may have had a significant impact on the vegetation adjacent to the stream. Initial conversations with NJDEP and Region II EPA personnel and visual interpretation of available color IR photography initially strengthened this hypothesis as the vegetation adjacent to Blackwater Branch below the site appeared to be dead or dying.

Arsenic, a heavy metal, is toxic to plants when taken up in relatively low concentrations and has been used in the past as an herbicide in forest management activities. Arsenic, unfortunately, is also persistent in the environment and can become concentrated through biological magnification.

Following co-registration of the 1951, 1962, and 1977 images, the ERDAS program SUBSET was used to extract a 2048 by 2048 pixel image providing coverage of the site. Figure III-4 is a greyscale image of the site and the immediate surrounding area as it existed in 1962. Major features that can be recognized include:

(1) the forest vegetation adjacent to Blackwater Branch which crosses the northern portion of the image and flows from the east to the west;

(2) Mill Road which crosses the left edge of the image and is oriented north/south; and

(3) Wheat Road, the northernmost east/west oriented street which dead ends at the Vineland Chemical Company site.

Within the image a number of buildings can be identified by the contrast of their roofs from the surrounding soil and vegetative background. Poultry houses, appearing either bright or dark in the image depending upon roofing material, are recognizable by their long linear shapes. Individual residences and adjacent structures are found adjacent to both Wheat and Mill Roads. At the Vineland Chemical Company site, a cluster of buildings and poultry houses are visible, but the scale of the image makes the discrimination of individual buildings difficult.

One of the significant advantages of utilizing a digital analysis approach is the ability to produce an image at a variety of scales. Figure III-5 is a 512 by 512 pixel subset of the 1962 image and provides additional detail. Within the image, the individual buildings at the Vineland Chemical Company site can be identified. The spatial resolution is such that individual automobiles parked on the site can be recognized. Co-registration of the image also allows the changes that have taken place at the site over time to be illustrated. Figure III-6 is a 512 by 512 pixel image of the 1951 image that is co-registered to the 1962 imaged displayed in Figure III-5. At this point in time, the buildings used by the Vineland Chemical

Company had not yet been built and the site was primarily forested. Differences in vegetation and contrast permit the edge of the floodplain of Blackwater Branch to be identified. Comparison of these Figures with Figure III-4 aids in this interpretation.

Figures III-7 and III-8 represent the overlay of the subset 1951 and 1962 images using two different color assignments (ie. green for 1951 and red for 1962; and green for 1962 and red for 1951 respectively). The overlay indicates the changes that have taken place at the site between these two dates and allows determination of the location of these changes. In cases where landfilling has taken place this capability is particularly useful for reconstructing a site history.

Analysis of the 1977 image (see Figure III-9 indicates the presence of ponds on the site and the construction of a large packing house on the adjacent property which fronts on Mill Road. Figure III-10 is a 512 by 512 pixel subset of Figure III-9 which has been contrast stretched to improve contrast. The spatial resolution of the image as digitized is relatively coarse so that edges do not appear particularly sharp. The 1977 image was also processed to enhance discrimination of the vegetative changes that may have taken place along Blackwater Branch as a consequence of the release of arsenic compounds from the Vineland Chemical Company site. A red/IR ration technique was used to identify some apparent qualitative differences in apparent biomass downstream from the site. The rational for using this ratio is based upon the absorption of red light by actively photosynthesizing vegetation and the high reflectance of IR light by healthy vegetation. Consequently, the ratio of reflectance values in the red and IR portions of the spectrum produced by stressed, dying, or dead vegetation should be relatively low when compared to healthy, actively photosynthesizing vegetation. This relationship appeared to be present in the 1977 image and a broad area of dead and/or stressed vegetation along Blackwater Branch was identified. Interpretation of these results was complicated by the lack of ground truth information for this date and by the fact that the imagery was acquired relatively late in the growing season (ie. 9-12-77).

Inspection of both the video imagery and the available aerial photography raised a number of questions about the potential cause of the apparently dead vegetation. In particular, the narrowing down of the swath width of the dead vegetation adjacent of Blackwater Branch where the stream crosses under Mill Road might provide an alternative explanation: If the culvert carrying the stream under Mill Road had been blocked, damming Blackwater Branch, standing water persisting long enough could account for the pattern of dead vegetation visible in both sets of imagery. Field inspection of the site on August 10, 1988 revealed no evidence of debris blocking the drainage way and that the band of dead vegetation continued downstream from Mill Road. Figures III-13 and III-14 represent frames acquired at 3000 feet to the west of the site and indicate the downstream extent of the pattern of dead vegetation.

Figures III-15 and III-16 represent video frames acquired at 2000 and 1000 feet respectively. Both provide coverage of the band of dead vegetation along Blackwater Branch after it has passed beneath Mill Road. The spatial resolution of both image is such that the canopies of individual trees are visible.

Although it is apparent from the color IR video data that the vegetation to the west to the Vineland Chemical Company site adjacent to Blackwater Branch is primarily dead, this situation cannot be attributed to the arsenic contamination from the site. A chance conversation with a local employer while field checking the imagery provided an alternative explanation that flooding of the area had in fact taken place as the result of the construction of a beaver dam downstream from Mill

Road. The dam resulted in backing up water to the extent that Mill Road became impassable. Complaints to the County Utilities Authority lead to the breaching of the beaver dam this past winter. Apparently, the death of the vegetation adjacent to Blackwater Branch downstream from the Vineland Chemical Company can be attributed to two alterative hypotheses:

(1) the release of arsenic into the environment; or

(2) the industrious engineering work of a beaver colony!

An answer to this question will require the sampling of the dead trees and vegetation along Blackwater Branch and an analysis of tree rings and plant tissues for the presence or absence of arsenic which may have been taken up over several growing seasons. Such a study is being planned for the future.

Kin-Buc and Lone Pine

Analysis of the multitemporal data sets for the two landfills and a hazardous waste site was hampered by certain critical time constraints. Additionally, as analysis proceeded, the results of the compromises made during the brief time the photography was available to the Department of Environmental Resources became apparent. Even though the spatial resolution of all the images was less than adequate, and the spectral resolution of most of the images was poor[13], several interesting phenomena were noted.

Both of the landfills did not have an obvious, devastating impact on their surroundings. The landfills themselves were near-barren regions with minimal vegetation for their location. Kin-Buc, as it is located immediately adjacent to the Raritan river, has less of a land region available for potential impact on vegetation.

[13] The images with the best spectral resolution had the worst spatial resolution. This is a frequent occurrence with remotely sensed data. Economics and data transmission rates often force compromises to be made.

According to the Site Status Report, "the primary environmental concern is the contamination of ground water under the site which discharges into the Raritan river[14]." The region to the north, east, and west is intensively developed. Industrial, transportation, and residential land use form the majority of the cover. To the south of Kin-Buc is a marsh that extends to the Raritan River. The marsh is laced with drainage ditches, apparently created as part of a mosquito control project. Kin-Buc itself is a barren series of mounds, covering 65 acres, and ranging in height from near-sealevel to ninety feet. The scanned photography, with its relatively coarse resolution, reveals few details. Any seepage from Kin-Buc would quickly reach the Raritan River, and be carried out to the bay.

Lone Pine's effects have the potential to spread over a much larger land area as Lone Pine is located far from a major river and the ocean. Many hazardous chemicals have affected the surface and ground water, as well as the soil in the vicinity of the fill. Chemicals similar to those found on-site have been found in the Manasquan river, downstream from Lone Pine. Borrow pits, some with small ponds, encircle the landfill. On the flanks of the landfill are several small regions with taller vegetation of a slightly different species composition. These regions seem to be related to seeps from the landfill, as the ground is moist in this region. Unfortunately, the scale of the scanned photography was not sufficiently large enough to locate these features. Analysis could not be made on their variability or on their impact.

In both landfills, but more noticeably in Lone Pine, small variations in the reflectance of vegetation were noticed in certain areas. This reflectance change occurred both spatially and temporally, and seemed to occur along stream corridors

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[14] Status Report On the Hazardous Waste Management Program in New Jersey, vol. II, Site Status Reports, N.J. DEP, October, 1986.

near the landfill. This could be the result of seepage from the landfills adversely impacting the vegetation, or it could be the result of climatic/hydrologic changes over the time of the photography, or it could be due to variations in solar elevation and azimuth. If this reflectance change is due to the impact of the landfill, it indicates that seepage from the landfill is moving into the streams and affecting the spectral response of the vegetation.

Field observations of the Lone Pine landfill were made by this analyst. Variations in vegetation type and density were noticed to exist in conjunction with areas of seepage. These anomalies are large enough to be detected on aerial photography, especially color-infrared photography. Unfortunately, the color-IR and the panchromatic photography were not scanned with sufficiently fine enough resolution to distinguish these features. It is highly likely that the photography will reveal these features.

Recommendations

The Vineland Chemical Company site provided an opportunity to evaluate a range of remotely sensed data for monitoring changes in the vegetation downstream from the site. Although the specific cause of the vegetation die back cannot at this time be linked to the movement of arsenic offsite into ground and surface water, conditions below the site did permit an evaluation of the imagery that was available for monitoring the changes that have taken place.

TM data, as a consequence of its relatively coarse spatial resolution (ie. 30 meters), could not be used to detect the band of dead and/or dying vegetation downstream from the site. Although SPOT data were not available for this site, the 20 meter spatial resolution of the multispectral mode imagery and 10 meter panchromatic mode imagery may permit the monitoring of site disturbances of this size. The planned inclusion of a 15 meter ground resolution panchromatic channel on the next Landsat satellite to be launched should improve the detection of smaller scale phenomenon.

The conversion of historic aerial photography to digital format appears to offer a number of very real advantages over conventional optical/manual interpretation of this data. As reviewed above, digital analysis allows the enhancement of the images to extract information that may not be readily apparent through visual inspection. In addition, the ability to perform an image to image registration of photographs at a variety of scales and subsequent geocorrection of these data sets to a desired coordinate system provides a powerful tool for reconstructing the history of such sites and developing cost effective monitoring programs. With the recent acquisition of an ERDAS upgrade of the image capture software and the purchase of a brighter illumination source for the Eikonix CCD camera, problems associated with our initial processing of such data have been greatly reduced. Research and development of techniques for both the conversion of photography into digital format and information extraction should be continued. Developing the ability to merge this information into the state's geographic information system should have a high priority.

The acquisition of remotely sensed data for the Vineland Chemical Company site using the Remote Sensing Center's Biovision IR video camera system demonstrated the utility of this technique for monitoring both existing hazardous waste sites and its potential for monitoring spill events in real time. The relatively low cost of the system (ie. $20,000) and its portability, mean that one or more systems could be available for monitoring spill events from a variety of platforms, including helicopters and light aircraft. With sufficient battery packs, a spill event could be monitored for several hours if necessary. The video tape record of such events might prove invaluable for monitoring the movements of materials in the environment, establishing the sequence of events taking place, monitoring clean up activities, and establishing legal liability. The ability to fly the camera system at a range of altitudes allows the capture of data with a wide range of spatial characteristics, providing both high resolution imagery as well as synoptic coverage of a site or spill event. Acquisition of one or more systems and the training of personnel for its operation should be strongly considered.

Conversion of the acquired video imagery into digital format as developed and demonstrated through this project permits the use of image processing techniques for information extraction. The presence of an ERDAS system within DEP should facilitate the transfer of this technology to the state. Future research and development of these techniques should be considered.

Remote sensing, especially aerial photography, has many potential uses in the analysis of landfills. Historic aerial photography has the capability of providing detailed synoptic information on the state of the landfill over the last forty to fifty years. Such information may well not be available from any other source.

If a landfill or spill monitoring program, that was to include the use of remote sensing, is developed, it should include some, if not all, of the following recommendations:

Identify and acquire all relevant historic aerial photography of the sites of interest, including the region of potential impact. Multiple copies[15] of the photography should be acquired. The copies would permit all concerned with the event to have access to good quality data to work with. Stereograms, which permit three dimensional viewing with a minimum of equipment, can be made from the additional

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[15] The exact number will probably be set by economic constraints, however, enough copies should be obtained to provide each potential researcher with a full set of prints and stereograms. The production of stereograms often requires more than one stereopair per stereogram, as irrevocable errors can occur during production.

copies. Stereograms would permit three dimensional viewing to take place under a variety of field conditions. If at all possible, the negatives should be acquired and safely stored, as additional copies can then be quickly and easily made. At the time of acquisition of the photography, all available information about the photography, and the mission that acquired it, should be obtained. This should include date, time, solar angles, exact type of film used, exposure information, exposure curve and other spectral properties, type of lens, filters used, the filter's properties, the contractual information for the mission, and any other information that may be available.

Scan the photography at the highest possible resolution[16]. The photography should be converted to a digital format, in order that the power of the computer can be used to process this tremendous amount of data. The exact resolution of the scan can vary, but it should not be less than what is needed to preserve photogrammetric standards[17]. Scans could be made at less than this standard, and significant decisions made on the basis of these data, but not meeting professional standards may cause problems if these decisions were challenged in court, or in any other review process.

Have topographic maps, with contour intervals on the order of one foot, made from the aerial photography. Landfills frequently have a tremendous impact on the hydrology of a region. Hydrologic investigations could be enhanced by the use of topographic maps, especially those made from photographs acquired prior to the

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[16] The Eikonix scanner requires multiple scans of a single photograph in order to derive the maximum amount of information from the photograph. A rotating drum scanner might accomplish this in a single scan, but the cost of this type of scanner is much higher.

[17] Information about photogrammetric standards is available from the American Society for Photogrammetry and Remote Sensing. Photogrammetric standards vary according to several variables, and a complete discussion of this subject is beyond the scope of this report.

initial event. Volume determinations could also then be made, with accuracy sufficient for most purposes. This would reduce the need for a field survey crew, which may have to be outfitted in expensive and cumbersome protective gear. If topographic maps are made, digital elevation models should also be made, in order that computer analysis can take place. Algorithms have been recently developed for use with three dimensional data. These programs provide valuable insights into surface and subsurface phenomena.

Have a soil survey performed on the aerial photographs, especially any photographs taken before the site became active[18]. Hydrologic studies could also be enhanced through an understanding of soil distribution and characteristics surrounding the event.

Attempt radiometric calibration[19] **of the scanned photography.** This is one of the most difficult of the suggestions to carry out. Radiometric calibration would be very beneficial in determining precise changes in vegetation, water, soils, and other earth surface features. Without calibration, change determination will be far more difficult to quantify.

Register the different dates of scanned and calibrated photography to the resolution of the largest scale photography and create multitemporal data sets. This will permit computer aided analysis to proceed in a simple fashion. Having the photographs at the same scale and in the same coordinate system permits simple

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[18] Historic soil surveys would be a means to accomplish this quite efficiently, especially if one exists for a period preceding initiation of the landfill.

[19] Radiometric calibration means mathematically transforming the digital values of each pixel in the multitemporal data set so that a feature that had the identical reflectance in each date of photography would have the same pixel value. This procedure requires a knowledge of the spectral properties of the film, the position of the sun, the amount of illumination that the target received at the time of the photography, and a host of other factors. It is a complex operation, but necessary if one is to draw accurate conclusions from these data.

change detection for any single point, as that rectified point can be recalled in seconds for any date of photography. If base maps of sufficient accuracy can be obtained, the rectified photography can be rectified to a standard coordinate system, such as Universal Transverse Mercator (UTM).

Produce photographic hardcopy of the scanned and registered photography. Photographic output permits carrying the data into the field. All dates of photography should be printed, and three date color combinations should be printed to the degree that budgets permit.

Through photographic processes, produce copies of the original photographs to the same scale as the scanned and registered hardcopy. By doing this, stereo pairs can be made of the photographically and digitally enlarged images. More precise analysis can be made of the event. The scanned and rectified photography will have much of the parallax removed during the rectification process. Therefore, scanned images of two overlapping air photos, when reproduced in hardcopy, will not provide the same stereo impression as they did before scanning. Using a photographically processed photo and a computer rectified photo will permit stereo viewing. Stereograms can be made from these pairs, and conveniently viewed with economical pocket stereoscopes at any time and at any place.

Analyze photographs for environmental impacts. Use stereo pairs and air photo interpretation techniques. Use computer classification algorithms to classify individual dates of photography[20], and use change detection GIS techniques.

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[20] If radiometric calibration is performed with sufficient accuracy, this step can be performed with a very small amount of human processing. If it is not, human analyst time will be greatly increased.

Identify areas of potential impact. Display data in a three dimensional mode whenever possible[21].

Acquire satellite data, such as TM or SPOT, of the region on a regular basis. Acquire the satellite data at the same time of year, preferably during the growing season. Satellite data are useful for their higher spectral resolution and regional view. They are one of the few remotely sensed data sources available for the growing season, as much aerial photography is acquired during leaf-off periods.

Acquire new photography on a regular basis. New photography would permit detailed study of changes that are taking place, effective monitoring of remediation schemes, and study of the continuing impacts of the event. New photography should not be panchromatic, and should not be acquired outside the growing season. The photography should be flown to as large a scale as is feasible. If only one type of photography can be flown it should be color-infrared. A two camera mission, with color and color-infrared photography would prove to be more useful than color infrared alone. The addition of a second camera and the extra film is frequently a very small portion of the total mission cost.

Acquire other types of remotely sensed data (video data, thermal scanners, airborne multispectral scanners, radar, etc.) whenever feasible. Increased spectral, spatial, and temporal resolution is frequently beneficial. Video permits real-time monitoring of a phenomenon. If unusual characteristics are noted, mission parameters may be adjusted while the aircraft is still on-site. Radar, especially ground based systems, has the ability to detect patterns associated with subsurface phe-

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[21] Recently developed software allows the user of a system, such as ERDAS, to display an image 'draped' over the terrain, if a digital terrain model exists. This allows a three dimensional display without the need for stereoscopes, colored or cross-polarized glasses, or similar devices. Also, this three dimensional capability permits quantifying the illumination component of the reflectance properties of a feature, thus enhancing classification accuracy.

nomenon. Thermal scanners would be especially useful in regions of suspected seeps, especially seeps of materials with unique thermal properties.

