Weighting Landsat Digital Data According to Land Cover Emissivity for Surface Temperature Mapping

Thomas Polanski
Western Kentucky University

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WEIGHTING LANDSAT DIGITAL DATA ACCORDING TO
LAND COVER EMISSIVITY FOR SURFACE TEMPERATURE MAPPING

A Thesis
Presented to
The Faculty of the Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Thomas Norwood Polanski
April, 1995
ACKNOWLEDGMENTS

First and foremost, I would like to thank my parents, Mr. and Mrs. Joseph T. Polanski, for their everlasting graciousness and without whom my graduate studies would not have been possible. Thanks also go to my wife, Mrs. Nancy A. Polanski, whose kindness and understanding have made the past two years a wonderful experience.

Finally, I would like to thank the faculty and staff in the Department of Geography and Geology at Western Kentucky University for their dedication to the student body and to the field of geography as a whole.
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Regional urban planning and natural resource management problems require efficient and accurate data concerning land use/land cover and temperature gradients for informed decision making. Remotely-sensed data provide a method for acquiring such information in a dependable and efficient manner. Regular data acquisition and a synoptic view make the Landsat Thematic Mapper (TM) an excellent resource for entities needing land cover and surface temperature information. Landsat 5 TM digital data (1985) are used to classify land cover in the vicinity of New Orleans, the study area encompassing approximately 185 square kilometers. The maximum likelihood, minimum distance to means, and the parallelepiped classifiers produce land cover classified images with highly significant differences and the maximum likelihood rule outperforms the other methods. The maximum likelihood land cover classification is used as ancillary
data for the surface temperature conversions and meets the standard of 85% thematic accuracy set by the United States Geological Survey (USGS).

The Landsat 5 TM thermal channel (band 6) provides exceptional spatial resolution and is an excellent tool for mapping surface temperatures. Variable emissivities of land cover types and atmospheric conditions often need to be incorporated into surface temperature calculations from TM data. The thermal channel digital counts are weighted according to land cover emissivity and converted into kinetic temperatures (atmospheric conditions are deemed negligible for the TM data). Statistics generated and qualitative analyses demonstrate a strong relationship between surface temperatures and land cover types, allowing for the prediction of the surface temperature change that a change in land use/land cover will incur. Applications of the research include modeling and monitoring of land use/land cover in a region, urban planning, urban heat island mapping, and natural resource management/conservation.
CHAPTER I

INTRODUCTION

Problem Statement

Urbanization greatly affects the natural surface temperature gradients of a region. The construction of buildings and streets on areas that formerly consisted of agricultural crops or natural vegetation and the release of particulates and gaseous pollutants all affect temperature gradients and the hydrological balance of an area (Hsu, 1984). While urbanization often brings about an increase in the quality of life on a short-term basis for a population, the long-term effects are often drastic and must be considered if a sustainable quality of life is to be maintained. By far, the most influential climatic changes are incurred where modern cities are developed with little or no concern for the local micro-climate, or even on a larger, macro-climate scale (Terjung and Louie, 1973). Such development includes "street canyons" where multiple reflection processes occur, roof areas, and construction materials, all of which contribute to the temperature gradient of the urban canopy as a whole (Arnfield, 1982).
The thermal characteristics of these urban materials act in harmony to produce what is known as the urban heat island, where urban daytime temperature increases of 5 to 10 degrees Celsius have been recorded using the Heat Capacity Mapping Mission satellite, or HCMM (Henry et al., 1989).

Remote sensors, specifically satellite-based sensors, are effective tools for urban heat island mapping and other large scale thermal mapping projects. These sources of data provide an excellent representation of temperature patterns with a synoptic view, regular coverage, and the opportunity to easily integrate computer analysis. When mapping surface temperatures using remote sensors, ancillary data concerning land cover emissivity and atmospheric conditions are often required for acceptable accuracy. Again, satellite-derived data outperform other methods for obtaining such ancillary information, as these characteristics may be derived from the same data set that is used for the surface temperature conversions.

Traditionally, thermal data for an area have been obtained with ground-based methods or by the expensive use of photogrammetry and aerial surveys. In addition to data acquisition, the cost of data analysis is relatively expensive when done by traditional, non-digital methods of map and statistical analysis (Hilborn, 1983). However, using satellite-based sensors, which provide data in digital format, analyses may be carried out with an image processing system that maximizes project efficiency and flexibility.
Project Proposal

Using a PC-based image processing system, IDRISI, this research examines a methodology for weighting surface temperature conversions according to land cover type emissivity. The research was carried out in essentially four phases.

The first phase consists of image and ancillary data acquisition. Landsat 5 TM images, acquired on March 24, 1985, are obtained for the study area and include all seven spectral bands recorded by the sensor. Ancillary data include USGS 7.5-minute topographic quadrangles, USGS land use and land cover maps, National High Altitude Photography (NHAP) program color infrared aerial photographs, National Oceanic and Atmospheric Administration (NOAA) data, National Wetlands Inventory maps, and other local maps.

The second phase consists of image display and automated land cover classification. Automated land cover classifications of the study area are performed using the standard classification rules included with IDRISI and the maximum likelihood rule is used for the final land cover classification as it statistically outperforms the other methods. The land cover classified images are tested for thematic accuracy using a photointerpreted base map.

The next phase consists of surface temperature conversions using the Landsat 5 TM thermal channel data. Surface temperatures are derived from the thermal channel data using knowledge of the internal calibration of the
Landsat TM sensor and land cover emissivities within the study area.

The final phase consists of examining the relationship between surface temperatures and land cover types using quantitative and qualitative indicators. The results are evaluated and the applicability of the research is discussed.

Objective of the Study

The goals of the researcher are separated into two objectives. The first objective is to test for pairwise significant differences between land cover classified images produced from Landsat 5 TM multispectral data using standard decision rules and to examine the land cover classification that is created with the optimal method. The second objective is to produce a surface temperature image of the study area and examine its relationship with the land cover of New Orleans. Given the results, it is determined if the methodology carried out in this research demonstrates effective techniques for automated land cover classification and mapping surface temperatures in a region.

Hypotheses

The maximum likelihood, minimum distance to means, and the parallelepiped land cover classified images of the study area are tested for pairwise significant differences between error matrices. The generation of error matrices and the
Kappa coefficient of agreement for each matrix allows for hypothesis testing. A discrete multivariate analysis technique is used to test for significant differences between error matrices derived from the three automated classifications (Bishop et al., 1975). The superior land cover classified image, created using the maximum likelihood classifier, is tested at the 85% thematic accuracy level set by the USGS using the Kappa coefficient of agreement and is used for the surface temperature conversions (Anderson et al., 1976). The conditional Kappa coefficients of agreement are calculated by land cover category for the maximum likelihood classification and these are examined. The conditional Kappa coefficients of agreement are also calculated and presented for the other classification rules.

The surface temperatures are statistically analyzed and examined for their relationship with land cover types. Examining the relationship between surface temperatures and land cover types is carried out using an analysis of variance (ANOVA) and a Duncan's Multiple Range (DMR) test for significant differences between mean temperatures by land cover type.
Summary

The effect of land cover on surface temperature is of great importance to land planners and resource managers. Remote sensing techniques, which allow for automated land cover image classifications and surface temperature conversions, are vital tools. The capability of satellite-based sensors to provide information in the form of digital data also allows for the efficient integration of computer-driven image processing systems.

The researcher uses an image processing system for testing the utility of Landsat 5 TM digital data in automated land cover classification routines. IDRISI classifies land cover at the test site with three different classification rules according to spectral patterns contained in the TM digital data. The land cover classified images are statistically analyzed with a land cover base map created using NHAP color infrared aerial photographs of the study area and used for pairwise tests of significant differences between error matrices.

The superior land cover classified image is then integrated as ancillary data for surface temperature mapping at the study area using the Landsat TM thermal channel (band 6). Atmospheric effects are not prevalent in the Landsat TM data and are deemed negligible in this study. After the thermal channel digital counts are converted into surface temperatures, tests are performed to determine the nature of
the relationship between land cover types and surface temperatures.

Many questions are addressed during this research. What is the error resulting from the techniques used in this research which may be expected in a similar attempt at land cover classification using Landsat TM digital data? What are the visual similarities and dissimilarities of land cover maps created using the automated techniques versus photointerpretation methods? Can the automated techniques used here detect the relationships between surface temperatures and land cover type? In what area of the test site are the highest/lowest temperatures found? What is the change in surface temperature one can predict if a given change of land cover occurred? Questions inherently addressed in any research project are addressed as well, such as the best methods for future research on this problem, the limitations of this type of research, and the possibilities for further research.

A review of the remote sensors and techniques used for this research is provided in Chapter Two. Chapter Three provides an extensive summary of the research previously carried out in the field of land cover and surface temperature mapping, and the applications of these techniques. Chapter Four includes discussion on the location of the study area, followed by Chapters Five and Six describing the methodology of the research and the
results obtained. Finally, in Chapter Seven the utility and limitations of the research are summarized.
CHAPTER II

REMOTE SENSORS FOR LAND COVER AND
SURFACE TEMPERATURE MAPPING

Introduction

In their study of the earth and its phenomenon, geographers have used field observations of natural and "human" systems since ancient times. Through maps and descriptions, geographers examine and spatially analyze the features present on the earth--such as hydrologic systems, climate systems, ecosystems, and landforms. Essentially, geographers study the earth and its inhabitants and, in doing so, rely on their own "tools of the trade."

Data that geographers utilize for research must fit certain criteria. Of course, the data must be accurate (or capable of being transformed to an accurate state), up-to-date, inexpensive, and also capable of being stored and retrieved for later use. Remotely-sensed data, which originate with aerial photography, provide an excellent source for geographic information that meets all of the requirements given above. Aerial photography and satellite-based remote sensors provide the broad "systems"
view which is required for the geographer's research.

Campbell, in Introduction to Remote Sensing, states that remote sensors provide map-like perspectives favoring convenient definition and delineation of land systems and portray the complex spatial patterns of topography, vegetation, and drainage in an integrated form that is compatible with the assumptions, methods, and objectives of a geographer's approach to analysis. Not only do remote sensors satisfy the characteristics above, they also provide data in real-time or near real-time for analysis. There are errors inherent with remotely-sensed data, but these errors are usually correctable through preprocessing routines. Such errors include relief displacement (aerial photography), skew (images generated by electro-optical scanners), and RADAR layover or foreshortening. However, the benefits reaped through the applications of remotely-sensed data far outweigh the inherent problems.

Aerial Photography

Aerial photography, acquired with specialized cameras, supports applications in photogrammetry (quantitative measuring of phenomena in aerial photographs), land use and land cover mapping, archaeology, agriculture, soils mapping, forest inventories, geologic mapping, engineering surveys, and much more. Specialized films support applications in topographic mapping (panchromatic films), hydrologic mapping (black and white infrared films), water quality assessment
(color films), and land use/land cover mapping (color infrared films). Aerial photography, originating from hot air balloons in the middle 1800's, uses films that detect reflected electromagnetic energy in the near-ultraviolet, visible, and near-infrared regions (Fig. 1).

![Figure 1. General Spectral Reflectance Curves for Typical Urban/Suburban Features (Simonett, 1983).](image)

Color infrared film, or false-color film, was used for camouflage detection during World War II. Three emulsion layers on the film are sensitive to green, red, and near-infrared radiation. In the spring or summer, healthy deciduous trees appear magenta or red and healthy conifers appear red to bluish-purple. Dead or dying vegetation appears as bright green. Healthy vegetation whose leaves
have turned red or yellow in the autumn appear yellow and white, respectively. Water bodies appear dark blue or black and urban areas appear gray to blue. As a result of the properties of color infrared films, vegetation (rendered as red) and camouflaged military equipment (rendered as gray to blue) are easily differentiated in a scene and allow for the delineation of enemy positions. Color infrared film is useful for resource management planning (e.g., land use and land cover mapping), as well as environmental mapping (disease or infestation detection).

