GUIDANCE ON USING REMOTE SENSING APPLICATIONS FOR ENVIRONMENTAL ANALYSIS IN TRANSPORTATION PLANNING

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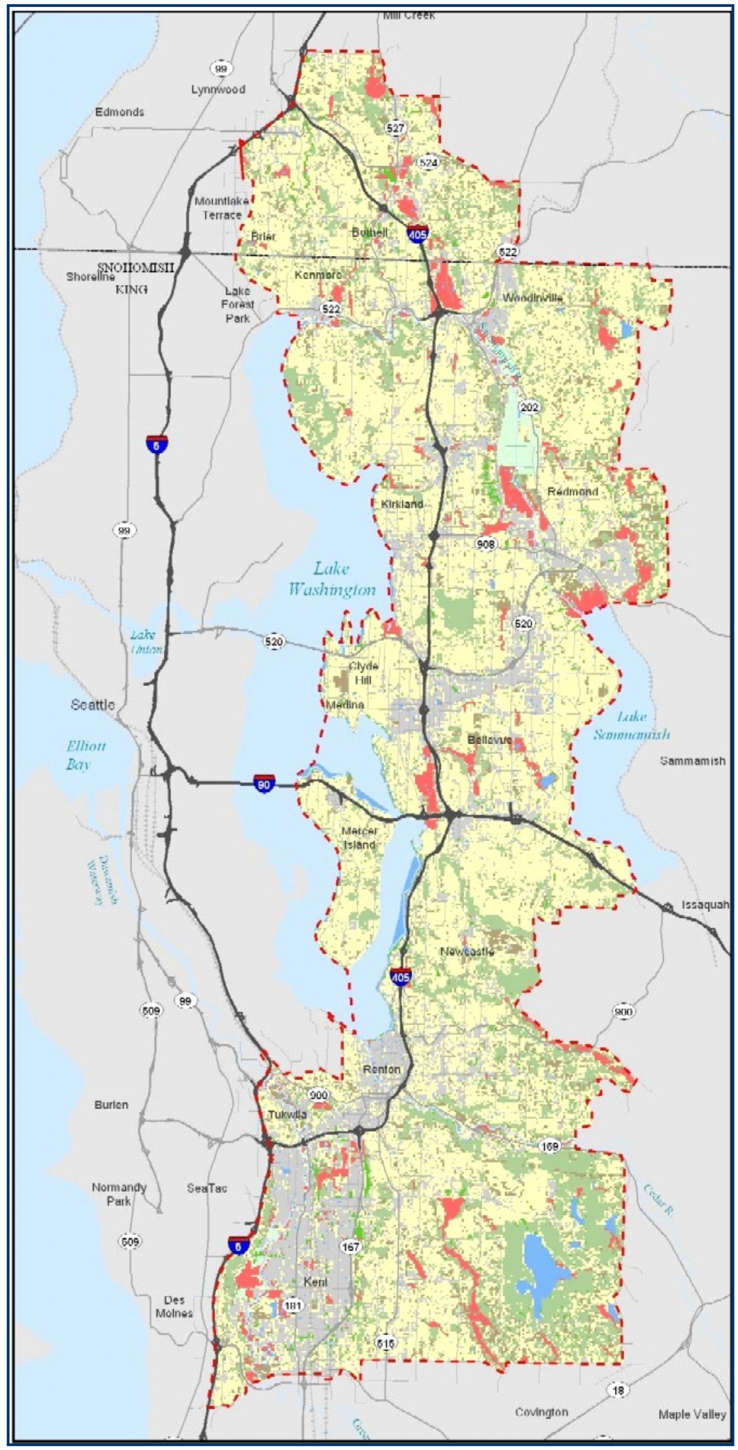

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This research project was part of the National Consortia on Remote Sensing in Transportation (NCRST) program, a collaborative effort between the US Department of Transportation and the National Aeronautics and Space Administration to foster the development of remote sensing applications in transportation.

16. ABSTRACT

This report is a "guidebook" on how to use remote sensing applications to support environmental assessment in transportation planning. The methods use Landsat 7 imagery and commercially available remote-sensing software to produce maps and related information suitable for a programmatic environmental impact statement. The report covers the following major topics:

- Background on environmental analysis in transportation planning, and the value and limitations of remotely sensed data;
- Staff, hardware, software, and data requirements;
- Software application for land use – land cover classification;
- Fieldwork for land use – land cover classification training and verification;
- Use and integration of other geographic information and imagery files; and
- Production of remote sensing – geographic information system maps and other information.

The methods are illustrated through applications to the I-405 corridor in the State of Washington.

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SUMMARY

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1. INTRODUCTION

1.1 Purpose

This document provides guidance on using remote sensing applications to support environmental assessment in transportation planning. The term "remote sensing" refers to (NASA 2002):

> "The acquisition and measurement of data/information on some property(ies) of a phenomenon, object, or material by a recording device not in physical, intimate contact with the feature(s) under surveillance; techniques involve amassing knowledge pertinent to environments by measuring force fields, electromagnetic radiation, or acoustic energy employing cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, seismographs, magnetometers, gravimeters, scintillometers, and other instruments."

The National Aeronautical and Space Administration's (NASA's) Landsat 7 satellite mission captures, processes, and archives 250 scenes from earth each day (NASA 2003). Landsat 7 imagery data provide broad coverage for the country and are readily available at relatively moderate cost.

The purpose of this document is to describe how to use Landsat 7 imagery with other remotely sensed data, geographic information systems (GIS), and commercially available software to classify land use and land cover. This document also describes how to use these results to generate maps and related products to help meet the needs of an environmental impact statement (EIS) for a transportation-corridor study area. Such EISs are required under the National Environmental Policy Act of 1969 (NEPA) for proposed transportation capital investment projects that could significantly affect the quality of the environment.

1.2 Use of Remotely Sensed Data in the NEPA Process

The NEPA process requires that geographic information be provided about the possible environmental impacts of transportation project alternatives, and about mitigation measures that address these impacts. An EIS provides documentation of the environmental assessment made under NEPA. A draft EIS (DEIS), that is written for public review and comment, and the detailed appendices typically include assessments

[1] Material in this report draws on draft reports, conference presentations, and other notes written as part of this research study, including Lanzer et al. (2002) and Xiong et al. (2003).

of impacts and mitigation measures across several environmental “disciplines” such as wetlands, farmlands, land use, and others, as described in Section 2.1.

Remotely sensed imagery has the potential to be a useful source of information about many of these environmental disciplines. The companion report to this document describes a study that developed maps and map-related statistical summaries of land use and land cover using remotely sensed imagery and geographic information systems (Xiong et al. 2004). We refer to these maps and related material as remote sensing - geographic information system (RS/GIS) products. A DEIS typically makes use of maps and other geographic information about each environmental discipline. Over the past several years, use of GIS methods in DEISs has become commonplace. On the other hand, use of remotely sensed data is still rare. In the future, RS/GIS might play an increasingly useful role in providing land use and land cover information for DEISs.

1.3 Summary of Sections

This document is a “guidebook” on how to use the commercial software, IMAGINE (Leica 2003), with remotely sensed Landsat 7 data (NASA 2000, 2003) to generate RS/GIS products that could be used in a DEIS or in similar environmental assessments at a transportation-corridor level of detail.

Following this introductory section, Section 2 provides background information about NEPA, and about consortia and other initiatives to develop and promote the use of remote sensing in environmental assessment. Section 2 also discusses the value and usefulness of RS/GIS products for corridor-level environmental assessment.

Section 3 summarizes staffing, hardware, software, and data resource requirements to produce the types of products reported in the companion document (Xiong et al. 2004).

Section 4 describes how to use IMAGINE software and other methods to classify land use and land cover using Landsat 7 imagery. The section discusses how to evaluate commercial software, the capabilities of IMAGINE software, the land use and land cover categories, types of input files needed, field work information, the classification process, output, and verification and validation methods.

Section 5 discusses fieldwork – its purpose, the selection of sample sites, file formats, the fieldwork process, and compilation of fieldwork data.

Section 6 describes other types of geographic information system (GIS) data that could be used with the classified imagery data, the steps to integrate these files, and the use of the results.

Section 7 describes the final set of remote sensing/geographic information system (RS/GIS) products. The section describes the integration of land use and land cover classification information with other data, and the generation of maps and statistics. The section also provides several examples of RS/GIS products that are the result of the procedures described in this document, and offers suggestions on other analyses and remote-sensing products that might be useful.

2. BACKGROUND

2.1 National Environmental Policy Act (NEPA) Implications for Environmental Analysis and Transportation Planning

The U.S. Congress passed the National Environmental Policy Act of 1969 (NEPA) which requires that prior to undertaking major Federal actions that could significantly affect the quality of the environment, the responsible Federal agency shall provide a detailed environmental impact statement on:

(i) the environmental impact of the proposed action,
(ii) any adverse environmental effects that cannot be avoided should the proposal be implemented,
(iii) alternatives to the proposed action,
(iv) the relationship between local short-term uses of the environment and the maintenance and enhancement of long-term productivity, and
(v) any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented.

The selection and environmental assessment of potential routes or corridors is one of the most expensive and time-consuming activities in the early stages of transportation project planning. Alternative routes and designs are evaluated not only with respect to transportation objectives, but also with regard to the degree to which significant negative environmental and socioeconomic impacts are minimized. NEPA generally requires extensive data collection to obtain information about potentially affected environmental resources for alternative transportation projects.

To be credible, NEPA analyses should use good quality data. Remotely sensed imagery data could contribute to improving the NEPA review process by providing a credible baseline of information to evaluate alternatives early in the process, and eliminating unnecessary and costly detailed analysis. A DEIS provides the public and decision-makers with information relevant to the impacts of proposed transportation improvements and potential mitigation measures.[2] The document contains information about the need for transportation investment in the area, alternative remedial actions, their impacts, and measures to mitigate these impacts.

The different impacts are categorized into environmental disciplines. For example, those used for the I-405 study area in the state of Washington are typical of "programmatic" DEISs for transportation corridor studies:

- Environmental justice;
- Farmland;
- Fish and aquatic habitat;
- Floodplains;
- Land use;
- Recreational resources;

[2] The final version of the EIS includes all public comments received during the DEIS public comment period.

- Shorelines;
- Surface water resources;
- Transportation;
- Upland vegetation, habitat, and wildlife; and
- Wetlands.

In the companion report (Xiong et al. 2004), RS/GIS products were generated for each of the environmental disciplines listed above. Environmental disciplines, for which RS/GIS methods are *un*likely to be useful, include:

- Air quality;
- Noise;
- Energy and natural resources;
- Geology and soils;
- Social impacts;
- Economic impacts;
- Public services;
- Visual quality;
- Historic, cultural, and archaeological resources;
- Hazardous materials and wastes; and
- Cumulative effects.

Part of the motivation for considering the use of remotely sensed data is to improve environmental assessments of proposed transportation projects, a goal that is also very much at the heart of "environmental streamlining."

2.2 Environmental Streamlining, Remote Sensing Applications, and NCRST-E

First enacted into federal legislation for highway and transit projects in the Transportation Equity Act for the 21st Century, "environmental streamlining" is a term used in the context of environmental assessments of proposed transportation projects, as required under NEPA and other legislation and regulations. The term refers to the goal of developing "faster, cheaper, and better" ways of satisfying these requirements. The objectives of environmental streamlining are:

- Expedited transportation project delivery,
- Integrated review and permitting processes that identify key decision points and potential conflicts as early as possible.
- Full and early participation by all relevant agencies that must review a highway construction or transit project or issue a permit, license and opinion relating to the project,
- Coordinated time schedules for agencies to act on project decisions,
- Dispute resolution procedures to address unresolved project issues, and
- Improved NEPA decision-making.

Because major transportation projects are affected by dozens of Federal, State, and local environmental requirements administered by many agencies, improved interagency

cooperation is critical to the success of environmental streamlining. Efforts currently underway within the U.S. DOT focus on solidifying interagency partnerships through pilot efforts, process reinvention, alternative dispute resolution, and a focus on performance evaluation. A web site describes the U.S. Department of Transportation's efforts to promote environmental streamlining:
http://www.fhwa.dot.gov/environment/strmlng/index.htm[3]

In Washington State, the Environmental Permit Streamlining Act (EPSA) was passed in 2001.[4] It was designed to reform transportation permitting by streamlining environmental permit decision-making. The Washington State Department of Transportation (WSDOT) has engaged the natural resource agencies and state decision-makers to work cooperatively to establish common goals, minimize transportation project delays, and develop consistency in the application of environmental standards. In March 2003, the Washington State Legislature reauthorized the Environmental Permit Streamlining Act to coordinate and streamline the environmental permitting process for transportation projects.

The I-405 Corridor in Washington is a NEPA Reinvention Pilot Project funded by the Federal Highway Administration (FHWA). The goal of this project is for WSDOT, in cooperation with federal, state, local, and tribal governments, to develop a process that will integrate NEPA environmental compliance early in the transportation planning process. This pilot effort will test early-action mitigation processes using a watershed approach. The I-405 Corridor Program recently issued its final environmental impact statement, completing three years of technical work and consensus building (WSDOT 2003).

In this EIS, as in virtually all EISs to date, remote sensing technologies were not used to develop any of the maps and related information in the document. The U.S. Department of Transportation (U.S. DOT) and WSDOT are seeking to determine whether remote sensing technologies could contribute to improving the information provided in DEISs and, thereby, to streamlining the environmental assessment process.

As part of this effort to foster the development of remote sensing applications in transportation, the U.S. DOT's Research and Special Programs Administration (RSPA) established the National Consortia on Remote Sensing in Transportation (NCRST) program. There were four thrusts to the NCRST: environmental assessment; infrastructure; transportation flow modeling; and hazards, safety, and disaster assessment. The goals of the environmental assessment consortium (NCRST-E) were to (King and O'Hara 2002):

- "Develop innovative remote sensing technology solutions for assessing the implications of transportation on the natural environment and protecting and enhancing the environment.

[3] The web site addresses provided in this report were current during the time of the study (2001-2003), but might have subsequently changed.

[4] Discussion of environmental streamlining in Washington State is taken from information on WSDOT (2003) web sites,
http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manuals/EPM/EPM.htm and
http://www.wsdot.wa.gov/environment/streamlineact/default.htm.

- Assess and plan, in particular the capabilities of new high resolution, multi-spectral 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."

Some recent reports contain discussions about the potential use of remote sensing technologies in transportation analysis. CH2M HILL (2000) reviewed several remote sensing technologies and their possible use. Several discussions took place at a conference on Remote Sensing for Transportation held in the year 2000 (TRB 2000). The discussions highlighted many opportunities as well as challenges for remote sensing applications in transportation. Summarizing discussions of a breakout session at the conference, Oman (2000) listed several areas to which remote sensing applications could be useful: helping to streamline the NEPA process; watershed assessments; wetlands, water quality, and storm water issues; land use changes; environmental justice; and several others. She also noted that two-way education is needed: the remote-sensing community needs to understand transportation environmental issues better, and *transportation professionals need more information on remote-sensing tools and techniques.* This guidance report is in response to this need.

2.3 Value and Limitations of Using Remotely Sensed Data

Remote sensing technologies can be used to provide images, data, maps, and other information that could be used in an EIS and similar documents. Laymon et al. (2001) aptly suggested, however, that just as GIS and GPS technology experienced impediments before being used widely in transportation planning and engineering, remote sensing technology is likely to undergo similar challenges. The companion document to this report (Xiong et al. 2004) provides results of a case-study survey on the value and usefulness of RS/GIS products, from the perspective of potential *users* of these products. This section is based largely on the responses to the survey, and on insights gained from these responses.

According to the survey results, the value and limitations of using remotely sensed data depend on a number of factors:

Users of the Information: There were three categories of survey respondents. One set of respondents were stakeholders in the I-405 project. Some of these respondents included those who were from the lead agency responsible for carrying out the EIS, as well as from the reviewing agencies. Another set of respondents were from the contractor team that prepared the EIS for the I-405 Corridor study. The other respondents were staff from state Departments of Transportation, other than the Washington State Department of Transportation. The I-405 stakeholder respondents and those from other state DOTs assessed the RS/GIS products to be valuable and useful for almost all of the environmental disciplines under consideration. Among the respondents, the I-405 stakeholders might have been the most attuned to viewing the RS/GIS products as providing useful insights to the reviewing agencies and stakeholders, not simply as something to meet the requirements of writing an EIS.

The contractor team tended to value RS/GIS products less than did the other respondents. The contractor team could have regarded the RS/GIS products as an added cost to its fixed budget and be inclined to be more conservative in valuing them (i.e., valuing them less). Although respondents from the other state DOTs were all familiar with the NEPA process in proposed transportation projects and the costs of an EIS, these respondents were not constrained by any explicit budget to carry out the EIS. Therefore, they might have been more “generous” in valuing these products.

Environmental Discipline Being Considered: RS/GIS products were regarded as being particularly useful for identifying land cover patterns, and for identifying the spatial proximity of different land uses and associated activity patterns in relation to sensitive habitats. Other than land use, the respondents thought that RS/GIS products were most useful for the following environmental disciplines: fish and aquatic habitat, shorelines, upland vegetation, wetlands, surface water resources, and transportation. Information about the spatial context and proximity to other land uses was frequently cited as a particularly valuable aspect of the RS/GIS products.

