UNIVERSITY OF CALIFORNIA
Santa Barbara

Validation of Three Land Cover Maps Utilizing Space Shuttle Photography and Landsat Thematic Mapper Imagery

A Dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Geography

by

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Validation of Three Land Cover Maps Utilizing Space

Shuttle Photography and Landsat Thematic Mapper Imagery

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ABSTRACT

Validation of Three Land Cover Maps Utilizing Space Shuttle Photography and Landsat Thematic Mapper Imagery

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Astronaut acquired photography (AAP) can be used as a quantitative reference source in land cover map validation. Three land cover maps were selected for validation with AAP and Landsat Thematic Mapper (TM): 1. United States Geological Survey Level II, 2. International Geosphere Biosphere Programme DISCover and 3. Olson Global Ecosystem. The area validated extended from California to Louisiana, encompassing all of the southwestern United States (Figure 8). At one hundred and sixteen sample points randomly distributed across the southwestern United States, the dominant type of vegetation was established using Landsat Thematic Mapper data for comparison to astronaut acquired photography. Photointerpretation and a supervised classification algorithm were applied to assess the dominant type of vegetation at sample points savanna, evergreen needle leaf forest, shrubland, grassland, or a cropland/vegetation mosaic. The comparison of results from Thematic Mapper and astronaut acquired photography were accomplished via confusion matrices, a Khat and Z statistic. The results showed that there was almost no significant difference between utilizing Thematic Mapper data versus astronaut acquired photography as a source of reference data for map validation. The only significant difference occurred when using the classified Thematic Mapper imagery as a reference data source. When that reference source was used, this resulted in the largest number of misclassified
land cover classes. Based on these results, several recommendations were made to streamline the efficiency of the Johnson Space Center photographic astronaut-training program. These recommendations include a web-based form to standardize and prioritize photographic requests, ease of interpretation maps, and additional ancillary images hot-linked to the locational software used to identify areas of interest. These recommendations will not only increase efficiency but also improve the accuracy with which astronauts acquire photography in the future.
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Chapter 1

Introduction

1.1. Justification for Research

Aerial photography has been used extensively in many different research programs, for example, vegetation analysis (Welch, et al., 1999), soil science (Friedle, et al., 1998), and change detection (MacLeod and Congalton, 1998). Essentially, aerial photographs are historical records that document conditions representative of the time they were acquired. These photographs may or may not prove of value to researchers depending upon several factors including but not limited to: subject matter, scale, resolution, and type of film used. Archives of historical aerial photography are an invaluable resource to the science community.

There is an archive of over 300,000 Earth observing photographs taken by United States astronauts dating back to the early 1960’s. This photographic archive covers the majority of the Earth’s surface and offers a wide variety of camera angles, focal lengths and lenses as well as extensive repeat coverage over many specific regions of the world’s landscape. The metadata associated with each astronaut acquired photograph is specific to each unique photograph. The unique factors defining each photograph are one of the major reasons this type of data has been largely ignored for use in quantitative land cover research. This study will show that those differences
can actually add to the value of the imagery, as opposed to detracting from its scientific merit.

The work presented in the following chapters is part of a larger effort begun by Johnson Space Center (JSC) to establish whether astronaut acquired photography (AAP) is appropriate for validating land cover maps for all or some land cover classes. Validation can be defined broadly as trying to show that a result is true or not true. In studies that use maps derived from remotely sensed data, validation entails establishing whether what a map depicts as the dominant land cover type at any given point, actually exists at that point in reality. Validation of land cover maps over large regions is challenging as demonstrated by the recent DISCover global land cover validation (Belward et al, 1999). Validation of land cover maps using AAP had not been done quantitatively.

1.2. Purpose of Study

The purpose of this research is to evaluate the efficiency of using AAP as validation data in comparison to the more commonly used Landsat Thematic Mapper imagery for validating land cover maps. It is proposed that astronaut acquired photography can be used to validate land cover products derived from remotely sensed data via expert interpretation and quantitative image classification.
1.3. Statement of Objectives

This dissertation pursued five objectives that jointly characterized a strategy for validating three global land cover products derived from satellite remotely sensed data. The specific science hypothesis of this work was addressed in several distinct steps.

After the selection of the three land cover maps, the first objective was to present the background characteristics of each map. Characteristics of critical elements of Space Shuttle Photography and Landsat Thematic Mapper (TM) Imagery are also described. This literature review provides the background necessary to show how the work presented here fills a niche that has been left empty because of the disinterest in examining AAP as a source of quantitative reference data that can be used to assess the accuracy of land cover maps.

The second objective of this research was to successfully implement expert interpretation, supervised image classification, and to compute confusion matrices and a Kappa analysis to determine the accuracy of the selected land cover maps using both AAP and Landsat TM images as validation data. Standard techniques of analysis, including a randomized selection of validation sites, were implemented.

The third objective was to use the validation results to determine whether and which individual land cover maps (of the three used for this study) were more effectively
validated employing AAP. The three land cover maps were chosen on a basis of comparative spatial resolution, where the finer resolution maps had a higher number of land cover classes. Often astronauts take these types of maps into orbit to aid in identification of land cover types, therefore determining which land cover map was most appropriate for validation employing this type of photography is very relevant.

The fourth objective of this research, also based on the results, was to determine whether and which land cover classes on each individual land cover map have the highest accuracy for validation purposes. Answering this question determined if one, or more, land cover class is more easily validated than another. To further this point, the results also showed which classes were most easily confused with others, and which classes were the most distinct.

The fifth objective presents the potential future uses of the methodology shown here as well as global applications for the results of this research. The method offered here suggests a computational technique that can be used to validate maps quickly and efficiently. Based on the validated maps, it is possible not only to better prepare the astronauts for landscape feature identification, but also to create a standardized system for prioritizing image acquisition.

Completing these five objectives fully addressed all aspects of the hypothesis directing this research. Not only did the results specific to this research show equality
between AAP and TM as sources of reference data, but also, the results revealed future possible global applications of this regional study.

1.4. Importance of this Research in the Field of Geography

The importance of this research to the field of geography is twofold. First, the work brings attention to a vast resource of photographs that can be used in quantitative studies that, up until this point, have been largely ignored. The neglect of these photographs stemmed from the lack of scientific research regarding their use. This study is the first step in revealing how important a source of information these photographs can be in quantitative analysis. The second important facet of this work is to highlight the value of including the human being in the process of obtaining Earth observing data. Since the first staffed orbital flight, obtaining Earth observing data has become increasingly automated. However, the International Space Station (ISS) will allow an increased interaction between astronauts and onboard sensors. This control will in turn, provide greater interaction between the sensors and the community that will use the future data collected from these sensors. In this way, we can have greater access to materials to study our planet in terms of changes in time, space and place.

1.5. Summary of Chapters

The remainder of this dissertation presents the background, methods, results, a discussion of the results and an evaluation of future applications of these results.
Chapter 2 presents the background through a comprehensive review of the literature describing derivation of the land cover classification systems used in this research. This provides insight into the rationale behind their composition. This chapter also gives a history of the Space Shuttle Program including program development to present day conditions, how astronauts are trained to observe the Earth, and which types of cameras have been used to gather worldwide photography for over thirty years. In this chapter, studies completed using this AAP are also reviewed, showing the timeliness of this research. These studies incorporate both looking at land cover change over time as well as demonstrating the importance of an astronaut presence with the photographic acquisition of episodic events. Finally, this chapter provides a review of the IGBP DISCover validation effort, illustrating the baseline methodology from which this study was derived.

The information and prior research described in Chapter 2 are the foundation for the description of materials and methodology presented in Chapter 3. An in-depth depiction of the materials used in this research is explored first in Chapter 3. A detailed explanation of various important aspects of the land cover maps, the AAP and the TM imagery are provided. With the comprehensive description of the materials utilized in this research presented, the methods applied to those materials are then described. The implementation of the design technique for the validation of three Advanced Very High Resolution Radiometer (AVHRR) - derived land cover maps is explained here. In Chapter 3, a review of how the three land cover maps
were chosen, as well as the reasons for the choice in study area are clarified. The procedure used to gather unbiased sample points is also summarized. In addition, the methods applied to perform photointerpretation as well as supervised image classification are explained. Chapter 3 features the computer programs used, and how the AAP and TM images were transferred into an environment where they could be documented and analyzed. This chapter also provides a thorough explanation of the parallelepiped classifier, how it works, and a thorough description of the target land cover classes in this study. Additionally, this chapter affords an explanation of the statistics employed to establish whether there was a significant difference between using TM imagery as opposed to AAP as a reference data source. Those statistics: the confusion matrix, Kappa and Z statistic, are explained in detail.

In Chapter 4, the results from the methodology described in Chapter 3 are shown. The results from the confusion matrix are summarized and the full results given in the Appendix. The results from the Kappa statistic and the Z statistic are also summarized.

The results presented in Chapter 4 are employed in Chapter 5 to discuss how the results from this research demonstrate the potential use of AAP and how these results have answered the hypothesis posed. In this chapter, the issue of AAP as a cost-effective alternative to TM imagery is addressed. Additionally, the importance of the method used here as a rapid and efficient evaluation of land cover maps is discussed.
This chapter also provides recommendations for scientists interested in doing a map validation in this manner. In addition, this chapter has recommendations for the future training of astronauts as photointerpreters, recommendations for upgrading the software that helps the astronauts identify land cover features, and recommendations for increased interaction between astronauts and those who request the Earth observing images. Future applications of this research are described in detail based on the results achieved.

In Chapter 6, the study is concluded with a summary of how the hypothesis was achieved through the completion of the science objectives. With the conclusion of these objectives, the question of whether AAP is appropriate for validation of land cover maps is answered. Finally, this chapter explores the importance of this study to both promote the value of humans in space as well as support the usage of astronaut acquired photography from the International Space Station in the future.

In the next five chapters, the need for performing an accuracy assessment on land cover maps is reviewed, methods for completing this assessment are demonstrated, and results from an assessment of three land cover products are determined using those techniques. Earth observations aid scientists in modeling global and regional processes important to our atmosphere, oceans and land processes. The results from this dissertation will provide future researchers with proof that an additional resource exists for land cover validation as well as provide an example of a simplified
validation methodology. Yet, the scope of this study is quite large, and in the chapters that follow, the limitations of this research will be described in detail and provide the elements that were beyond the scope of this investigation.
Chapter 2

Background and Literature Review

This chapter contains three main sections. The first is a background section that details facts describing the history of the Space Shuttle Program. Based on this history, this section also gives a comprehensive account of the astronaut Earth-observation training program. The cameras utilized on the Space Shuttle are also featured in this first section. Section 1 concludes with a literature review pertaining to research already completed on the subject of astronaut acquired photography. The second section yields a thorough depiction of the land cover map that served as the basemap for this research and from which six other maps were derived. This section concludes with a literature review focusing on past validation efforts. The third section of this chapter illustrates the application of the background and literature review to the research completed in this dissertation.

2.1. History and Role of Aerial Photography in Earth Observation and Land Cover Map Creation

2.1.1. Map Creation from Ground Observations

In the past, maps were made from simple, human observations. Some of the first land cover maps were made not by scientists or biologists but by farmers and frontiersmen. White (1953) noted that Robert Beverly in 1705, an early Virginia farmer, documented the geomorphic variations between the area of Virginia, which is now designated as the piedmont, coastal plain, and folded Appalachians. In 1951, White
also brought forward the important publication by Lewis Evans titled *Map of the Middle British Colonies*. This 1755 publication appears to be the first effort to demarcate geomorphic regions as they are commonly portrayed today.

In addition to White and Evans, two men from this era can be singled out as those who broadly classified and mapped landscapes: J.P Lesley and Major J.W. Powell. Possibly Lesley’s most noteworthy mapping contribution was a 15 square foot map of the United States upon which he completed his interpretation of all obtainable information on the topography of the United States. In finishing this effort, Lesley created a geological map of the region west of the Mississippi for the report of the United States and Mexican Boundary Survey (Hall and Lesley, 1857). This report was based on the results of a boundary survey as well as Pacific Railroad surveys and other expeditions. Powell also contributed to the field of geomorphology, especially in the western United States. Among Powell’s significant contributions was his paper in 1895 titled *Physiographic Regions of the United States*. This paper was the first endeavor to segregate the entire United States into geomorphic regions as they are currently pictured in most atlases.

2.1.2. Map Creation from Early Aerial Photography

Thirty-seven years before the completion of Powell’s 1895 paper, the first aerial photograph of Paris was acquired by Gasper Felix Tournachon from a hot air balloon in 1858. The camera technology was eventually developed further in the 1860’s,
when balloons were altered to hold camera systems that mapped forests in the American Civil War. After the American War, in 1887, the Germans began conducting research with photography for the purpose of forest delineation. With the completion of this research, they developed photogrammetric techniques for measuring features and areas. Therefore, it was during the late 1800’s that the union of land cover mapping and photography took place.