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Philipson, W. R., Barnaba, E. M., Ingram, A. and V. L. Williams. 1988. Landcover monitoring with SPOT for landfill investigations. Photogrammetric Engineering and Remote Sensing, 54(2): 223-228.

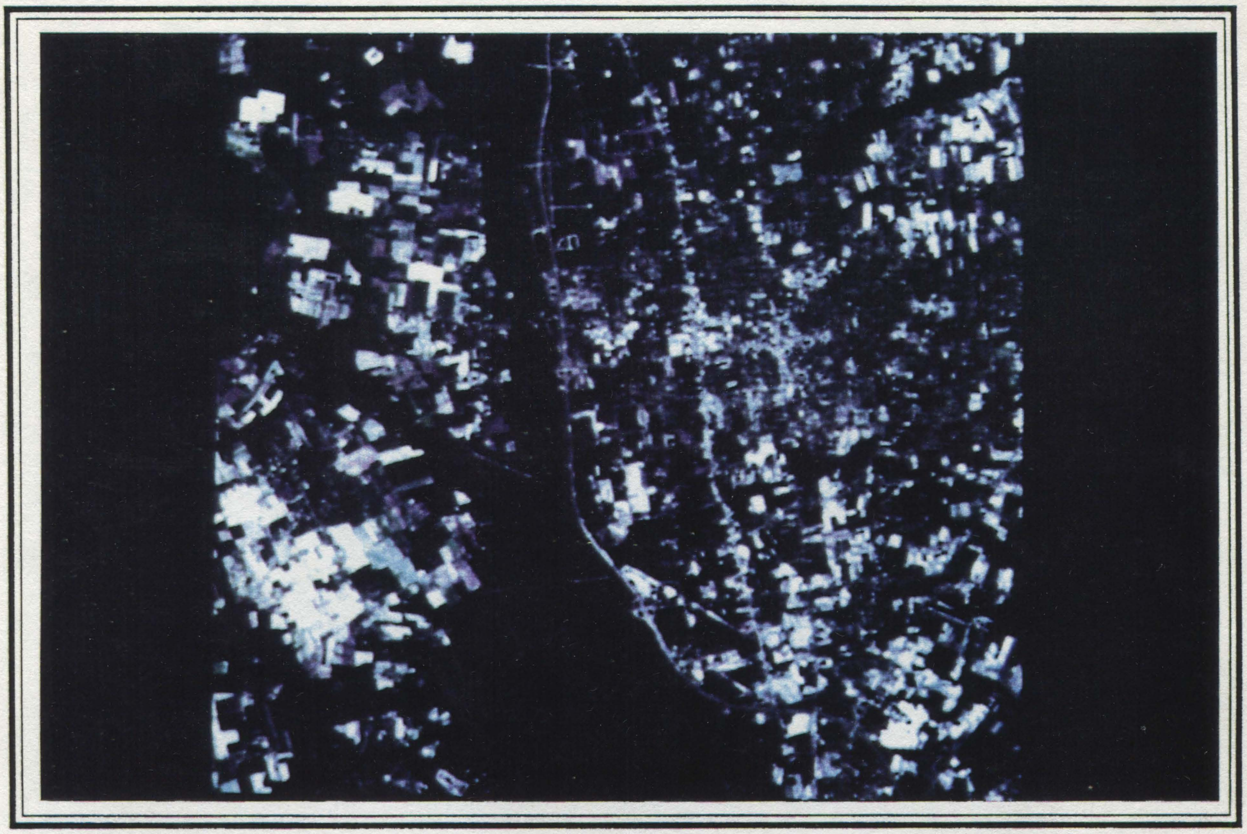

Figure III-1. Simulated color TM image of the area surrounding the Vineland Chemical Company site.

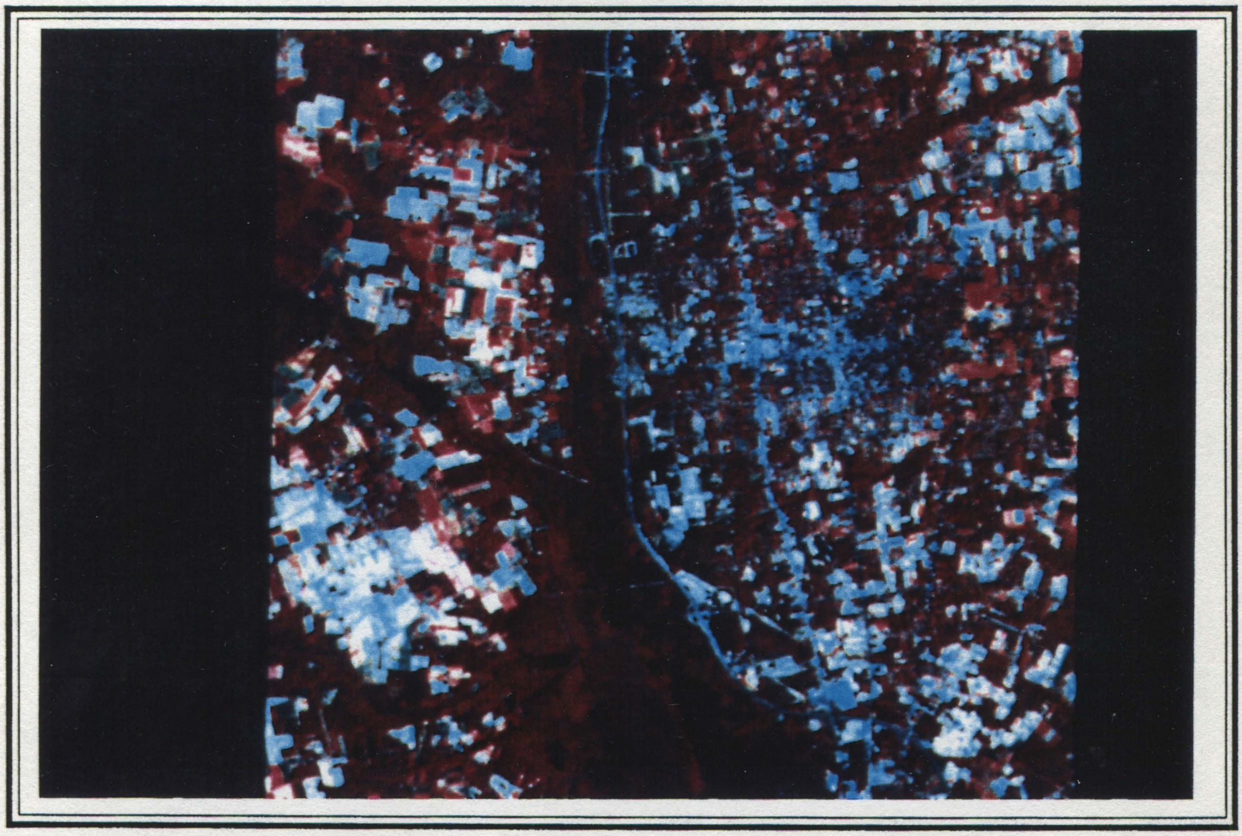

Figure III-2. Simulated color IR TM image of the area surrounding the Vineland Chemical Company site.

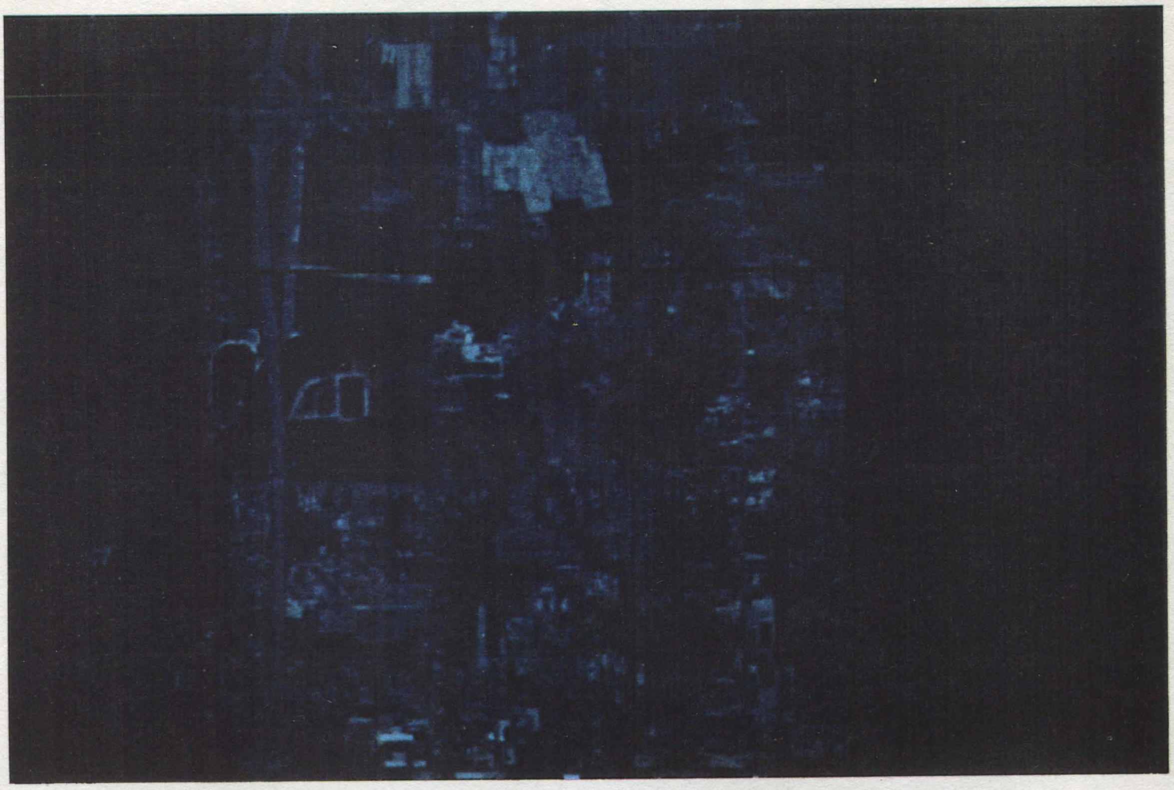

Figure III-3. Digitized color IR photograph of the Vineland Chemical Company site for 1986.

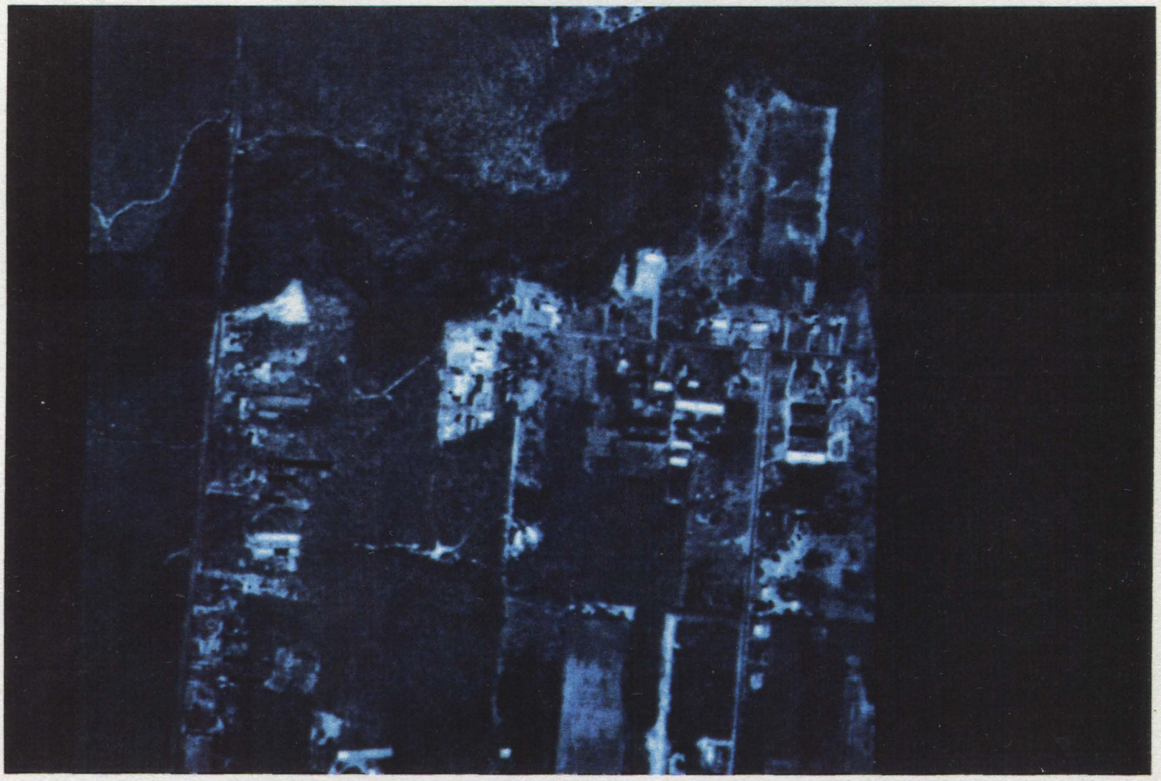

Figure III-4. Digitized black and white photograph of the Vineland Chemical Company site for 1962.

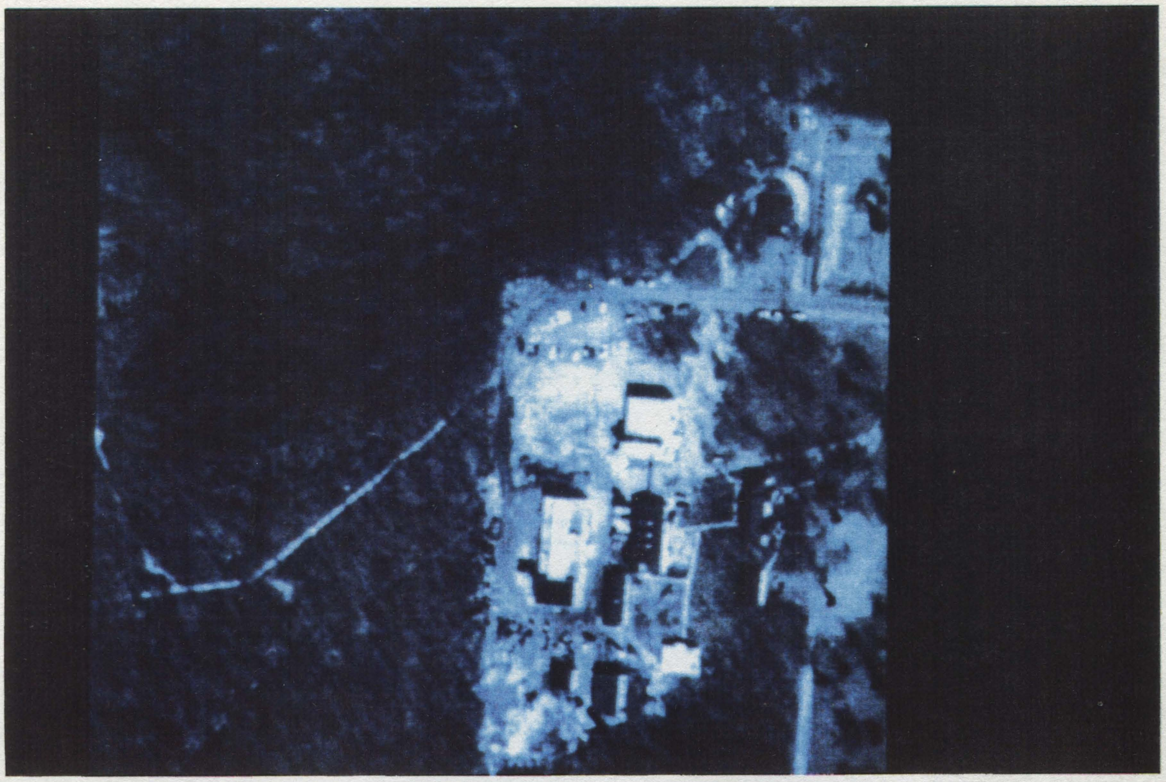

Figure III-5. Digitized subset of the 1962 black and white IR photograph of the Vineland Chemical Company site.

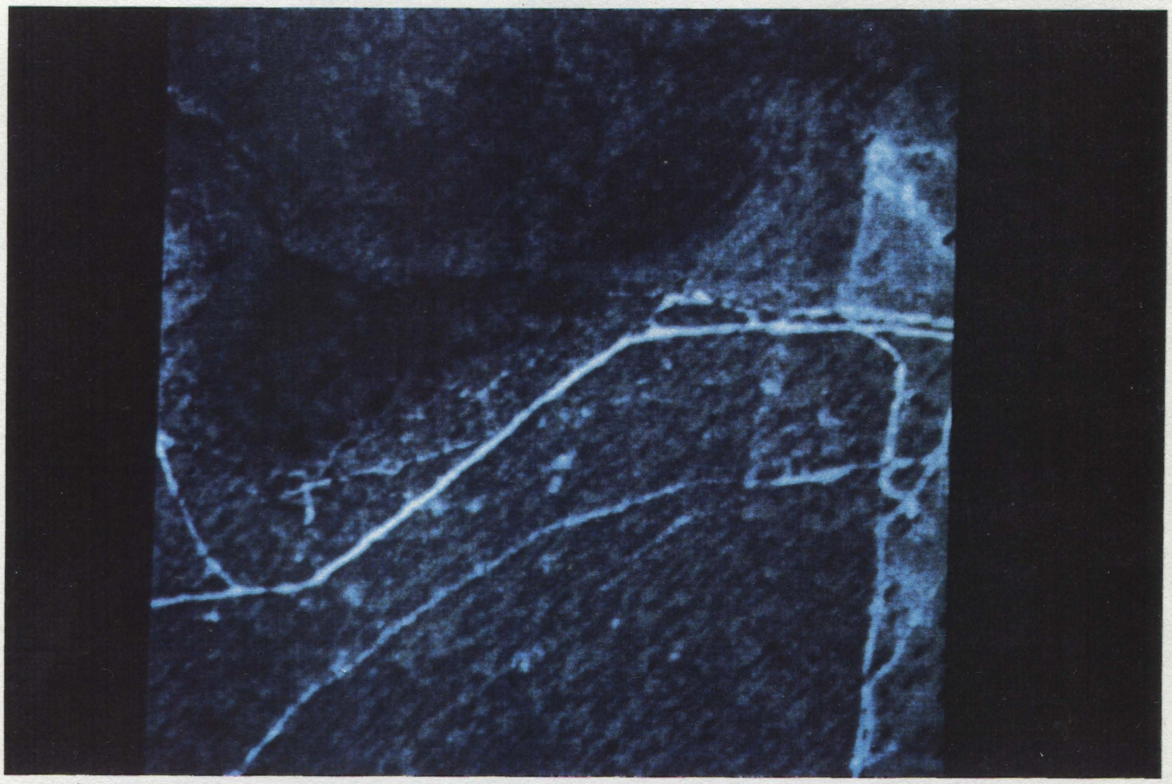

Figure III-6. Digitized subset of the 1951 black and white IR photograph of the Vineland Chemical Company site.

