A SYNTHESIS OF REMOTE SENSING APPLICATIONS
FOR ENVIRONMENTAL ASSESSMENT

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ABSTRACT

The National Consortium on Remote Sensing in Transportation – Environmental Assessments (NCRST-E) is one of four consortia established by the US Department of Transportation to lead in the application of remote sensing and geospatial technologies in the transportation industry. The primary mission of the consortium for Environmental Assessment is to develop and promote the use of remote sensing & geospatial technologies, and requisite analysis products by transportation decision-makers and environmental assessment specialists to measure, monitor, and assess environmental conditions in relation to transportation infrastructure. The consortium is composed of university (Mississippi State University, Auburn University, University of Alabama in Huntsville, University of Mississippi), government (NASA Marshall Space Flight Center and Global Hydrology and Climate Center), and commercial (DigitalGlobe, EarthWatch Incorporated, Intermap Technologies, Inc, &, ITRES) partners. The NCRST-E also manages three Technology Application Projects (TAPS) for the USDOT being performed by Veridian Systems, Virginia DOT, and Washington DOT. The purpose of this paper is to synthesize research results from the consortium's efforts and to show how they can be used in environmental assessment and planning. Much of the text used in this paper is gleaned from published results from the consortium partners. References are listed so readers can gain a better appreciation of the details of some of the projects highlighted in this paper. Also, more detailed results can be obtained at the consortium's web site – www.ncrste.msstate.edu.

MISSIONS AND GOALS

The primary mission of the consortium for Environmental Assessment is to develop and promote the use of remote sensing & geospatial technologies, and requisite analysis products by transportation decision-makers and environmental assessment specialists to measure, monitor, and assess environmental conditions in relation to transportation infrastructure (King, 2001). The consortium conducts research to improve our understanding about how remote sensing and geospatial technologies can provide planners, managers, engineers, and analysts with information resources that can be used to improve multimodal transportation planning, design, operation, and maintenance efforts. Consortia activities also are focused on conducting technical outreach with transportation agencies and organizations to demonstrate how remote sensing and geospatial technologies can be effectively implemented and to improve understanding of where additional research, outreach, and training activities are most needed. To accomplish this mission the NCRST-E has articulated four goals:

- Develop innovative remote sensing technology solutions for assessing the implications of transportation on the natural environment and protecting and enhancing the environment.
- Assess and plan, in particular the capabilities of new high resolution, multispectral sensors, and develop the tools necessary to extract information content from remote observations in an efficient manner.
- Streamline and standardize data processing for information necessary to meet federal and state environmental regulations and requirements.
- Increase the awareness and understanding of remote sensing technologies and products through workshops and educational materials.

These four goals were established in response to a needs assessment conducted in conjunction with the Transportation Research Board of the National Academy of Sciences to determine areas in which remote sensing and geospatial technologies could be used by the transportation industry in environmental planning and assessment. The following list summarizes the environmental subject areas identified by the user groups:

- Regulatory Streamlining
- Watershed Assessment
- Wetlands
- Water Quality / Stormwater
- Land Use Change
- Air Quality
- Species
- Floodplain Management
- Environmental Justice
- Cultural Resources

There were also several environmental process issues identified by the group:

- Regulatory Acceptance of remote sensing data
- Accuracy
- Real Time Data
- Data Directory
- Metrics / Measurement
- Benefit Cost Information
- Education / Outreach

A more detailed needs assessment report (Laymon, 2001) developed by the Global Hydrology and Climate Center can be accessed at the consortium's web site.

# ENVIRONMENTAL ASSESSMENTS FOR CORRIDORS

NEPA Planning Process

One of the most expensive and time-consuming aspects of early transportation project planning is the selection and environmental assessment of potential routes or corridors. Alternative routes and designs are evaluated not only on how well transportation objectives are met, but also on the degree to which significant negative environmental and socioeconomic impacts are minimized. The environmental review processes mandated under National Environmental Policy Act generally require extensive data collection on potentially affected environmental resources for alternatives, including the proposed action. This process can require several years of study and field work to develop an adequate baseline of information on existing environmental conditions for such resources as air and water quality, geology, soils, hydrology, water use, aquatic and terrestrial ecology, socioeconomic resources, cultural resources, and aesthetics.

In order to be credible, National Environmental Policy Act analyses should be based on good quality data and a clear demonstration that appropriate alternatives have been considered and evaluated in an objective fashion. Remote sensing data can contribute to improving the National Environmental Policy Act review process by providing a credible baseline of information for evaluating alternatives early in the process and eliminating unnecessary and costly detailed analysis.

I-10 Mississippi – Coastal Corridor

An environmental assessment is being planned to study the impacts of relocating segments of the CSX railroad out of significant population growth areas along the environmentally sensitive Mississippi Gulf Coast. The environmental assessment project, which is being jointly managed by the Mississippi DOT and FHWA, will make broad use of remote sensing and geospatial technologies. The project has been awarded and is being supported by the technical and research resources of the National Consortium on Remote Sensing in Transportation (www.ncrst.org).

