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The Application of GIS and Remote Sensing Technologies for Site Characterization and Environmental Assessment

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ABSTRACT

Environmental cleanup and restoration of hazardous waste sites are major activities at federal facilities around the U.S. Geographic information systems (GIS) and remote sensing technologies are very useful computer tools to aid in site characterization, monitoring, assessment, and remediation efforts. Results from applying three technologies are presented to demonstrate examples of site characterization and environmental assessment for a federal facility. The first technology involves the development and use of GIS within the comprehensive Oak Ridge Environmental Information System (OREIS) to integrate facility data, terrain models, aerial and satellite imagery, demographics, waste area information, and geographic data bases. The second technology presents 3-D subsurface analyses and displays of groundwater and contaminant measurements within waste areas. In the third application, aerial survey information is being used to characterize land cover and vegetative patterns, detect change, and study areas of previous waste activities and possible transport pathways. These computer technologies are required to manage, analyze, and display the large amounts of environmental and geographic data that must be handled in carrying out effective environmental restoration.

BACKGROUND AND INTRODUCTION

Over the last 50 years, the operation of many Department of Energy (DOE) and Department of Defense (DOD) facilities has resulted in significant levels of environmental contamination from both radioactive and chemical wastes. The contamination occurred during a period when defense and technological development were of utmost importance and concerns for environmental safety and human health were secondary. In recent years federal legislation - the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) 1980, and the Resource Conservation and Recovery Act (RCRA) 1976 - established cleanup requirements and regulatory oversight functions to be enforced by the Environmental Protection Agency (EPA). Environmental restoration (ER) programs are now a major activity at many federal facilities to identify, characterize, clean up, and monitor inactive hazardous waste sites. In addition, federal organizations at some sites have entered into interagency agreements with the states and EPA to assist in remediation and oversight arrangements.

Major restoration efforts are underway at five federal installations operated by Martin Marietta Energy Systems (Energy Systems) for the DOE. These include three facilities on the Oak Ridge Reservation (ORR) in East Tennessee - the Oak Ridge National Laboratory (ORNL), the Y-12 weapons plant, and the K-25 site - along with uranium enrichment installations at Paducah, Kentucky and Portsmouth, Ohio. To conduct successful cleanup efforts and meet regulatory requirements at these facilities, many types of questions must be investigated, including:

- the types and characteristics of contaminants,
- the location of possible pollutant sources,
- previous waste disposal techniques,
- the spatial extent of the contamination,
- relationships among nearby waste sites,
- current and past environmental conditions including surface, subsurface, and groundwater characteristics,
- possible pollutant transport mechanisms,

- efficient methods for analyzing and managing the information,
- effective cleanup strategies, and
- mechanisms for long-term monitoring to verify compliance.

To aid in these activities, a variety of technologies, analysis tools, and data types are being integrated within a data management program that is under development for Environmental Restoration at the DOE Oak Ridge Operations Office (DOE-ORO). Three major technologies supporting this effort include the development and application of:

(1) GIS techniques as part of the Oak Ridge Environmental Information System,

(2) subsurface groundwater analyses, and

(3) remote sensing studies of aerial survey data.

Preliminary results from these activities will be used to present examples of site characterization and environmental assessments on the Oak Ridge Reservation.

GIS AND OREIS DEVELOPMENT

Objectives and Scope

The Oak Ridge Environmental Information System (OREIS) is being developed to support ER activities at the five installations previously mentioned, to meet the requirements mandated by State Oversight Agreements and the Federal Facility Agreement (FFA) between DOE-ORO and EPA (1). The primary focus of this effort is three-fold:

- Development of a consolidated data base,
- Development of an environmental information system, and
- Development of data management procedures that will assure the integrity of environmental and geographic data throughout the facilities.

Potential users of the system and the data include internal Energy Systems staff, DOE, and subcontractors as well as external organizations such as EPA, State Governments (Tennessee, Kentucky, Ohio), and other environmentally related agencies. OREIS is intended to be the repository providing access to all types of geographic and environmental data for the DOE-ORO facilities. A wide range of data types are being incorporated within the system, including:

- Well construction parameters
- Groundwater hydrology and quality
- Surface water hydrology and quality
- Air quality
- Radiation data, field and aerial surveys
- Remote sensing information
- Administrative boundaries
- Geophysical logs
- Soil/sediment analyses
- Meteorology
- Biological monitoring
- Demographics
- Site geography and imagery
- Metadata

The OREIS system also provides a diverse suite of functional capabilities such as controlled data import and export, data storage and retrieval, report generation, statistical analyses and summaries, 2-D and 3-D graphics, all types of GIS techniques, and production of maps and imagery. Three commercial software systems are being integrated within a networked workstation environment using central servers to manage the consolidated data base. The three primary tools include:

- ARC/INFO for GIS analysis, query, and display capabilities
- ORACLE as the relational data base management system (RDBMS), and
- SAS for statistics, graphics, and report generation.

The power of the GIS results from linking the geographic features with tabular environmental data stored in the RDBMS. This linkage extends the analytical capabilities beyond computer-aided design (CAD) packages which typically support only input, output and manipulation of graphic data. Logical and spatial queries can be performed based on user-specified criteria addressing specific environmental questions. With a GIS, multiple data bases can be integrated, and several criteria can be considered simultaneously to reveal spatial relationships and environmental trends that would otherwise be undetected. Topologically based queries can include "what is inside or outside" or "how big" or "find the nearest" (2).

Geographic location is an essential ingredient required for the management and use of ER data. The geography of hazardous waste sites and their environs not only documents the extent and proximity of problem areas to the surrounding landscape, but also implies ownership and liability from an administrative, regulatory, and operational standpoint. For these reasons, it is important that consistent, accurate, and current geographic data be maintained for all Energy Systems installations (3). Developing an understanding of waste sites on the DOE ORR and their potential impacts begins with a characterization of the area within and around the reservation. The GIS provides an excellent mechanism to portray and analyze various spatial features simultaneously.

General Reservation-Wide Characterization

The ORR encompasses an area of approximately 35,000 acres located west of Knoxville, TN and just south of the city of Oak Ridge, here shown on a regional population density map computed from raw census data (Figure 1). The most dense patterns correspond to urban areas of more than 2,000 people per square mile. The three facilities within the ORR (ORNL, Y-12, and K-25) are north of the Clinch River (Figure 2), which flows in a general east to west direction. The ridge and valley pattern of East Tennessee is evident in Figure 3 which shows a 3-D perspective view from the southwest as computed from SPOT satellite imagery and elevation models. The three DOE plants and the city of Oak Ridge are in the valley bottoms depicted as clusters of white. The same satellite multispectral scanner data have been used to compute nine general classes of land cover at a pixel resolution of 20 meters. Approximately 15-20% of the ORR consists of industrial and other cultural features such as roads, buildings, utilities, parking areas.

A large portion of the reservation is covered with deciduous and coniferous trees with some scrubland and a number of streams, seeps, and springs. Four initial classes of environmentally sensitive areas, both surface and aquatic, have been computerized based on special plant species, animals, habitats, and communities (Figure 4). The background features on this map depict some of the surface hydrology and cultural features including the network of electrical transmission lines that cross the reservation. The geology and groundwater movements are rather complex with fractures, faults, and outcrops interrupting sedimentary segments, limestone and shale units.

There are a number of areas on the reservation that have been used for waste sites, landfills, disposal lagoons, underground tanks, buried trenches, and injection wells. These sites that deal primarily with contaminated soil, geology, and groundwater have been grouped into Operable Units (OUs) based on geographic proximity, similarity of waste characteristics, site type, and possible cost savings in assessment and cleanup. Both groundwater and surface operable units have been defined within the ORR and for some areas off the reservation. Figure 5 is a delineation of the surface OUs (primarily burial grounds) at ORNL. The surface OUs have been combined with the environmentally sensitive areas in the GIS to visually determine the congruence of the two.

System Integration and Analysis Tools

The different geographic and image data bases used in OREIS are being structured as GIS layers for quick recall and integration with other information. Large amounts of environmental measurement data, such as groundwater characteristics and pollutant concentrations, are being linked with the geographic data so that spatial and logical queries of the tabular data can be displayed in map form. Figure 6 displays GIS menus that are being developed to overlay imagery with vector data and allow the user to build structured queries of specific variables within the RDBMS. User-friendly interfaces are available within the RDBMS to peruse the variables, create structured query language (SQL) operations on the data, review the table structures, analyze relationships between elements in the tables, select and aggregate subsets of the data, prepare reports, and output converted files.

Interfaces to statistical exploratory tools are available to quickly analyze the tabular data by computing standard statistics, studying correlations between variables, plotting frequency distributions, and displaying 2-D and 3-D scatter diagrams while key items of interest are automatically identified in all graphic windows simultaneously. The integration of analysis and data management tools with user interfaces and diverse data types can assist scientists, engineers, planners, and managers in their investigation and cleanup of waste sites. The GIS can provide an aggregate view of multiple data themes and on-going activities across the reservation to aid in oversight functions.

GROUNDWATER MODELING AND DISPLAY TECHNIQUES

The Problem

A variety of different radionuclides (e.g., strontium, uranium, tritium, cobalt, cesium) as well as organic and inorganic wastes have been generated and disposed of for years on the ORR. In some cases, these wastes have migrated through the soil and geologic strata into groundwater aquifers or sometimes into nearby waterways. The pollutants may be deposited in the sediment or eventually move downstream into the Clinch River which leaves the reservation along its western boundary. Extensive boreholes and monitoring wells have been drilled within the burial ground areas at all three ORR facilities to study the hydrogeologic characteristics and to determine the extent of groundwater contamination.

GIS Spatial Analysis

GIS tools can be useful in two-dimensional analyses and mapping of potentiometric surfaces and certain subsurface features. For example, Figure 7 shows monitoring well locations within the central portion of ORNL as a series of "plus" symbols. The groundwater elevation for each well has been interpolated to create contours that give an indication of flow direction, generally spreading out from north to south. Although trends may be easily seen, it is recognized that the validity of the contours is affected by the interpolation technique, the sampling point distribution, and certainly by the structural geology of this part of East Tennessee.

Subsurface Modeling and Display

Since most current GIS capabilities are oriented around two-dimensional phenomena, it is sometimes necessary to use additional spatial modeling tools to study and visualize three-dimensional subsurface characteristics. For example, the groundwater contours shown previously actually represent a 3-D surface as portrayed by another ORNL system (4) in Figure 8. The top layer represents the ground-level facilities (buildings, streams, roads) while the lower layer displays the monitoring wells and 3-D contours. Note that for ease of viewing, the lower layer has been separated from the ground facilities and exaggerated in the vertical dimension by a factor of 10. An actual rectangular mesh can be computed for the surface of the groundwater as well as for the ground topography by interpolating from the ground elevations at the tops of the wells. These features are shown in the three-layer diagram in Figure 9. The same 3-D techniques can be used to display lithologies within any subset of the boreholes to estimate the extent of geologic strata. Pollutant concentrations can be displayed numerically or as variably-sized spheres at the screening depth of each 3-D monitoring well. A later example will show how pollutant concentrations can be analyzed and displayed in contour form.

Interactive techniques that allow the hydrogeologist to select specific data for study, generate 3-D models, and review the results from any observer position can be very helpful in gaining an understanding of subsurface structures, groundwater, contaminant plumes or "hot-spots", and possible remedial actions. Other more sophisticated 3-D modeling packages are being investigated and used at ORNL along with the development of hydrologic transport models. The long-term intent is to link these modeling tools with the GIS (5) to take advantage of the best features of both technologies, thus enabling data and graphics to flow easily between the two.

Use of Analytical Tools for an ORNL Burial Ground

One of the primary operable units at ORNL is referred to as Waste Area Grouping 6 (WAG 6) shown as the dark shaded area in the lower left corner of Figure 10. The lighter shades depict all the waste areas at ORNL. Although a series of thick mylar caps have been constructed above some of the burial trenches and pits to divert the runoff, some radionuclides periodically migrate south into White Oak Lake and eventually into the Clinch River. Hydrologists are very interested in using whatever tools are available to determine the extent of the migration and track changes over time. In Figure 11, the GIS was used to overlay selected monitoring well locations on rectified aerial photography and vector map data. The pollutant data measured for each well are shown in a scrollable tabular window linked directly to well locations on the map. With a mouse, the user can select wells of interest on the map or in the table. Through easy-to-use menus any type of logical or numeric query can be built from user-specified criteria. As one example, the user could easily select and map contaminant values above a given threshold for shallow wells during a specific time period. The results could be mapped as numeric values alongside the wells or as colored symbols of varying size and shape.