Color infrared and black and white film coverages have been acquired systematically since 1978 for the conterminous United States by NASA with RB-57 and U-2 high altitude aircraft for medium and high altitude scales under the National High Altitude Photography program. The photography, available from the EROS Data Center in Sioux Falls, South Dakota, is available at scales of 1:80,000 and 1:58,000. In 1986, the specifications of this program were changed to include only color infrared photography at a scale of 1:40,000 and the program was renamed the National Aerial Photography Program (NAPP). Though aerial photography demonstrates geometric errors, these errors are well understood and may be compensated for through the use of photogrammetry. The corrected photography can then be used in a wide variety of applications, from large-scale topographic mapping to small-scale resource assessments.
Electro-Optical Scanners

Unlike photographic sensors which record radiation directly on to film, electro-optical sensors convert reflected or emitted radiation from a scene into proportional electrical signals. The electrical signals are then converted into digital counts, or digital numbers, for subsequent image display and processing. These electrical signals are often transmitted over radio links which allows for the use of robotic spacecraft as platforms for remote sensors. Not only does the use of satellite-based platforms allow for the integration of digital data (and the continuous generation of data) but also for the capabilities of real-time image display and efficient image processing and storage. The wavelengths capable of being detected and recorded by electro-optical sensors are effectively increased to include the ultraviolet, visible, reflected infrared, and thermal infrared. The capability of electro-optical sensors to record energy in many regions of the electromagnetic spectrum as digital data provides a wide variety of tools and data sources with which to carry out complex image analysis.

Across-track scanners consist of multispectral scanners and thermal infrared scanners. Unlike photographic cameras, across-track scanners do not record an entire ground scene at once. Across-track scanners record data with a rotating or oscillating mirror and acquire narrow ground strips of data at right angles to the platform's flight path.
Multispectral scanners are capable of recording data in all of the electromagnetic regions supported by electro-optical sensors, including both reflected and emitted radiation. Thus, a ground scene may be examined by an analyst in any wavelength recorded by the sensor or a combination of those collected. Thermal infrared scanners operate in a smaller range of the electromagnetic spectrum and record data in the far infrared, atmospheric windows of 3 \( \mu \text{m} \) to 5 \( \mu \text{m} \) and 8 \( \mu \text{m} \) to 14 \( \mu \text{m} \). However, because of significant ozone absorption in the atmosphere at wavelengths of 3 \( \mu \text{m} \) to 5 \( \mu \text{m} \), thermal infrared detectors generally operate in the 8 \( \mu \text{m} \) to 14 \( \mu \text{m} \) region. Image distortions in across-track scanners include scale compression and one-dimensional relief displacement. Scale compression is correctable and is the enlargement of total ground area covered at the end of a ground swath relative to ground area covered directly beneath the sensor. One-dimensional relief displacement is not correctable and occurs at right angles from the flight line of the sensor platform. The Landsat sensors (except for the Return Beam Vidicon Cameras on Landsats 1, 2, and 3) are across-track scanners and are discussed further in the next section.

**The Landsat System**

In 1972, with the launch of Landsat 1, orbital images became available in digital format and in a repetitive and systematic manner with which to study the earth's features. The sensors on board the Landsat satellites are excellent
tools that complement a wide variety of applications. Not only are the applications of Landsat data numerous but also there is a significant savings in cost associated with the use of orbital data compared to airborne remote sensors and ground based methods (Fig. 2 and 3).

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<tr>
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<tr>
<td>8 Years</td>
<td>18 Months</td>
<td>6 Months</td>
</tr>
<tr>
<td>40 Categories</td>
<td>5 Categories</td>
<td>16 Categories</td>
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<tr>
<td>3 Counties</td>
<td>3 Counties</td>
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<td>1786 Sq. Miles</td>
<td>3792 Sq. Miles</td>
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<td>Map Preparation</td>
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<td>Miscellaneous Supplies</td>
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<td>TOTAL</td>
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<td>Per Square Mile</td>
<td>$ 59.46</td>
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Figure 2. Cost Comparisons for Land Cover Inventories (NCSL, 1979).
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<td>Detecting Hazard Zone</td>
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<td>Rangeland Management</td>
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Figure 3. Applications of Landsat Data (NCSL, 1979).
Landsat 1 carried the Multispectral Scanner (MSS) and three Return Beam Vidicon (RBV) cameras. The RBV cameras obtained data in three spectral regions including the following:

- **Band 1** = 0.475 – 0.575 μm (green);
- **Band 2** = 0.58 – 0.68 μm (red); and,
- **Band 3** = 0.69 – 0.83 μm (near-infrared).

The three RBV cameras obtained data for the same ground scene and at a resolution of (80 m)$^2$. The ground scene dimensions for the RBV cameras are 99 kilometers by 185 kilometers in size.

The MSS is an across-track scanner with a ground swath of 185 kilometers in the east-west dimension and 170 kilometers wide in the north-south dimension (the same ground swath dimensions covered by the TM). The MSS obtained data over four bands at a spatial resolution of (76 m)$^2$ and included the following:

- **Band 4** = 0.5 – 0.6 μm (green);
- **Band 5** = 0.6 – 0.7 μm (red);
- **Band 6** = 0.7 – 0.8 μm (near-infrared); and,
- **Band 7** = 0.8 – 1.1 μm (near-infrared).

Landsat 1 was operational from June 23, 1972 to June 1, 1978. However, the RBV cameras experienced electrical failures and only acquired data for less than a month after launch. Landsat 2 was operational from January 22, 1975 to September 30, 1983. The sensor configurations on board
Landsat 2 were identical to that of Landsat 1, and similar problems were experienced with the RBV cameras.

Landsat 3 was operational from March 5, 1978 to September 30, 1983. The RBV cameras on board Landsat 3 consisted of a two camera system instead of the earlier three camera system. The RBV cameras sensed reflected radiation from 0.505 µm to 0.750 µm and had an increased spatial resolution of (40 m)².

Again, the RBV cameras experienced technical problems and were not used as originally hoped. The Landsat 3 MSS was similar to those on board Landsats 1 and 2 but included an extra band that recorded data in the far infrared region from 10.4 µm to 12.6 µm (band 8). The spatial resolution of this thermal band was decreased to (234 m)² because this band only included two detectors.

Landsat 4 was operational from July 16, 1982 to March 1983. Landsat 4 has been operating at reduced power since March 1993 due to technical problems and has thus made Landsat 5 the primary data collector for the Landsat satellite program. Landsat 5 has been in operation since March 1, 1984 and is still collecting data. Landsats 4 and 5 have identical sensor configurations and include the Thematic Mapper sensor. The RBV cameras are not carried by Landsats 4 or 5. The MSS is carried by both Landsats 4 and 5 and is identical in configuration to the MSS carried on board Landsats 1 and 2.
The Thematic Mapper on board Landsats 4 and 5 acquires data at a spatial resolution of (30 m)\(^2\) and includes the following narrow spectral bands:

- **Band 1** = 0.45–0.52 \(\mu\)m (blue-green);
- **Band 2** = 0.52–0.60 \(\mu\)m (green);
- **Band 3** = 0.63–0.69 \(\mu\)m (red);
- **Band 4** = 0.76–0.90 \(\mu\)m (near-infrared);
- **Band 5** = 1.55–1.75 \(\mu\)m (mid-infrared);
- **Band 6** = 10.4–12.5 \(\mu\)m (far infrared); and,
- **Band 7** = 2.08–2.35 \(\mu\)m (mid-infrared).

Band 6 acquires data at a decreased spatial resolution of (120 m)\(^2\). Because of their narrow spectral resolutions, the seven bands of the TM each exhibit unique properties that enable them to specialize in different applications. Band 1 is useful for water penetration studies such as bathymetry and coastal research, and for differentiating between soil, rock, and cultural features. Band 2 is useful for water turbidity, sediment, and pollution plume studies. Band 3 is useful for differentiating soils, vegetation, snow cover, and urban/rural areas.

Band 4 is useful for delineating vegetation types and water boundaries (dry versus moist soils, wetlands, swamps, flooded areas, etc.). Band 5 is also useful for delineating vegetation types, as well as soil moisture content studies and snow monitoring. Band 6 is useful for thermal mapping applications. Finally, Band 7 is useful for lithologic
mapping, mineral deposit detection, and moisture variation studies such as wetlands mapping.

All of the Landsat satellites are in sun-synchronous orbits. A sun-synchronous orbit essentially places the satellite so that the plane of the satellite's orbit maintains a constant angular relationship with the incoming solar radiation. Satellites in a sun-synchronous orbit are placed at desired orbital altitudes where the satellite obtains complete coverage of the earth's surface over a given period of time. Satellites in geostationary orbit are placed at an orbital altitude of approximately 22,300 miles and cover a single large region of the earth's surface. Weather monitoring satellites, such as the GOES satellite series operated under the direction of NOAA, are often placed in geostationary orbit.

The orbital parameters of Landsats 1, 2, and 3 differ significantly from that of Landsats 4 and 5. Landsats 1, 2, and 3 orbited the earth at an altitude of 570 miles (912 kilometers). This altitude allowed the satellites to orbit the earth every 103 minutes, or 14 times a day. Because of the rotation of the earth on its axis from west to east, the satellites produced repeated coverage of a ground scene every 18 days.

Landsats 4 and 5 orbit the earth at an altitude of 423 miles (705 kilometers). The lower altitude helps increase the spatial resolution of the TM sensor. Landsats 4 and 5 orbit the earth 14 times per day and obtain repeated
coverage of a ground scene every 16 days. As a result of the sun-synchronous orbit of the Landsat satellites, the satellites pass over any given point on the earth at the same local sun time which minimizes variations in solar illumination.

Data transmitted from Landsats 4 and 5 are relayed through two tracking and data relay satellites (TDRS). The TDRS satellites are in geostationary orbits and allow for the transmission of data directly to a ground station near White Sands, New Mexico. Unlike the earlier Landsats, this data relay system allows for the minimization of data storage within the actual satellites themselves. Landsats 1, 2, and 3 utilized troublesome tape recorders for the storage of data until the satellites were in direct access to any one of the 16 ground stations designed to receive the satellite transmissions.

Landsat 6, launched on September 28, 1994 and subsequently lost, was to have an increased resolution of (15 m)$^2$ in the panchromatic bands. However, the Land Remote Sensing Policy Act of 1992 assures Landsat data continuity by outlining objectives for the Landsat 7 project. Other highlights of this act mandate the maintenance of an international network of Landsat ground receiving stations, acknowledgment of the importance of the private sector in all aspects of Landsat data management, and the simplification of licensing procedures for private remote sensing systems.
As of May 15, 1994, the Presidential Decision Directive/National Science and Technology Council-3 provides a new Landsat remote sensing policy. Essentially, the new strategy ensures the continuance of the Landsat 7 program, quality control and continuance of Landsats 4 and 5, and the assurance of no "data gaps." The directive also prompted NASA to announce the scheduled launch of Landsat 7 in 1998 with its sensor specifications equivalent to Landsat 6. The research into and the applications of the remote sensors discussed in this chapter are addressed in the following chapter.
CHAPTER III

BACKGROUND AND LITERATURE REVIEW

Land Cover Mapping

Land use is defined as the activity or activities supported on a tract of land, whereas land cover is defined as the natural and artificial features covering the earth's surface (Avery and Berlin, 1992). Land use and land cover information is required for all scales of urban planning problems and allows development to occur in an environmentally safe manner. The National Environmental Policy Act, Section 208 of the Federal Water Pollution Control Act, the Coastal Zone Management Act, and the Forest and Rangeland Renewable Resource Protection Act all require land use/land cover information to be synthesized into planning decisions and thus protect the quality of the environment. Beginning in 1974, the USGS commenced systematic land use/land cover mapping of the United States at a scale of 1:250,000 and the more recent 1:100,000 scale. NASA high-altitude U-2 and RB-57 aircraft provided platforms for data acquisition and 30% of the nation was completed by 1977. Magnetic tapes in polygon format store the data, and
the database is referred to as the Geographic Information Retrieval and Analysis System (GIRAS). The Central Atlantic Regional Ecological Test Site (CARETS) was integral as a precursor to the GIRAS project. CARETS, carried out from 1972-1977, examined coastal processes, land use effects on air quality, and land use effects on climatic processes (i.e., the urban heat island effect).

Guidelines set by the USGS for the GIRAS project include an overall thematic accuracy of at least 85%, equivalent accuracy between land use/land cover categories, repeatable results, and a classification scheme that is extendable over large areas (Anderson et al., 1976). The classification scheme used by the USGS is one developed specifically for remotely-sensed data and includes the following Level I categories (Anderson et al., 1976):

**Urban or Built-up (100):** Majority of the land is covered by structures and streets. If criteria for several categories are present (Forest, Water, Wetlands, etc.), the Urban or Built-up category takes precedence. For example, a residential area may have sufficient tree cover to meet the Forest criteria, yet it would still be classified as Urban or Built-up.