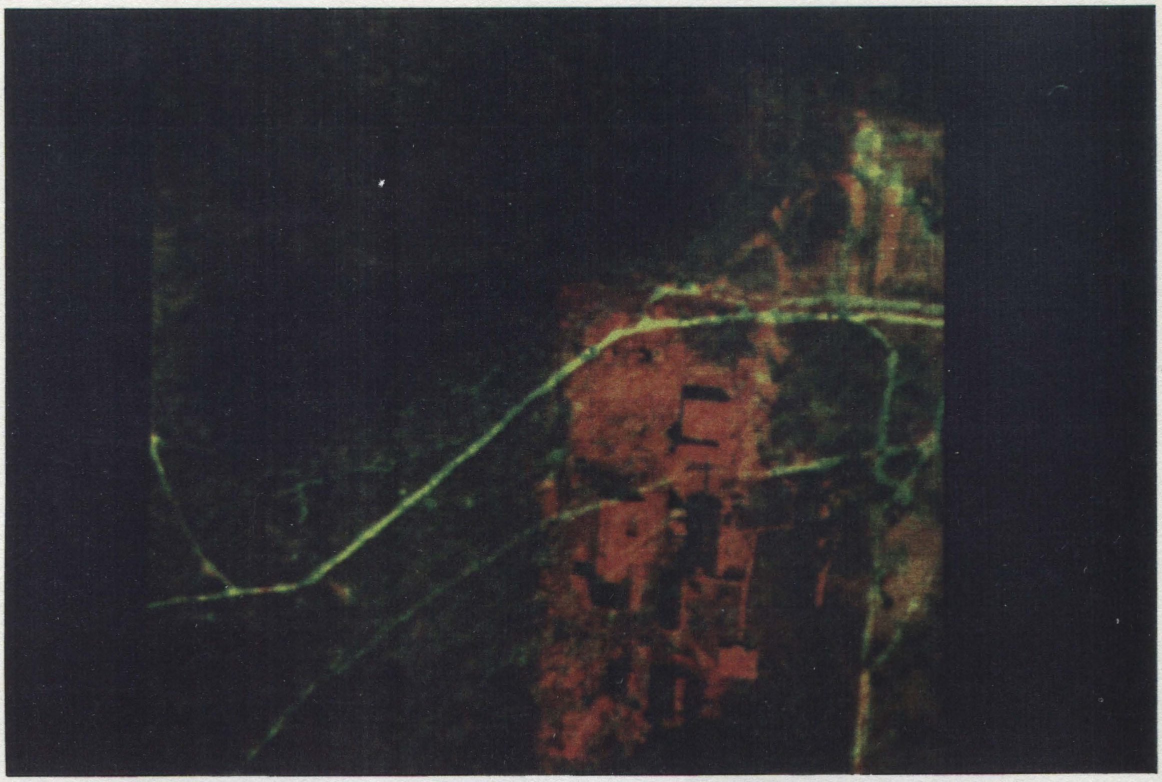

Figure III-7. Simultaneous display of the 1951 (green color plane) and 1962 (red color plane) black and white IR photography of the Vineland Chemical Company site.

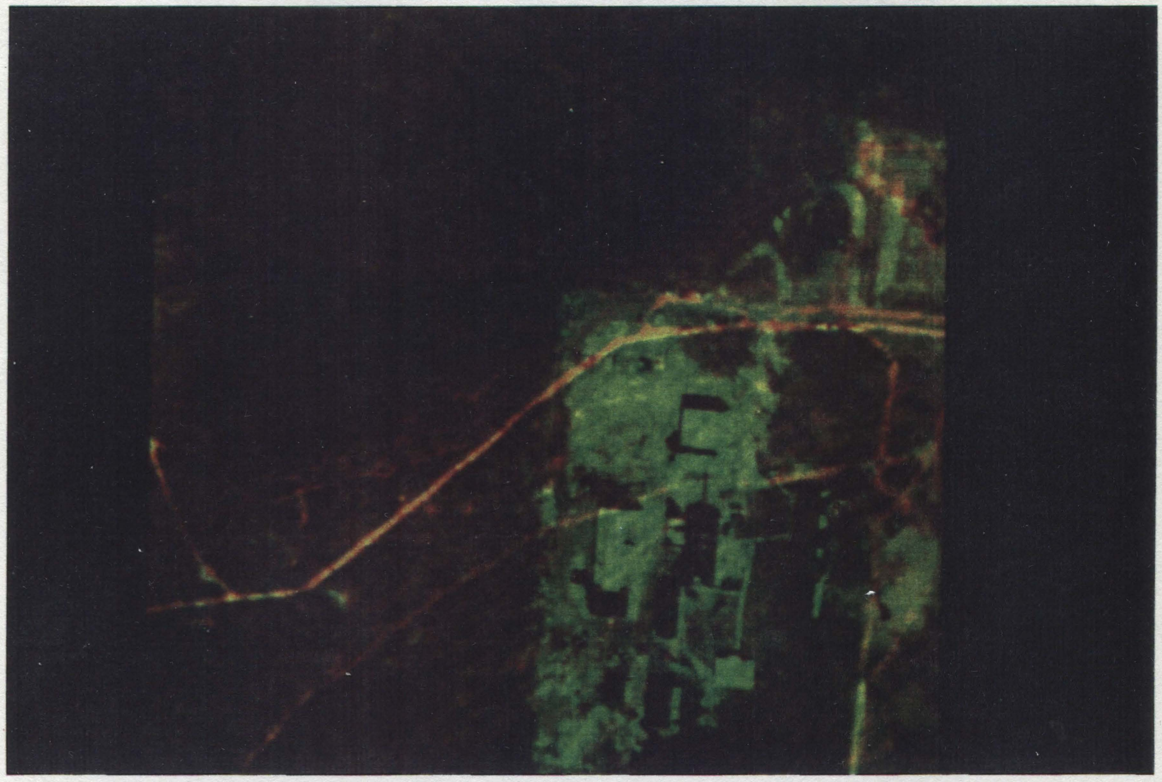

Figure III-8. Simultaneous display of the 1951 (red color plane) and the 1962 (green color plane) black and white IR photography of the Vineland Chemical Company site.

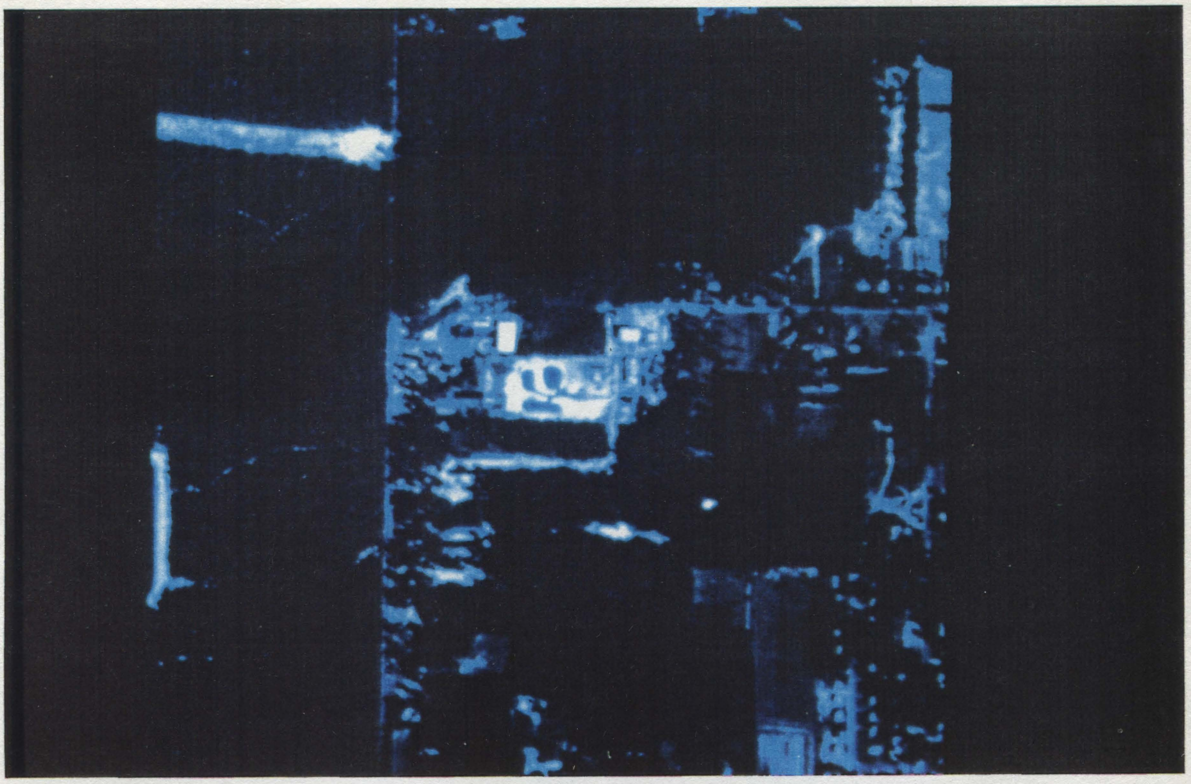

Figure III-9. Digitized color IR photograph of the area surrounding the Vineland Chemical Company site in 1977.

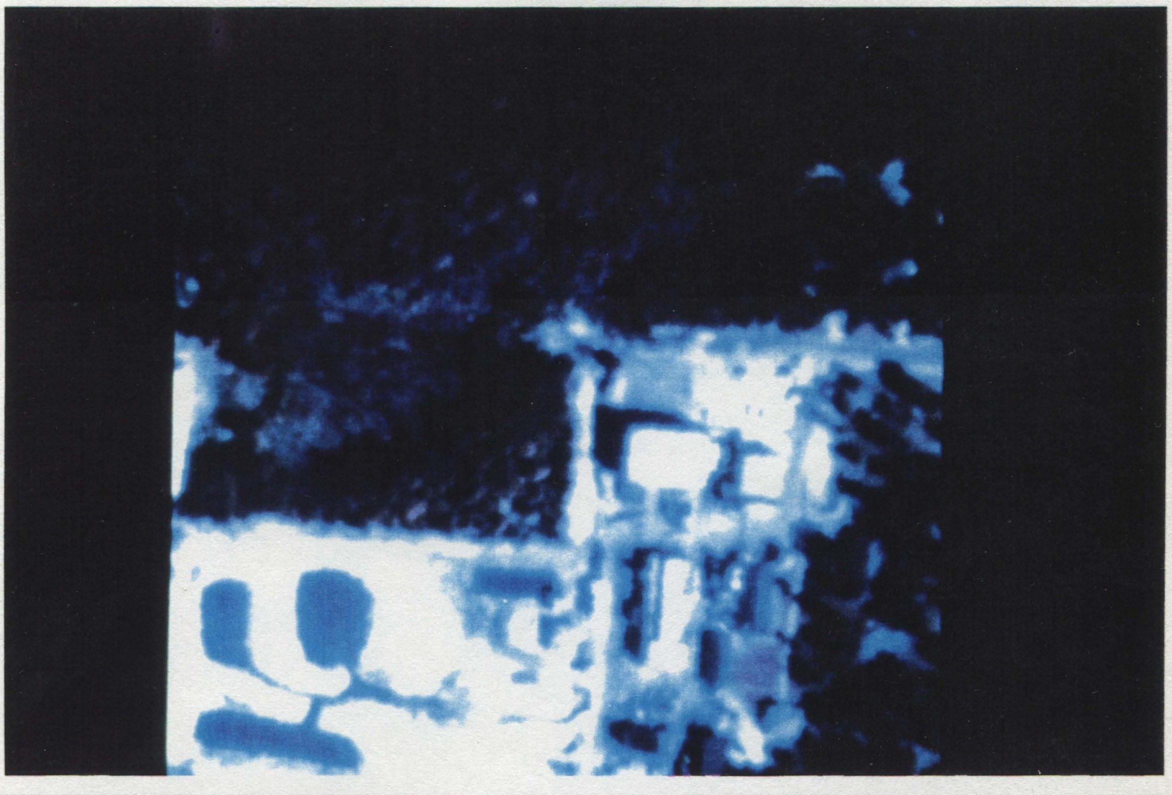

Figure III-10. Subset of the 1977 digitized color IR photgraph of the Vineland Chemical Company site.

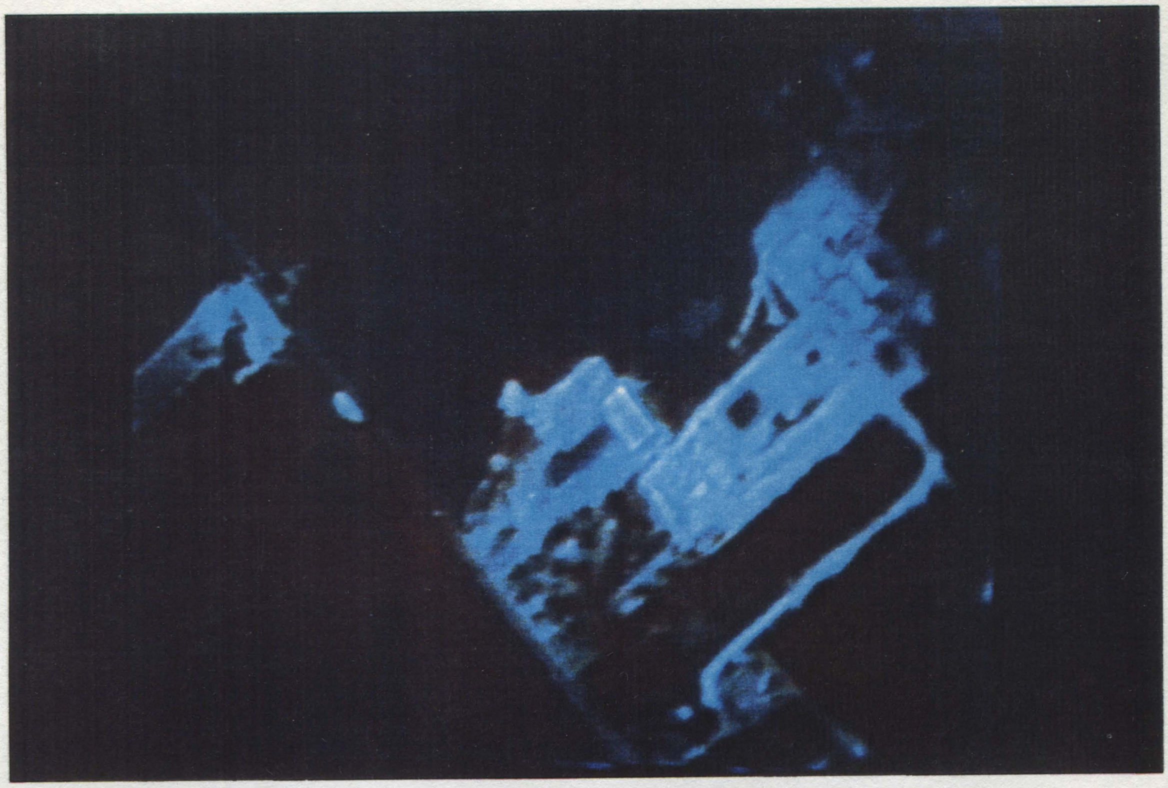

Figure III-11. Color IR video frame of the Vineland Chemical Company site acquired at 3000 feet.

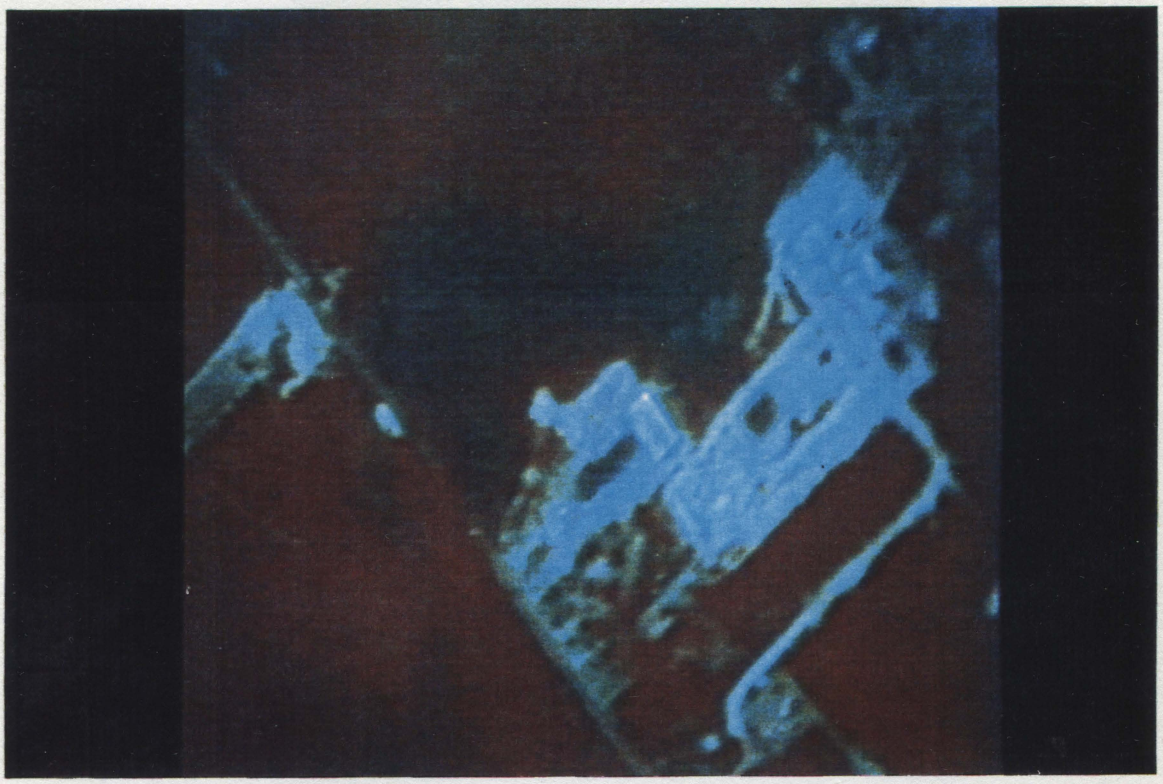

Figure III-12. Enhanced color IR video frame of the Vineland Chemical Company site acquired at 3000 feet.