Availability of Other Data: Remotely sensed data are most useful when used in combination with other GIS data. If other GIS databases are available, then remotely sensed imagery could be classified and used as another data layer. Most of the maps generated in the I-405 case study were of this nature. If recent studies have already provided all of the information needed, then it would not be cost effective to undertake additional studies. On the other hand, if existing data were compiled a long time ago, then it could be worthwhile to use remotely sensed imagery to update the information.

Official Designations: If certain land has been officially designated, for example as a 100-year floodplain, protected farmland, or protected recreational resources (e.g., under Section 4(f)), then remotely sensed imagery would itself be insufficient for identifying these areas. Imagery could be used to help update some of the information, and to identify land uses and land cover that might have some impact on these areas. Remotely sensed imagery could also be used to identify wooded areas, ravines, and natural environments that, although they have no official designation, could still be important to consider as planning for a transportation project proceeds.

Geographic Context and Scale: The nature of the region under investigation and the accuracy and precision required of the task will affect the appropriateness of different types of remote sensing technologies. The mixture of trees, shrubs, and grasses mixed with residential, commercial, and mixed urban land uses makes land use classification challenging. Higher-resolution multi-spectral images can be useful in discerning among these land uses. For corridor-level analysis, Landsat 7 data appear to be sufficient for many applications. For project-specific EISs, greater precision is needed.

3. RESOURCE REQUIREMENTS

The use of remote sensing and other geospatial technologies has great potential to improve the efficiency and cost-effectiveness of data acquisition, management, analysis, and visualization; and to provide a powerful means of communicating environmental information with the public. At the same time, state and local governments need to carefully allocate their resources to make effective use of these technologies. Remote sensing is a relatively new technology to many transportation agencies. A basic understanding of resource requirements is the first step toward successful implementation of the technology.

3.1. Staff Requirements

The most important requirement for remote sensing applications is the existence of qualified professional staff with basic knowledge of remote sensing principals and techniques. Many transportation agencies already have a GIS program with a sizable GIS staff that have been trained in spatial data analysis, management, and mapping. In this case, additional training in remote sensing and image processing software can be provided to existing staff to allow these agencies to develop remote sensing capabilities. New hiring of college graduates or experienced specialists should be considered when application programs have to be developed in a short time period, or when extensive image processing and analysis responsibilities are involved. In general, development of proficiency in remote sensing technology, as in GIS, requires systematic training and takes a significant amount of time, which may not be achieved effectively in a short period by training existing GIS staff.

Adequate training in basic theories and principles of remote sensing is essential. It is recommended that the staff in remote sensing be trained in the following:

- Fundamentals of remote sensing, including remote sensing platforms, physical basis, visual interpretation, and automated image interpretation.
- Digital image processing, including multi-spectral analysis, image rectification, enhancement, and pattern recognition.
- Raster analysis, including raster data analysis, overlay, and spatial characterization.
- Photogrammetry, including fundamentals of air-borne or space-borne photography, principles of stereoscopes, orthophotography, and aerotriangulation.
- Project management skills, including skills for data collection, field studies, and project planning.

It is also important that the hired or retrained staff have practical working experience with at least one of the commercial image processing systems, which will allow them to move quickly into the production stage even when different image processing systems have to be used. It is preferred that both the GIS staff and the remote sensing staff work collaboratively to tackle the same application problems.

3.2. Hardware Requirements

Adequate computing hardware is required for remote sensing projects. The general requirements of this hardware may not be significantly different from those used in existing GIS applications. In many circumstances, remote sensing projects may share the same hardware as that used in GIS applications. Nevertheless, special attention must be given to storage space, response time, and network configuration when large-scale application projects or high-resolution images are involved.

Storage Space: Large-scale remote sensing projects or projects that use high-resolution images need to deal with massive amounts of image data. For instance, image data that provide complete coverage of an average-sized county with 6-inch resolution might easily exceed 100 gigabytes. Although not all the image data have to be stored in the computer at the same time, it is essential to plan adequate storage space to reduce the frequency of swapping the storage space. For planning purposes, storage space requirements can be estimated using the size of the study area and the resolution and number of images (including the number of image layers and bands) to be used. The size of the study area and the resolution of the images together determine the total number of pixels, P, of an image required to cover the study area. Let L represent the number of image layers or bands to be used, and let B represent the number of bytes needed for storing the value of each pixel. The total storage space, S, required can be computed with the function: $S = P * L * B$.

Response Time: Many image processing tasks are computationally expensive. Any remote sensing applications should take full advantage of the most recent advances in computer hardware. The use of top-of-the-line personal computers available in the mass market usually represents the best choice because they provide good performance-to-cost ratios. Response time is important for many image processing tasks that require constant human interaction. Fast processors and large random access memory are highly recommended. Most existing commercial image processing software works on either Windows or Unix platforms. An organization may need to consider an array of factors, including hardware costs, reliability, staff skills, and interoperability when a platform is selected.

Network Configuration: Computer networks must be leveraged to effectively store, process, and move massive amounts of image data in an organization. It is suggested that a server or servers be used to meet the needs for data storage, centralized data processing, and data update and backup. Individual users can access the data at the central site(s), but most data processing will be done on the front-end desktop computer. The centralized server(s) will allow agencies to effectively share and manage the data, while individual image processing tasks can be performed more effectively on the front end. Network speed is another key factor. The use of fast Ethernet, e.g., data transfer speed at or higher than 100 mbps, and broadband technology (technology that transmits voice, video, and data at the same time over the same line at high speeds) is highly recommended for many remote-sensing applications.

Large, high precision, and color scanners and printers are needed for data input and output for remote sensing applications. In most cases, however, remote sensing projects can share scanners and printers used for GIS applications.

3.3. Software Requirements

Image processing software is required for most remote sensing applications. It is used to handle tasks from image format conversion, to image rectification, to enhancement, to automated feature extraction and classification. As image processing software evolves rapidly and specialization becomes widely available, it is difficult to make a general statement about the suitability of specific software. However, we suggest some functional requirements that can be evaluated, depending on the specific application:

Data format: A variety of data formats have been developed for image data storage and exchange. It is highly recommended that the selected image software will be able to import and export image data in different formats. Compression functions are essential in this consideration because vast volumes of image data can make it extremely difficult to move and share data. With the compression functions, data volumes can be effectively reduced for storage and exchange. Variations with the same type of data format are constantly overlooked, but sometimes require special attention. For instance, for software that claims to recognize the GeoTiff format, it may be necessary to examine further whether the software will recognize 11 bit GeoTiff format or tiled GeoTiff format.

Basic image data management: Functions such as image data creation, update, and retrieval in an image processing system are essential for day-to-day data management and processing. Some of the required data management functions include viewing and modifying the values of individual cells; adding or changing the definitions of image layers (e.g., layer names, attribute labels, and projections); and stacking/merging/mosaicking/subsetting image layers.

Image processing functions: The core functions for the selected image software should include capabilities for radiometric and geometric corrections, warping, image enhancement, supervised and unsupervised classification, and raster analysis and modeling. Special image processing functions may be necessary such as the processing of radar images and LIDAR data, and stereoscopic reconstruction of digital elevation models.

User interface and graphical displays: Adequate user interface and graphical displays are required to allow users to effectively access system capabilities and generate maps or image processing products to meet their needs. “Easy-to-learn” and “easy-to-use” are basic criteria for the evaluation of an interface. Other factors such as output data types, quality, and customizability are important to the creation of the end products. In general, output data must allow different resolutions and be in an electronic form (e.g., an electronic file in the form of GeoTiff, GIF, or JPEG).

Macros, scripting, customization, and extension: Routine and repetitive operations are common in image processing. Macros and scripting capabilities are very useful tools to program those routine and repetitive operations to improve productivity and reduce operation errors. Also, an application may require functions that are not available in existing systems. In this case, extensions to the existing system will be necessary. Therefore, flexibility for customization and extension is another major factor in the evaluation of an image processing system.

3.4. Remotely Sensed Data

Remotely sensed data can be in the form of digital photography, video imagery, or digital scanning of the objects or phenomena on the ground. Most of the data that are used for environmental analysis come from air-borne or satellite-borne sensors. Some of the data are collected through government programs, e.g., Landsat imagery from NASA or U.S. Geological Survey digital orthophotos, and can be purchased at a nominal fee. Others are available through commercial sources, e.g., the Quickbird imagery from Digital Globe and IKONOS from Space Imaging.

Remotely sensed data must be evaluated for suitability when specific applications are determined. A given set of data might be useful for one application, but not for others. Image resolution is perhaps the most frequently used criterion for image suitability analysis. Image resolution can be identified using spectral resolution, spatial resolution, temporal resolution, and radiometric resolution.

Spectral resolution: The spectral resolution is the number of bands (wavelength intervals) in the electromagnetic spectrum that is used for a remote sensor. The spectral resolution provides a measure of the spectral sensitivity of the remote sensing instruments. For example, Landsat MSS has one green, one red, and two infrared (IR) bands, while Landsat TM has one blue, one green, one red, one near-infrared (NIR), two mid-infrared (MIR), and one thermal IR band. Since Landsat TM has more spectral bands than Landsat MSS, we would say that Landsat TM has a better spectral resolution than Landsat MSS. NASA's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) has 224 bands in the 0.4-2.5 micrometer range, which indicates that AVIRIS is much more spectrally sensitive than either Landsat TM or MSS. For corridor level environmental analysis, spectral resolution like Landsat MSS or TM is likely to be satisfactory. Higher resolution, like AVIRIS, might be useful for more detailed vegetation characterization, wetland studies, or impervious surface analysis.

Spatial resolution: The spatial resolution refers to the smallest angular or linear separation that can be discerned by an instrument. More frequently, the size of a pixel on the ground is used as a nominal spatial resolution measure. For instance, the SPOT Panchromatic band has a 10x10 meter pixel size, and the resolution of the image is usually referred to as 10 meters. Similarly, Landsat TM has a 30 meter spatial resolution and IKONOS has a one meter resolution for the panchromatic band and 4 meter resolution for the multi-spectral band. Different spatial resolutions provide different spatial discerning capabilities. For example, a one meter resolution image can be used to identify small roads and streams, which is difficult with a 30 meter resolution image.

Temporal resolution: The temporal resolution refers to the frequency by which the data can be obtained at the same location by the same instrument. Landsat has a fixed orbit and revisits the same location on the Earth every sixteen days, so it has a sixteen-day temporal resolution. SPOT sensors and sensors on the IKONOS satellite are pointable, which allows data to be collected more frequently in a specific area. High temporal resolution is essential for monitoring changes of rapidly evolving spatial phenomena, e.g., floods and ocean oil spills.

Radiometric resolution: The radiometric resolution measures the sensitivity of an instrument by defining the number of discernable signal levels. The original MSS has 6-bit radiometric resolution that allows a radiometric intensity ranging from 0 to 63. The TM has 8-bit radiometric resolution that allows a value of radiometric intensity ranging from 0 to 255. IKONOS can be both 8 bit and 11 bit. The larger the number of signal levels, the better the radiometric resolution.

Given existing remote sensing technology, many alternative data sources are available. Image resolution is an important criterion to analyze. Other factors such as application requirements and project budgets must also be considered. Usually better data means higher cost. But at the same time, better data might also mean higher benefit to cost ratio. In the study that this guidebook is based on (Xiong et al. 2004), Landsat 7 imagery data were used for corridor-level environmental assessment. The data are captured by the satellite's Enhanced Thematic Mapper+ (ETM+), which offers broad coverage for the country as a whole, with 15 m resolution for the panchromatic band and 30 m resolution for the multi-spectral bands (NASA 2003):

Landsat 7 Instrument: Enhanced Thematic Mapper+ (ETM+) --

Scene Size:

- 183 km cross-track
- 170 km along-track
- 3.6 Gbits in 24 seconds
- 42.6 mrad/30m pixel

Radiometric Accuracy:

- 5% absolute, 2% relative
- Band-to-Band Registration:
- 0.28 pixel (90%)

Data Rate:

- 150 Mbps on two 75 Mbps channels

Scan Frequency:

- 7 Hz

Spectral Bands:

- 1) 0.45 - 0.52 µm, 30 m resolution
- 2) 0.52 - 0.60 µm, 30 m resolution
- 3) 0.63 - 0.69 µm, 30 m resolution
- 4) 0.76 - 0.90 µm, 30 m resolution
- 5) 1.55 - 1.75 µm, 30 m resolution
- 6) 10.4 - 12.5 µm, 60 m resolution
- 7) 2.08 - 2.35 µm, 30 m resolution
- 8) 0.50 - 0.90 µm, 15 m resolution

3.5. Other Data

In addition to remotely sensed data, in-situ data and existing GIS databases are critical data components for many remote sensing projects.

In-situ data: In-situ data are data obtained from field observations and usually represent ground truth information. These data are useful in several different circumstances. First, in-situ data can be used to extract image signatures for features that need to be identified on images. For instance, supervised image classification requires computer programs to be trained with image signatures of a feature before the feature can be recognized. Second, in-situ data can be used to evaluate image processing results. By comparing data obtained from image processing with data obtained from the field, discrepancies can be identified and can be used to indicate the accuracy of the image processing results. In other applications, in-situ data have to be acquired because the same type of data may not be obtained from image sources (e.g., street addresses or road names). The collection of in-situ data is a time-consuming process, and can be expensive, particularly when large geographic areas are involved.

Refer to Section 5 for a discussion of fieldwork for the compilation of in-situ data for land use and land cover classification.

GIS data: GIS data are important resources because they already exist, and some of the data are already validated and verified, thus greatly reducing the cost of acquiring them. GIS data sources that are readily available may include Census TIGER (Topologically Integrated Geographic Encoding and Referencing) files, the National Wetlands Inventory (NWI) of the US Fish & Wildlife Service, and USGS land use–land cover maps. When data collected in an area are reliable and current, such information can be treated as "ground-truth information." In this case, the data could serve the same role as in-situ data. Existing GIS data can also be used as ancillary data during the image analysis process. For instance, image data and GIS data can be combined to maintain and update existing GIS layers. For the case of land use and land cover maps, an outdated land use and land cover layer in an existing GIS file could be combined with a newly obtained image to derive an update of the land use and land cover map for the same area. More often, remotely sensed data layers and existing GIS data layers are used together, each layer providing a specific type of information that meets a particular application requirement.

Refer to Section 6 for further discussion on using GIS data in combination with remotely sensed data.

4. SOFTWARE APPLICATION FOR LAND USE – LAND COVER CLASSIFICATION

This section describes the use of the commercial software, IMAGINE (Leica 2003) for land use–land cover (LULC) classification. We first provide a rationale for the selection of the software and the determination of LULC categories. Then we focus on procedures used for LULC classification and verification of the classification results.

Special Note: Many image processing systems are commercially available. The use of a software system must be based upon the needs of specific applications. The use of IMAGINE in the demonstration study was based on the particular project requirements and we do not suggest that every remote sensing project should use the same software. The main purpose of this guidebook is to provide discussion of considerations when a software system such as IMAGINE is selected for a specific project.

4.1 Software Used

To effectively manipulate and analyze imagery and GIS data, software such as IMAGINE image processing system can be selected to perform major image and data processing tasks. IMAGINE, a commercial product by ERDAS (now Leica), provides a comprehensive set of functions for image processing, analysis, data management, and mapping or visualization, which meets most of the functional requirements discussed in Section 3.

Data input and output: IMAGINE supports all major data formats, including those used in the demonstration project for the I-405 corridor. In particular, it is able to read and write Arc/Info's Grid files. This capability makes IMAGINE very attractive for the demonstration study because data must be converted frequently between Arc/Info and IMAGINE.

Basic image data management: IMAGINE handles most of the tasks for image data creation, update, retrieval and cataloging. The system makes it relatively easy to view raster and vector layers, and to edit image attributes. Functions such as stacking, merging, mosaicking, and subsetting are all included.

Image processing functions: Different image processing functions are provided by IMAGINE, including geometric corrections, image enhancement, supervised and unsupervised classification, and raster analysis and modeling. The resolution merging (image sharpening) was particularly useful to the demonstration project because the function is needed to sharpen multi-spectral bands with a higher resolution panchromatic band. The raster modeling capability available in IMAGINE is another feature that is required by the current project for image data preparation and post processing.

User interface and graphical displays: IMAGINE provides a graphical user interface organized by functional modules, which is relatively “easy-to-learn” and “easy-to-use”. The software allows a variety of formats for image output.

Macros, scripting, customization, and extension: Both graphical and script modeling capabilities are provided in IMAGINE to develop procedures to handle routine and repetitive operations and to simplify the use of the system.

4.2 LULC Categories

The first step in LULC classification is to determine the LULC categories. The decision of which land use or land cover categories to use depends on several factors. The first consideration is the needs of the environmental assessment itself. Information required for the EIS process is divided into environmental disciplines. LULC categories are relevant to several such disciplines:

1. Environmental Justice
2. Farm Land
3. Fish/Aquatic Habitat
4. Floodplains
5. Land Use
6. Recreation
7. Shorelines
8. Surface Water Resources
9. Transportation

10. Upland Vegetation/Habitat/Wildlife
11. Wetlands

Thus, it is desirable that the LULC classification provides information related to these environmental disciplines.