**Agriculture (200):** Lands which are used for agricultural practices. This category is readily recognizable on remotely-sensed data using pattern-recognition of the rectangular, circular, or square shapes
of agricultural fields (also includes the tone, texture, and color of this type of land cover).

**Rangeland** (300): Natural grasses and shrubs, including non-woody plants such as weeds and flowers. Grazing animals are capable of being supported by rangelands.

**Forest Land** (400): Exhibit a crown density of 10% or greater and support trees capable of producing timber and other wood products. Land that has a crown density reduced below 10% may also be classified as Forest given there is no development for other uses on the land.

**Water** (500): Includes lakes, reservoirs, ponds, canals, and other features considered as predominantly water.

**Wetland** (600): Found mainly in proximity to water bodies and include marshes, swamps, tidal flats, and floodplains. Areas that do not support typical wetland vegetation and are only seasonally flooded are classified into another category.

**Barren Land** (700): Includes land that has less than one-third of the total area covered by vegetation and a relatively limited ability to support life. Soil, sand, and rocks are common indicators of barren land. Land that is barren as a result of a human activity is assigned to the class which includes that activity (e.g., dumps, agriculture, etc.).
Tundra (800): Regions beyond the limit of the boreal forest which are treeless. Land above the timberline in high mountain ranges is also classified as Tundra.

Perennial Snow or Ice (900): Lands that exhibit a constant accumulation of snow and ice throughout the year (i.e. snowfields or glaciers).

The Level I categories listed above are also broken down into more specific Level II categories and are defined by the USGS (Figure 4). The information contained in the GIRAS database consists of Level I and Level II categories. Land is classified into Level I and II categories on the basis of the largest percentage of any one class present (i.e., the category which covers the largest percentage of an area). Information for the GIRAS system is acquired such that the minimum mapping unit for urban, water, transitional, agricultural, and extractive areas is 10 acres and the remaining classes have a minimum mapping unit of 40 acres. Level III and Level IV categories are increasingly specific and are to be developed according to user needs and project objectives. Level I categories are readily interpretable from satellite data or high-altitude photography, whereas Level II, III, and IV categories require successively finer resolution available from high-altitude (40,000 feet or above), medium-altitude (10,000 to 40,000 feet), and low-altitude (below 10,000 feet) photography, respectively.
|   | Urban or Built-up Land       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 1 | Residential                 | 11| Residential.                         |
|   | Commercial and Services.    |   | 12| Commercial and Services.             |
|   | Industrial.                 |   | 13| Industrial.                          |
|   | Transportation, Communications, and Utilities. |   | 14| Transportation, Communications, and Utilities. |
|   | Industrial and Commercial Complexes. |   | 15| Industrial and Commercial Complexes. |
|   | Mixed Urban or Built-up Land. |   | 16| Mixed Urban or Built-up Land.         |
|   | Other 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| Nonforested 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 Gravel 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.                    |

Figure 4. Land Use and Land Cover Classification System for Use with Remote Sensor Data (Anderson et al., 1976).
The following films are useful for land use/land cover mapping in order of decreasing capability: color infrared, color, black and white, and black and white infrared.

GIRAS contains information on the following characteristics: land use/land cover, political units, hydrological units, census units, federal land boundaries, and state land boundaries. The GIRAS encoding method is similar to that of the topology stored by the Dual Independent Map Encoding (DIME) system used for census information. Applications of the information contained in the GIRAS database are enormous.

Agricultural problems are examined and solved using land use/land cover data. The Large Area Crop Inventory Experiment (LACIE) was carried out by NASA, NOAA, and the USDA from 1974 to 1977. LACIE provided crop yield estimates using Landsat MSS data for the Central U.S., Canada, and the Soviet Union. This project demonstrated the capabilities of remote sensors for providing worldwide wheat crop forecasts, a responsibility of the USDA and the United Nations Food and Agricultural Organization (FAO). Other remote sensing projects which integrate crop yield models are the Monitoring Agriculture by Remote Sensing (MARS) project in Europe and the sugar beet yield project in the United Kingdom (Harris, 1993). SPOT imagery is helping farmers in the pacific northwest locate areas of low production as a result of infestations, diseases, or poor farming techniques.
so that preventive measures can be taken to increase crop yields (Nelson, 1993).

Research using satellite-based sensors for urban applications is extensive as well. Using Landsat MSS imagery data, and 1980 aerial photographs of Kano, Nigeria, land cover maps were produced which consisted of four categories (Adetiba, 1980). The four classes consisted of built-up, mixed built-up, non-built-up, and tree covered lands. The maximum likelihood classifier was used to process the data and accuracy was deemed "acceptable." Mixed built-up and tree covered areas were often confused in the classification process, whereas non-built-up areas were rarely confused with other categories.

In a 15 kilometer by 25 kilometer study area in the Salt Lake Valley, the Landsat TM channel 6 was used as an ancillary data layer in a land cover classification routine to aid in the classification of pixels according to their thermal properties (Wheeler, 1985). Fourteen classes were assigned using two different approaches of unsupervised classification which resulted in a map with 90% accuracy.

In the Bangkok area, the Landsat TM was used to classify land use/land cover as the developing countries in tropical climates are those who stand to gain the most from this technology (Thomson, 1990). Developing countries can reap the full benefits of remote sensing technology because these areas are not yet fully developed, allowing for planning practices to integrate remotely sensed data.
Wavelengths from each major portion of the spectrum were used in the Bangkok classification, though TM bands 3, 4, and 5 were found to be most useful. The accuracy of the final map was 85% and detection of stressed vegetation, cover proportion, and height of ground cover was possible.

The registration of Landsat MSS data with RBV data was utilized to create a land use/land cover map of Cambridge, Maryland (Block, 1983). The data, registered with a Zoom transferscope, were classified into thirteen categories to study spectral and textural effects during classification. The data were classified using the minimum distance to means and angular distance classifiers with accuracy resulting below expectations at 60%. However, it was determined that natural classes are best defined in spectral terms (i.e., deep or shallow water, dry grassland, barren land), whereas urban classes are best defined by textural means (i.e., residential, industry, outlying commercial areas).

Land use/land cover information is also vital for detecting development occurring at the rural-urban fringe (Jensen and Toll, 1982; Martin, 1989). With high spatial resolution sensors--such as the Landsat TM, the Landsat MSS, and the SPOT High Resolution Visible (HRV) sensors--urban growth may be monitored and modeled. Satellite data are also used in planning decisions and site analysis for engineering projects such as defense systems, communications, and transportation networks. Where such development takes place in areas consisting of wetlands,
information is required concerning the spatial extent of the wetlands in order to minimize their destruction.

Executive Order 11990 of 1977 requires all federal agencies to minimize the destruction of wetlands and enhance their value (Koeln, 1992). Section 404 of the Clean Water Act, the "Swampbuster" requisite of the Food Security Act, and the Wetland Preserve Program also call for the preservation of the nation's wetlands. Once thought to be wasteland, wetlands carry significant value including improving water quality, flood control, groundwater replenishment, and providing habitats for fish and wildlife.

Ducks Unlimited, Inc., a group that protects the needs of North American waterfowl, uses Landsat TM data for monitoring wetlands in the prairie pothole region of Canada and the United States. The mid-infrared region gives planners a tool with which to search for wetlands and map their extent (Hough, 1992). In the Uplands area near Austin, Texas, a geographic information system integrated SPOT data with a development plan aimed at preserving the natural vegetation and wetlands, and identifying those areas susceptible to severe erosion (Hough, 1992). Wetland change detection research was carried out in Eastern Ontario with an overall accuracy of 90%, where the majority of the wetlands were converted into agricultural uses, primarily to pasture and forage crops because converted wetland soil is ideal for these agricultural activities (Bruce, 1988).
The use of satellite-based sensors is the most effective method with which to detect land cover over the entire globe or large regions. The digital data supplied by the sensors are relatively easy to manipulate and process for producing land cover maps. These land cover maps are produced to provide sequential coverage of an area or the entire globe where research into regional or global processes occurring over time may then be effectively carried out. The applications of land cover maps created from satellite-based sensors are numerous and provide users with the information necessary for improving resource planning/management and problem solving.

**GIS Support for Automated Land Cover Classification**

The use of geographic information systems is fast replacing manual interpretation methods of remotely-sensed data because land cover maps may be derived from digital data and produced efficiently using computer-based algorithms. The capabilities of a GIS include spatial analysis, prediction, ease in generating statistics, efficient storage and retrieval, and the relative ease of including ancillary data for analysis. Essentially, the interpretation of images consists of detection, identification (classification), and the measurement of scene features, as well as problem solving. These characteristics of interpretation are fundamental processes that geographic information systems are often effective at
carrying out. Artificial intelligence is, at times, capable of classifying land cover data with such methods as statistical pattern-recognition, scene-specific labeling, and symbolic reasoning.

Statistical pattern-recognition uses training sites to characterize data of interest with statistical methods. The interpreter develops training sites that indicate to the computer what certain spectral signatures in an image correspond to with respect to the designated land cover categories. The computer then classifies the entire image using defined classification rules and data concerning each land cover category's spectral signature. Such algorithms include the minimum distance to means, the maximum likelihood, and the parallelepiped classification formulas.

The parallelepiped classification scheme classifies data according to the ranges of values contained in the training data. This method is quick, but, where classes have spectral ranges that overlap, a pixel is classified according to the order that each range is analyzed (last signature checked receives priority). The minimum distance to means classification scheme uses the centroid of a signature pattern, often the mean value, to classify pixels. Pixels are assigned to the land cover class which contains the mean that is closest to the unassigned pixel value. The maximum likelihood classifier scheme incorporates the mean value of a land cover signature as well as the variability of the signatures for each group. Of the three
standard classification methods mentioned above, the parallelepiped rule generally performs the worst and may also leave a significant portion of a scene unclassified. The maximum likelihood classifier requires extensive calculations and takes longer than the other methods, but, it generally performs better than the other rules. However, if training sites are poorly defined, the minimum distance to means classifier may perform better than the maximum likelihood rule.

IDRISI, an image processing system developed by the Clark Labs for Cartographic Technology and Geographic Analysis at Clark University, has most or all of the capabilities of some larger systems for image processing and includes the supervised classification methods mentioned above. The classification routines mentioned above are all supervised techniques, where prior knowledge of a study area is required for the development of training sites, whereas unsupervised classification techniques do not. Unsupervised classification is essentially a classification of data by natural groups (such as spectral homogeneity), where identifying the land cover category for each spectral group is a secondary process. IDRISI's cluster routine performs unsupervised classification as well.

The classification methods above do not function where a knowledge of context is needed for determining land use/land cover. Syntactic pattern-recognition utilizes hierarchical "keys" for categorization of land cover data.
This method essentially recognizes shapes and patterns based on image components. Symbolic reasoning goes beyond the methods mentioned above by using deductive logic in data classification and accounting for relationships between objects for deriving information. The computer system not only analyzes the image but also recognizes the characteristics of features defined earlier in the classification process (e.g., edge and line detection). Spatial relationships are defined and "understood" by the computer program, parallel to association in manual photointerpretation. For example, the computer is capable of identifying sailboats on a lake and inferring that the lake is a recreational facility (Estes et al., 1986). This approach was used with multi-date Landsat imagery for the detection of crops and the modeling of crop signatures as they change over time (Badwhar and Henderson, 1981).

Landsat TM data were used in the forested Lake States area of northern Minnesota and Wisconsin to test a rule-based classification model for creating land cover maps. The rule-based classification model, named CLASMOD, is similar to the syntactic pattern-recognition approach mentioned earlier. However, the CLASMOD system not only uses hierarchical decision making but also direct classification using ancillary data layers. The ancillary data layers included soil data from USDA Soil Conservation Service 1:20,000 maps (constructed from manual photointerpretation of black and white panchromatic aerial
photos), USGS 7.5 minute topographic quadrangles, Wisconsin Department of Natural Resource vegetation maps, and NHAP color photographs. Landsat TM bands 3, 4, and 5, along with the ancillary data, were used to classify the area into Levels I and II of the USGS Classification System for Remotely Sensed Data. The researchers reported a land cover classification accuracy of 83% using CLASMOD, as compared to 69% classification accuracy using the traditional maximum likelihood classification method (Bolstad and Lillesand, 1992).