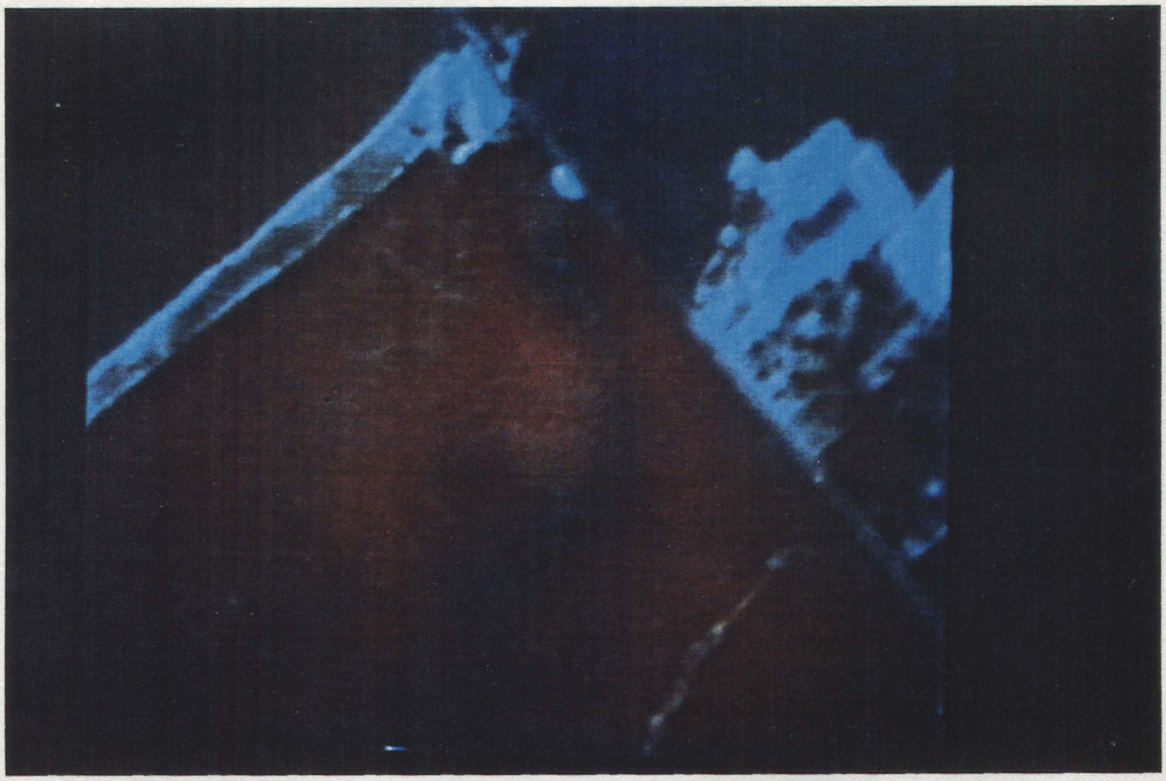

Figure III-13. Color IRvideo frame downstream from the Vineland Chemical Company site acquired at 3000 feet.

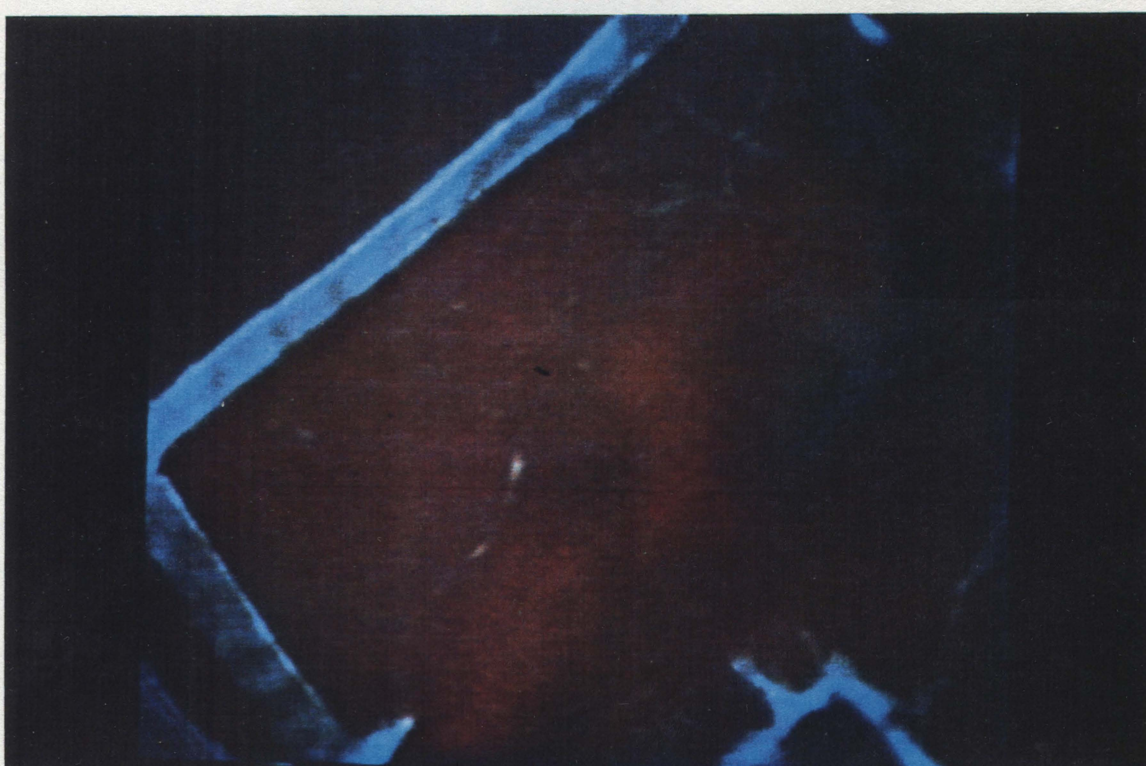

Figure III-14. Color IR video from downstream from the Vineland Chemical Company site acquired at 3000 feet.

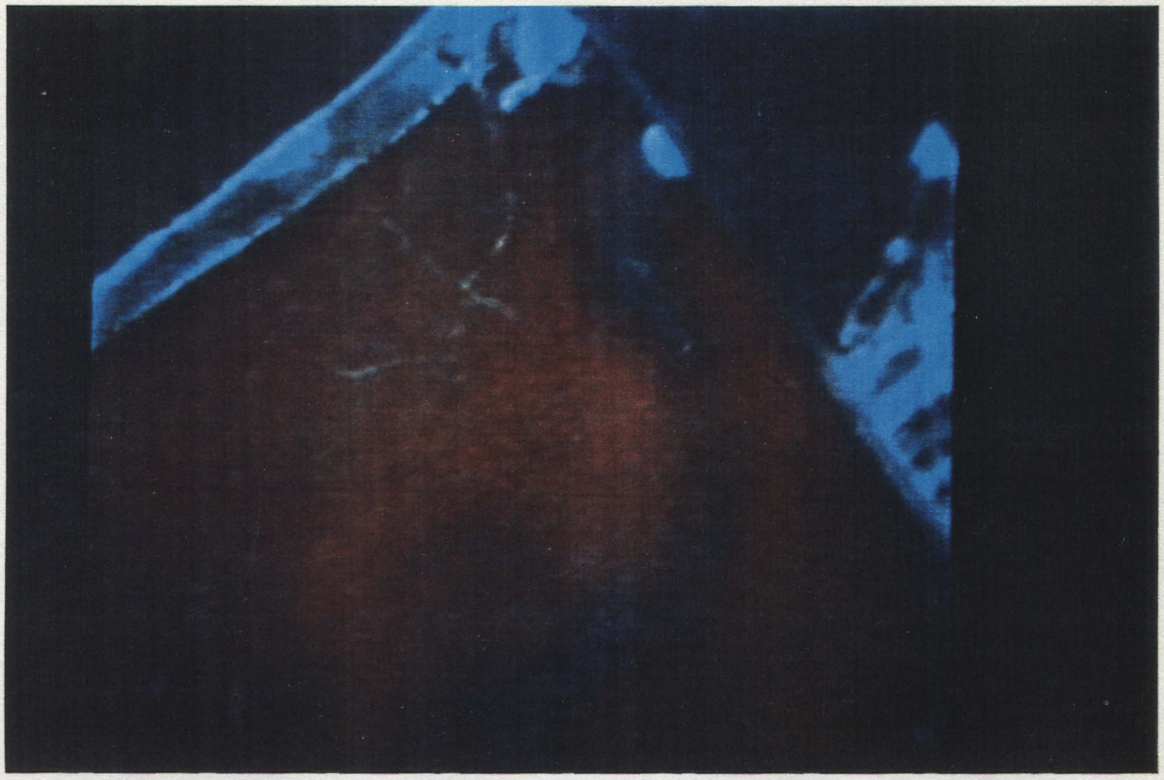

Figure III-15. Color IR video frame downstream from the Vineland Chemical Company site acquired at 2000 feet.

Figure III-16. Color IR video frame downstream from the Vineland Company site acquired at 1000 feet

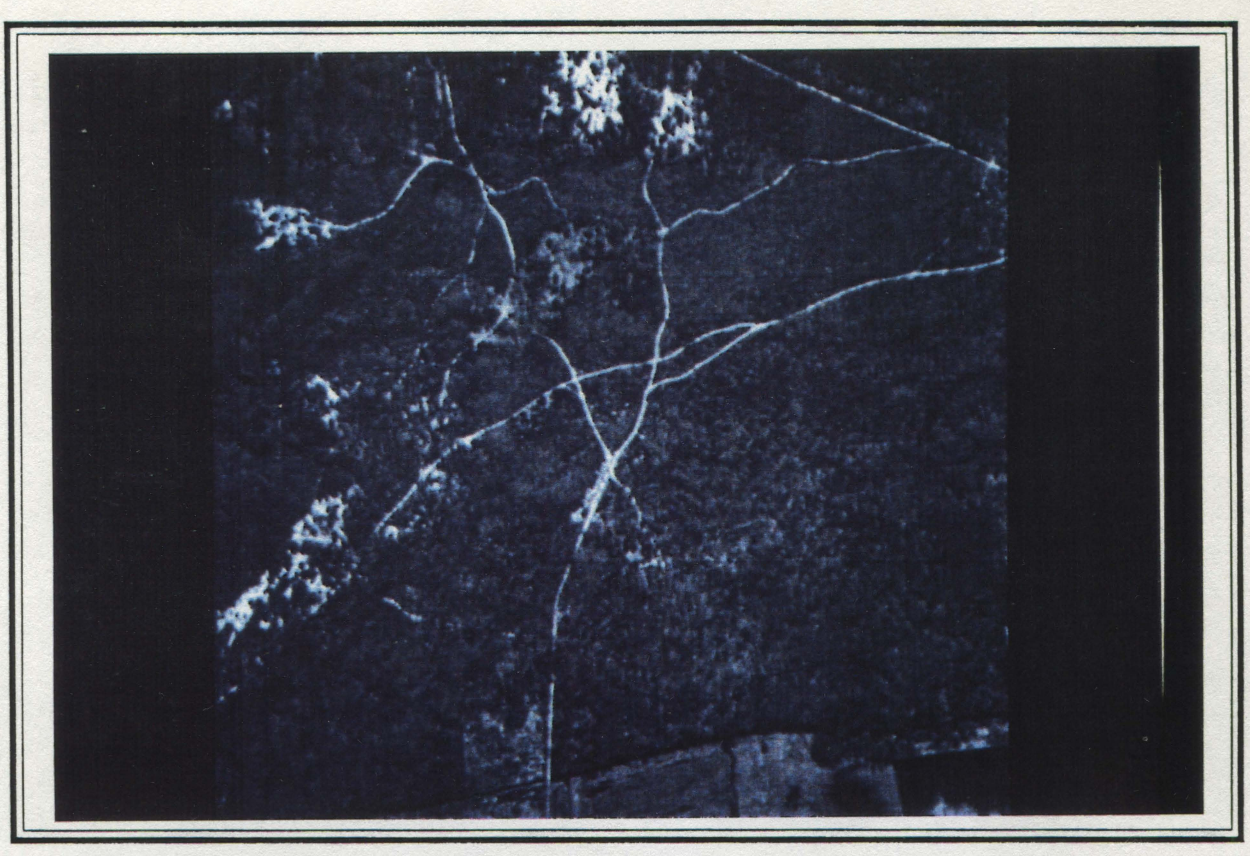

Figure III-17. Scanned Aerial photograph of Lone Pine Landfill, 10 April 1940.

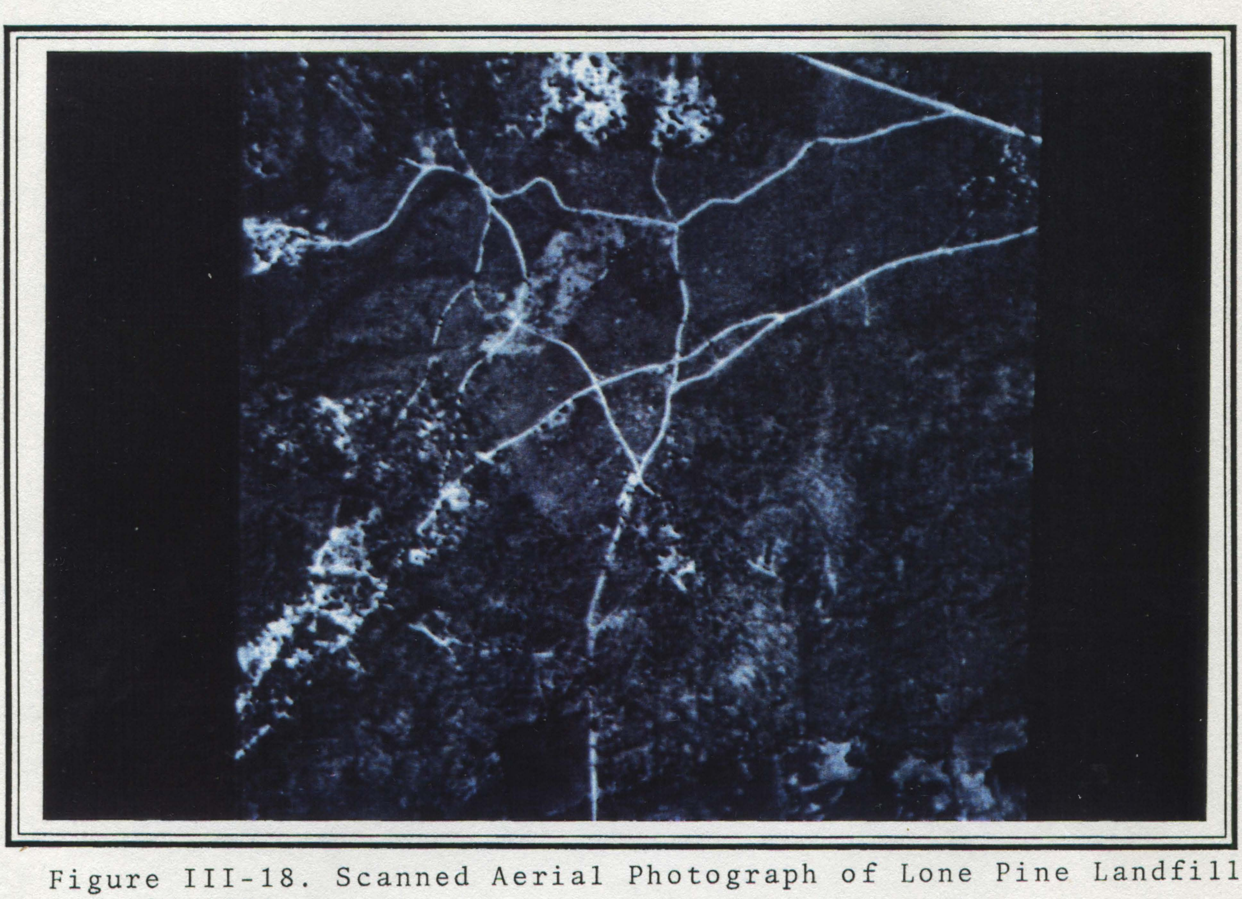

Figure III-18. Scanned Aerial Photograph of Lone Pine Landfill, 6 April 1951.

Figure III-19. Scanned Aerial Photograph of Lone Pine Landfill, 13 January 1962.

NON-THERMAL POLLUTANT PLUMES IN WATER

J. Wasrud, E. Cary, and M. H. Morse

Introduction

This chapter of the report presents work done on detecting and identifying pollutant plumes in water. Plumes were identified on the basis of their morphology. Plumes are comprised of three parts: a point from which the plume starts; a zone of spreading (diffusion) away from that point; and a tail section or area at which the plume is no longer distinguishable from the surrounding water.