While aerial photography from balloons had become commonplace, Albert Maul obtained the first aerial photograph from a rocket in 1906. Only three years later, Wilbur Wright captured the first aerial photograph from an airplane flying over Centocelli, Italy. After this early experimentation with aerial photographs, there was an increased interest in utilizing them for creating military maps during World War I. During World War II, more sophisticated techniques in Aerial Photographic Interpretation (API) were developed. At that time, Germany led the world in photographic reconnaissance. Germany had considerable success with V-1 rockets, radar, and vegetation indicators, which revealed troops and machinery.

2.1.3. Map Creation from Early Rockets, Manned Earth-Observations, and Satellites

With these advances from aerial photography to rocket-based image acquisition, advances were made toward not only orbital automated, Earth-observation but also manned Earth-observation. In 1946, the first photographs from space were taken
from V-2 rockets. In the 1950’s, there were major advances in sensor technology to access imagery displaying the multispectral range of the electromagnetic spectrum. A decade later, the first astronaut acquired photography was obtained of the Earth’s surface. The launch of the first Earth Resources Technology Satellite (ERTS-1) occurred in 1972. This system was eventually renamed Landsat-1. It carried a Return Beam Vidicon (RBV) and a multispectral scanner (MSS). Since 1972, there have been many private and government sponsored satellite imaging systems. These systems include but are not limited to: platforms with polar-orbiting versus sun-synchronous capabilities, sensors that create images from pulses of energy directed at the Earth (radar), sensors that allow for thermal imaging for fire detection, as well as many combinations of sensitivities within the electromagnetic spectrum (Jensen, 1996). The satellite imaging system that is utilized in this research in called Landsat-5. The second imaging system utilized in this dissertation is astronaut acquired photography. The following sections outline the history of each system. Details specifying image and photographic properties, as well as spectral and spatial characteristics of these systems can be found in Chapter 3: Materials and Methods.

2.1.4. Earth Observation Photography

The exploration of the Earth’s surface from space was initially achieved using both standard and custom-built classified camera systems. When the United States’ Space Program began, there was not much Earth observation with camera systems, but instead a focus on public-relations glossy prints of launches, factories where booster
rockets were being assembled, and of astronauts being trained. The United States government sought the support of the people to back their manned space flight ventures. On the first missions to space, astronauts did not take cameras with them. This changed with the historic flight of John Glenn orbiting the Earth in 1962. With a drugstore camera, Glenn was the first American to take pictures of the Earth and space from orbit. There was a great deal of skepticism as to whether unmanned satellite sensors would be useful when taking pictures of Earth weather patterns and pictures of distant planets as well. Soon after these first experimental flights with both manned and unmanned imaging platforms, photography became ingrained into the Space Program. As a result, thousands of pictures were acquired of the moon’s surface to determine the best landing site for future manned Apollo missions (Dickson, 1977).

It is interesting to note that there has been an ebb and flow of interest in these pictures. In the beginning of the United States’ Space Program, administrators believed such pictures to be of little value, detracting time from the essential duties of an astronaut. After this initial disinterest, preparations for the Apollo missions’ landing on the moon proved the necessity of these pictures. As the Space Program developed, and increasing numbers of unmanned sensors began orbiting the Earth to gather data, astronaut acquired photographs became less utilized. Currently, with an increased focus in mapping the landscape and establishing an International Space
Station in Earth’s orbit, interest in astronaut acquired photography is once again on the increase.

2.1.4.1. **Space Shuttle Earth Observation Photography (SSEOP), A History**

The launch of Sputnik on October 4, 1957, the world’s first artificial satellite, engineered by the Soviet Union, began the “Space Age”. The launch of Sputnik had an enormous influence on the United States and their Western allies. It became clear that if the Soviet Union had rockets able to carry a satellite into space, they could also distribute nuclear weapons worldwide. In the United States, top priority was placed on launching an American satellite into Earth’s orbit and producing an operational long-range missile. With this top priority status, the United States launched its first satellite, Explorer 1, in 1958. The Explorer 1 Team consisted on: Dr. William H. Pickering, Dr. James A. Van Allen and Dr Wernher von Braun. Explorer was the first satellite created by the United States that was launched on a Jupiter-C rocket, with the technical experiments of Van Allen.

There was public interest as well as government interest for classified projects in imaging the Earth from space. In February 1958, President Eisenhower approved the Corona Project. The project’s purpose was to take pictures from Earth’s orbit of the Soviet Bloc countries and then de-orbit the photographic film for processing and as an aid to military operations. While in orbit, Corona acquired photographs with a constantly rotating stereo panoramic camera system and then loaded the exposed
photographic film into recovery vehicles. The Corona recovery sequence is shown in Figure 1 (http://www.nro.gov/index7.html, 2000).

**Figure 1.** The Corona recovery sequence of the photographic film it collected while in orbit.

Based on public interest as well as covert, military interest, aerospace research was separated into two divisions. The first division was the National Aeronautics and Space Administration (NASA); it was created in 1958 to achieve the peaceful exploration of space and to carry out fundamental aeronautics research. The second division was the Department of Defense (DOD). This group became accountable for
research and development in the subject of aerospace military activities
(http://www.jrotc.org/aviation_history.htm).

When these divisions were created, it was hoped that maps of the Earth would be completed and become available to the public. However, the majority of the funding for these Earth observation programs came from the intelligence world for their surveillance projects. Therefore, once satellites were deployed which were camera-equipped, the cameras, their film, and all ensuing photographs were classified (Burrows, 1989). All remained classified until recently, when an Executive Order was published to commence the ultimate declassification of the photography from the CORONA, LANYARD, and ARGON camera systems (Burrows, 1998).

Despite this recent Executive Order, the majority of the Department of Defense’s activities have continued to remain classified. NASA was, and continues to be, very much in the public eye however, and human space flight is still its most publicized pursuit. There have been six major phases of human space flight throughout U.S. history, they are the following NASA programs: the Mercury Program (1961-1963), the Gemini Program (1965-1966), the Apollo Program (1968-1973), the Skylab Program (1973-1974), the Apollo-Soyuz Test Project (1975), and the Space Transportation System which began in 1981.
2.1.4.1.1. The Mercury Program

Project Mercury was the United States' first attempt at launching a human being into space. The objectives of the program, which made six manned flights from 1961 to 1963, were explicit:

(1) Place a manned spacecraft in orbital flight around the earth;
(2) Investigate man's performance capabilities and his ability to function in the environment of space;
(3) Recover the man and the spacecraft safely (Dickson, 1977).

Shortly after the above goals were attained for the Mercury project, a number of guiding principles were created to insure that the quickest and safest approach for realization of the objectives was followed. The principal guidelines that were established are as follows:

(1) Existing technology and off-the-shelf equipment should be used wherever practical;
(2) The simplest and most reliable approach to system design would be followed;
(3) An existing launch vehicle would be employed to place the spacecraft into orbit;
(4) A progressive and logical test program would be conducted (Dickson, 1977).
A more detailed list of requirements for the spacecraft were established as follows:

(1) The spacecraft must be fitted with a reliable launch-escape system to separate the spacecraft and its crew from the launch vehicle in case of impending failure;

(2) The pilot must be given the capability of manually controlling spacecraft attitude;

(3) The spacecraft must carry a retrorocket system capable of reliably providing the necessary impulse to bring the spacecraft out of orbit;

(4) A zero-lift body utilizing drag braking would be used for reentry;

(5) The spacecraft design must satisfy the requirements for a water landing (Dickson, 1977).

The Mercury unmanned missions preceded the manned missions. A list of the manned and unmanned missions can be found in Appendix B.

The Mercury Program constituted a number of firsts in space flight: the first United States citizen in space, and the first photography taken by a human in space. Alan B. Shepard, Jr. was the first American in space onboard the Freedom 7 and launched May 5, 1961 9:34am Eastern Standard Time (EST). He achieved an altitude of 116.5 statute miles, remained above the Earth for 15 minutes and 28 seconds, and went a distance of 303 statute miles at a velocity of 5,134 miles per hour (mph). Astronaut John Glenn took a camera purchased in a drugstore with him on the flight of the
Aurora-7 on May 24, 1962 and acquired photographs of terrestrial features and meteorological phenomena. Those amateur photographs became the first Earth observation photographs taken by an astronaut in history (NASA SP-45, 1963). On a 1963 mission the Hasselblad camera was tested for the first time in space. (Dickson, 1977).

2.1.4.1.2. The Gemini Program

The Gemini Program took place directly after the conclusion of the Mercury Program from 1965-1966. Gemini consisted of 12 manned missions, as well as 2 unmanned flight tests of the equipment. Like the Mercury Program, Gemini Program leaders established very specific goals; these are shown below.

(1) To subject equipment and human beings to space flight for up to two weeks in length;
(2) To rendezvous and dock with other orbiting vehicles and to maneuver the docking vehicles by utilizing the target vehicle’s propulsion system;
(3) To precisely establish a methodology of entering the Earth’s atmosphere and landing at a pre-selected point on land.
The Gemini Program goals were met, with the exception of a landing on solid Earth (3), which was cancelled in 1964. There were two Gemini unmanned missions that preceded the manned missions, these were GT-01 Gemini I and GT-02 Gemini II. The manned missions of the Gemini Program are listed in Appendix B.

The only difficulty in the success of this flight was that the mission of Gemini-Titan 1 was much shorter than its actual trip. Only the first three orbits were part of the flight plan. When Spacecraft 1 passed over Cape Kennedy for the third time, approximately 4 hours and 50 minutes after launch, the first Gemini flight came to a formal close. The spacecraft had originally been predicted to orbit Earth for three and a half days. However, because of its somewhat higher than planned orbit, it in fact remained in orbit for almost four days.

Most of the photography was organized through two science experiments, Synoptic Terrain Photography and Synoptic Weather Photography. The objective of the first experiment was to obtain high-quality pictures of significant land areas that had been previously well mapped by aerial photography and to serve as a standard for interpretation of photographs of unknown areas of Earth, the Moon, and other planets. In addition to this, the overall goal was to collect high-quality photographs of comparatively poorly mapped areas of Earth to answer questions pertaining to continental drift, structure of the Earth's mantle, and overall configuration of the continents. This was achieved with a 70 mm modified Hasselblad camera, model
500C, with 55 frames per roll of film. This flight yielded 100 high-quality terrain photographs (http://www.hq.nasa.gov/office/pao/History/SP-4203/appd1.htm).

The second major experiment was the Synoptic Weather Photographic Test. The objective of this photography was to supplement information taken from meteorological satellites. At that time, satellites usually took photographs from an altitude of 643.7 km (400 n.m.) or more; Gemini photos were taken from altitudes of approximately 161 km (100 n.m.) (http://www.hq.nasa.gov/office/pao/History/SP-4203/appd1.htm). The same camera was used in this experiment as for the Synoptic Terrain Photography experiment. Overall, approximately 200 pictures proved to be useful in achieving the goals of this project. Many of the best photos were published in NASA (1967) and NASA (1968). In terms of the photography gathered from this flight, this was a triumph and major achievement for the astronauts. The foci of the astronaut acquired photography were divided into several categories: Geology, Oceanography, Weather and Water Resources. A description of each category is listed in Appendix B.

2.1.4.1.3. The Apollo Program

The Apollo Program began in 1968 and extended to 1973. The motivation of this program was simple: to reach the moon and claim it with an American Flag before the Russians did so. The focus of the Apollo program intended to place humans on the Moon and carry the astronauts safely back to Earth. Apollo Missions 11, 12, 14,
15, 16, and 17 achieved this goal. Apollo Missions 7 and 9 were Earth orbiting missions. Their objective was to test the Lunar and Command Modules; they did not retrieve any lunar data. Apollo Missions 8 and 10 tested a variety of apparatus while in the Moon’s orbit. Missions 8 and 10 also took photography of the lunar surface. Apollo 13 could not land on the Moon due to a malfunction, but returned photographs. All six missions that landed on the Moon retrieved an abundance of scientific data and nearly 400 kilograms of lunar samples. Experiments completed during these missions included soil mechanics, magnetic field studies, meteoroid collection, heat flow experiments, seismic studies, lunar surface exploration, and solar wind experiments (http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo.html).

"That’s one small step for a man, one giant leap for mankind."

Astronaut Neil Armstrong spoke these words on behalf of the entire United States as he stepped onto the lunar surface. However, the Apollo Mission goals went beyond landing Americans on the Moon and returning them safely to Earth, they were:

1. To attain superiority in space for the United States;
2. To complete a program of scientific exploration of the Moon; and
3. To improve humankind's ability to work in the lunar environment.

The Apollo Program goals were met, and the United States accomplished the long sought after lunar landing (http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo.html). A
list of the unmanned and manned Apollo missions can be found in Appendix B.

Shown in Figure 2 is the holding place for the instruments and camera systems taken on the Apollo missions. The highlighted areas illustrate the photographic capabilities of this mission (Eppler, 2000).