The use of satellite data in conjunction with other data layers is standard practice and allows for land cover classification using artificial systems to exceed acceptable levels of accuracy. Such ancillary data includes maps of discrete phenomenon (e.g., soils maps, vegetation maps, etc.) and continuous phenomenon such as elevation data. The incorporation of geographic information systems with satellite data has given way to extraordinary capabilities in the field of land cover mapping.

Thermal Mapping

A thermogram is an image representing the temperatures in a scene which have been recorded in the far-infrared region of the electromagnetic spectrum (Artis and Carnahan, 1982). The Landsat 5 TM band 6 records radiation from 10.4 μm to 12.5 μm in wavelength, a small portion of the far-infrared region which contains radiation from 7.0 μm to 15.0
µm in wavelength. Atmospheric windows, or wavelengths that are readily transmitted through the atmosphere, exist from 8.0 µm to 9.2 µm and from 10.2 µm to 12.4 µm and are suitable for thermal mapping. Other windows exist in the ultraviolet, visible, near-infrared and mid-infrared, and the microwave regions of the electromagnetic spectrum.

The resolution of the Landsat 5 TM band 6 is (120 m)². The Landsat 3 MSS carried a thermal infrared sensor, obtaining data from 10.4 µm to 12.6 µm in wavelength, with a resolution capability of (240 m)². The HCMM satellite thermal channel acquired data from 10.5 µm to 12.5 µm in wavelength, with a resolution of (600 m)². The Advanced Very High Resolution Radiometer (AVHRR) achieves spatial resolution of (1.1 km)² and collects data from 10.5 µm to 11.5 µm in wavelength, as well as from 3.55 µm to 3.93 µm (just beyond the photographic spectrum). The SPOT satellite also collects data from 0.79 µm to 0.89 µm (in the near-infrared region of the spectrum), but, at an increased resolution of (20 m)². Of the sensors mentioned above, only the Landsat 5 TM collects data in the thermal infrared region with acceptable spatial resolution capabilities for carrying out regional surface temperature mapping.

When measuring electromagnetic energy in the far-infrared region of the spectrum, consideration must be given to differences in the abilities of objects within a scene to absorb shortwave visible and near-infrared radiation and then to emit this energy as radiation at longer wavelengths
in the mid-infrared and far-infrared regions (Campbell, 1987). Emissivity of an object is defined as the ratio between the radiance emitted by an actual object to the radiance emitted by a blackbody at the same temperature (Fig. 5). A blackbody is defined as an object which absorbs and emits 100% of the radiation it receives. Though the blackbody is a theoretical object, it aids in the description and modeling of real objects. Thus, a blackbody has an emissivity of 1.0 and actual objects have emissivities of less than 1.0. A graybody has an emissivity of less than 1.0 and has a constant emissivity for all wavelengths of energy. A selective radiator exhibits varying emissivities depending on wavelength.

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature (°C)</th>
<th>Emissivity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polished copper</td>
<td>50-100</td>
<td>0.02</td>
</tr>
<tr>
<td>Polished brass</td>
<td>200</td>
<td>0.03</td>
</tr>
<tr>
<td>Polished silver</td>
<td>100</td>
<td>0.03</td>
</tr>
<tr>
<td>Steel alloy</td>
<td>500</td>
<td>0.35</td>
</tr>
<tr>
<td>Graphite</td>
<td>0-3,600</td>
<td>0.7-0.8</td>
</tr>
<tr>
<td>Lubricating oil (thick film on nickel base)</td>
<td>20</td>
<td>0.82</td>
</tr>
<tr>
<td>Snow</td>
<td>-10</td>
<td>0.85</td>
</tr>
<tr>
<td>Sand</td>
<td>20</td>
<td>0.90</td>
</tr>
<tr>
<td>Wood (planed oak)</td>
<td>20</td>
<td>0.90</td>
</tr>
<tr>
<td>Concrete</td>
<td>20</td>
<td>0.92</td>
</tr>
<tr>
<td>Dry soil</td>
<td>20</td>
<td>0.92</td>
</tr>
<tr>
<td>Brick (red common)</td>
<td>20</td>
<td>0.93</td>
</tr>
<tr>
<td>Glass (polished plate)</td>
<td>20</td>
<td>0.94</td>
</tr>
<tr>
<td>Wet soil (saturated)</td>
<td>20</td>
<td>0.95</td>
</tr>
<tr>
<td>Distilled water</td>
<td>20</td>
<td>0.96</td>
</tr>
<tr>
<td>Ice</td>
<td>-10</td>
<td>0.96</td>
</tr>
<tr>
<td>Carbon lamp black</td>
<td>20-400</td>
<td>0.96</td>
</tr>
<tr>
<td>Lacquer (matte black)</td>
<td>100</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Figure 5. Selected Materials and Emissivity Ratings (Avery and Berlin, 1992).
Satellite-based sensors detect radiant energy, or sometimes called "radiant temperatures," which must be converted into kinetic temperatures (or "true" temperatures) using knowledge of scene emissivities. Essentially, given two objects at the same temperature, but with different emissivities, the object with the higher emissivity will radiate more strongly.

The first step in deriving surface temperatures from Landsat TM digital counts is the conversion of the digital counts into radiant temperatures. Depending on the range of the thermal data being examined, a simple linear, quadratic, or cubic equation will produce accurate radiant temperatures from the data. The form of the equations, which are all derived in consideration of the internal calibration of the TM sensor, are as follows (Malaret et al., 1985):

**Linear Model.**

\[ T(K) = 219.972 + 0.526DC \]

**Quadratic Model.**

\[ T(K) = 209.831 + 0.834DC - 0.0013DC^2 \]

**Cubic Model.**

\[ T(K) = 206.127 + 1.0545DC^2 - 0.00371DC + (6.606 \times 10^{-6})DC^3 \]

where:

\[ T(K) = \text{radiant temperatures in degrees Kelvin;} \]
\[ DC = \text{Landsat data digital counts.} \]

There is no a linear relationship between digital counts and surface temperatures greater than 10°K, and the cubic equation performs well on data sets with a range of
temperatures from 16°C to 31°C (Bartolucci et al., 1973; Malaret et al., 1985).

After radiant temperatures are calculated, conversion of the radiant temperatures into kinetic temperatures is performed using the following formula, which weights the radiant temperatures according to scene emissivities (Artis and Carnahan, 1982):

\[
T = \frac{T_B}{1 + \left(\frac{\lambda T_B}{\alpha}\right) \ln E}
\]

where:

- \(T\) = kinetic temperature of observed object (K);
- \(T_B\) = radiant temperature;
- \(\lambda\) = wavelength of emitted radiance in meters;
- \(\alpha = \frac{hc}{k} = 1.438 \times 10^{-2} \text{mK}\);
- \(h = 6.26 \times 10^{-34} \text{ J-sec, (Planck's constant)}\);
- \(c = 2.998 \times 10^8 \text{ m/sec, (velocity of light)}\);
- \(k = 1.38 \times 10^{-23} \text{ J/K}\);
- \(\ln\) = natural logarithm; and
- \(E\) = surface emissivity.

Provided with quantified surface temperatures for an area, useful analyses may be undertaken. Thermal-mapping techniques are effective tools for studying the landscape within a wide variety of applications including regional planning and urban heat island mapping.
The Urban Heat Island Effect

Knowledge concerning quantified surface temperature patterns for a region and the distribution of urban microclimates is valuable for city design, engineering urban hydrologic systems, combating air pollutant problems, and insuring that inadvertent weather modifications by urbanization are avoided (Morgan et al., 1977). Pollution drifts are also examined using quantitative thermal data for an area. Such information is vital, because a vegetated zone encompassing a central business district may produce air currents capable of hindering the movement of industrial air pollution into the central part of a city (Anderson, 1977).

The urban heat island phenomenon, or increased temperatures within urbanized areas, is one that is well documented in a variety of climates and urban regions (Mcboyle, 1968). The urban heat island is a result of many factors including the thermal behavior of urban construction materials and the structure and composition of the urban canopy (Goward, 1981). The urban canopy consists of three broad land cover types: natural areas, pavements, and buildings. Natural areas such as lawns, parks, and other types of relatively unchanged land cover behave similarly to rural landscapes. Pavements or areas that consist of materials that are in direct contact with the underlying lithology behave similarly to exposed bedrock. Buildings are made of materials similar to pavements but, as a result
of their "hollow" structure and relatively thin composition, display a lower thermal inertia than pavement type cover (buildings heat and cool faster than pavement). As a result of the arrangement of these materials into street canyons and corner reflectors, radiation build-up increases in urbanized areas compared to surrounding rural or undeveloped areas. Also, factors that lead to radiation build-up differ as a function of season where temperature contrasts in the summer are largely caused by wetness variations and those in winter are largely caused by the absorption of incoming radiation by "street canyons" (Pease et al., 1976).

In a study carried out in Columbia, Maryland, then a newly developing city, urban temperature patterns evolved in direct relationship with the development of land into urban cover types (Landsberg and Maisel, 1972). Structural densities and urban land cover types directly relate with the urban heat island effect (Auer, 1978; Clarke and Peterson, 1972; Clough and Morley, 1977). A high correlation (0.90) between heating effects and urban densities within a 500 meter radius of a recording site was found to exist (Chandler, 1970). Indeed, a structure such as a suburban shopping center may increase the surrounding temperatures as much as 4°C (Norwine, 1973). Urban thermographs are also capable of delineating building position, building geometry, and the differentiation of three-floor closed building blocks versus those covered with separate two-floor buildings (Clough and Morley, 1977).
Areas where evaporation is limited, such as central business districts, industrial, or freeway areas, a large amount of electromagnetic radiation contributes to heating processes. However, in an area of predominantly green vegetation, the majority of the electromagnetic energy contributes to evaporation and transpiration processes. This phenomenon becomes increasingly important in areas where vegetation cannot survive outside a zone of homogenous land cover. Typical methods of preserving as much of the natural surroundings as possible during urbanization is not a viable alternative in humid tropical zones where native trees will not grow outside of the cool and shady rain forest (Nichol, 1993).

In Singapore, as a result of urbanization, exotic tree species are imported for the city's vegetated zones because the rain forest of the outer areas cannot survive within the city. The rain forests surrounding Singapore not only provide a large cold island, or heat sink, for the region but also act as water catchments for the surrounding reservoirs. In a thermal study of Singapore using the Landsat TM, a high correlation (0.78) was calculated between biomass and surface temperatures (Nichol, 1993). Hot spots on the island included commercial complexes, hospitals, bus terminals, sports facilities, and a large number of schools. These buildings are generally low-rise buildings and are typically surrounded by large areas of barren concrete such as parking lots and playgrounds. These findings support the
results obtained in a thermal study in Vancouver, where closely-spaced high rises were cooler than the areas consisting of light industrial activities that encompassed a larger area (Roth et al., 1989). However, open areas such as parks or playgrounds which are covered with a large percentage of vegetation will exist as cool spots in the city as a result of the transfer of heat to latent energy and high albedos (Pease et al., 1976).

Continuous green areas in an urban area are also effective for filtering and renewing air with a high content of pollutants. While removing dust particles from air masses and distributing the pollutants by generating air currents, continuous green areas may serve as recreation areas in an area of extensively urban land use/land cover. It is readily apparent that remote sensing provides the tools with which to carry out such surveys in an efficient and cost effective manner. The data supplied by remote sensors generally require preprocessing procedures, discussed below, for dependable and accurate analysis results.

**Preprocessing Landsat Digital Data**

When deriving surface temperatures or land cover information from Landsat TM digital data, internal calibration, atmospheric interference, land cover emissivities, and topographic distortions are often accounted for, insuring accurate results. During land cover
classification, topographic distortions may cause different land cover classes to be classified as the same land cover type and vice versa. Radiance reaching the scanner is not merely a measure of ground radiance but is also a product of atmospheric moisture and any radiance emitted by the atmosphere that corrupts the sensor readings. The scanner itself also depletes the incoming radiance because the scanner optics do not transmit 100% of the incoming radiance and the detectors are not 100% responsive to the corrupted radiance reaching them (Artis and Carnahan, 1982). If surface temperature calculations are performed with no regard for internal calibration of the sensor, calculations may exhibit a root mean square error in excess of 6°C (Schott and Volchok, 1985). If temperature estimates are made that incorporate an internal calibration procedure, whether using knowledge of the temperatures of internal calibration sources on the TM sensor or underflight data (ground-based measurements), accuracy of temperatures are reported within ±2°C. A root mean square error of ±1°C may be expected given the physical capabilities of the present generation of thermal radiometers (Maul, 1981).