Three areas in the State of New Jersey were examined using remotely sensed data. They were western Raritan Bay, the Toms River and Seaside Heights area of Barnegat Bay, and the coastline in the vicinity of Atlantic City. The areas were chosen on the basis of *a priori* information on the likelihood of detectable plumes in these regions. The techniques developed here are also applicable for regions that lack prior information on the presence of plumes.

Data Description

Three types of remotely sensed data were used in this study. They were: SPOT multispectral digital data, LANDSAT Thematic Mapper (TM) digital data, and scanned aerial photography.

SPOT multispectral data encompass the green, red, and near-infrared portions of the spectrum and have a spatial resolution of approximately 20 meters. The near-infrared band contains very little information about plumes in water, but is very useful for discriminating water from land. This is due to the low reflectance of water in the infrared portion of the spectrum. The images used for this project were collected by the SPOT satellite on 8 July 1986.

The TM data used for this part of the study were a subset of the total TM data set. TM data are available for seven bands, which span the blue through thermal infrared portions of the spectrum. As the mid- and far-infrared portions of the spectrum are not useful for analysis of water plumes, TM bands 5, 6, and 7 were not used in this portion of the study. TM band 4, the near-infrared band, was used only for land/water discrimination. The TM data set used was acquired by LANDSAT on 22 August 1985.

An aerial photograph, encompassing the western part of Raritan Bay, was obtained for this study. The photograph was scanned, using an Eikonix scanner and the ERDAS program CAPTURE, to create a 512 x 512 three band data set. This data set was then used for analysis.

Methodology and Results

The methods used in the analysis of the selected plumes evolved over the course of this study. Some areas had unique problems that required more intensive processing, others were analyzed with minimal analyst effort. The general methodology was:

Identify an area of likely plumes. This was accomplished through discussion at project meetings, through analysis of maps, and through analysis of small scale imagery.

Obtain appropriate data. TM data were available for the entire state. SPOT data were available for coastal New Jersey from Barnegat Bay to Raritan Bay. An aerial photograph of western Raritan Bay was also acquired. Areas of high plume potential were then subset from the larger data set.

Create a land mask. Using supervised classification techniques, the image was classified on the basis of the infrared response. The resulting GIS file was used as a mask to remove the non-water portions of the image. This reduced processing time and made viewing the image easier. The masked image contained only the visible bands, as the infrared band contains little information on the nature of plumes in water.

Enhance the image of the plume(s). Contrast stretching, ratios, and other statistical or mathematical functions were applied to the data set in order to enhance the appearance of the plumes. Several different methodologies were used, depending on the nature of the plume and the remotely sensed data.

Classify the water features. This was done through supervised and/or unsupervised techniques. The classification parameters were adjusted through experimentation until optimum results were obtained.

Analyze classified image. Attempt to determine the source and contents of the plume and identify critical areas of potential impact.

Although the procedure was essentially the same for each site, some variation did occur in the exact procedure. Therefore, the methodology used for the analysis of each site is described in some detail.

Raritan Bay

Raritan Bay was the only region that was examined through the use of all three data sources (SPOT, TM, and scanned aerial photography). As Raritan Bay was the first region selected for analysis, the methodology for the other regions evolved from the work performed on these data. Analysis focused on the western portion of the bay, as there were several potential plumes in this region.

The first data set to be examined was the SPOT data set. A 512 x 512 subset was taken from the SPOT image (see figure IV-1). Several plumes were identified in the raw data set. These plumes were located near South Amboy, near Perth Amboy, at the mouths of Cheesequake Creek and the Raritan River, and in the southern portion of Arthur Kill.

Several classifications were performed on the SPOT data, after the data were masked. The first classification used was a supervised classification, based on training samples taken from "clear" water and from the plumes. The training samples were based upon the analyst's decisions about the spectral properties of the feature. Many similar features, such as plumes, have similar spectral properties. Therefore, it is to be expected that some plumes, that are in different locations, will be classified as the same spectral class. Therefore, further human analysis is needed to determine the composition and source of the plume if a plume-like feature is classified. Figure IV-2 shows the results of the supervised classification of the SPOT data. Several plumes can be observed, and it should be noted that some plumes, and portions of plumes, have been classified as members of the same class.

Several unsupervised classifications were also performed on the SPOT data. The ERDAS program CLUSTR was used in conjunction with methodologies developed by Ackelson, et al. The unsupervised classification results deemed most satisfactory by the analyst are presented in Figure IV-6. The data were rotated ninety degrees before classification to reduce the effect of along-track striping on the classification results. Plumes, similar to those classified in the supervised classification process, are visible in this figure.

The scanned aerial photography is presented in Figure IV-3. The photograph (Photo ID # JSS-RC-815) was a color-infrared photograph, from a Mark Hurd mission on 23 March, 1986. A plume can be observed in the Raritan River.

Ground surveys were performed in this region by M. Morse, in an attempt to determine the origin of the plumes found in the imagery. Ground surveys were difficult to perform, due to the lack of public access to the shores of Raritan Bay. It was not possible to examine every potential source of the plumes, but the candidates deemed most likely to be the source of the plume were examined.

The region of the South Amboy plume was the first to be surveyed. Three sites were identified as being probable sources of the plume. The first was an electric power generating plant. However, it was found to be far from the location of the plume observed in the imagery, and it is unlikely that the generating station is discharging large amounts of particulates. The second potential source of the plume was the Middlesex County Sewage Pumping Station. However, the New Jersey Pollution Discharge Elimination System (NJPDES) data show that the station was not operating at the time of the satellite overpass. The third potential source of the plume was a sand and gravel yard that accepts dredge spoil from Raritan Bay ship channel dredging operations. The dredge spoil is transported by barge to the doc at the yard, where it is pumped to storage piles by a wet slurry system. No sediment or water retention structures were observed to exist in the yard, and piles of sand that had spilled into the bay were noted. It is highly likely that this yard was the source of the plume, as:

1) The location of the yard, relative to the plume observed in the image, is close enough to suspect the yard as the origin of the plume.

2) The yard has no obvious sediment retention structures in place.

3) No other potential plume source was found.

The region of the plume located near south-eastern Perth Amboy was also examined. The only logical source of a plume is an upwelling that was observed near the Perth Amboy Sewage Treatment Plant. This upwelling had a distinctive color and odor. The regions of the remaining plumes (Cheesequake and Matawan Creek) were also examined. No positive source of the plumes was identified.

Toms River - Seaside Heights

The Toms River - Seaside Heights region of Barnegat Bay was selected for a number of reasons, including: the Ciba-Geigy outfall is located in this vicinity, land use changes from intensively developed to nearly natural in a relatively short distance, and the DEP has expressed interest in Barnegat Bay. A 512 x 512 TM image was selected for analysis (see figure IV-5).

Land masking proved to be quite difficult, as this data set had a variety of water features associated with it. The final masking classification results had to be filtered to prevent canals, streams, and other small water bodies from remaining in the image. After masking and filtering, the image was then classified through unsupervised techniques and analyzed.

The unsupervised classification reveals a plume about 400 meters off Seaside Heights. The origin of the plume could not be determined.

Atlantic City

A 504 x 1017 subset of the TM data set was used to study Atlantic City and the surrounding regions (Figure IV-7). Because of the larger size, several masks were created in addition to the land mask in order to reduce computer processing time. The additional masks were used to eliminate areas of clear water from the image. The image was then classified by an unsupervised, twenty-seven class classification.

The classification results show a large plume emanating from the Atlantic City inlet (Figure IV-8). This plume is likely to be natural in origin. No plumes that could be attributed directly to pollution were noted in the image. However, analysis of the inlet plume does have an important lesson for analysis of pollutant plumes. The plume returns to shore some distance from its discharge point, where it can have an impact on the beach.

Conclusions and Recommendations

Pollutant and natural plumes were successfully found, enhanced, and analyzed in all of the imagery used in this part of the study. The procedures developed here could be used in a system of monitoring pollutant plumes in water on a regular basis. If a such a system is developed, the State of New Jersey may want to:

Acquire remotely sensed data on a regular basis. TM data are cheaper, on a per acre basis, then SPOT or aerial photography. At current prices, complete coverage of the state is available for approximately $7000. TM data also have spectral resolution that is more appropriate for monitoring water-borne plumes than does SPOT or aerial photography. Therefore, acquisition of TM data is recommended.

Locate known and unknown plumes in the remotely sensed data. By implementing the methods developed here on a larger computer, a map of all water plumes present in the imagery could be created. This could be a valuable resource for monitoring programs and for locating previously unknown discharges.

Develop a near real-time monitoring program. Discovering that a plume existed months or years prior to analysis is probably of limited value to the DEP. If spill events could be monitored through on-demand remotely sensed data, or if regular coastal overflights were made with a real-time sensor system, the resulting data would be much more valuable than historic data. Video systems are available that are economical when compared to multispectral scanners. If a color-infrared video camera is used in conjunction with a standard color video camera, imagery could be acquired rapidly and monitoring could be performed in real-time. This could be especially valuable to the DEP in the case of a spill event, or in the appearance of pollution from an unknown source.

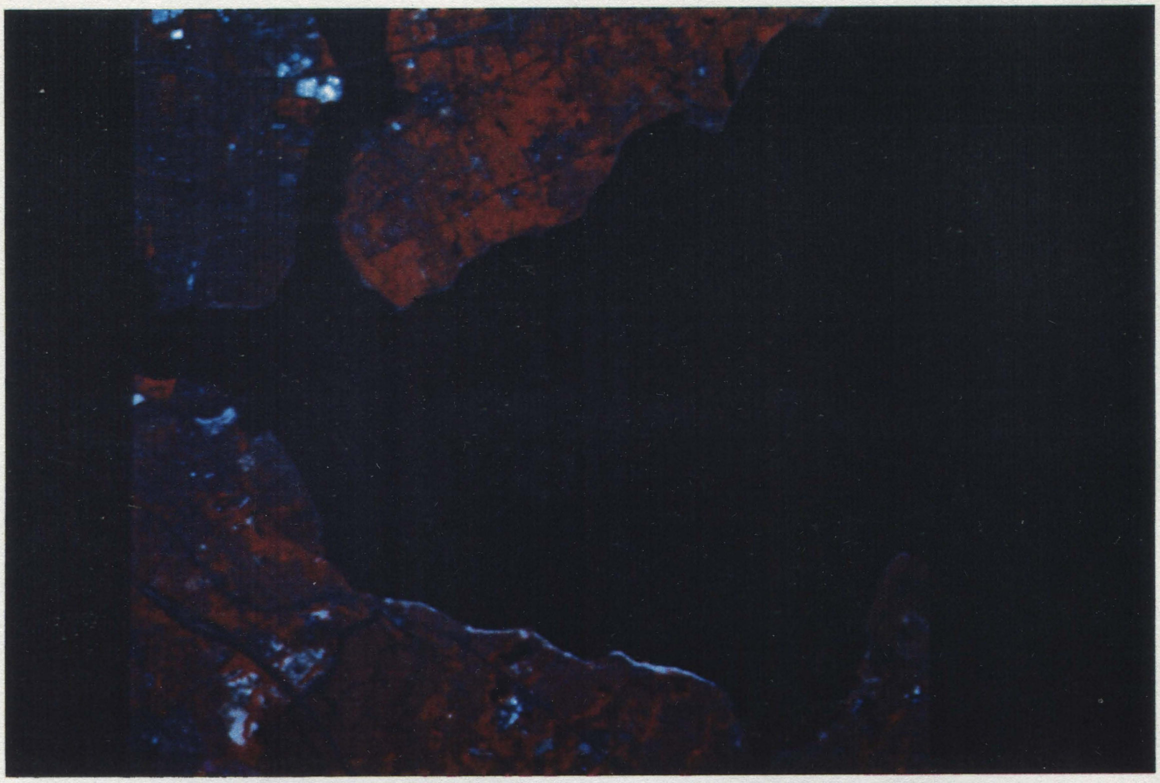

Figure IV-1. SPOT image of Western Raritan Bay.

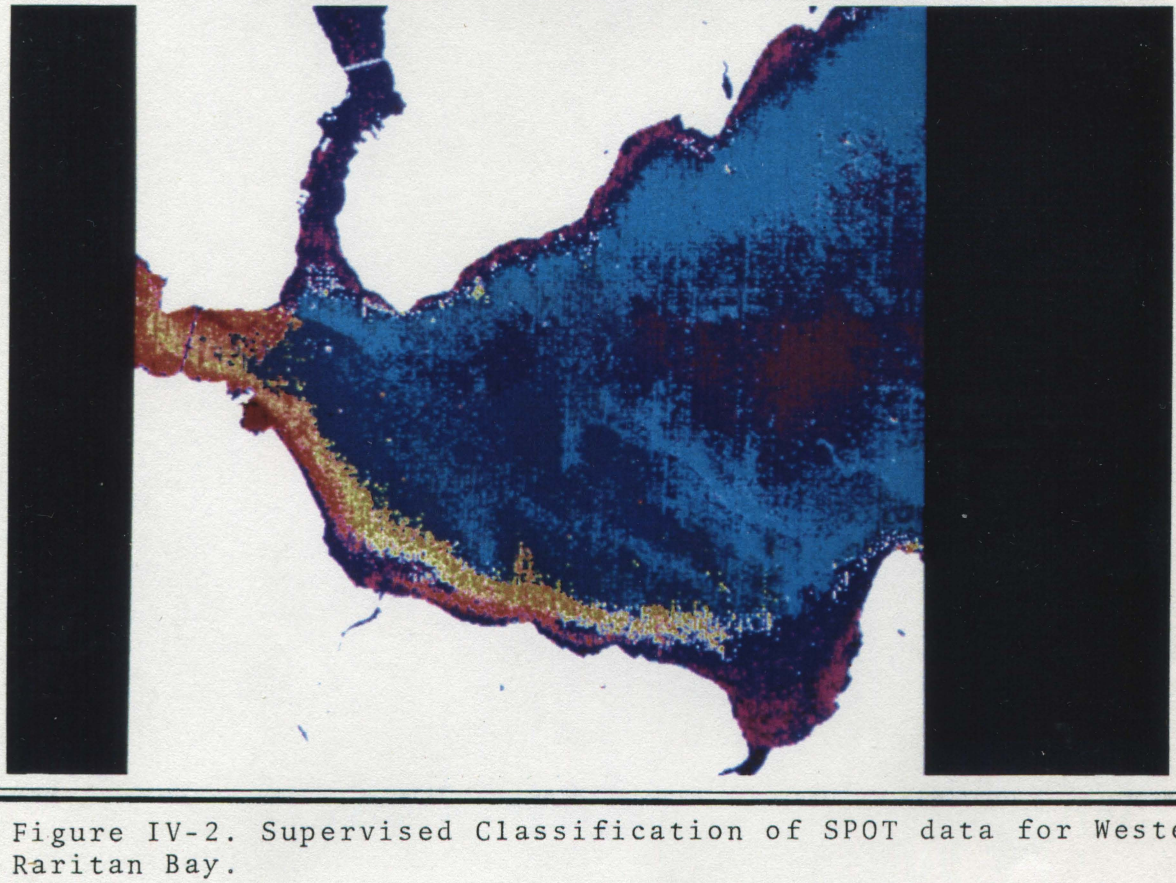

Figure IV-2. Supervised Classification of SPOT data for Western Raritan Bay.

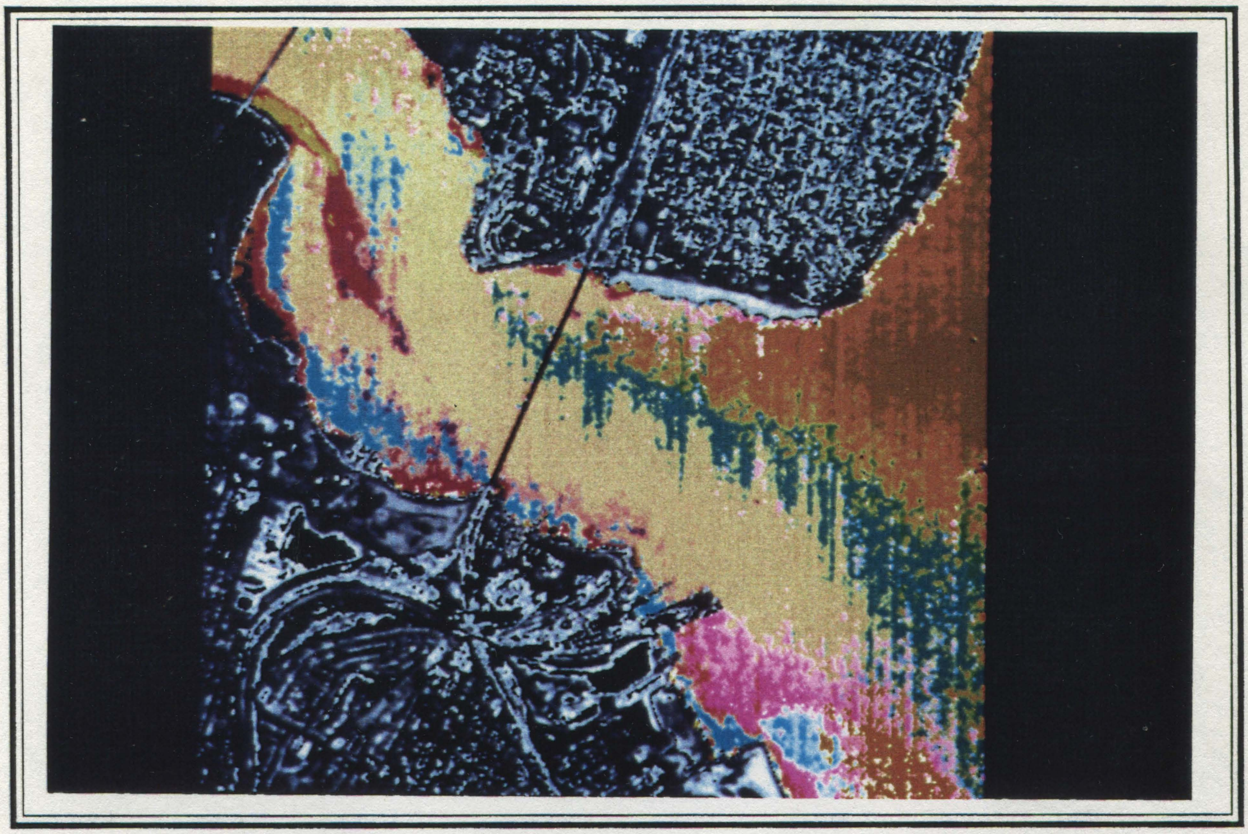

Figure IV-3. Scanned Aerial Photography of Western Raritan Bay.