**Figure 2.** Apollo Mission Scientific Instrument Module.
2.1.4.1.4. The Skylab Program

By 1969, NASA had successfully flown humans to the moon and brought them back safely. The next phase in space exploration was to examine the possibility of humankind as space settlers. However, one unknown factor was how well humankind could adapt to long-term space exploration. Based on this unknown fact, NASA began the Skylab Project. The Skylab program began in 1973 and lasted only one year through 1974. It was to be much larger than either Gemini or Apollo space capsules. On such a vehicle, astronauts could assume certain aspects of “normal life” that would potentially adapt them to long periods in space. The initial plans for Skylab were that astronauts would work for eight hours, sleep undisturbed for an interval of time, and have free time for relaxation. What actually occurred was astronauts had extended work shifts, and few constant sessions of sleep. Three successful crews stayed for record-breaking lengths. The Space Shuttle was to be built and serve as a “bus” for transporting crew and materials to Skylab as well as future space flights. Unfortunately, the Shuttle was not built in time and NASA saw Skylab’s re-entry into the Earth’s atmosphere on July 11, 1979 (Osman, 1983).

There were three crewed flights in Skylab and one unmanned. During these flights, the astronauts had access to an onboard data book and a world map exhibiting the locations that were utilized by the astronauts as ancillary information for the features and phenomena that were identified by scientists during preflight training. These
men used the binoculars (10x), handheld Hasselblad (70mm) and Nikon (35mm) cameras. The lens and camera combinations provided wide, medium, and narrow fields of view. Color exterior Ektachrome film was employed almost exclusively for astronaut acquired photography. However, the small number of frames taken with Ektachrome color-infrared film was usually not as satisfactory as natural color. The Skylab 4 crew accomplished a “first” in space by acquiring stereo photographs of a sequence of eruptions of the Sakura-Zima Volcano in Japan.

In summary, three three-man crews occupied the Skylab Space Station for a total of 171 days, 13 hours. Skylab acted as a platform for almost 300 scientific and technical experiments: solar observations, medical experiments and observations of human adaptation to zero gravity, and many exhaustive Earth resources experiments. An empty Skylab Space Station re-entered Earth’s atmosphere July 11, 1979, spreading debris across the Indian Ocean and the thinly settled region of Western Australia (http://science.ksc.nasa.gov/history/skylab/skylab.html). Figure 3 depicts an artist’s rendition of the Skylab Space Station.
Figure 3. Cutaway depiction of the Skylab Space Station.

2.1.4.1.5. The Apollo-Soyuz Test Project (ASTP)

The Apollo-Soyuz Test Project was the first international effort in the United States history of space flight. On May 24, 1972, President Nixon and Premier Aleksei N. Kosygin signed a five-year “Agreement Concerning Cooperation, that would lead to a goal of a 1975 test mission which involved Apollo and Salyut (later Soyuz) in the Exploration and Use of Outer Space for Peaceful Purposes” (Burrows, 1998). The primary focus of this project was to test the compatibility of rendezvous and docking systems for American and Soviet spacecraft. What this project achieved was a
strategy for potential international rescues in space as well as future joint manned flights between the United States and the Soviet Union (http://science.ksc.nasa.gov/history/astp/astp-goals.txt). In terms of photography, there were also a series of experiments called the Earth Observations and Photography Experiment. The objectives of these experiments were to test the abilities of the camera systems as well as astronaut and cosmonaut ability to examine areas of the earth that had changed over time. There were predetermined terrain features photographed and documented during Skylab 4 two years previously. This experiment tested the crew’s abilities to identify and document those same features on this mission. Details of this project included the use of special color wheels that were created to permit astronauts to distinguish between colors of terrain features. Another interesting aspect of these tests was the use of high-altitude aircraft, which were flown with cameras to photograph the same target sites as those focused on by the Apollo-Soyuz crew. The purpose of this exercise was to examine and compare the visual perception and photography of the sites from Apollo-Soyuz to that of high-altitude photographs (Cloud, 1995). This project lasted for only one year: 1975.

2.1.4.1.6. The Space Transportation System (SSEOP)

The Space Shuttle flights began in 1981 and continue today with multiple purposes behind each mission. Currently the main function of the Shuttle and the astronauts is outfitting the International Space Station (ISS). Up until this point, however, the Shuttle has had an extremely varied history in terms of its astronauts, scientific
experiments, and photography of the Earth as well as other celestial bodies. The small fleet of Space Shuttles include the Atlantis, Endeavor and Columbia (the Challenger malfunctioned and was accidentally destroyed in January, 1986).

In terms of photography, all the Shuttles have the same capability for viewing out of the available windows. The cameras that have been employed onboard the Shuttles include the Linhof Aerotechnica 4x5 large format camera, and the Hasselblad 70-mm cameras. There have been experimental camera systems taken onboard Shuttle missions such as the European Space Agency’s Metric Camera flown in 1984. There was also an experiment which involved combining a digital camera with a HERCULES orientation system. This arrangement combined camera orientation and space shuttle position at the exact time the photograph was taken to calculate the coordinates of the resulting image (NASA-STS-70, 1995). More recently, there have been radar missions completed onboard the Shuttle called SIR-C. These radar readings from the Shuttle were combined with photographs from the Linhof cameras. The two SIR-C missions, completed in 1994, yielded more photographs than any preceding Shuttle mission (Cloud, 1995). Even more recently, the important radar exercise called the Shuttle Radar Topography Mission (SRTM) was completed from the Space Shuttle Endeavor in February 2000. The objective of this project was to produce digital topographic data for 80% of the Earth's land surface (all land areas between 60° north and 56° south latitude), with data points located every 1-arc second (approximately 30 meters) on a latitude/longitude grid. The absolute vertical
accuracy of the elevation data was 16 meters (at 90% confidence). This data from C-Band is still being processed at EROS Data Center and should be available sometime in 2002 for public use (USGS, 2001).

During all Shuttle missions, there have been a number of photographs taken of either the Earth or outward towards the stars and solar system. With the creation of the SSEOP program and the construction of the Shuttle fleet, there has been an increased interest in documenting phenomena in space as well as on Earth. There are at present more than 400,000 photographs from all the Space Shuttle missions combined. All of these archived photographs of the Earth, space and the moon are held at the NASA Johnson Space Center (JSC) in Houston, Texas. With permission, it is possible to view and scan these photographs from the negatives of the Linhof and Hasselblad (as well as other experimental camera systems) into a digital format that may be used for analysis. Each photograph has metadata associated with it so that the user can query, from the Internet, the vast numbers of photographs to find the exact area and date of interest. This search engine was established by JSC employees and can be accessed several different ways via the Internet: by a clickable map, geographical text, a technical search, browse by mission-roll-frame, select cities from space, or outstanding selections already chosen under the title Earth From Space. To access this search engine go to the following Internet address:

http://eol.jsc.nasa.gov/sseop/
Based on this history of Earth observations in the American Space Program, it is important to understand how astronauts are trained to use the camera systems. The following section describes how astronauts are trained to utilize Shuttle camera systems as well as how to identify target locations from space.

2.1.5. Earth Observation Training

“NASA astronauts began making earth observations with the first Mercury suborbital flight in 1961. The present working procedures, information, equipment, and training provided to orbital observers have been developed within NASA because of gradual operational improvements and scientific experimentation during the Mercury, Gemini, Apollo, Skylab, Apollo-Soyuz, and Space Shuttle Programs. The objective of these improvements over time has remained constant, that is, to enhance human capabilities to acquire scientifically meaningful and systematic Earth observations data while in orbit” (Helfert, 1989).

Astronaut preparation, in terms of taking photographs from the Shuttle, begins on the ground with a preflight, Earth Observations Training Manual which gives detailed site descriptions of each location to be photographed. This manual splits the site descriptions into four major parts: significance of the site, physical characteristics of the site, observation techniques for the specific site, and a previous Shuttle photograph of the site, if available (Earth Observations Training Manual, STS-51). They are then assisted by “photottrainers” who train the astronauts to identify specific
land cover characteristics. These “phototainers” show the astronauts how to handle the cameras as well as the software that accompanies the instrument. A training manual, which details the hardware and software of camera operation, is taken onboard. When onboard the Space Shuttle, the astronauts have an orbital chart of their particular mission available to them, which has the designated sites highlighted for the astronauts. Onboard they also have a 1:10,000,000-scale atlas. Each day, they receive “flight notes” which include a weather satellite image showing where the least and most cloud-covered areas of the globe will be. This image translates into which designated sites will be available for photographing and which will not. The astronauts also receive daily updates on ephemeral events that require documentation (Lulla, 1998).

2.1.6. Camera Systems Used Onboard Shuttle

With this ancillary information, the astronauts are then able to manage the camera systems described in the following paragraphs.

2.1.6.1. Linhof Aero Technika Cameras

NASA technicians have customized the Linhof cameras to function in zero gravity onboard the Space Shuttle. This camera employs a five-inch film format, and is outfitted with transposable lenses (250 mm and 90 mm). A data-recording module (DRM) is also mounted to the camera to record the date, time (Greenwich Mean Time), roll number, mission number, and frame number for all photographs. The
Linhof camera is utilized to obtain earth-observing photography through four viewing ports on board the Shuttle (http://edc.usgs.gov/glis/hyper/guide/shuttle).

**Figure 4.** The Linhof Aero Technika Camera

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### 2.1.6.2. Hasselblad 500 EL/M 70-mm Cameras

In addition to the Linhof camera, NASA has also tailored traditional off-the-shelf Hasselblad 70 mm cameras to operate in zero gravity onboard the Space Shuttle. A data-recording module (DRM) has also been installed on each camera to record the date, time (Greenwich Mean Time), frame number, mission number, and roll number. These cameras require a 70 mm film format and function with one of three lenses (50, 100, or 250 mm) to acquire high quality photographs through four viewing ports on the Shuttle (http://edc.usgs.gov/glis/hyper/guide/shuttle).

**Figure 5.** The Hasselblad Camera
2.1.6.3. LFG – Large Format Camera

The LFC was a high altitude, aerial mapping camera that was upgraded to perform from the Space Shuttle in Earth-orbital altitudes. LFC requirements incorporated a film format size of 9 x 18 inches (23 x 46 cm), a lens aperture of F/6.0, a lens focal length of 12 inches (30.5 cm), and an exposure interval of 7.5 seconds. The exposure range for this system was 1/250 to 1/31.25 seconds. It ground resolution was 20 meters at 160 nautical miles. And finally, the LFC’s ground coverage was 120 x 240 nautical miles at 160 nautical miles (http://edc.usgs.gov/glis/hyper/guide/shuttle).

Figure 6. Large Format Camera

![Large Format Camera Image]

2.1.6.4. Return Beam Vidicon (RBV)

Return-beam vidicon (RBV) is a system in which images are created on the photosensitive surface of a vacuum tube. The resulting image is then scanned with an electron beam and transmitted or recorded. The return beam vidicon (RBV) is a framing camera system that acts like an instantaneous television camera. It has not had the same recognition as the Multispectral Scanner (MSS), despite the fact that it yields valuable information. Landsat 1 and 2 carried three RBVs that obtained red,
green, and solar IR images of the same scene as the MSS did. It was capable of producing color IR images with 80-meter spatial resolution, the same as the MSS, but was unquestionably inferior due to technical issues that arose. Landsat 3 included an RBV system that acquired single black and white images in quadrants of the MSS scene in the 0.50mm to 0.75mm waveband, a spectral response which ranges from the green through red. The ground resolution was 40 meters. This was a large improvement on the existing MSS and the earlier RBV resolution. This improvement enabled the detection of natural hazard evidence at a larger scale (Primer on Natural Hazard Management in Integrated Regional Development Planning, 1991).

Cameras and photographic techniques have improved since the days of the Mercury. These improvements allow astronauts to combine their photographic training with new developments in software that accompany the missions. For example, there is an onboard program, WORLDMAP, which prompts the astronauts to ready the cameras before the designated site comes into view (Reilly, 1998). The Hasselblad camera and video are always present on each mission. The Hasselblad lens has a 100 mm transparency with 167x167 km coverage. A 250 mm transparency lens is also available which has 67x67 km coverage. The Linhof camera lens can have 75 mm, 135 mm, or 250 mm options with coverage of 361x483 km, 201x268 km and 108x145 km coverage, respectively (Lulla et al. 1996). Film types generally range from color infrared to color visible.
2.1.7. Research Based on Astronaut Acquired Photography

The training of the astronauts combined with improved technology and advanced onboard software increase the possibility of providing more information per each photograph detailing scientifically significant and ephemeral events. For example, in June 1991, Mt. Pinatubo, one of the 20 active volcanoes in the Philippine Islands, erupted. This was one of the largest global volcanic events of this century, and has recently been noted as responsible for lowering global temperature. A photograph of Mt. Pinatubo and the surrounding area was taken by a Shuttle crew in 1982 (STS3-10-567), before the eruption. The Space Shuttle Earth Observations Photography Database (SSEOP) has a series of post-eruption photographs of this volcano. The time series begins in December 1991 (STS044-82-33) and continues until 1993 (STS055-151A-184). These series of photographs clearly document the large areal extent of the area directly affected by the blast, and those areas covered with ash. This time series is being utilized to document the dispersal of debris, ash and mudflows around the mountain after two tropical storms and a second eruption in July 1992. Another example of an ephemeral event documented and researched employing Shuttle imagery is the study conducted by Evans et al (1999) concerning the 1997-1998 El Nino. The researchers analyzed the photographs obtained during this period representing the 1997-1998 El Nino impacts and thus allowed a visual assessment of the effects of this recurring, intense weather pattern. A final example of documentation of a common episodic event is research conducted by L.M. Shipilova documenting eddy formation in the Caspian Sea. These eddies are a result
of the collective effects of hydrological parameters, various atmospheric conditions, and coastal influences. Eddy formation is an important function to understand because these eddies affect local currents, sediment deposition, nutrient quantity and dispersal, plankton levels, and pollution movement.