A second consideration is that LULC categories should generally conform to standard categories. The USGS LULC classification by Anderson et al. (1976) has been widely adopted in the remote sensing and GIS communities, because it was designed specifically for use with remotely sensed data. The Anderson classification is a hierarchical system in which LULC categories are classified on different levels (see Table 4.1). Each category level contains multiple lower level categories. Usually, only the top two levels of classification (i.e., level 1 and level 2) are needed for a given application. The top classification (level 1) consists of nine categories, which are further divided into subcategories (e.g., Urban or built-up land has seven subcategories, including: 11-Residential, 12-Commercial or services, 13-Industrial, 14-Transportation, communication, utilities, 16-Mixed urban or built-up land, and 17-Other urban or built-up land).

A third consideration, when defining LULC categories, is the capability of the remotely sensed data to distinguish between these categories. Not all the required information can be obtained from image sources. For this reason, the selection of LULC categories must consider the limitations of the data to be used. The final decision on LULC categories is a compromise among all these factors because not all the considerations are compatible with each other. Particularly, there are differences between the USGS LULC classes and the EIS categories. Some LULC categories such as recreational resources, which need to be explicitly represented for EIS purposes, are mixed with other categories in the USGS LULC classification. Other LULC categories that are used for EIS purposes are not identified in the Anderson classification at all (e.g., wildlife habitat and threatened and endangered species). The approach we suggest is to use USGS LULC categories as a starting point. The classification results can then be mapped into the EIS discipline categories as described in Section 7.

4.3 Input Imagery and Preprocessing

Landsat ETM+ data were selected as the major data source for LULC analysis for the demonstration project. This selection was based on several factors. The I-405 EIS is a programmatic EIS, not a site-specific EIS, so the requirements for spatial detail can be met with Landsat resolution. The Landsat data are inexpensive, provide large geographic coverage, and are collected on a sixteen-day interval. More importantly, they provide seven spectral bands with wavelengths between 0.5 and 12.6 micrometers, with a resolution of 30 x 30 meters (60 x 60 meters for band 6) plus a panchromatic band with a resolution of 15 meters.

Note: Evaluation was conducted on some of the IKONOS 1-m panchromatic and 4-m multi-spectral images, contributed by Space Imaging for experimentation and comparison purposes. It was found that high resolution panchromatic and multi-spectral imagery would be particularly useful for EIS land use and land cover classification; unfortunately, the available IKONOS data did not cover any part of the study area, and the demonstration project did not have the funds to acquire IKONOS data for this locale.

Geometrically terrain-corrected EROS Landsat 7 ETM+ image data can be obtained from the Washington State Remote Sensing Consortium (WARSC). For areas outside the State of Washington, the Landsat data can be ordered on-line from NASA's EOS Data Gateway (EDG) facilitated by USGS (http://edcdaac.usgs.gov/order.html). The imagery must then be preprocessed to make it ready for LULC classification. The preprocessing of the Landsat ETM+ data includes the following procedures:

File format conversion: The image data, when ordered in the GeoTiff format, come in eight separate files. Among the eight separate files, seven of the files correspond to different color bands; the other file is the panchromatic band. The IMAGINE Import/Export function can first be used to convert the GeoTiff files into IMAGINE system files, files with an *img* extension. This conversion needs to be done separately for each band.

Layer Stacking: Initially, all the spectral bands for the study area are in separate files. IMAGINE's layer stacking function is used to overlay the separate spectral bands to form a single IMAGINE file. (The panchromatic was left separated.) Layer stacking establishes an implicit spatial-correspondence relationship between all the spectral bands, which facilitates subsequent data processing and analysis.

Image Subsetting: As the study area is only a small portion of the area covered by an entire image, only the windowed images that contain the study area are extracted using the IMAGINE subsetting function, under the data preparation module. This function allows the windowed area to be defined interactively or to be defined with the corner coordinates of the window.

Image Sharpening: As the Landsat ETM+ images have different resolutions (i.e., 30 m for multi-spectral bands and 15 m for the panchromatic band), image sharpening allows lower-resolution spectral images to be merged with the higher resolution panchromatic band. By doing so, LULC classification can be performed on the merged image data, which will have a 15 m spatial resolution and contain all spectral bands. Both the function built with IMAGINE's macro-language and IMAGINE's built-in resolution merge function can be used to implement the image sharpening process. In general, the built-in principal component (PC) merging procedure can achieve good results. This procedure first generates the PC images using multi-spectral bands as input, and then replaces the first PC image with the panchromatic image. Transforming the PC images back into the spectral space derives the sharpened image. Figure 4.1 shows a portion of the sharpened Landsat ETM+ imagery for the study area.

Table 4.1. The Anderson Land Use and Land Cover Classification System for Use with Remote Sensor Data

Level I	**Level II**
1 Urban or Built-up Land	11 Residential.
	12 Commercial and Services.
	13 Industrial.
	14 Transportation, Communications, and Utilities.
	15 Industrial and Commercial Complexes.
	16 Mixed Urban or Built-up Land.
	17 Other Urban or Built-up Land.
2 Agricultural Land	21 Cropland and Pasture.
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas.
	23 Confined Feeding Operations.
	24 Other Agricultural Land.
3 Rangeland	31 Herbaceous Rangeland.
	32 Shrub and Brush Rangeland.
	33 Mixed Rangeland.
4 Forest Land	41 Deciduous Forest Land.
	42 Evergreen Forest Land.
	43 Mixed Forest Land.
5 Water	51 Streams and Canals.
	52 Lakes.
	53 Reservoirs.
	54 Bays and Estuaries.
6 Wetland	61 Forested Wetland.
	62 Non-forested Wetland.
7 Barren Land	71 Dry Salt Flats.
	72 Beaches.
	73 Sandy Areas other than Beaches.
	74 Bare Exposed Rock.
	75 Strip Mines, Quarries, and Grave Pits.
	76 Transitional Areas.
	77 Mixed Barren Land.
8 Tundra	81 Shrub and Brush Tundra.
	82 Herbaceous Tundra.
	83 Bare Ground Tundra.
	84 Wet Tundra.
	85 Mixed Tundra.
9 Perennial Snow or Ice	91 Perennial Snowfields.
	92 Glaciers.

4.4 Extraction of Signatures for LULC Categories

After a preliminary analysis and comparison between supervised and unsupervised classification methods in the demonstration project, it was determined that a supervised classification method would achieve better LULC classification for the study area. The main idea of the supervised classification method is that a computer program is first trained with known LULC categories; the program will then use these characteristics as the signatures to automatically establish LULC classifications for areas where LULC attributes are unknown. Image signatures may include mean vectors, maximum and minimum band intensity values, variance vectors, and co-variance matrices, which are uniquely associated with specific LULC categories. The areas where LULC is known, when utilized for signature extraction, are referred to as training samples, because their extracted signatures can then be used to train the computer program to recognize particular types of LULC categories.

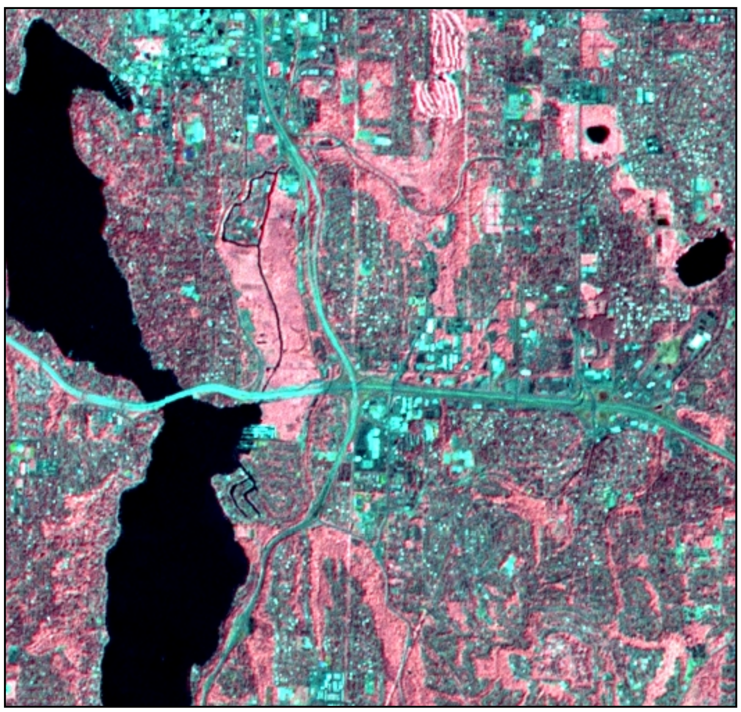


Figure 4.1. Landsat ETM+ Multi-spectral Imagery Shows the Intersection of I-405 and I-90. Graphical Display Generated with Landsat ETM+ Band 4 (Red), Band 3 (Green) and Band 2 (Blue) Sharpened to 15 Meter Resolution Using the ETM+ Panchromatic Band.

Training samples can be obtained using several different methods, or a combination of these methods:

Field observations: To establish training samples in the study area, the sites of training samples are first identified in-house, and then the LULC categories at these sample sites are checked in the field. A training sample is usually defined as a polygon, which must contain a sufficient number of pixels, typically more than 100, for statistical significance and for visibility during the field trip. Sometimes, one LULC category may show different image characteristics (e.g., different crops growing on agricultural land). In this case, different samples for the same LULC must be established.

The use of existing maps: Good existing maps can provide valuable references to identify training samples. For instance, an existing LULC map can be utilized to conduct a preliminary screening of the study area. This map may allow an analyst to quickly identify a set of sample sites where LULC attributes have not changed drastically since the map data was collected. Especially when information from several maps is synthesized, a great amount of LULC information can be obtained and this information can be used to establish training samples.

Visual interpretation: Some LULC categories are self-evident on an image (e.g., water body, forest, and agriculture land). In this case, the training samples can be directly identified through visual interpretation of the image.

IMAGINE Signature Editor can be used to facilitate the delineation of training samples and the extraction of image signatures. Specifically, the delineation of training samples on an image is done with the area of interest (AOI) tools. With the image layer on display, the AOI tools allow an analyst to interactively draw a polygon or to “grow” a polygon with a seed point. The image characteristics defined by the polygon can be added to the signature table, which is then used for supervised classification.

4.5 Supervised LULC Classification

With the signature table established, the next step is to determine the method to be used for the classification. Depending on the decision rules, the methods used for supervised classification can be divided into two categories: parametric classification methods and non-parametric classification methods.

Non-parametric versus parametric methods: Parametric classification methods use parametric signatures defined by mean vectors of spectral bands and the covariance matrix. Non-parametric classification methods are based on minimum and maximum values of the training sample, which determine whether given pixel values are within the defined signature boundary. Due to the use of parallelepiped boundaries, non-parametric classification itself may leave some pixels unidentified due to overlapped decision boundaries or uncharted classification space. For this reason, classification rules must be defined for situations in which the signature boundaries overlap or where there is uncharted space. Parametric classification methods operate in a continuous decision space, which allows all the pixels on an image to be identified. Sometimes non-parametric and parametric methods can be combined to perform the classification task.

Maximum likelihood method: The maximum likelihood method is probably the most frequently used method for supervised classification. Maximum likelihood is a parametric classification method that has the advantage of allowing complete classification of an image when proper samples are specified. The strength of the maximum likelihood method lies in the mathematical principles used to derive the parameters of the mean vector and the covariance matrix. Theoretically, the parameters derived with maximum likelihood methods maximize the probability of obtaining the samples that generate the best classification results.

Once a decision is made on the classification method to use, its implementation using IMAGINE is a relatively simple process. In the classification module, the user first selects the supervised classification function, which brings out the supervised classification dialogue window. In the dialogue window, the user then specifies an image file as input, another image file as classification output, and a classification method. After this, the software will run a supervised classification procedure that automatically labels each pixel of the input image with different LULC categories.

4.6 Classification Outputs and Post-Processing

A major product of supervised classification is the LULC classification map, which is a thematic raster layer. This thematic raster layer contains information about (see IMAGINE Tour Guide):

- The class values assigned for individual LULC categories
- The LULC class names
- Color table that defines colors for each LULC category
- Layer statistics (e.g., pixel numbers for each LULC category)
- Layer coordinate information

The LULC map obtained from the image classification process might contain misclassification that requires additional enhancement and post-processing. In the demonstration project, we used two procedures after automated classification: manual improvement and merging with existing GIS data.

Manual improvement: After the automated classification was completed in the demonstration project, misclassification was found for a few LULC categories (e.g., farmland versus forestland, golf courses versus grassland, and the disappearance of some small streams in the area). To fix these problems, the ETM+ imagery and digital orthophotos were utilized together in a manual interpretation process. ETM+ imagery provided spectral information that was particularly useful for generalized recognition between vegetation, water bodies, and urban built-up areas. At the same time, the one-meter digital orthophotos provided the geometric detail that allowed structural recognition of specific features on the ground (e.g., rivers, streams, buildings, and so on). Displaying the ETM+ imagery and the digital orthophotos on top of each other facilitated visual analysis. Through this analysis, farmland, golf courses, and several river streams were manually extracted using the on-screen digitizing function of ArcView, a commercial GIS product from ESRI.

Merging with existing GIS data: Because of the complex spatial patterns of the LULC classes in the study area, spectral signatures given by ETM+ alone were insufficient to identify some of the LULC classes. This problem was particularly true in the urban built-up category. Therefore, several existing GIS layers were utilized to improve the classification process. These included the USGS LULC map, the Census population data, and the road networks file. Although all three types of data were analyzed and tested, the USGS LULC map was found to be particularly useful in generating the final classification results for the study area. Aside from facilitating LULC classification, the existing wetlands map, parks boundary map, and transportation networks were utilized by layering them onto the information generated from the LULC classification. Procedures on the use of existing GIS data are described in Section 6.

LULC Classification Results: In the demonstration project, the initial LULC classification and post-processing generated four LULC layers. Each layer is described below:

LULC layer I is a direct classification from the sharpened Landsat ETM+, with some manual modifications on farmlands and streams. As the classification focuses more on the biophysical materials on the ground, it can be particularly useful for impervious surface estimation. It provides several environmental discipline categories required for the EIS, e.g., forest land, farmland, and water. The categories in LULC layer I were:

1. Forest
2. Grass and shrubs
3. Residential/low density urban built-up
4. Commercial/Industrial/high density urban built-up
5. Water
6. Farmland

LULC layer II was created using LULC layer I, the existing USGS LULC map, and the existing transportation network layer. This layer can be used for the following EIS disciplinary categories: transportation; shorelines; farmland; fish, aquatic habitat; and land use. The LULC categories that are contained in LULC layer II were:

1. Green, Forest
2. Grass and shrubs
3. Residential
4. Commercial
5. Water
6. Farmland
7. Transportation
8. Industrial
9. Urban built-up, mixed or unclassified

LULC layer III was created with the LULC layer I map and the wetlands map. From this layer, wetlands and their surrounding LULC types can be referenced. Compared with LULC layer I, the land cover categories within the wetland areas can be identified, which could be useful in reviewing and/or prioritizing possible impacts on wetlands in the study area. The LULC categories that are contained in LULC layer III were:

1. Forest
2. Grass and shrubs
3. Residential/low density urban built-up
4. Commercial/Industrial/high density urban built-up
5. Water
6. Farmland
7. Wetlands, classified as low sensitivity

8. Wetlands, classified as high sensitivity

LULC layer IV was created with LULC layer I and with the park layer added. This layer also shows some golf courses that were manually extracted from the orthophotos and ETM+ imagery. This layer was specifically used for the recreation category. The LULC categories that are contained in LULC layer IV were:

1. Forest
2. Grass and shrubs
3. Residential/low density urban built-up
4. Commercial/Industrial/high density urban built-up
5. Water
6. Farmland
7. Parks
8. Golf Course

4.7 Verification and Validation

To assess the results of the LULC classification, the LULC categories generated by the image process need to be compared with a reference map that contains ground-truth information. In general, two approaches can be used to validate and verify the LULC classification: the use of training samples and the use of random samples.

The use of training samples: The training samples that are used to extract LULC classification signatures contain ground truth information. By comparing the LULC categories on the newly derived LULC map and the LULC categories on the training sample map pixel by pixel, we can calculate the ratio of correct LULC classifications by dividing the total number of correctly classified pixels by the total number of pixels. The ratio is then used as a measure of the accuracy of the classification results. Usually, a ratio can be calculated for each type of sample or for an individual LULC category. Such a ratio might provide additional information about the accuracy of the classification. A major problem of using the training samples for verification is that when training samples are classified with the signatures extracted from the same samples, there is a tendency for higher classification accuracy in the sample points. That is, samples may be classified accurately with sample signatures, but the classification for non-sample points may not have the same level of accuracy.

The use of random samples: Because of this drawback in using training samples for verification, accuracy evaluation is usually conducted with independent samples. To allow unbiased checks of the accuracy of the LULC classifications, sample sites are randomly identified in the study area. Then, LULC categories on these sample sites are obtained by using field trips, reliable maps, or higher resolution imagery. Once the LULC categories are identified on the sample sites, these LULC categories are then compared with the LULC categories on the newly derived LULC map to compute the correction classification ratio for the study area.