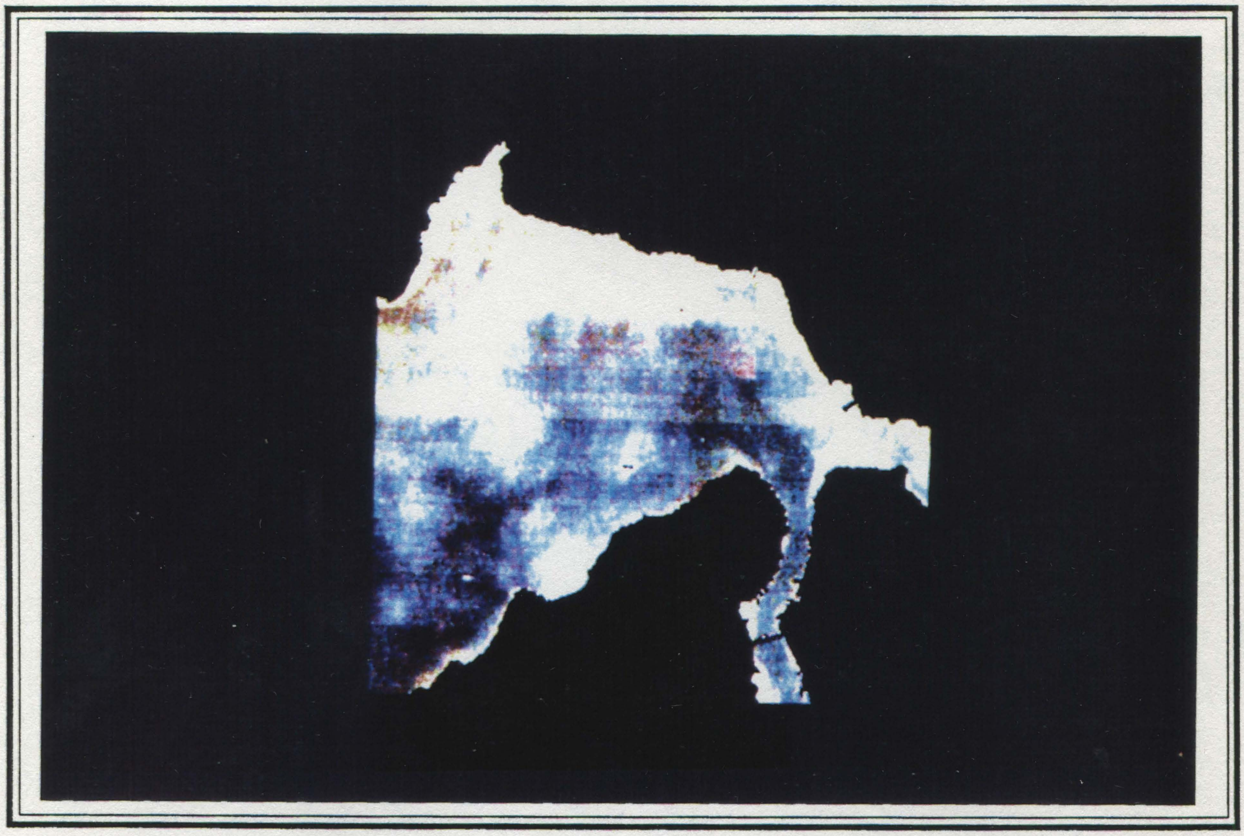

Figure IV-4. Enhanced TM Bands 1,2, and 3 Image of Raritan Bay.

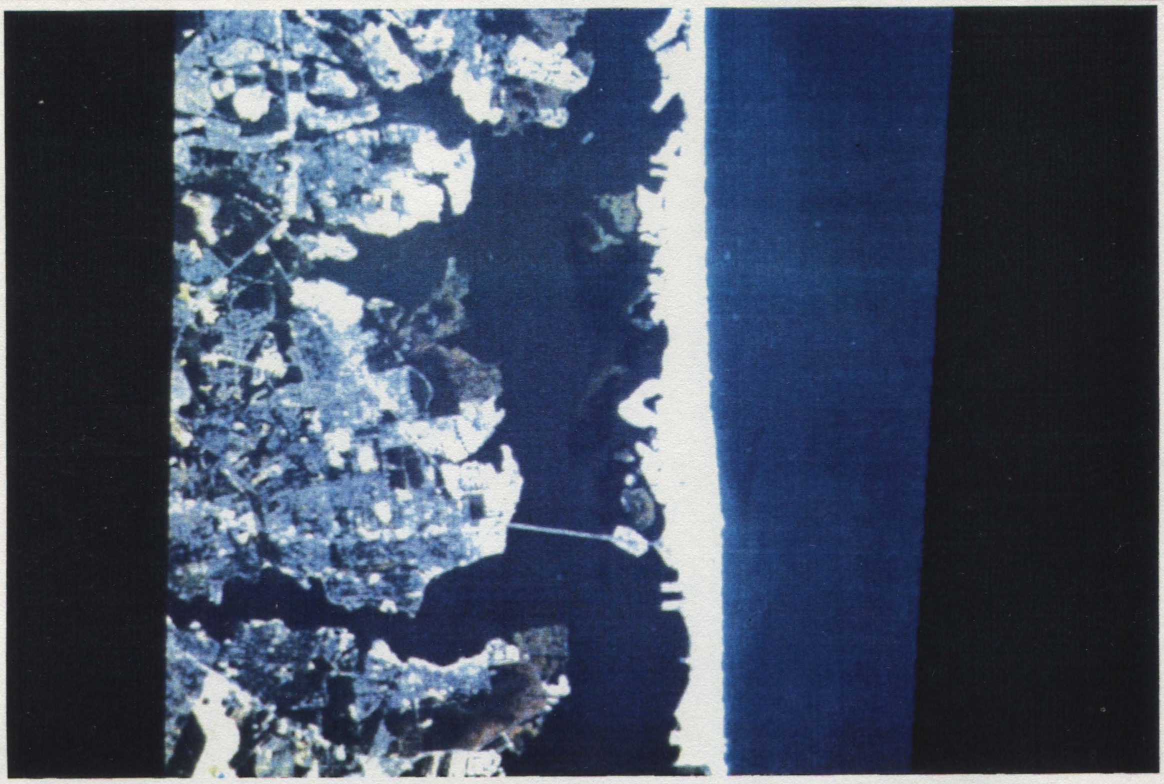

Figure IV-5. TM Band 1,2, and 3 image of Toms River - Seaside Heights.

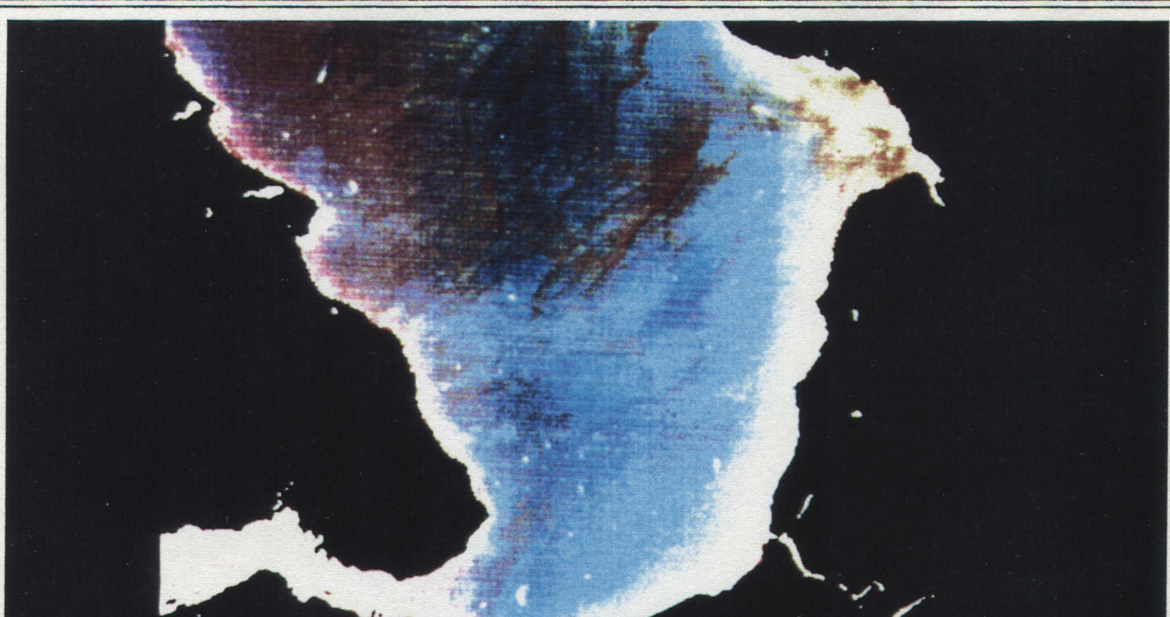

Figure IV-6. Unsupervised Classification Results of SPOT data. SPOT data were rotated ninety degrees prior to classification.

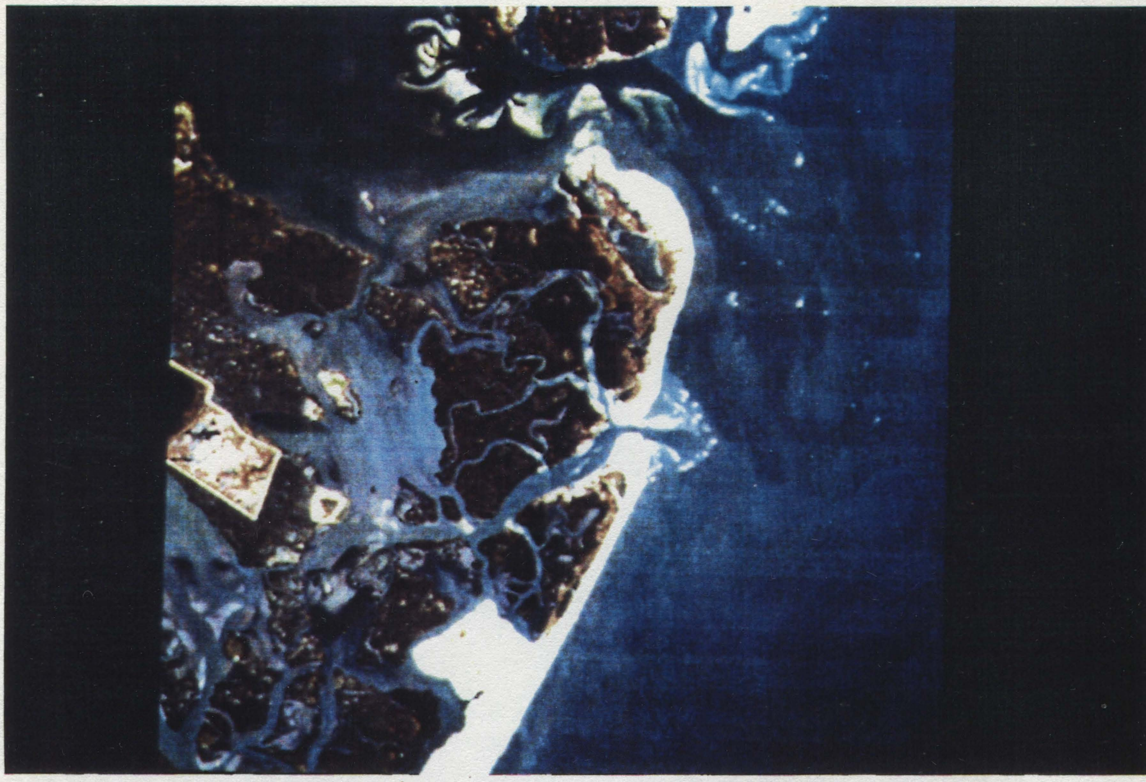

Figure IV-7a. Enhanced TM image of Atlantic City (northern portion).

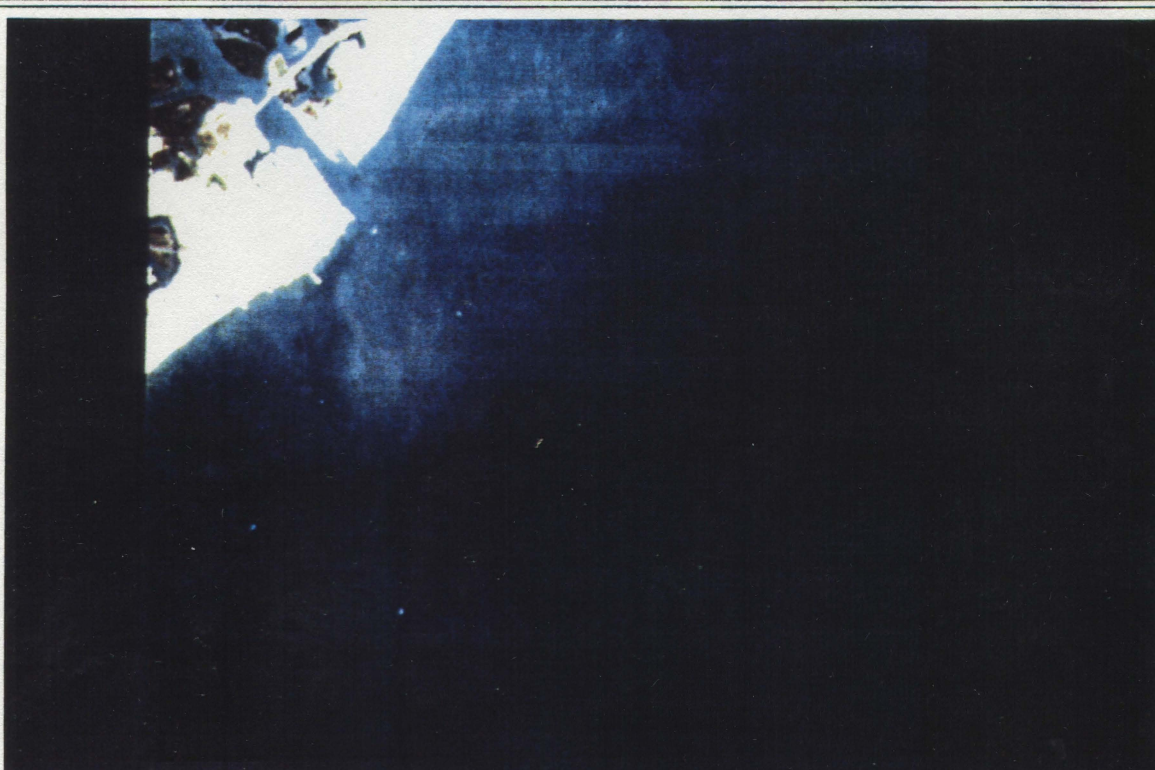

Figure IV-7b. Enhanced TM image of Atlantic City (northern portion).

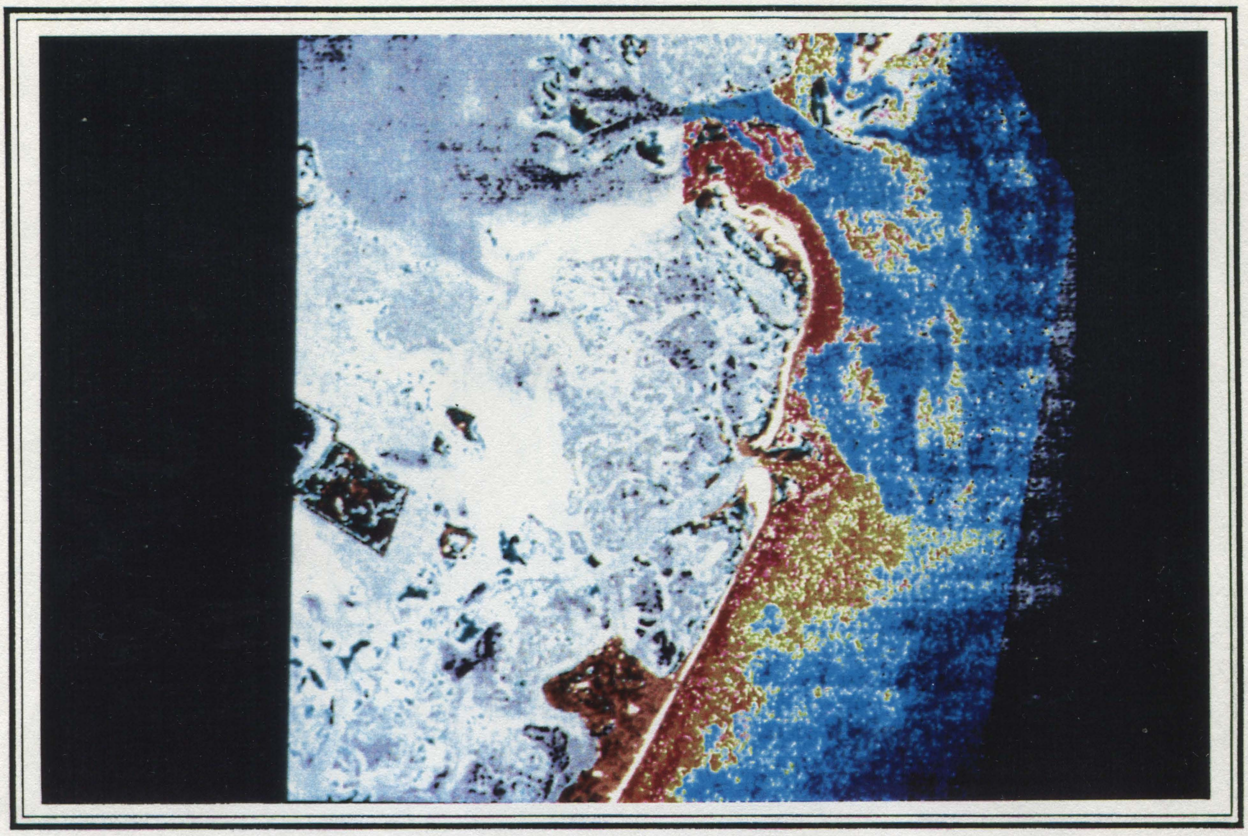

Figure IV-8a. Classification Results for TM image of Atlantic City (northern portion).