Referring to long-term studies, Shuttle and Skylab photography have been used to map the areal magnitude of Amazonian smoke palls linked to biomass burning (1973-1988). From these photos, Helfert and Lulla (1990) have been able to assess that the area surfaced by these smoke palls has expanded from approximately 300,000 sq km in 1973, to continental size smoke palls measuring nearly 3,000,000 sq km in 1985 and 1988. A second example of a long-term study is the research of A.S. Shestakov concerning land-use changes in the northwest Caspian coastal area during 1978-1996. This study was based on Shuttle photography in conjunction with field studies, cartographic materials, aerial photographs and regional statistical data. From this data, Shestakov determined that rising seas have been the reason behind the flooding of 150,000 hectares of agricultural lands. A third example of a long-term scientific investigation involves shoreline dynamics and the hydrographic system of the Volga Delta by Alekseevskiy et al. (2000). Alekseevskiy et al. determined changes in this area over the past 200 years based on historical data as well as Space Shuttle photographs and other sources of space-based imagery.
The documentation of urban change in cities is another application of Shuttle photography. In spite of the fact that there are a multitude of consecutive, astronaut acquired photographs of cities as well as other areas around the world, there have been relatively few papers written in scholarly journals documenting urban change using AAP as a resource (Robinson, 1998). However, there is a recent study by Robinson et al (2000), which examines twenty-eight years of urban growth in North America quantified by an analysis of photographs from Apollo, Skylab, and Shuttle-Mir missions. This research introduces a rapid method for estimating urban area employing a time series of photographs taken from low Earth orbit. The reason for this may be that only until recently has there existed a way for researchers to orthorectify space shuttle photographs. Once these photographs have been digitally orthorectified, they are useful for discovering phenomena of interest as well as gathering quantitative measurements of various regions of the Earth’s surface (Zheng et al, 1997).

With this extensive ground training, onboard manuals, and increasing quantitative research, it is clear that astronaut acquired photography can assist in the identification of specific types of land cover change and, potentially, the immediate local causes of such change. These facts logically lead to the importance of human controlled space photography. There has been a shift toward satellite digital imagery such as that afforded by Landsat, SPOT or NOAA Polar Orbiter’s AVHRR. A marketing survey attests that approximately 74 percent of Landsat imagery is ordered as hardcopy
photographs for end user photointerpretation (EOSAT, 1994). This means that experts are bringing to the table their photointerpretation skills, combining this proficiency with the expertise of a satellite analyst and producing scientifically acceptable output from orbital photographic analog data (Helfert, 1989).

The advantage of human-controlled photography is multiple: observing an episodic event as it occurs and documenting it from several different angles or alerting scientists to undocumented human-induced change in regions hard to access on Earth are two such advantages. The extent to which Shuttle crew photography can assist in the identification of specific types of land cover change was part of the fact-finding mission of this study. Dr. James Reilly, who was part of the January/February, 1998 crew docking with the MIR Space Station related that forested terrain, grasslands, farmlands and deserts are very easy to pick out. He also pointed out that human modification to an area, natural vegetation alteration, for example, are also easy to separate from the surrounding landscape. Dr. Reilly stated that if the air quality is good, with a 400 mm lens it is possible to see detail to the level of a city block, or individual buildings, depending on the altitude (Reilly, 1998).

Therefore, with advances in camera systems, improved software technology of and the enhanced astronaut training programs for Earth-observing photography, this type of research will continue.
Despite the recent increased interest in utilizing AAP for research purposes in the past several years, it had still not been employed for map validation. The research completed in this dissertation utilized the AAP as one reference data source to validate land cover maps, thereby filling that niche. The following section gives a comprehensive background on the basemap used to generate the three land cover maps utilized in this study. A complete description of the three land cover maps validated in this study can be found in Chapter 3, Materials section.

2.2. Global Land Cover Characteristics Database

The North American Land Cover Characteristics Dataset is a part of the global Seasonal Land Cover Characteristics (SLCC) Database that is being developed on a continent-by-continent basis. Every continent in the global data bases share the same map projections (Interrupted Goode Homolosine and Lambert Azimuthal Equal Area), have 1-km spatial resolution, and are based on 1-km AVHRR data spanning April 1992 through March 1993. This 12-month image composite is created from the Normalized Difference Vegetation Index (NDVI) and is related to the proportion of photosynthetically absorbed radiation.

NDVI is calculated from atmospherically corrected reflectances from the visible and near infrared AVHRR channels as:

\[(\text{CH2} - \text{CH1}) / (\text{CH2} + \text{CH1})\]
Where CH1 is the reflectance in the visible wavelengths (0.58-0.68 um) and CH2 is the reflectance in the reflective infrared wavelengths (0.725-1.1 um). The principle behind this is that Channel 1 is in a part of the spectrum where chlorophyll causes considerable absorption of incoming radiation, and the Channel 2 is in a spectral region where spongy mesophyll leaf structure leads to considerable reflectance (Tucker 1985 and Tucker et al. 1986). The unsupervised classification of multitemporal NDVI clusters together pixels that have similar seasonal characteristics. This clustering applies to all of the land cover maps produced; it is simply the combination of land cover classes that is different.

Each continental database has unique elements that are based on the prominent geographic aspects of the specific continent. In addition, a core set of derived thematic maps produced through the aggregation of seasonal land cover regions is included in each continental database. These are listed below:

- Global Ecosystems (Olson, 1983, 1985);
- IGBP Land Cover Classification (Belward, 1996);
- U.S. Geological Survey Land Use/Land Cover System (Anderson et al, 1976);
- Simple Biosphere Model (Sellers et al, 1986);
- Simple Biosphere 2 Model (Sellers et al, 1996);
- Biosphere-Atmosphere Transfer Scheme (Dickinson et al, 1986).
For all datasets listed above, the following characteristics apply and are important considerations.

(1) Although the AVHRR data are reported as having 1.1-km spatial resolution at nadir, because of scan-angle effects and the maximum value compositing technique, the actual spatial resolution is considerably diminished. The mean pixel area is approximately 1.59 to 1.85 km, and the minimum mapping unit can be conservatively estimated at 3.5 to 4.0 km. When deliberating whether a landscape feature should be represented in the dataset, one should establish the spatial extent of the feature and its relative influence within at least a 2x2 km region.

(2) The second major limitation of this dataset is the classification technique, which was used to generate the (NDVI) clusters from the AVHRR imagery. This classification technique inherently produces a certain amount of confusion around class boundaries that is difficult to eliminate when generating global class categories (Loveland, 1998).

(3) A third limitation of this dataset illustrates factors that could affect the derived land cover map classification accuracy. The original data quality of the AVHRR NDVI composites used to create the Seasonal Land Cover Database should be noted. Duggin and Robinove (1990) present a thorough review of the many data quality elements that affect image classification. In that review, sensor radiometric
calibration, atmospheric effects, and sensor spectral and spatial response functions are identified as fundamental variables that influence image classification. Sensor spectral and spatial response functions and radiometric calibration commonly have an equal affect on most data. The AVHRR data utilized to create the Seasonal Land Cover Database were always calibrated employing post-launch calibration coefficients (Teillet and Hoblen, 1993). Therefore, all data used in the creation of the Seasonal Land Cover Database had equivalent radiometry. Additionally, the pre-launch performance of the AVHRR sensor is very well documented (Rao, 1987). Therefore, while sensor performance is imperfect, it can be assumed to have been consistent in all AVHRR data used to create the Seasonal Land Cover Database (Loveland, 1998).

(4) There are also atmospheric effects that could have affected the original AVHRR image composites used to classify the Seasonal Land Cover Database. These effects vary in both space and time, and thus may have had a considerable impact on the consistency of the classification. Eidenshink and Faundeen (1994) summarized the AVHRR composite development process that incorporated atmospheric corrections that, in theory, lessen or remove numerous atmospheric artifacts, especially those caused by Mie scattering and variable ozone concentrations (Loveland, 1998). Mie scattering results from wavelengths of light interacting with relatively large particles in the atmosphere (as big as a wavelength or larger).
(5) The scientists at Eros Data Center (EDC) who generated this base dataset caution that many land cover types share similar seasonal characteristics. Separating these land cover types is usually performed by using other characteristics derived from ancillary earth science information, such as elevation or ecoregions. Despite these efforts to separate disparate land cover types in this manner; pixels occasionally escape this interactive scrutiny. These pixels often occur far from the main group of their parent cluster and are of a very different land cover type. Therefore, their misclassification stands out starkly. For example, urban and suburban areas, occurring even in temperate climates, are sometimes represented as desert shrubland or barren lands. Although they are obviously not of this land cover type, they do, indeed, have little surface vegetation and have similar seasonality to desert lands.

(6) The sixth limitation of the North American portion of the SLCC dataset is its scale. Because the data are serving a wide variety of users, it was determined early on that a flexible database approach would have to be taken. This approach accommodates many different types of users by providing translation tables to several widely used classification schemes. The technique is to first categorize land cover at the finest detail possible and define these areas as seasonal land cover regions (SLCR). The AVHRR images were combined with elevation and ecoregion data to classify North America into 205 seasonal land cover regions (SLCR). These 205 regions were then mapped into the classes specified by each of six standard land cover schemes. Therefore, these 205 regions were yielded from one type of
classification algorithm and then were reclassified to one of the six coarser land cover characterization schemes previously listed. All of the classification schemes were derived from a global data set, with approximately 1-km spatial resolution. It is extremely important for the user to realize these two facts when formulating questions of the data. Is it logical to ask a local question within one state from data assembled on a global basis? Could it be problematic to try to obtain a detailed analytical result when working in a small area surrounding a major river from this global data set? Solutions to these questions completely depend on the user’s needs.

The first global validation was performed using a land cover map derived from the global seasonal land cover characteristics database. The global validation utilized the IGBP land cover map. Details of each land cover map derivation can be found in Chapter 3, Materials Section. The importance in understanding the methodology used in the IGBP global validation effort was that those methods served as a baseline for the methods presented in this dissertation research.

2.2.1. IGBP DISCover Validation

In 1998, the International Geosphere Biosphere Programme (IGBP) completed the first independent validation ever conducted to determine the accuracy of the IGBP DISCover global land cover data set. To validate this global 1-Km scale land cover data set, derived from Advanced Very High Resolution Radiometer (AVHRR) data, Landsat Thematic Mapper (TM) imagery was used by expert interpreters to validate
the dominant land cover type within a 1-km area (Belward et al. 1996). One kilometer uses the minimum mapping unit for the DISCover data set. A full explanation of the IGBP DISCover methodology is given in Chapter 3, Methods and Materials.

The methodology presented in the following chapter is based on the International Geosphere-Biosphere Data and Information System (IGBP-DIS) Global 1-Kilometer Land-Cover Data Set (DISCover) validation that was completed in 1998. The IGBP DISCover validation was a global study, whereas this research is only regional, but both are based on the same data. The DISCover validation procedure also used only Landsat TM imagery whereas this study uses both TM and astronaut acquired photography as the reference data. These two sources of validation data offer a new perspective on accuracy assessment. Not only is a known (TM) being compared to an unknown (AAP) in terms of a source of reference data, but this study also confirms the ability of a user to utilize AAP in a quantitative manner. The other major difference between the DISCover validation method and the procedure presented here is not only utilizing expert interpretation but additionally employing a parallelepiped algorithm to classify different land cover classes at a given sample point. Lastly, the final difference is the use of a Khat statistic, taken from the parallelepiped confusion matrix results. These differences and similarities will be reviewed in the following chapter.
Chapter 3

Materials and Methods

This chapter is divided into two major sections: materials and methods. The materials section describes the materials chosen for this study, the reasons supporting those choices, and the limitations of the materials chosen. The materials section also describes the rationale behind the selection of the research area as well as the land cover classes chosen in this study. The second section in this chapter describes the methods used, why these methods were chosen, and any limitations of these methods.

3.1. Materials

The materials necessary to address the hypothesis were three land cover maps, Landsat TM imagery, and astronaut acquired photography. The three land cover maps were the components that were validated. The Landsat TM imagery and the astronaut acquired photography were the reference data sources used to validate the land cover maps.

3.1.1. Land Cover Maps

The three land cover maps utilized in this research were derived from the Land Cover Characteristics Database, described in Chapter 2. The three land cover maps used in this study were the USGS Land Use/Land Cover System, International Geosphere Biosphere Program (IGBP) DISCover Land Cover System, and the Major World Ecosystem Complexes Ranked By Carbon In Live Vegetation: A Database (Figure 7).
Figure 7. The figure below shows the North American portion of the Global Land Cover maps used in this research.

The reasons supporting the choice of these three land cover maps were based on several factors. The motivation behind the choice of the IGBP DISCover land cover map was that it was a map that had been validated previously. The validation methods used in that effort were the basis for the methods that were employed to complete the research presented in this dissertation. Additionally, the IGBP land cover classification system only has 17 land cover classes, the USGS land cover
classification system has 24 and the Olson’s Global Ecosystem Land Cover Database has 94 land cover classes. It was of interest to discover if there were differences in the results due to a high versus low number of land cover classes. The details of each land cover map are described in the following pages.

