Chapter 6.
Remote Sensing Applications in USACE

6-1 Introduction. Remote Sensing is currently used by Corps scientists and engineers at the seven research and development laboratories as well as at the Districts and Divisions. Remote sensing has proven to be a cost effective means of spatially analyzing the environment and is particularly usefully in regions with limited field access. A vast amount of literature covering remote sensing applications in environmental and engineering projects has been published and much of it is available through the ERDC and USACE library system. This chapter only touches the surface of the material that describes the variety of applications and products in use. Some of the references listed in Appendix A also have internet web sites providing more in-depth information on the subject of remote sensing and current research.

6-2 Case Studies.

a. Each study presented below uses remote sensing tools and data. Special emphasis have been placed on Corps works and contracted work related to civil projects. Non-Corps projects, such as NASA works, are also presented in an effort to provide broader examples of the potential use of remote sensing and to aid in the implementation of remote sensing into existing and future US Army Corps of Engineers projects. This chapter 1) reviews the capabilities of sensors, 2) illustrates the value of remote sensing data analysis and integration into spatial data management systems, and 3) communicates recent studies to promote cooperation between Corps Districts, local government, and the general public.

b. The following topics are presented in this chapter:

- Water Quality.
- Wetland mitigation.
- Archeology.
- Engineering.
- Soil science—sediment transport.
- Forestry.
- Agriculture.
- Environmental projects.
- DEM generation.
- Applications in snow and ice.
- Emergency Management.

6-3 Case Study 1: Kissimmee River Restoration Remote Sensing Pilot Study Project Final Report

- *Subject Area*: Environmental Assessment.
- *Purpose*: To evaluate the vegetative response to the restoration of the Kissimmee River floodplain ecosystem using hyperspectral data.
- *Data Set*: Hyperspectral Airborne.

a. Introduction. Historically, the Kissimmee River meandered 103 miles (~166 km), connecting Lake Kissimmee to Lake Okeechobee. The river and its floodplain supported diverse wetland communities including aquatic and terrestrial plants and animals. The Kissimmee River was hydrologically unique owing to prolonged and extensive flood inundation. During the 1960s, the river and its 1- to 2-mile (1.6- to 3.2-km) wide floodplain was channelized and drained in an effort to control flooding. Canal excavation eliminated one-third of the channel, and drainage destroyed two-thirds the floodplain. This Corps of Engineers project lead to a significant decrease in waterfowl, wading bird, and fish populations.

(1) An environmental restoration plan is underway in an attempt to restore the pre-1960 ecosystem in the Kissimmee River floodplain. The USACE Jacksonville District and the South Florida Water Management District are jointly responsible for this 3000- square mile (7770 km^2) restoration project. The primary goal of the restoration project is to re-establish a significant portion of the natural hydrologic connectivity between Lake Kissimmee and Lake Okeechobee. With the natural hydrologic conditions in place, the objective of the project is to rebuild the wetland plant communities and restore the local biological diversity and functionality.

(2) The study reviewed here represents a pilot study conducted by SAIC (Science Applications International Corporation) to establish a baseline for environmental monitoring of the Kissimmee Restoration Project. Their study explored the utility of hyperspectral image data in aiding vegetative mapping and classification. The hyperspectral remote sensing data demonstrated themselves to be highly useful in delineating complex plant communities. Continued use of such a data set will easily aid in the management of the Kissimmee River Restoration Project.

b. Description of Methods. The test area within the restoration site was chosen by USACE. Preliminary field studies conducted in1996, established approximately 70 plant communities, a handful of which were not present during the study of interest (conducted in 2002). It was determined that the rapid changes in hydrologic conditions had altered the plant community structure during the interim between studies; in places, some plant species and groups had entirely disappeared. Researchers monitoring the vegetation restoration at the Kissimmee site were concerned with the establishment of native versus non-native invasive and exotic plant species. The colonization by non-native plant species, such as Brazilian Pepper and Old World Climbing Fern, are of interest because of their potential affect on other revitalization efforts; those focusing on fauna restoration, for instance. The spectral analysis of heterogeneous plant species communities is difficult owing to the commonality of plant chemistry and morphology. The spectral difference between native and non-native plants is therefore narrow, and difficulties in distinguishing them are compounded by their mixing (or sharing of habitat). Additionally, the domination by one plant species in many places added to the problem of accurately classifying the plant communities. See below for vegetation classes established for this study.

(1) Examples of vegetation classes include:

- Aquatic vegetation.

- Broadleaf marsh.
- Miscellaneous wetland vegetation.
- Upland forest.
- Upland herbaceous.
- Upland shrub.
- Wetland forest.
- Wetland shrub.
- Wet prairie.
- Vines

(2) Geological constrains did not aid in the identification of the vegetation classes. Geologic constrains tend to be more useful in mapping plant communities in areas with a more mature ecosystem or were there is significant variation in the substrate or soil. Choosing a sensor capable of delineating healthy vegetation versus stressed vegetation was another consideration that needed to be addressed by the researchers. This would allow land use managers the opportunity to closely monitor the decline and rise of various species throughout the duration of the wetland restoration.

c. Field Work.

(1) Airborne hyperspectral data were collected in conjunction with 146 ground-truth data points (also known as training sites); this collection was made on-foot and by airboat. Fieldwork was done and data collected during a flood by a botanist and a GIS specialist. In the field, SAIC's hand held spectrometer was used to collect the spectral data associated with mixed plant communities from within the Kissimmee River floodplain. These ground-control points were then used to test the accuracy of the vegetation map developed from the hyperspectral data.

(2) Problems arose using the plant classes defined by the 1996 field study. Classes were subsequently altered to better suit the dechannelized ecology. A supervised classification was applied to the data and two vegetation maps were produced denoting 68 vegetation communities and 12 plant habitat types (Figure 5-25). The hyperspectral map was then compared to the existing vegetation map produced in 1996.

d. Hyperspectral Sensor Selection. Researchers on this project had the opportunity to choose between AVIRIS and HyMap. HyMap was eventually chosen for its accuracy, spectral capabilities, and reasonable expense. HyMap, a hyperspectral sensor (HSI), was placed on board a HyVista aircraft. HyMap maintains 126 bands across the 15- to 20-nm range. The error in HyMap data was found to be at ±3 m, equivalent to the accuracy of the on board GPS unit. To learn more about HyMap and HyVista view http://www.hyvista.com/main.html.

(1) For this project, the hyperspectral (HSI) data maintained clear advantages over other sensor data. HSI's high spectral resolution allows for the distinction of spectrally similar vegetation and had the potential to monitor vegetation health status. The shortwave infrared (SWIR) wavelengths where found to be most sensitive to the non-photosynethic

properties in the vegetation. This further helped to discriminate among the vegetation classes.