Atmospheric effects on the radiant temperature readings such as atmospheric moisture and scattering are accounted for using various methods. Atmospheric moisture and scattering lead the radiant values in digital data to be effectively shifted towards a higher level of brightness than would occur with no such interference. Thus, where
such interference occurs, dark pixels are lost and forced to brighter values, corrupting the distribution of the data.

Such methods as the physical modeling of radiation as it is affected by the atmosphere (radiosonde data), the histogram minimum method (shifting digital counts so that the lowest values in a band are at zero), and regression techniques are sometimes capable of indicating and correcting for atmospheric influences (Campbell, 1987; Chavez, 1975; Conese et al., 1993; Switzer et al., 1981). However, the integration of radiosonde data with remotely-sensed images is often of limited value because such data generally applies to only a few points within a scene, and the number of these points that contain atmospheric data over different altitudes are even fewer.

Regardless of the correctional method used, unnecessary preprocessing of data for atmospheric conditions should be avoided when possible because all of the methods mentioned above result in an alteration of the radiometric qualities of data and may introduce a loss of spectral resolution (Leckie, 1982). After close examination of the frequency histograms for bands 1 and 3 (indicators of atmospheric reflectance due to scattering and moisture), as well as all other bands, atmospheric interference is deemed negligible within the test site for this study because dark values are consistently demonstrated at or near zero (Campbell, 1987; Chavez, 1975; Conese et al., 1993).
Estimates of surface temperatures are made within ±2-3°C for an area of 100 to 300 kilometers using atmospheric water vapor data as a function of height (Price, 1983). Atmospheric water vapor data are indirectly calculated from radiosonde data published by the NOAA-Environmental Data and Information Service. Using the HCMM satellite thermal channel for estimating surface temperatures in the eastern Gulf of Mexico, estimates of ground-based measurements were made within ±1°C (Vukovich, 1984). The HCMM digital counts are adjusted for calibration errors and atmospheric effects, then converted into surface temperatures using a linear equation. Cloud cover is also an atmospheric concern, producing thermograms that exhibit patched patterns, corresponding to the shading (cool) and non-shading (warm) effect of cloud cover.

High winds also affect the apparent temperature recorded by a thermal detector through the production of smears and streaks on an image (parallel lines of alternating bright and dark signatures and areas exposed to wind that appear cooler, respectively). Wind speeds should be less than 7.5 miles per hour, though adequate results may be obtained with wind speeds of up to 10 miles per hour (Colwell, 1983). Cloud cover at the test site is recorded at zero percent and wind speed is recorded at 8.1 m.p.h. at 9:00 a.m., and the same wind speed is recorded at 10:00 a.m. on March 24, 1985, the date and time of satellite overpass (LOSC, 1985).
As a result of the variation in slope angles for areas of high relief, dark pixels occur on slopes facing away from the sun and brighter pixels result from sun-facing slopes. As the test site in this study exhibits relatively little relief (from 5 feet below sea level to 12 feet above sea level), topographic influences are considered negligible. Traditional methods of correcting topographic distortions include statistical transformation methods such as band ratios, principal component, and HIPHERPHIRECAL Direction Cosine transformations. However, these methods result in a loss of accuracy and information content.

Recent uses of such methods include the Brigade/Battalion Battle Simulation database at the U.S. Army Corps of Engineers Waterways Experiment Station and the Mid-America Remote Sensing Center (Naugle and Lashlee, 1992). In the battle simulation database, Digital Elevation Models incorporate topographic conditions of the ground surface for correcting Landsat TM bands 3, 4, and 5 for land cover mapping. This model did not correct for atmospheric conditions, known to have a considerable effect on the application of topographic normalization procedures. The land cover maps generated for the mobility and combat model are located in a high relief area of Korea, which included part of the Demilitarized Zone. Both Level I and Level II Digital Elevation Models, with 90 meter and 12.5 meter contour resolution, respectively, were used to correct for topographic effects in the model.
More recently, atmospheric conditions have been taken into account in conjunction with topographic influences. A study carried out in 1993 using Florence, Italy, as a test site for the corrective methods found that by locating dark pixels on TM bands 1 and 3, atmospheric conditions can be estimated and the total real irradiance of a given pixel is determined (Conese et al., 1993). Thus, along with Digital Terrain Models at a contour resolution of 25 meters, the land cover classification in Florence, an area of high relief topography, was significantly improved by the corrective procedure. The data for the experiment, obtained from the Landsat 5 TM during different seasons, were classified into seven land cover types using the maximum likelihood classifier. Acquiring the images during different seasons allowed for the effect of varying sun angles to be emphasized. Also noted was the increase in topographic distortions in the images acquired during February, as well as a decrease in pine forest classifications in the corrected images (as pines are positively correlated with darker pixels).

Given the techniques that are fast becoming standard procedures for the preprocessing of satellite digital data, land cover and surface temperature information are becoming increasingly accurate and useful within a wide range of applications.
CHAPTER IV

STUDY AREA

Location

The study area, located in the southwestern region of Louisiana, provides a heterogeneous surface with which to classify urban and natural land cover at a scale of 1:84,000 (Fig. 6). The study area is located just northeast of downtown New Orleans, Louisiana, and occupies an area of approximately 184.77 square kilometers (71.34 square miles). New Orleans is located at North 30.00 degrees latitude and West 90.05 degrees longitude. The center point for the study area is located at North 30 degrees 15 seconds latitude and West 89 degrees 59 minutes longitude. The study area is bounded by the following four corners: North 30 degrees 4 minutes 47 seconds latitude by West 90 degrees 2 minutes 43 seconds longitude (upper left corner), North 30 degrees 3 minutes 28 seconds latitude by West 89 degrees 53 minutes 47 seconds longitude (upper right corner), North 29 degrees 57 minutes latitude by West 90 degrees 4 minutes 13 seconds longitude (lower left corner), and North 29 degrees 55 minutes 42 seconds latitude by West 89 degrees 55 minutes 17 seconds longitude (lower right corner).
Figure 6. The Study Area.
Landforms and Climate

New Orleans, by way of the Mississippi River, lies approximately 110 miles (180 Kilometers) from the Gulf of Mexico. One may enter the city from the Gulf of Mexico by way of Lake Borgne to Lake Pontchartrain (through the Chef Menteur Pass/Rigolets) and then down Bayou St. John to the heart of New Orleans. From the Bayou St. John (just outside of the study area), it is only about 2.1 miles to the Mississippi River. One may then follow the Mississippi River 110 miles back to the Gulf of Mexico.

The Inner Harbor Navigation canal, built in 1908, links the Mississippi River, the Intracoastal Waterway (which runs from Texas to Florida), Lake Pontchartrain, and the Mississippi River Gulf Outlet Canal. The Mississippi River Gulf Outlet Canal, built in 1958-1963, cuts 40 miles off of the water route from New Orleans to the Gulf of Mexico. The outlet canal that links Lake Pontchartrain to Chalmette is 76 miles long, 500 feet wide, 36 feet deep, and is crossed by the Paris Road Bridge. The France Road Terminal, located on the Inner Harbor Navigation Canal, includes a 1,000 feet by 2,000 feet turning basin and other facilities for bulk container cargo. The turning basin is located where the Inner Harbor Navigation Canal meets the Mississippi River Gulf Outlet Canal with the France Road Terminal just below that (both are located within the study area).

Lake Pontchartrain occupies a large portion of the northwest corner of the test site. Tides entering from the
Gulf of Mexico pass Lake Borgne through the Chef Menteur Pass/Rigolets, salinating the water of Lake Pontchartrain. The lake provides an excellent recreational resource and is surrounded by beaches, parks, several yacht harbors, colleges, and the New Orleans Lakefront Airport. The New Orleans Lakefront Airport is easily recognized on the TM imagery as a large piece of land, located just east of the Inner Harbor Navigation Canal, jutting into Lake Pontchartrain. The Pontchartrain Causeway (just outside of the test site) crosses Lake Pontchartrain, is 23.75 miles long, and is one of the longest twin-span bridges in the world. Other lakes located in the test site include Lake Michoud, Lake Marseille, other smaller bodies of water, and Rogers Lagoon.

The study area consists of little relief with the minimum elevation at about 5 feet below sea level and the maximum elevation at about 12 feet above sea level. As a result of its low-lying situation, a large network of levees, canals, and pumping stations is a major concern in the area. Levees on the Mississippi River are 25 feet high, whereas those along Lake Pontchartrain are 10 feet high. The study area is made up in large part by wetlands that are associated with such coastal, low-lying areas. The wetlands in the study area consist primarily of salt and fresh water marshes. The wetlands of this area provide habitats for the Baltimore Oriole and the Monarch Butterfly, as well as the
normal functions such as erosion/flood control, groundwater recharge, and water filtration (Handley and Mergist, 1994).

Other areas of interest within the study area include the Pontchartrain Park Golf Course (located near the airport just west of the Inner Harbor Navigation Canal), the University of New Orleans East campus (just west of the golf course), the U.S. Naval-Marine Corps and Army Reserve (at the junction of the Inner Harbor Navigation Canal and Lake Pontchartrain), a large spoil area (just below the Intracoastal Waterway and outlet canal intersection), and the sewage disposal area (east of the Inner Harbor Navigation Canal and below the outlet canal). The study area is also heavily populated with schools, parks, and cemeteries. Essentially, the heavily urbanized New Orleans East area occupies the western portion of the study area, whereas the eastern portion largely consists of wetlands, forested areas, rangeland, water bodies and encroaching residential areas.

Transportation networks cross the landscape and include Interstate 10 (runs diagonally across the study area), Interstate 90 (Chef Menteur highway; runs east-west across the center of the study area), Paris Road (runs north-south across eastern side of the study area), Claiborne Avenue and St. Claude Avenue (run east-west across the southern portion of the study area), extensive railroad networks, and the Inner Harbor Navigation Canal lock which is evident at the southern edge of the study area.
Other landmarks that are just outside of the study area are the New Orleans Superdome, the New Orleans Central Business District, Loyola and Tulane Universities, two other airports which serve the New Orleans area, the Huey P. Long and the Greater New Orleans Bridge (both cross the Mississippi River), Pontchartrain Amusement Park and Beach, the New Orleans Fairgrounds, City Park, and the French Quarter.

New Orleans is situated in a humid subtropical climate zone. The average rainfall in the area is 57 inches per year. New Orleans has a relatively mild climate, with an average temperature of 60°F (16°C) from October to March, and an average temperature of 77°F (25°C) from April to September. Freezing weather is uncommon and the temperature rises above 95°F (35°C) about 6 times a year.

History/Economy

New Orleans, the largest city in Louisiana and known as the "Birthplace of Jazz", now has a population of 1,238,816 (1990 census) and is part of a National Standard Metropolitan Statistical Area (SMSA). The New Orleans Port, which consists of 25 miles of public and private docks, is the United State's second largest port and can handle over 85 commercial cargo ships at any one time. The New Orleans Port is the chief port serving the southern hemisphere, and is also the lighter aboard ship (LASH) cargo and Seabee barge capital of the world. The port deals in a variety of
goods including grain, fabricated metals, textiles, petroleum products, tobacco, coal, chemicals, oils, and animal feed. Manufactured goods in New Orleans include food products, clothing, stone clay, glass articles, primary and fabricated metal items and transportation equipment. Petrochemical facilities located above New Orleans on the Mississippi and in the Gulf of Mexico are proving to be serious polluters. Oil-rig fires, oil slicks, and other chemical discharges threaten the drinking water and ecology of this Gulf region.

The NASA Michoud Assembly Facility, located along the Michoud Canal and within the study area, was established in 1961 and encompasses an area of 900 acres. The Michoud Canal is located at the eastern edge of the study area and has an upside-down hook shape. The facility, which produced Saturn rocket boosters for moon missions, is part of the George C. Marshall Space Flight Center. The facility consists of a manufacturing building (43 acres), vertical assembly building (21 stories), four position S-IC Final Stage test facility, hazardous material storage building, vertical component supply building, and the Michoud Steam Electric Generating Station. The Michoud Assembly Facility spurred residential growth in nearby areas such as New Orleans East (32,000 acres) and Lake Forest (5,000 acres). Saturn rocket boosters were carried from the Michoud Assembly Facility by the Promise barge to the Space Flight Center in Huntsville, Alabama, for static firing tests.
Again, the study area provides a heterogeneous surface with which to classify urban and natural land cover, and an excellent example of urban development encroaching upon the natural surroundings that consist mainly of wetlands.
CHAPTER V

METHODOLOGY

Thematic Mapper and Ancillary Data

The Landsat TM imagery for the study area, acquired March 24, 1985, is located on the Worldwide Reference System index path 22 and row 39.