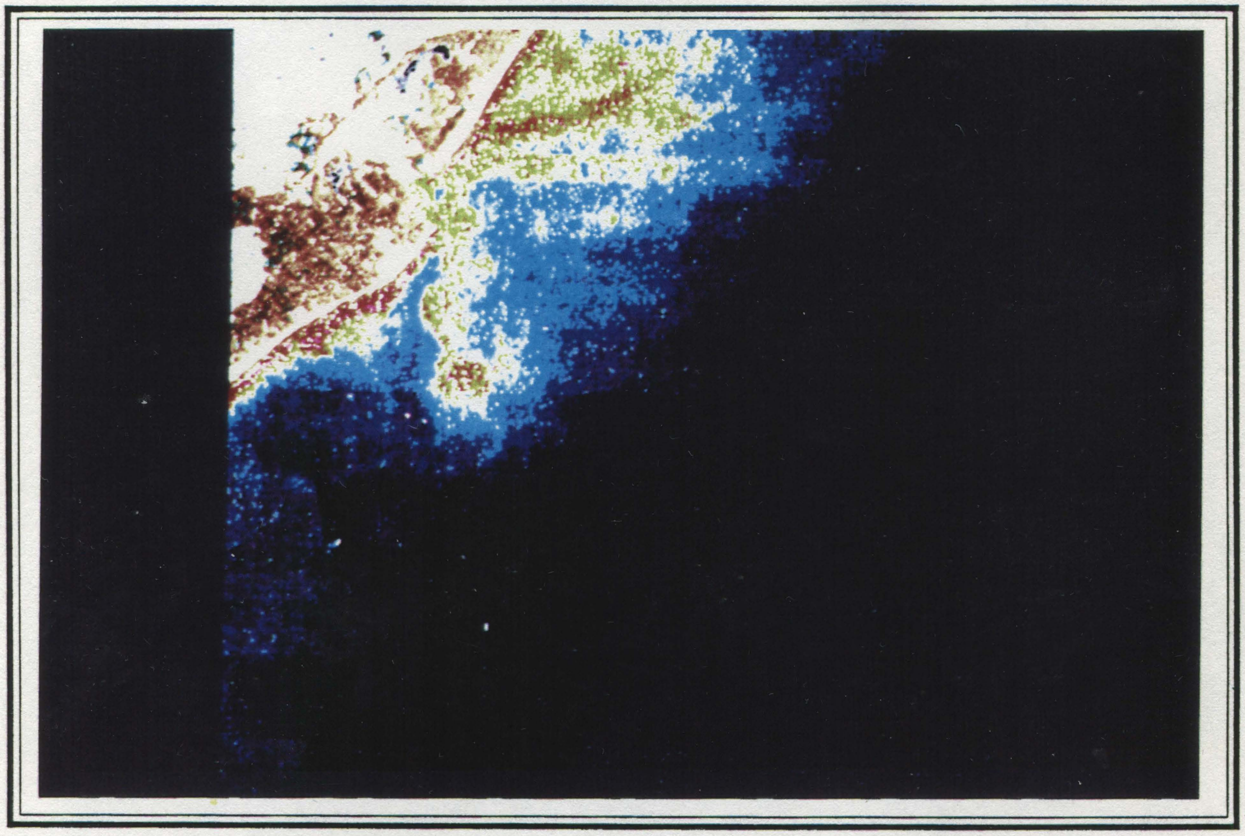

Figure IV-8b. Classification Results for TM image of Atlantic City (northern portion).

THERMAL PLUMES

E. Cary, J. Wasrud, T. M. Airola, and M. Morse

Introduction

One of the objectives of this component of the project was to evaluate remote sensing technology for detection and tracking of plumes, including the discharge of heated waste water into receiving water bodies. The same principles and techniques would be applicable to the detection and tracking of plumes that are substantially cooler than the temperature of the water body.

In the remainder of this chapter, the theoretical background is briefly discussed and relevant literature reviewed. Study sites will be located, data sources identified, and procedures specified. Results will be illustrated and discussed. The final section provides several recommendations.

Theoretical background

The temperature one measures by direct contact is the *kinetic* temperature. Temperature measured at a satellite is the *radiant* temperature, also called the brightness temperature. These two temperatures are related to each other as follows:

$$T_{rad} = e^{1/4}\, T_{kin} \qquad (1)$$

where

T_{rad} = radiant temperature (Kelvin)

e = emissivity

T_{kin} = kinetic temperature (Kelvin)

Emissivity can vary with wavelength, target material, and viewing geometry. For water, emissivity can be treated as a constant over all wavelengths (i.e., water is a graybody). For satellite platforms, viewing geometry can be considered vertical and constant (within one scene). Therefore, emissivity for a uniform water target is a constant, and kinetic temperature can be calculated from measurements of radiant temperature.

In practical applications, complications arise because of the presence of the atmosphere between the target and the sensor, the atmosphere is not necessarily uniform, and because emissivity is not always known.

Literature Review

Buettner and Kern (1965) discuss the emissivities of several materials, including pure water (.993), water with a thin film of petroleum oil (.972), and water with a thin film of corn oil (.966). As shown in Equation 1 above, radiant or brightness temperature is related to kinetic temperature by the fourth root of the emissivity of the target. For emissivity of .966, the fourth root is .991; for emissivity of .993, the fourth root is .998. Using one radiant temperature, these differences in emissivity would lead to differences of 2.1 degrees in calculated values of kinetic temperature.

The work of Bartolucci, Swain, and Wu (1976) on the use of a layered classifier in mapping water temperature was a forerunner of the approach used in this work. In their study, as in ours, a water class is first separated from non-water cover types by spectral classification, and then the water class is analyzed.

Leckie (1982) analyzed sources and magnitudes of errors when thermal infrared scanner data are used to determine surface temperature. For a general survey, he found emissivity errors and atmospheric errors more important than system and calibration errors[1].

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[1] In our study the goal is not a general survey, and assuming the emissivity of water to be a constant would probably not be the major source of error it is for the general survey.

Schott and Volchok (1985) found that the Thematic Mapper's Band 6 sensor gain has shifted since the launch of Landsat 5. The shift is to such an extent that predicted temperatures (in the absence of ground truth) would be significantly in error.

Tracey and Lawrence (1986) reported a study of power generating stations in Florida. Thematic Mapper data gave surface temperatures four degrees C less than the temperatures measured by an airborne thermal imaging system. When they used radiosonde data to calculate atmospheric attenuation, and incorporated that in calculating temperature from the satellite data, the satellite-based measurements were less than one degree C different from the airborne-based measurements.

Study Areas

Study areas for thermal plumes were selected by reference to the New Jersey Pollutant Discharge Elimination System. Power plants (SIC = 4911) listed as active and major were selected. Nineteen power plants met these two criteria. Two of those power plants (in Holland Township) could not be located in the data. The Thematic Mapper data for the region surrounding the 17 power plants to be studied were initially subset into nine data sets of 512 lines x 512 columns; these are the nine data sets for which color plates are included in the Results section below. To fit all of the results onto one floppy disk, subsets of size 256 lines x 250 columns were created, resulting in 11 data sets. Table V-1 shows the eleven data sets, and which power plants are in each data set.

Data Set	NPID	Name	Location	Receiving Body	Topographic Sheet
Rfield	0000621	PSE&G Bergen G.S.	Ridgefield Boro	Hackensack R.	Weehawken
Jerseyc	0000639	PSE&G G.S.	Newark	Passaic R.	Jersey City
	0000647	PSE&G Hudson G.S.	Jersey City	Hackensack R.	
	0000655	Kearny G. S.	Kearny	Hackensack R.	
Linden	0000663	PSE&G Linden G.S.	Linden	Piles Cr.	Arthur Kill (NY)
Woodbrdg	0000680	PSE&G	Woodbridge Twp.	Arthur Kill	Arthur Kill (NY)
Ssa	0002747	Sayreville G.S.	Sayreville	Raritan R.	South Amboy
	0002755	E.H. Werner G.S.	South Amboy	Raritan R.	
Hamilton	0004995	Mercer G.S.	Hamilton Twp.	Delaware R.	Trenton East
Burlngtn	0005002	PSE&G	Burlington	Delaware R.	Beverly (PA) and Bristol
Pennsvil	0005363	Atlantic Electric	Pennsville	Delaware R.	Delaware City (DE)
Gegg	0005444	Atlantic Electric	Upper Twp.	Great Egg Harbor	Marmora and
	0005461	Atlantic Electric	Upper Twp.	Great Egg Harbor	Ocean City
Friver	0005550	Oyster Cr. Nuclear	Forked River	Oyster Cr.	Forked River
	0031097	Forked River Site	Forked River	Oyster Cr.	
Salem	0005622	PSE&G Salem G.S.	Lower Alloways Cr.	Delaware R.	Taylors Bridge (DE)
	0025411	PSE&G Hope Creek G.S.	Lower Alloways Cr.	Delaware R.	

Table V-1. Power generating stations chosen for this study. The data set name is the name of the Erdas .GIS and .TRL files provided on floppy disk as part of this final report. NPID is the identifier in the New Jersey Pollutant Discharge Elimination System.

Data

Since the focus of this part of the project was thermal plumes, the data source was Thematic Mapper (TM) band 6 (TM6). TM6 collects information in a part of the thermal infrared portion of the spectrum, i.e., 10.4 to 12.5 micrometers, and has a spatial resolution of 120 meters. The particular data set used was collected 22 August 1985, and covers all of New Jersey.

Topographic maps in the U.S.G.S. 7.5 minute series (scale 1:24,000) were used for determining the locations of generating stations. Table V-1 also identifies the quadrangles associated with each data set.

Tide tables were consulted and compared with the data.

Procedures

Analysis was performed through the use of Erdas software, Versions 7.2 and 7.3. Throughout this discussion, the names of the Erdas routines will be in all capital letters.

The first step was to use SUBSET for selecting the data that contained generating stations and selecting band 4 and band 6 from the full data set. Since band 4 and band 6 were needed as separate files, SUBSET[2] was run twice for each of the study sites. Band 4, in the middle infrared part of the spectrum (0.76-0.90 micrometers), was used to differentiate between land and water. A supervised approach with two to four training classes (FIELD) was used. MAXCLAS, when run on a small area (512 x 512 for example) with four training classes and only one band, runs very fast. The resultant .GIS file was used in MASK with the TM6 data

[2] SUBSET is very time-consuming. CPYSCR is much faster, and can be used if: (1) no more than three bands of data are needed and (2) the data set needed is no larger than the screen resolution (generally 512 x 512).

file to produce a new .LAN file which has zeros for the land areas and band 6 data values for water areas.

Initial processing of the data involved experimenting with color assignments using LSLICE on the .LAN files. A more successful approach was to copy the .LAN file to a .GIS file, run FIXHED, run BSTATS, and then use PALETTE to assign colors to digital numbers (DNs). Working with the data in this way, one learns the range of digital numbers occurring in the water, and the values which occur in plumes. For TM6 on 22 August 1985 over New Jersey, water had digital numbers from 124 through 146. A single color scheme was developed for use on all sites, ranging from blue through green and yellow to red as DNs progressed from low to high. The keyboard option of COLORMOD was used to create this color scheme, and then the trailer files were updated. Table V-2 lists the color scheme, specifying the intensity of red, green, and blue assigned to each digital number.

Calculations were done to relate DNs to spectral radiances, then to effective at-satellite temperatures, and then to kinetic temperatures. However, due to the difficulties outlined in the sections on Theoretical Background and Literature Review, these values are subject to unknown amounts of error, and can be taken as rough indicators only. The relationship of spectral radiance to DN is as follows:

$$L = Lmin + ((Lmax - Lmin)/DNmax)\ DN \qquad (2)$$

where, for TM6 on Landsat-5,

L = spectral radiance in $mW \cdot cm^{-2} \cdot ster^{-1} \cdot um^{-1}$

Lmin = 0.1238

Lmax = 1.5600

DNmax = 255

DN = digital number

DN	Red	Green	Blue
0-123	0	0	0
124	0	0	100
125	0	0	100
126	0	0	100
127	0	0	150
128	0	0	200
129	0	0	225
130	0	0	255
131	0	100	0
132	0	150	0
133	0	200	0
134	0	225	0
135	0	255	0
136	100	100	0
137	150	150	0
138	200	200	0
139	225	225	0
140	255	255	0
141	100	0	0
142	150	0	0
143	200	0	0
144	225	0	0
145	255	0	0
146	200	200	200
147-255	0	0	0

Table V-2. Color scheme used on all study areas in color plates.

The relationship of effective at-satellite temperature to spectral radiance is as follows:

$$T = K2 \; / \; \ln \left((K1 \; / \; L) + 1 \right) \qquad (3)$$

where, for TM6 on Landsat-5,

T = effective at-satellite temperature in Kelvin

K2 = 1260.56 K1 = 60.776

L = spectral radiance from Equation 2 above

Kinetic temperatures were calculated twice using Equation 1 above, once using .993 for emissivity and once using .966 (see Table V-3). T from Equation 3 was taken to be T_{rad}. This assumes the atmosphere does not attenuate the signal, an assumption which may result in temperatures four degrees C too cold (see Tracey and Lawrence (1986)).

Results[3]

PSE&G Bergen G.S. (Figure V-1)

The initial plume emanating from the power station appears to be flowing downstream. This point on the river should be nearing low water[4], with the incoming front moving up from Newark Bay. There are several hot spots downstream from the plant, as well as upstream. The upstream hot spots could be from the previous evenings incoming tide which carried heated effluent north, or from other facilities along the river. The effect of upstream movement on the Overpeck Creek appears to be limited by the Route 95 bridge/overpass. The water east of the bridge is about 6° C cooler than the water on the western side.

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[3] The results and the conclusions sections were prepared by M. H. Morse, with the assistance of J. Wasrud and T.M. Airola.

[4] Analysis of tide tables was performed by M.H. Morse.

	T_{rad}		
DN	K	C	F
126	292.9	19.75	69.5
145	301.3	28.15	85.5

TABLE V-3a. Radiant temperature for range of digital numbers occurring in water.

	T_{kin}	
T_{rad}	e=.993	e=.966
292.9	293.4	293.1
301.3	301.8	301.6

TABLE V-3b. Kinetic temperature for range of digital numbers occurring in water, for two different emissivities.

The effect of tidal movement in this area allows water temperatures to reach relatively high levels. The areas depicted in red are about 85° F. The small white areas in the middle of the red have higher digital values than any assigned colors (> 85.5°).

Further downstream from the Bergen Generating Station, the water returns to levels seen in other water bodies such as the Hudson. Approximately 8 kilometers downstream from the plant is the farthest extent of the plume. This point is where Berry Creek flows into the Hackensack River. If one assumes that the atmosphere has an attenuating effect on measured temperatures of 4° C (Tracey and Lawrence 1986) then the areas in red are approximately 90° F and white areas are > 90° F.

<u>PSE&G Hudson G.S., PSE&G Newark G.S., and Kearny G.S.</u> (Figure V-2)

The largest plume emanates from the PSE&G Hudson generating station. This plume is cooler and of greater homogeneity than the Bergen G.S. plume. The area of highest temperatures does not extend across the river as does the plume from the Bergen G.S. The Hudson G.S. plume stays in the 74 - 78° F range until it flows into Newark Bay.

The tidal change (flood tide starting) is just starting to push heated effluent back upstream. The other warm spots on the Hackensack River are likely due to the Kearny Substation. Heated sections on the Passaic River, not as widespread, are probably from the Newark PSE&G substation.

<u>PSE&G Salem G.S., Hope Creek G.S.</u> (Figure V-3)

The photograph shows the plume with standard color scheme. Although the photograph lacks some contrast, the results show a 3 km long by an average of 0.5 km wide plume tending towards southeast. The plume shows considerable variability in width from 170 meters wide to 650 meters. The plume has areas of warmer and cooler water incorporated into it. Hope Creek, to the east, appears to be warmer due to the mixed pixels that include some land radiation as well as radiation from the creek.

Conclusions

In terms of measuring and mapping the distribution of heat downstream from these generating stations, it would take significant amounts of equipment and manpower to measure temperatures to produce what can be produced from satellite imagery. Aerial thermal scanner can acquire more detailed data, but in many cases at a much higher cost. One of the benefits of satellite data is relative cost vs. information gained. The same data that are used for thermal studies can sometimes be used for sediment concentration and algal studies.

Thermal plumes are also useful as surrogate indicators of releases of substances into water bodies. It is likely that a release into a water body will not be of the same temperature as the water body. Thermal scanners can be used to monitor releases such as these.

In future work, concurrent temperature sampling from at least a few locations would assist in calibration of the measured emissivity.