(2) HyVista pre-processed the digital data. Pre-processing included a smoothing algorithm to reduce the signal to noise ratio (SNR) across the scene, to an impressive >500:1. The data were geographically rectified using ground control points identified on a geo-registered USGS orthophoto. The geo-positional accuracy was determined to be within ± 3 pixels across 95% of the scene. This was established by comparing the image with a high-resolution orthophoto. A digital orthophoto was then over laid on top of the digital hyperspectral data to verify geo-positional accuracy.

e. Study Results. Analyst used KHAT (Congalton, 1991), a classification statistic used to test the results of supervised versus unsupervised classification (Equation 6-1). KHAT considers both omission and commission errors. Statistically it is "a measure of the difference between the actual agreement between reference data and the results of classification, and the chance agreement between the reference data and a random classifier" (see http://www.geog.buffalo.edu/~lbian/rsoct17.html to learn more on accuracy assessment). KHAT values usually range from 0 to 1. Zero indicates the classification is not better than a random assignment of pixels; one indicates that the classification maintains a 100% improvement from a random assignment. KHAT values equaled 0.69 in this study, well within the 0.6 to 0.8 range that describes the class designation to be "very good" (≥ 0.8 is "excellent"). For this study, KHAT indicated good vegetative mapping results with the supervised classification for distinguishing plant species and for mapping surface water vegetation. The KHAT also verified the potential value of image classification to map submerged aquatic vegetation using HIS data.

$$k = \frac{\text{observed accuracy} - \text{chance agreement}}{1 - \text{chance agreement}} \tag{6-1}$$

$$N \overset{r}{\underset{i=1}{S}} xii - \overset{r}{\underset{i=1}{S}} (xi + \times x + i)$$

$$k = N2 - \overset{r}{\underset{i=1}{S}} (xi + \times x + i)$$

where

r	=	number of rows in the error matrix
xii	=	number of observations in row i and column i (the diagonal)
xi+	=	total observations of row i
x+i	=	total observations of column i
N	=	total of observations in the matrix .

The estimated time savings of the mapping project as compared with the manual analysis using color infrared was calculated to be a factor of 10 or better. Additional benefits include a digital baseline for change detection and managing restoration. The study did not establish under which conditions HSI did not work. HSI processing and analyses was shown to be a generally valuable tool in a large-scale riparian restoration.

f. Conclusions. HSI's advantages over aerial panchromatic and color infrared include its ability to automate data processing rapidly; this will be highly useful for change detection if the hyperspectral data are collected over time. This data can then be easily coupled with other useful GIS data when researchers attempt to combine hydrographic and wildlife data. Wetland hyperspectral imaging paired with advanced data processing and analysis capabilities were shown to be a valuable tool in supporting large-scale programs, such as the Comprehensive Everglades Restoration Program (CERP). For continued successful management of the Kissimmee Restoration Project, the Corps' Jacksonville District and the South Florida Water Management District will have to decide on a mapping method that provides the detail needed to monitor plant community evolution while balancing this need with budget constraints.

Point of Contact: Wiener Cadet, Project Manager, Phone: (904) 232-1716

6-4 Case Study 2: Evaluation of New Sensors for Emergency Management

- *Subject Area*: Emergency Management.
- *Purpose*: To test the resolvability of high-resolution imaging to evaluate roof condition.
- *Data Set*: Visible and infrared.

a. Introduction.

(1) Emergency response and management efforts are best facilitated with timely and accurate information. Typically, these data include an enormous amount of geo-spatial information detailing the extent and condition of damage, access to emergency areas or support services, and condition of urban infrastructure. Remotely sensed imagery has the capability of delivering this type of information, but it is best combined with geo-spatial data when they are rectified and pre-processed in a way that allows for easy visual and algorithm analysis. The amalgamation of geo-spatial data into one comprehensive map will aid emergency management organizations in their effort to coordinate and streamline their response.

(2) Understanding the utility and limitations of a sensor is highly valuable to emergency response workers. This study evaluated the effectiveness of Emerge, a new airborne sensor that collects visible and infrared radiation. Emerge was tested in relation to four primary requirements, listed below.

- Ground sampling distance (GSD).
- Capability for storing large volumes of digital data.
- Pre-processing and the vendors ability to orthorectify up to "500 single frames of imagery in 12 hours or less" and save these data onto a CD-ROM or ftp for fast delivery.
- Indexing system for all resolutions collected, allowing for easy determination of image location.

b. *Description of Methods*. Originally, this study intended to evaluate roof damage caused by an actual emergency. In the absence of such an emergency, alternate imagery was collected over a housing development under construction in Lakeland, Florida, located 30 miles (48 km) northeast of Tampa, Florida. The different phases of housing construction provided an analog to roof damage during an event such as strong winds or a hurricane. The different structural states of both residential and commercial roofs included exposed rafters, exposed plywood, and plywood covered by tarpaper or shingles.

c. Field Work. Initially, field reconnaissance established the appropriateness of using two neighboring test areas in Lakeland, Florida. Roof conditions at individual buildings were evaluated and geo-referenced. After the first flight, an assessment of the ground sampling distance (GSD) and sensor data determined that a finer resolution would be required to adequately examine roof condition. Two additional flights were then acquired, resulting in a collection of data gathered at resolutions of 3, 2, and 1 ft (91.4-, 61-, and 30.5- cm respectively), and 8-in (20.3 cm). Landscaping features, such as tree type and leaf on/off state, were also documented with digital photos. This information was later used to establish the feasibility in mapping vegetation using the Emerge system.

d. Sensor Data Acquisition. The two test sites, occupying 8 square miles (~21 km^2), were surveyed at several resolutions using Emerge imagery (see http://www.directionsmag.com/pressreleases.php?press_id=6936 for more details on the Emerge System). Multiple resolutions were collected over a 2-month period. As a result, a one-to-one comparison of the effect of resolution on image analysis was difficult, as house construction in some areas was completed during the 2-month interval. The volume of data collected was equivalent to that required for a 60 square mile (~155 km^2) area, with approximately 25% image overlap (at a single resolution). This volume of data totaled 5 gigabits.

e. Study Results. Evaluation of the imagery showed that roof rafters were best resolved at a 1-ft and 8-in. (30.5 and 20.3 cm) resolution. At this resolution, plywood can be distinguished from other construction materials and individual rafters can be observed. Tarpaper was not distinguishable from shingles owing to their spectral similarities.

(1) Despite the functionality of the 1-ft and 8-in (30.5 and 20.3 cm). resolutions, in places with bright spectral response, saturation on the high end of the intensity scale lowered the resolvability of rafters relative to the flooring material. This was the result of a high gain set for radiation detection within the sensor. Over-saturation lowers the contrast between rafters and the flooring, making it difficult to fully evaluate the condition of the roof. Lowering radiation saturation requires collecting data during low to medium sun angle. This may, however, delay data acquisition.

(2) Sun angle controls image contrast in two ways. First, a low sun angle may increase shadowing, leading to a loss in target radiation data. Secondly, a high sun angle may over-saturate the sensor. Both extremes were shown to lower contrast in this study, making roof analysis difficult.

(3) A scatter plot breakdown of band 1 relative to band 2 was performed to evaluate the possibility of automating an analysis that would delineate intact roofs and damaged

roofs. A preliminary analysis suggests that this is possible because of the strong covariance displayed by roofs shingled with monochromatic materials. Any automated process developed would need to address the limitations posed by non-monochromatic shingles (which would appear spectrally mixed and indistinguishable from damaged roofs).