Given an equatorial crossing by the satellite at 9:45 a.m., the time of overpass is estimated at 9:36 a.m. To estimate the time of overpass one must first determine the time it takes the satellite to make one revolution around the earth (pole to pole circumference divided by speed of the satellite: 24,860.54 miles/14,538 m.p.h. = 1.71 hours per revolution). Dividing 1.71 hours per revolution by 360° equals 0.00475 hours per degree for the given satellite speed. Multiplying 0.00475 hours per degree by 30 degrees latitude (latitudinal distance from New Orleans to the equator) equals 0.1425 hours per 30° latitude. Multiplying 0.1425 hours by 60 to obtain minutes equals 8.55 minutes for the satellite to travel 30° latitude. Subtracting 8.55 minutes from the equatorial crossing time of 9:45 a.m. (no time zones are crossed in the path from New Orleans to the equator), one obtains an estimation of the time of overpass.
at 9:36 a.m. The time of overpass estimation aids in the acquisition of pertinent atmospheric data (cloud cover, wind speed, and precipitation).

The time of overpass is also significant to this study with respect to the various thermal properties demonstrated in a scene according to the time of day. Previous studies indicate that urban heat island build-up mainly occurs in the morning hours (Anderson, 1977; Pease and Nichols, 1976). Also, thermal contrast in a scene is often maximized during daylight hours, such as the early afternoon when thermal properties of scene features become highly differentiated. However, reflected thermal radiation that falls in the range of 3 μm to 6 μm can be recorded as noise during daylight hours, though the Landsat TM band 6 sensor (10.4 μm to 12.5 μm) does not record in this range of the electromagnetic spectrum (Campbell, 1987). Shadows are also possible during daylight hours making data acquisition before dawn appropriate as well. However, thermal contrast in a scene is not maximized during predawn hours and differentiation between broad land cover classifications according to thermal properties becomes difficult.

Ancillary data includes six United States Geological Survey NHAP program color infrared aerial photographs at a scale of 1:58,000 for the construction of a land cover base map, training site development, and accuracy assessment (Fig. 7 12).
Figure 7. NHAP Photograph #1.
Figure 8. NHAP Photograph #2.
Figure 9. NHAP Photograph #3.
Figure 10. NHAP Photograph #4.
Figure 11. NHAP Photograph #5.
Figure 12. NHAP Photograph #6.
The photographs were taken using adjacent north-to-south flight paths with three photographs for either flight path. The photographs for either flight path have an overlap of approximately 60%, allowing for stereoscopic viewing, and a sidelap of approximately 33%.

The first photograph was obtained on November 13, 1982, almost one year before the remaining five photographs. The second and third photographs were obtained on the same date, October 27, 1983, as the adjacent flight path (photographs #4, 5, and 6). The second and third photographs exhibit more atmospheric haze than the others and cover the most densely urbanized areas of New Orleans.

Using stereoscopic viewing and magnification techniques, the test site is classified into USGS Land Use and Land Cover Classification System for Use with Remote Sensor Data Level I categories (Fig. 13). The six land cover categories include the following: Urban or built-up land, Rangeland, Forest land, Water, Wetland, and Barren land. The land cover categories are classified according to characteristics outlined in the photointerpretation key (see Appendix, "Photointerpretation Key"). The Level I categories Tundra and Perennial Snow or Ice are not found in the study area and Agricultural land is considered a land use type, not a land cover category. A minimum mapping unit of \((3600 \text{ m})^2\) is used for the base map, approximately equal to four Landsat Thematic Mapper pixels. Ground-truthing is not performed for the photointerpreted base map.
LAND COVER, 1983
NEW ORLEANS, LOUISIANA

1 - Urban/Built-Up Land
3 - Rangeland
4 - Forest Land
5 - Water
6 - Wetland
7 - Barren Land

Minimum mapping unit: 0.89 acres.
USGS Level I land use/cover categories.
Thomas Polanski 8-17-1994

Figure 13.
Four USGS 7.5 Minute Topographic Quadrangles are registered with the imagery using eight ground control points that are easily identified on the satellite imagery. The topographic quadrangles are then used as base maps for delineating the six land cover categories (Fig. 14). The test site lies on the following topographic quadrangles: Spanish Fort (1992), New Orleans East (1992), Little Woods (1979), and Chalmette (1989).

Also used as an aid for classifying land cover in the study area are four USGS Land Use and Land Cover maps. The study area lies on the following USGS Land Use and Land
Cover maps: Baton Rouge, LA.; MISS. (1978), New Orleans, LA (1978), Mobile, ALA.; Miss.; LA. (1974, 1976, 1978), and Breton Sound, LA. (1978). The USGS Land Use and Land Cover maps are produced using Level II land use/land cover categories and at a scale of 1:250,000. National Wetlands Inventory maps (1988), at a scale of 1:24,000 are also used as an aid for producing the land cover base map.

Image Display

The IDRISI software system is used for display and analysis. The system is a microcomputer-based system and provides extensive capabilities for image processing as well as geographic analysis tools. The IDRISI package performs geographic routines such as cost analysis, distance determination, shortest path specification, contouring, hillshading, viewpoint determination (visible land from any given viewpoint on a surface), watershed mapping, and supply area determination (from point demand centers). Extensive statistical analysis routines are provided that include an autocorrelation module, a histogram module, and regression capabilities. IDRISI also provides an extensive array of algebraic capabilities with which to process data. IDRISI boasts change analysis capabilities, spatial decision support modules, spatial and attribute data management modules, a digitizing package, extensive data import/export routines, and a large selection of display capabilities. Essentially, IDRISI provides these capabilities in a user-
friendly, PC-based system with which to manipulate remotely-sensed data.

The Landsat 5 TM digital data are contained on 3.5 inch IBM-PC/Compatible computer disks and in a straight binary format. The imagery is processed before shipping and registered to a space oblique Mercator (SOM) projection by the Earth Observation Satellite Company, Lanham, Maryland. The SOM projection is based on Gerhard Mercator's projection developed in 1569. This projection is used for satellite imagery where the point of tangency for the projection is parallel to the ground track of the satellite. Essentially, the line of tangency for the SOM is registered to the curved ground track of the satellite rather than to a circle as with the transverse Mercator or with the Mercator centered on the equator. The Space Oblique Mercator demonstrates distance and area distortions, as do the other Mercator projections, but these errors are minimal along the ground track of the satellite.

The original disks contained the imagery (all seven bands recorded by the Thematic Mapper sensor), as well as header information. The imagery is loaded into IDRISI using its PARE routine. PARE imports binary digital files into IDRISI and deletes the header information. Using the WINDOW module, the original satellite imagery, consisting of 512 rows by 512 columns, is simultaneously decreased in size to 445 rows by 512 columns (Fig. 15-21).
Figure 15. Landsat Thematic Mapper Band 1.

Figure 16. Landsat Thematic Mapper Band 2.
Figure 17. Landsat Thematic Mapper Band 3.

Figure 18. Landsat Thematic Mapper Band 4.
Figure 19. Landsat Thematic Mapper Band 5.

Figure 20. Landsat Thematic Mapper Band 6.
The data are reduced in size using the WINDOW routine because the original image could not be displayed on the computer monitor without the loss of several rows of pixels while also displaying the title and labeling information that are vital for analyst clarity.

For image display and interpretation, a false color composite is rendered using IDRISI's VGACOMPOSIT routine which produces color composite images for standard VGA graphics systems (Fig. 22). Band 2 (green) is assigned the color blue, band 3 (red) is assigned the color green, and band 4 (near-infrared) is assigned the color red. This assignment of colors is traditionally known as a false color
Figure 22. False Color Composite.

Figure 23. False Color Composite Close-Up.
composite and mimics the colors produced by color infrared films. Such a color assignment aids in the interpretability of the Landsat TM imagery by enhancing the differentiation between vegetation, water, urban materials, and other objects (Fig. 23).

Image Classification

Training sites are created using IDRISI's on-screen digitizing module while displaying the false color composite. Training sites for each land cover class included 3,904 pixels for Urban or built-up land, 500 pixels for Rangeland, 1,654 pixels for Forest, 6,281 pixels for Water, 6,321 pixels for Wetland, and 538 pixels for Barren land. Rangeland and Barren cover types are defined with the least number of pixels as these categories are not well represented in the study area. Given the number of bands contained in the Landsat TM data, approximately 200 to 400 pixels are necessary for an adequate statistical representation of each land cover class. Signature files are then generated using IDRISI's MAKESIG and compared using SIGCOMP. The IDRISI package allows for the comparison of signature files according to the ranges and means of the land cover categories for each band of data. The signature means for each land cover type indicate that there is significant overlap of the signatures in bands 1, 2, and 6 (Fig. 24). Signature overlap implies that these bands of
Figure 24. Land Cover Signature Means.
data will perform poorly with regard to land cover differentiation and classification. The signatures for bands 3, 4, 5, and 7 exhibit much greater mean separations and may be expected to perform well in a multispectral classification.

Following signature development, a principal components analysis (PCA) is performed using IDRISI's PCA module and a correlation matrix is generated (Fig. 25). A principal components analysis examines all of the data available to an analyst and indicates which bands of data are not necessary for analysis, increasing processing efficiency. More specifically, because there are seven bands of data available from the TM, it is common to find that a significant amount of useful information is contained in only three or four bands and the rest of the bands contain data that are highly redundant.

<table>
<thead>
<tr>
<th></th>
<th>Band 1</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
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<tr>
<td>Band 1</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band 2</td>
<td>0.98</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band 3</td>
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<td>0.98</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band 4</td>
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<td>0.53</td>
<td>0.52</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Band 5</td>
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<td>0.70</td>
<td>0.73</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Band 6</td>
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<td>0.53</td>
<td>0.56</td>
<td>0.59</td>
<td>0.72</td>
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<td></td>
</tr>
<tr>
<td>Band 7</td>
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<td>0.82</td>
<td>0.85</td>
<td>0.75</td>
<td>0.95</td>
<td>0.75</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 25. Correlation Matrix.
All seven bands of the TM are included in the PCA. Bands 1, 2, and 3 are highly correlated with one another, thus supporting the indication given by the signature files that bands 1 and 2 may be excluded from the classification without a significant loss of information. Because the study area is covered in large part by wetlands, band 7 is included in the classification because of past research that indicate its capability for delineating wetlands (although it is correlated well with band 5). Also, band 6 is dropped from the classification procedure as a result of its overlapping signature files and its correlation with bands 5 and 7. Though band 6 could be included and would further weight the classification results, the reduction of the data set for automated classification into four bands increases processing efficiency and the loss of information is minimal. In summary, Landsat TM bands 3, 4, 5, and 7 are kept for the classification routines.

Land cover classifications are performed for the study area using the maximum likelihood, minimum distance to means, and the parallelepiped classification rules while keeping the training sites and TM band choices (3, 4, 5, and 7) identical for each method. Error matrices are generated for each method using the training sites as reference data and are presented in Figures 26, 27, and 28, allowing for the calculation of the Kappa coefficients of agreement.
### Figure 26. Maximum Likelihood Classification Error Matrix.