Here we provide specific steps to evaluate the accuracy of the LULC classification results using random samples. It is worth noting that IMAGINE has an accuracy assessment tool in the classifier module. This accuracy assessment tool can be used to generate random points in the study area and to identify the LULC categories for these random points on the classified image. The user can input the LULC categories for these random points using ground-truth information and then the accuracy assessment tool will be able to compute the error rates and accuracy statistics. The random points generated with the accuracy assessment tool can be displayed along with the classified image, which is particularly convenient for visual analysis. Externally generated points can be imported or merged with points internally generated. These internally generated points, however, cannot be edited or saved as a file that can be viewed by other types of software, e.g., ArcView.

Because of this restriction, we provide an alternative procedure to evaluate the classification accuracy:

Step 1: As described in Section 5.1, a special random point generator can be used to generate random checking points in the study area. These points, when first generated, are contained in an ASCII format and are imported into Arc/Info using the GENERATE function. By overlaying the random points with the boundary of the study area, a user can then eliminate random points that are not located in the study area, even though they are inside the window that contains the study area. A text file is created for these checking points using Arc/Info UNGENERATE function for subsequent use.

Step 2: An ArcView shapefile is created using the Arc/Info ARCSHAPE function. The attribute table of the ArcView shapefile is then populated with information based on ground-truth information (see Section 5). This information includes checking point ID, the description of the LULC category for each checking point, the LULC code and some special notes for the site as shown in the first four columns on the table in Figure 4.2.

Step 3: The text file created with the Arc/Info UNGENERATE function can now be imported into IMAGINE using the accuracy assessment module. The accuracy assessment module will automatically identify LULC categories for these checkpoints on the classified LULC map and list these LULC categories in the accuracy assessment table.

Step 4: The LULC categories identified with the IMAGINE accuracy assessment model are now manually transcribed into the attribute table of the checking point shapefile. Three fields are created in the attribute table. The first field contains the LULC categories that are identified using ground truth information. The second field contains LULC categories identified on the classified LULC map. The value in third field is determined by the LULC categories in the first two fields. If the values in the first two fields are the same, the value assigned to the third field is zero; otherwise, the value will be the same as the second field. A zero in the third field means the LULC category is correctly classified. A value greater than zero in the third field means that the LULC category is incorrectly identified and that the LULC category coded in the first field is incorrectly classified as the LULC category in the third field. These three fields are shown in the last three columns on the table in Figure 4.2.

Arcid	Lulctype	Lulccode	Comments	Lulc_1st	Lc_1st	Cls_error
1	Residential	11	Forested portion of Rural Residential area	1	1	0
2	Residential	11	Forested portion of Rural Residential area	1	1	0
3	forested wetland	61	near the edge of a clearing	6	1	1
4	Other Urban or Built-Up Land	17	service area at end of the lake	1	1	0
5	Residential	11		1	1	0
6	Residential	11		1	1	0
7	Residential	11		1	1	0
8	Residential	11	rural residential	1	1	0
9	Other Urban or Built-Up Land	17	unbuilt residential & golf	1	1	0
10	Mixed Urban or Built-Up Land	16	Scrub/Shrub between Commercial and Residential	1	1	0
11	Commerical and services	12	strip is 1/2 residential, site is in commerical the best	1	1	0
12	Other Urban or Built-Up Land	17	Scrub/Shrub east of soccer field complex	1	2	2
13	industrial	13	boeing secure site grasslands	1	1	0
14	Residential	11		1	1	0
15	Residential	11	Forested portion of residential area	1	1	0
16	Transportation, communications & utili	14	scotchbroom	1	4	4
17	Residential	11	Forested portion of residential area	1	1	0
18	Residential	11		1	1	0
19	Residential	11	steep, tree-lined shoreline residential	1	1	0
20	Other Urban or Built-Up Land	17	Parking lot?	1	1	0
21	deciduous forest	41	forested parkland	4	4	0
22	Residential	11		1	1	0
23	Other Urban or Built-Up Land	17	Baseball Field	1	1	0
24	mixed forest land	43	Cedar Rvr Watershed	4	1	1
25	Residential	11		1	1	0
26	Residential	11		1	1	0
27	Transportation, communications & utili	14	roadside undeveloped edge of watershed	1	4	4
28	Residential	11		1	1	0
29	Residential	11	might be in median trees	1	1	0
30	Residential	11		1	1	0
31	Commercial and Services	12	School	1	1	0
32	non forested wetlands	62		6	1	1
33	Residential	11		1	1	0
34	deciduous forest	41	site is on hill above apartments	4	1	1
35	lakes	52	lake washington	5	5	0
36	non forested wetlands	62		6	1	1
37	mixed urban or built-up land	16	Mercer Is shopping / civic center	1	1	0
38	Other Agricultural Land	24	next to a soil pit, cleared	2	1	1
39	Residential	11		1	1	0
40	Other Urban or Built-Up Land	17	undeveloped, near wetland bewteen residential blocks	1	1	0
41	mixed forest land	43	no access- undeveloped urban/forest fringe	4	4	0
42	Residential	11	older res area w/ trees	1	1	0
43	Residential	11	Forested portion of Residential area	1	1	0
44	forested wetland	61	wetland stromwater control for Natl Cemetary	6	4	4
45	cropland and pasture	21	small farms and pastures	2	2	0
46	Transportation, communications & utili	14	I-90 roadside	1	1	0
47	evergreen forest	42	site is in the woods off a res development	4	1	1
48	mixed forest land	41	site is in coal creek watershed park	4	1	1
49	Residential	11		1	1	0
50	Residential	11		1	1	0
51	Residential	11		1	1	0
52	Residential	11	older res area w/ trees	1	4	4

Figure 4.2. Ground-Truth Information Included in the ArcView Shapefile Attribute Table.

Step 5: Using the three fields created in step 4, a misclassification matrix can be constructed to indicate the misclassifications and accuracy rates for each of the LULC categories and the overall classification. Table 4.1 shows the misclassification matrix and accuracy rates for each of the LULC categories and the overall classification for LULC Layer I on Level 1 USGS LULC classification. By looking at a row of the table, one can identify how many of the checked points from a given LULC category were correctly classified. For instance on the row for the urban category, the number 64 means that 64 urban samples are correctly classified as urban, while 1 urban sample is identified as farmland, 5 identified as forest, among a total of 70 urban samples whose LULC categories are determined with the ground-truth information. The accuracy for urban land use classification therefore is dividing 64 by 70, which equals 91.2%. Similarly for farmland, 2 samples are correctly identified as farmland, 1 identified as urban and 1 identified as forest. The accuracy rate is computed as 50.0%. The numbers with bold cases in the diagonal cells of the table indicate the numbers of checking points that are correctly classified. The total number of checking points is 91 and 73 samples are correctly classified so the overall accuracy is 80.2%.

Table 4.1. Misclassification Matrix and Classification Accuracy Rates

		Predicted						
		Urban	Farmland	Forest	Water	Wetlands	Total	Accuracy
Actual	Urban	**64**	1	5	0	0	70	91.2%
	Farmland	1	**2**	1	0	0	4	50.0%
	Forest	4	0	**4**	0	0	8	50.0%
	Water	0	0	0	**3**	0	3	100.0%
	Wetlands	4	0	2	0	**0**	6	0.0%
	Overall Accuracy							80.20%

Note that in this example, urban land and water were accurately identified. On the other hand, farmland, forest, and wetlands were not correctly classified. Trees are sometimes found on farmland, on urban land, and in wetlands. Wetlands can be engulfed in urban areas. The classification method is generally better for identifying land cover than land use. Higher resolution hyper-spectral data, in contrast to the Landsat 7 data used in this example, would provide better classification of both land cover and land use.

5. FIELDWORK FOR LULC CLASSIFICATION TRAINING AND VERIFICATION

To obtain ground-truth training samples for LULC classification and to validate LULC classification results, the collection of ground-truth data through field trips is an essential part of the LULC classification process. Usually, two rounds of field studies are needed: one prior to the LULC classification process, and a second round after the classification is completed. The purpose of the first field trip is to gain familiarity with the study area and to obtain training samples for the LULC classes. The purpose of the second field trip is to validate, verify, and if necessary, modify the classification results. The general procedure for both rounds of fieldwork is similar. Below, we provide a description of the general procedure and note when the procedures are different for the two rounds of fieldwork.

5.1 Selection of Sample Sites

An important task of the fieldwork is to determine the LULC categories for a set of sample sites. The methods are different to select the sample sites for supervised classification training, and to select the sites for checking and verification. For the training sample sites, our purpose is to select those sites that have representative image characteristics that can be extracted as signatures. For verification sample sites, in contrast, our purpose is to select those sites that can provide unbiased measurement of the accuracy of the classification results.

The selection of training samples: Several basic principles can be used for the selection of the sample sites. First, samples must include all the LULC categories that need to be classified. In order to extract the signatures of these LULC categories, the samples for these different categories must first be identified. Before the field trips, the LULC categories of some of the identified sample sites are uncertain. It is a good strategy to select multiple sample sites for each LULC category. Second, it is a good practice to locate sample sites that are spread evenly across the study area. In many cases, image signatures for LULC categories are heterogeneous over the area (e.g., forest spectral characteristics are different between ridges and low valleys). The selection of spatially dispersed sample sites increases the likelihood of capturing these differences. Third, for those LULC categories that display significant internal signature differences (farmland where different crops grow), a single LULC category may be divided into several subcategories and samples can be obtained for each subcategory.

For signature extraction, a sample site must contain a large number of pixels. Also, the selected sample site must provide easy reference for field identification. Usually a homogeneous area that extends across a reasonably sized neighborhood, say more than 100 pixels, will serve both of these purposes.

The selection of verification sites: To eliminate human bias in the selection of the verification sites, they are usually randomly identified with a computer program. As previously discussed, IMAGINE provides a random point generation function for this specific purpose, but these randomly generated points cannot be exported for viewing with software other than IMAGINE. In the demonstration project, we coded a simple random number generator that generates two independent random numbers, which are used as the (x, y) coordinate pairs for the checking points. The (x, y) coordinates were constrained by the rectangle bounded with the maximum and minimum coordinates of the study area. These (x, y) coordinates are first contained in a text file and then imported into Arc/Info to create Arc/Info coverage and an ArcView shapefile. Overlaying the (x, y) coordinates with the boundary of the study area eliminates those points that are inside the area bounded with the maximum and minimum coordinates of the study area, but that are not actually inside the study area itself.

As shown in Figure 5.1, the verification sites generated by the automated procedure have a random distribution pattern across the study area. Strictly speaking, each verification site is a single pixel. In practice, an extended neighborhood area is considered as the site for field identification purposes. The number of verification sites is mainly constrained by the resources available for the fieldwork and by the accuracy requirements. In the demonstration project, we limited the number of random field sites to 95, which was mainly due to resource constraints.

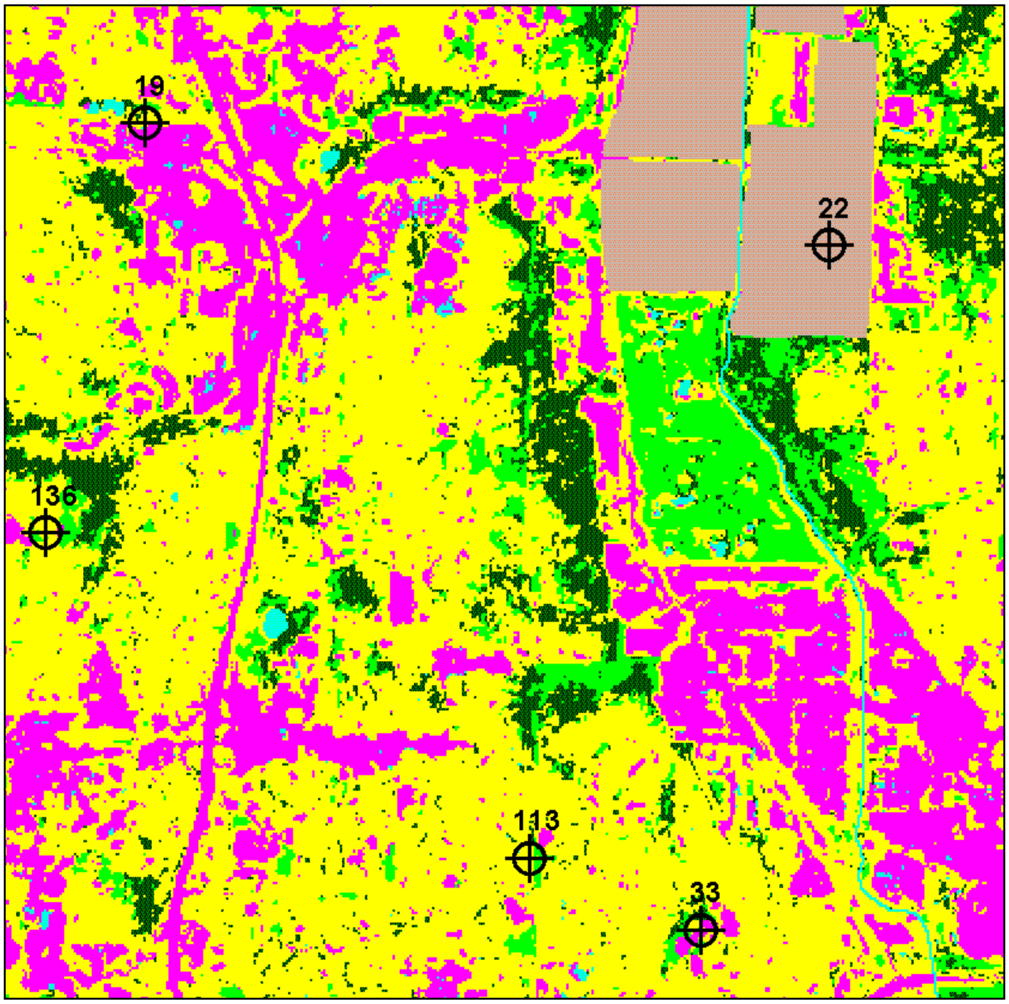


Figure 5.1. Randomly Generated Verification Points.

5.2 Fieldwork Preparation and Planning

Field data collection is a time consuming process, whether it is for ground-truthing, training samples, or verifying classification results. To minimize the field effort, it is helpful to conduct a preliminary analysis of the study area using images and existing GIS data. This preliminary analysis can significantly reduce the number of sites to be visited or simplify data entry in the field. Good trip planning is also essential for productive fieldwork. Fieldwork preparation and planning includes the following procedures:

Preliminary analysis of the study area: To become familiar with the study area and to help prepare field tasks, a preliminary analysis of the study area can be conducted using images and existing GIS data to determine known and unknown LULC categories and their distributions within the study area. For the sites where LULC classes appear obvious, field observations on the ground are eliminated or only a quick verification check is conducted. Sites selected for field trips are those where the LULC classes cannot be determined by preliminary analysis. The use of existing data can positively identify the LULC categories for many sites both for classification training and verification purposes. This is particularly effective for LULC categories such as water bodies, forest land, and residential areas.

Field data specification: It is essential to precisely specify data items that are to be collected in the field. For LULC classification, the focus is on LULC categories. During the in-house preparation, it is necessary to determine the LULC classes to be identified, the code, and the description of each LULC category. Also, it might be necessary to specify additional means to annotate the field data, e.g., photo logs. With the widespread use of laptop computers, it is also suggested that a GIS layer be created with all the field sites included in this layer. Then a table can be generated to list these field sites and the data items to be collected at the sites. Through the preliminary analysis and the use of existing data, the data to be collected for the table can be filled with some preliminary information. In some cases, information to be collected in the field can be more specifically defined for a given site. For instance, when LULC data are collected for a site in a forest area with a limited number of households, the data collection at that site can be limited to whether the site belongs to either forest land or is part of a residential area.

Trip Planning: In preparation for the actual field trips, commercially published detailed local street maps will be necessary. Detailed points of interest contained in these maps, such as parks, schools, and shopping centers, can be very helpful in locating specific sites. For practical reasons, the sample sites determined in previous procedures may need to be plotted out on custom maps, showing major highways and local roads necessary to access the exact locations. The combination of these custom maps with the street guides can greatly reduce the time required for the fieldwork. A laptop computer, loaded with the GIS layer that defines the sites and data items to be collected on the field trips along with relevant images and vector layers, can be prepared for field use.

5.3 Fieldwork

Careful preparation and planning will make for efficient fieldwork. In many cases, a site can be quickly identified on the map and the location of that site can be correspondingly identified in the field. In these cases, the LULC categories are identified and registered into the GIS layer in a computer or marked on a map. Pictures are taken and additional descriptive notes are written for the sites.

However, special cases constantly arise in the field. Not all of the sites identified on the map or in-house are accessible in the field due to physical or man-made access constraints (e.g., no road access or private property). In such circumstances, we need either to choose a new site as a replacement or just simply leave it out. In other cases, the sample sites contain mixed land uses, which make it difficult to describe in concise field notes. In these cases, pictures can be taken and can be brought back to office for additional assessment. In the demonstration project, LULC is changing rapidly in the study area. Some of the sites are in a transitional stage, and their LULC categories cannot be identified even in the field. In this case, interviews with local planners or developers will be necessary to collect the necessary information about their historic LULC categories and intended land use.

5.4 Compiling Field Data for Input to Software Application

To provide data for software application, data collected from the field are compiled into a GIS data layer that identifies the location of the field sites and their corresponding LULC categories. Obviously, the compilation of the field data can be coordinated with fieldwork preparation. As previously described, the ArcView shapefile was already created prior to the field trips and this shapefile can be referenced for field data collection. That is, either the attribute table of the shapefile can be directly used to contain the field data or the field data is contained in a table that can be matched with the attribute table. Figure 5.2 shows a shapefile attribute table that contains compiled field data.

