Chapter 9
Remote Sensing

9-1. Introduction

a. Reasons for development. There are many reasons for the development of a historic land-use profile of sites as a tool for thorough evaluation of the site. Among these are: simple site characterization for project planning, soil conditions, water-land conditions, vegetation analysis, and U.S. Environmental Protection Agency (EPA) requirements such as "Superfund" activities. In addition, good common sense and "best practice" engineering require a thorough knowledge of the site characteristics, including both its historic use and the geotechnical properties of surficial materials. Current site-use parameter studies are comprised of these characteristics, along with indicators and interpretations of historic site development and use. Information recorded in the form of aerial photographs, airborne multispectral scanner imagery, and satellite-borne multispectral scanner imagery provides most of the available, useful, and reliable sources of this historic site development and use data when such data and interpretations are plotted on site base maps.

b. Requirements. Requirements for site characterization include such items as (a) site inspections, (b) site investigation, (c) remedial investigations, (d) cultural studies, (e) resource evaluations -- particularly soils, (f) habitat and vegetation studies, and (g) feasibility studies. Clearly, before such actions can be undertaken, the historic use of the site must be known. Valid historic land-use characterization and site descriptions are best developed where aerial photographs or scanner images have been recorded during previous site use. Ground-borne site characterization efforts can then be cost-effectively allocated to those portions of the site containing the greatest interest or concerns, while historically undisturbed portions or portions of little concern may be excluded from such detailed efforts, or verified as areas suitable for limited field exploratory and sampling work.

9-2. Capabilities of Remote Sensor Data

a. General.

(1) A well-constructed historic site characterization becomes the driving control for the nature, area, and extent of any newly planned land use or development at a site. Sub-areas of the site can be classified as needed. Surficial material properties (geotechnical properties) can be inferred from signatures interpreted from this remote sensor data.

(2) Aerial photography provides a cost-effective base map of the site. Photogrammetric topographic mapping is so relatively cheap in terms of other expenditures (*e.g.* environmental remediation work, which might cost from several hundred thousand to millions of dollars per site, in 1993 U.S. dollars), that this technique should always be considered. Most modern U.S. Geological Survey (USGS) topographic maps (1:24,000) are of insufficient scale and contour interval (3 and 6 m, 10 and 20 ft) to be of use in detailed site engineering analysis, design, and construction/operation.

(3) An approximate chronology of site activities is the first characterization step. Activity types and previous land use may be identified by photographic or image clues, such as open trenches, burning debris piles, ground and water discoloration, grading scars, vehicle tracks, and structure remains. The sequence of the disturbance and initiation and termination of activities at the site and at specific points on the site may be established within the time frames of the available sequential data sets. Such time frames range from 2 to 3 years up to 5 to 7 years, depending upon local land-use history and past and present development trends.

(4) Specific site activities can now be identified, within time periods, and located on the site base map as a direct guide to field investigation planning for detailed site exploration and sampling. The remains of buildings and other structures may be traced through time modifications and use modifications. Equipment used, material handling methods, and site preparation and abandonment procedures may be identified and evaluated. Changes in these parameters may be noted and many of the daily operational procedures can be interpreted from the evidence recorded on aerial photography.

(5) Offsite impacts of site development and use will be observable on the remote sensor data. However, the exact relationship between site activities and attendant changes adjacent to the site may be difficult to evaluate.

b. Data requirements for site characterization.

(1) Historic site use and general, surficial geotechnical characterization require a high degree of detail that is generally well within the normal resolving power of aerial photography collected under normal conditions. These resolution values of about 1 m (or, in the case of large-scale photography flown at low flying

heights, a fraction of a meter) are more than adequate for identification of features and identification of boundaries between material types. The scale of the photographs, images, and of existing maps requires careful consideration. Data collected at a common scale are most desirable. When portions of a data set must be enlarged to match scales of other data with the set, the resolution and detail of the enlarged data set are not equivalent to that of the larger-scale data.

(2) Since 1935, many improvements have been made in aerial photographic collection tools: cameras, lenses, and films. Thus, the data user must recognize the corresponding shortcomings in detail and quality when using historic aerial photography. Photographic data and electromechanical, multispectral scanner data must be mixed with the understanding that film data and scanner data are quite different in recorded spectral information, resolution, and detectability, and different in scale and geometry. Scale selection and data set merging (interpreted thematic maps at photograph and image scales and available or constructed maps) must be carefully considered. Notes and explanations must appear on the thematic maps, identifying ages and scales of the original data, and methods of change in scale, as well as the estimated accuracy of any finished product, with respect to actual field conditions. It is of utmost importance that no overrepresentation of quality be created by scale changes.

c. Limitation of remote sensor data.