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Wetland</th>
<th>Forest</th>
<th>Range</th>
<th>Barren</th>
<th>Urban</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
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<td>249</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6366</td>
</tr>
<tr>
<td>Wetland</td>
<td>152</td>
<td>5249</td>
<td>191</td>
<td>37</td>
<td>3</td>
<td>25</td>
<td>5657</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>721</td>
<td>1400</td>
<td>10</td>
<td>0</td>
<td>6</td>
<td>2137</td>
</tr>
<tr>
<td>Rangeland</td>
<td>0</td>
<td>75</td>
<td>53</td>
<td>432</td>
<td>14</td>
<td>72</td>
<td>646</td>
</tr>
<tr>
<td>Barren</td>
<td>6</td>
<td>10</td>
<td>0</td>
<td>8</td>
<td>452</td>
<td>281</td>
<td>757</td>
</tr>
<tr>
<td>Urban</td>
<td>6</td>
<td>17</td>
<td>10</td>
<td>13</td>
<td>69</td>
<td>3520</td>
<td>3635</td>
</tr>
<tr>
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<td>6321</td>
<td>1654</td>
<td>500</td>
<td>538</td>
<td>3904</td>
<td>19198</td>
</tr>
</tbody>
</table>

### Figure 27. Minimum Distance to Means Classification Error Matrix.

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Wetland</th>
<th>Forest</th>
<th>Range</th>
<th>Barren</th>
<th>Urban</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>6001</td>
<td>210</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6211</td>
</tr>
<tr>
<td>Wetland</td>
<td>280</td>
<td>4750</td>
<td>629</td>
<td>53</td>
<td>8</td>
<td>214</td>
<td>5934</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>565</td>
<td>985</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1555</td>
</tr>
<tr>
<td>Rangeland</td>
<td>0</td>
<td>110</td>
<td>33</td>
<td>302</td>
<td>4</td>
<td>124</td>
<td>573</td>
</tr>
<tr>
<td>Barren</td>
<td>0</td>
<td>0</td>
<td>66</td>
<td>66</td>
<td>379</td>
<td>888</td>
<td>1333</td>
</tr>
<tr>
<td>Urban</td>
<td>0</td>
<td>686</td>
<td>7</td>
<td>77</td>
<td>147</td>
<td>2675</td>
<td>3592</td>
</tr>
<tr>
<td>Total</td>
<td>6281</td>
<td>6321</td>
<td>1654</td>
<td>500</td>
<td>538</td>
<td>3904</td>
<td>19198</td>
</tr>
</tbody>
</table>

### Figure 28. Parallelepiped Classification Error Matrix.

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Wetland</th>
<th>Forest</th>
<th>Range</th>
<th>Barren</th>
<th>Urban</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified</td>
<td>3740</td>
<td>3443</td>
<td>828</td>
<td>250</td>
<td>0</td>
<td>1957</td>
<td>10494</td>
</tr>
<tr>
<td>Water</td>
<td>2179</td>
<td>337</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2516</td>
</tr>
<tr>
<td>Wetland</td>
<td>360</td>
<td>240</td>
<td>47</td>
<td>8</td>
<td>3</td>
<td>66</td>
<td>724</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rangeland</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Barren</td>
<td>0</td>
<td>1</td>
<td>8</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Urban</td>
<td>2</td>
<td>2300</td>
<td>771</td>
<td>242</td>
<td>257</td>
<td>1881</td>
<td>5453</td>
</tr>
<tr>
<td>Total</td>
<td>6281</td>
<td>6321</td>
<td>1654</td>
<td>500</td>
<td>538</td>
<td>3904</td>
<td>19198</td>
</tr>
</tbody>
</table>
The training sites are overlaid on the classified images, as opposed to a random sampling of pixels, because ground truthing is not carried out. Using the training sites for accuracy assessment allows the analyst to significantly reduce the time and costs necessary for accuracy assessment. However, when possible, a stratified random sample should be used for ground truthing (Genderen and Lock, 1977). Training sites are chosen for accuracy assessment because ground truthing is beyond the limitations of this research, ground truthing might not be as accurate as desirable (depending on the ground points chosen and land cover changes that occurred over time as the satellite imagery was acquired over nine years ago), and the NHAP color infrared aerial photographs were acquired within a reasonable time frame allowing for the development of training sites. However, the error rate in training site development is unknown because the NHAP photography was acquired a year and a half before the satellite imagery, seasonal variations in water saturation (photography acquired in the fall and imagery acquired in the spring), tidal variations, and ground truthing is not carried out. Unknown training site error rate makes the evaluation of the error rate for each classification scheme difficult.

A Kappa coefficient of agreement is generated for each error matrix. It yields the proportion of agreement after removing the proportion of agreement due to random chance in the classification procedure (Foody, 1992). The Kappa
The coefficient of agreement lies on a scale from 0 to 1 and when multiplied by 100 provides a measure of classification accuracy. Unlike the overall Kappa coefficient of agreement, which takes into account the entire matrix, the conditional Kappa coefficient of agreement is calculated for and indicates the accuracy of any one category (Rosenfield and Fitzpatrick-Lins, 1986). The conditional Kappa coefficient of agreement provides a better representation of agreement by category than does percentage classified correctly/incorrectly as the proportion classified correctly due to random chance is integrated into the procedure.

The matrices for all three methods are then used for pairwise tests of significant differences between each independent Kappa statistic using the normal curve deviate (Cohen, 1960). Results are presented in Figure 29. Confidence intervals are calculated using the approximate large sample variance for each Kappa statistic (Congalton and Mead, 1983; Bishop et al., 1975).
<table>
<thead>
<tr>
<th>Error Matrix</th>
<th>Kappa Statistic</th>
<th>Variance of Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum likelihood</td>
<td>0.8581</td>
<td>0.013112</td>
</tr>
<tr>
<td>min. dist. to means</td>
<td>0.7128</td>
<td>0.052234</td>
</tr>
<tr>
<td>parallelepiped</td>
<td>0.1252</td>
<td>-0.004309</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pairwise Comparison</th>
<th>Z Statistic</th>
<th>99% C.I. Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum likelihood &amp;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>min. dist. to means</td>
<td>2.698006</td>
<td>significant</td>
</tr>
<tr>
<td>maximum likelihood &amp;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>parallelepiped</td>
<td>53.101442</td>
<td>significant</td>
</tr>
<tr>
<td>min. dist. to means &amp;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>parallelepiped</td>
<td>11.211294</td>
<td>significant</td>
</tr>
</tbody>
</table>

Figure 29. Results of the Pairwise Tests for Significant Differences between Error Matrices.

The test statistic for the pairwise comparisons is calculated using the following formula (Congalton and Mead, 1983):

\[
\frac{\hat{K}_1 - \hat{K}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \sim Z
\]

where:

\(\hat{K}_1\) and \(\hat{K}_2\) = Kappa coefficient of agreement for each matrix;
\( \hat{\sigma}_1 \) and \( \hat{\sigma}_2 \) = approximate large sample variance of \( \hat{K}_1 \) and \( \hat{K}_2 \), respectively.

The test for significant differences between the error matrices is possible because the large sample asymptotic distribution of the Kappa coefficient of agreement is normal. Thus, the test statistic, or \( Z \), may be compared to values in a standard normal table to determine if any two error matrices are significantly different. Essentially, this procedure allows for the comparison of two matrices where all but one of the factors in the classification are kept constant (e.g., algorithm, analyst, scene coverage, scene date, etc.)

The results presented in Figure 29 indicate that all three of the classification algorithms produced land cover classified images with highly significant differences. The maximum likelihood classifier performs the best and is the only method to meet the 85% thematic accuracy standard set by the USGS, followed by the minimum distance to means classifier, and finally, the parallelepiped classifier performs the worst of all the methods. The conditional Kappa coefficients of agreement are presented in Figure 30 for each method to allow for accuracy comparisons by category.
Figure 30. Conditional Kappa Coefficients of Agreement for Each Classification Method.

The optimal supervised classification is completed using IDRISI's MAXLIKE module which carries out image classification according to the maximum likelihood decision rule (Fig. 31). The module allows the analyst to include probabilities for the occurrence of any one class and to exclude a given percentage of the data set which does not conform to a minimum probability of belonging to any land cover category. For the maximum likelihood classification, all classes are assumed equally likely to occur and the exclusion percentage is set at zero (or all pixels are classified). By convention, all classes are assumed equally
likely to occur because image analysts need information concerning the performance of such a classification method where prior knowledge of the total area covered by each category for the study area is not available.

Figure 31. Automated Land Cover Classification (Maximum Likelihood Rule).

Surface Temperature Conversion

To convert the TM band 6 digital counts into surface temperatures, the digital counts are first transformed into radiant temperatures. Again, the radiant temperature of an object is the temperature at which a blackbody would have to be in order to emit the same amount of energy as the object being observed. A quadratic equation is used for this step.
because the range of the surface temperatures, 17.52°C to 151.52°C, indicates that this type of equation will best represent the data set (Fig. 32). The digital counts are converted into radiant temperatures using a combination of IDRISI's algebraic and arithmetic functions (SCALAR and OVERLAY). The quadratic equation yields radiant temperatures in degrees Kelvin.

Figure 32. Surface Temperature Frequencies.

The next step is to assign emissivity values to the land cover classes on a pixel basis in order to derive actual surface temperatures from the data. Published emissivities are assigned to each land cover class on a pixel basis and include: Urban or built-up land: 0.88; Rangeland: 0.97; Forest land: 0.99; Water: 0.98; Wetland: 0.98; and Barren land: 0.90 (Avery and Berlin, 1992; Nichol,
1993). IDRISI's attribute data management and algebraic functions are utilized to assign the land cover classes emissivity values (EDIT, ASSIGN, and TRANSFORM). The radiant temperatures are then weighted by land cover emissivities and converted into surface temperatures (Artis and Carnahan, 1982). This operation effectively increases the resolution of the TM band 6 data to $(30 \text{ m})^2$. Finally, the surface temperatures in degrees Kelvin are converted into degrees Celsius for image interpretation.
CHAPTER VI

RESULTS

Land Cover Accuracy Assessment

The maximum likelihood classification error matrix indicates a land cover classified image of relatively high accuracy, and the overall Kappa coefficient of agreement is calculated at 0.8581. However, the conditional Kappa coefficients demonstrate the difficulty in classifying wetlands and the overall Kappa coefficient reflects, in part, the ease of interpreting the water category. Again, as the accuracy of the training sites is unknown, the overall Kappa coefficient is not only a result of the misclassification and correct classification of the imagery but also the misclassification and correct classification of the training sites. The conditional Kappa coefficients of agreement, calculated for each land cover category, are as follows:

- Urban or Built-up Land: 0.8787;
- Rangeland: 0.8593;
- Forest land: 0.8272;
- Water: 0.9609;
- Wetland: 0.7596;
- Barren land: 0.8336.
Figure 33. Maximum Likelihood Classification Error Matrix.

Several characteristics of the automated classification are evident from examination of the error matrix (Fig. 33). Errors of commission are indicated along the rows, or pixels in the classified image that are wrongly classified, and errors of omission are indicated along the columns, or pixels in the reference data that are not classified in that category (Janssen and van der Wel, 1994). Water is generally classified correctly, though there is significant confusion with wetlands. The confusion of wetlands with water is an expectable result of the high content of water in wetlands, sediment clouding of water, and relatively shallow water bodies, all of which can mimic the spectral response of either category (Campbell, 1987; Horwitz et al., 1974; Jensen, 1978; Trolier and Philipson, 1986).

The urban category is often confused with barren lands, followed by rangeland. The confusion of urban with barren or rangeland is an expectable result of the heterogeneity of urban land cover which includes construction materials and a high percentage of tree or grass cover (Adetiba, 1980;
Heller et al., 1974; Jensen, 1978). Again, barren lands often consist of materials such as cement, asphalt, dirt, and gravel which can mimic the spectral response of urban areas. Urban cover is often confused with rangeland as a result of the large percentage of grass covered areas within urban zones such as residential areas, parks, golf courses, baseball diamonds, grasses within freeway interchanges, etc (Fig. 34).

Rangeland is often confused with wetlands and, to a lesser extent, forested land. Wetlands will not necessarily be inundated with water, leaving the vegetation in these areas to dominate the spectral response patterns and mimic the rangeland signatures. Forest land exhibits significant confusion with wetlands as well. Of all the land cover categories, the wetland category performs the worst at 0.7596, followed by forest lands at 0.8272.

Surface Temperature/Land Cover Analysis

The surface temperatures derived from the Landsat TM thermal channel are converted into degrees Celsius for image interpretation. The surface temperature data exhibit a range from 17.52°C to 54.52°C and 149.1°C to 151.52°C. The surface temperatures are extracted by land cover type to calculate the means and ranges by land cover type. An analysis of variance is then performed to determine if there is a significant difference between means of surface temperatures by land cover type (Fig. 35). A significant F-
statistic is calculated at the 99% confidence interval. Thus, there are highly significant differences between the means in degrees Celsius for the six land cover types.

Figure 34. Pontchartrain Park Golf Course and Vicinity.