The data base system is normally used to manage and analyze numeric or textual information in a tabular format. However, graphic images (e.g., graphs, charts, pictures, and diagrams) can now be treated as data entities or variables referenced within a table. As shown in Figure 12, such images can be recalled from the table with the touch of a mouse. In this example, the user has recalled an oblique view of part of WAG 6 that might be associated with a subset of wells. All these types of tools are intended to place pertinent information at the fingertips of the analyst to aid in interpretation of the data and design of cleanup approaches.

As a final example of using spatial tools to analyze historical well data within WAG 6, maximum tritium readings have been contoured in Figure 13 to indicate possible areas of high concentrations. These contours have then been superimposed on a computer-generated groundwater surface in Figure 14 to give a general idea of the location and flow direction of tritium within the groundwater. This is a simplified approach that may only apply in an aggregate long-term view because the fractured geology of the region and local conditions greatly affect daily movements and distribution of the groundwater.

AERIAL SURVEY AND REMOTE SENSING STUDIES

Objectives and Scope

The Oak Ridge Aerial Survey Program is intended to support environmental assessment and restoration activities at all five Energy Systems installations. This effort includes the acquisition, management, and analysis of all remotely sensed information collected by aerial survey techniques. The data and analysis results are integrated with ancillary information to support specific environmental and ER data base projects, and to load the information into the OREIS system for user access and product generation.

A two-phased aerial survey of the ORR was begun in April 1992 to aid in characterizing known waste sites, to identify possible waste areas that might have been used in the past, and to study possible transport mechanisms and impacts (e.g., seeps and springs, vegetative stress). The imagery acquired from the aerial surveys will be used to validate and interpret data, update facility information, delineate waste sites, and to gain a better understanding of the relationships among spatial phenomena involving monitoring activities, potential contaminant sources, nearby facilities or off-site areas that might be impacted, and cleanup activities underway. Specific geographic data bases will be developed including land cover, vegetation, topographic, and aquatic-related classes.

The Phase I survey collected several types of information from jet and helicopter aircraft flown from 150 feet to 40,000 feet above ground level (AGL). These include:

- gamma radiation data from helicopter flown at 150 feet AGL,
- multi-spectral scanner (MSS) imagery in 12 channels from 3,000 to 6,000 feet by jet,
- pre-dawn thermal MSS imagery flown at 4,000 feet AGL,
- color infrared (IR) photos flown from 3,000 to 6,000 feet AGL, and
- natural color photos flown from 6,000 to 40,000 feet AGL.

The Phase II survey, begun in November 1992, used airborne electromagnetic and magnetic sensing techniques to search for geologic structures and manmade features associated with previous waste disposal activities. The data collection included helicopter electromagnetic (HEM), magnetic, video, and gamma radiation surveys at different detector heights ranging from several meters to roughly 30-40 meters AGL. Typical targets included buried drums, trenchs and pits, pipelines, karst cavities, faults and fractures, and geologic contacts.

A third aerial survey was conducted in early April 1993 (before leaf-out) to acquire detailed natural color and color IR photography for the whole ORR and the surrounding area. On board the aircraft was a new real-time differential global positioning system (GPS) linked with a GPS at a nearby airport. The GPS system aided in accurate positioning of the aircraft during flight, in controlling the operation and timing of the camera exposures, and in collecting precise geometric information on camera position, photogrammetric parameters, and ground control. With this new technology (6) accurate photogrammetric rectification can be established with very few ground control points. The photo products are to be used in developing very accurate ortho-photo mosaics, digital elevation models, and a high resolution map data base (1" = 200') for the reservation and its environs. These data bases are critically needed for all ER activities because existing ORR map data are years out of date and have poor resolution.

Examples of Phase I Activities and Results

As part of the Phase I aerial survey, the jet aircraft generally flew a series of east-west flight paths, as shown in Figure 15, to acquire the MSS and stereo photography. The helicopter flew designated study areas (Figure 16) to acquire the gamma radiation data. Some preliminary results from the gamma survey were computerized as specific contours and superimposed on scanned aerial photos to assess the validity of the initial data and to help estimate possible sources of the gamma readings (Figure 17). Interim results of the processed gamma data were provided as gross radiation contours from all gamma sources, contours from all man-made radionuclides, and contours for a few specific radionuclides (e.g., cesium, cobalt). Figure 18 presents the interim contours for man-made nuclides at ORNL superimposed on a base map of the area. The patterns of gamma measurements correlate well with past waste activities at all the ORR facilities. Note that both the preliminary and interim gamma contours are subject to further adjustments and improvements as final validation of the processed results is completed.

The Phase I aerial photographs and MSS data are being analyzed on special image processing systems at ORNL (Figure 19). The aerial photos are being computerized with a flatbed color scanner as three-band digital images. However, there are significant geometric distortions in the stereo images due to high terrain relief and radial camera distortions. This is evident in portions of two stereo images shown in Figure 20. Note that the cleared north-south feature on the right side of Frame 64 is fairly linear. However, the same feature taken just a few seconds earlier in Frame 63 has a distinct curvature in the middle of the lineation.

This type of distortion is normally removed through traditional photogrammetric techniques so that the imagery may be georegistered with map data for interpretation purposes (7). Digital ortho-imaging techniques are a recent development that can be integrated nicely with GIS (8). These techniques have been tested at ORNL using coarse digital elevation models and ground control points derived from GPS readings and known map features. An experimental ortho-photo mosaic has been computed for ORNL from portions of 19 color IR images flown at 3,000 feet AGL. The result is shown in Figure 21 with the grid lines of the geographic coordinate system superimposed. No smoothing of the color intensities across boundaries has yet been done. The same procedure has been applied to other portions of the ORR using natural color imagery flown at altitudes ranging from 9,500 feet to 30,000 feet AGL. These different ortho-images, including the ORNL color IR, have been mosaiced together as one large ORR image.

Because ortho-images are geographically registered to a given map projection, it is possible to combine other types of map data and thematic information with the imagery. This ability significantly aids data interpretation. Integrating rectified images with digital elevation models (DEM) allows 3-D draping and viewing of the imagery as shown in the perspective view of Figure 22, even though the DEM was very coarse. The general view is towards the east with the closest facility to the observer being the K-25 site. The rural portions of the image with the least contrast represent higher altitude photos taken from 30,000 feet AGL. Thematic data can then be superimposed on the 3-D terrain surface to give the analyst a much better understanding of topographic relationships with the environmental measurement data; this is shown in Figure 23 where the gamma contours from man-made radionuclides have been superimposed on the 3-D color IR ortho-mosaic. WAG 6 and White Oak Lake are in the lower right corner of the image and the main research buildings are in the upper left. Note that some of the higher radiation levels are in the sediments just upstream from White Oak Lake where the lake has dried up in recent years.

Radiometric Analyses

Most of the previous imaging examples involved geometric or spatial manipulation of the pixel geometries. Another powerful suite of tools are used in analyzing the MSS radiometric bands that represent intensity levels for different wavelengths of reflected sunlight or thermal radiation. Some of the same techniques can also be applied to the red, green, and blue bands of the scanned aerial photography. Investigators frequently incorporate land cover data into analyses and models to help determine wetlands, sensitive areas, natural habitats, runoff calculations, and waste site cover. Figure 24 presents a raw daytime MSS image of ORNL using three dominant bands from different parts of the spectrum to highlight various geographic features. The image analyst has applied statistical imaging techniques, principal components analysis, and clustering techniques using several of the MSS bands to compute a preliminary land cover data base from the raw MSS data. Figure 25 shows the result with 11 land cover classes as indicated in the legend.

The predawn MSS flights captured thermal radiation intensities to aid in the detection of saturated zones including seeps and springs which are quite predominant on the ORR. These zones can represent potential pathways for movement of pollutants into nearby surface waters, and can aid in determining underground location and migration of contaminants. Many are located at the headwaters of small streams. Figure 26 is a grey-level image depicting thermal differences across a study area located on the eastern edge of the reservation. This parcel of land was to be transferred to the City of Oak Ridge and was given early attention to ensure that there was no evidence of contamination (9). The dark patterns represent the coolest areas (e.g., open fields that have lost heat quickly in the early predawn hours.) The lightest shades represent the warmest areas, primarily water bodies that have not cooled off as quickly. Thermal contours have been superimposed on the image to aid the interpretation. These same thermal contours were superimposed on a daytime mosaic of scanned aerial photos after initial rectification. The contours conformed closely to the land cover patterns following around the tree lines. The warmest area is on the right side of the image around the discharge outflow point from the Bull Run Power Plant. Based on a review of the pre-dawn thermal imagery for Parcel A, no seeps and springs were identified, although several small ponds were quickly recognized.

Preliminary Results from Initial Phase II Activities

A few products are currently being produced from preliminary electromagnetic and magnetic data on a few test areas. Geophysicists at ORNL (10,11) are combining these results with ancillary data characterizing the test areas. Final maps, post-processing of the data, and final interpretations have not been made and results are subject to change. Vertical magnetic gradient contours have been computed from the airborne magnetometer and displayed in map form in Figure 27 for part of the burial grounds at ORNL. The WAG boundaries have been superimposed. The magnetometer does an excellent job of delineating the WAG areas containing buried metal and disturbed earth. The areas outside the WAG boundaries are mostly undisturbed and do not show the same type of anomalies.

Figure 28 is a preliminary map of predicted clay thickness, which was computed from the electromagnetic measurements. It has been compared with the contacts between geologic units. The correlation is excellent with the map showing the boundaries between the shale and limestone bedrock. Computational adjustments must be made to the thickness calculation over the shale to compensate for assumptions made about the insulating properties beneath the clay.

Other tests indicate that these airborne methods are capable of detecting clusters of four or more 55 gallon drums, trench boundaries, and other subsurface features. The results are very promising and further work is underway.

CONCLUSION

The use of advanced spatial technologies are critical to conducting a successful environmental restoration program for federal facilities. Estimates of the costs for remediating the hundreds of sites across the U.S. is in the billions of dollars. Developing and applying these information based technologies can reduce restoration costs by improving efficiency in all phases of the effort as well as directing attention to the most serious problems. Considering the savings for cleanup of just a few of the more complex sites, the return on investment can be significant. The ability to collect, manage, and analyze the vast amounts of environmental information is vital to identifying the problems, modeling and assessing their impacts, prioritizing and designing effective cleanup solutions, meeting regulatory requirements, and long-term monitoring to verify compliance.

This document has briefly described three technologies underway for ER at DOE facilities operated by Martin Marietta Energy Systems: (1) the development and use of GIS and the OREIS program, (2) subsurface modeling and display techniques for groundwater analysis, and (3) remote sensing studies using aerial survey data. These represent only a few of the many tools and systems that need to be integrated into an overall data management and analysis structure for large complex installations. Technology transfer efforts should be undertaken to pass the results and experiences on to others and to improve the environmental legacy passed on to future generations.

REFERENCES

1. OREIS. Data Management Plan for the Oak Ridge Environmental Information System, Version 1.1. Prepared for the Environmental Restoration Program, Martin Marietta Energy Systems, Inc., Oak Ridge, TN. Lead author, R. J. Olson, August 1992.

2. McCord, R. A., Durfee, R. C., and Thomas, J. K. GIS Applications in Environmental Restoration at Federal Facilities, in 1993 International GIS Sourcebook, October 1992.

3. OREIS. Guidelines for the Creation and Management of Geographic Data Bases Within a GIS Environment, Version 1.0, Volumes I and II. ES/ER/TM-56, Prepared for the Environmental Restoration Program, Martin Marietta Energy Systems, Inc., Oak Ridge, TN. Lead author, R. C. Durfee, February 1993.

4. Coleman, P. R. and Durfee, R. C. An Overview and Tutorial for the Oak Ridge HydroGeochemical System (HGCS) Version 2.2. Oak Ridge National Laboratory project report for U.S. Air Force, Kelly Air Force Base. Oak Ridge, TN, April 1992.

5. Kilborn, K., Rifai, H. S., and Bedient, P. B. The Integration of Ground Water Models with Geographic Information Systems (GIS), in Proceedings: ACSM-ASPRS, Vol. 2. 1991.

6. Goad, C. C. Positioning With the Global Positioning System Satellites, in Proceedings: GIS/LIS, Vol. 1. 1991.

7. Colwell, R. N. (ed). Manual of Remote Sensing. Vol. 1 and Vol. 2. American Society of Photogrammetry, Falls Church, VA. 2440 pp., 1983.