(1) Remote sensor data record only those conditions at or near the terrain surface which influence electromagnetic spectral response. In particular, most historic data have been collected in the blue-visible wavelength (0.4 µm) to the reflective infrared (1.1 µm). Some expanded bands of collection have been made available with the development of electromechanical sensors, the multispectral scanner (MSS), since 1965. However, most of the available, easily accessed, and useful data for historic characterizations are film plate, visible spectrum, and reflective IR data. Although these data record only the details of the terrain surface or surface cover, proper interpretation of tones, patterns, textures, and vegetation provides primary information on geologic and other conditions at some limited depth.

(2) The groundwater regime is one of the most important site characteristics. Remote sensor data have limited application for this type of evaluation of the site, aside from the interpretation of moisture variations based on tone or vegetative response. Some interpretations may be made with respect to the vegetation response or stress where ground examination of vegetation and soil and water conditions are confirmed to be related to the vegetative stress. Aside from such an indirect means of correlation, groundwater quality and quantity are not particularly extractable from remote sensor data.

(3) Use of remote sensor data for the identification of waste bodies or caches, leachate, or slightly polluted water on the site requires ground-truth verification. Physical facilities, vegetative types, machinery, stock piles, and other items which possess specific shape, pattern, form, erosional features, and so forth, are easily and reliably identified, but more detailed identification of nondescript features without ground examination is risky at best.

(4) Infrequent historic remote sensor coverage over the site, using comparable systems and recording media, may be either limiting or desirable, depending upon the exact study requirements. Historic photography collected for the purpose of topographic map construction will have been collected during leaf-down, nongrowing season conditions, thus yielding minimal information about the vegetative cover and its growth vigor, but allowing for maximum observation of the actual terrain surface conditions. Color-infrared (CIR) photography is generally collected during the peak of the growing season and is most useful for identification of disturbed areas, water/land boundaries, and vegetative characteristics.

(5) The user is clearly limited by having only that site information available on the specific date of the exposure and by the specific weather, vegetative growth, soil moisture, and other conditions at that time. These factors influence terrain contrast, as do atmospheric effects at the flight time and must be considered when evaluating the available photography or imagery. Ground checking of interpreted information from recently or currently acquired remote sensor data is absolutely necessary. Joyce (1978), although a bit dated, provides guidelines for this procedure using Landsat MSS data; these guidelines apply to other types of remote sensor data.

(6) The scales, system, film-resolving properties, and instantaneous field of view of a scanner and its flight line height are factors which control the amount of available detail on a given data set. These factors control the use of data and must be evaluated with respect to all available materials and the scale at which interpreted information is to be displayed as a final thematic map or other product. The problem of implied resolution or detectability that exceeds the capability of the data collection system must always be addressed in any interpretive reports. Lillisand and Kiefer (1994) provide a thorough explanation of how

to calculate resolving and detecting capabilities for remote sensing data.

9-3. Characteristics of Various Remote Sensor Data

The remote sensing literature is filled with extensive listings of the characteristics and capabilities of various data sets--both aerial photography and scanner collected. Table 9-1 (Eastman Kodak 1982, 1983) summarizes film sensor capabilities for characterization of historic land-use and geotechnical evaluation.

a. Aerial photography—camera-film systems. Camera-film systems have many similar characteristics regardless of film type. Different film types enable the same camera system to capture a different set of spectral data. The three common aerial films are panchromatic (black and white), commonly called "pan," natural color, and CIR.

(1) Panchromatic film.

(a) Panchromatic films are most frequently used. These films are sensitive to the visible spectrum; however, in order to eliminate effects of haze and blue scatter from the atmosphere, these films are usually filter exposed only to the visible green and red light wavelengths, that is, minus-blue exposure. This enables the film to record the tonal variations of soil and rock, as well as limited information regarding vegetation. The film is reliable for identification of land forms, erosional and depositional features, water/land boundaries, disturbed land, and all kinds of man-made features.

(b) Historic pan photography frequently has resolution and interpretability similar to that of modern photography, but requires consideration of the effect of exposure conditions in terms of weather, soil moisture, and vegetative conditions at the time of exposure. These conditions have significant impact on terrain contrast, resolution, and the contrast of film prints. Historic climatological data for most U.S. locations are available from the National Oceanographic and Atmospheric Administration (NOAA).

(2) Color-infrared film.

(a) Color-infrared (CIR) films have been increasingly used since the 1960s for land-use mapping and evaluation of vegetation types and growth characteristics. CIR films are generally sensitive to visible blue through the reflective infrared wavelengths (about 0.4 to 1.2 µm). These films are used with an orange filter, thus eliminating collection of information at wavelengths shorter than the visible green in order to minimize atmospheric effects and to make available a false color reproduction scheme for the reflective IR spectral response.

(b) The major advantage of CIR film processing is that atmospheric effects are reduced by complete elimination of blue light and haze leaving the reflective IR radiation enhanced so as to show the degree of growth vigor or vegetation stress. The reproduction of the terrain observed is normally made in a false color manner: the visible green response is reproduced in blue tones, the visible red response is reproduced in green tones, and the reflective IR response is reproduced in red tones.