The three coastal counties in Mississippi (Figure 1) Jackson, Hancock, and Harrison, have undergone considerable change in land use, population, wildlife habitat, demographics, and socio-economic conditions in the past 30 years. In that time, Interstate 10 (I-10)
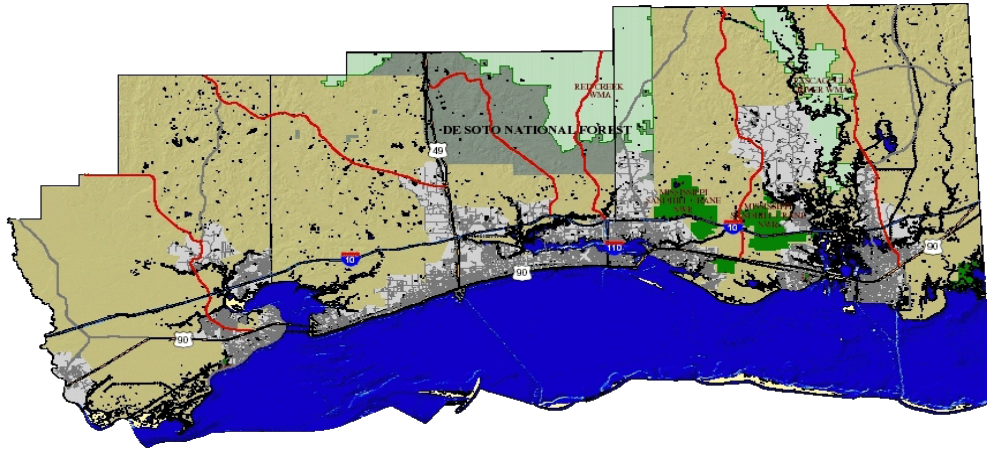

Figure 1. Location of the planned rail relocation EIS.

has been completed, extensive population growth has occurred, and the coastal counties have changed from being mostly small fishing communities to communities with a complex mixture of residential, commercial, industrial, urban, resort, and relatively unspoiled coastal wilderness areas. The population has gone from around 240,000 in 1970 to over 350,000 in 2000, showing a growth of almost 50 percent (O'Hara, 2002a)

A significant portion of the 3-county Gulf Coast area is within National Forest, state parks, wildlife management and refuge areas, conservation areas, or wildlife sanctuaries. The sensitive environmental conditions coupled with a high rate of population growth, and land development combine to provide a challenge to develop the region in a manner that is sustainable and preserves the natural environment. NCRST-E has used available GIS and remote sensing to assess general trends in land cover and land use change and the development of areas along the Mississippi Gulf Coast. Through inspection of existing land cover data, such as the USGS Multi-Resolution Land Characteristics 1992 (USGS, MRLC 1992) data set and the Mississippi Automated Resource Information System land cover data for 2000 (MARIS, LCLU 2000) it is possible to readily observe some aspects of the development trends in the 3 coastal counties. However, different approaches were used to develop these data sets making direct comparison to determine land cover change problematic.

NCRST-E research has focused on developing approaches for classification and analysis of satellite image data for coastal areas to determine change in regional land cover and land use over time. A series of satellite image data for the area collected over the past 30 years has been processed and analyzed using consistent classification techniques resulting in data that can be more readily compared to assess growth and development patterns for the region (O'Hara, 2002b). By using similar data, processing methods, and classification schemes, it is possible to improve the consistency of results and with increased assurance assess such factors as growth in developed areas and change in land cover types (Figure 2). It is also possible to evaluate change in land cover and land use as it relates to proximity to new transportation infrastructure or proximity to other spatial features.

Through completed and ongoing NCRST research, regional trends in growth, development, and land cover change have been quantified with the use of Landsat satellite imagery. Landsat satellite imagery (TM, ETM+) provides data with a spatial resolution of 28.5 meters and multiple channels in the spectral range of 0.45 - 12.5 μm. While the resolution of Landsat satellite image scenes provides data sufficient for regional assessment and determination of general trends, the data do not provide sufficient resolution for preliminary transportation corridor
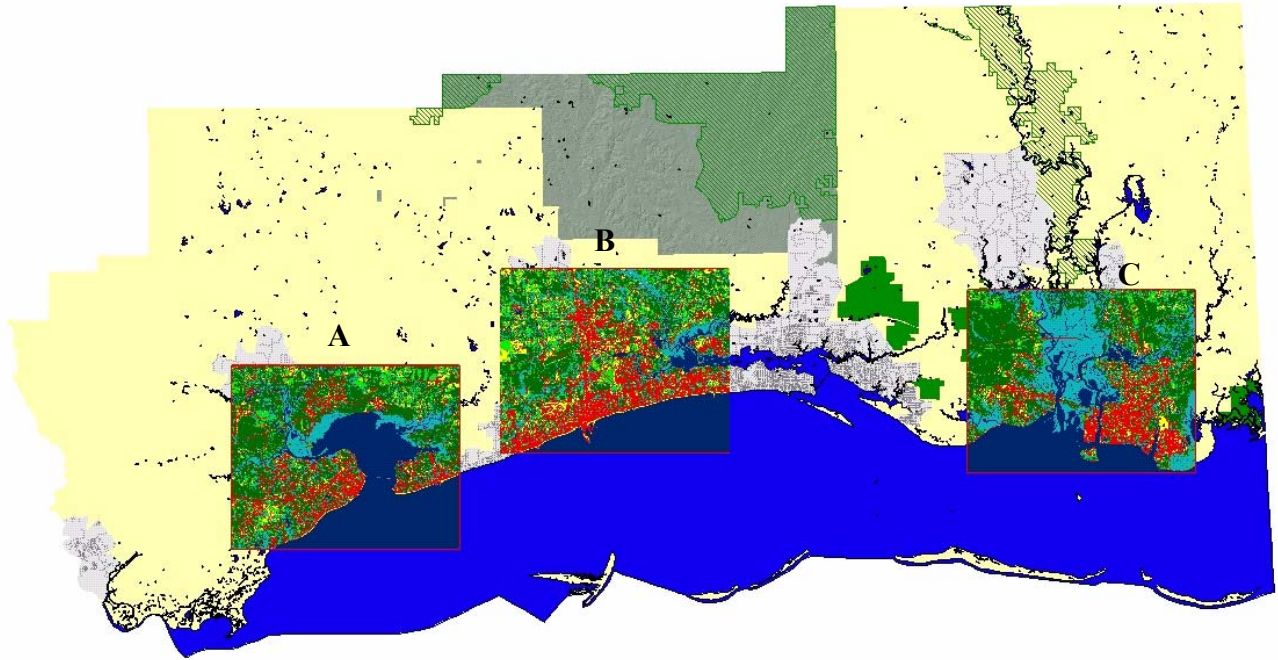
Figure 2. Land cover information in development by NCRST for selected areas along the Mississippi Gulf coast overlaying a map of the coastal region highlighting areas of growth shown in red for areas around Bay St. Louis (**A**), Gulfport (**B**), and Pascagoula (**C**).