(4) A vegetation analysis was also explored to test the resolution required to accurately describe tree type and condition. At the 1-ft (30.5 cm) resolution, researchers were able to determine leaf on/off conditions (data were collected in February). However, at this resolution it was not possible to delineate any details regarding leaf morphology. At the 8-in (20.3 cm). resolution, palms were distinguishable, although it was not possible to differentiate broad versus narrow leaves.

f. Conclusions. Evaluation of the Emerge sensor led to the development of a detection matrix. This matrix reviews the capabilities of the sensor at various spatial resolutions for all objects studied (see Table 6-1). This study determined that Emerge could adequately meet the requirements of emergency management systems. High-resolution data can be acquired within 4 hours of the plane's landing. This includes the time needed for pre-processing (orthorectification and the production of geo-TIFF files for CD-ROM and ftp). Shingles and tarpaper are not resolvable, though rafters and plywood are at the 2-ft (~61 cm) resolution. For high-resolution images, a medium sun angle increased roof detail. Palm trees and leaf on/off conditions can be visually identified at the 8-in (20.3 cm). resolution; however, broad-leafed trees cannot be distinguished from narrow-leafed trees. The only limitations placed on these data centered on over-saturation and sensor inability to distinguish tree types. The covariance displayed by band 1 relative to band 2 indicates the potential success for developing an automated algorithm to locate and count damaged roofs.

Table 6-1
Detection Matrix for Objects at Various GSDS

Objects/GSD	3-ft (91.4)	2-ft (61 cm)	1-ft (30.5 cm)	8-in. (20.3 cm)
Roof rafters	Not visible	Barely visible	Often visible	Visible
Shingles/tarpaper (other) vs. plywood	Can sometimes separate	Can often separate	Can determine wood vs. other cover	Can determine wood vs. other cover
Rafters in 3-band saturation	Causes rafter detail loss	Causes rafter detail loss	Causes rafter detail loss	Causes rafter detail loss
Broad-leaf vs. narrow-leaf	Cannot separate	Can determine leaf on/off	Can determine leaf on/off	Palms are always visible
All in cloud shadow	Degrades image	Some info recoverable	Some info recoverable	Some info recoverable
Roofs as a function of sun zenith angle	Best detail, near zero angle, overhead sun	Best detail, medium angle, shadow casting	Best detail, medium angle, shadow casting	Best detail, medium angle, shadow casting
All in 1, 2, 3 RGB, 2∑ stretch	Enhances imagery	Enhances imagery	Enhances imagery	Enhances imagery

Point of Contact: Robert Bolus, Phone: (603) 646-4307

6-5 Case Study 3: River Ice Delineation with RADARSAT SAR

- *Subject Area*: Ice monitoring
- *Purpose*: To evaluate the concentration and condition of river ice.
- *Data Set*: RADARSAT SAR

a. Introduction. Remote sensors operating in the microwave region of the spectrum have the advantage of seeing through clouds and atmospheric haze. RADARSAT SAR (synthetic aperture radar) collects spectral data in the microwave region and is capable of imaging ground targets during adverse weather conditions, such as storms. Additionally, RADARSAT SAR collects 10-m pixel sized data, a high spatial resolution well suited for studies examining ice in narrow river channels. The study reviewed here explored RADARSAT SAR's potential in delineating and monitoring ice and ice floes in rivers ranging in stream widths of 160 to 1500 m. A better estimate of ice conditions along large streams will allow for better navigation planning and will provide river dam regulators the information needed to plan and prepare for ice breakup and floes.

b. Description of Methods. Three rivers of varying widths were evaluated for ice cover over the course of two winters (2002 and 2003). The first winter was relatively mild with partial river ice development at the three sites. Winter 2003 possessed a number of below freezing days and was an ideal time for examining river ice in the northern mid-west. The rivers chosen for this study were the Mississippi River near St. Louis, Missouri, the Missouri River at Bismarck, North Dakota, and the Red Lake River in Grand Forks, North Dakota. Each site offered unique contributions to the study. The Mississippi River represented a stream with heavy navigation use, the Missouri River site included a hydropower dam, while the Red Lake River had extensive ice jam and flood records. Coordinated efforts among CRREL researchers, the local Corps Districts, and the RADARSAT International (RSI) aided in the acquisition and timing of satellite data collection.

(1) Stream channels were subset and isolated for river ice classification. To accomplish this, a band ratio was applied to Landsat TM data. They were then classified by an unsupervised process and extracted for mask overlay onto the radar data. This sufficiently outlined the land/water boundaries and isolated the stream in images with wide river channels. This process omitted vegetation and islands from the resultant image. The subsequent SAR subset did not include mixed pixels (land/water/ice).

(2) Images with narrow channels required hand-digitization and a textural analysis, followed by a supervised classification (to further eliminate land pixels). The hand-digitization proved less successful than the Landsat TM overlay and extraction method. Hand-digitization did not thoroughly omit pixels with mixed water, vegetation, and land (i.e., river islands).

(3) In the SAR images, only the channel reaches were analyzed for ice conditions using an unsupervised classification. The classification mapped brash ice (accumulated floating ice fragments), river channel sheet ice, shore ice, and open water.

c. Field Work. Direct field observations were not necessary as a web-camera mounted on a bridge provided the visual documentation of ice conditions in the river. At the Missouri River site, web-cameras have been strategically placed in a variety of locations in the US by ERDC/CRREL. To view the Missouri River images used in this study, as well as other river web-camera images, go to http://webcam.crrel.usace.army.mil. Study sites without a web-camera relied on District contacts for field information. At Red Lake River near Grand Forks, North Dakota, field reconnaissance ice surveys were conducted by the Corps St. Paul, Minnesota, District office.

d. Sensor Selection and Image Post-Processing.

(1) As stated above, RADARSAT SAR data was chosen for this study. Radar data have already proven their utility in sea ice mapping and monitoring (Carsey, 1989). Radar can aid in determining ice concentration, classification, ice motion monitoring, and ice feature changes. The study reviewed here adapted methods used to study large ice sheets to the evaluation of smaller more temporal river ice.

(2) The acquired radar images were visually analyzed and classified using an unsupervised classification to delineate open water, moving ice floes, and stationary ice covers. The delineation of river channels was undertaken by two methods, described above (hand-digitization and TM extraction and overlay).

e. Study Results. The following description summarizes the ice condition results stemming from each river surveyed:

> "In the Mississippi River imagery near St. Louis, Missouri, the wide channel width (500–2000 meters) contributed to identifying river ice with RADARSAT imagery. In the 2002 image it was determined that 30% of the channel had ice in the flow, and in the 2003 image, it was determined that there was 100% ice cover. Additionally, this ice cover was separated into forms of ice; brash ice and border ice. In the 2003 image it is believed that the brash ice formed as a result of navigation ice-breaking activities.

(1) In the Missouri River imagery near Bismarck, North Dakota, the channel width (400–1000 m) was suitable, and river ice was determined from the RADARSAT imagery. The 2002 image showed that 77% of the channel had ice in the flow, and in the 2003 image, only 21% of the channel had ice. The 2003 imagery was acquired before full icing conditions, and a small amount of ice was interpreted to exist.

(2) In the Red Lake River imagery near the confluence with the Red River of the North at Grand Forks, North Dakota, the river channel is narrow (40–75 m). The narrowness of the channel limited the process of delineating the channel boundary on the imagery. As a result of the narrow channel width, river ice was not determined by this process. However, ice surveys were conducted by the US Army Corps of Engineers during the time of image acquisitions, and an ice cover was recorded in both 2002 and 2003.

f. Conclusions. RADARSAT SAR data were able to detect ice on rivers with widths ranging from 400 to 2000 m. Despite RADARSAT's 10-m resolution, this data set was unable to detect the present of ice on the narrower Red Lake River, with a width of 40–75 m. RADARSAT's overall suitability for detecting river ice and ice conditions was shown to be of potential use. The method presented here details an important tool that may aid in hazardous wintertime navigation and assist dam regulators on decisions regarding stream flow and reservoir levels.