Photographs taken from the field trips can provide additional information for the study sites. These photographs, when organized properly, can be used conveniently for after-trip analysis and assessment. ArcView provides a hotlink function that allows a user to click on a site and bring its photographs to the screen. The function can be implemented easily by specifying the file name and the directory of the photographs in the layer's attribute table. After activating the special hotlink tool, the photographs can be viewed instantly when the sites are analyzed on a map. This can be especially effective when images and other GIS layers are overlaid with the site map and the photographs shown on the screen.

Additional checking and verification with the information collected from the field are necessary. This check involves synthesizing information from the field notes, marked maps, remotely sensed imagery, and existing GIS databases as well as the field photography. Then the GIS layer is finalized for LULC classification training or for the verification of the classification results. It should be noted that the GIS layer prepared for LULC training is a polygon layer, in which each polygon represents a LULC category. The layer used for classification verification is a point layer, each point identified with a LULC category.

Shape	Recid	Lulctype	Lulccode	Office	Field	Photo	El_or_ap	Comments
Point	15	Residential	11		x		EL	rural residential
Point	16	Other Urban or Built-Up Land	17		x	13, 14	EL	unbuilt residential & golf
Point	19	Mixed Urban or Built-Up Land	16		x		AP	Scrub/Shrub between Commercial and Residential
Point	21	Commerical and services	12		x	23	EL	strip is 1/2 residential, site is in commerical the best
Point	22	Other Urban or Built-Up Land	17		x		AP	Scrub/Shrub east of soccer field complex
Point	23	industrial	13		x	19	EL	boeing secure site grasslands
Point	24	Residential	11		x	22	EL	
Point	25	Residential	11	x			AP	Forested portion of residential area
Point	26	Transportation, communications & utili	14		x	4	EL	scotchbroom
Point	27	Residential	11	x			AP	Forested portion of residential area
Point	30	Residential	11	x			AP	
Point	31	Residential	11		x	3	EL	steep, tree-lined shoreline residential
Point	33	Other Urban or Built-Up Land	17	x			AP	Parking lot?
Point	34	deciduous forest	41		x	12	EL	forested parkland
Point	35	Residential	11				AP	
Point	36	Other Urban or Built-Up Land	17	x			AP	Baseball Field
Point	37	mixed forest land	43	x		none	EL	Cedar Rvr Watershed
Point	38	Residential	11	x			AP	
Point	41	Residential	11	x			AP	
Point	44	Transportation, communications & utili	14		x	31	EL	roadside undeveloped edge of watershed
Point	47	Residential	11	x			AP	
Point	48	Residential	11		x	none	EL	might be in median trees
Point	50	Residential	11		x	3	EL	
Point	51	Commercial and Services	12		x		AP	School
Point	53	non forested wetlands	62		x	21	EL	
Point	57	Residential	11		x	7	EL	
Point	59	deciduous forest	41		x	16	EL	site is on hill above apartments
Point	60	lakes	52	x			EL	lake washington
Point	63	non forested wetlands	62		x	9,10,11	EL	
Point	65	mixed urban or built-up land	16		x	1	EL	Mercer Is shopping / civic center
Point	66	Other Agricultural Land	24	x			EL	next to a soil pit, cleared
Point	67	Residential	11		x		AP	
Point	68	Other Urban or Built-Up Land	17		x	20	EL	undeveloped, near wetland bewteen residential blocks
Point	69	mixed forest land	43	x		4	EL	no access- undeveloped urban/forest fringe
Point	70	Residential	11		x	5	EL	older res area w/ trees
Point	73	Residential	11		x	1	AP	Forested portion of Residential area
Point	74	forested wetland	61		x	30	EL	wetland stromwater control for Natl Cemetary
Point	76	cropland and pasture	21		x	17	EL	small farms and pastures

Figure 5.2. The Shapefile Attribute Table That Contains Compiled Field Data

6. OTHER GEOGRAPHIC INFORMATION AND IMAGERY FILES

Because of complex spatial patterns of LULC classes in the real world, spectral signatures given by one type of imagery might be insufficient for identifying some of the LULC classes, particularly in urban built-up areas. Therefore, other images and existing GIS layers need to be utilized to improve or enhance LULC classification results. These data may include different types of images, existing LULC maps, Census population data, road networks, or a previous wetlands inventory. The use of other image files and geographic information can be separated into two phases. In the first phase, these data are directly utilized in the classification process to generate LULC maps. In the second phase, existing maps are merged with the LULC classification to provide information on environmental disciplines.

6.1 Other Data

Many types of images and GIS layers can be utilized to enhance LULC classifications or directly provide information for EIS purposes. Below, we focus our attention to those layers that we investigated for the demonstration project. Actually the same data layers can be found for many other areas as well.

Orthophotos and IKONOS Imagery: Orthophotos might include both the black-and-white digital orthophotos and color or multi-spectral digital orthophotos, which have a one-meter-or-higher spatial resolution. They provide ideal structural identification for features such as buildings, roads, and other infrastructures. However, because of their fine spatial resolution, it is difficult to use these images for automated LULC classification. These images are utilized for ground-truthing, verification, and selected feature extraction. Both the one-meter IKONOS panchromatic band and the four-meter multi-spectral bands can provide the same benefits as orthophotos. In addition, multi-spectral bands can be directly used for automated LULC classifications. Particularly, the four-meter multi-spectral bands can be sharpened on the one-meter panchromatic band to allow detailed LULC characterization for the study area.

The USGS LULC map: The USGS LULC map provides national coverage and is in the public domain. A major drawback of this map is that its information is somewhat outdated because the series was developed during the 1970's and 1980's. This map can be a valuable reference when new LULC maps are generated. There are frequently patterns to LULC changes. For instance, the forestland in the fringe of a city is more likely to be converted into urban land. In contrast, the likelihood of conversion of built-up areas to agriculture land is small. Based on this type of regularity, a preference for classification can be prescribed when the LULC category on the USGS LULC map is known. That is, if a wetland is identified on the USGS map and forestland is identified for the corresponding area on an ETM+ image, the prescribed rule classifies this area as wetlands. Similarly, if a residential area is identified on the USGS map and a built-up urban category is identified on an ETM+ image, then residential land use would be assigned to this area.

Census population data: Census population data are needed for the environmental justice discipline. Using Census population data, maps of nonwhite population distributions can be created to evaluate potential effects of a transportation project on minority population.

Census population data are useful in several other circumstances. In urban areas, highly concentrated residential, commercial and industrial land use might have similar image characteristics, which makes it difficult to identify their differences. The use of population and household counts in these areas can provide additional evidence of whether the areas under question have the presence of residential housing. In suburban areas, low-density housing with extensive coverage of trees and grasses can be easily confused with forest or agricultural land. The population data can also be helpful in resolving these differences because the presence of houses would be a clear indication of residential land use. It must be realized, however, that Census population boundaries do not coincide with the LULC boundaries. The use of the population data may turn some of the unpopulated areas into residential areas. The user has to look into the specific situation when population data are utilized in the LULC classification process.

Road networks: Road networks themselves constitute a LULC category, which can be merged with a LULC map to form the transportation LULC category. Road networks can also be used as a background layer when environmental disciplinary maps are developed.

In addition, a road network layer can be used for the classification of other LULC categories. The presence of a road is highly correlated with human activities. For instance, combining the distance to a road and the population density, we may be able to more precisely define potential residential areas. Similar to the use of Census population data, however, a user has to evaluate the situation very carefully when road networks are used for the classification of other LULC categories.

Wetlands Inventory: Information about wetland locations in a given study area is critical to the EIS process. It is possible to use remotely sensed data to directly derive wetlands information (O'Hara 2002). Here we focus on the use of existing wetlands data, such as those contained in the U.S. Fish and Wildlife Service's National Wetlands Inventory. In the case of the demonstration project, we used an existing wetlands layer that was created during the EIS process. This data layer can be directly overlaid with the LULC classification results to represent wetland distributions in the study area.

Recreational facilities: Information about recreational facilities such as parks, trails, recreation areas, or wildlife refuges is also needed in the EIS process. Some of the forest areas or rivers belong to parks or recreational facilities and are identifiable on imagery. However, in many cases, the boundaries of recreational areas are drawn administratively, which makes it difficult to directly extract recreational boundaries from imagery. For this reason, existing maps of recreational facilities, if they are up to date, should be utilized.

6.2 Steps to Integrate Other Data

Because of the use of various types of data, these data have different formats, different coordinate systems, and different spatial resolutions, which make the use of the data extremely difficult. To integrate the data, we recommend the following steps:

Data format conversion: Format conversion is a simple but important process in data integration. Before any type of format conversion, it is essential to select a set of standard formats that will allow the representation of different types of data including raster data types (single bands, multiple bands, integer or real values for grid cells) and vector data types (points, lines, and polygons). In the demonstration project, we used three types of formats as the standard data formats and any data from other formats were converted into one of these formats:

1. The ERDAS IMAGINE .img file format was used for image data.

2. The Environmental Systems Research Institute (ESRI) Arc/Info coverage format was used for vector data layers and raster data layers.

3. The shapefile format was used for vector data layer. In general, the same data layer in the shapefile format may also be maintained as an Arc/Info coverage to allow effective conversion and overlay between IMAGINE and Arc/Info.

Projection Conversion*:* After data are converted into the standard file formats, projection conversion is also necessary to reference these data in the same spatial coordinate system. The selection of a coordinate system may consider several factors. Most importantly, the selected system must be commonly used and recognizable, e.g., the State Plane Coordinates System. The consideration may also include whether the selected system must have certain properties (equal area or no azimuthal distortion). The selection of a measurement unit and a Datum is also important.

Resolution merge: For Landsat imagery and IKONOS data, the panchromatic images and the multi-spectral images come in different resolutions. In this case, the image sharpening procedure can be utilized to interpolate lower resolution multi-spectral imagery onto a panchromatic band of a higher resolution.

Vector to raster conversion: IMAGINE provides the ability to directly display raster and vector data without converting the vector data layers into raster or image data formats. This is also true for the ArcInfo and ArcView software. IMAGINE also allows direct overlay between the raster and vector layers. Nevertheless, converting a vector layer to a raster layer is necessary when a layer has to be evaluated in a raster environment. For example, calculating distances to a road for each location on a map would need a road map to be prepared in raster layer first.

6.3 Use of Other Data Files

Images and existing GIS data are important to almost all the image analysis tasks. We first describe their general use in preparing information for the EIS process and then focus on a specific example to illustrate how to apply the USGS LULC map to enhance LULC classification results.

Classification training and verification: As discussed in previous sections, existing maps and images can be utilized in selecting training samples and verification points, identifying LULC categories for these training samples and verification points, providing aids to field trips.

Classification: Several GIS data layers, including the USGS LULC map, Census population data, and road networks, can be directly used during the LULC classification process. These data can be treated either as a “spectral” band to participate in a supervised or unsupervised classification or they can be merged with classification results during the post-processing operations.

Visual Analysis: Integrating imagery with existing GIS data also provides a rich information environment in which a user can easily cross-reference data from different sources and quickly identify LULC classes for selected features or locations. This environment is important when manual enhancement to the automated LULC classification is necessary and this enhancement must be done through manual interpretation.

Map background: To prepare the maps for environmental disciplines, various background information must be presented on the maps, e.g., highways, railways, hydro –networks, the boundary of the study area, location names, etc. This information will be most effectively obtained from existing GIS layers.

Here we provide a specific example of using existing GIS data to enhance the LULC classification with IMAGINE. After a LULC map is obtained from Landsat ETM+ imagery with a supervised classification, a user may want to use the USGS LULC map to further resolve some of the urban built-up categories, e.g., commercial, residential, or industrial land uses. Also the user may want to overlay an existing road network map on the LULC classification, as transportation infrastructure is not completely identified with the initial classification. The following procedure can be used to merge the ETM+ LULC classification, the USGS LULC map, and the road network map:

Step 1: In IMAGINE, by selecting the Modeler tool and selecting the Model Maker, a user is able to interactively construct a model in the Model Maker window as shown in Figure 6.1. (Refer to IMAGINE Tour Guide for a detailed description of the use of the Model Maker.) In Figure 6.1, the three icons named n1_landcover, n2_roadgrid, and n3_ulu represent the three data layers: the ETM+ LULC classification, the road network map, and the USGS LULC map respectively, which are used as the model input. The All_Criteria table (see step 2) contains the rules used to merge the three layers. The n4_lulc is the output layer. The arrows in Figure 6.1 define the directions of data flows.

Step 2: The next step is to specify the rules used to merge the three layers. This is done with the criteria function. By clicking on the All_Criteria icon, a criteria table window is displayed on the screen. The user then can interactively construct a criteria table that contains the rules. As shown in Figure 6.2, the criteria table defines values on the output layer based on values of the input layers. For instance, in the first row, the rule states that for a cell if n1_landcover > -1, n2_roadgrid > 0, and n3_ulu > -1, then the value in that cell for the output layer n4_lulc will be assigned to 7. Here “n1_landcover > -1” means for all LULC categories, “n2_roadgrid > 0” means road cell only, and “n3_ulu > -1” means for all LULC categories. The value 7 assigned to the output layer n4_lulc is the code for a road cell. In the ninth row, the rule states that for a cell if n1_landcover = 4, n2_roadgrid < 1, and n3_ulu > -1, then the value in that cell for the output layer n4_lulc will be assigned to 3. This means that if a cell belongs to the mixed urban built-up category identified on n1_landcover, is not a road in respect to n2_roadgrid, and is a residential area identified on n3_ulu > -1, the cell will be classified into the residential category in the output layer.

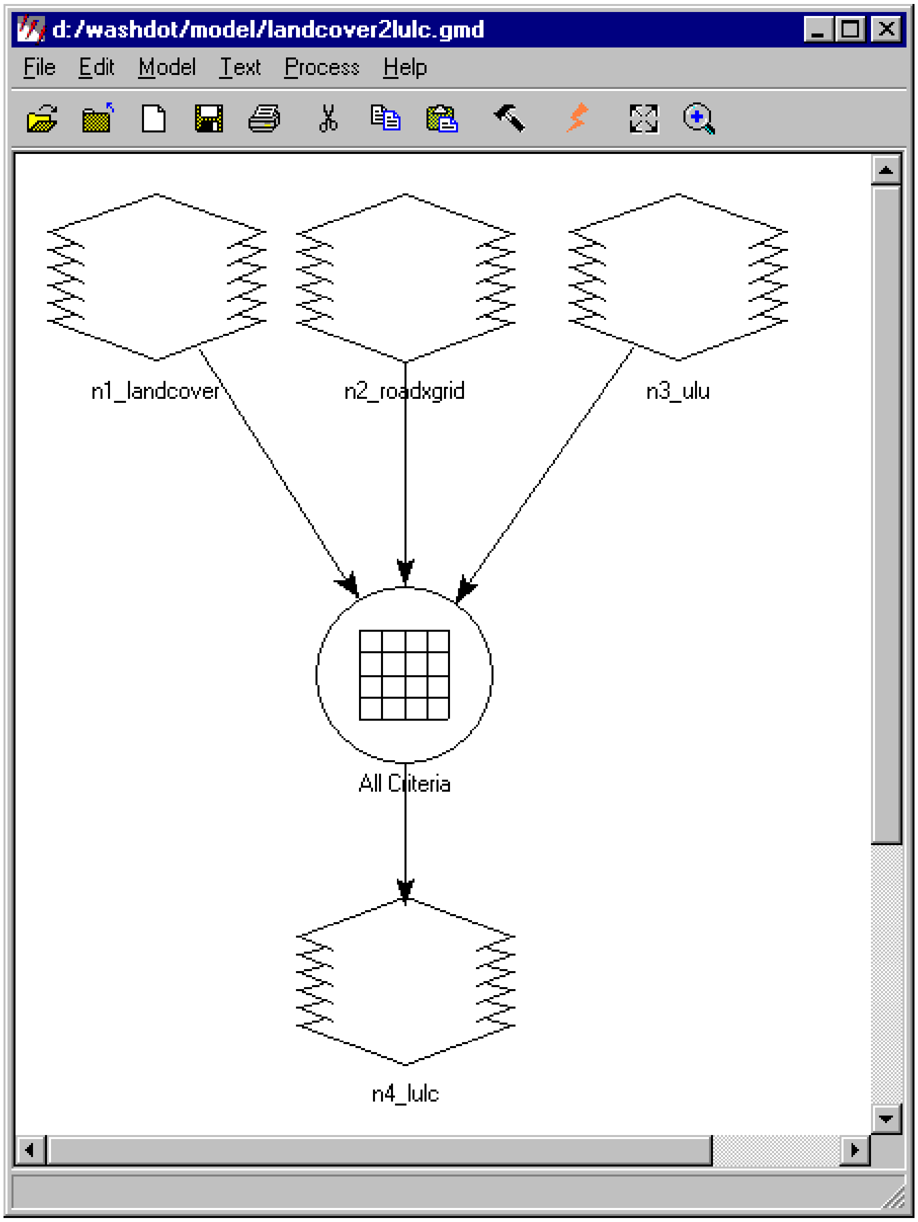
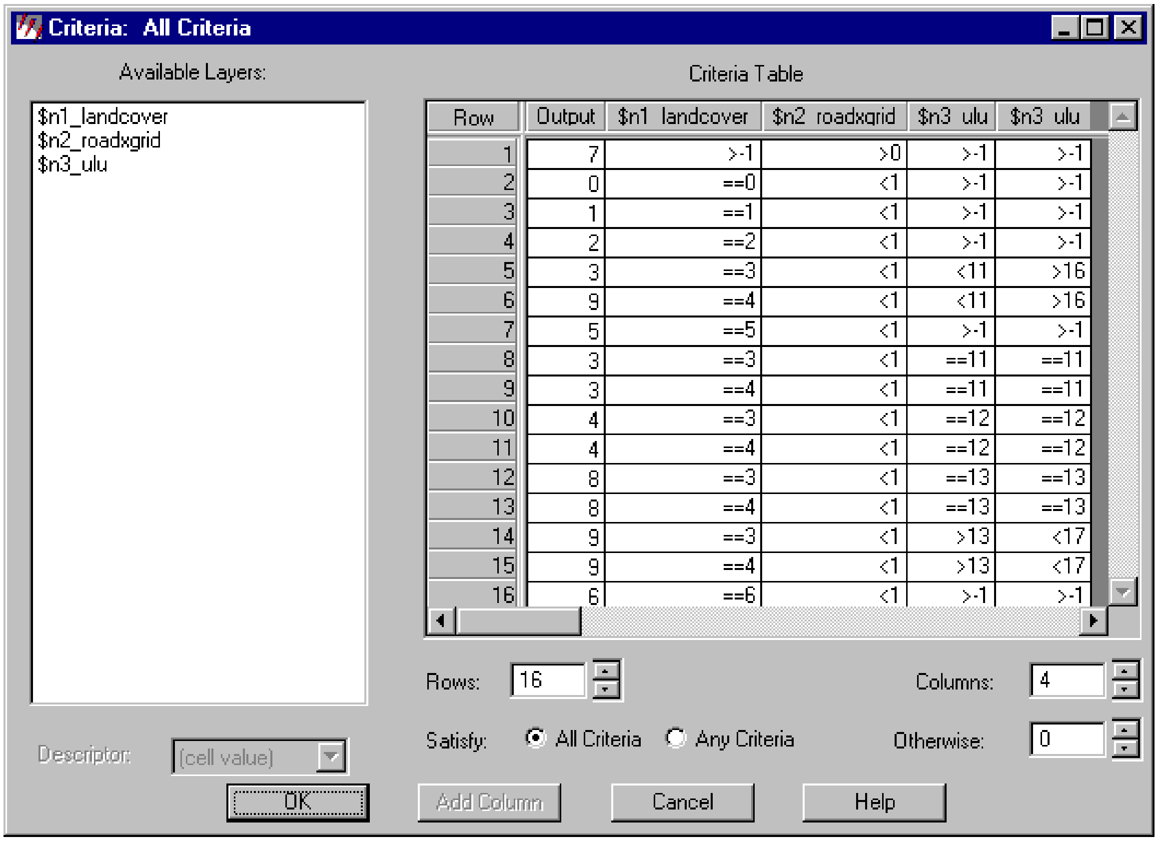