designs, planning, or environmental assessment. For planning, design, and environmental assessment, engineers and environmental analysts require data with significantly higher spatial resolutions.

Rapid advances are being made in remote sensing and geospatial technologies. New systems for collecting aerial remote sensing data include high spatial resolution image data, high spectral resolution multispectral and hyperspectral image data, LIDAR elevation data, and IFSAR elevation data sets provide rich sources of information that can be collected rapidly for large areas, but at considerable cost. New satellite platforms such as Space Imaging's Ikonos and DigitalGlobe's QuickBird provide commercial satellite image data with spatial resolutions far higher than have been available in the past. In fact, the spatial resolution of the panchromatic (black and white) data from Quickbird exceeds that provided by USGS DOQQ data.

NCRST-E is working to identify sources and providers of existing remote sensing and geospatial data for the region and is working with agencies such as NASA and commercial data providers to identify sources of new high resolution data for the area. It is hoped that these data, among others, can be made available to the environmental assessment effort. NCRST-E will work to facilitate the availability of these and other data products for the assessment efforts. Although the selection of specific data types and acquisition details will be determined by the contractor in consultation with the Mississippi DOT and FHWA, who are managing the project, it is likely that the following data types will be used to some extent in the environmental assessment process:

- Historic satellite image data
- Historic land cover and land use data
- Digital elevation data from available data sets
- USGS Digital Raster Graphics of topographic quadrangle maps
- Digital orthophoto quarter quads (DOQQs) from the USGS
- New high spatial resolution aerial image data
- New high spatial resolution multispectral satellite image data
- New high spectral and spatial resolution aerial hyperspectral image data
- New high vertical resolution digital elevation data
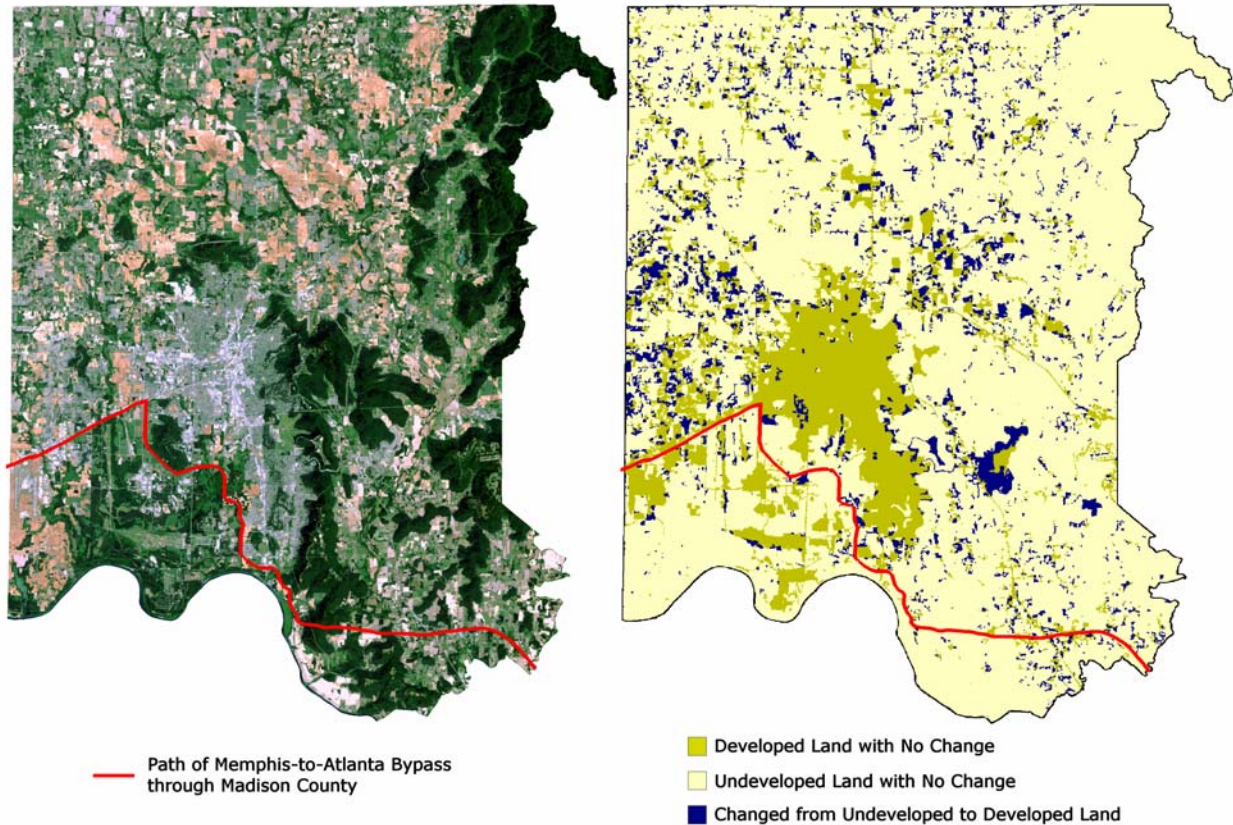
Figure 3 Landsat imagery of Madison County, AL and a map of urban development over the last 10 years derived from Landsat imagery. The location of the preferred alternative for the siting of the Memphis to Atlanta highway through Madison County is shown in red.