Point of Contact: Brian Tracy, Phone: (603) 646-4739

6-6 Case Study 4: Tree Canopy Characterization for EO-1 Reflective and Thermal Infrared Validation Studies in Rochester, New York

- *Subject Area*: Forestry and climate change
- *Purpose*: To collect forest canopy structure and temperature data.
- *Data Set*: Multispectral and hyperspectral

a. Introduction. Tree and forest structure respond strongly to environmental conditions and change. Subsequently, studies have successfully shown the utility of remote sensing in monitoring environmental conditions through the analysis of vegetation. The study reviewed here surveyed a mixed forest in northern New York State in an attempt to better understand the interaction between solar radiation and tree/forest structure. An additional objective of this study was to validate the Earth Observing satellite (EO-1, launched in 2000). The validation was performed by comparing the EO-1 satellite data with that of the Landsat-7 ETM+ data. The EO-1 satellite acquired data at the same orbit altitude as Landsat-7 while flying approximately 1 minute behind. EO-1 reflective bands were combined with the Landsat-7 ETM+ thermal infrared bands to estimate canopy temperature. The 1-minute delay in synchronization between the two sensors was evaluated to test the effects of separating the thermal and reflective measurements in time. Relating scene exitance (the radiative flux leaving a point on a surface, moving in all directions) and reflectance to the landscape provided insight to prevailing environmental characteristics for the region.

b. Description of Methods. Ground and tree canopy data were collected from mature healthy forest stands at a site in Durant-Eastman Park in Rochester, New York. Characterization of the forest included a stem and trunk survey, tree structure geometry measurements, regional meteorology, and leaf area index (LAI) measurements (see http://www.uni-giessen.de/~gh1461/plapada/lai/lai.html for more information on LAI). Two smaller field sites, Ballard Ridge and Smith Grove, were selected for detailed study from within the larger forested area. Tree heights for both sites averaged 20–30 m. Ballard Ridge consisted of a dense mature stand of maple, cottonwood, elm, and oak trees. The Smith Grove consisted of a dense mature stand of locust trees and cottonwood. Thermal and reflective spectral measurements were made on leaves, tree bark, leaf litter, soil, and grass.

c. Field Work. Leaf area index (LAI) was calculated in the field with the use of a non-imaging instrument, which measures vegetation radiation in the spectrum of 320–490 nm. Leaf area index is a ratio of the foliage area in a forest canopy relative to the ground surface area. It estimates the photosynthetic capability of a forest. The measured light intensity was used to calculate the average LAI for each location within the field site. High-resolution hemispherical photographs were collected at each site using a digital camera with a fisheye lens (148° field-of-view). The digital photographs were taken during the early morning and late evening hours to reduce the effects of atmospheric haze. The digital hemispherical photographs were later analyzed using a specialized forestry software, which measures both LAI and canopy leaf structure. LAI calculations based on the computed hemispherical digital images compared favorably with the LAI measurements from the meter instrument.

d. Sensor System.

(1) Satellite data were collected with the use of Landsat MTI, Hyperion, and ALI (Advanced Land Imager) on 25 August 2001. The ALI sensor has nine spectral bandwidths plus a panchromatic band. Three bands where analyzed for this study 773.31 nm, 651.28 nm, and 508.91 nm. The forested areas appear bright red, urban areas are gray-blue, and the water is depicted by the dark blue regions.

(2) The sensor radiance was converted with the use of 6S, an atmospheric corrections model that converts sensor radiance to estimated surface reflectance. The differences and consistencies in the two sensors were then easily compared with the spectral data collected in the field. Then, a more detailed study of the forest site was made, using measured geometric and optical parameters as input to the SAIL multi-layer canopy reflectance model. The ETM+ and ALI data were then compared with the SAIL (Scattering by Arbitrarily Inclined Leaf) reflectance model and the high resolution Hyperion, a hyperspectral imaging instrument (see http://eo1.usgs.gov/instru/hyperion.asp for details).

e. Study Results. A comparison of the panchromatic ETM+ and ALI data show dramatic differences. The ALI data provided better definition of the marina and pier area as well as natural water features (urban and water targets). Relative to the ETM+ images the ALI data maintained a reduced DN value for all forest pixels, increasing the contrast in the forest region. The authors suggested the higher resolution and the narrow bandwidths accounted for the dramatic contrasts between the image data sets.

(1) Spectral plot comparisons of the multispectral bands for different ground targets (grass, water, urban features, and forest) illustrating the relationship between reflectance and wavelength indicated a close match between the two sensors. The spectral plots were created by the selection of training pixels for each target group. ALI spectral values were closer in value than those seen in the ETM+ data; again, this is a result of the narrow bandwidths and higher resolution. The only notable difference in the spectral response between the two sensors was evident in band 5 for grass and urban features. These targets had up to 20% variation in signal response between the sensors. Specifically, the ALI band 5 with a reflectance of 0.35 μm is ~20% higher than the ETM+ value of 0.29 μm.

(2) The combined spectral plot of data from ETM+, ALI, Hyperion, and the empirically derived SAIL show overall an excellent agreement. The three satellite data sets closely match one another, with slightly different values recorded in the SAIL model data. SAIL values best matched those of the sensors in the visible portion of the spectrum.

f. Conclusions. The authors of this study were able to establish a simple, multi-layer canopy reflectance model using measured parameters from the site to compare the ETM+ and ALI spectra. Hyperspectral data were also compared against the satellite and ground data. Additional work is needed to establish the relationship between leaf area index (LAI) and satellite data. The potential use of ALI and hyperspectral Hyperion for studies of forests in remote locations and forests at risk may greatly enhance forest management and lower the costs associated with ecological monitoring. Accurate estimates of LAI based on satellite imagery have the potential to support forest biomass monitoring, and hence forest health and changes in canopy structure attributable to pollution and climate change. The ability to estimate LAI with remote sensing techniques is, therefore, a valuable tool in modeling the ecological processes occurring within a forest and in predicting ecosystem responses.

Point of Contact: Jerry Ballard, Phone: (601) 634-2946

6-7 Case Study 5: Blended Spectral Classification Techniques for Mapping Water Surface Transparency and Chlorophyll Concentration

- *Subject Area*: Water quality
- *Purpose*: To establish water clarity and algal growth in a dam reservoir
- *Data Set*: Landsat TM - Visible and infrared

a. Introduction.

(1) An accurate portrayal of water clarity and algal growth in dynamic water bodies can be difficult owing to the heterogeneity of water characteristics. Heterogeneity can stem from the spatial distribution of sediments delivered to a lake by a tributary. Water turbidity associated with tributary sediment load controls water clarity and subsequently will impact algae growth. Additionally, algal growth will influence water clarity by reducing water transparency during times of algal blooms. Both algal growth and sediment turbidity are controlled by such factors as water depth, flow rate, and season.