(c) Many notable terrain features are easily interpreted from this film or its products. CIR film resolution is adequate to evaluate and identify features critical to site characterization, such as the following: presence and quality of vegetative growth; identification of land/water boundaries and recognition of turbid water, variations in soil, rock, or granular materials; and moisture content variations in exposed soil and rock.

(d) Transport of some waterborne contaminants, as noted by stressed vegetation, is most interpretable from CIR photography. Inventories of vegetative species and habitat are also most easily accomplished using CIR photography. In addition, the advantages of color tones over gray tones (or pan photography) enable the human interpreter to consistently distinguish and identify many more tones.

(3) Natural color film.

(a) Natural color films have the sensitivity to collect data in the visible spectrum and to produce a latent recording exactly as the human eye would view the site over the range of the visible spectrum. Only haze filtering is used in the exposure of these films. This filtering is done to provide maximum contrast without the clouding of the film due to the blue light scatter of the atmosphere.

(b) However, the fact that natural color films are exposed to the blue wavelength range of light severely limits the length of the atmospheric path through which the terrain-reflected radiation can travel and adequately create a high-contrast exposure. In comparison with minus-blue exposures, pan film, and CIR film, natural color film is limited from the standpoint of quality of data recorded and flying height for the mission. The principal result is that natural color film must be exposed under

Table 9-1
General Characteristics of Aerial Film (modified from Eastman Kodak (1982, 1983))

Kodak Film Type	Film Number	Sensitivity	Description and Applications	Resolving Power, lines/mm T.O.C., 1000:1[a]	T.O.C., 1.6:1[a]	Diffuse RMS Granularity[a]	Kodak Literature References (Other than M-29)[b]
Plus-X Aerographic (Estar base)	2402	Panchromatic (with extended red)	Medium-speed, high dimensional stability for aerial mapping and reconnaissance	160	50	20	M-45
Tri-X Aerographic (Estar base)	2403		High-speed, high dimensional stability for aerial mapping and reconnaissance under low levels of illumination	100	40	40	M-24
Double-X Aerographic (Estar base)	2405		Medium-speed to high-speed, standard film for mapping and charting- high dimensional stability	125	50	26	M-75
Panatomic-X Aerographic 11 (Estar base)	2412		Intermediate-speed, very fine-grain, medium-altitude to high-altitude mapping and reconnaissance film; suitable for small negative formats	400	125	9	M-112
Panatomic-X Aerecon 11 (Estar thin base)	3412		Similar to 2412; thin base for increased spool capacity; for medium-altitude to high-altitude reconnaissance	400	125	9	M-112
Plus-X Aerecon (Estar thin base)	3411		Medium-speed, fine-grain, medium-altitude to high-altitude reconnaissance film	160	50	28	M-116
High-definition aerial (Estar thin base)	3414		Thin-base, slow-speed, high-definition film for high-altitude reconnaissance	800	250	8	M-73
Infrared Aerographic (Estar base)	2424	B & W IR	Reduction of haze effects, water location, vegetation surveys, and multispectral aerial photography	125	50	27	M-58
Aerochrome infrared (Estar base)	2443	Color IR	False-color reversal film, high dimensional stability for vegetation surveys, camouflage detection, and earth resources	63	32	17	M-69
High-definition Aerochrome infrared (Estar thin base)	S0-131[c]		Slow-speed, high-definition, false-color reversal film for high-altitude reconnaissance; high dimensional stability	160	50	9	. . .
High-definition Aerochrome infrared (Estar ultrathin base)	S0-130		similar to S0-131; ultrathin base for maximum spool capacity; for high-altitude reconnaissance	160	S0	9	. . .
Aerocolor negative (Estar base)	2445	Color	High-speed, color-negative film for mapping and reconnaissance	80	40	13	M-70
Aerochrome MS (Estar base)	2448		Color-reversal film for low-altitude to medium-altitude aerial mapping and reconnaissance	80	40	12	M-113
Aerial color (Estar thin base)	S0-242		Slow-speed, high-resolution color-reversal film for high-altitude reconnaissance	200	100	9	M-74
Ektachrome EF Aerographic	S0-397		High-speed, color-reversal film for aerial mapping and reconnaissance	80	40	13	M-78

[a] The image structure characteristics of the black and white camera acquisition films are based on processing in a Kodak Versamat film processor, Model 11.

[b] Kodak Publication No. M-29 141 refers to all the films listed.

[c] Films having an SO designation represent averages for relatively few coatings and are the best available data at the time of printing. Future coatings may show variations as products are improved to meet changing customer requirements.

only ideal sky or atmospheric conditions and at low-flying heights (say, less than 1,000 m) or large scales. A large scale increases interpretation problems because of parallactic distortion by the camera lens system.