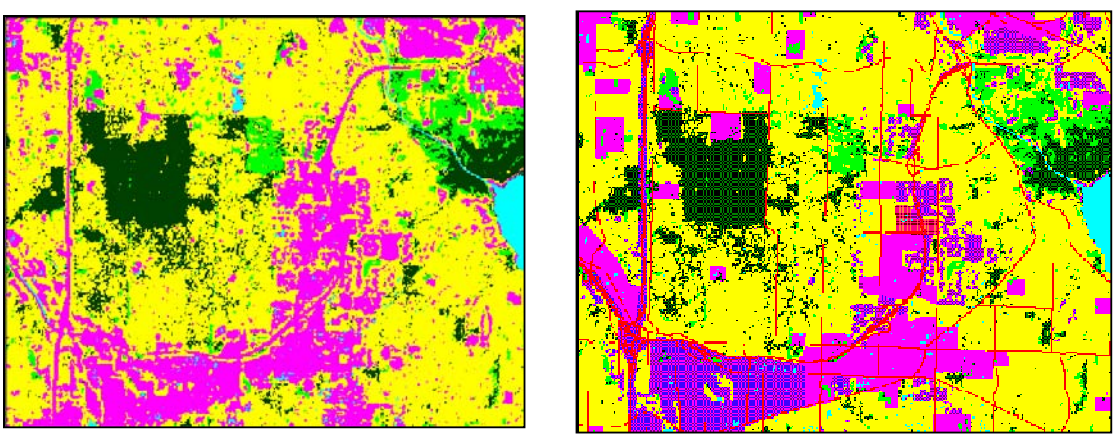
Figure 6.1. The IMAGINE Model Maker is used to construct a model to merge information from three different layers: the ETM+ LULC classification, the road network map, and the USGS LULC map, to generate a new LULC map.

Step 3: Once the model is constructed, it can be saved into a file. This file can be retrieved or modified in the subsequent process. When the user chooses to run the model, the output layer will be generated automatically. See Figure 6.3 for a comparison of the input layer (n1_landcover) and the output layer (n4_lulc).



Row	Output	$n1 landcover	$n2 roadxgrid	$n3 ulu	$n3 ulu
1	7	>-1	>0	>-1	>-1
2	0	==0	<1	>-1	>-1
3	1	==1	<1	>-1	>-1
4	2	==2	<1	>-1	>-1
5	3	==3	<1	<11	>16
6	9	==4	<1	<11	>16
7	5	==5	<1	>-1	>-1
8	3	==3	<1	==11	==11
9	3	==4	<1	==11	==11
10	4	==3	<1	==12	==12
11	4	==4	<1	==12	==12
12	8	==3	<1	==13	==13
13	8	==4	<1	==13	==13
14	9	==3	<1	>13	<17
15	9	==4	<1	>13	<17
16	6	==6	<1	>-1	>-1

Figure 6.2. The Criteria Table Is Used to Define Rules to Derive the Output Layer Based on Values of the Input Layer(s).



(a) **(b)**

Figure 6.3. A Comparison of the Input Layer (n1_landcover) and the Output Layer (n4_lulc) (Color Code for LULC Categories: Dark Green, Forest; Green, Grass and Shrubs; Yellow, Residential; Magenta, Commercial; Turquoise, Water; Tan, Farmland; Red, Transportation, Maroon, Industrial; and Purple, Urban Built-up).

7. REMOTE SENSING/GIS PRODUCTS

Conventionally, the initial products of LULC classifications are compiled into a map, in which the study area is divided into different LULC categories. Usually, this map has a single label on a given location to exclusively indicate the LULC category of the location. In contrast, LULC information required for the EIS process is organized by environmental disciplines (see Section 4.2). In general, a single LULC map cannot provide sufficient information for all the environmental disciplines. If information for all the disciplines were mapped into a single layer, this layer would be too crowded for reasonable interpretation, and it would be too restrictive to assign a single mutually exclusive LULC category to every location on the map. In addition, in the EIS process, a single location may be identified with several different environmental-discipline categories, e.g., a stream in a park may be considered a recreational facility and at the same time a wildlife habitat.

7.1 Merging LULC Classifications with Other Data: General Approach

To align LULC information with environmental discipline categories, the LULC map generated from the image analysis must be transformed into a set of layers extracted from the overall LULC image. Each layer provides specific information on an environmental discipline. During this transformation process, the LULC map is first converted from IMAGINE's native format into the ESRI ARC/INFO GRID format. Discipline layers are then generated in the ESRI ArcView environment.

Not all the information required for the environmental discipline is provided by the image LULC classifications. Existing GIS data sets are therefore used to complement the image LULC classification results. In some cases, existing GIS data layers simply provide annotated information for the discipline map, such as road signs or the name of a lake. In other cases, existing data layers are combined with image LULC categories to provide information for a specific environmental discipline (e.g., the map for the surface water resources could be prepared with the image-LULC water category and the existing GIS hydrography network layer). Some of the maps are created exclusively with existing GIS data files (e.g., the map for the environmental justice category could be directly created with Census population data), though land use information provides a spatial context for the analysis of nonwhite population.

To provide relevant information for the EIS process, simple data overlay techniques are also utilized to derive LULC statistics for the study area. IMAGINE provides overlay functions that can involve both raster and vector data. For this overlay analysis, one could focus, for example, on LULC statistics for different drainage basins. Therefore, the LULC classes and the drainage basin boundaries are overlaid to summarize LULC categories for each drainage basin. It is possible that buffer zones could be used to generate the LULC statistics. However, drainage basin boundaries could be more useful than zones if mitigation measurements are implemented in the same drainage basins as where the environmental impacts occur. In this situation, information about specific impacts on a drainage basin is more relevant than information on impacts within a buffer zone.

The overall results of the task described in Section 7.2 include a set of data layers that directly correspond to EIS environmental discipline categories, and several tables that provide LULC statistics.

7.2 Generating Maps for Environmental Disciplines

To provide maps and related information that would be most relevant for a programmatic EIS process, image analysis results and selected GIS data are reprocessed to prepare thematic information for the environmental disciplines. The thematic information for each discipline could contain either single or multiple map layers. The thematic information for different disciplines is usually different, but in some cases, the same map layer may be shared among different disciplines. The following environmental disciplines are identified for data preparation and representation:

- Environmental Justice
- Farm Land
- Fish/Aquatic Habitat
- Floodplains
- Land Use
- Recreation
- Shorelines
- Surface Water Resources
- Transportation
- Upland Vegetation/Habitat/Wildlife
- Wetlands

Maps for these disciplines are shown in the Appendix of the companion report (Xiong et al. 2004). For distribution and review, Adobe Acrobat .PDF files allow the users to scroll and zoom capability to focus in on specific locations.

7.2.1 Environmental Justice

Executive Order 12898 requires that Federal agencies identify and address adverse effects of their programs and projects that disproportionately fall on minority and low income populations. The Federal Highway Administration has issued guidance on how to implement this Order to implement Environmental Justice analysis for proposed highway projects (FHWA Order 6640.23). The map prepared for this discipline represents the location of the potentially-affected minority population in relation to Commercial, Transportation, and Industrial land uses. This map was generated using a combination of Census data and remotely sensed imagery. The minority population data were compiled from the year 2000 Census. The land use categories were identified through automated classification of the imagery based on spectral signatures and texture, supported by field verification and validation. The land use layer was overlain onto a standard map-template that has major roads, lakes, places, and other features.

7.2.2 Farm Land

The viability of land in long-term agricultural use and the importance of individual farms are reflected in farmland protection legislation in the State of Washington. The LULC data prepared for Farm Land represent the location of potentially affected farmlands along the corridor. They were generated using a combination of satellite imagery and digital aerial photography. These data were overlain onto a standard map-template that has major roads, lakes, places, and other features. Hillshading was added to the farmlands map using 10m U.S. Geological Survey digital elevation model (DEM) data. A map showing projects for Alternative 3 in the I-405 EIS (both highway and transit) was also prepared for the study area.

7.2.3 Fish/Aquatic Habitat

The data prepared for Fish/Aquatic Habitat provides information on the streams and water bodies in the study area. The level of detail was intended to be suitable for a corridor-level environmental review. The data contains the same GIS stream networks as that used for the DEIS. Lakes were extracted from interpretation of Landsat 7 imagery. The locations of dams, fishways, and culverts were identified from the Washington Department of Fish and Wildlife Fish Passage Barrier and Surface Water Diversion Screening (SSHEAR) database.

The data layer for Alternative 3 Projects by Basin contains additional information about Alternative 3 projects (both highway and transit) overlain onto the streams-and-basins map. A third data layer, Land Use and Major Streams, was prepared by overlaying major river streams onto a land use map (described in the Land Use section) to indicate the spatial proximity of various land uses to these streams.

7.2.4 Floodplains

Floodplains are lowlands that are relatively flat and subject to flooding. The 100-year floodplain is the area adjacent to a stream, river or lake that is subjected to inundation by water with a probability of at least 1% in any given year. The Federal Emergency Management Agency (FEMA) floodway is the channel of a river and adjacent land that must be unobstructed to provide for the discharge of the base-year flood.

The data prepared for Floodplains delineates the 100-year floodplain. It contains the same floodplain information as that used for the DEIS for the I-405 corridor, but this data is overlain onto a standard map-template that has major roads, lakes, places, and other features. Hillshading was added to the floodplains map using 10m U.S. Geological Survey digital elevation model (DEM) data. An additional map layer was prepared to represent Alternative 3 projects (both highway and transit), overlain onto the RS/GIS floodplain map.

7.2.5 Land Use

Land use in the study area of the demonstration project is managed through comprehensive plans prepared for each jurisdiction and guided by county planning policies in accordance with the state's Growth Management Act (GMA). Under the Growth Management Act, cities and counties plan for growth, establish commercial and residential zones, and approve variances to those decisions. Transportation projects managed by WSDOT are built in response to the congestion and public safety issues surrounding a growing state.

The Puget Sound Regional Council (PSRC) has adopted multi-region planning policies provided by GMA. The PSRC has also adopted VISION 2020 – a long-range growth management, economic development, and transportation strategy – and the Metropolitan Transportation Plan to guide the region's transportation investments in the central Puget Sound region.

The data prepared for the EIS Land Use discipline came from automated classification of Landsat 7 imagery based on spectral signatures, supplemented by manual interpretation, field verification, and validation. The resulting database was overlain onto a standard map-template that has major roads, lakes, places, and other features. The land use categories used were:

- Forest,
- Grass and shrubs,
- Residential,
- Commercial,
- Water,
- Farmland,
- Transportation,
- Industrial, and
- Urban built-up, mixed, or unclassified.

The data mainly reflects land-cover information from the remotely sensed imagery, and identifies areas of grass and shrub land cover within what could be classified as residential areas. The land use and land cover map is shown in Figure 7.1. This and other RS/GIS maps are in pdf format, which allows users to scroll and zoom to focus on specific locations in detail.

7.2.6 Recreation

Under section 4(f) of the Transportation Act of 1966 (49 USC 303), a project-specific environmental document generally includes a review of the impacts of a transportation project on public parks, recreation areas, or wildlife refuges. The data prepared for the study was intended to provide information about the affected recreation environment, suitable for a corridor-level environmental review. The map was generated using a combination of data prepared for I-405 corridor DEIS and remotely sensed imagery. Data on parks that were developed for the DEIS were overlain onto a standard map-template that has major roads, lakes, places, and other features. Hillshading was added to the affected recreation map using 10m U.S. Geological Survey digital elevation model (DEM) data. Parks are local- or state-administrative designations. In the remotely sensed imagery, parks appear as "grass and shrubs" and "forest" land-cover. Some urban built-up or mixed land cover is identified within park boundaries as well. Golf courses were identified through automated classification of the imagery based on spectral signatures, followed by interpretation of aerial photography.

A map was also prepared for Alternative 3 projects (both highway and transit) overlain onto the recreational resources map. A third map showed the boundaries of the parks overlain onto the land cover map to indicate the make-up of the land cover within parks (generally "grass and shrubs", and "forest"), as well as their proximity to other land

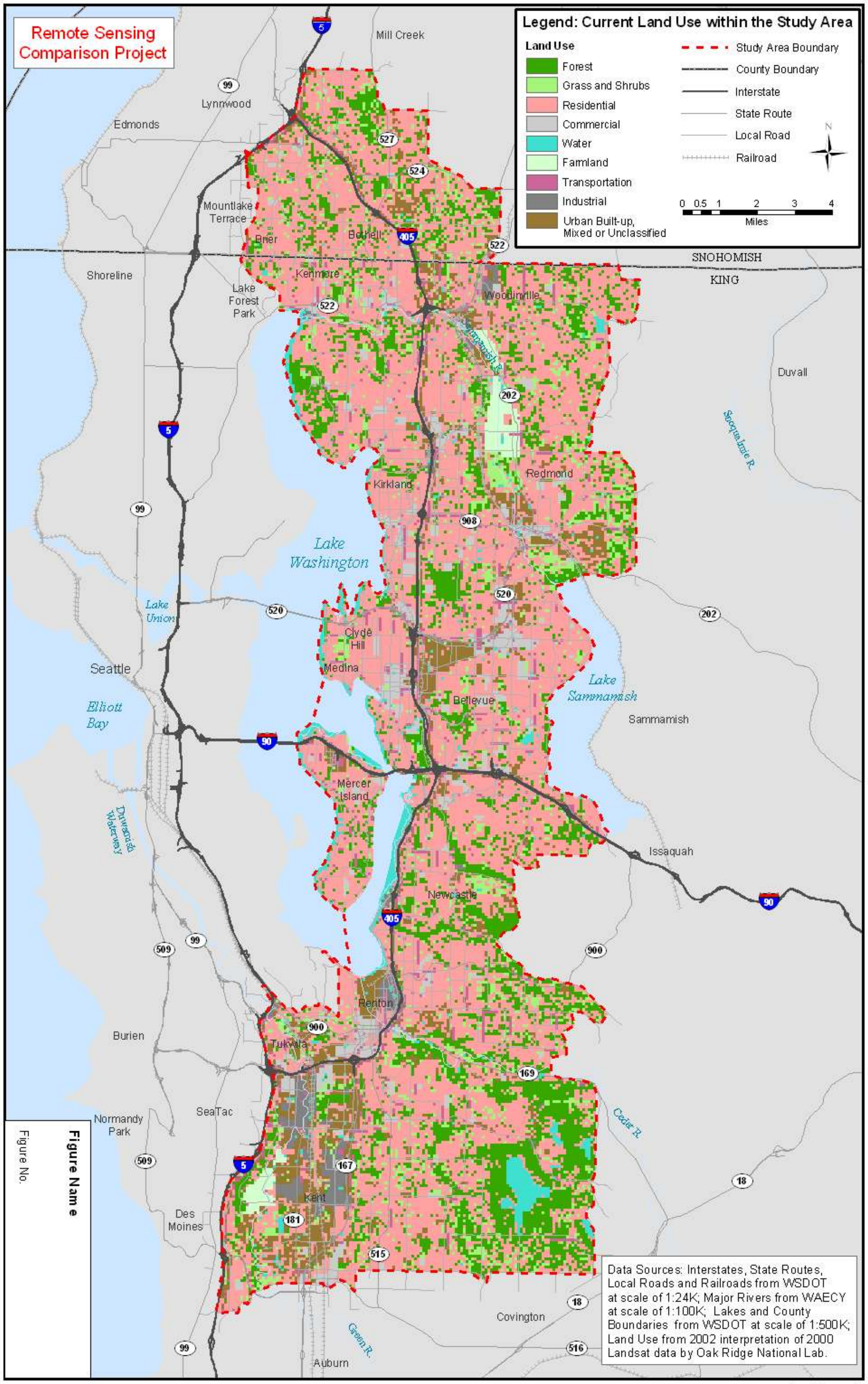


Figure 7.1. Land Use and Land Cover Map.

cover. A fourth map showed drainage basin boundaries and the affected recreation environment.