Corridor 7 – Memphis to Atlanta

Land cover classification from Landsat data can aid in informing the public of the proposed action and facilitate engaging the public in the EIS process during the scoping phase. Landsat data can be used at a smaller scale to provide a contextual framework for siting transportation around a city. For example, Landsat data can be used in the siting phase of planning Corridor 7 through Madison County, Alabama enroute from Memphis, TN to Atlanta, GA (Figure 3). FHWA Guidelines require that proposed actions be put into the context of current development trends. The EIS must also identify the state and/or local government plans and policies on land use that will be impacted. Remote sensing data are used to characterize urban sprawl over the past ten years thereby identifying the shift in population demographics of Huntsville, Alabama. This information was not readily available from any other source. Since most of this development has been to the west and north of the city, these areas could be excluded from consideration as areas of preferred residential development. Alternatively, the city is lies on the northeast edge of the US Army's Redstone Arsenal military base. The Arsenal's access restrictions and vast wetlands posed additional constraints. The preferred alternative is a bypass or limited access highway inside the Arsenal boundaries which is elevated over wetlands.

Landsat data at 30 m resolution is suitable for relatively general natural resource classes, such as softwood and hardwood forests, pasture, cropland, residential and industrial areas, water bodies, etc. Recently, high resolution multispectral data are becoming available from commercial data providers. These data are better suited for mapping more detailed land cover/land use classes and may be used to estimate and report the number of displaced households, businesses and farms, and identify affected neighborhoods and public facilities as required by an EIS for proposed actions that displace existing structures and facilities. Processing imagery to distinguish between

single-family and multi-family homes and businesses will not be 100 percent accurate, but will reduce the amount of time required for validation on the ground. Given the newness of commercial remote sensing data, improvements in image analysis techniques are required to take full advantage of these data. Techniques are being developed in multiscale image segmentation and object oriented classification, textural classification and back propagation artificial neural network classification.

I-405 Washington State

Transportation system improvements are desperately needed in Washington State's Puget Sound metropolitan area. The highly urbanized Interstate 405 corridor is one of several programmatic environmental analyses for transportation improvements either in-process or planned for the metropolitan area (Figure 4). The regional transportation planning process has identified the I-405 corridor as being a high priority for congestion relief. By comparing the cost and quality of results obtained from traditional data collection methods used to meet National Environmental Policy Act requirements with those using the methods which this project will develop, this project aims to demonstrate an approach that uses remote sensing technologies to streamline environmental analysis in the transportation planning process.

The project consists of six major tasks: 1) Undertake field study in two stages, first to collect ground-truth data prior to image analysis, and then to evaluate the image-analysis results against the "real-world." 2) Compile and evaluate available image data and fuse these data to create the best possible resource for image data analysis. 3) Characterize land use and land cover (LULC) in the region. 4) Integrate the land use and land cover characterization from the previous task, with GIS and other data, to provide land use/land cover and transportation images, and related analysis. 5) Develop estimates and compare the cost and quality of information developed with conventional methods with those developed in this project. 6) Document the procedures, analysis, and findings to institute technology transfer steps.

The strategy of this project is not to lock into a specific technology, but to adopt an approach that makes combined use of different technologies in order to achieve synergistic advantages. Methods are being developed to fuse a variety of available data such as black-and-white and color orthophotos, IKONOS images, and Landsat-7's Enhanced Thematic Mapper Plus (ETM+) images to take advantage of their different attributes to achieve synergistic results. The black-and-white and color orthophotos have a half foot spatial resolution will be utilized to achieve high geometric accuracy for ground feature identification and delineation. Landsat ETM+, on the other hand, will be utilized to cover large geographic areas, and provide multi-spectral information that is particularly useful for discriminating among different LULC types. Image data available for this project include Landsat 7 and IKONOS multi-spectral scenes, black and white orthophotos produced by the Washington State Department of Natural Resources, and high resolution color orthophotos produced by the Washington State Department of Transportation.