(c) Potential uses of natural color film include identification of water bodies, tone variations in water bodies, dense vegetation versus disturbed areas, evaluation of man-made features, and site layout or siting studies — particularly useful at public hearings.

b. Electromechanical scanner system imagery. Electromechanical scanner systems have been used to collect radiation reflected and radiated from terrain. These systems have been borne by both aircraft and satellites. The EPA Environmental Monitoring Systems Laboratory aircraft MSS is a well-known example of one of these systems. Recently the National Aeronautics and Space Administration (NASA) has successfully orbited the thematic mapper (TM) scanner system on Landsat V. The basic specifications of these electromechanical systems are summarized in Table 9-2.

(1) All electromechanical scanner systems have the same basic operational and data display characteristics. Essentially, the scanner system receives radiation from scan lines, oriented perpendicular to the flight path. These data are electronically "chopped" into small units usually of a length approximately equal to the scan line width. Radiation from these small units, called picture elements or pixels, is divided into wavelength bands, and the average intensity of the radiation received for each band is measured by a detector. This magnitude is, via electronics, converted into a digital value and recorded. The pixel size is thus a function of the optical system of the scanner and the flying height. Radiation intensity values are averaged over the entire pixel and then recorded.

(2) *Detectability* applies to the detection and identification of individual targets, in terms of their dimensions and spectral characteristics. This feature of scanner data is significantly impacted by many terrain factors [for example, contrast, reflectivity, moisture content, and pixel composition (what exists within the pixel area on the terrain)], as well as atmospheric transmission of the energy, and the operational condition of the sensor. It is generally accepted that features 2 to 3 pixels in size and homogeneous in composition and spectral characteristics may be reliably and repeatedly identified. Spectral reflections of certain small features or targets with great contrast will also be recorded by a scanner. This brighter target frequently is misrepresented by the mechanism of data collection. For example, 8-m-wide graveled roadbeds in Iowa's cornfields frequently reflect such large quantities of radiation that the Landsat MSS data will record 57- by 79-m pixels of road signature. Scanner data are often limited by loss of detail when highly reflective terrain materials obscure less-reflective terrain materials in the pixel area.

(3) The nature of multispectral data makes them attractive for land-use and surface character analysis. By selectively evaluating responses; in particular, spectral bands of scanner data, interaction of responses in various bands, or other processing techniques, the interpreter can select and study the spectral responses in a unique fashion for any site. Such unique spectral responses are not easily studied from film-plate data. Spectral enhancement techniques enable the interpreter to analyze rather unusual spectral characteristics and study features or spectral responses which are otherwise overlooked or never detected on film-plate data.

(4) A major limitation of multispectral image interpretation is the requirement for a computer system to process the scanner data. Software must be tailored to processing exact types of multispectral data. Landsat MSS data manipulation requires digital techniques conceptually similar to aircraft MSS data, but the exact manipulation is quite different.

(5) A major advantage of Landsat MSS and TM data lies in its repeated (as frequently as 8- or 9-day intervals) coverage of any site. MSS data have been available worldwide since 1973. Other sources of satellite-acquired data, such as SPOT, fall into this group. The availability of this coverage provides an opportunity to view the spectral characteristics as they change with seasonal conditions and as the site has historically evolved. This advantage is complicated, though, by 2- to 3-acre detectability and the problem of data absence for possibly critical time periods. Also, MSS data come in large packets; an entire 185- by 185-km (115- by 115-mile) frame is the minimum purchase quantity.

c. Base maps. The process of developing a site use or geotechnical characterization starts with selection or construction of a base map, which includes not only the site but also such adjacent terrain as may be influenced by offsite effects and potential site remediation activities.

(1) The most abundant supply of available maps with measured accuracy is the various series of USGS topographic maps. These maps are constructed to meet

Table 9-2
Spectral Sensing Characteristics of Various Platforms (modified from ASTM (1988))

Band	Spectral Range: Wavelength (μm)	Spectral Range: Color	General Applications
Landsat Multispectral Scanner (element size is 57 x 79 m)			
4	0.5 to 0.6	Green	Greatest potential for water penetration; shows some contrast between vegetation and soil
5	0.6 to 0.7	Lower red	Best for showing topographic and overall land-use recognition, especially cultural features, such as roads and cities, bare soil, and disturbed land
6	0.7 to 0.8	Upper red to lower infrared	Tonal contrasts reflect various land-use practices; also gives good land/water contrast
7	0.8 to 1.1	Near infrared	Best for land/water discrimination
Landsat Thematic Mapper Scanner (element size is 30 x 30 m)			
1	0.45 to 0.52	Blue	Designated for water body penetration, making it useful for coastal water mapping. Also useful for differentiation of soil from vegetation, and deciduous from coniferous flora
2	0.52 to 0.60	Green	Designed to measure the visible green reflectance peak of vegetation for vigor assessment
3	0.63 to 0.69	Red	Chlorophyll absorption band important for vegetation discrimination
4	0.76 to 0.90	Reflected infrared (IR)	Useful for determining biomass content and for delineation of water bodies
5	1.55 to 1.75	Reflected IR	Indicative of vegetation moisture content and soil moisture. Also useful for differentiation of snow from clouds
6	10.40 to 12.50	Thermal (emitted) IR	Thermal infrared band of use in vegetation stress analysis, soil moisture discrimination, and thermal mapping
7	2.08 to 2.35	Reflected IR	Band selected for its potential for discriminating rock types and for hydrothermal mapping
EPA Airborne Multispectral Scanner System IFOV of 1.5 mrad (element size is height- and IFOV range- dependent)			
1	0.38 to 0.44	Violet	See information above: TM bands and these bands have the same applications
2	0.44 to 0.47	Blue	
3	0.495 to 0.535	Cyan to green	
4	0.54 to 0.58	Green to yellow	
5	0.58 to 0.62	Yellow to orange	
6	0.62 to 0.66	Orange to red	
7	0.66 to 0.70	Red	
8	0.70 to 0.74	Far to near infrared	
9	0.76 to 0.86	Reflected IR	
10	0.97 to 1.06	Reflected IR	
11	9.50 to 13.50	Thermal (emitted) IR	