7.2.7 Shorelines

Public access to shorelines and shoreline protection, enhancement, and preservation are important goals of local shoreline master plans. Jurisdictional shorelines are designated as such by Washington's Shoreline Management Act, and are incorporated into local Shoreline Master Programs. Shoreline impact evaluation was conducted for the I-405 study on the basis of whether proposed project improvements would be within 200 feet of a designated shoreline.

The data prepared for the Shorelines map combined the GIS data used in the DEIS and the LULC categories that were identified by automated classification of Landsat 7 imagery. The resulting data were overlain onto a standard map-template that has major roads, lakes, places, and other features, as well as Alternative 3 projects (both highway and transit). This map shows the proximity of land uses to jurisdictional shorelines.

7.2.8 Surface Water Resources

Surface water is a valuable resource to a community. It supports aquatic species and ecosystems, provides water recreation, and is a source of drinking water. The quantity and the quality of these resources are both important. Water quality is affected by construction, operation and maintenance of roadways; and by commercial, residential and industrial activities. The quantity of impervious surfaces within an individual drainage basin affects runoff and thus water quality.

Maps prepared for Surface Water Resources assessment include: (1) stormwater management facilities; (2) data layers prepared for other disciplines, e.g., the Surface Water Stream Basins map that was prepared for the Fish and Aquatic Habitat category and the100-Year Flood Plains map that was prepared for the Floodplains category; (3) Soils Potentially Suitable for Stormwater Recharge (showing land cover); and (4) Water Quality Impaired Lakes and Streams (with adjacent land use). The data were compiled from existing GIS data, the LULC layer from image analysis, and a standard map template that has major roads, lakes, places, and other features.

7.2.9 Transportation

Transportation performance is obviously a key metric for gauging the desirability of alternative transportation investments. Each Alternative in the I-405 EIS was evaluated based on three primary criteria: mobility improvement, congestion reduction, and safety improvement – when compared to the No-Action Alternative. Many different measures were used to assess the performance of each Alternative with respect to each of these criteria.

The data prepared for the Transportation map included the same three screenlines (vehicle throughput measurement points) used in the I-405 Corridor Program EIS. In addition, urban centers and centers of employment were identified. Urban centers were assumed to correspond to commercial land uses. Centers of employment were identified based on commercial, urban, built-up, and mixed land uses. The land use information used came directly from the image analysis results.

7.2.10 Upland Vegetation/Habitat/Wildlife

Large transportation projects such as those being considered under the I-405 corridor study could directly impact vegetation, habitat, and wildlife. To make preliminary assessments of these potential impacts, information about the geographic distribution of habitats is critical in identifying locations that could be the sites of such impacts. Data prepared for this purpose include:

- Existing Habitat within the study area, identified with Landsat 7 imagery, overlaid on forest land and water, and
- Wetland data derived from a combination of the GIS database used in the DEIS and LULC information extracted from remotely sensed imagery.

An additional data layer was prepared for Alternative 3 projects (both highway and transit), and was overlain onto the priority-habitats map.

7.2.11 Wetlands

Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water (U.S. Fish and Wildlife Service). Section 404 of the Clean Water Act defines wetlands on the basis of their having a prevalence of hydrophytic vegetation, undrained hydric soils, and certain hydrological indications.

Wetland data for this section were generated based on the GIS database used in the DEIS, in combination with LULC information extracted from remotely sensed imagery. Wetlands that have been identified by a jurisdiction in the study area as Category I (or similar rating of the highest value) are classified as high priority wetlands that have high biological and hydrological value. Any wetland that contains or that is in close proximity to threatened or endangered species is also classified as a high priority wetland. Those not rated as high priority are classified as lower priority.

The resulting data on wetlands were overlain with land cover data onto a standard map-template that has major roads, lakes, places, and other features. A second map was prepared that included Alternative 3 projects (both highway and transit).

7.3 Generating Statistics

To provide information for assessment of impacted LULC along the corridor, a set of statistical tables can be prepared to summarize the LULC acreage within drainage basins and within the study area. These tables are prepared based on the LULC maps generated from image analysis, and the drainage basin boundary GIS layer used in the DEIS. In the demonstration study, IMAGINE's Spatial Modeler was utilized to overlay the LULC maps onto the drainage basin boundaries to generate the statistics for various LULC characteristics.

The LULC image analysis data files are in raster data format. The drainage basin boundaries are prepared in an ArcView shapefile, which is in a vector format. IMAGINE's

Spatial Modeler allows a direct overlay of the vector and raster layers; this simplifies the overlay process considerably, because no vector- to-raster conversion is necessary. The Spatial Modeler is built along a graphical interface, called Model Maker. With the Model Maker, a user can create spatial models graphically (see the IMAGINE Tour Guide for details). For the demonstration study, the Model Maker was used to create overlay models. These models take the LULC maps and the drainage basin boundaries as the input to create raster layers that are coded with both the LULC classes and the drainage basin information for each pixel. The content table of the resulting layer then provides the counts of the number of pixels for a complete list of pixel values, each count corresponding to an LULC category within a drainage basin.

The following example demonstrates a procedure to generate a summary of LULC acreage for LULC layer I categories within drainage basins in the study area.

Step 1: A graphic model can be constructed using the IMAGINE Model Maker as shown in Figure 7.2. In this model, the n1_basinnpl_BASINNPL and n2_lc represent the drainage basin polygon map in Arc coverage and LULC layer I. The n4_basin_lc is the output layer. The circle labeled with “n1_basinnpl_BASINNPL * 10 + n2_lc” is the function used to overlay the LULC layer and the drainage basin layer.

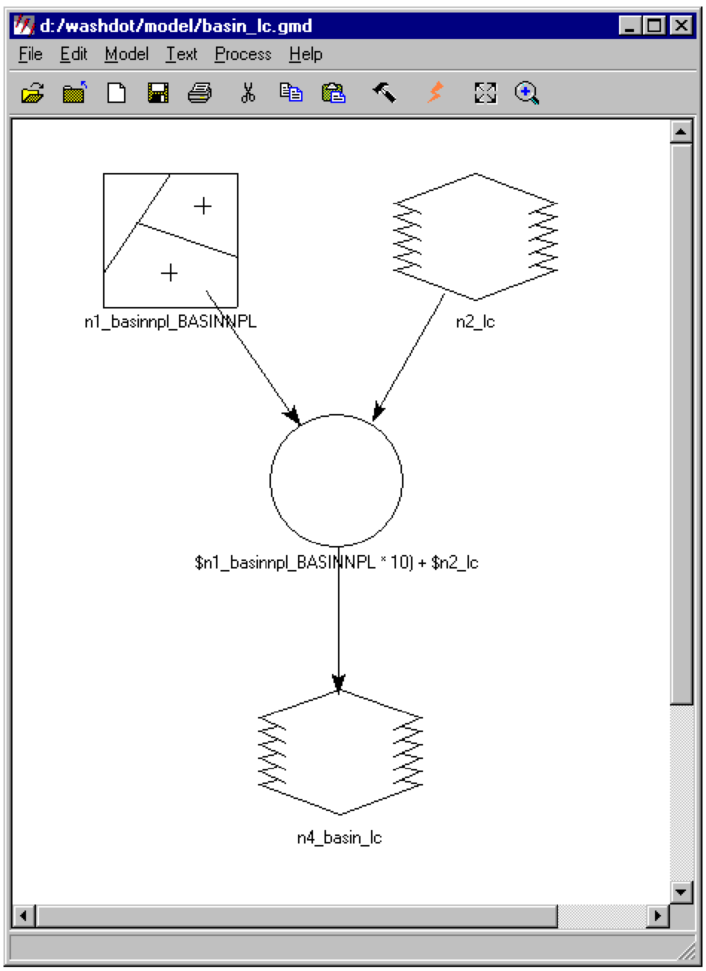


Figure 7.2. Graphic Model Constructed to Perform an Overlay between the Drainage Basin Polygon Map and the LULC Layer I.

Step 2: The overlay function is defined in the function definition window, as shown in Figure 7.3. The cell value on the n2_lc layer is coded between 1 to 6 for six different types of LULC. The basins are uniquely identified with a numerical ID. If we multiply the numerical number used to represent a basin by 10 and then add the product to the LULC cell value, we will create a number that can unambiguously identify the basin to which the cell belongs and the LULC type of the cell.

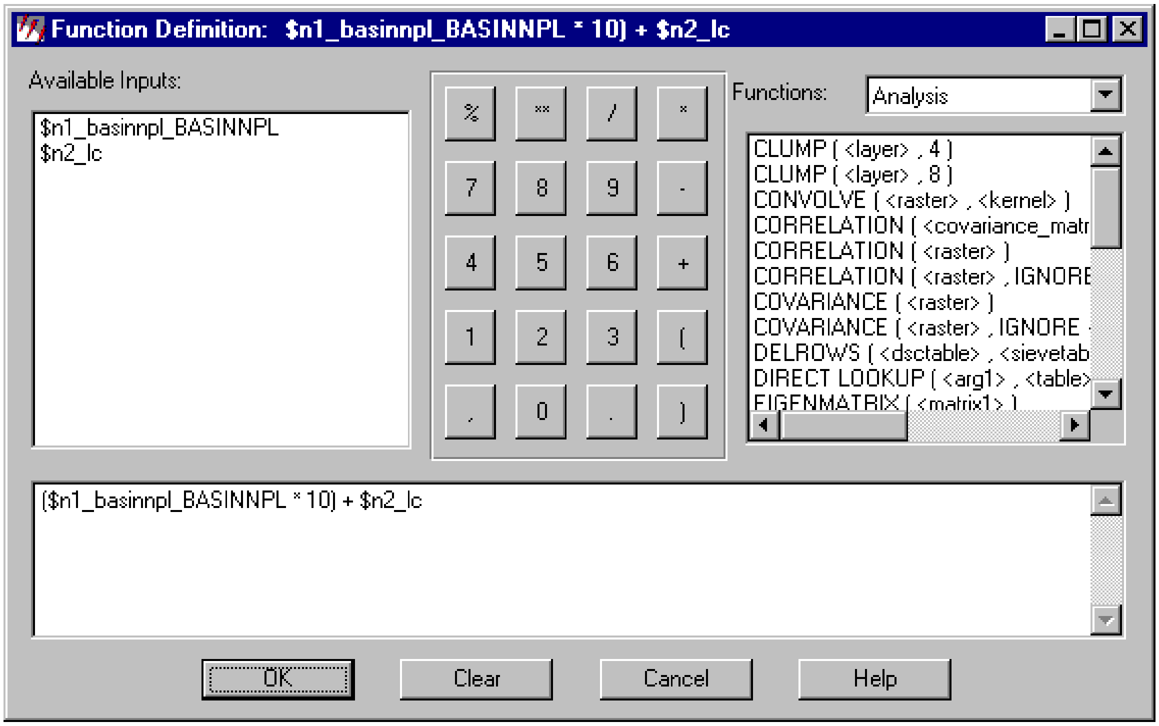
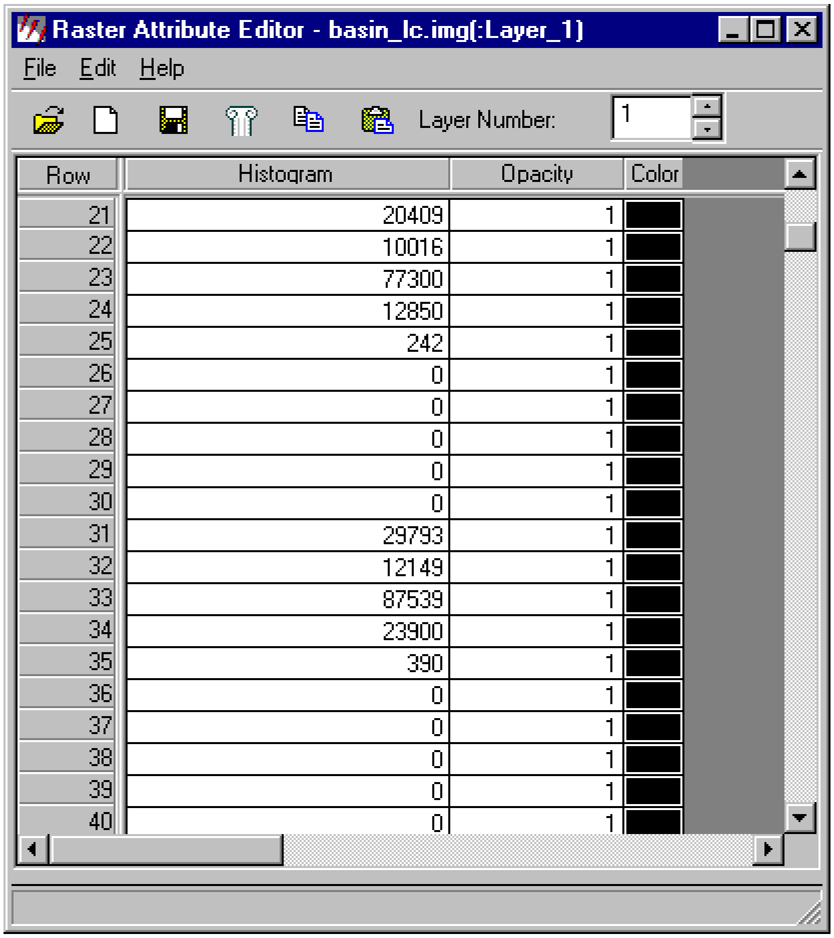


Figure 7.3. Specification of the Overlay Function.

Step 3: Running the model defined in Step 1 and Step 2 will create a new raster layer, n4_basin_lc, in which the value in each pixel can be used to identify the basin to which the cell belongs and the LULC type of the cell.

Step 4: The n4_basin_lc layer then can be added to the viewer's window in IMAGINE. Raster Attribute Editor can be selected from the "Raster" menu. In the Raster Attribute Editor, the number of cells for each cell value is counted and listed in the attribute table. As shown in Figure 7.4, each row in the attribute table gives the count of cell numbers for the cell value corresponding to the row number. For example, row 21 represents the cell value 21, which can be interpreted for basin #2 and LULC category #1, given the function defined in Step 2. Based on the table, there are 20,409 cells for LULC category #1 in basin #2. The table can be saved into an ASCII file and can be formatted into a summary table, as shown in Table 7.1 (the size of cell is 15 x 15 meters, which must be converted into acreage in the final calculation).



Row	Histogram	Opacity	Color
21	20409	1	
22	10016	1	
23	77300	1	
24	12850	1	
25	242	1	
26	0	1	
27	0	1	
28	0	1	
29	0	1	
30	0	1	
31	29793	1	
32	12149	1	
33	87539	1	
34	23900	1	
35	390	1	
36	0	1	
37	0	1	
38	0	1	
39	0	1	
40	0	1	

Figure 7.4. The Raster Attribute Table.