3.1.1.1. USGS Land Use/Land Cover System

The United States Geological Survey (USGS) began the inventory and mapping of land use and land cover at a scale of 1:250,000 in 1975. The USGS established a methodological framework using the capabilities at that time, which included:

- Landsat Multispectral Scanner (MSS) imagery,
- High resolution, color-infrared aerial photography obtained from high altitude platforms (like the U2),
- Panchromatic, color-infrared, and color aerial photography obtained from low altitude flights, and;
- Corona and successor systems.

In terms of a multilevel classification system, Anderson et al. (1977), were the first to address the need for such a system based on remotely sensed imagery. According to Anderson, for this type of system, the following requirements must be met:

(1) Both activities (land use) and resources (land cover) should be classified.
(2) The minimum level of accuracy in identifying land-use and land-cover categories from remote sensing data should be at least 85 percent.
(3) The accuracy of interpretation for all categories should be approximately equal.

(4) Repeatable results should be obtainable from one interpreter to another and from one time of sensing to another.

(5) The system should be applicable over extensive areas.

(6) The system should be usable for remote sensing data obtained at different times of the year.

(7) The system should allow use of subcategories that can be derived from ground surveys or from larger-scale remote sensing data.

(8) Aggregation of categories should be possible.

(9) Comparison with future land-use data should be possible.

(10) Multiple land uses should be recognizable.

The system that is developed can be used depending on the needs of the user in terms of scale and type of image that fit the goals of the project (Sabins, 1997). Three levels resulted from this classification. The levels I and II have been modified since the original definition of Anderson et al in 1976. Level III categories were adapted from those characterized by the Florida Bureau of Comprehensive Planning (1976). These three levels can be viewed in Appendix A, Table 1.

There are advantages and disadvantages of using this classification scheme, much of which has to do with the definitions of the categories. Differentiating between land
and water may appear to be simple, until land cover classes such as wetlands, beaches or marshes are considered. A second concern is those classes that inherently are mixed or have similar spectral signatures. The spectral signature difference among beaches, sand and gravel other than beaches and exposed rock may be very small. There may also be a high percentage of class mixing because of association among different land cover classes. For instance, if the user is employing coarse resolution satellite data, it may not be possible to separate Level III differences between light and heavy industrial. In addition to this, several uses of a parcel of land introduce another quandary to the interpreter. For example, (191) Undeveloped land within urban areas may closely resemble a park (172). It is important that the researcher note the differentiation presented not only by the classification system but also create some of their own categories derived from that system (Sabins, 1997).

Despite these potential disadvantages, this classification system has much to offer. It allows the researcher to apply its categories to a multitude of different instrument calibrations and scales. This system can be used with satellite imagery, high aerial photography and low aerial photography at different spatial and spectral resolutions. Both the commercial as well as the academic sector have utilized Anderson’s classification scheme. These categories, at all three levels, can provide the base for various environmental modeling endeavors, landscape/atmosphere interaction models, land cover change analyses, and urban growth research, for example. Anderson and others at the US Geological Survey clearly broke very important,
needed ground for the mapping community when they presented this classification system to the public and private sector in 1976.

3.1.1.2. International Geosphere Biosphere Program (IGBP) DISCover Land Cover Legend

The IGBP DISCover classification scheme is based on the Land Cover Working Group (LCWG) global land cover requirements consisting of 17 separate land cover classes. These classes were identified based on the requirements of the Core Projects and the well-known limitations of the AVHRR data regarding the separation of diverse land cover types. The Core Projects were scientific ventures funded by the IGBP Programme that helped establish global data needs in terms of a lack of data for specific global efforts. Some examples of these projects include: the Biospheric Aspects of the Hydrological Cycle (BAHC), Global Change and Terrestrial Ecosystems (GCTE), and Land Ocean Interactions in the Coastal Zone (LOICZ). The classification scheme has been evaluated at LCWG workshops and by the IGBP Core Projects who plan to employ the new global land cover database. The land cover categories established by the IGBP are linked to the needs of gas exchange research, vegetation attributes for modeling Net Primary Productivity (NPP), burn emissions and gas exchange, wetlands cover and wetland water regimes, changes in vegetation/land cover over time, biological attributes, physical attributes, and landscape characteristics (Belward, et al, 1999).
The imagery for the DISCover classification map was produced on a continent-by-continent basis. An unsupervised classification was run on a 12-month collection of 30-day AVHRR Normalized Difference Vegetation Index (NDVI) maximum value composites. Clustering was executed via a variant of the K-means algorithm, optimized for use with extremely large image data sets. Image classification personnel then decided on the land cover classes and distinctiveness associated with each cluster category. Based on interpretation, clusters consisting of two or more classes are separated into single land cover types. To assist in the interpretation procedure, spectral, emissive, and NDVI temporal synopsis from the AVHRR 1 Km database, elevation statistics, and climate summaries were computed for each cluster. All clusters were then allocated a final land cover class category. This interpretation procedure was repeated until image classification personnel reach an agreement on land cover type assignments. In this way the process of land cover class assignment to cluster is optimized to reflect the unique environmental and cultural influences that form the landscape of each continent (Belward, 1996). A comprehensive list of all 17-land cover classes can be seen in Appendix A, Table 2.

As is the case with the Anderson levels, there are advantages and disadvantages to using this land cover classification. One of the disadvantages of using this system is the fact that the classes are quite broad. For instance, cropland in the IGBP classification system encompasses dryland/cropland/pasture, irrigated cropland and pasture, and some water bodies in the Anderson Level II categories. Another aspect
of the IGBP system that is of interest to a user and could prove to be a disadvantage or advantage, depending on user requirements, is the fact that these IGBP categories were determined by running a classification on 1-km imagery. This is very coarse imagery. The lack of fine resolution may not be a problem if the user needs to perform a global analysis. However, this classification system may not be appropriate for someone doing research over a very small area looking for a high number of land cover classes. Another element concerning this system that could affect the science in either a positive or a negative manner is the fact that this classification was run on a 12-month collection of NDVI composites. If a user is seeking a dataset that comprises only one time of year and excludes seasonal variation, this is not the system for them. If however, the user desires a classification system that incorporates spectral seasonality at a global scale, this map is ideal.

3.1.1.3. Major World Ecosystem Complexes Ranked by Carbon in Live Vegetation: A Database

The Olson Ecosystem Map, as it is more commonly known, was first established in 1980. It consists of 94 separate land cover types. This database and the resultant map were finished after more than 20 years of field investigations, consultations, and examination of published literature. They differentiate the use and vegetative cover of the Earth's land surface with a 0.5° × 0.5° grid. The data include latitude, longitude, and a vegetation code. This world-ecosystem-complex data set and the associated map offer a current reference base for understanding the role of vegetation
in the global cycling of CO₂ as well as some additional gases and a basis for better estimates of vegetation and soil carbon, of natural exchanges of CO₂, and of net historic shifts of carbon between the biosphere and the atmosphere (Olson, Watts, and Allison, 1985).

The cells of every type in each 0.5-degree latitude band, in addition to adding their areas over latitude bands, yield total area estimates for these ecosystem complexes. A number of independent area estimates are brought together by Olson et al. (1983) and confirm the hypothesis that some earlier estimates of forest area and forest contribution to global carbon inventories were apparently overestimated. Current estimates of the range in density of carbon- per-unit area are discussed in Olson et al. (1983). Multiplying the low, medium, and high-density estimates by ecosystem area gives corresponding estimates of the global total carbon by ecosystem complexes.

Estimating the inventory of carbon in major world ecosystems and the exchanges with the atmosphere and other major reservoirs has been approached in two ways by Olson. The first approach involved developing broad global patterns and associates vegetation types with climatic or other environmental factors independent of local disturbance. The second technique developed modern regional or stand-type estimates and is based on analyses of current vegetation and land-use practices. This method uses updated resource maps of natural vegetation, forestry surveys, agricultural yields and human, economic, and geopolitical considerations. Both
approaches were applied in the development of Olson’s ecosystem map (Olson, 1982).

There are advantages and disadvantages to using Olson’s land cover scheme. It largely depends on the motivation of the end-user as to whether some aspect of this classification system is negative or positive. This map is clearly advantageous to a scientist whose aim is to analyze vegetative aspects of global carbon cycles. The data contained in these maps provide users with a baseline for improved estimates of vegetation and soil carbon, and of natural exchanges of carbon dioxide as well as net historic shifts of carbon between the biosphere and the atmosphere. Olson’s map also shows that tree formations still hold most of the plant carbon. Therefore, this map is excellent for those interested in modeling of global biomass as carbon sinks. There are limitations to this map however. The limitations of this map are important to note by end-users because they can potentially restrict the level of research that can be posed based on the data contained in the map. The first restriction of this map is the fact that the estimated areas for carbon sinks are made up of averages across an area. Since these are regional or large-area averages, a user wanting to pose a science question using Olson’s data over a local area would be better suited by a more locally generated map and classification system. A second limitation of this map is the scale. It was generated using AVHRR satellite imagery that has approximately a 1-km spatial resolution. Lastly, a major uncertainty lies in the “nonwoods” class concerning the amount of carbon that should be added for scattered trees or woody
inclusions not counted in the “woods” classes. A comprehensive list of all 94-land cover classes can be seen in Appendix A, Table 3.

These three land cover maps have both shared characteristics and dissimilarities. The elements they have in common include the imagery from which they were generated. To review, this was the Advanced Very High Resolution Radiometer sensor. All of these maps are global in nature and can be utilized in a myriad of global modeling efforts. Aside from the spatial and spectral similarities of these maps, there are several important differences. Clearly, from the descriptions above, there are differences in the number of land cover classes. The different total number of land cover classes was dependent on the clustering algorithm used by Anderson, Olson, and IGBP scientists. The final three maps used here, based on the individual clustering algorithms, not only have a different total number of classes but also have a different total area that defines each land cover type. Arguably the most important aspects of using land cover maps is understanding why they were created, what factors went into choosing the different land cover classes, and how they have been utilized in the past. A user should be acutely aware of these “picture elements” before making use of any map for a project.

To validate these land cover maps requires the use of reference data. The two types of reference data that were utilized in this research were Landsat Thematic Mapper imagery and astronaut acquired photography. Landsat TM imagery was chosen
because it was the primary reference source in the IGBP DISCover validation effort. Since the methodology presented here was based on the IGBP DISCover effort, Landsat TM imagery was a logical choice as a reference data type. It was also selected because numerous studies have used it for many different reasons.

3.1.2. Landsat Thematic Mapper Imagery

The Landsat series made available the first recurring worldwide database with a constant spatial and spectral resolution for many applications (Sabins, 1997). Applications using the Landsat data include but not limited to: land cover change analysis (Sohl, 1999), aerial extent of land cover type (Okamoto and Fukuhsara, 1996), segregation of different vegetation types over a designated area (Foody and Hill, 1996), mineral exploration (Bryant, 1996), and assessing wildfire effects (Pereira and Setzer, 1996). Landsat has been used in scientific applications as a photointerpretation resource as well as a data type on which to perform automated image classification. In addition, Landsat TM imagery was the major source of photo-interpretative reference data for the IGBP DISCover Validation effort (Belward et al, 1999). The IGBP DISCover Validation laid essential groundwork for future attempts at validating land cover maps derived from satellite imagery. Thus, the major advantages in using Landsat data were that it was employed successfully in the IGBP DISCover validation effort; and it has a long and well-documented history of applications.
The Landsat images used in this research were given to the Remote Sensing Research Unit (RSRU) by Eros Data Center (EDC) through the Multi-Resolution Land Characteristics Consortium (MRLC) program. Most of the Landsat data that was utilized was from Landsat 5. This data, because it had already been selected for the MRLC program, was already geocoded and terrain corrected. Geocoding is the process by which the data is resampled to a uniform pixel size that is registered to a geographic coordinate system (Sabins, 1997). Terrain correcting is done to the data through radiometric and geometric corrections using the satellite model and platform/ephemeris information. This is done to improve the geodetic inaccuracy caused by a parallax error that occurs due to local terrain elevation (Sabins, 1997). Those images that were not MRLC data had to be terrain corrected by processes available in Imagine software, all were geocoded, however.

There were also issues concerning the TM data quality that could have possibly affected the results completed in this study. The Thematic Mapper data are received directly from the Landsat sensor by a network of 16 worldwide ground stations. The data are recorded on high-density tapes (HDT) and then processed. The data processing involves first manually and then automatically assessing the data for cloud cover and data quality in terms of noise or bad scan lines, for example. The data is then required to go through another quality screening where it is systematically corrected in the following ways:
• It is corrected and validated for any mirror scan inconsistencies;
• Each scene is provided with image framing by generating a series of scene center parameters;
• The telemetry data is synchronized with video data;
• Any linear motion deviation of mirror/scan line is corrected;
• Specified map projections are generated; and
• Along and across-scan errors are assessed (if they are found).