Figure 35. Surface Temperature Range by Land Cover Type.
The means are then separated using a Duncan's Multiple Range test with unequal replications. Unlike the Duncan's Multiple Range test with equal replications, significant studentized ranges are obtained and multiplied by the standard deviation of the data set (not the standard error) to give an intermediate set of significant ranges. The intermediate values are then multiplied by the equation below to obtain the final significant ranges (Steel and Torrie, 1980):

$$\sqrt{\frac{1}{2} \left( \frac{1}{r_i} + \frac{1}{r_j} \right)}$$

where:

$r_i$ and $r_j$ = number of replications for each mean.

The DMR test indicates that there are highly significant differences between all of the means in degrees Celsius for the six land cover types. Water is the coolest land cover type, followed by forest, wetland, rangeland, barren, and finally, urban or built-up land. A change in land cover from water to forest or wetland results in a surface temperature increase of approximately 4°C. The forest and wetland cover types demonstrate a surface temperature difference of only 0.72°C. This relatively small difference between forest and wetland cover surface temperatures may be attributable to shadowing effects produced in areas of forest cover.
A change in land cover from forest or wetland to rangeland results in a surface temperature increase of approximately 5°C. A change in land cover from rangeland to barren results in a surface temperature increase of approximately 4.3°C. Finally, a change in land cover from barren to urban results in a surface temperature increase of approximately 7.87°C.

The surface temperatures are then apportioned into classes and displayed as a choropleth map for further interpretation (Fig. 36). The surface temperatures in the outlying range of 149°C to 152°C are found within a tall section of one of the fabrication buildings located at the NASA Michoud Assembly Facility (Fig. 37). The roof of the building is either acting as a blackbody or there are significantly hot emissions coming from the facility. Other buildings at the assembly facility demonstrate relatively higher temperatures than the surrounding areas and another "hot spot" in the range from 50°C to 56°C. The manufacturing building also exhibits a large zone of temperatures within the coolest class of 17°C to 25.99°C, where the metal roof is acting as a reflector. There is also a recognizable encroachment of higher surface temperatures within the Michoud Canal, effectively connecting the NASA Michoud Assembly Facility on the west bank and the chemical/heating industry facilities on the east bank.
Figure 36. Surface Temperatures in Degrees Celsius.

Figure 37. NASA Michoud Assembly Facility.
Other features demonstrating surface temperatures that lie within the 50°C to 56°C range are the University of New Orleans East Campus (largely pavement covered area), the Lake Forest shopping center, several mechanical processing industries located along the Inner Harbor Navigation Canal, several barren areas, and other one-story, large commercial complexes that are surrounded by a high percentage of pavement (Fig. 38). The shapes of buildings are readily interpretable where there exists a surrounding cover that lies within a cooler temperature class. Residential areas generally demonstrate temperatures within the 42°C to 49.99°C range and exhibit consistently higher temperatures than
most barren land, docking facilities, transportation routes, and coastal areas found within the 32°C to 41.99°C range.

However, several areas used for extraction activities (gravel pits and quarries) demonstrate temperature patterns similar to that of residential areas. The highly urbanized, southwest region of the imagery, located near the central business district of New Orleans, is essentially a homogenous area of surface temperatures within the higher 42°C to 49.99°C range.

The cooler areas consist of large tracts of forest, wetlands, and water, all of which are easily interpreted from the surface temperature classified image. Rangeland or urban areas covered with a significant percentage of grass are cooler than the highly urbanized areas and generally lie within the range of 26°C to 31.99°C range and the 32°C to 41.99°C range (e.g., the Pontchartrain Park Golf Course and the Brown Memorial Park). Various fields operated by schools demonstrate surface temperatures similar to those exhibited by water covered areas, the 17°C to 25.99°C range, and essentially act as "cool spots" within the urban landscape.
CHAPTER VII

DISCUSSION

Summary

The test site provides a heterogeneous landscape with which to test the capabilities of the Landsat TM sensor for mapping urban land cover surrounded by a high percentage of wetlands. As a result of such legislation as the National Environmental Policy Act, Section 204 of the Clean Water Act, Section 208 of the Federal Water Pollution Control Act, the Coastal Zone Management Act, Executive Order 11990 of 1977, and others, the detection and mapping of wetlands is a vital concern to planners, developers, and resource managers. Regional coverage and mapping of land cover information for all land cover types is equally important to entities involved in informed decision-making processes.

Landsat 5 TM digital data are used in automated land cover classification routines to test the capability of the Thematic Mapper data for providing land cover information in a PC-based image processing system. United States Geological Survey NHAP color infrared aerial photographs are used to produce a base control map for developing training sites and accuracy assessment. IDRISI performs the
automated land cover classifications using the maximum likelihood, minimum distance to means, and the parallelepiped classifiers. The land cover classification error matrices are used for pairwise comparisons with discrete multivariate analyses to test for significant differences between each classification method. There are highly significant differences between all of the land cover classified images produced using the different classification rules and the maximum likelihood classifier is the only classification that meets the 85% thematic accuracy criterion set by the USGS. However, there is significant confusion in the automated classification using the maximum likelihood rule between certain land cover types, such as water/wetland, forest/wetland, urban/barren, urban/rangeland, and rangeland/wetland.

Of all the land cover categories, the automated techniques used in this research perform the worst for classifying wetlands, followed by forest lands. The results indicate that a different choice of TM bands, ancillary data, improved training site selection, or other modifications to the techniques used may be necessary for delineating wetlands at an accuracy level of 85% or better. However, the techniques used here for mapping wetlands may perform within project standards depending on the scale of study and the land cover type surrounding the wetlands (coastal versus inland wetlands).
The maximum likelihood land cover classified image is then used as ancillary data for surface temperature mapping at the test site. The Landsat 5 TM thermal channel is used for deriving surface temperatures where the land cover classified image allows for weighting the surface temperatures by land cover types and their corresponding emissivities. Statistics are generated from the surface temperature classified image that indicate highly significant differences between all of the mean surface temperatures by land cover type. Further examination of the surface temperature classified image and the NHAP photography demonstrates strong relationships between specific land cover types and their surface temperatures.

Highly urbanized, residential, extractive industries, processing industries, and other land cover types surrounded by or consisting of a large percentage of pavement generally produce higher surface temperatures. Lower surface temperatures are found in areas of water cover, wetlands, forests, parks consisting of largely natural cover, and schools with fields adjacent to them. The methods used for deriving surface temperatures from the Landsat TM digital data prove to be effective for mapping the urban canopy and its surrounding temperatures. Such data are vital, especially in tropical zones where development completely limits the growth of natural vegetation. The applications of the techniques used are by no means limited to surface temperature mapping but also include pollution detection,
Limitations

Despite the overall performance of the techniques used, there are, of course, limitations to this research. Atmospheric effects including atmospheric scattering and moisture data as a function of height are neglected in this study and may affect the validity of quantified surface temperatures. However, with close examination of the frequency histograms for bands 1 and 3, indicators of atmospheric reflectance due to scattering and moisture, as well as all other bands, atmospheric interference is deemed negligible within the study area as dark values are consistently demonstrated at or near zero (Campbell, 1987; Chavez, 1975; Conese et al., 1993).

Wind speed at the test site is recorded at 8.1 m.p.h. at 9:00 a.m. and the same wind speed is recorded at 10:00 a.m. on March 24, 1985, the date of the satellite overpass (LOSC, 1985). Though surface temperatures of acceptable accuracy can be derived from remotely-sensed data acquired during wind speeds of up to 10 m.p.h., the optimal wind speed for such an operation is at zero, or at least below 7.5 m.p.h. Also, the Landsat TM imagery does not demonstrate any visually recognizable evidence of cloud cover in the study area and local weather data indicate cloud cover at zero percent, leaving only the negligible
effect of atmospheric scattering to corrupt the thermal readings (LOSC, 1985; Price, 1983).

The detection of wetlands in the study area yields the most confusion in the classification routine. Thus, where one has a singular concern for delineating wetlands, other methods may be more appropriate. For example, it may be necessary to incorporate ancillary data in the automated land cover classification, such as prior knowledge of the extent of wetlands in a region or the use of ground truthing. Also, the NHAP program color infrared photographs used for training site delineation and accuracy assessment were acquired over a year and a half before the satellite imagery. The time lapse in data acquisition may have played a significant role in producing errors, especially in the wetlands category, as the wetlands in the study area are constantly evolving and are currently increasing in size (Handley and Mergist, 1994).

In conclusion, the assignment of emissivity values according to land cover type is of great importance. Though published values are used for this assignment, significant differences may exist between assigned and actual emissivities for ground surfaces. Thus, where possible, ground based measurements should be performed to determine land cover type emissivity (Nichol, 1994). Nevertheless, information concerning the performance of Landsat TM data in automated land cover classification routines and surface temperature mapping projects, the capabilities of the IDRISI
image processing system, and other elements of this research are all vital tools for the urban planner, natural resource manager, or other entities needing such information. Possibly even more important where tight budgets and personnel constraints are concerned, this research demonstrates techniques for mapping land cover and quantifying surface temperatures which are exceptionally efficient and accurate.
APPENDIX
### PHOTINTERPRETATION KEY

<table>
<thead>
<tr>
<th>Class</th>
<th>Subclass</th>
<th>Color</th>
<th>Texture/Pattern</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>n/a</td>
<td>dark to medium blue</td>
<td>smooth</td>
<td>varies</td>
</tr>
<tr>
<td>Wetlands</td>
<td>emergent</td>
<td>light blue to pinkish-white</td>
<td>mottled</td>
<td>varies</td>
</tr>
<tr>
<td></td>
<td>scrub-shrub</td>
<td>pink with dark blue undertones</td>
<td>smooth</td>
<td>varies</td>
</tr>
<tr>
<td></td>
<td>forested</td>
<td>dark pink or magenta with dark blue undertones</td>
<td>rough</td>
<td>varies</td>
</tr>
<tr>
<td></td>
<td>intertidal</td>
<td>consistent light blue or light pink</td>
<td>smooth to medium/patchy</td>
<td>elongated</td>
</tr>
<tr>
<td></td>
<td>subtidal</td>
<td>dark blue</td>
<td>medium/mottled</td>
<td>varies</td>
</tr>
<tr>
<td>Forest</td>
<td>n/a</td>
<td>dark red; absence of blue undertones</td>
<td>rough</td>
<td>varies</td>
</tr>
<tr>
<td>Range</td>
<td>n/a</td>
<td>pinkish-gray</td>
<td>fine</td>
<td>varies</td>
</tr>
<tr>
<td>Barren</td>
<td>n/a</td>
<td>white or gray</td>
<td>smooth</td>
<td>varies</td>
</tr>
<tr>
<td>Urban</td>
<td>n/a</td>
<td>white or gray</td>
<td>varies</td>
<td>varies</td>
</tr>
</tbody>
</table>
## Analysis of Variance

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sums of Squares</th>
<th>Mean Squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>227,839</td>
<td>19,257,321.3</td>
<td>120,807.78**</td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>5</td>
<td>13,983,500.0</td>
<td>2,786,700.00</td>
<td>23.15</td>
</tr>
<tr>
<td>Error</td>
<td>227,834</td>
<td>5,273,821.7</td>
<td>23.15</td>
<td></td>
</tr>
</tbody>
</table>

where: \( F_{0.05} = 2.21 \);
\( F_{0.01} = 3.02 \);
\( F_{0.005} = 3.35 \);
Error df = \( \infty \).

**Conclusion:** There are highly significant differences between the means in degrees Celsius for the six land cover types tested for surface temperature characteristics.
DUNCAN'S NEW MULTIPLE-RANGE TEST

<table>
<thead>
<tr>
<th>( p )</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_{a}(p, \infty) )</td>
<td>3.64</td>
<td>3.80</td>
<td>3.90</td>
<td>3.98</td>
<td>4.04</td>
</tr>
<tr>
<td>( Rp_{1} )</td>
<td>33.427</td>
<td>34.896</td>
<td>35.815</td>
<td>36.549</td>
<td>37.1</td>
</tr>
</tbody>
</table>

\[
Rp = Rp_{1}\left(\sqrt{\frac{1}{2}\left(\frac{1}{r_{i}} + \frac{1}{r_{j}}\right)}\right)
\]  

(least significant ranges)

where:

\( Rp_{1} = [q_{a}(p, \infty)](s) \) (used as an intermediate value);

\( s = 9.1834; \)

\( r = \) replications (total pixels) for each class.

Water: Forest: Wetland: Range: Barren: Urban:
22.50  26.03  26.75  31.57  35.87  43.74

Conclusion: There are highly significant differences between all of the means in degrees Celsius by land cover type tested for surface temperature characteristics.

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