National Map Accuracy Standards and are field checked to assure compliance. The use of these maps is severely limited for waste-site-specific studies because of scale and contour interval demands. The largest scale USGS topographic map available in a standard series is the 7-1/2-min series at a scale of 1:24,000 (1 in. to 2,000 ft). Contour intervals vary with relief on the map sheet but are seldom less than 3 m (10 ft) and may be as large as 13 m (40 ft).

(2) Scales and contour-interval limitations become significant when studying a typically small site of only 4 to 6.5 ha (10 to 40 acres). Methods that might be used to

provide larger scale maps include site surveys, photogrammetric map-making from specific flight-line photography, and enlargement of existing maps. Photogrammetric base maps can be compiled in a matter of weeks, at relatively low cost in comparison with site survey mapping. Photographic interpretation and mapping at existing large-scale photographic scales serve as means of construction of an uncontrolled base map, which must be carefully field checked if it is to be a basis for measurements and calculations or designs.

(3) Enlargement of existing maps which meet National Map Accuracy Standards may be accomplished by many methods: through photographs; through the use of enlarging equipment and drafting, such as Map-o-Graph and zoom transfer scope; or, by grid or slave plotting procedures. The recommended upper scale limit for such enlargements has been determined by the USGS Mid-Continent Mapping Center to be two times, that is, 1:24,000 to 1:12,000; an enlargement of two times is recommended only when it is accomplished in a quality-controlled fashion by means of large-format photographic methods. Without any added information, such as additional contour lines or boundaries, this enlargement will have the integrity of the original map. Enlargements greater than two times require field verification of all information presented. Enlargements of orthophotography and other scale-controlled photography for map production must be made and executed with equal accuracy and precision.

9-4. Sources and Characteristics of Available and Historic Data

Many federal, state, and local government agencies have sponsored aerial photographic surveys over the past 50 years. Earlier photography was collected primarily for topographic mapping or agricultural land-use acreage estimates. Since about 1960, much more wide-ranging reasons for photographic surveillance of the terrain have motivated the use of different types of film for environmental quality analysis and monitoring. The development of MSS systems and satellite platforms, beginning about 1965, has added greatly to both the amount and quality of remote sensor terrain data. The following paragraphs summarize the most easily accessed, public domain sources of remote sensor data, the types of data available, and their general capabilities for problem solving with respect to site studies.

a. U.S. aerial photography. The USGS began its program of mapping photography in the 1930s. The vast amount of this historic photography is pan photography at good scale and with good exposure reliability. Flight lines were completed with contract specifications of 60 percent forward frame-to-frame overlap and 30 percent flight-line side-lap. These specifications make USGS photography an excellent source of scaled data for use as uncontrolled base map drawings and for identification of the changes in the site layout boundaries and in disturbances through time.

(1) The specified flight and exposure conditions required by USGS for mapping photography make it consistently the best-quality photography available. Cloud cover is not allowable during mapping photography acquisition; flights must be made during clear, minimum-haze conditions. Terrain conditions must be at least leaf-down conditions, without snow or floods. As a result of these requirements, the photography is of high quality, and interpretation of it is straightforward. The only real limitations are that successive missions are years apart, along with those mentioned above in the discussion of pan photography.

(2) USGS mapping photography is well indexed, and a search to determine what is available for a given location is a cost-free service of the USGS and ESIC office. Available photography may be previewed at ESIC offices around the nation, or photo index sheets may be purchased for preview purposes. Contact prints of the 9- by 9-in. photograph negatives are available at the cost of production. Details for searching, examination, and ordering photographs are discussed later in this manual. Appendix II, “Sources of Remotely Sensed Data,” in ASTM (1988), identifies sources of photography and imagery.