8. Shanks, R., and Wang, S. Integrating Digital Orthophotography and GIS: A Software-Based Approach to Vector/Raster Processing, in Proceedings: GIS/LIS, Vol. 2. 1991.

9. Department of Energy (DOE). Progress Report of the Aerial Survey of Parcel A, Oak Ridge Reservation, DOE/OR-1038/R1 (ES/ER/TM-37/R1), Environmental Restoration Program, Oak Ridge, TN, 1992.

10. Doll, W. E., Nyquist, J. E., Holladay, J. S., Labson, V. F., and Pellerin, L. Preliminary Results of a Helicopter Electromagnetic and Magnetic Survey of the Oak Ridge Reservation, Tennessee for Environmental and Geologic Site Characterization, Proceeding of the Symposium for the Application of Geophysics to Engineering and Environmental Problems, San Diego, April 1993.

11. Doll, W. E., Nyquist, J. E., King A. D., Bell, D. T., Holladay, J. S., Labson, V. F., and Pellerin,L. Aerial Remote Sensing Surveys Progress Report: Helicopter Geophysical Survey of the Oak Ridge Reservation,. ES/ER/TM-62, Environmental Restoration Program, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, Oak Ridge, TN, March 1993.

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E. A. Bright	F. E. Latham	L. D. Voorhees
D. M. Carden	M. R. Miller	B. C. Zygmunt
P. R. Coleman		

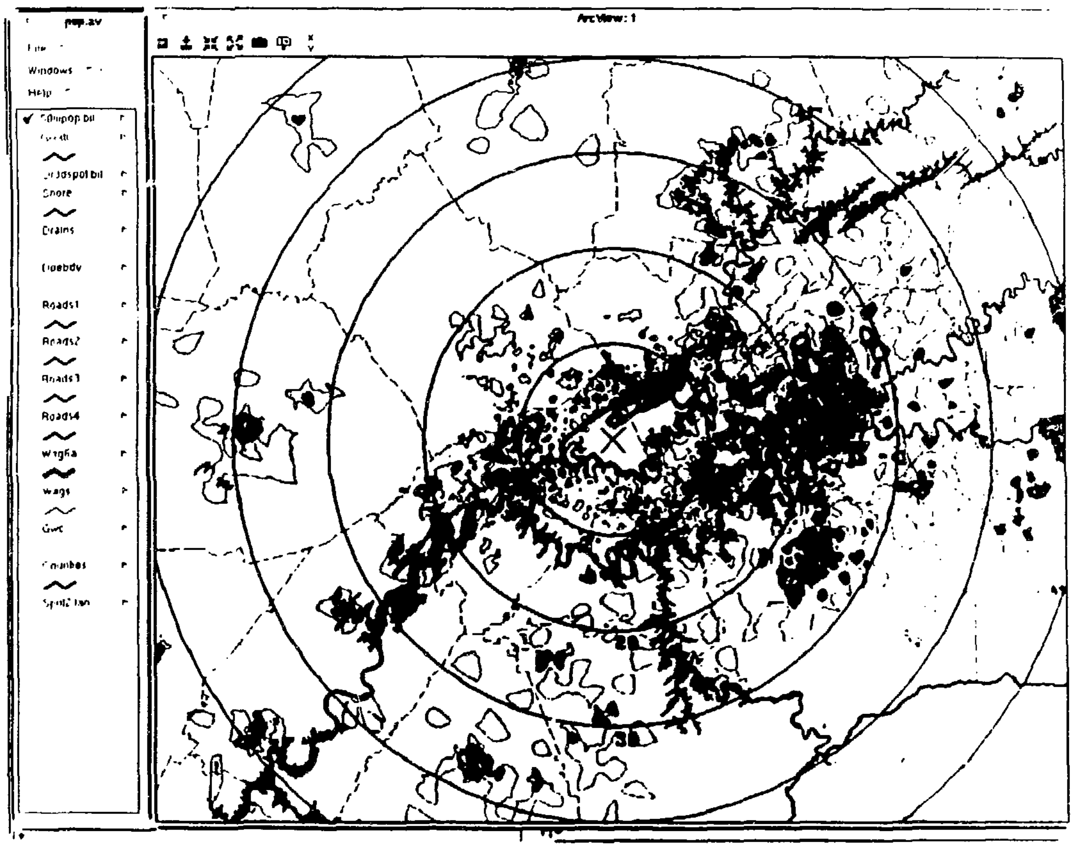

Figure 1. Regional population density map of the area around the DOE Oak Ridge Reservation (ORR) computed from raw census data. The major city to the east of the ORR is Knoxville, TN and the city of Oak Ridge is just to the north. The dark patterns represent urban areas of more than 2,000 people per square mile.

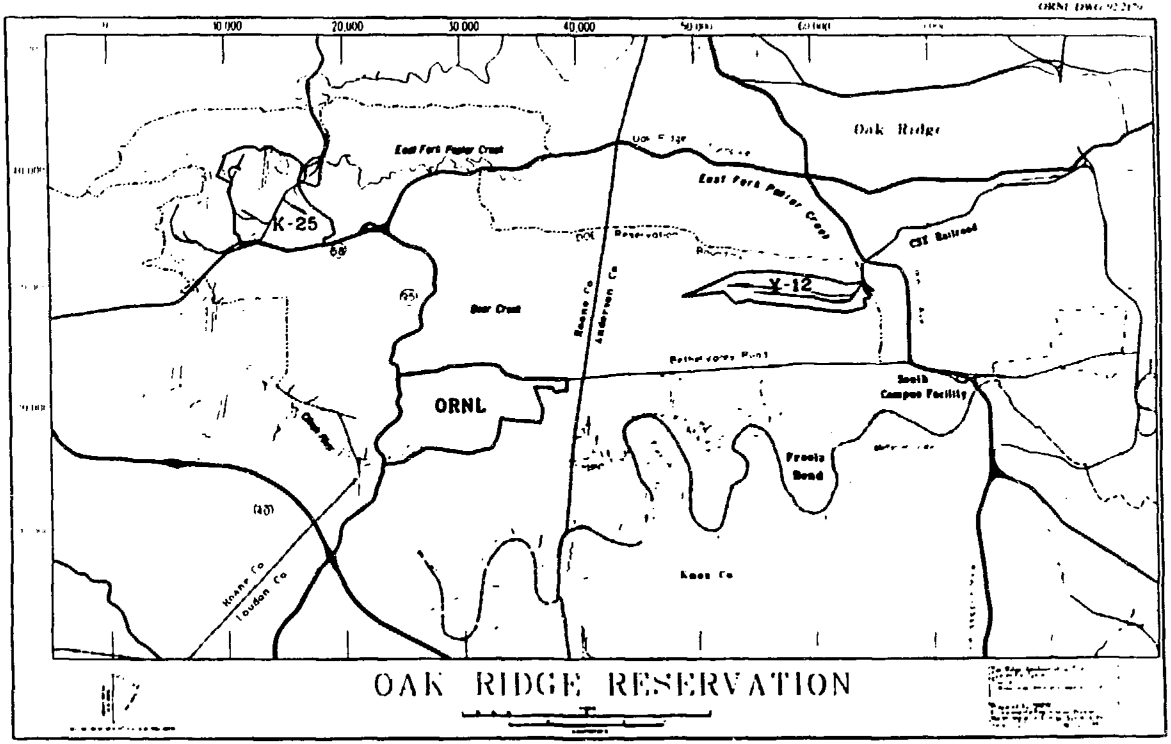

Figure 2. Overview map of the Oak Ridge Reservation including the primary roads and three major facilities north of the Clinch River.

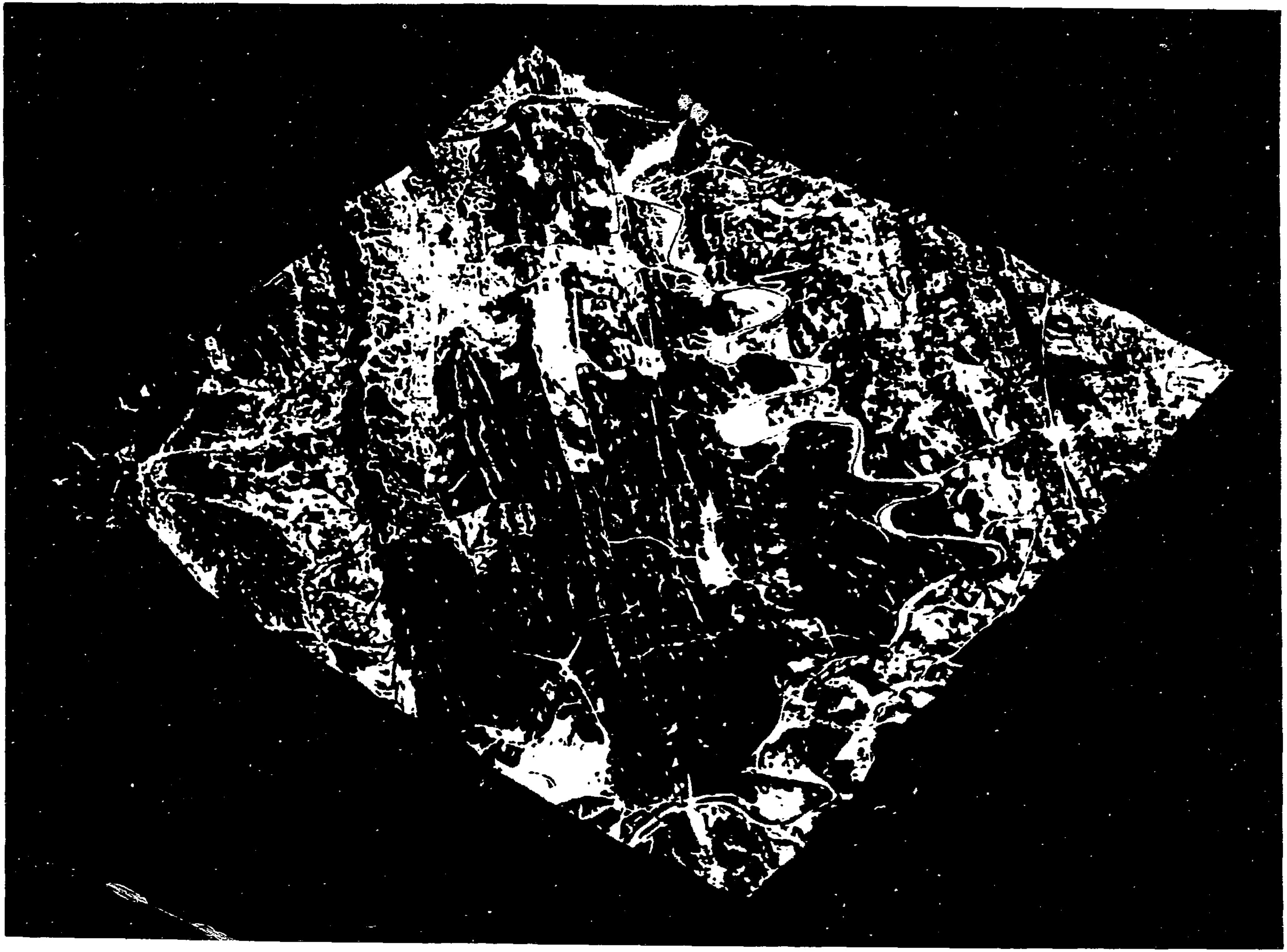

Figure 3. Three-dimensional perspective view from the southwest computed from raw SPOT satellite imagery with the DOE boundary superimposed.