The multi-spectral imagery provided by Landsat-7 have the spectral signatures of many different features, which can be exploited to obtain information on land use and land cover classes – information that is important for environmental analysis and the transportation planning process. Using IKONOS imagery, road pavement, edge lines, and central stripes can be accurately mapped. Bridges, parking lots, and even vehicles on or along the roads can be identified.
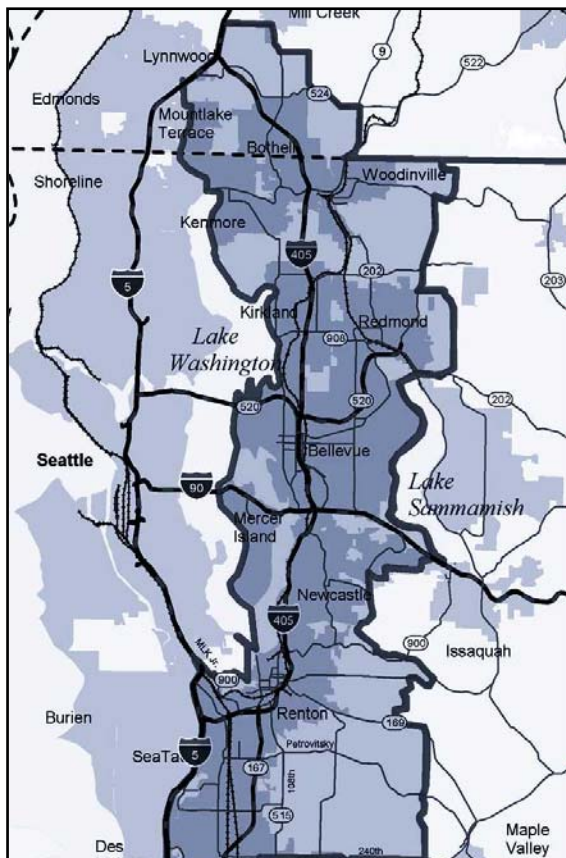
Figure 4. The primary study area extends one to three miles on either side of I-405, between SeaTac and Lynnwood

Environmental conditions and transportation impacts such as urban growth, increased area covered by impervious surfaces, or habitat fragmentation can be now evaluated at much improved accuracy.

Available GIS data layers such as transportation networks, demographic data, and topographic map data along I-405 have also been collected. Imagery and vector data are being integrated to form a source database for analysis. To handle data integration, the project will use two major commercial software products: the IMAGINE image processing system and ARC/INFO GIS. IMAGINE, which was developed by one of the study partners, ERDAS, Inc., is a full suite of products for image mapping and visualization, image processing and advanced remote sensing. ARC/INFO is one of the leading GIS products capable of performing many data integration functions such as projection transformation, rubber sheeting for local coordinate adjustment, and data display for visual editing and correction.

Products to be generated include: 1) A spatial database of raw image data from a variety of remote sensing sources, and derived and interpreted information in GIS format including land use and land cover information. 2) Software procedures accessing multiple data sources to derive land use land cover information and to identify and delineate areas where proposed transportation development are likely to cause environmental impacts. 3) Cost-benefit analysis of study methods and a comparison to costs of conventional practices, including qualitative comparison of content, accuracy and timeliness. 4) Guidelines for use of these methods and techniques by other DOTs.

INFORMATION TECHNOLOGY FOR DATA MANAGEMENT AND COORDINATION

Computational Mapping Engine (CME)

One of the most difficult challenges in transportation and regional planning is data management and map product creation. Providing needed geospatial data (i.e., map products) to decision makers, planners, engineers, and analysts is a difficult task that is further complicated by the use of large geospatial image data sets that are needed for the products. These data sets usually comprise large data files that are difficult to transfer, require significant storage resources, and are time-consuming and complicated to process. The development of computational solutions for the storage, management, custom product creation, and distribution of image data and other geospatial data sets is of vital interest to transportation agencies. To address these challenges, Mississippi State University is developing a computational mapping engine (CME). One of the first tasks proposed for the CME will be serving specific data and information products to MDOT and other EIS project participants for the Mississippi coastal corridor effort.

Traditional image processing and geospatial data workflows typically involve highly skilled analysts who prepare data for use by engineers, planners, and other data users who in turn use the data to create custom maps, perform analyses, and tabulate data. Image analysts usually have expensive graphics workstations, complex software, and access to extensive data storage. Much of the work of these analysts is conducted using complicated image processing and GIS software. One of the most time-consuming set of tasks involves the preparation of image and base map materials that are useful for custom maps and analysis. Tasks such as, image registration, ortho-rectification, coordinate transformation, creating mosaics, creating digital terrain models, and fusing data to produce custom products can be extremely time consuming and labor intensive. Mississippi State University will develop resources to perform many of the "heavy-lifting" tasks of geospatial data management, image processing, custom product development, and product distribution that are an increasingly significant part of transportation planning, environmental assessment, and transportation design.