(2) To better monitor the water quality at dam reservoirs, a spatial estimate of both water clarity and algal chlorophyll over a broad area is required. To accurately capture these properties a large number of water samples must be taken, a task that may not be feasible for most studies. Remote sensing lends itself well to the assessment of water quality testing at a variety of spectral scales due to the response of suspended sediment in the visible and thermal spectrum. Chlorophyll, produced by algae, can also be detected by its visible and infrared emission. The study reviewed here developed a classification algorithm to predict water clarity and chlorophyll concentrations. The algorithm was based on a correlation between spectral data and the empirical field data. Previous studies attempting to classify water clarity and chlorophyll required field sampled training sites. The goal of this study was to develop an algorithm based on empirical data that would illuminate the need for such test training sites. Thus, researchers testing for water quality would then need only the Landsat TM data to monitor water quality at a fresh water lake.

b. Field Work. Secchi Disk measurements and water samples were collected at a dam reservoir in conjunction with a Landsat fly-over at West-Point Lake, Georgia. Water samples were frozen and stored in a dark room to preserve the algae populations. These samples where later analyzed for chlorophyll (C_a) concentrations. Water clarity was measured in *situ* with a Secchi Disk (S_d). This 20-cm disk estimates water clarity by measuring the depth to which the disk is visible. Remote sensors generally detect water clarity to 20–50% of the S_d measurement. Sampling sites were chosen evenly across the reservoir and adjacent tributaries. A global positioning unit was used to locate 109 sample sites. Drift during sampling occurred but was compensated for with the use of a 3×3 kernel during image classification. Samples and data were collected during two periods—summer and fall of 1991.

c. Sensor System. Two Landsat TM data sets separated in time were used to develop a linear-logarithmic cluster analysis. Visible, near, and middle infrared radiation band ratio was employed with a stratified sampling technique. Using a variety of band ratio, the workers were able to accurately develop a blended classification scheme, which is detailed below.

d. Study Results. The authors adapted multivariate density estimation with the use of an algorithm k-NN density estimator. This was used to group spectrally similar pixels. The spectral classes and class structures (or groupings that separated the spectral classes) were developed using an unsupervised classification. Within each of the two scenes, 16 unique classes were determined. These classes were combined with the empirical data, leaving four logarithmic algorithms. Applying a 3×3 kernel to the data compensated for the drift that occurred during data collection. This placed the positional accuracy to within ±30 m.

(1) The average spectral value was determined by a log estimation of the band ratio for the given pixel within the kernel (Equation 6-2). Combinations of band ratios were tested. A middle infrared ratio against the visible red showed the largest correlation with S_d and C_a. Visible green versus near infrared also provided a good separation of the spectral response for estimating S_d and C_a.

$$\text{IR} = \frac{1}{9}\sum_{x=1}^{3}\sum_{y=1}^{3}\ln\frac{(\text{mid IR})}{(\text{visible red})_{x,y}} \qquad \text{6-2}$$

(2) Observed versus predicted S_d and C_a were well correlated with the use of this log estimate. Focused sampling and spectral blending led to the development of an accurate unsupervised classification with a 95% confidence interval. Sampling positions near tributaries were overestimated at only five sampling sites (relative to 109 sampling sites).

e. Conclusions. A strong correlation was made between the Landsat TM middle IR and the empirical Secchi Disk and chlorophyll concentrations. Chlorophyll was shown to have increased from 12.64 to 17.03 mg/m^3, contributing to a decline in water clarity. The application of this log estimate now eliminates the need to collect empirical water quality data, likely reducing the cost in a water quality survey.

Point of Contact: Robert Bolus, Phone: (603) 646-4307

6-8 Case Study 6: A SPOT Survey of Wild Rice in Northern Minnesota

- *Subject Area*: Agriculture
- *Purpose*: To estimate the percentage of wild rice in a wetland environment
- *Data Set*: Visible and near infrared

a. Introduction.

(1) A vegetation survey of natural wild rice surrounding three neighboring lakes 200 miles (518 km) south of St. Paul, Minnesota, was conducted to provide a base map for pollutant and water level monitoring. The study presented here utilized standard supervised classification, based on ground-truth, of high-resolution SPOT data. Wild rice is a natural marsh grass that is sensitive to water level changes and to changes in phosphorous concentrations; increases in phosphorous and water levels can significantly destroy wild rice communities. This is of concern as this important grass is a staple in the Chippewa Indian diet and is consumed by migratory birds.

(2) The researchers in this study were tasked with mapping and estimating the acreage of wild rice surrounding three lakes in Minnesota. Three spectral classes where developed with the use of a supervised classification to delineate the grass and its varying substrate.

b. Description of Methods. Ground truth data were collected simultaneously with SPOT over flight. The ground truth data included information regarding vegetation and substrate type as well as the sites corresponding UTM (global position in the Universal Transverse Mercator coordinate system).

c. Field Work. In the field, 18 ground control points (GCPs) were collected for rectification of the SPOT image and an additional 132 ground truth points were collected for the supervised classification algorithm. This data collection coincided with the SPOT over flight.

d. Sensor System. SPOT was chosen for its optimal detection of vegetation in the presence of inorganic ground cover (i.e., water). Vegetation absorbs both red and blue radiation, while reflecting green and near infrared (NIR) because of chlorophyll production. This matched well with the spectrum data provided by SPOT (which maintains green, red, and NIR bands among others).

e. Study Results.

(1) Prior to the classification process, it had been predicted that the wild rice would dominate one spectral class, as wild rice is spectrally distinct from other vegetation. Openings in the grass canopy, however, contributed to the spectral mixing observed in the image scene. Three spectrally distinct populations were noted, likely because of the heterogeneity of the background reflectance, varying crop canopy, and varying water content in the substrate.

(2) A histogram plot of the digital number value assigned to each pixel in the scene clearly reveals three distinct spectral populations. These three classes were determined to be wild rice growing in the lake, wild rice in marsh, and wild rice in a saturated soil. Wild rice growing in shallow or marsh water produced pixels that overlapped with more than one class. The near-infrared (N-IR) band allowed for better spectral separation by eliminating the effect of varying amounts of water in the substrate.

f. Conclusions.

(1) An estimate of the acreage percent based on a supervised classification determined that 1% of the scene was dominated by wild rice. Habitat was shown to predominately exist along the lakeshore, at inlets, ponds, on banks, and in marsh areas. Wild rice was determined to grow in saturated soil, marsh, and in shallow lake waters. The author recommend 200 ground truth points be collected per class (100 for spectral determinations and 100 for classification designation). Application of the ground truth data to a SPOT scene collected 5 days after the ground truth data did not produce an accurate classification. This test reveals the limitations on the usefulness of SPOT data for surveying vegetation—ground truth must be collected at the time of data acquisition.

(2) A detailed map of the distribution of wild rice will allow land managers to better predict the impact of changes in water level and phosphorous input on the natural production of wild rice.

Point of Contact: Robert Bolus, Phone: (603) 646-4307

6-9 Case Study 7: Duration and Frequency of Ponded Water on Arid Southwestern Playas

- *Subject Area*: Hydrology.
- *Purpose*: To delineate playa inundation frequency and duration.
- *Data Set*: Multispectral/thermal (Landsat 4, 5, and 7 and MTI – Multi-spectral Thermal Imager).

a. Introduction.

(1) Playas are ephemeral shallow lakes found in the arid southwest United States. Their hydrology is dominated by rainfall and runoff in the wet season and evaporation throughout most of the year. Surface hydrology, particularly frequency and duration, is poorly understood in the playa environment. US waters, including playa water, are Federally regulated under article 33 CFR 328.3 [a] of the *Clean Water Act*. Water bodies are delineated to their outermost extent termed their "Ordinary High Water" (OHW). OHW is defined by the presence of physical hydrological features representing the ordinary reaches of high water in its bed or basin.