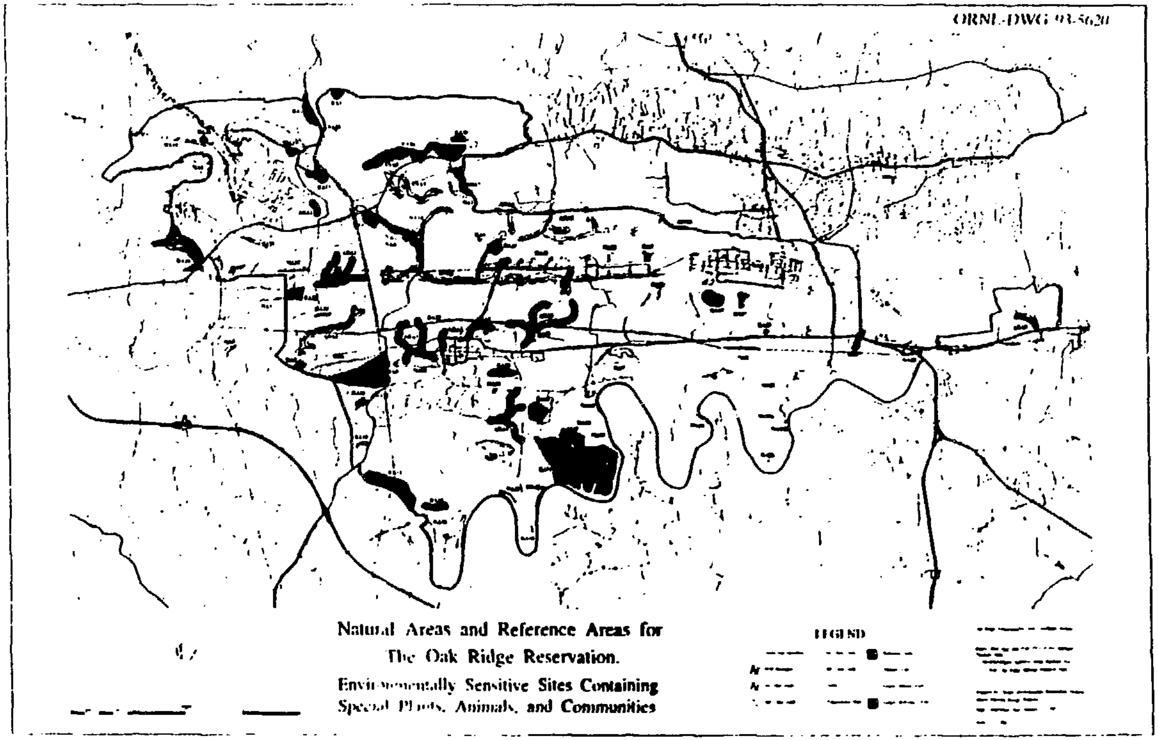

Figure 4. Environmentally sensitive areas on the Oak Ridge Reservation based on special plant species, animals, habitats, and communities.

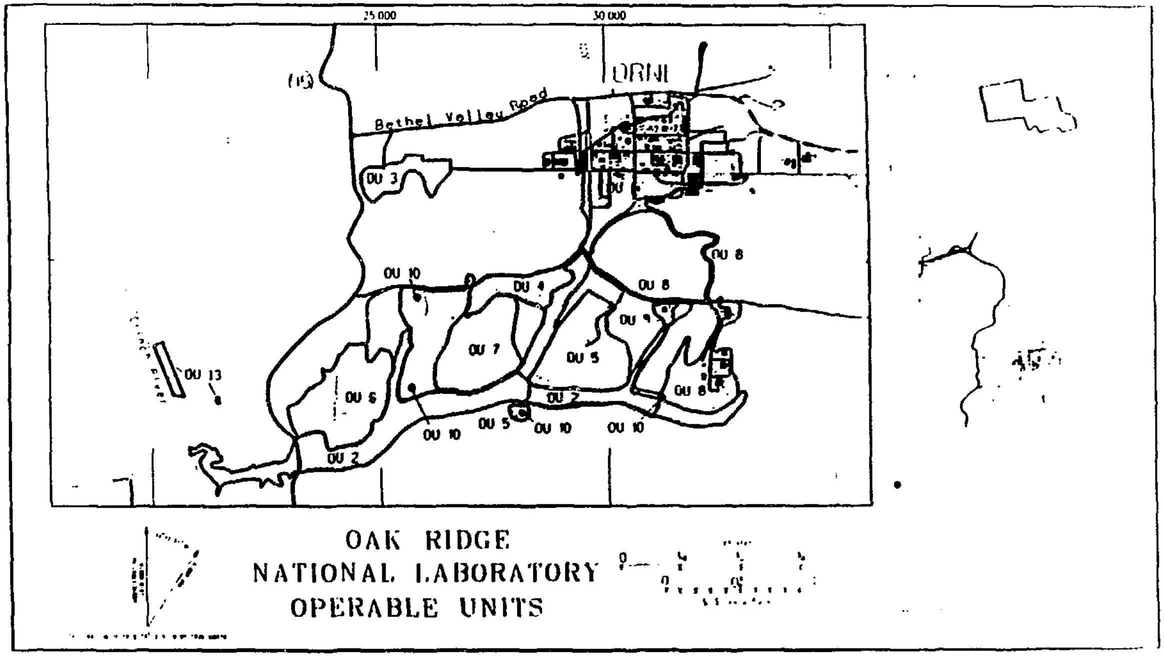

Figure 5. Surface operable units (primarily burial grounds) delineated at the Oak Ridge National Laboratory.

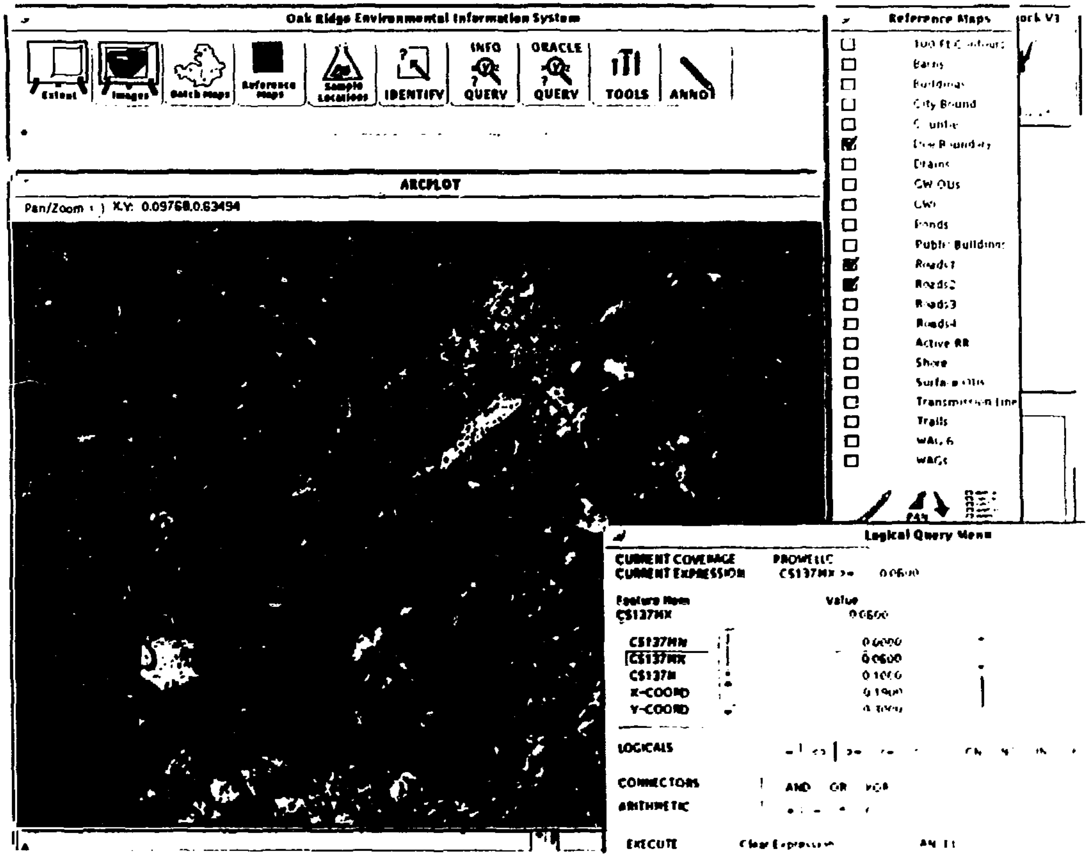

Figure 6. An example of GIS menus being developed to overlay imagery with vector map data and allowing the user to build structured queries of specific variables within the RDBMS for display in map form.

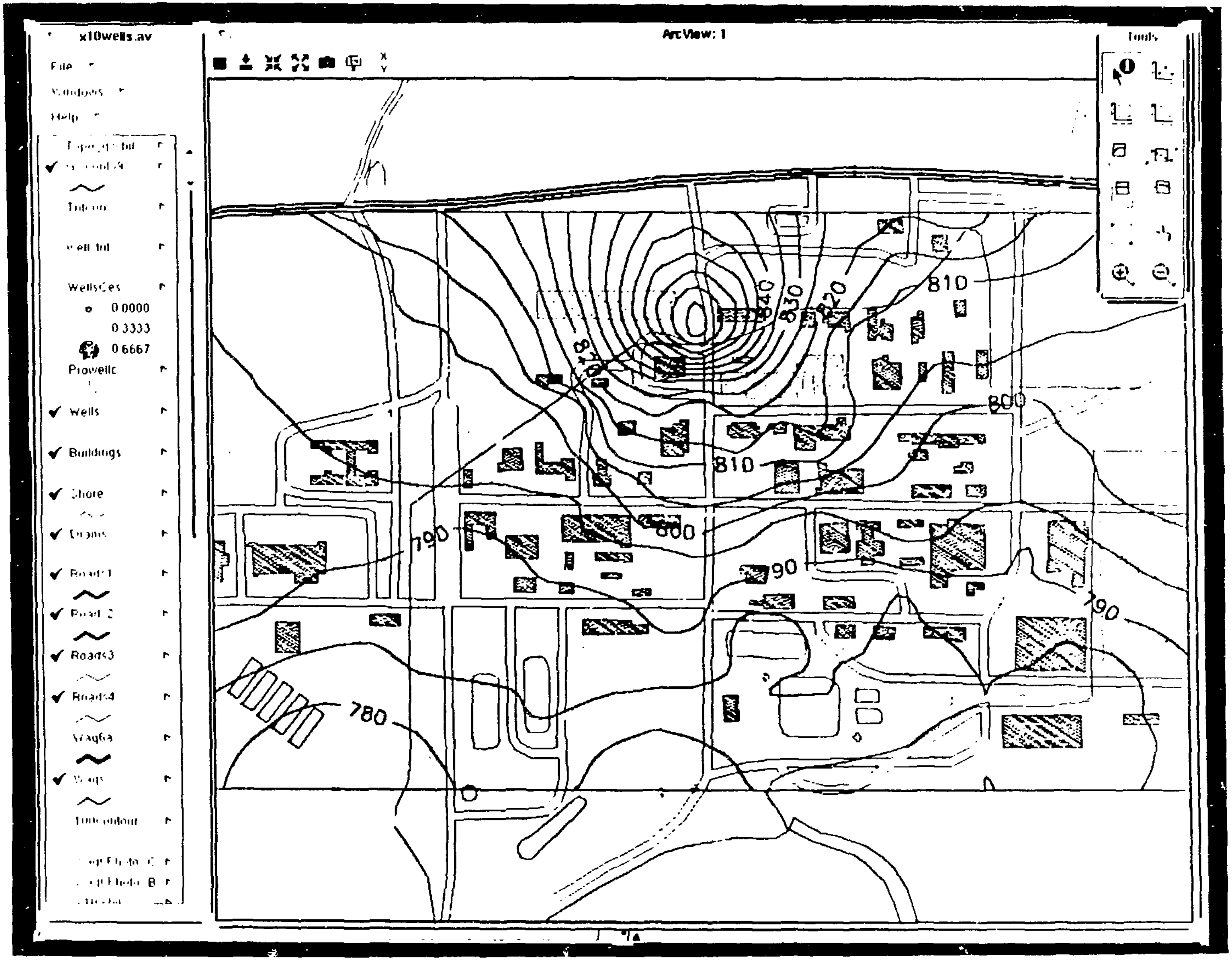

Figure 7. Sample contour map computed from monitoring well data to depict the general groundwater table for a selected time period within a portion of ORNL.