7.4 Use of RS/GIS Products in the NEPA Process in Transportation Planning

RS/GIS products can provide useful data and information for the NEPA process in transportation planning. Laymon et al. (2001) have previously discussed several environmental-discipline categories as candidates for using remote sensing:

- Land use – combining published socioeconomic data with land cover classifications, the latter from commercial high resolution multi-spectral data;
- Farmland – identifying farmland in relation to adjacent land and proposed transportation project alternatives;
- Coastal zone and barrier – using remote sensing to update maps of the highly dynamic, rapidly changing coastal environment;

Table 7.1 Summary of LULC Acreage of LULC Layer I Within Drainage Basins

Acres of Land Use Type by Drainage Basin

Basin Name	WRIA	Watershed Name	Forest	Grass & Shrubs	Residential	Commercial	Water	Farmland	Transportation	Industrial	Urban Built-up, Mixed or Unclassified
Big Bear Creek	8	Cedar-Sammamish	1954.3	895.3	5539.8	145.6	87.5	0.0	163.5	0.0	285.0
Coal Creek (Cedar)	8	Cedar-Sammamish	618.5	197.9	1803.8	26.8	1.1	0.0	91.6	21.7	134.0
East Lake Sammamish	8	Cedar-Sammamish	8.5	0.6	33.6	0.0	0.3	0.0	4.1	0.0	7.3
East Lake Washington	8	Cedar-Sammamish	1948.1	520.7	8195.2	1073.9	281.8	0.0	726.8	263.4	466.2
Evans Creek	8	Cedar-Sammamish	460.7	239.2	599.9	0.0	3.7	0.0	26.4	0.0	253.0
Forbes Creek	8	Cedar-Sammamish	228.2	85.2	1614.1	107.6	13.0	0.0	99.7	84.5	74.4
Issaquah Creek	8	Cedar-Sammamish	99.3	35.0	71.3	0.0	0.0	0.0	4.9	0.0	0.8
Juanita Creek	8	Cedar-Sammamish	229.8	129.3	3044.3	279.9	23.8	0.0	178.2	1.8	313.6
Kelsey Creek	8	Cedar-Sammamish	661.5	280.2	2813.5	746.2	53.2	0.0	226.4	0.0	487.3
Lake Washington	8	Cedar-Sammamish	5.7	0.4	70.6	0.3	3901.3	0.0	3.3	1.7	12.5
Little Bear Creek	8	Cedar-Sammamish	624.4	243.5	1596.4	31.2	10.9	0.0	95.1	186.6	280.5
Lower Cedar River	8	Cedar-Sammamish	4579.6	909.5	6349.1	236.0	252.0	0.0	293.3	122.3	850.9
Lyon Creek	8	Cedar-Sammamish	90.7	27.5	516.1	5.8	9.5	0.0	9.0	0.0	8.8
May Creek	8	Cedar-Sammamish	1974.5	531.8	2954.7	38.0	17.7	0.0	145.9	34.8	207.4
Mercer Island	8	Cedar-Sammamish	572.2	112.6	2650.7	205.9	34.5	0.0	224.7	0.0	180.1
Mercer Slough	8	Cedar-Sammamish	599.1	148.6	2644.3	575.9	53.8	0.0	420.8	0.0	734.3
North Creek	8	Cedar-Sammamish	1643.5	670.4	5126.9	42.0	21.5	0.0	186.8	0.0	853.8
North Lake Washington	8	Cedar-Sammamish	53.1	42.6	838.3	41.9	5.1	0.0	31.5	17.6	3.1
Sammamish River	8	Cedar-Sammamish	2279.7	1459.0	8773.4	820.6	179.4	1079.0	588.5	70.8	1337.3
Swamp Creek	8	Cedar-Sammamish	1126.6	555.2	4477.8	150.6	13.4	0.0	105.7	0.0	286.8
West Lake Sammamish	8	Cedar-Sammamish	911.6	230.2	5326.7	173.5	97.9	0.0	326.0	0.0	278.0
West Lake Washington	8	Cedar-Sammamish	27.0	61.7	390.5	69.9	0.3	0.0	48.9	0.0	73.2
Black River	9	Duwamish-Green	1352.9	860.5	6030.2	962.5	209.4	10.0	575.4	968.9	3424.3
Des Moines Creek	9	Duwamish-Green	2.8	0.7	25.6	0.0	0.1	0.0	9.0	0.0	8.8
Duwamish River	9	Duwamish-Green	56.8	93.4	374.1	0.0	24.6	0.0	69.5	5.8	144.2
Jenkins Creek	9	Duwamish-Green	563.6	143.9	511.1	26.0	46.5	0.0	23.1	0.0	11.1
Lake	9	Duwamish-Green	11.0	0.0	12.3	0.0	663.8	0.0	0.0	0.0	7.6
Lower Green River	9	Duwamish-Green	602.4	233.9	1029.4	194.0	77.9	417.8	227.2	485.5	553.9
Lower Puget Sound	9	Duwamish-Green	9.0	1.9	85.0	1.3	0.0	0.0	18.7	0.0	37.9
Soos Creek	9	Duwamish-Green	2608.4	855.1	3719.9	61.8	39.3	0.0	146.9	0.0	151.2

- Floodplain – using LIDAR and IFSAR (Interferometric Synthetic Aperture Radar) technologies to collect topographic information to delineate floodplains;
- Wetlands – acquiring imagery (preferably early in the growing season before canopy closure due to leaf emergence) using multi-spectral imagery to distinguish water from adjacent terrain and wetland vegetation in combination with soil and elevation data;
- Water body and wildlife – identifying the location and extent of water body modifications;
- Threatened or endangered species – using multi-spectral remote sensing to identify biomes or assemblages of vegetation species, potential habitats, and their location and potential fragmentation;
- Historic and archaeological preservation – searching for and analyzing Native American ceremonial mounds and canals;
- Relocation impacts – combining imagery with socioeconomic data to identify residences and businesses;
- Water quality – using remote sensing to detect changes in water temperature, productivity, turbidity, and aquatic vegetation; and
- Air quality – remote sensing of particulate aerosols in the atmosphere.

Xiong et al. (2004) report on a case study of the usefulness of RS/GIS products within the context of a corridor-level DEIS. According to the survey respondents, the usefulness of these products varies depending on the environmental discipline.

Environmental justice: The information provided by RS/GIS products is comparable to that provided by conventional analysis and maps. The primary source of data is the population Census rather than remotely sensed imagery. The latter could be used to provide information about nearby land uses, compared to the pattern of minority population in an urban area. The labeling on the maps should make clear that remote sensing is *not* being used to identify minority people, but rather to provide the supplementary layer of land use data.

Farmland: Remote sensing and other data could be used to identify farmland. If farmland has already been identified and classified as being subject to protection, then this information should be used as the primary source of data on farmlands. Remote sensing would be more useful in situations in which farms have not been identified and classified yet, or in which changes in land use have taken place since the last time the data were compiled. In general, remote sensing technologies do not identify legally or administratively defined areas, such as designated protected farmland. They need to be verified in the field.

Fish and aquatic habitat: Again, the usefulness of remote sensing technologies depends on how much information is already available. RS/GIS can provide cost-effective estimates of “land cover” and “land use” acreage, such as water bodies. These estimates could also be used to estimate impervious surface area in different parts of a river basin. If these statistics have already been compiled, then RS/GIS methods could be used to verify previous estimates. RS/GIS products could also be used to estimate water quality and its impacts on fish and aquatic habitat by combining estimates of impervious-surface area, traffic volumes, and the locations of impervious surfaces relative to streams and lakes. Care should be taken to avoid having too much information on any one map.

Floodplains: Delineation of floodplains, such as the 100-year floodplain, usually relies on information other than remotely sensed imagery. However, LIDAR and IFSAR can be used to provide DEMs, which could be used with hydrologic data to define floodplains. Information provided by remotely sensed data can be useful in viewing the floodplain in relation to LULC areas in close proximity.

Land use: The respondents in the case study (Xiong et al. 2004) regarded the RS/GIS maps and statistics as improving identification of most major land uses in each drainage basin: “This added information is helpful in portraying the overall extent and location of land uses potentially sensitive to project alternative actions.” Another respondent commented that the comparison of land use and land cover information "gives a better depiction of the landscape context." The DEIS contractor team noted that maps based on remotely sensed imagery could be manually augmented, for example adding a category for government land use. The respondents pointed out that the RS/GIS maps had more detail and they thought that they would have improved the DEIS study.

Recreational resources: If recreational resources have an administrative or regulatory designation, such as a Section 4(f) resource, then remotely sensed imagery should not be used alone. Identification of such resources requires field investigation, which could be used to validate and revise classifications developed from remotely sensed data. These data can also provide useful information about land uses and their proximity to recreational resources. Remotely sensed data could also be used to identify natural environments, which although not officially designated as 4(f) resources, could be worth bearing in mind in planning for the transportation project.

Shorelines: The additional layer of land use information in an RS/GIS map is useful in portraying the overall extent of natural condition shorelines within the study area.

Surface water resources: Stream and basin information are usually available, prior to any remote sensing analysis. However, RS/GIS products can provide land cover patterns that would be useful for DEIS analysis. One person commented, “RS/GIS products help to clearly identify potential contaminant receptors such as wetlands, areas of stressed vegetation associated to surface water runoff or other factors, the presence of suspected contaminated soils in areas of proposed construction, etc.” Another survey respondent commented that, " ... the products helped answer the 'next question.' Where, specifically are sediment loads or other water quality problems occurring ..."

Transportation: The usefulness of remote sensing depends on what information is already available. In the I-405 case study, respondents thought that the RS/GIS transportation maps were preferable to the conventional maps because the RS/GIS products would replace a “sketched” approximation with more accurate information. One respondent noted that the RS/GIS map would allow “more precise screenline analysis for traffic volumes, travel times, and person demand.” Although the benefit of these improvements would not likely change the conclusions of the analysis, it could improve the public’s confidence in it.

Upland vegetation, habitat, and wildlife: In viewing the RS/GIS products, one person thought that they would both complement and improve conventional maps because they provided more detail. The person also thought that it would be useful to have statistics on linear feet of habitat affected.

Wetlands: O'Hara (2001), for example, has demonstrated that remote sensing methods can accurately identify wetland areas. The methods he developed identified areas that matched known areas well, though not perfectly. High resolution RS/GIS can provide a realistic look at the resource. Even lower-resolution Landsat data, when used in conjunction with other GIS data, can provide maps that are "much better by showing far more complexity than (conventional) maps," which is "useful for comparing areas of impacts as well as potential mitigation areas (Xiong et al. 2004). The key difference of the RS/GIS maps in the I-405 case study was that they provided information about the spatial context of the wetlands relative to other land uses. One of the I-405 stakeholders commented that, "having the land cover background ... puts the wetlands in a better context for analysis."

7.5 Future Applications and Research

This document provides guidance on the use of commercial software and remotely sensed data to produce products that help the environmental analysis process in the planning of transportation projects. Its purpose is to contribute to: (a) developing procedures for applying remote sensing products to data compilation and analysis at the local and state level, (b) enhancing and streamlining the collection and display of data on environmental attributes to meet National Environmental Policy Act (NEPA) requirements; and (c) developing procedures for identifying attributes of land use and land cover that are important to environmental analysis for transportation, through the integration of remote sensing information and geographic information systems (GIS).

Even though the scope of the demonstration project was limited, it proved the value of using commercial remote sensing and GIS software with remote sensing and spatially referenced data. Nevertheless, perceptual gaps exist between remote sensing/GIS professionals and professionals who are currently responsible for the preparation of environmental impact statements (EIS), which can be major roadblocks for the practical use of the technology. Three major areas are suggested for application and research to narrow these gaps:

Data requirements analysis and modeling: Data requirements for the EIS process under NEPA are extensive and specific. To meet these data requirements, a basic understanding of these data requirements is the first essential step. Currently, most of these data requirements are implicitly embodied in existing EIS documents. Extensive knowledge and experience are needed to translate these requirements into a format that can be understood by remote sensing/GIS professionals. Also specific EIS processes may differ case by case. A specification of data requirements that defines features, attributes, quality, and formats required for the EIS process would be highly desirable for future applications. Enhanced collaboration and mutual understanding between remote sensing/GIS professionals and EIS professionals may be established through this suggested process of specifying data requirements.

Use and comparison of different technologies: Remote sensing technologies are very diverse. A combination or selective use of some of these technologies could meet different application requirements. To determine the potential usefulness of different technologies, comparative testing of different technologies will be necessary for specific EIS purposes. High-resolution imagery such as 1-meter or better resolution panchromatic images along with multi-spectral or hyper-spectral bands is particularly promising. High spatial resolution images can effectively identify and measure structural differences among features such as transportation and utility infrastructures. Multi-spectral images can effectively establish spectral identities for features such as vegetation, water, and impervious surfaces. The use of LIDAR combined with high-resolution multi-spectral or hyper-spectral imagery and existing GIS data, as studied by O'Hara for wetlands, is an important direction to pursue as the needs for EIS are diverse and in some cases specific and highly detailed.

Cost-Benefit Analysis: Uncertainty about the costs and benefits of using remote sensing technologies is a key factor that limits their use. Reliable estimates of the costs and value of RS/GIS products can reduce this uncertainty. However, very few such studies have been done. The case study reported in Xiong et al. (2004) reveals that the benefits of RS/GIS products depend on the remotely sensed imagery available, land use/land cover classification methods, the regional context (e.g., urban versus rural), the data that have previously been compiled, hardware and software used, and even the abilities of the analysts themselves. It is a challenge to quantify the different types of benefits. They depend on the particular users of the information and the ways in which they value it. "Faster" and "cheaper" are relatively straightforward to estimate in terms of comparing alternative technologies, but "better" (and in what way and by how much) is more difficult to assess. "Quality" depends on subjective preferences. Such preferences are important to understand because they will ultimately determine the value and usefulness of these products. It is because of these difficulties in assessing their benefits, value, and quality that much more study on them is needed.

REFERENCES

Anderson, J.R., Hardy, E.E., Roach, J.T., and R.E. Witmer (1976), *A Land Use and Land Cover Classification System for Use with Remote Sensor Data*, Washington, DC: U.S. Government Printing Office.

Chavez, Jr., P.S., Sides, C.S., and J. A. Anderson (1991), "Merge Multiresolution and Multispectral Data: Landsat TM and SPOT Panchromatic," *Photogrammetric Engineering & Remote Sensing*, Vol. 57, No. 3, pp. 295-303.

CH2M HILL (2000) "Remote Sensing Technologies," chapter 4 in *Technologies to Improve Consideration of Environmental Concerns in Transportation Decisions*, NCHRP 25-22, Washington, DC: National Academy of Sciences.

Cowen, D.J. and J. R. Jensen (1998), "Extraction and Modeling of Urban Attributes Using Remote Sensing Technology," *People and Pixels: Linking Remote Sensing and Social Science*, Washington, DC: National Academy Press, pp. 164-188.

King, R.L. and C.G. O'Hara (2002), "A Synthesis of Remote Sensing Applications for Environmental Assessment," paper in the proceedings of the Pecora 15/Land Satellite Information IV, Integrated Remote Sensing at the Global, Regional and Local Scale Symposium, 10-15 November 2002, Denver, Colorado, http://www.isprs.org/commission1/proceedings/paper/00095.pdf

Jensen, J. R. (2000*), Remote Sensing of the Environment: An Earth Resource Perspective*, Upper Saddle River, New Jersey: Prentice Hall.

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

Leica Geosystems (2003*) ERDAS IMAGINE Field Guide for IMAGINE v8.6*, Atlanta, Georgia: Leica Geosystems.

Leica Geosystems (2003*) ERDAS IMAGINE Tour Guide for IMAGINE v8.6*, Atlanta, Georgia: Leica Geosystems.

National Aeronautical and Space Administration (NASA) (2000), "Landsat-7 Level-0 and Level-1 Data Sets Document," http://landsat.gsfc.nasa.gov/main/PDF/L7_L0L1_usgs.pdf

National Aeronautical and Space Administration (NASA) (2002), "Introduction: Technical and Historical Perspectives of Remote Sensing," Section 1 of *Remote Sensing Tutorial*, Web site hosted by Earth Observing Systems Program Office, NASA, http://rst.gsfc.nasa.gov/Intro/Part2_1.html

National Aeronautical and Space Administration (NASA) (2003), "Landsat 7," http://landsat.gsfc.nasa.gov/

National Consortia on Remote Sensing in Transportation (2001), *Remote Sensing and Spatial Information Technologies in Transportation, Synthesis Report 2001*. Washington, DC: U.S. Department of Transportation, and National Aeronautical and Space Administration.

O'Hara, C.G. (2001), "Remote Sensing and Geospatial Applications for Wetland Mapping and Assessment," Technology Guide: NCRSTE_TG003, http://www.ncrste.mssstate.edu/publications/ncrste_tg003.pdf

O'Hara, C.G., King, R.L., Cartwright, J., and J. King (2002), "Remote Sensing and Geospatial Technologies Application for Developing Options to Relocate CSX Railroad from Mississippi Gulf Coast Townships," *Proceedings of International Mechanical Engineering Congress and Exposition 2002*, November 17-22, 2002, New Orleans, Louisiana, TTSRP-32912.

Washington State Department of Transportation (WSDOT) (2003a), "I-405 Congestion Relief and Bus Rapid Transit Projects," http://www.wsdot.wa.gov/projects/I-405/

Washington State Department of Transportation (WSDOT) (2003b), "I-405 Project Final Environmental Impact Statement," http://www.wsdot.wa.gov/projects/I-405/feis.htm

Welch, R., and W. Ehlers (1987), "Merging Multiresolution SPOT HRV and Landsat TM Data," Photogrammetric *Engineering & Remote Sensing*, Vol. 53, No. 3, pp. 301-303.

Xiong, D., Lee, R., Saulsbury, J., Lanzer, E., and Perez (2004), *Remote Sensing Applications for Environmental Analysis in Transportation Planning: Application to the Washington State I-405 Corridor*, report prepared for the Environmental Affairs Office, Washington State Department of Transportation, Oak Ridge, TN: Oak Ridge National Laboratory.