(3) Since 1980, a group of federal agencies has jointly operated the National High-Altitude Photography (NHAP) Program with the objective of acquiring quality CIR and pan photography over the conterminous 48 states. This photography is of excellent quality, with a CIR scale of 1:57,000 and a pan scale of 1:80,000. This photography was flown during growing conditions, and the CIR capability of recording vegetative growth-signature data makes it a particularly valuable source of recent site history. The first complete coverage, done under leaf-down conditions, was finished in 1986; the second coverage, done under growing-season conditions, was subsequently started; and has been completed.

b. U.S. Department of Agriculture aerial photography. Various US Department of Agriculture (USDA) agencies have acquired aerial photography dating from the 1930s. Most of this coverage is on a 7-year cycle, particularly where agricultural activities are the basis for the local economy.

(1) USDA photography is nearly all panchromatic, acquired for the purpose of crop-acreage measurements. Most of the missions are flown for stereo coverage, but not with the strict specifications used by USGS. However, the resulting bare soil/growing season pan photography at scales of 1:20,000 to 1:40,000 (with some as small as 1:85,000) is quite usable for following time-related site changes.

(2) Availability of the photography does not match that of USGS photography. Search of the Aerial Photography Summary Records System may be made at ESIC offices to determine what coverage is readily available. However, it has been the authors' experience that contact with the county Agricultural Stabilization and Conservation Service (ASCS) or Soil Conservation Service office is much more productive. In fact, these offices frequently have on file a time series of county photography in their offices which may cover the past 20 to 40 years.

c. National Aeronautics and Space Administration photography and imagery. NASA has collected CIR and pan photography, and MSS and TM imagery since about 1965. NASA CIR photography is generally exposed at high altitude (1:60,000 to 1:120,000 scale) and during the growing season. An example is Mission 289 (flown in 1974), which covers much of the Mississippi River system and was collected during the early 1970s. This photography is high-resolution stereo coverage and would be quite useful for studies requiring the 1970s site-history coverage. Much of the NASA photography is related to a specific mission objective at the time of its collection. NASA photography is indexed at the EROS Data Center, in Sioux Falls, South Dakota, and will appear on ESIC searches.

(1) Flight plans and conditions of exposure vary considerably. These variations require utility evaluation for each site set of NASA photography. The photography generally has good utility without resolution limitations.

(2) NASA has recently collected high-resolution natural-color, CIR, and pan photography from a satellite-borne camera, a large-format camera aboard the Space Shuttle. The photography, in addition to 70-mm photography collected during the earlier Skylab and Apollo missions, provides some usable data, but all photographs are limited to small-area coverage, existing atmospheric conditions, and flight schedules with respect to terrain and growing conditions.

(3) Satellite-borne multispectral scanners have been the major NASA data collection systems since the successful orbit of Landsat I in 1972. Frames of MSS data are available for the entire 48 states and the rest of the world during all seasons of the year. In many cases, repeated coverage of historic MSS data on an 8- to 19-day basis is available. These data are subject to cloud or terrain condition limitation, but this source remains the single most frequent remotely sensed data available. Some of these frames of MSS data are supplemented by return-beam vidicon data, which is of better detail, much like a high-altitude photograph. Such information is collected over the entire visible spectrum.

(4) Satellite MSS and TM imagery is amenable to map-accurate reproduction. Hard-copy MSS image reproductions at 1:250,000 scale meet National Map Accuracy Standards. Other hard-copy data forms have similar capabilities. These products may be interpreted in a fashion similar to that for CIR and pan photographs. Digital-format data computer-compatible tape (CCT) may be computer processed or enhanced.

(5) Care must be exercised in selection of MSS and TM data. Atmospheric and terrain conditions at the time of imaging must be carefully evaluated in order to determine the value of individual frames. Detectability of specific spectral signatures must be assured by evaluation of terrain conditions since they have an impact on the contrast and spectral response at the time of imaging. Cloud cover, growing season, crop calendar, and moisture content of soils are influential to the image value. If such an evaluation indicates that a particular MSS or TM frame will provide needed data, a search by ESIC will yield a listing of available scenes with the quality of the imaged spectral band, the cloud cover, and the geographic location shown on the printout. The scenes may be previewed at an ESIC office. Alternatively, a single, red-visible band, 1:1,000,000 scale (approximately 9 by 9 in.) is recommended. A hard-copy, photograph type of product should be ordered for preview.

d. U.S. Environmental Protection Agency (EPA) photography and imagery. In 1974, the U.S. EPA established a remote sensing branch, which has more recently become known as the Environmental Monitoring Systems Laboratory (EMSL), located at Las Vegas, NV. Through activities of the laboratory and the use of contractors, copious aerial photography and aircraft imagery have been collected over hundreds of known and potential sites of interest to the EPA. EMSL capabilities include pan, natural color, and CIR photography, as well as aircraft-borne multispectral scanner imagery.

(1) EPA/EMSL flight plans and films are mission-specific and quite variable in scales and coverage. Availability of the data for studies is limited to those locations where no current legal action is pending, unless the data user is a member of the enforcement team. In addition, indexing and library storage of these data are not systematized.