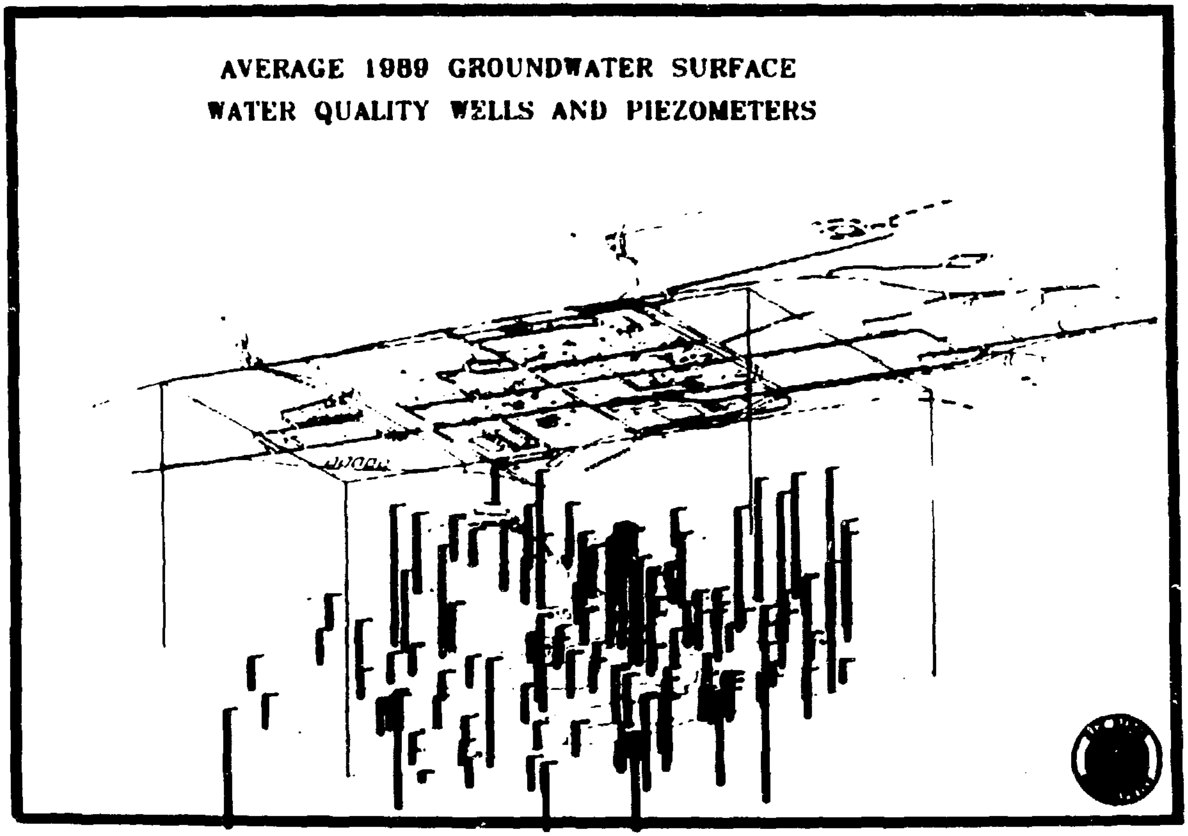

Figure 8. Three dimensional representation of groundwater contours, monitoring wells, and ground-level facilities (buildings, road, streams) for a portion of ORNL with the two layers separated for ease of viewing.

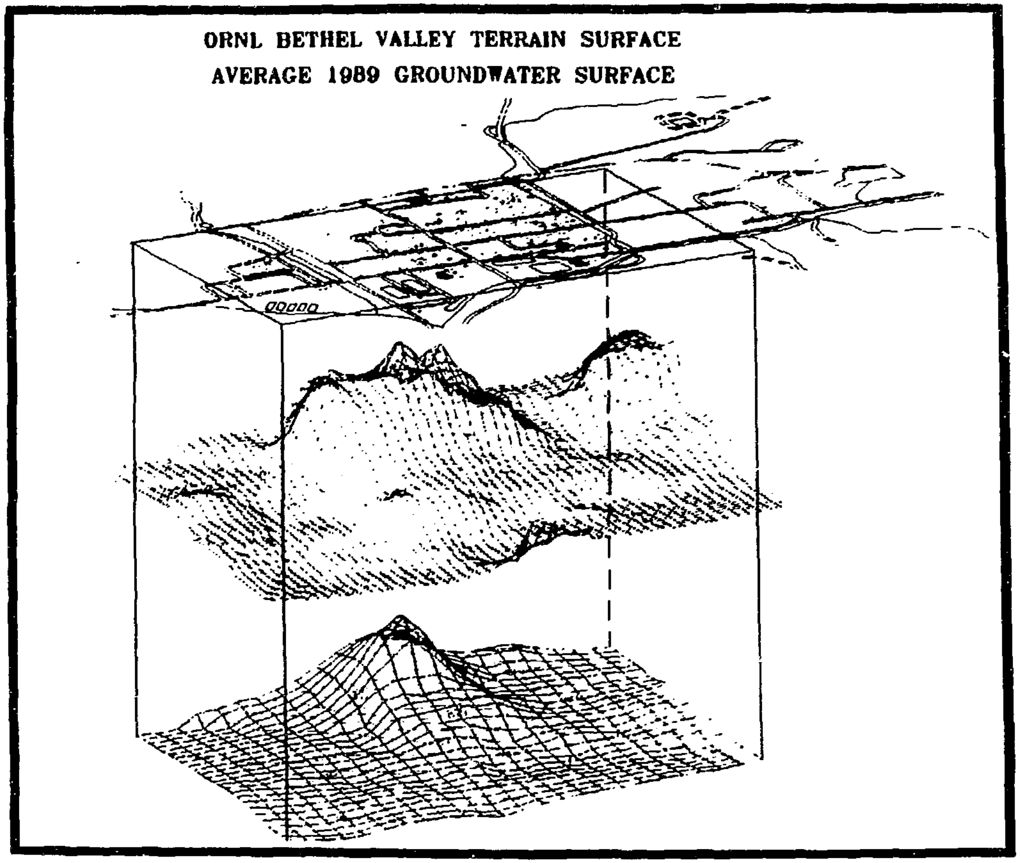

Figure 9. Three ORNL layers depicting ground-level facilities, computed topography, and a groundwater mesh.

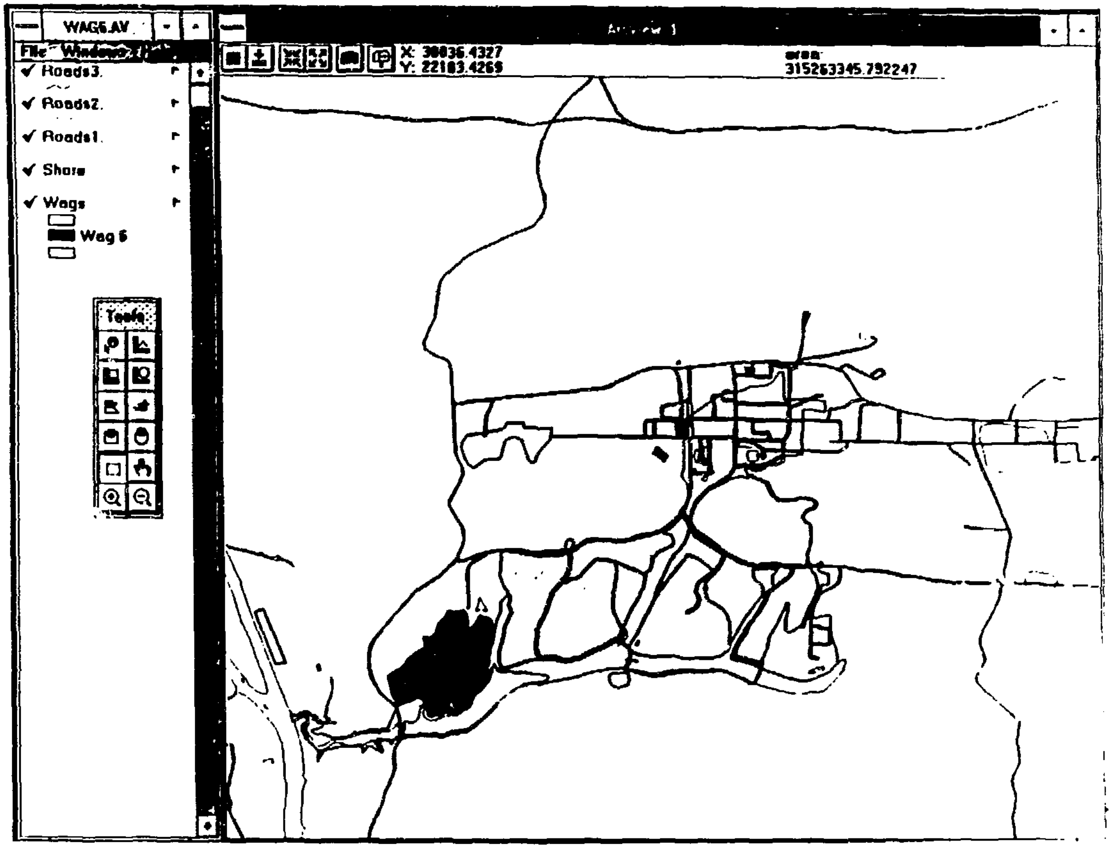

Figure 10. Map of burial grounds at ORNL highlighting the special Waste Area Grouping 6 (WAG 6) in the lower left corner.

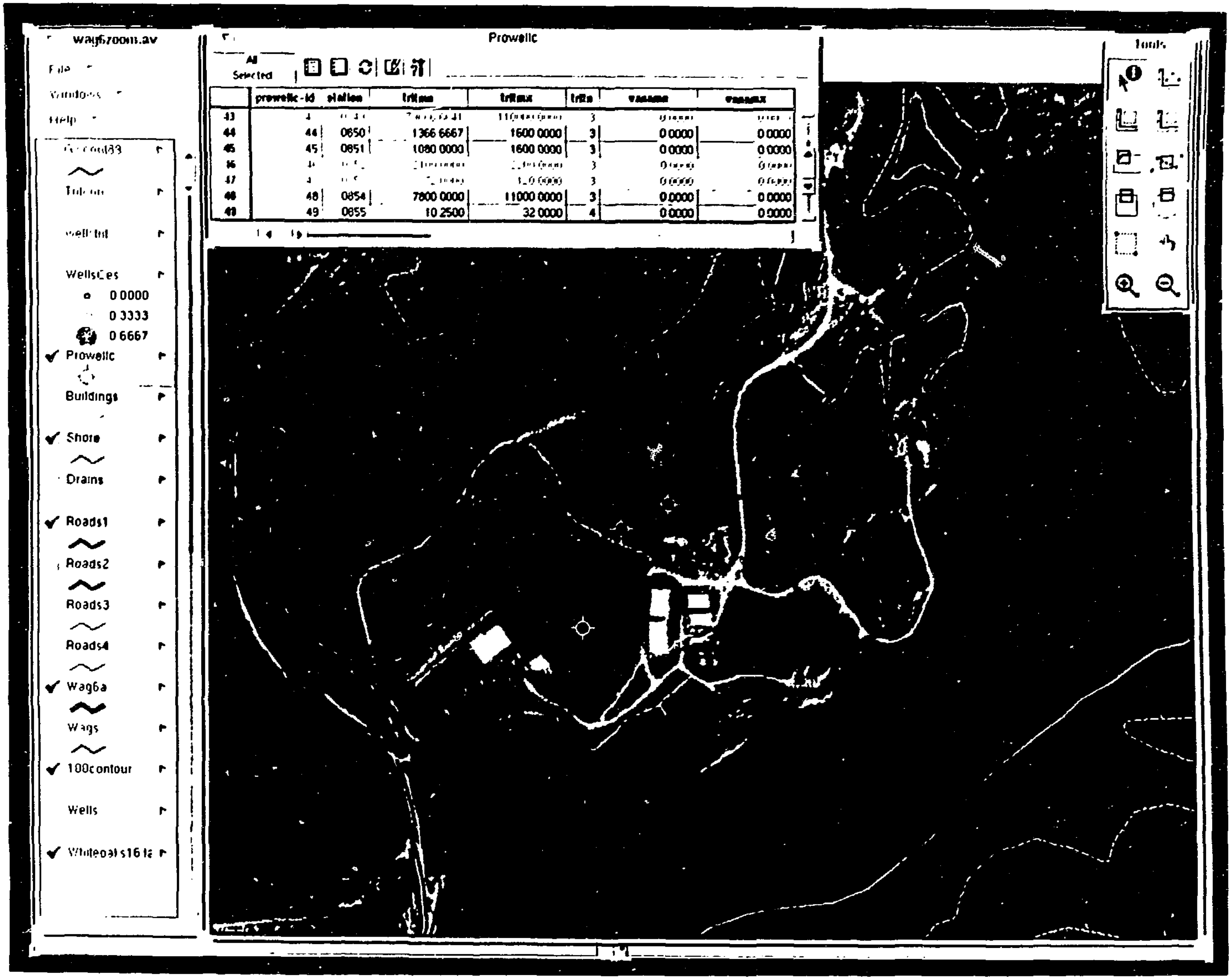

Figure 11. A sample GIS screen showing monitoring wells in WAG 6 mapped on top of rectified aerial photography and map data along with an interactive table of pollutant concentrations.