The next step is resampling the data after the completion of satellite orbit model generation/refinement and radiometric calibration. The resampling includes three separate components: coarse resampling table generation, resampling table densification, and two-dimensional convolution resampling. Coarse table generation consists of calculating relationships between product line/pixel values at a set of grid-points and the corresponding line/pixel values in the raw data. Table densification consists of interpolating similar relationships between the remaining product line/pixel values and the corresponding raw data line/pixel values. Table densification also includes performing a number of corrections to the interpolation to account for various inaccuracies in the raw data. The convolution step involves using the fine table to convolve the output pixel values from the raw data.
Radiometric calibration is the process of converting raw digital numbers (DNs) observed by a sensor into physical units. The radiometric calibration of Landsat TM data is performed in two steps:

(1) Absolute Calibration: the recovery of radiance (as observed by the sensor) from the raw digital number recorded. This involves modeling the characteristics of the optics and electronics of the sensor.

(2) Relative Calibration: the removal of residual errors in the calibrated data to improve the qualitative appearance of the imagery.

This detailed account of the transformation from raw TM data to the images that were used for this effort is to emphasize the point that these are rigorous transformations of the original data. These transformations follow the SDTS standards for reduction in data loss as closely as possible. The implication here is that as closely as data loss standards are adhered to, the more data is transformed, transferred among different hardware and software platforms, resampled, and distorted to fit a worldwide projection, the more potential for data to be lost or changed. That being said, however, these transformations have proved to be an excellent standard because they remove some of the distortions and correct atmospheric interference. There are also continuously evolving methodologies by scientists and engineers to improve sensor calibration and error removal (Teillet, 1993). The details here in terms of
transforming the TM raw data to a usable image are important because each of the astronaut acquired photographs was registered to one TM scene.

3.1.3. Astronaut Acquired Photography

Landsat TM imagery has a well-documented, quantitative history, which has been defined by the many scientific applications using it as the primary data type. Astronaut acquired photography does not have this type of record. The combination of Landsat TM data with AAP places a known against an unknown, respectively. There is a vast database of variable angle, Earth-viewing photographs dating back to the first (American) image captured by John Glenn in 1962, a full ten years before the introduction of Landsat and twelve years before the launch of SPOT-1. Astronaut acquired photography existing this many years before the Landsat program is significant because of its historical perspective. Thousands of high quality, Earth observing photographs exist that cover a period of ten years before the creation of Landsat. Despite the lack of scientific applications linked to AAP, much is known about the characteristics of this type of photography (Lulla, 1996). One of the advantages of astronaut acquired photography over Landsat TM imagery is the multiple look angles obtainable by AAP as opposed to TM, which is always pointed at nadir. A second distinct advantage of AAP is that there is a person behind the instrument. A decision by a person to capture an Earth image at a certain perspective to obtain the best viewing angle or change filters or film to record episodic events are invaluable. While it is important to acknowledge the significance of astronaut
acquired photography, it is even more critical to prove its usefulness in a quantitative manner.

The AAP used in this research was not geocoded nor was it terrain corrected. However, the information to complete both of these necessary tasks was available for each AAP. Both of these processes were done using Imagine software using the platform/ephemeris information from each Space Shuttle flight during which the photographs were obtained. To insure correct geometric information, a point-to-point registration was done, also in Imagine, and this procedure is described at length in both the methods section and in the Appendix.

3.1.4. Study Area

The area that was selected for this project was the southwestern United States. This area extends from Santa Cruz, California south to Baja, Mexico east to Baton Rouge, Louisiana and north to the St Francois Mountains in Missouri (Figure 8, next page). The particular land cover classes chosen were savanna, evergreen needle leaf forest, grassland, vegetation/cropland mosaic, and shrubland. This specific aerial extent and land cover classes were decided upon for several significant reasons. The first reason was that there existed reasonable knowledge of the area in terms of what types of vegetation would likely exist there based on prior knowledge of this area from field experience. This was important in terms of the photointerpretation segment of this
research. Secondly, this area was close enough to Santa Barbara that ground-truthing approximately 10% of the sample point locations was feasible.

**Figure 8.** The figure below shows the extent of the study area for this research.

Third, after extensive research, this area had a reasonable number of cloud-free TM and AAP of the different vegetation types existing the in the western half of the United States. The fourth rationale supporting this study area was the aerial extent offered significant diversity of land cover types. In other words, the area was not so heterogeneous that utilizing a 30-meter resolution TM image would have many mixed pixels it would be impossible to use as a reference source. Yet, conversely, the area
was not so homogeneous that there were only one or two land cover classes existing over the entire region. The fifth reason supporting this choice of study area was that ancillary data of this region was easily obtainable. The last supporting reason for this choice of study area pertained to the issue of seasonality.

This area includes the states of: California, Nevada, Utah, Arizona, Colorado, New Mexico, Kansas, Oklahoma, Texas, Missouri, Arkansas, Louisiana, and 5 Mexican States: Baja California Norte, Baja California Sur, Sonora, Chihuahua, and Coahuila De Zaragoza. The research area provided a diverse enough seasonality that, if this validation effort proved successful, the methodology presented here could not only be used in areas of desert, but also in areas that have strong seasonality. For example, New Mexico has hot and cool temperatures defining its seasons whereas Colorado has spring, summer, winter and fall. These different seasons can also be viewed as different climatic zones. The importance in this fact is to prove that the methodology presented here can be used in more than simply one climate zone in the world. The different climatic zones in the study area are shown in the Figure 9 (http://www.mrgrow.com/content/zonechrt.htm).
Figure 9. The below figure illustrates the various climatic zones existing in the United States.

<table>
<thead>
<tr>
<th>USDA Hardiness Zones</th>
<th>Average Minimum Temperature</th>
<th>Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Below -50°</td>
<td>Zone 1</td>
</tr>
<tr>
<td>Zone 2</td>
<td>-40 to -50°</td>
<td>Zone 2</td>
</tr>
<tr>
<td>Zone 3</td>
<td>-30 to -40°</td>
<td>Zone 3</td>
</tr>
<tr>
<td>Zone 4</td>
<td>-20° to -30°</td>
<td>Zone 4</td>
</tr>
<tr>
<td>Zone 5</td>
<td>-10° to -20°</td>
<td>Zone 5</td>
</tr>
<tr>
<td>Zone 6</td>
<td>0° to -10°</td>
<td>Zone 6</td>
</tr>
<tr>
<td>Zone 7</td>
<td>10° to 0°</td>
<td>Zone 7</td>
</tr>
<tr>
<td>Zone 8</td>
<td>20° to 10°</td>
<td>Zone 8</td>
</tr>
<tr>
<td>Zone 9</td>
<td>30° to 20°</td>
<td>Zone 9</td>
</tr>
<tr>
<td>Zone 10</td>
<td>40° to 30°</td>
<td>Zone 10</td>
</tr>
</tbody>
</table>

3.2. Methods

This section describes the design criteria; specifications and methodology for validating land cover maps using TM imagery and AAP. The determination of the design criteria for this validation effort required consideration of three major elements: (1) accuracy issues; (2) technical considerations; and (3) logistical constraints. These three elements combined to significantly influence validation methods completed in this research. Accuracy standards were affected by the SDTS data requirements for reduction of data loss due to transfer between computing and
software systems. Adherence and execution of these standards is discussed in this chapter. Accuracy assessment, in terms of results, was determined by the methods described in this chapter with reference to the confusion matrix and the Kappa statistic. Technical considerations such as data volume, data quality and landscape diversity, combined with accuracy issues affected the final methodology presented here. Finally, logistical constraints such as computing facilities and time constraints also helped define the final validation methodology. The following sections provide a description of how the methods were developed to test the hypothesis, implementation of the methods, and the limitations of the methods chosen.

3.2.1 Evolution of This Method

The method used here was a derivative of the IGBP methodology. The major differences between the two were that here, the validation area was much smaller, an untested validation data source was carefully assessed, and lastly, the confusion matrix results were rigorously evaluated via the Kappa and Z statistics. These three statistics were used to analyze the results of the automated image classification and the photointerpretation. The following sections describe the methodological steps beginning with the map preparation procedure and ending with the Z statistic.

3.2.2. Map Preparation

As previously described, there were three land cover maps utilized in this research. These three land cover maps are global in extent. Since this study only included the
southwestern United States, this area of interest had to be a subset of the original, global map. This area was subset using the “CLIP” command in ArcView 3.2 to cut out the smaller, study area shown in Figure 8. After the study area was clipped from the larger land cover map, this area was then imported into ArcView and viewed as a (Band Line Sequential) BSQ file type. This file type then had to be associated with a header file. A header file is a file that contains information describing where the image is located on Earth in a projection. Once the header file was created for this clipped area, it was then a file type that was compatible with the ArcView data such as roads, state outline, rivers and cities. This was important in terms of establishing context for the purpose of photointerpretation. Once the subset, land cover basemap was imported into ArcView, five land cover classes were extracted from the land cover map. These land cover classes were extracted in ArcView by selecting only those pixels that represented, according to each land cover map, each of the land cover classes. Once these pixels were selected in the map’s data attribute table, they were exported (in ArcView) to a new file that only contained savanna, evergreen needle leaf forest, grassland, shrubland, and a cropland vegetation mosaic.

There were three land cover maps in this study, and because those three land cover maps have different numbers of land cover classes, it was important to know whether evergreen needle leaf forest in the IGBP land cover classification actually was one or more classes in another classification system. This was true most of the time. Thus, in choosing the land cover classes for extraction, since IGBP was the most general
with 17 different land cover classes, the pixels for savanna, evergreen needle leaf forest, grassland, savanna, shrubland, and a cropland vegetation mosaic were first derived from the IGBP map and exported into a new map only containing those five classes. Then, a dendogram was utilized (Loveland, 1993) to translate from IGBP classes to USGS and then Olson’s Land Cover Classification Systems to make three new maps for validation that only contained five land cover classes. This translation dendogram can be found in Appendix C.

3.2.3. Sampling Procedure

The three maps utilized in this study were already stratified into 17, 24 and 94 different land cover classes or strata. A further division of strata, as described in the previous section, was limited to five land cover classes. To introduce as little bias as possible, stratified random sampling was chosen as the method to obtain sample points. Four additional sampling procedures are commonly used to gather sample points. Based on the following descriptions of each sampling procedure, it is clear that stratified random sampling was the most appropriate choice for this research.

In a simple random sampling procedure, each sample unit in the study area has an equal chance of being selected. In most cases, a random number generator is used to pick random x, and y coordinates to accumulate samples. The chief advantage of simple random sampling is the sound statistical properties that result from the random sample. Systematic sampling is a technique in which the sample units are selected at
some equal interval over the study area. In most situations, the first sample is randomly selected and each successive sample is taken at some precise interval thereafter. The major advantage of systematic sampling is the ability to sample somewhat uniformly over the entire study area. Cluster sampling is also employed to collect many samples quickly. However, merely using sizeable clusters is not a valid method of collecting data, because each pixel is not independent of the other and adds very little information to the cluster. Congalton (1988) suggested that no clusters larger than 10 pixels be used because of the lack of information added by each pixel beyond these cluster sizes. Stratified systematic unaligned sampling is a method which endeavors to join the advantages of randomness and stratification with the ease of a systematic sample, without dealing with the drawback of periodicity common to systematic sampling. Stratified random sampling is similar to simple random sampling. However, some prior knowledge of the research area is used to partition the area into groups or strata, and then each stratum is randomly sampled. In accuracy assessment of land cover characterizations; the map has been stratified into vegetation types or land cover. The major advantage of stratified random sampling is that all land cover types, no matter how small, will be included in the sample.

After the selection of the appropriate sampling procedure, the next step was to determine how many sample points were required to characterize a significant representation of these land cover classes. The formulas required to complete this step as well as the reasons supporting their choice, are shown below.
The numbers of sample points needed are yielded from the following formula:

\[ N = \frac{Z^2(p)(q)}{E^2} \]

Where \( p \) = expected percent accuracy, \( q = 100-p \) and \( E \) is the allowable error, \( Z=2 \) from the standard normal deviate of 1.96 for the 95% two-sided confidence level. Therefore, a sample for which the expected accuracy is 85% at an allowable error of 5%, the number of points essential for dependable results is shown below:

\[ N = \frac{2^2(85)(15)}{5^2} = \text{a minimum of 204 points} \]

(Jensen, 1996).

According to the pioneer paper by Anderson, et al. (1976), one of the classification criteria that a classification system must meet is that the “...minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensor data should be at least 85 percent”. The work completed here was based on this criterion as well as the other nine criteria listed previously. How to get that 85 percent expected accuracy is shown above. The key flexibility that the above formula allows users is the luxury of making the allowable error (E) greater, which then lessens the number of sample points necessary in the study. This is an important flexibility option because although Congalton (1991) suggests that a “good rule of thumb” with sampling is for each land cover class in the error matrix to have 50 samples. However, there were also the issues of time, cost and other practical
limitations that factored into the final number of sample points generated per class for this study. The most important restraint was available, cloud-free AAP and cloud-free, available TM imagery. Therefore, only approximately 25 sample points per land cover class, totaling to 125 sample points total for 5 land cover classes were used. Due to errors with the data that were unforeseen before they were purchased, that total shrunk to 116 total sample points with slightly varied numbers per land cover class. Ultimately, using the above formula, with an allowable error of 6.5%, this yielded 120 sample points. However, with the unforeseen errors taken into account causing those images to be unusable, a slightly higher allowable error was generated to approximately 6.65% yielding 116 sample points, which was the number finally validated. The program that was used to generate the random sample points can be found in Appendix D.