(2) Playas exhibit tremendous temporal variation, as they may not pond at all during a particular year or may remain ponded for several years. The extent to which water remains

on the surface is influenced by the ambient climate, surface properties, evaporation rate, salinity, and infiltration or discharge of groundwater. Spatial and temporal factors such as inundation, evaporative rate, relocation of brine pools by winds, and desiccation of surface water hinder the ability to approximate the duration and frequency of ponding necessary to accurately model flood events or to determine whether certain Federal environmental regulations apply. This study attempted to model the frequency and duration of playa inundation in an effort to better delineate playas for regulations.

b. Description of Methods.

(1) For this study, three playa lakes on the Edwards Air Force Base were examined with the use of 20 years of historical Landsat and MTI imagery. These data were coupled with 59 years of precipitation records collected on the base. Rogers Lake (114 km^2) and Rosamond Lake (53 km^2) occupy the eastern and western region of the study area, respectively. Smaller playa lakes separate Rogers and Rosamond Lakes, including Buckland (5 km^2). The playa lakes are located on a Pleistocene glacial lakebed; the Pleistocene features dwarf the present geologic structures. Chenopod vegetation and saltbush plant communities dominate the terrestrial plain surrounding the playa.

(2) The playas remain dry for most of the year; however, winter rainstorms and summer thunderstorms cause water to periodically inundate playas. The duration of flooding depends on the magnitude and location of precipitation and ambient prevailing climate. Significant flooding is also associated with El Niño events in the Pacific Ocean, which leads to above-normal precipitation in the Southwestern US. Precipitation records maintained at Edwards Air Force Base provided precipitation data for the years 1942 to 2001. The average annual precipitation was calculated to be 13 cm/year with an estimated 280cm/year evaporation rate.

c. Sensor System. The department of energy on collected visible and near infrared data with the use of a Multi-spectral Thermal Imager (MTI) from February through May of 2001 Two sequential daily MTI images were acquired at 16-day intervals. This was done to ensure the capture of water that may exist at any time throughout the course of 31 days. The acquisition of multiple scenes eliminated the lack of data due to cloud coverage. Seven years of data were analyzed for this inundation study.

d. Study Results.

(1) The visible bands were not useful in visually delineating ponded water. Ponded water was best defined by a band ratio technique of B5/B2, which evaluated the proportion of reflective energy to input energy. The ratio values for each pixel were consistently greater than 1.0 for non-water objects and less than 1.0 for water objects. This ratio method was then followed by a classification that grouped pixels with values less than 1.0. Workers then assigned a DN value of 0 for objects displaying a ratio value of less than 1.0, thereby coloring all water bodies black in the scene. This ratio technique aided the image analysis by eliminating the problems caused by sun angle, sun intensity, and seasons—problems intrinsic to multi-temporal image analysis.

(2) The average precipitation was calculated to be 8.28 cm/year. These data, coupled with the image data, established the inundation frequency to be 51% of the time. This suggests that the playas are inundated, on average, every other year.

e. Conclusions. Results indicate that ponding that persists 16 days or longer occurred approximately every other year. The average precipitation needed to initiate ponding is estimated at 8.29 cm. Duration of ponding was shown to range from 1 to 32 weeks, with a direct relationship between length of inundation and total seasonal rainfall. Playa inundation, duration, and frequency can be determined from precipitation data and satellite imagery. The authors suggest the addition of contributing factors such as soil type and geometry may lead to a more robust hydrologic model of the playa system. A thorough understanding of the playa hydrologic regime may one day lead to new land use regulations.

Point of Contact: Robert Lichvar, Phone: (603) 634-4657

6-10 Case Study 8: An Integrated Approach for Assessment of Levees in the Lower Rio Grande Valley

- *Subject Area*: Engineering.
- *Purpose*: To detect weak areas within levees prior to flood events.
- *Data Set*: LIDAR.

a. Introduction. A series of levees were constructed along the Lower Rio Grande in Texas and Mexico in the 1930s. Local farmers, working with the county government, constructed the levee system to prevent flood damage to crops in low-lying areas near the river. The levees were constructed of sediment and soil materials obtained locally. The Federal government later completed the levee system in the 1940s and continued expansion and repairs through the 1940s. The US Army Engineer Research and Development (ERDC), working recently with the International Boundary and Water Commission, developed a GIS database to catalog levee condition. Knowledge of levee conditions prior to a flood is helpful in determining where repair and rebuilding are necessary on these man-made structures. A visual display of the levee and detail on the location of potential structural failure could then be used to prioritize levee repair and reconstruction.

b. Description of Methods.

(1) This study maintained four primary objectives. The first was to survey the levee system of the Lower Rio Grande River. The information compiled during the course of this survey was organized into a GIS database. The second was to extensively evaluate levee condition. The third was to compare the results of the airborne survey with those obtained from ground-based surveys. This objective tested the validity of implementing a remote sensing survey. Fourth, ground-truth locations were selected based on LIDAR data, and at these locations soil and subsurface strata were mapped using a cone penetrometer.

(2) In the course of developing the GIS database, ERDC developed a 10-point criterion for evaluating the condition of the levee system. Traditional geophysical tools were

then merged with remote sensing methods to proceed with the levee assessment. Levee topology was assessed with the use of LIDAR, digital video, aerial photographs, soil maps, and geological maps. Topographic deviations of 6 in (15.2 cm). or more along the centerline of the levee were then targeted for detailed seismic field studies. In addition to targeting segments with an undulating topography, several stretches of the levee (on the US side) were seismically surveyed.

c. Field Work.

(1) Ground surveys were conducted at five sites ranging in length from 3000 to 5000 ft (0.91 to 1.5 km). Electrical resistivity, EM, and magnetic surveys were collected in conjunction with the airborne EM and magnetic survey. The ground-based geophysical sites were geo-referenced with the use of a global position unit.

(2) Much of the data acquired for the GIS database were collected from previous sources. Information was taken from state and Federal survey maps, and from new and old aerial photographs. Digital photography and aerial photographs were used to map Holocene and Pleistocene deposits and geomorphologic structures. In areas with recent urban development, older images dating to the 1930s were used to evaluate the underlying geology.

d. Sensor Data Acquisition. LIDAR was utilized to survey levee elevation to determine deviations from the original design. Deviations in height indicate segments with potential damage attributable to seepage or sediment voids. Floodwater overtopping, slope failure, and seepage all potentially compromise levee stability. Seepage can create void spaces in the sediment and soil, resulting in subsequent levee collapse.

e. Study Results.

(1) The levee was then mapped and tagged with a conditional assessment of good, marginal, acceptable, or high-risk zones. The assessment was based on a numerical measure of 10 features deemed important in determining levee stability. These 10 features were chosen by agreement among Corps experts specializing in levee construction and repair. Table 6-2 lists the 10 features ranked in order of importance.

(2) Low scores in any one of the 10 features could result in a poor rating for a given levee segment. The levee was divided into segments based on conductivity measurements (shown to be controlled by levee material make-up); each segment was then given a numerical value based on a weighted measure of the 10 features. Segment ratings were color coded and presented as a layer within the GIS database. The color-coded maps provided an easy to interpret assessment of levee condition.