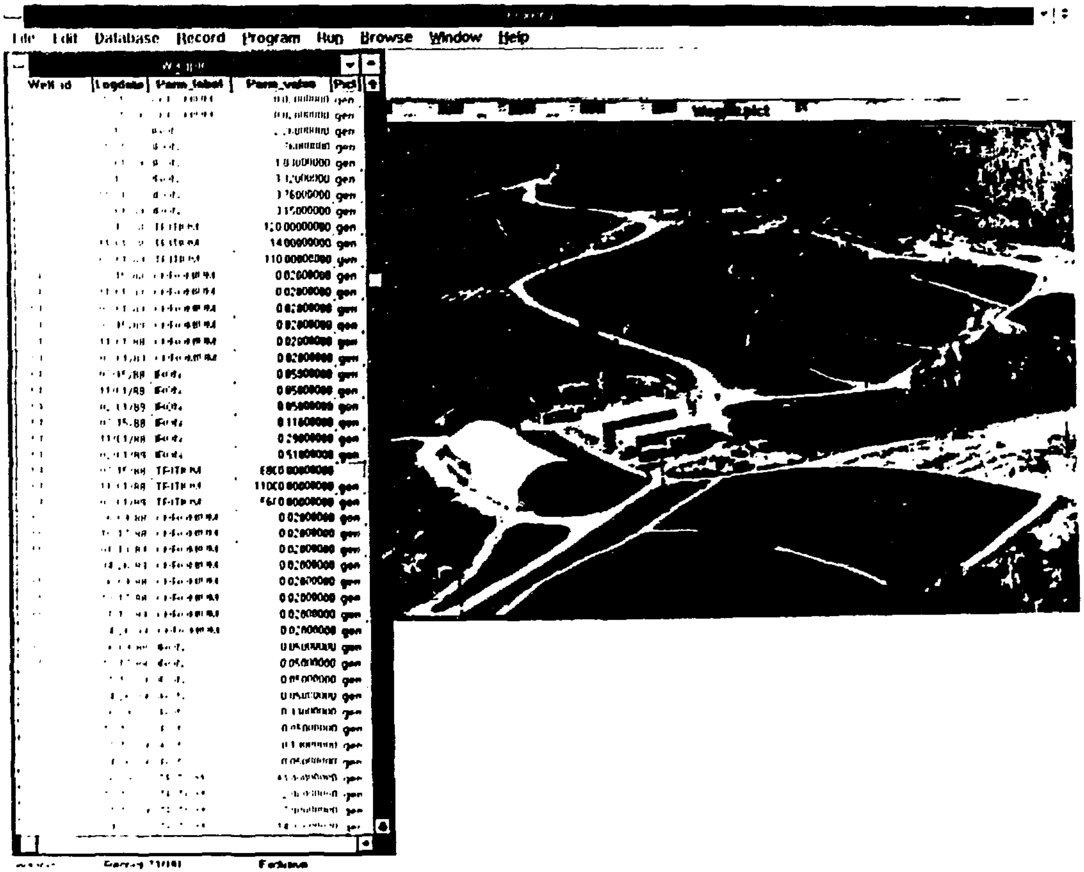

Figure 12. An example of incorporating images (e.g., graphs, pictures, and diagrams) as another retrievable data type within a tabular data base for WAG 6.

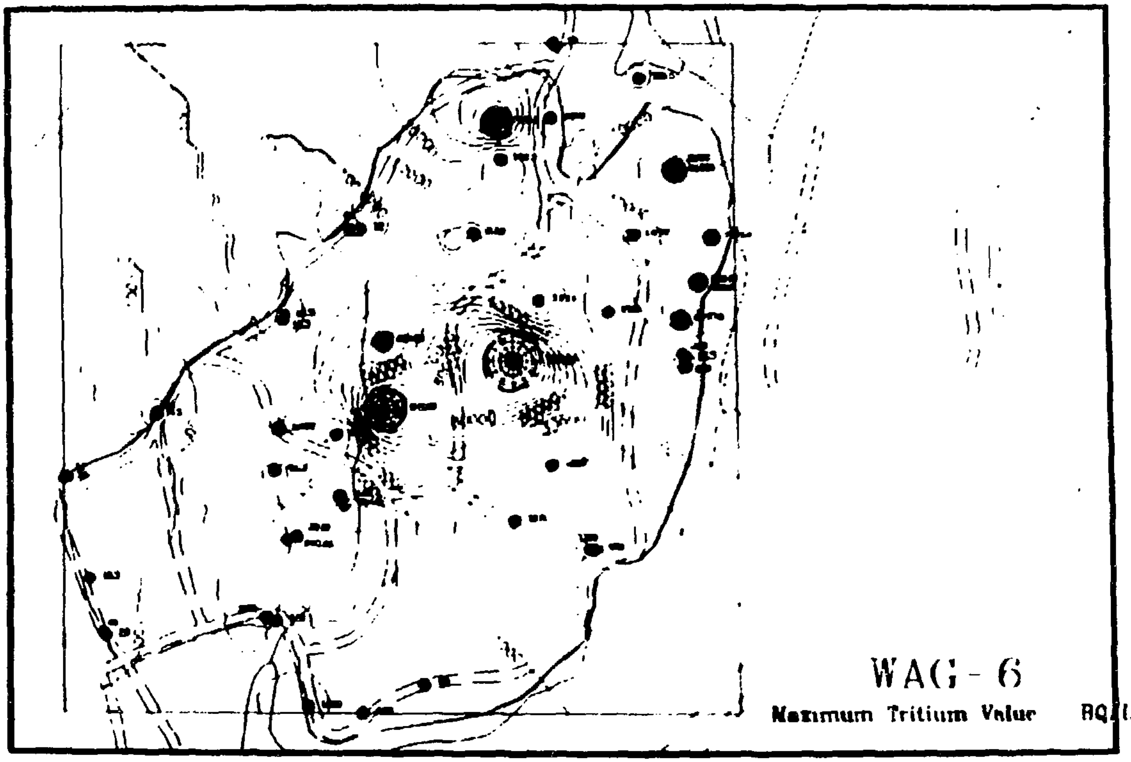

Figure 13. Computer-generated contours of maximum tritium readings for WAG 6 interploted from historical monitoring well data.

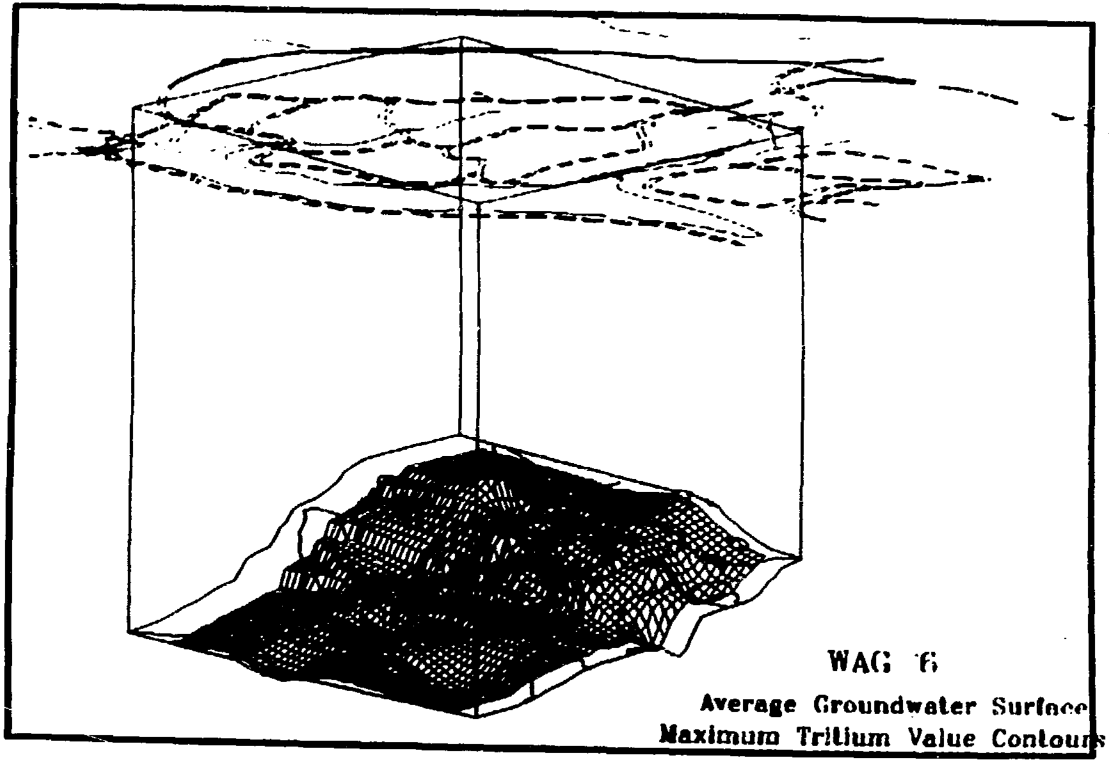

Figure 14. Three dimensional view of maximum tritium contours superimposed on a calculated groundwater surface beneath ground level features of WAG 6.

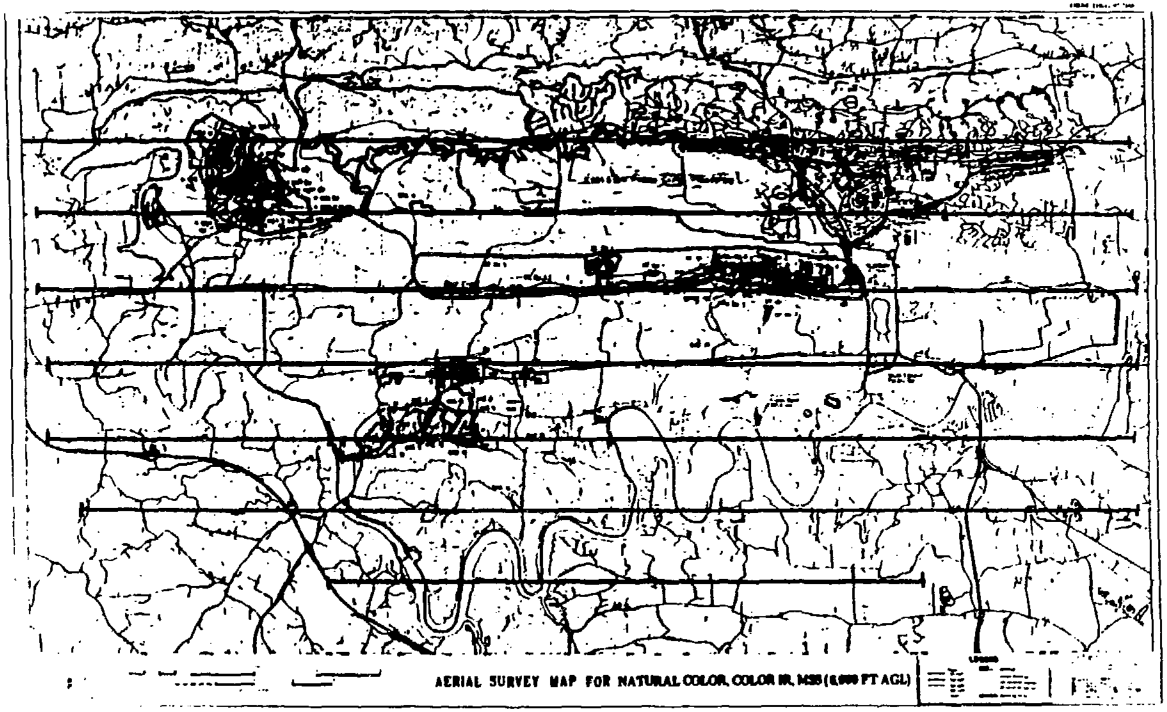

Figure 15. Typical flight paths flown over the Oak Ridge Reservation by jet aircraft conducting an aerial survey in April 1992.