3.2.4. Acquiring the Validation Data

As stated above, the final number of validation sample points was 116. However, the limiting factor in acquiring the validation reference data was the AAP. This was chiefly because the Space Shuttle has only five to six missions per year and, therefore, coverage of the study area would be limited compared to the constant coverage of the TM imagery. Because of this limitation, the number of sample points to start, was 204, as indicated in the formula in the previous section. This higher number was simply to allow extra sample points for some areas where there would be no Space Shuttle coverage of the desired sample point. Therefore, the AAP
acquisition was the starting point for gathering the sample point data because it was the limiting factor in this research. The sections below detail the criteria considered necessary to acquire both AAP and TM imagery for this research. These search criteria were important not only for consistency, but also for the success of this study.

3.2.4.1 AAP Acquisition

The AAP acquisition was completed using a search engine that was available through the Internet. The search engine, called the Space Shuttle Earth Observation Photography database (SSEOP) has several search options including a “Clickable Map”, “Cities from Space”, and a “Technical Search Page”. The Technical Search Page allowed for all the criteria listed in this section to be specified, thus this was the search engine utilized.

There were several set criteria for obtaining AAP. The first criterion was the sample point had to be as close to the center of the photograph as possible. This was accomplished in that each sample point had a latitude and longitude associated with it. Each AAP had a latitude and longitude that marked its center. Therefore, finding a match between these two sets of coordinates was the first criterion. The second criterion was finding cloud-free photography. Cloud-free was not strictly defined by the search engine as “having no clouds” in the photograph. Cloud-free was defined as a range: 0-10%. The third criterion was to find AAP that were obtained during the 1992-1993 period, which was when the original basemap was generated. The fourth
criterion was having the photograph taken “at nadir”. “At nadir” was as close to nadir as possible. The fifth criterion was selecting photographs with a 250mm focal length. This was the most commonly used focal length. The sixth criterion was choosing only those photographs taken with color film. The seventh criterion was establishing that the altitude of the Space Shuttle was between 100-150 nautical miles. The eighth criterion was making sure that the camera utilized was the Hasselblad camera system.

Therefore, it was in this manner that each astronaut acquired photograph was selected. The web page for doing this type of technical search can be found at the following address:

http://earth.jsc.nasa.gov/page.html

Through this website it is also possible to see thumbnail photographs of the full-size photographs. In this way, it was possible to detect any problems with the photographs such as overexposure, underexposure, noise, or clouds directly over the sample point.

After the photographs were selected, a trip to Johnson Space Center was made. During this visit, several key steps were accomplished. The first was to find the selected photographs in the JSC photographic archive. Once the photographs were obtained, they were scanned at 1600 dots per inch (dpi) on a color scanner.
According to JSC personnel, this yielded the best results in terms of a clear, crisp digital image. They were then compressed using Adobe Photoshop and burned onto compact discs. Fifty astronaut acquired photographs were obtained in this manner.

3.2.4.1.1. AAP Processing

After these photographs were acquired, several steps were necessary to import them into ArcView 3.2 and Imagine. All of the photographs were saved in Joint Photographic Experts Group (.jpg) format before they were burned onto the compact disc. They were then compressed, as mentioned earlier, using Adobe Photoshop "Z compression" tool. This is important because neither Imagine nor ArcView 3.2 will recognize photographs or images that are compressed in a "Z" format. These photographs, therefore, must be uncompressed using Adobe Photoshop before they can be viewed. Once this is done for all photographs, the file size increases almost three times, in some cases. The next step involved opening these .jpg photographs in Imagine as well as opening the corresponding TM image in another Imagine viewer so the two are situated side by side. This allows the user to perform a raster-geometric correction to rectify the AAP to the coordinate system of the TM image using a second order polynomial. The resampling method was cubic convolution. In all cases, there were between 40-60 ground control points between the TM image and the AAP. The Root Mean Square Error (RMS) was shown for each sample point and for all sample points combined at the bottom of the screen. As past studies have shown, if the RMS error is kept below 0.10, the resampling will be completed within
acceptable limits as described by Congalton (1991). All of the RMS error that was recorded for this study was well below that value. The exact steps for completing this step are in the Appendix. This rectification also gives the AAP a header file corresponding to TM image so that the two will overlay correctly in ArcView and in Imagine.

This processing not only allowed the photographs to overlay with the TM images, but the photographs were then ready for manual and machine assisted validation processing. These steps are crucial for anyone aspiring to perform this type of research in the future. The Landsat TM images were also acquired and processed in a similar manner, as is discussed in the following section.

3.2.4.2. Landsat Thematic Mapper Imagery Acquisition

The Landsat TM imagery acquisition used the Global Land Information System (GLIS) Internet search engine sponsored and housed by the United States Geological Survey (USGS). The GLIS search page allowed for all the criteria listed in this section to be specified, thus this was the search engine utilized. This website can be found at the following address:

http://edc.usgs.gov/webglis

There were several pre-set criteria for obtaining TM imagery. The first criterion was to obtain cloud-free imagery. This, like the AAP, was defined as a range: 0-10%. The second criterion was choosing the same platform: Landsat 5. The third criterion
was selecting imagery that was acquired during the period between 1992-1993. The fourth criterion matched the sample point latitude and longitude with the center point of the TM image. The fifth criterion established that all seven bands were available for analysis and combination. As previously stated, the MRLC data was already geocoded and terrain corrected. After the TM images were selected through this search engine, an order was placed through EDC. Those images were compressed with WinZip software and burned onto compact discs. Thirty-two TM images were acquired in this manner.

3.2.4.2.1. Landsat TM Processing

After these images were acquired, there were several steps necessary to prepare them for manual and machine assisted validation. The first step was to create a header file for each image. This information came from another file burned onto each image compact disc called a .dda file. This file contained all of the information necessary to create a complete header file. An example of a correct header file format can be found in the Appendix. Once the header file was created, the second step was to take all the bands from the compact disc and save them as one file. The importance in this step is to enable different band combinations to be viewed at one time. Completing this step in Imagine (using the Layerstack command) takes approximately 45 minutes per image. Completing this step in MSDOS (using Append command) takes approximately 5 minutes. After these two steps, the Landsat TM images were then ready for manual and machine assisted validation procedures.
3.2.5. Manual and Machine Assisted Validation

The manual and machine assisted validation procedures incorporate both photointerpretation and supervised image classification, respectively. The reason for executing each type of validation was to identify the specific class of vegetation beneath each sample point. Each TM image and each AAP was subjected to both procedures detailed in this section.

3.2.5.1. Manual Validation

For the manual validation process, standard photointerpretation methods were used for both the AAP and the TM imagery to establish the dominant type of vegetation at each sample point. In photointerpretation, there are eight major recognition elements, as describe by Avery and Berlin (1992), which include: shape, size, pattern, shadow, tone or color, texture, association and site. Almost all of these elements proved useful with the exception of shadow and size. Shadow was not particularly useful because of the coarseness of the images’ spatial resolution. Size was not very informative since most land cover classes tended to occur over vast areas, size was often more a confusing factor than helpful. Shape proved most useful in determining cropland. This was mainly due to the regular geometrical shapes that define agricultural areas as opposed to more irregular, naturally occurring vegetation. Pattern was also helpful because of the repetitive patterns clearly seen in agriculture. Pattern was also useful in determining where fields lay fallow, the transition from
distinct active fields to vague outline of fallow fields was sometimes quite clear.
Tone and color were both valuable when different band combinations were used both with the photographs (RGB) and with the TM images (bands 1-7). Texture was very important in determining evergreen needle leaf forest from surrounding vegetation. Association and site were significant elements in determining whether a given land cover class truly belonged in a certain area. For example, a pixel indicating cropland on top of Mt. Shasta clearly has been classified in error. These recognition elements were significant in determining the dominant type of vegetation beneath each sample point.

In addition to these recognition elements, there was ancillary information that aided in the identification of the vegetation class at each sample point. This ancillary information included high aerial photography, SPOT imagery and numerous vegetation atlases. Furthermore, there existed previous field excursions to numerous locations including the areas containing the sample points, thus, prior knowledge of many areas of the southwest existed before this research began. Supplementing this knowledge was the training of many local botanists, university and forest service staff who had ample education in terms of the local flora.
Figure 10. The figures below illustrate an example of three data sources.

In Figure 10, both types of reference data are used. The red dot on each image shows the location of the same sample point. The USGS land cover map indicates that the dominant land cover class at this sample point is shrubland. The location of the sample point is Santa Cruz Island in the Channel Islands Marine Sanctuary, California. In this case, field excursions to the site support this "shrubland class" interpretation. Photointerpretation of both the AAP and TM data showed shrubland as well. Therefore, there is total agreement between the two sources of reference data and the land cover map. This agreement, or in some cases disagreement, is described later in this chapter in the statistics section. This manual photointerpretation was done for each of the fifty astronaut acquired photographs and each of the thirty-two TM images.

At this point in the methodology, the AAP and the TM image have been imported successfully into ArcView, overlain in the same coordinate system, and have the
same sample points distributed on their surface. What is not shown is the ability of the software to show numerous band combinations (three at a time) to help the interpreter differentiate among the various land cover types that exist in this area of the United States. The bands that were used most frequently for photointerpretation of the TM imagery were combinations of bands 1, 3, 4, 5 and 7. The only bands that were available for the AAP were the red, green and blue portions of the electromagnetic spectrum. Figure 11 summarizes the results of the data processing to this point.

**Figure 11.** The figure below illustrates data overlay.
The next major portion of the data processing was the machine-assisted classification of the TM imagery and the AAP. These steps are described in the following section.

3.2.5.2. Machine Assisted Validation Procedure

The second major data-processing segment of this research was the machine assisted validation procedure. For the automated validation process there were specific standards used. The machine-assisted validation consisted of choosing a supervised classification algorithm to classify images and photographs based on training sites. A supervised classification algorithm assigns unidentified pixels to one of \( X \) number of classes. The choice of the parallelepiped supervised classification algorithm was based on several important factors.

According to Jensen (1996), the parallelepiped classification algorithm is computationally efficient and uses training sites defined by the user. Since there were a large number of both photographs and images to be processed by this algorithm, computational efficiency was important in terms of time conservation. The definition of training sites by the user was important because in future applications of this method, astronauts and technical support teams would be choosing the training sites. This future application is discussed in detail in the last chapter. The training sites specify an acceptable range of spectral signatures representing a land cover type. In the determination of the dominant type of vegetation at each sample point, a 3-band combination was utilized for the TM data. For each band of the TM images, an
acceptable range for each of the land cover classes was defined. The upper and lower
thresholds of these ranges are known as decision boundaries. Based on these ranges,
if a pixel value lay above the lower threshold and below the upper threshold for all
three bands evaluated, that pixel was assigned to that class. When an unknown pixel
did not fall within any range of acceptable brightness values in any band, it was
assigned to an unclassified category. A two standard deviation threshold was utilized
in the determination of the classes for this research. The standard deviation was
subtracted and added to the mean of each class (+/- 2) thus; in this manner, each band
could identify the lower and upper edge of the parallelepiped thresholds. Therefore,
only a predetermined range of spectral signatures was acceptable for each band, for a
pixel to be assigned to a given class. This was the supervised classification process
completed for the Landsat TM images.

For the classification of the astronaut acquired photography, the training data was
also based on an acceptable range of values. However, in this case the parallelepiped
supervised classification was based on a minimum and a maximum set of values
represented only in the red, green and blue portions of the electromagnetic spectrum.
The range for the AAP was also +/-2 standard deviations. Therefore, in order for a
pixel to be classified into a given land cover category, it had to fall into the acceptable
ranges for that class in the red, green and blue bands.
For both the TM images and the AAP, the same training site locations were used. These training sites were first determined in the TM image and then applied to the same area in the AAP. This consistency was to ensure that no location bias would be included when training the algorithm. The training sites established the ranges for water, urban, shrubland, cropland/vegetation mosaic, savanna, evergreen needle leaf forest, and grassland, if all of these categories appeared in that area. At times there were a reduced number of categories if some of these land cover types did not exist in the given area.

After the supervised classification algorithm was trained, it processed both the AAP and the TM scene were analyzed to produce an outcome (Figure 12).

Figure 12. Comparison of the supervised classification processing stage for TM and AAP.

Landsat TM – Lake Powell

AAP – Lake Powell
These two images show the result of running a supervised classification algorithm on these areas specifically classifying water (blue), savanna (light & dark green), shrubland (pink), and forest (dark maroon). This process was completed on fifty photographs and thirty-two TM scenes.

For each of the 116 sample points, the process of photointerpretation and supervised image classification was completed. The results of determining the dominant type of vegetation beneath each sample point were placed in statistics that used these results to assess the accuracy of the three land cover maps utilized in this research.