Table 6-2
Factors Important in Levee Stability

Performance history (under flood stage)
Construction history (original or upgraded)
Visual inspection apparent condition (on-site observation)
Material type (sand [worst] transition to clay [best]; (from EM, borings, soil maps)
Topographic irregularity (swags, erosion) (from LIDAR)
Potential slope stability (material type, relation to flow)
Man-made intrusions (utilities, bridges, pump stations, etc.)
Geology (old stream beds, river deposits)
Proximity of borrow area (size, depth, distance, side of levee)
Anomalies (unexplained radical conductivity "spots")

List is modified from Dunbar et al. (2003)

f. Conclusions. LIDAR, accurate to within 2 to 3 in (5.1 to 7.6 cm), was beneficial in economically mapping the surface morphology of the Lower Rio Grande Valley levee system. The merged remote sensing and geophysical data onto a GIS database facilitated easy retrieval of information for individual segments and can continue to aid in the management of the levee system. The authors view this study as a success and acknowledge that the application of these techniques to other geographical regions, while potentially of benefit, may not hold true for levee projects in other regions.

Point of Contact: Joseph Dunbar, Phone: (601) 634-3315

6-11 Case Study 9 : From Wright Flyers to Aerial Thermography—The 1910 Wright Brother's Hangar at Huffman Prairie

- *Subject Area*: Archeology
- *Purpose*: To review developing NASA products and detail their use in Corps works
- *Data Set*: Airborne CAMS

a. Introduction.

(1) The Huffman Prairie Flying Field, a National Historic Landmark located at Wright-Patterson Air Force Base, was surveyed using a variety of ground and airborne sensors in an effort to locate the forgotten Wright Brother's hanger. This hangar, in use from 1910 to 1916, was the training and testing site for the Wright Aeronautical Company activities. The hanger was demolished during the 1940's with no record of its precise location.

(2) In the early 1990s, CERL researchers investigated the Huffman Prairie Flying Field using traditional and common archeological methods, such as excavation, magnetic and electromagnetic surveys, and ground penetrating radar (GPR). NASA aided CERL's effort with the addition of thermal data collected from an airborne platform. The airborne

data isolated a rectangular footprint, which corresponded with the location of the Wright hangar. Later ground truth data collection and excavation works unearthed well-preserved wall posts constructed of wood. This project exemplifies the technological methods currently being adopted by archeologists. Geographic Information Systems (GIS) practices are now in wide use among archeologists, who take advantage of the utility of spatially related data.

b. Description of Methods. This study had two objectives; the first was to locate the precise position of the Wright hangar. In archeological terms, the site and the history centering on the Wright Brother's and their activities is well documented. The historical record contains many photographs and aerial photographs that trace the approximate location of the Wright buildings. In 1994 an architectural firm established the dimensions and structural details of the Wright hangar with the use of these photographs. They determined that the hangar was approximately 70 by 49 ft (21.3 by 14.9 m). Knowing the approximate dimensions and location of the building would seemingly make the archeological work a simple task. The second objective of the study was to determine if traditional and modern archeological work could add insightful information to the already well-documented site, and thereby further detail the history of early American aviation.

(1) The authors describe the general area surrounding the Huffman Prairie Wright Brothers field as being relatively undisturbed despite the growth and development of the Wright-Patterson Air Force Base neighboring the site. The prairie had been subject to burning, but not plowing. The task in locating the hanger included fieldwork, near surface geophysical work, and aerial remote sensing. The initial excavation made it apparent that identifying remains of the hangar would require either a significant amount of additional excavation or the use of technologically sophisticated, noninvasive methods. Further excavation was deemed too destructive for the site, leading to the decision to employ near-surface and aerial remote sensing.

(2) The geophysical work included magnetic, electromagnetic, and ground penetrating radar (GPR). Combining multiple geophysical techniques is a good practice, as one instrument may easily pick up features not identified by another. Geophysical survey methods typically involve data collection in a grid pattern across the study site. Anomalies in the subsurface potentially indicate natural phenomena or anthropogenic disturbances in the strata. Some anomalies may then be excavated for ground-truth data collection. It is generally good practice to conduct some ground-truth to verify the geophysical interpretations.

c. Field Work.

(1) Fieldwork, prior to collecting the remote sensing, began in 1990. The researchers hoped to find underground building remnants or surface features, such as the hanger's footings or drip lines that paralleled the absent roofline. Long trenches were hand-excavated unearthing 60% industrial debris, 2% domestic articles; the remaining material consisted of wood debris and other uncategorized items. Excavation did not identify any intact architectural remains of the actual building, and did not locate the precise position of the hanger.

(2) Additional fieldwork verifying the geophysical results uncovered three features. Feature 1 was a well-preserved, intact wood post—possibly one of the hangar's major wall

posts. Features 2 and 3 were pits filled with artifacts and debris. Feature 2 fill included nails, a shell casing, and flat glass. The function of this pit was undetermined. Feature 3 contained wood, glass, nails, and roofing fragments. It was assumed that this was a posthole pit excavated in 1924 during the remodel and repair of the hanger. The posthole was subsequently back filled with reconstruction debris. These three features were not evenly spaced nor in a parallel or perpendicular orientation relative to the predicted location of the hanger. The authors did assert that possibly two of these features represented intact hangar posts.

d. Sensor Data Acquisition. The airborne remote sensing study conducted by NASA incorporated a calibrated airborne multispectral sensor (CAMS), which collects data in the visible, infrared, and thermal bands. A hand held inframetrics thermal scanner was also used.

e. Study Results.

(1) The geophysical survey results indicated that a rectangular area defined by the conductivity, magnetic, and GPR anomalies most likely encompassed the hangar location, which was initially indicated by the 1924 air photo. The airborne hand held inframetrics confirmed the shape and location of the hanger. An explanation for the distinct thermal response remains unclear. The authors suggested that soil compaction and heat retention related to spilled petroleum products may account for the unique thermal signature at the hangar site. The field research led to the collection of over 6000 individual samples; the majority of which were buried industrial artifacts. The authors stated that with “no historical records, it might have been very difficult to infer the primary function of the hangar building” from the collected fragments.

(2) All artifacts were georeferenced and a GIS map was generated to indicate the distribution of materials relative to the hangar and other building units. The majority of artifact categories are concentrated on the northern portion of the hanger as a result of demolition processes. The inframetrics was useful in locating the hanger footprint and delineated gullies adjacent to the road. The CAMS detected the actual roadbed.

f. Conclusions. This study demonstrates how remote sensing technologies can further traditional research efforts in the area of archeology and history. The amalgamation of GIS with airborne and ground remote sensing methods proved highly successful in providing additional information on the already well-documented site. The distribution mapping of artifacts indicated that the building had been demolished by a bulldozer, differing from the theory that the building had simply collapsed on its own accord. Even though the hangar may have been demolished using a bulldozer, its archaeological evidence maintained some integrity and was easily detected by the thermal sensor. Thermal sensors are thus likely to join the growing array of near surface geophysical and aerial remote sensing techniques that can enhance researchers ability to detect and study archaeological sites.

Point of Contact: Michael Hargrave, Phone: (217) 352-6511, x7325

6-12 Case Study 10: Digital Terrain Modeling and Distributed Soil Erosion Simulation/Measurement for Minimizing Environmental Impact of Military Training

- *Subject Area*: DEM generation and soil erosion modeling
- *Purpose*: To adequately model soil erosion and transport for land use management
- *Data Set*: Digital Elevation Models (DEM)

a. Introduction.