The CME will be developed in a multi-tier architecture with a back end, middleware, and a front end for client applications (Figure 5). Each part of the architecture may eventually be geographically distributed among different sites. However, the initial development will focus on development at Mississippi State University with the primary facilities at the Engineering Research Center as well as at the University Libraries, MSU Extension Service, and the Remote Sensing Technologies Center. Extensibility of the CME to other sites not at the MSU campus will be explored and developed over time as funding permits, partnering relationships are established, common standards and methods are agreed upon, and infrastructure put in place (O'Hara, 2002c).
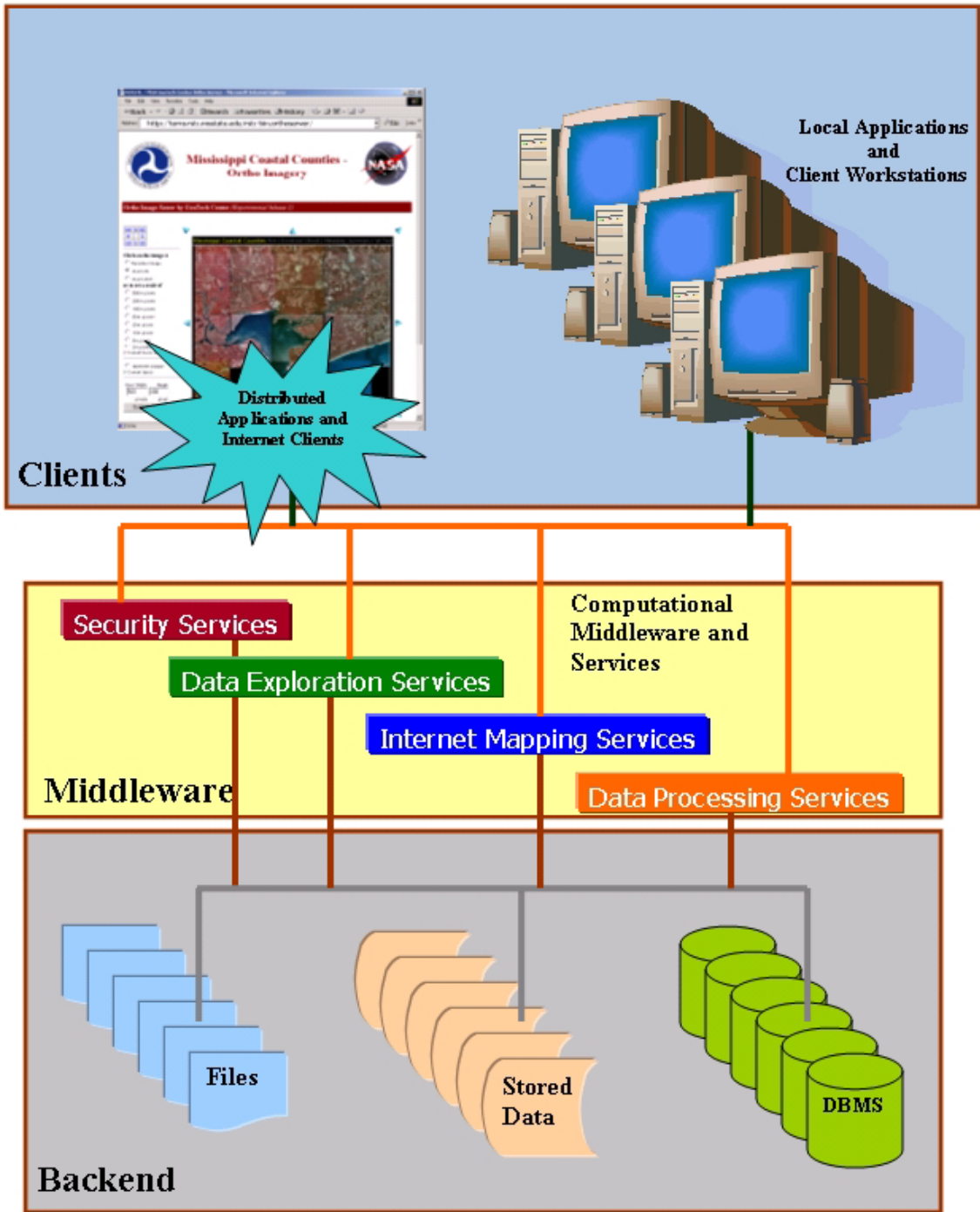
Figure 5. Basic architecture of the computation geospatial data library.

The back end will comprise server hardware, data storage, databases, and data processing engines. The middleware will provide computational services that will include security for all connection types, data exploration services, internet mapping and analysis services, and data distribution services. The front end will be provided through web browsers and client applications that either connect locally or via internet methods. MSU is developing research activities for components within all parts of the CME with a preference toward COTS and open source software.

REGIONAL DATABASES FOR TRANSPORTATION PLANNING

Regional information is an important element for transportation planning. It is therefore logical that the development of information on a regional scale would be beneficial for planners for a variety of reasons. Perhaps the most important reason for developing regional databases are that they provide a starting point from which planners can make preliminary decisions about where to place transportation facilities.

Information about local conditions is often insufficient to meet the needs of transportation planners. A major reason for this is that local traffic conditions are often impacted by features and phenomena outside of the immediate area of interest. This is particularly evident if the area of interest does not contain significant destinations such as businesses, schools or neighborhoods. Another reason for this is that localized data is often incomplete or out of date, requiring that time and resources be used to acquire the necessary information.

In order to fully predict the utilization of a transportation corridor, it is necessary to understand the reasons that the facility will be used, and it is also necessary to understand where the traffic will be coming from, and why. Planners also require a wide variety of environmental information to plan exactly where facilities can be developed without having significant impacts upon the physical, social and cultural environment.

Geographic Information Systems (GIS) provide a means for analyzing all of the information layers necessary to derive a suitable solution for locating facilities. GIS solutions, however, are only as good as the information that is input into the system. It is possible to develop a comprehensive GIS database and not have enough information to make the best decision. Remote sensing is one method for collecting and deriving information about project areas on a regional scale.

During the spring of 2000, on behalf of the Gulf Regional Planning Commission (GRPC), Veridian Systems developed a regional database for the six southernmost counties in Mississippi. The purpose of this project was to develop a comprehensive geographic database using readily available geographic data for use by high-level planners, particularly for transportation planning. One issue that was evident early in the process was the potential for identification of a suitable location for a high-speed rail facility.