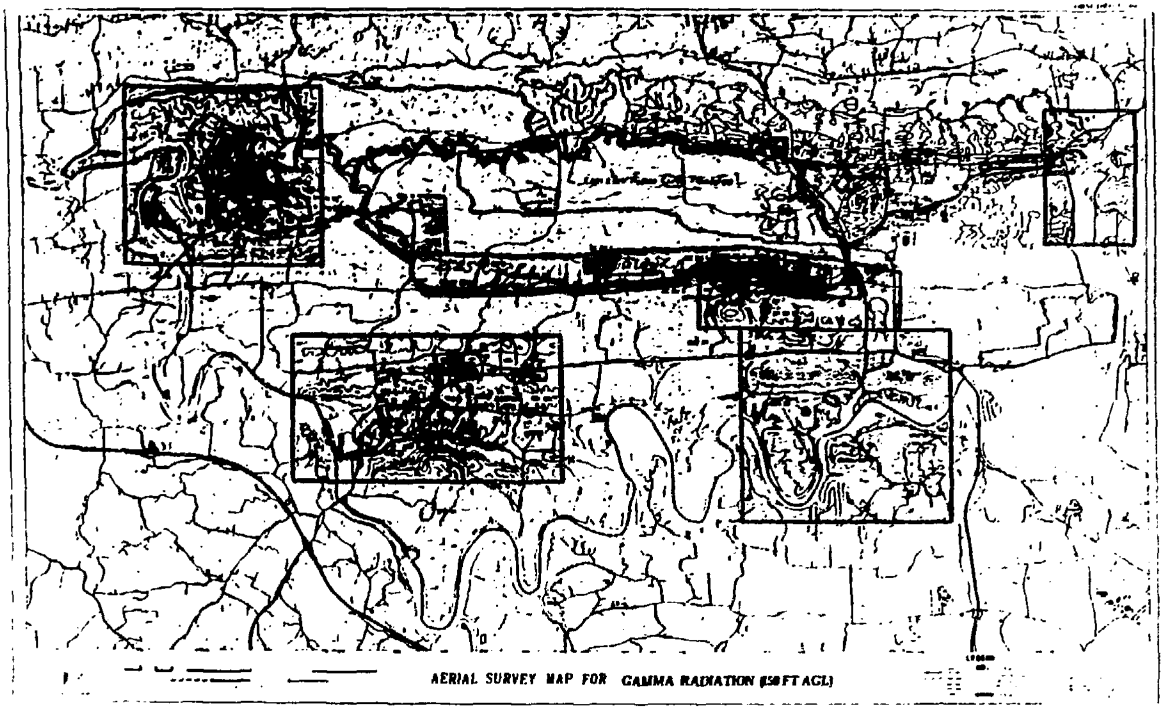

Figure 16. Designated study areas flown over the Oak Ridge Reservation by low altitude helicopter (150 feet AGL) for a gamma radiation survey in April 1992.

Figure 17. Very preliminary gamma radiation data superimposed as selected contours on a scanned aerial photo of the K-25 facility to aid in initial data validation and interpretation.

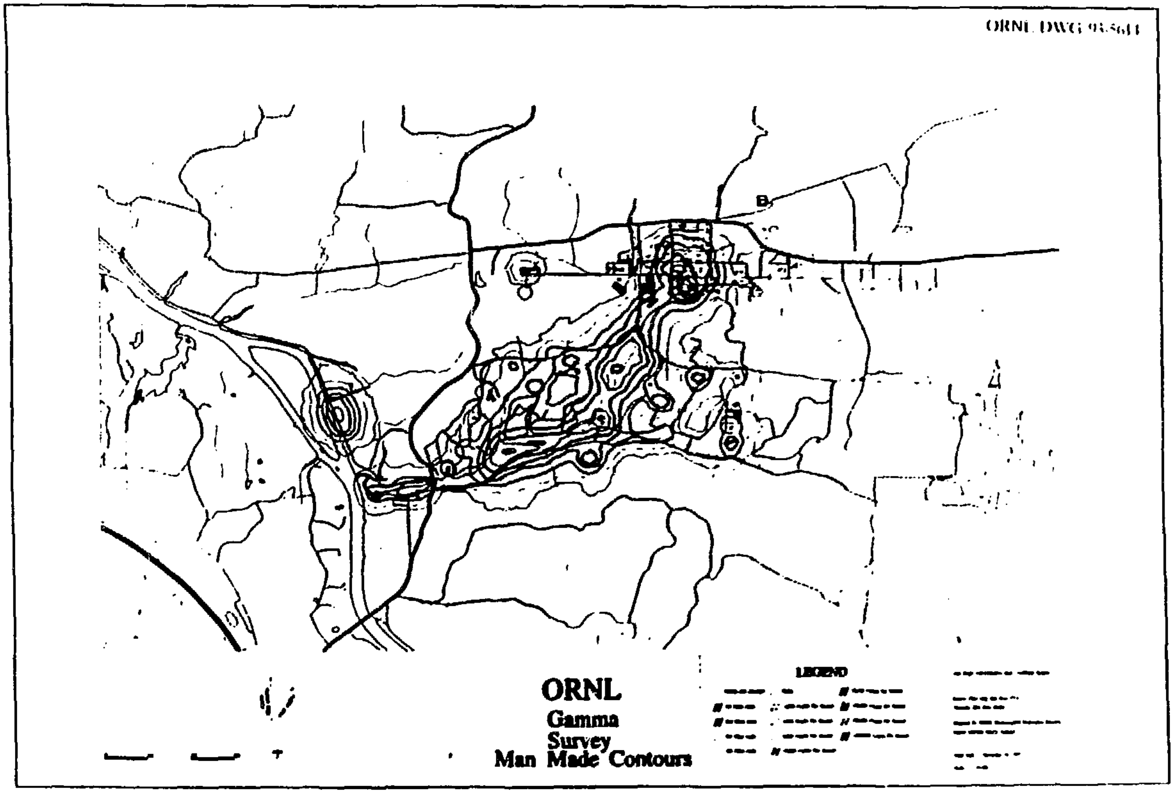

Figure 18. Gamma radiation contours computed from interim aerial survey data for man-made radionuclides at ORNL.

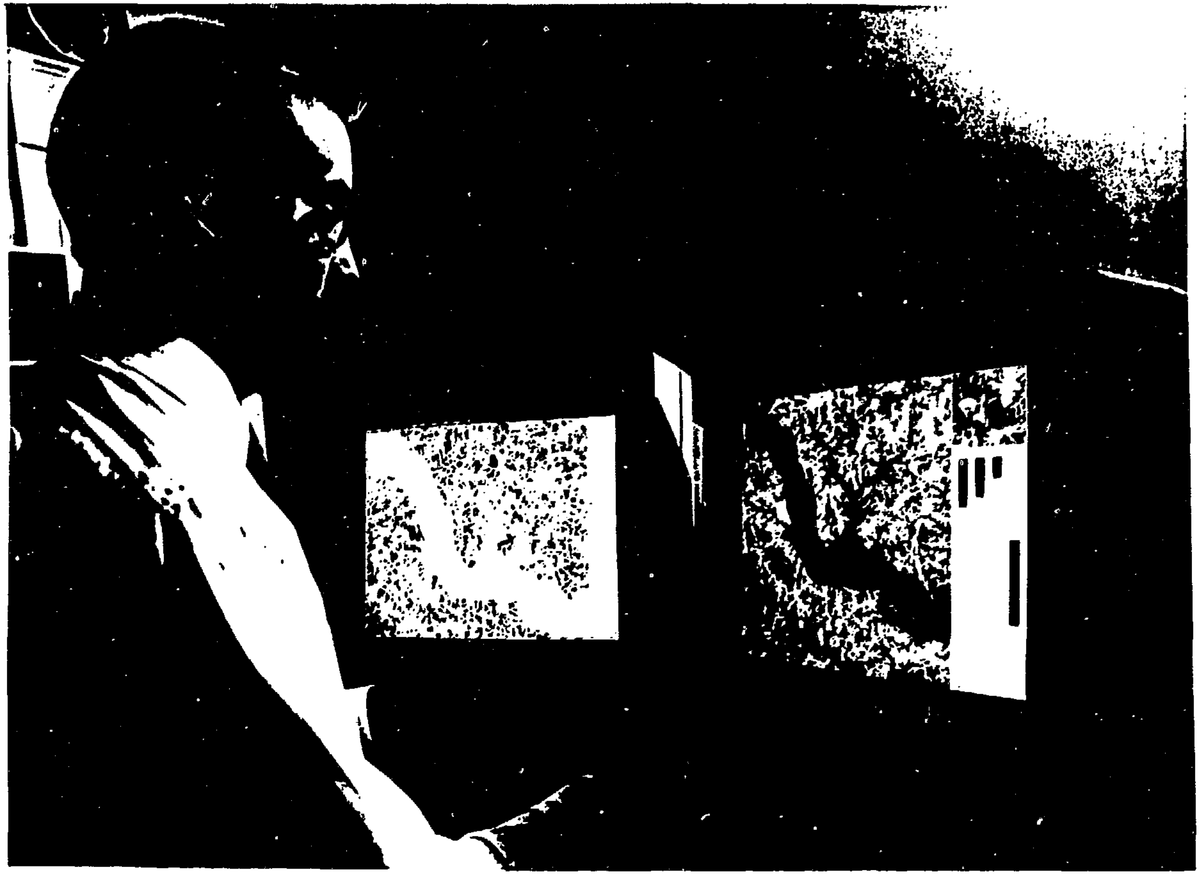

Figure 19. Hi-resolution image processing systems used to analyze aerial photography, multi-spectral scanner imagery, and other spatial data at ORNL.

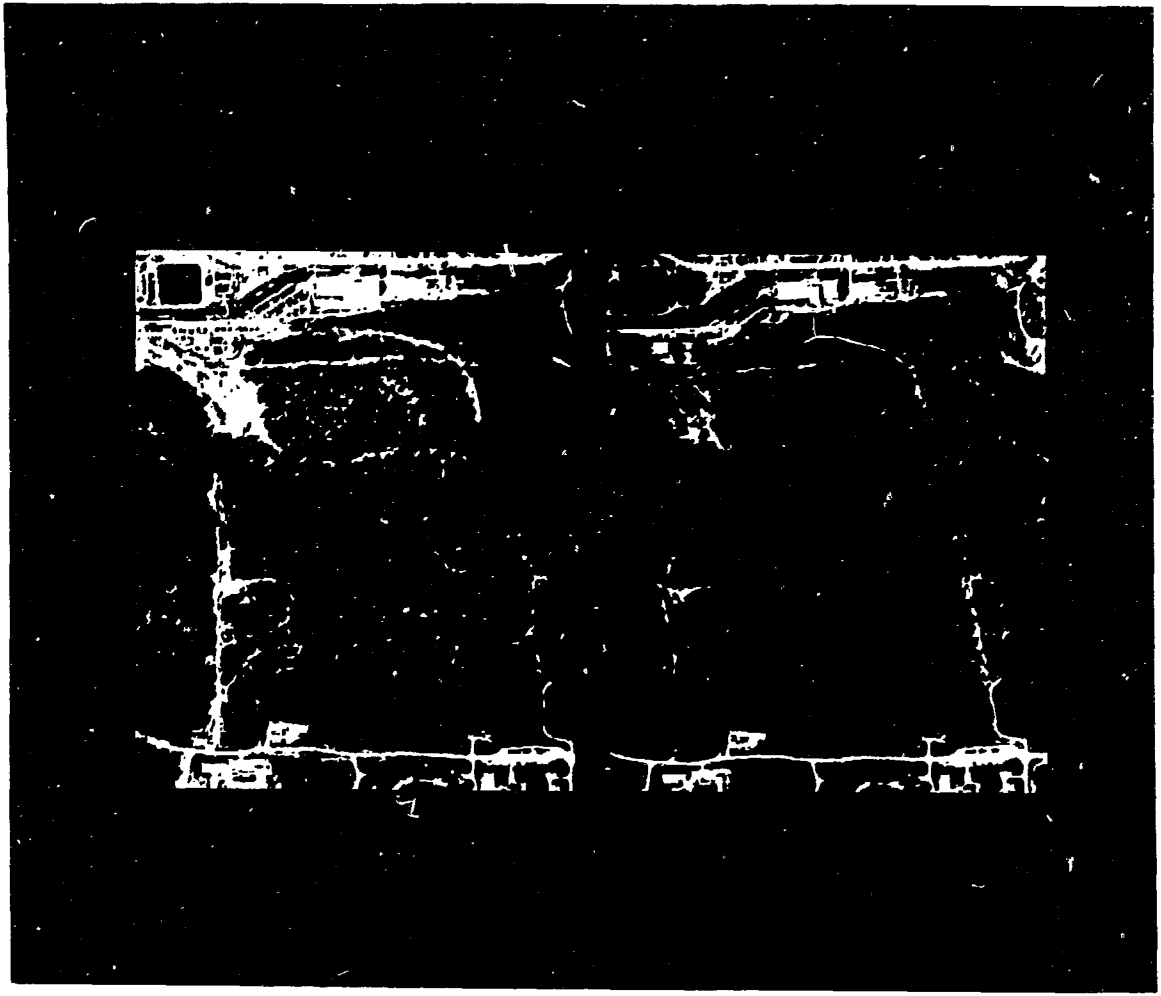

Figure 20. Example of geometric distortions in raw stereo imagery from color infrared photos taken from 3,000 feet AGL. Note the difference in curvature of the north-south linear feature on the right side of each frame.