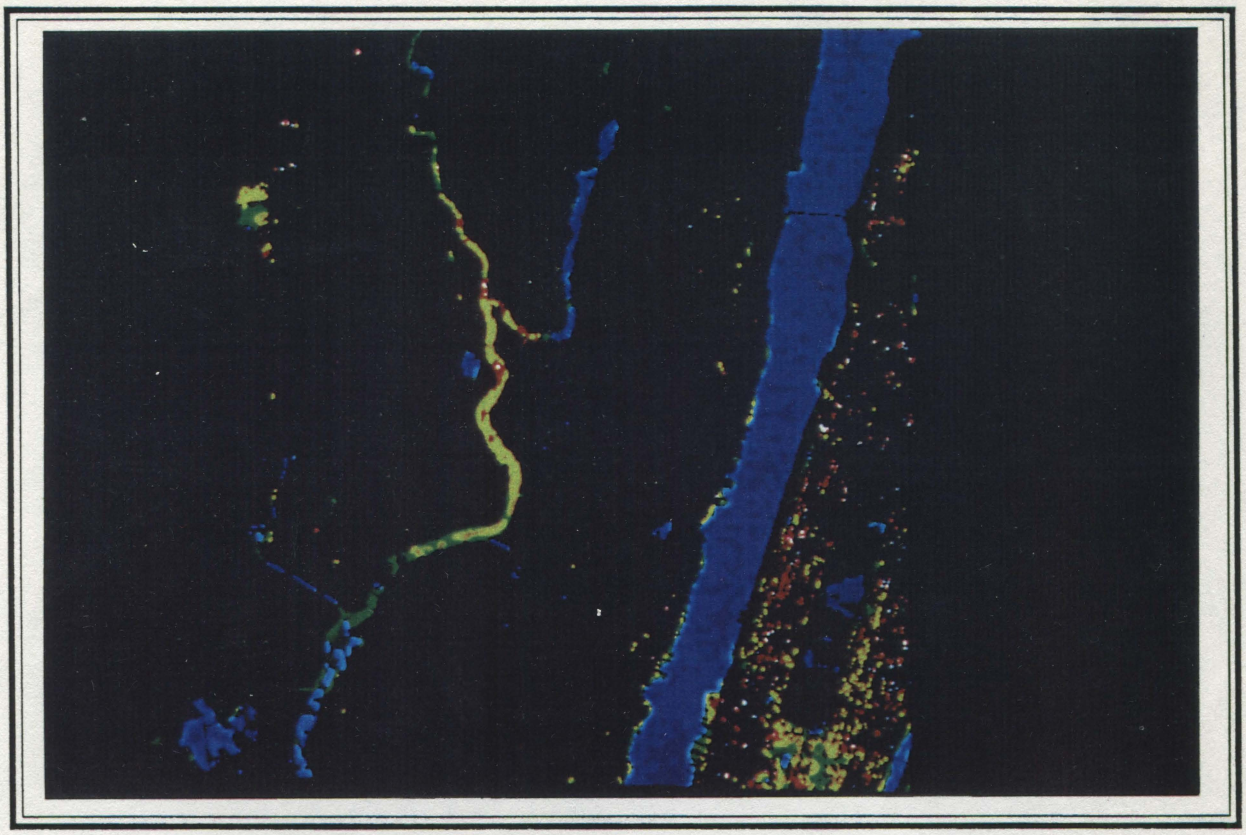

Figure V-1. PSE&G Bergen Generating Station Plume, from the RFIELD data set.

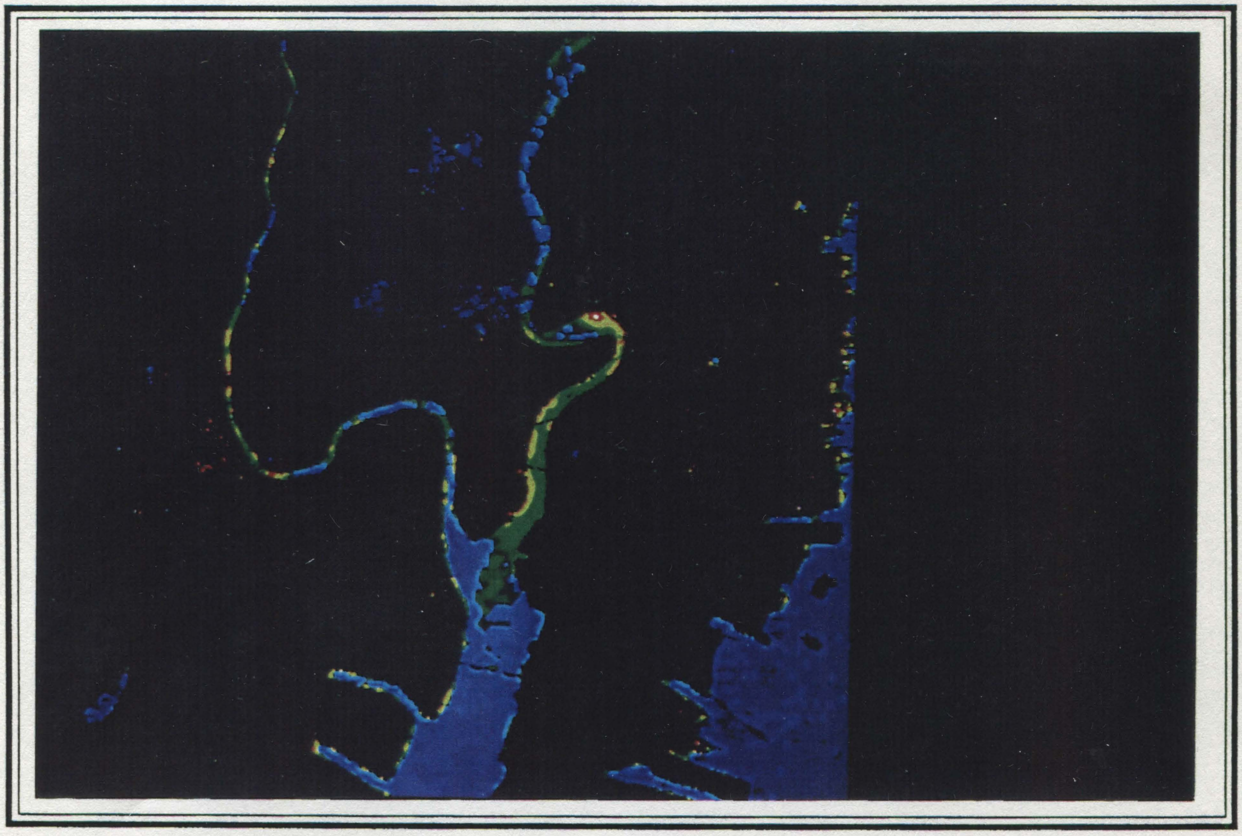

Figure V-2. PSE&G Hudson, Newark, and Kearney Generating Station, from the JERSEYC data set.

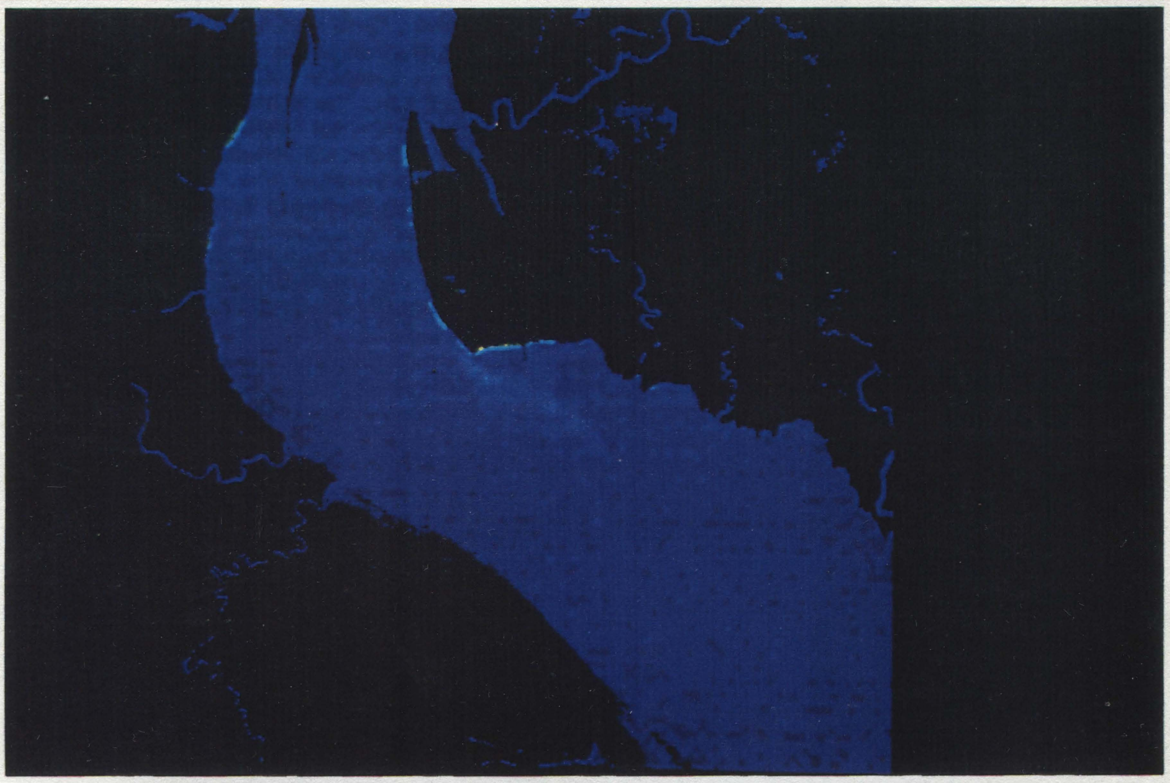

Figure V-3. PSE&G Salem and Hope Creek Geneating Stations, from the SALEM data set.

CONCLUSIONS

Jeffrey Wasrud

This study has shown some of the benefits and some of the difficulties associated with remotely sensed data. Perhaps the most important problem to overcome in implementing many of our suggestions is the lack of data with sufficiently high temporal resolution. For example, 16 photographs of landfills were acquired. Of these 16, only two were acquired during the peak of the growing season, and two more were acquired at the very beginning or end of the growing season. Therefore, seventy-five percent of the data acquired of these landfills was of marginal usefulness for visual analysis of vegetation, and useless for automated analysis of vegetation. Of the four photographs that were acquired during the growing season, only two were color-infrared. The other two photographs were black and white, and contained very little information about the relative health of the vegetation. Unfortunately, the color-infrared photographs were at a much smaller scale than the black and whites, and so had some spatial resolution problems.

Remotely sensed data can provide information about a phenomenon that the investigator cannot, or does not wish to, visit. The spatial, temporal, and spectral properties of the phenomenon can be precisely determined through the use of photogrammetric techniques. This can be accomplished when the acquisition of the data is carefully planned for the phenomenon to be investigated. Unfortunately, none of the data made available for this project were acquired with this type of use in mind.

Remote Sensing of ephemeral phenomena

If the State of New Jersey is to use remotely sensed data in monitoring hazardous landfills, spills, and plumes, as part of the general remediation, monitoring, and enforcement program, it must acquire remotely sensed data of adequate spectral, spatial, radiometric, and temporal resolution. Ephemeral phenomenon, such as accidental spills and small atmospheric plumes require a dedicated remote sensor and platform. If the budget for acquisition of remotely sensed data was quite generous, the ideal system might consist of: an Airborne Imaging Spectrometer, with 128 to 255 spectral bands, covering the ultraviolet to mid-infrared portions of the spectrum; a thermal multi-band scanner; a Side-Looking Airborne Radar (SLAR); a LIDAR system; two aerial cameras; and a large, high-speed airplane that is equipped with precise navigational equipment and a real-time monitor that provides a view of the events taking place directly below the camera. This is an ideal system, and it is doubtful that New Jersey can acquire such a system in the near future. However, there are a range of alternatives that need to be considered.

The most critical problem to solve is the temporal resolution problem, especially in the case of events that are an immediate hazard to life. We cannot expect those involved in the transporting of hazardous materials to wait for a satellite or aircraft overpass before they accidentally discharge their cargo. If a discharge occurs, we cannot expect the people affected to wait until we get a picture before the accident can be cleaned up. Therefore, any system of monitoring through remotely sensed data must be capable of quick response. Having a real-time system, with recording capabilities, above the site would: aid in the immediate problem of clean-up, provide a means to assess the impact of the event, and provide evidence if judicial or administrative review of the event occurs. An economic way of providing this information would be through the use of a video system. The standard color video camera has been used as a remote sensor in aircraft with some success. When complimented by a video camera sensitive to non-visible portions of the spectrum, such as the Biovision camera, video becomes a multi-channel, real-time, high-spatial resolution system with great potential, especially when mounted for vertical imaging in a quick response platform. Such a system would have better spatial and temporal resolution than the Landsat satellites, and a better spatial, temporal, and spectral resolution than SPOT, and could be purchased for less than the cost of acquiring complete SPOT coverage of the state. The system could be mounted in any of a variety of aircraft, if an FAA approved port is made in the floor of the aircraft, or if one of a variety of through-the-window or through-the door mounts are fabricated or purchased[1]. If the video camera(s) are equipped with zoom lenses driven by a remotely controlled and calibrated[2] step motor, resolution and field of view can be modified from within the aircraft. This will permit the aircraft to maintain a safe and legal flight path, while collecting as much data as possible.

Video data have two problems that have prevented wider use. First, the video scene is much smaller than the scene obtained from sensors such as scanners or photography. Second, video data do not maintain radiometric fidelity between scenes. Therefore, if room in the aircraft permits, another remote sensor might be installed. Such a sensor might be a camera, preferably 35 millimeter or large format. A camera would allow a greater field of view while maintaining spatial resolution. Photographic sensors are not real-time, and so are not useful in the initial clean-up. However, photography does allow a greater field of view while

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[1] Photogrammetric Engineering and Remote Sensing has had several articles over the years on how to mount cameras in aircraft without cutting a hole in the floor (which requires FAA approval). Some require going through an open window, others through a hole cut in a door acquired from an aircraft junk yard, and others prop open the door in flight. Although these are quite useful and economical, if there is a need for communication between the aircraft and ground crews during an overflight, these economical mounts may cause the noise level in the aircraft cabin to rise to the point that radio communication is impossible.

[2] Calibration of the zooming process is necessary for post-flight analysis, and is absolutely critical for administrative or judicial review.

maintaining the spatial resolution of the video system. It also permits easy archiving and comparison to historic remotely sensed data sources.

Another sensor to consider is a thermal sensor. Those cooled by higher-temperature coolants, such as the FLIR system, are safer to operate in an enclosed aircraft cabin, as there is little danger of window fogging. Many environmental contaminants, such as oil on a water body, have "signatures" in the reflective portion of the spectrum that are similar to the likely natural background, but have much more unique signatures in the thermal portion of the spectrum. Thermal sensors have also proven to be of value in law enforcement work, especially for nocturnal surveillance.

The Coast Guard's Aireye system should be investigated further by the State of New Jersey. The Aireye system is designed for monitoring oil spills, and includes: Side-Looking Airborne Radar (SLAR), aerial photography, and a scanner with an ultra-violet band and two thermal band. These data would be of value to those investigating oil spills in New Jersey waters, if an Aireye mission were requested upon discovery of a spill event. If possible, an Aireye mission should include images of active generating stations and other coastal thermal emitters, in order that the data may be analyzed for their utility in monitoring thermal plumes. It may be possible to get the Coast Guard to fly an Aireye mission independent of a known spill event. This might be accomplished through suggesting that a training mission be flown from the Aireye base in Cape Cod to New York Bight and south along the New Jersey shore.

Remote Sensing of Long-term phenomenon[3]

Events of long duration and little immediate impact on health and safety can be monitored as part of a regular program of acquisition of remotely sensed data. Satellite data are constantly being acquired, although cloud cover frequently obscures much of New Jersey, especially during the growing season. The state is also photographed from aircraft fairly regularly, although the photography is often acquired during leaf-off periods, rendering vegetation assessment difficult. Leaf-off photography makes mapping of urban features easier, and as this is a prime use of the aerial photography, it is logical to require the photography to be acquired under those conditions. However, if the purpose of the photography is to update existing maps, it may be possible to acquire the photography during the growing season. This can be accomplished if the interval between acquisition is small enough that the tree canopy has not closed over the feature to be mapped. It is unusual to find a feature, large enough to be mapped from an aerial photograph, that has been constructed under the existing tree canopy. Therefore, it may be possible to acquire leaf-on photography for mapping purposes if it is acquired on an interval less than the interval needed for a tree to grow to a height and width sufficient to cover the features to be mapped.

Thermal Plumes

The literature has shown air- and space-borne thermal sensors to be useful in monitoring plumes of unique thermal properties, such as oil and heated waste water. This study has shown that Landsat TM data can be used to map plumes from some New Jersey power plants. Unfortunately, the TM thermal data used in this study were resampled from 120 meter pixels to 30 meter pixels using a cubic convolution

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[3] Many of the recommendations at the end of the Landfills section are also appropriate for long-term phenomena.

algorithm. The cubic convolution algorithm does not preserve radiometric fidelity. Future acquisitions of TM data for analysis of thermal plumes should include a request for nearest-neighbor resampling version of the thermal data.

Airborne sensors provide a synoptic view of an event. Although "ground-truth" measurements of a thermal plume may be more precise, the cost of making ground (or water) based temperature measurements over a large area, with a 120 meter sampling interval, could be quite prohibitive. TM data provide these measurements once every sixteen days, and thermal scanners can be flown in aircraft to provide a finer sampling interval on demand. Every effort should be made to obtain airborne thermal scanner data of New Jersey for a comparison to TM data[4]. Many contaminants and hazardous wastes have unique thermal properties, and thermal scanners may be the most economical way to track and identify these substances.

Remote sensing has the potential to be of benefit to the Department of Environmental Protection. In order to maximize the potential benefit, it is suggested that:

> **Potential users become acquainted with remotely sensed data.** This can be economically accomplished through the acquisition of remotely sensed images for office decoration, through tours of remote sensing laboratories, and other non-threatening and subtle educational techniques.
>
> **Training in the use of remotely sensed data be provided to potential users.** Training should include photo interpretation, image processing, and computer classification techniques. Training should emphasize the benefits and the disadvantages of remotely sensed data.
>
> **Remotely sensed data be acquired with environmental problems in mind.** Much of the data used in this study was less than optimum for certain of the research problems. For example, no suitable remotely sensed data of a spill in New Jersey was found. Potential users, with an interest in environmental problems in New Jersey, may be hindered by a lack of adequate data. A way should be found to acquire data at spatial, spectral, temporal, and radiometric resolutions suitable for a larger user base.

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[4] The Aireye system would be one potential source.