The final product consisted of the geographic database of imagery and vector data layers on a
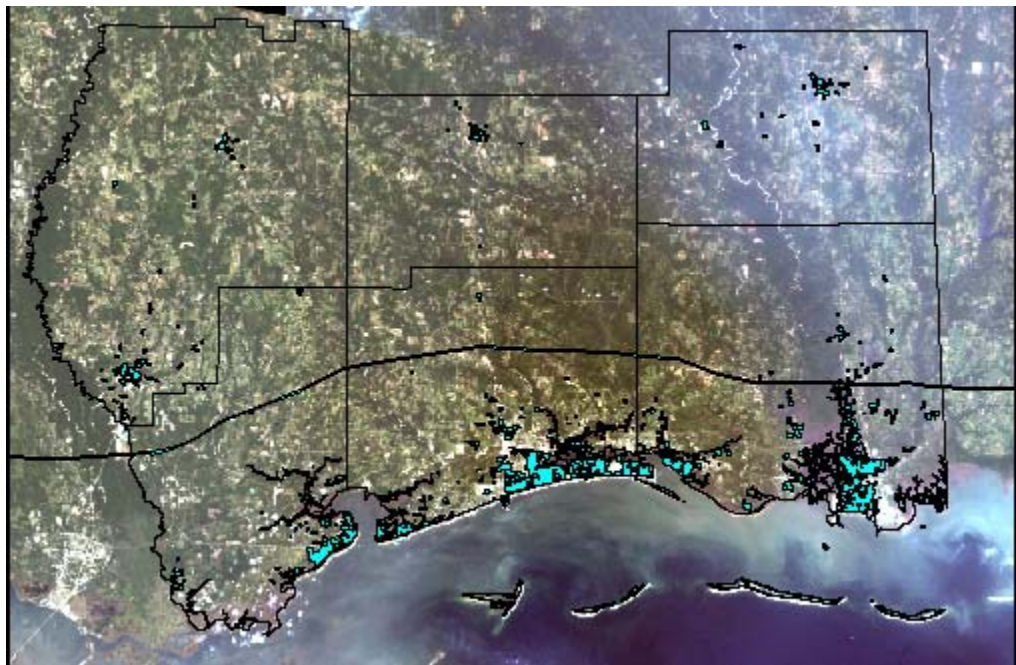
Figure 6. GRPC Planning Tool example showing urban areas over Landsat 7 image mosaic.

CD-ROM along with viewing software (ESRI ArcExplorer). A tutorial was developed to show how to use the software with the provided data. In addition, a Data Dictionary was developed that explained each of the data layers. Finally, a tutorial was developed within the Data Dictionary that showed the user how to use the geographic data provided to solve specific types of planning problems related to transportation and site identification. Figure 6 shows an example of the GRPC Planning Tool.

While the GRPC planning tool provides an excellent starting place for regional planning, some of the data is at scales that are not suitable for transportation planning. In addition, some of the data layers were derived from data that was ten years old, and does not represent the current conditions within the region. Remotely sensed data provides an excellent tool for updating the geographic data layers within the GRPC Planning Tool. Veridian Systems via a USDOT TAP project is presently using remotely sensed data to update and refine the data layers that already exist within the planning tool for use in regional transportation planning, particularly as it pertains to the location of a high-speed rail facility.

TUNABLE LASER REMOTE SENSING TECHNOLOGY FOR AIR QUALITY MEASUREMENTS

The tunable pulse laser DIAL (DIfferential Absorption LIDAR) technology is being used in this study to measure independent O_3 and NO_2 concentrations related to transportation and their effects on air quality. Both NO_2 and O_3 could be measured with the proper combination of wavelengths, therefore, 3080 Angstroms (308 nanometers) was chosen as the on-resonance wavelength for Ozone for this work, 4478.5 Angstroms (447.85 nanometers) was chosen as the on-resonance wavelength for NO_2, and 4500 Angstroms (450 nanometers) was chosen as the off-resonance wavelength for both NO_2 and O_3. Around 4,500 Angstroms, the nitrogen dioxide absorption is largely interference free.

The airborne XeCl excimer dye laser equipment setup used for an aircraft platform was modified, and a single laser system was adapted as a truck mounted unit for horizontal measurements in this study. The first pilot air quality study site was on MS Highway 6 in Oxford, Mississippi. This section carries a typical weekday traffic volume of 20,000 to 22,000 vehicles per day. The DIAL measurements were carried out in May 2001 by tunable DIAL equipment in the first pilot air quality study in Oxford, Mississippi (CAIT 2001). The laser beam could be seen as blue light at nighttime in the NO_2 spectral band. The laser beam in UV range for Ozone measurement was not visible.

During the measurements at this site, moderate traffic was observed on the highway during the day, and very low traffic was observed during the night. Traffic data were collected on the test site as a part of the on-going City of Oxford's Intelligent Transportation System (ITS) study, funded by the US DOT and conducted by the University of Mississippi. Airborne LIDAR and color aerial photo missions were completed in March-April 2001 to develop a comprehensive GIS of the Oxford area.

Wind and other weather data were collected from the nearby NOAA SURFRAD weather station in Batesville. The traffic modeling and simulation effort, being conducted at the University of Mississippi, for the Oxford ITS project will provide an opportunity to evaluate the effects of improved traffic flow on air pollution caused by the highway and surrounding area traffic and improved quality of life.