Figure 21. Experimental ortho-photo mosaic computed for ORNL from extracts of 19 color infrared photos flown at 3,000' AGL.

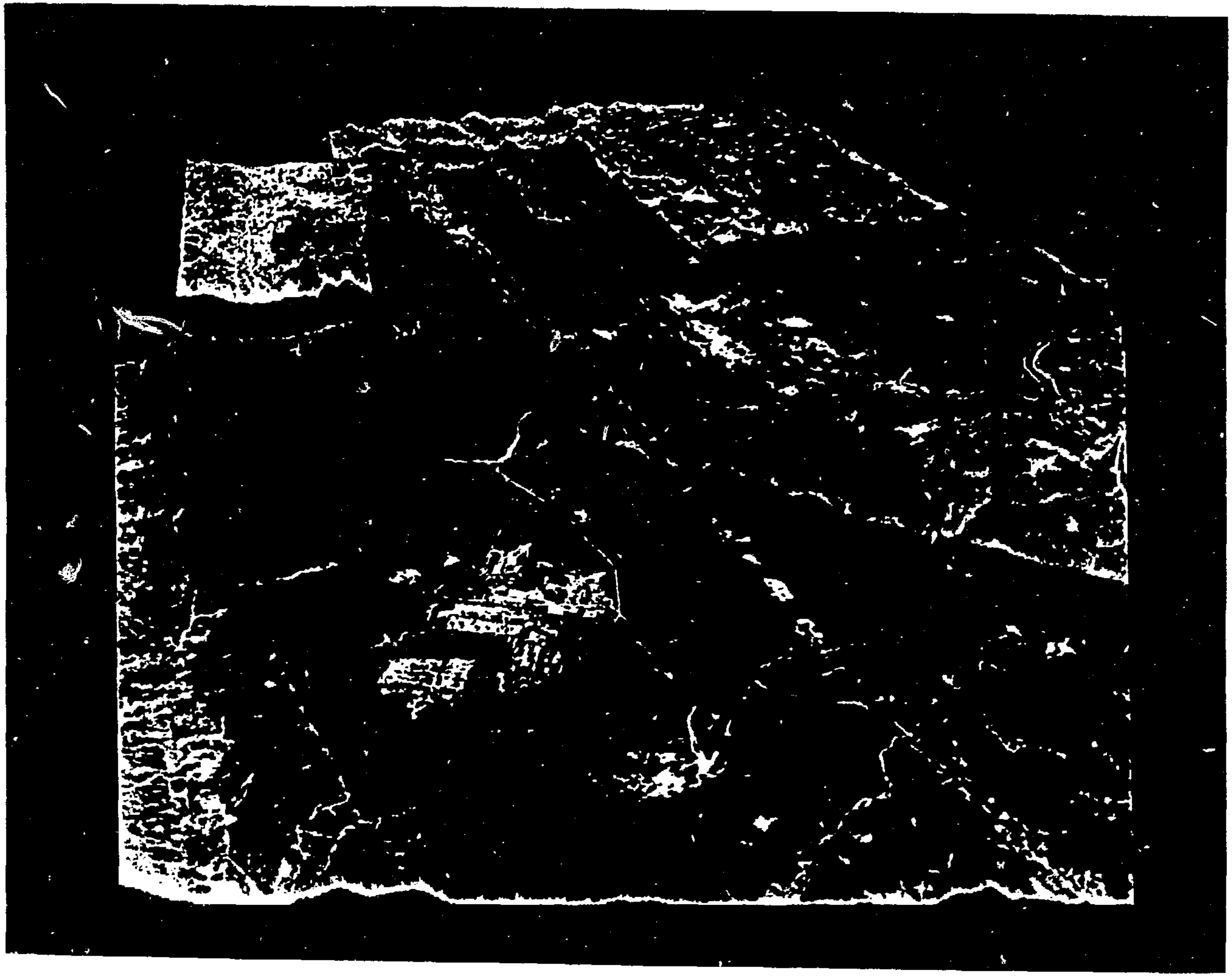

Figure 22. Three-dimensional perspective view of the ORR ortho-photo mosaic viewed from above the K-25 site across the reservation.

Figure 23. Gamma radiation contours from man-made radionuclides at ORNL superimposed on a 3-D perspective view of a color infrared ortho-mosaic depicting the burial grounds in the foreground.

Figure 24. Raw daytime multi-spectral scanner image for ORNL using three dominant bands from different parts of the spectrum.

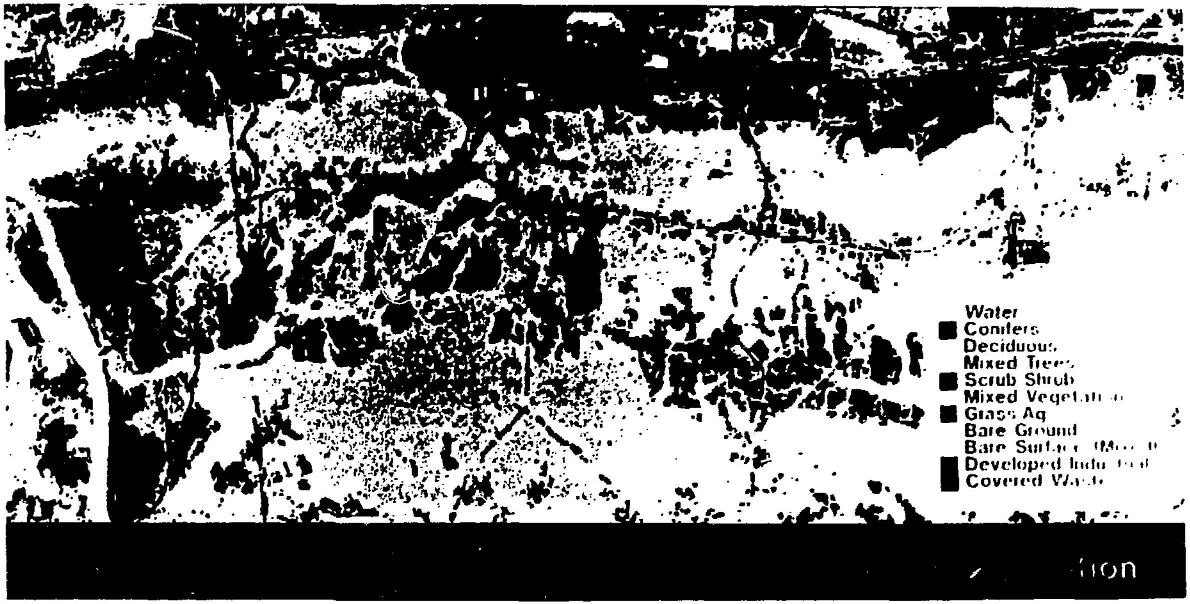

Figure 25. Preliminary landcover map with 11 classes computed for ORNL from 6 multi-spectral scanner bands using statistical imaging techniques.

Figure 26. Grey-level image depicting thermal intensities from pre-dawn MSS flights over the eastern edge of the Oak Ridge Reservation to aid in detecting seeps and springs. Thermal contours are superimposed on the image.

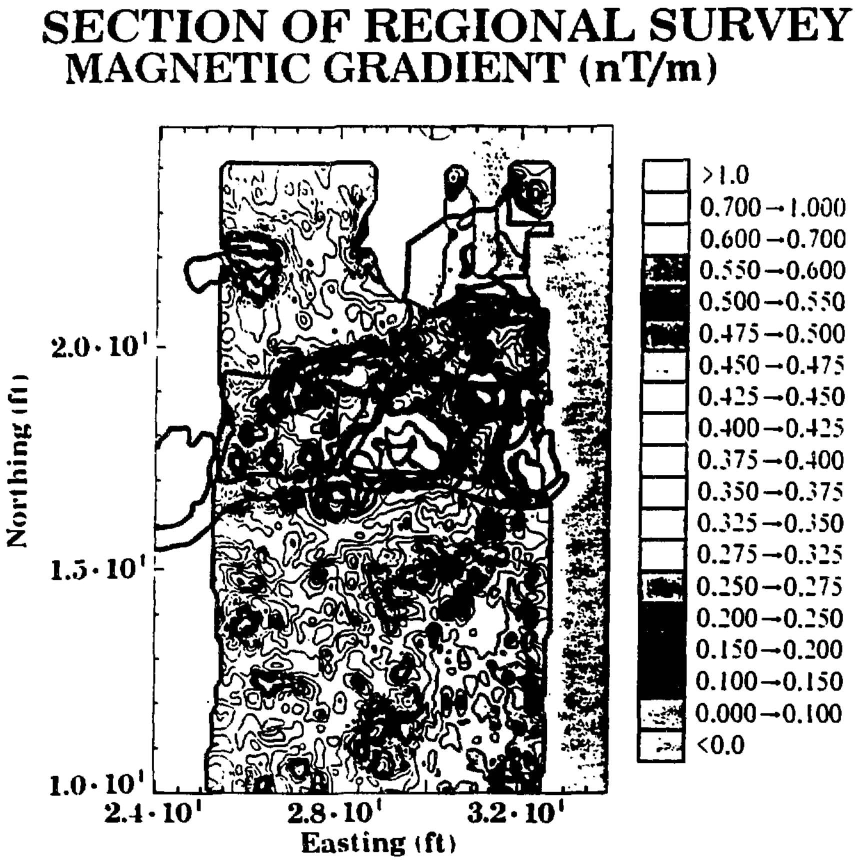

Figure 27. Vertical magnetic gradient contours computed from an airborne magnetometer for part of the burial grounds at ORNL showing high correlation with WAG areas containing buried metal and disturbed earth.

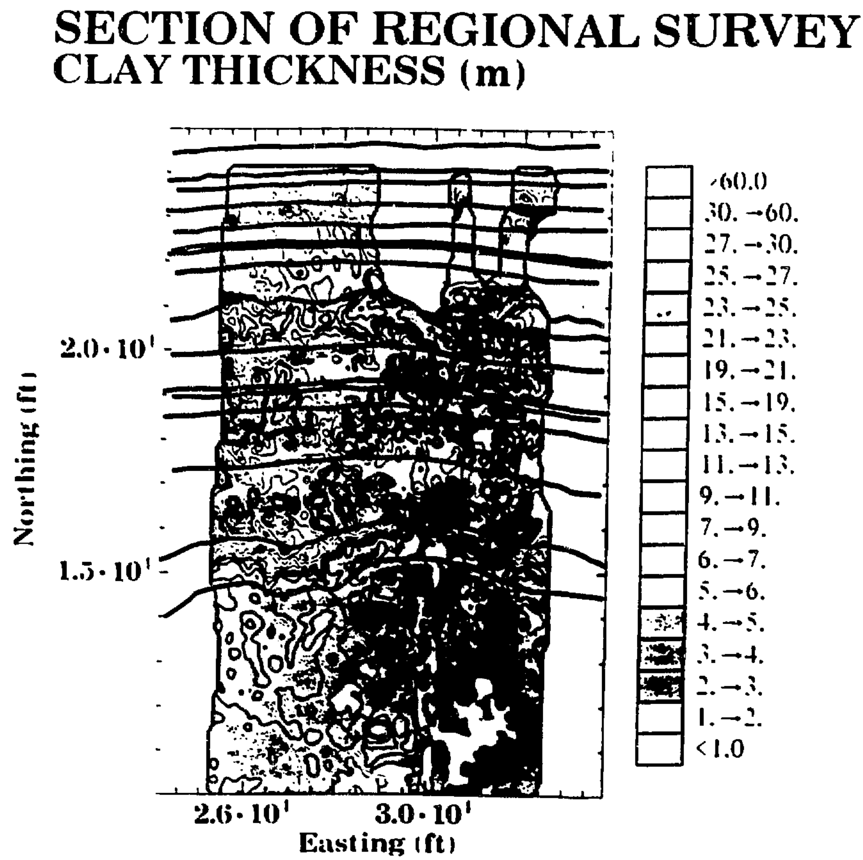

Figure 28. Predicted clay thickness computed from airborne electromagnetic measurements for part of the burial grounds at ORNL showing boundaries between limestone and shale bedrock very nicely.