(2) Much of the EMSL photography is affected by atmospheric, climatic, or terrain conditions which were present at the scheduled mission time. This often renders the data marginal for use in general site characterization from a historic standpoint. EMSL photography flown at various times is not commonly scale-compatible or equivalent to scales used by other agencies, thus requiring scale modification.

(3) EMSL multispectral scanner data have been collected under much the same conditions as the photography; however, when these data are processed by computer, they are quite usable. Some MSS imagery is flown close enough to the terrain surface to produce small enough pixels for identification of rather small features of interest. Computer processing is required, but this service may be contracted with institutions or agencies which have laboratories with such capability.

e. Other agencies. Other federal, state, and local agencies frequently contract for aerial photography for planning or study purposes. The U.S. Army Corps of Engineers, state geological or resource survey agencies, and regional and local planning agencies hold a large amount of uncatalogued photography available only through the office that specified the project. However, such data sets are valuable as a historic record and should be evaluated for use in a site history characterization. From these data sets, local aerial survey firms may be identified and contacted for information regarding photography available from their corporate files. The authors have found that such photography is the best available source of time-sequenced, large-scale, base map capability data. A variety of film types and scales are identified in these sources. Difficulty in securing print or negative copies should be anticipated, as many of the collections are poorly archived. Novel arrangements to gain access for interpretation must be considered where the photography is unique or protected by agency requirements and not releasable on an unrestricted basis.

9-5. Data Set Procurement and Merging

a. Sequence of procurement procedures. This chapter has identified the most reliable data collections utilized by the author for site characterization. Appendix II, "Sources of Remotely Sensed Data," in ASTM (1988) summarizes the addresses of these sources and indicates, to some extent, how to access the sources. However, it is important to understand the usual sequence of the procurement and evaluation procedures, and that library locations and methods of access to collections are constantly changing situations.

(1) The initial step in procurement of any data is the identification of available photography or imagery. The ESIC offices access only select repositories; those of the EROS Data Center and Aerial Photo Summary Records System (APSRS). These repositories include a very large percentage of USGS mapping photography, NASA photography and imagery, USDA agency photography, available NHAP photography, and other federal, state, and local planning agencies which have chosen to list their data with APSRS or the EROS Data Center.

(2) A search is initiated by contact with the nearest ESIC office or with the EROS Data Center (User Services Section). The basic information required to implement a search is the site location, type of photography or imagery of interest, data quality, data format, and dates of coverage. The search is a cost-free service and yields printout listings of all available photography or imagery with the quality, geographic coverage, date of collection, cloud cover, and other information for each individual data item.

(3) Evaluation of the search output will require consideration of the weather, soil, vegetation, possible site conditions, and so forth, at the date of each available data set. Reference to National Oceanic and Atmospheric Administration climatological data for the site at the time of data collection will indicate many of the environmental conditions at the collection time. USDA Agricultural Crop Reporting Service information will assist in evaluation of the condition of the land vegetative cover and soil moisture at the time of data collection. Evaluation of these data and inspection of the search printout will usually lead to identification of those data sets that will be potentially most usable.

(4) Selection of the most usable data sets is essential to ensure that the order will indeed provide the required site characterization information. Microfilm is available at ESIC offices for previewing most products listed on a search printout. In cases where a trip to the office is not practical to search for photographic coverage, the investigator should order a photo index, as an inexpensive means of previewing the photography. A pan 1:1,000,000 scale

print of the visible red band of MSS or TM data also serves as an ideal preview sheet. Delivery lead times for USGS, NASA, and NHAP data are 6 to 8 weeks at counter prices. For twice counter price, 1-week delivery is assured. For other sources, such as USDA, longer delivery times should be anticipated.

(5) Discovering historic photography in other source libraries presents a considerably more difficult task. Most local agencies have a means of inventory that will allow quick examination of the available data, but this requires a trip to the agency office. Larger state and federal agencies frequently do not have accessible inventories of photography. It has been found that the best access method is an employee who is familiar with the scope of the collection. Contact with commercial aerial survey contractors is usually profitable and will quickly indicate what has been flown over a site. However, some of this coverage will require permission from contracting agencies to receive prints. In nearly all of the above situations, it has been the experience of the authors that these methods are time-consuming and costly when compared to acquiring USGS or USDA photography, but the same sources should not be overlooked as potentially valuable to the site characterization, starting from the EMSL compilation, and progressing to other sources.

b. Guidelines for data evaluation, interpretation, and merging. A number of quality control parameters must be evaluated on each data set in order to assure that the whole database assembled for a site is of equal reliability. These parameters include the reliability of each set of photographs or images, the reliability of the interpretation of each set, the scale quality of each set, and the relationship of the set to selected base maps.

(1) Data interpretation involves photograph interpretation techniques. Clues such as access roads and their landscape scars, disturbed terrain, interpretations of the natural vegetative cover, and spots of bare soil or rock may be the first indications of waste-disposal activities. More subtle indicators will be found during detailed examination of the data. Lillisand and Keifer (1994), Avery and Berlin 1985, Loelkes et al. (1983), and Johannsen and Sanders (1982) contain valuable information and examples of interpretation techniques.