(1) The conservation of soil on military land is a priority among land use managers, second only to the protection of threatened and endangered species. A realistic model of soil erosion and subsequent transport will provide managers the information required to better plan military activities, such as training. A better model of the various factors that contribute to soil loss will give insight into the best temporal and spatial use of military land.

(2) The optimal soil loss model incorporates information regarding the diurnal, seasonal, and temporary elements influencing soil properties, as well as incorporating terrain details. Prior to this 1997 study, soil loss models tended to measure soil loss along a linear slope, calculated as the average slope across the study area. Models with these simple slope inputs do not consider the dynamic nature of slope terrain and its consequential control on soil erosion, transport, and deposition. The study summarized here attempted to improve upon existing soil erosion models by incorporating details associated with an undulating surface. The model extracted high resolution terrain information from a digital elevation model (DEM) to better mimic erosional provenance and sediment sinks within a watershed.

b. Description of Methods. This study applied three sediment erosion/deposition models to 30- and 10-m DEM data. The models included CASC2D, a two-dimensional rainfall/runoff model, USPED, an improved Universal Soil Loss Equation model, and SIMWE (SIMulated Water Erosion), a landscape scale erosion/deposition model. All models attempted to simulate watershed response to military training scenarios.

(1) The first model, the CASC2D is a two-dimensional rainfall-runoff model that simulates spatially variable surface runoff. This modeling process can be found in GIS/remote sensing software packages (http://www.engr.uconn.edu/~ogden/casc2d/casc2d_home.html). Model inputs include runoff hydrographs, and water infiltration rate and depth, surface moisture, surface runoff depth, and channel runoff depth.

(2) The second model, the Revised Universal Soil Loss Equation (RUSLE; see equation 6-3), is the most widely used empirical erosion model, and is best applied to homogeneous, rectangular agricultural fields. The equation quantifies major factors that affect erosion by water. The LS (slope length factor) accounts for only the steepness of the terrain over a given area. The authors of this study developed an LS analog for the RUSLE and refined the soil loss equation creating the Unit Stream Power Erosion and Deposition

(USPED) model. This model increases the accuracy of erosion and deposition prediction on uneven terrain.

$$A = R \times K \times LS \times C \times P \quad \text{6-3}$$

where

A = estimated average soil loss in tons per acre per year
R = rainfall-runoff erosivity factor
K = soil erodibility factor
LS = slope length factor
C = cover-management factor
P = support practice factor.

(3) See http://www.iwr.msu.edu/rusle/about.htm for details on the Revised Universal Soil-Loss Equation.

(4) The two models described above use statistical averages of hill slope segments for the entire watershed, leading to inaccurate outputs. The SIMulated Water Erosion (SIMWE) model, the third model used in this study, overcomes these shortcomings by adding a continuity equation. SIMWE is based on the solution of the continuity equation (solved by Green's function Monte Carlo Method) that describes the flow of sediment over the landscape area. The factors included in the SIMWE model include measurements relating to steady-state water flow, detachment and transport capacities, and properties of soil and ground cover. The primary advantage of this model is its ability to predict erosion and deposition on a complex terrain on a landscape-scale, thereby improving land use assessments.

c. Remotely Sensed DEM Data. In an effort to minimize environmental impacts at military training sites, CERL scientists evaluated the effectiveness of applying standard soil loss equations with the use of DEM at varying resolutions. The optimal pixel size for landscape level erosion and deposition modeling ranges from 5 to 20 m. Most readily available DEM data is at the 30-m resolution. Higher resolution DEM data are slowly becoming more available ; for older DEM data sets and the easily accessible Landsat data, it is possible to interpolate the low resolution data and resample the data at a finer resolution. For this study the authors converted 30-m resolution data to 10-m resolution data by applying a regularized spline with tension (RST) method, a spatial interpolation tool included in some GIS software. The method is a smoothing function, which interpolates the resampled data from scattered data (RST was developed by Lubos Mitas at North Carolina State University).

d. Study Results. The authors illustrated the issues associated with modeling soil loss over a large area by evaluating a mountainous, 3000-km^2 region in Fort Irwin, California. Topographic inputs into the models served as both a tool in evaluating erosion potential and in determining the quality of the DEM. Low quality DEMs hold a high proportion of noise in the data. The noise in the data creates two related problems: 1) the signals could easily be interpreted as landscape features, and 2) large terrain features could be obscured by the noise. Resampling and smoothing techniques using the RST reduced the noise and produced a 10-m resolution DEM. This process better highlighted prominent topographic features.

(1) The potential for net erosion/deposition was calculated using two different resolutions (the 30-m DEM and a 10-m DEM developed by the resampling of the 30-m data).

These calculations provided the test required to determine the effectiveness of the smoothing and resampling techniques. The visual analysis of the image overlaid onto the 10-m resolution DEM revealed little noise. The USPED model is described as being "very sensitive to artifacts in a DEM as it is a function of second order derivatives (curvatures) of the elevation surface." With the reduced noise in the data, the USPED model is predicted to accurately assess soil erosion and deposition.

(2) Sediment flow rates were calculated for a subset area from within a 36-km^2 area of Fort McCoy, Wisconsin. The rate was determined with the use of the SIMWE, which solves for the continuity of mass equation. The results indicated high sediment flow rates in valley centers and varying flow rates in adjacent areas. The SIMWE model compared well with the USPED model results

(3) The USPED and SIMWE models were also compared in an analysis of soil transport in the Fort McCoy, Wisconsin, area. Topographic potential for erosion and deposition were estimated with the USPED model using a 30-m and a 10-m DEM. The 10-m data were again derived from the 30-m data by a smoothing and resampling technique.

(4) The GIS map is based on the 10-m data denoting areas of high potential for soil erosion, typically shown to be hilly areas adjacent to streams. This landscape model showed areas of temporary deposition, where soil and sediment resided before entering the main stream. The map created with the 30-m data inadequately predicted the areas of soil loss; it was suggested this was the result of concentrated flow in valleys. Furthermore, artificial waves of erosion and deposition were shown in flat areas. This was due to the vertical resolution of up to 1 m in the 30-m pixel size DEM. The 10-m data maintains a lower 0.1-m vertical resolution.

(5) When the 10-m resolution DEM was used with the USPED model, intense erosion was predicted in the hilly regions adjacent the main streams and tributaries. Deposition continued to be evident in the concave areas. Distinct from the map derived with 30-m DEM, the 10-m resolution DEM GIS map indicated high erosion in areas with concentrated flow that could reach the main streams. The artificial pattern of erosion/deposition along nearly flat contours was not depicted in the 10-m GIS data.

e. Conclusions. The CASC2D, USPED, and SIMWE soil erosion models significantly advanced the simulation of runoff, erosion, and sediment transport and deposition. With the application of factors relating to three dimensions, these models better predict the spatial distribution and motion of soil and sediments in a watershed. The 10-m resolution was shown to be most advantageous in revealing the detail required to model soil erosion and deposition. The 10 m resolution was easily developed from 30-m pixel sized data with the use of software resampling tools followed by a smoothing algorithm. In summary, this work potentially improves land management and should reduce land maintenance and restoration costs.

Point of Contact: Steven Warren; swarren@cemml.colostate.edu