Figure 7 shows the air pollution concentration of NO_2 and traffic volume data measurements at Oxford test site. The DIAL results showed nearly 25 times more NO_2 concentration at 10 AM (daytime) compared to the measurement at 11 PM (nighttime) when the traffic was minimal. Daytime traffic volume on Highway 6 was 6.4 times the traffic at nighttime, as shown in Figure 5. Higher NO_2 concentration was also associated with higher air temperature in the daytime measurement. These results are greater than 30 ppb, which is generally assumed for natural background level of NO_2 in rural areas (Uddin, 2002).

Because the tunable laser measurement is real-time and uses a long sampling distance, it is less time consuming and is free from sampling inaccuracies which plague the conventional monitoring stations and direct vehicle exhaust measurements. The real-time in situ character of the long-path spectroscopic measurement allows the concentrations of trace gases to be measured as they naturally exist in the atmosphere, over path lengths which are more representative of actual volume-averaged concentrations than point monitors. Therefore, real-time effects of transportation related air pollution can be assessed, and the uncertainty in many parameters of dispersion models can be reduced if an investment is made on laser based remote sensing monitoring of air pollution.
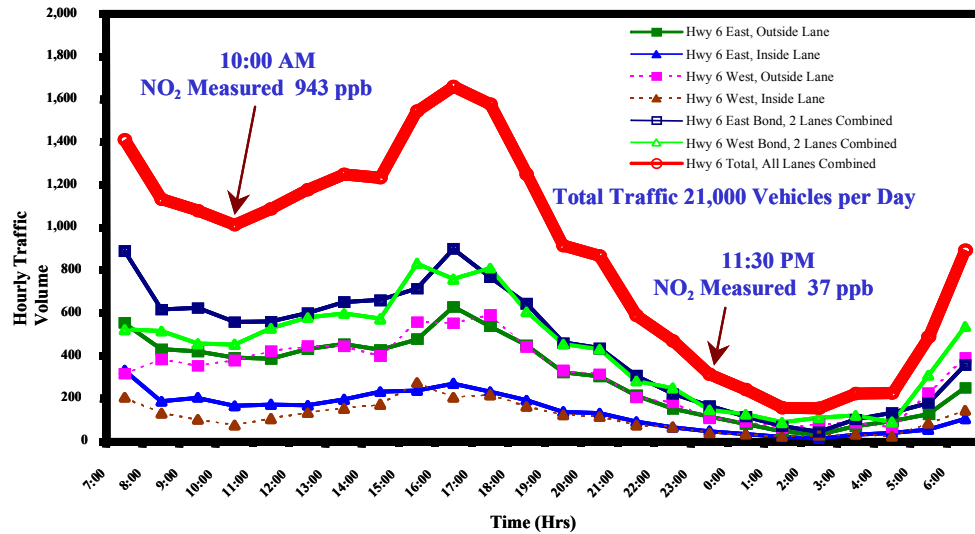
Figure 7. Air pollution and traffic data measured at Oxford test site

CONCLUSIONS

The National Consortium on Remote Sensing in Transportation for Environmental Assessments is a multi-year research and education center funded by the US Department of Transportation to facilitate the use of remote sensing and geospatial technologies. NCRST-E has developed partnerships with several state Departments of Transportation for the utilization of imagery in a variety of environmental subject areas and processes. This paper has provided a synthesis of several of the projects either being accomplished by the partners of the consortium or by TAPS working under its direction. Research has shown that there are efficiencies that can be gained by state Departments of Transportation by utilizing remote sensing and geospatial technologies for appropriate projects. However, the volume of data and map products that might be used by states in performing an environmental study can be voluminous and require special information technology tools. This need has been acknowledged and work is ongoing to demonstrate the application of regional databases and more extensive computationally based libraries of geospatial data and products.

ACKNOWLEDGEMENT

REFERENCES

King, R.L. and C.G. O'Hara (2001). The National Consortium on Remote Sensing in Transportation - Environmental Assessment. In: Proceedings of the IEEE 2001 International Geoscience and Remote Sensing Symposium, Vol. 4, pp. 1820-1822.

Laymon, C., J. Cruise, M. Estes, B. Howell (2001). Assessing the Need for Remote Sensing Information to Conduct Environmental Assessment in Transportation, Technology Guide: NCRSTE-TG001, http://www.ncrste.msstate.edu/publications/ncrste_tg001.pdf.

Mississippi Automated Resource Information System (2000). Land Cover and Land Use Digital Data for Mississippi. http://www.maris.state.ms.us/.

O'Hara, C. G., Johnson, A., Cartwright, J., and King, R.L. (2002a). Change Detection on the Mississippi Gulf Coast. In: Proceedings of the 98th Annual Meeting of the Association of American Geographers, Los Angeles, California.

O'Hara, C.G., King, R.L., Cartwright, J., and King, J. (2002b). Remote Sensing and Geospatial Technologies Application for Developing Options to Relocate CSX Railroad from Mississippi Gulf Coast Townships. In: Proceedings of the 2002 ASME International Mechanical Engineering Congress and Exposition. (CD)

O'Hara, Charles and Barnwell, Claiborne (2002c). Coordinating and Managing Remote Sensing and Spatial Technology Information for Environmental Assessment in Transportation Projects. In: Proceeding of the 27th Annual Meeting of the National Association of Environmental Professionals. (CD)

Uddin, W. (2002). Application of Remote Sensing Tunable Laser Technology for Measuring Transportation Related Air Pollution. In: Proceedings of ASCE 7th International Advanced Transportation Conference.

U.S. Geological Survey (1992). Multi-Resolution Land Characteristics – Statewide digital data for Mississippi. http://landcover.usgs.gov/nationallandcover.html