(2) A few more important considerations relate to the total database in order to ensure integrity and maximize the returns in terms of site-use history.

(a) Resolution or detection properties of the data must be clearly identified with each set, in order to ensure that no misleading detail is implied. Ideally, all sets of like data should be interpreted with the largest ground resolution capability representing the smallest identifiable target.

(b) Degree of organization and accessibility for each data set collection must be indicated.

(c) The original data scale must be identified; a means of scale modification to reach the common study base map scale must be described. Alternatively, interpreted thematic maps may be displayed at the original photograph/image scales, without common-scale conversion. However, this does not provide a basis for comparison of mapped data.

(d) The impact of improved technology of photography and image collection over the period of coverage must be indicated.

(e) Geographic positioning of interpreted features from one time frame to another must be carefully monitored. A good-quality scale-compatible base map will serve to minimize this problem.

(f) Quality control on drafting procedures, the use of stable base materials, and careful workmanship are absolutely necessary.

(3) Equipment requirements are relatively simple and have been discussed in detail in Elifrits et al. (1979), Hudson (1976), and Hudson, Elifrits, and Barr (1976). In summary, the laboratory must be well-lighted, preferably by natural light, must have stereo-viewing equipment, and must have a quality engineering graphics capability.

(4) Digital-format data require a computer system (PC-type or larger) designed to operate image-processing software to enable the investigator to analyze digital data. Output may be in the form of tabular data from the statistical processing routines or in the form of images produced via CRT imaging of the data, or both forms, for visual evaluation and recording by photography or via printer-plotter mechanism.

c. Geographic information systems - GIS.

(1) Recent developments in the ability to use geographically registered data sets in what is known as geographic information systems, or GIS, enable the investigator to carefully study combinations of many varieties of data for a given site. Digital format data such as topographic maps and scanner-type remotely sensed data lend

themselves to rapid and easy entry into such computer-contained record systems.

(2) A digitizing capability for entry of maps or other site data that are not initially recorded in digital form is desirable for database-type merging. Digitizing of mapped data may be accomplished by a variety of methods. USGS map products are currently being digitized by the agency for marketing as computer compatible tapes which can be used directly in computer-contained databases. Newly created and revised USGS maps are produced in digital form. Other line maps may be scanned for digitization.

(3) A variety of software and hardware systems for the construction of geographic databases is available. Most systems have the common characteristic of storing information in rows and columns with geographically registered cells assigned values for each theme or file of information. Many advantages of database information management are apparent. Among these are the rapid retrieval of data, the merging and interaction of data files, the mathematical manipulation of files for area or other computational activities, and the capability of addressing the variations in scales of the input data.

9-6. Presentation of Data

a. Presentation format. Information that has been interpreted from available remote sensor data must be presented in scale-accurate, easily understood form. The most desirable presentation format is that of a base map with various single-thematic overlays which align with base map boundaries, either in hard copy or as files in a computer-contained database. Thematic maps may be constructed at photographic scale, on an acetate overlay, and then scale-adjusted to the base map scale by using a reducer-enlarger. Cultural features (such as levees and roads) may be used for control of the scale adjustment.

b. Engineering geologic map. In addition to the presentation of the site historic land-use data and other thematic data taken from remote sensor sources, the final product report should contain an engineering geologic map portraying site exploration efforts, such as water and soil sampling locations, holes, backhoe pits, and geophysical traverses.

9-7. Remote Sensing Recommendations

a. Resource availability. Readily available, historic remote sensor data are found in a variety of aerial photographs, MSS imagery, and satellite-collected MSS or TM imagery. This is a powerful source for developing site chronologies and inventory of geotechnical parameters. Proper selection and interpretation of remotely sensed data enable the investigator to develop the most accurate evaluation of historic activity and conditions at the site. The impact of site operations on vegetation, soil, surface water, and groundwater may be monitored through time. Bare-soil conditions are especially helpful in evaluating material properties and other geotechnical parameters through photograph interpretation methods. Base maps may be constructed to exhibit these interpreted details.

b. Quality. The value of remote sensor data is limited by only a few important factors which must be taken into consideration in any site characterization. Central to this concern is the fact that bits of information can be used to interpret the composition of materials and hydrogeologic parameters. The conditions under which data are collected and the dates of collection control the quality and quantity of information available.

c. Standardization. Standardizing the uses of the data will improve outcomes. Examples include the following:

(1) Vegetation evaluation using CIR photography.

(2) Appropriate selection of data with respect to collection date and weather and growing conditions, and selection of the terrain conditions which would enable the desired information to be recorded.

(3) Consideration of the resolution or detection capabilities which would provide the anticipated details.

(4) Consideration of the scale and comparison of scales which would allow reliable representation of all data, both interpreted and mapped.

An important and common standard for all presentation of data includes proper and sufficient notation on maps indicating the data sources, data interpretation and preparation methods, and their geographic integrity.