3.2.6. Validation Statistics

In this section, the results of detecting the vegetation class at each sample point are utilized in statistics that determine the accuracy of the three land cover maps employed in this dissertation. These results were placed in confusion matrices, and Kappa and Z statistics were computed. The reason for utilizing these specific statistics was to identify significant differences between using AAP and TM imagery as a reference data source.

3.2.6.1. Confusion Matrix

The confusion matrix is also called a truth table or an error matrix. It is a classic way of assessing map accuracy in that the individual accuracies of each land cover class are plainly described along with both the errors of inclusion (commission errors) and
errors of exclusion (omission errors) present in the classification (Congalton & Green, 1999). This matrix can also be used to calculate overall map accuracy, producer’s accuracy and user’s accuracy. These calculations are determined by assessing the agreement or disagreement between the classified data and the reference data. The columns in this matrix represent the reference data while the rows indicate the classified land cover map (Congalton, 1983). In this research, both the TM and the AAP were the reference data while the land cover maps were the classified data. Therefore, when using sample points, attempting to measure accuracy of land cover maps, and comparing different types of reference data, the first, basic statistic that can incorporate all those functions is the confusion matrix.

Congalton (1988) reviewed different higher level accuracy assessments all based on data generated from the results of an error matrix. Based on this review and others, the error matrix has become a remote sensing standard upon which all other accuracy assessments are based.

There is another significant reason supporting the use of an error matrix. The error matrix allows for both subjective as well as quantitative measurements to be made. In this research, both photointerpretation and image classification were performed. The error matrix allows for a comparison of not only the types of reference data used, but also how they were used. In both types of pixel classification, however, there is room for subjective error. There are potential problems with subjectivity because of
the choice of training samples for the supervised classification algorithm, and the
subjectivity of the photointerpreter based on experience and availability of other
ancillary data of these areas (Smits et al, 1999). However, part of the importance of
this study was to compare the human observer to the machine assisted classifier to
assess the differences in the outcome of agreement and accuracy. Thus, the
incorporation of this potential error was meaningful in the outcome of this study. A
representation of the confusion matrix is shown in Figure 12 as described by Stehman
(1999):

**Figure 12.** Error matrix where $p_{ij}$ represents the proportion of area mapped in land
cover class $i$ and reference land cover class $j$, and $q = \#$ classes.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>...</th>
<th>4</th>
<th>5</th>
<th>...</th>
<th>q</th>
<th>6</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classified Map Data</td>
<td>$p_{11}$</td>
<td>$p_{12}$</td>
<td>...</td>
<td>$p_{14}$</td>
<td>$p_{15}$</td>
<td>...</td>
<td>$p_{1q}$</td>
<td>$p_{1+}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$p_{21}$</td>
<td>$p_{22}$</td>
<td>...</td>
<td>$p_{24}$</td>
<td>$p_{25}$</td>
<td>...</td>
<td>$p_{2q}$</td>
<td>$p_{2+}$</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>q</td>
<td>$p_{q1}$</td>
<td>$p_{q2}$</td>
<td>...</td>
<td>$p_{q4}$</td>
<td>$p_{q5}$</td>
<td>...</td>
<td>$p_{qq}$</td>
<td>$p_{q+}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$p_{q+}$</td>
<td>$p_{q+}$</td>
<td>...</td>
<td>$p_{q+}$</td>
<td>$p_{q+}$</td>
<td>...</td>
<td>$p_{q+}$</td>
<td>$p_{q+}$</td>
<td></td>
</tr>
</tbody>
</table>

Also according to Stehman (1999), in order to ascertain overall map accuracy the
following formula is used:

$$p_e = \sum_{i=1}^{q} p_{ii}$$

where $q = \text{number of land cover classes.}$
User's accuracy, the probability in which an region classified as land cover type $i$ by the map is classified as $i$ by the reference data can be established by the following formula:

$$P_{ui} = P_{ui}/P_{i+}$$

Producer's accuracy, which can be defined as the probability that a region classified as land cover type $j$ by the reference data is classified as class $j$ by the map can be found using:

$$P_{aj} = P_{aj}/P_{+j}$$

(Stehman, 1999)

The confusion matrix results can be misleading however, because of its generality and the fact that it does not include all of the data that the matrix offers (Fitzgerald, Lees, 1994). Therefore, it is necessary to take the accuracy assessment a step further with the Kappa test.

3.2.6.2. Kappa Statistic

The Kappa test is a discrete multivariate technique that yields a Khat statistic. This Khat statistic, an estimate of Kappa, is a measurement of agreement or accuracy. The Kappa analysis shows whether the agreement between the reference data and the land cover classification was strong, moderate or poor. Determining this agreement is dependent upon utilizing the results from confusion matrices. The Khat computation
includes the off-diagonal elements as a product of the row and column marginals whereas the confusion matrix only includes diagonal elements and summations of rows and columns. The resulting Khat value demonstrates how well, or poorly, the agreement was between the reference data and the classified data. These values can range from +1 to −1. Positive values are usually expected because this would indicate a positive correlation between the two. Landis and Koch (1977) characterized the potential ranges for Khat into three groups: >80% denotes strong agreement, 40-80% denotes moderate agreement, and <40% denotes poor agreement between the reference data and the remotely sensed classification (Congalton and Green, 1999). Because the Kappa analysis incorporates data not included in confusion matrix results, depending on the amount of error contained in the matrix, these two tests may not agree (confusion matrix results and Kappa results).

Additionally, the Khat value can be included in a third statistic that can reveal more information in terms of comparative accuracy assessment. The statistic reveals whether the reference data (for both the AAP and TM imagery) yielded better than a random classification of those sample points analyzed. This is done for each independent error matrix. This is then taken a step further by establishing if two independent error matrices, via their Khat values, are significantly different (Jensen, 1996). With this test, called the Z statistic, it is possible to statistically compare two classifications, two algorithms, or even two dates of imagery and to see which provides the higher overall accuracy. Therefore, the application of the Kappa statistic...
in this research tells us whether, for any given sample point, Shuttle photography yields better, the same, or worse accuracy assessments than Landsat TM. If it is proven that Shuttle data yield the same accuracy as Landsat TM, then we can assume that for some land cover classes: it is possible to utilize AAP in lieu of Landsat TM data. The results of these statistics show the varying degrees of accuracy between the different reference data but also produce a comparison of human interpretation skills and human-produced algorithms that separate land cover classes into distinct groups.

The Kappa statistic is computed as:

$$Khat = \frac{\sum_{i=1}^{r} x_{i,i} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})}$$

$r$ = number of rows in matrix

$x_{i,i}$ = number of observations in row $i$ and column $I$

$x_{i+}$ and $x_{+i}$ = are the marginal totals for row $i$ and column $i$ respectively

$N$ = the total number of observations

(Jensen, 1996).

There are additional tests that one can do to further assess map accuracy but the Kappa test seemed the most appropriate for this study according to Congalton (1983, 1988, 1991), Congalton & Green (1999), Fitzgerald, & Lees (1994), Rosenfeld, &
Fitzpatrick-Lins (1986), Jensen (1996), and Dellepiane, Smits, & Schowengerdt (1999). According to all these studies, Kappa is a better estimate than the overall accuracy, user’s accuracy and producer’s accuracy (provided by the confusion matrix) because the Kappa formula encompasses row and column elements in addition to those included in those three agreement assessments. Therefore, while the values yielded from the Kappa statistic generally show less agreement in the matrix between reference and classified data, this is a more accurate picture of all the error included in the matrix.

3.2.6.3. Z Statistic

The Z statistic uses the Kappa value result and statistically determines two things:

1. If one error matrix is significantly different than another, and
2. If the results from the error matrix were significantly better than a random result.

In order to test if two error matrices are significantly different, the following formula can be used to obtain a “Z” statistic:

\[
Z_A = \frac{|\hat{K}_1 - \hat{K}_2|}{\sqrt{\text{vår}(\hat{K}_1) + \text{vår}(\hat{K}_2)}}
\]
To calculate if an error matrix provided better than a random result, the following formula is used:

\[ Z_B = \frac{\text{Khat}_1}{\sqrt{\text{vår}_1(\text{Khat}_1)}} \]

The calculations for variance (vår) are quite extensive and are described in detail in Smits, (1999).

At the 95% confidence level (see 3.2.3.), the discriminating value is 1.96, thus, if the absolute value of \( Z_A \) is greater than 1.96, the result is significant, and the classification is better than a random result. The same value, 1.96 is used to determine if two error matrices are significantly different. If the resulting \( Z_B \) is greater than 1.96 doing the pairwise analysis of two error matrices, then these matrices are significantly different. If the resulting Z value is less than 1.96, they are not significantly different.

In sum, the three analyses that were used to measure accuracy assessment in this research include the confusion matrix, the Kappa statistic and the Z statistic. With these three measurements, it was possible to conclusively determine the following things central to this study:

1. How well the land cover maps were validated,
2. The differences and similarities between utilizing different sources of reference data,
(3) Whether there was a significant difference in using one reference type as opposed to another, and;

(4) If the classifications were better than a random result.

The results of the three above accuracy assessments are shown in the following chapter.
Chapter 4

Results

This chapter summarizes the results in three main sections. The first section displays examples of the classified images and, comparatively, the photointerpretation of TM and AAP that were used to determine the vegetation type at each sample point. The second section is a summary of the confusion matrix statistics. The full statistics are quite lengthy and therefore are shown in Appendix H. The third section summarizes the Kappa and Z statistic results in tabular format. In the second two divisions of this chapter, the results are fully described. A discussion of these results is presented in Chapter 5.

4.1. Usage of TM Image and AAP

There were 116 sample points in this research. As described in Chapter 3, at each sample point there was a Landsat TM image and an AAP to deduce the land cover class. For illustrative purposes, several figures are shown as examples of images and photographs used in both manual and machine assisted classification of the dominant vegetative class at each sample point. They are portrayed in ArcView 3.2, along with streams, rivers, roads, cities and states. For brevity, not all 72 photographs and images are shown.
Figure 13. Data Summary for the Texas/Mexico border.

Texas/Mexico Border

Figure 13 illustrates an example of the overlay of reference source data. In this example, the sample points are shown in yellow and represent grassland. The smaller box is the AAP and the larger image is a TM scene. This figure shows all the data processing steps up through and including the integration of data types, importation into ArcView 3.2, and full access to all seven bands in the TM image as well as all three bands in the astronaut acquired photography. Bands 1, 4, and 7 were used in this display. The red, green and blue bands were employed in the AAP. The second stage of the data processing is shown in Figure 14.
Figure 14. Classified images for Texas/Mexico border.

Figure 14 illustrates all data processing up through and including the supervised image classification of both AAP and TM images. In this example, shrubland (red), grassland (yellow), shrubland (dark green), savanna (light green) and cropland (orange) are characterized in the classification results.

The next example (Figure 15) illustrates another case of the entire data processing procedure. This example shows the area surrounding Lake Powell, on the border of Arizona and Utah.
Figure 15. Complete example of the reference data processing for the Lake Powell region.

For Figure 15, the following classes were established: water (blue), shrubland (light and dark green), grassland (pink and gray), and savanna (gray). The supervised classification algorithm was trained to produce land cover classifications for water,
urban, grassland, shrubland, evergreen needle leaf forest, savanna and a
cropland/vegetation mosaic. If it did not find any of those specified pixels, it created
an unclassified category that appeared in white. From these supervised classifications
of the AAP and the Landsat TM images, as well as the photointerpretation of the
unprocessed images and photographs, the results for the confusion matrices were
established. The results from this data processing determined what type of vegetation
occurred at each sample point. Those results are summarized in the following pages.

4.2. Confusion Matrix Summary

The results in Table 1 are an example of a confusion matrix.

**Table 1.** The matrix below represents the results from utilizing AAP as the reference
source data to photointerpret the each sample point.

<table>
<thead>
<tr>
<th>Reference Data (right)</th>
<th>AAP (P.I.)</th>
<th>row total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classified Data (below)</td>
<td>E.N.F.</td>
<td>Shrub</td>
</tr>
<tr>
<td>IGBP L.C. Map</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.N.F.</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>Shrub</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>Grass</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Crop Veg</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Savanna</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>column totals:</strong></td>
<td><strong>19</strong></td>
<td><strong>25</strong></td>
</tr>
</tbody>
</table>

P.I. = Photointerpretation
L.C. = Land Cover
E.N.F. = Evergreen Needle Leaf Forest

The confusion matrix shows a rectangular array of rows and numbers that express a
number of sample points assigned to a particular category in one classification
relative to the number of sample points assigned to a particular category in another
classification. The reference data, in this example, are from AAP.
In the top row, there were two sample points that were classified as evergreen needle leaf forest, when the reference data showed that they were shrubland. Additionally in the top row, there were three sample points that were classified by the IGBP land cover map as evergreen needle leaf forest when the reference data showed that they were actually in the cropland/vegetation mosaic land cover class. With these two pieces of information it is possible to state that five sample points from the evergreen needle leaf forest class were omitted from their correct category and committed to another, incorrect category.

The statistics that can be directly derived from the confusion matrix include the Producer’s Accuracy, User’s Accuracy and Overall Map Accuracy (Table 2).

**Table 2.** Overall Map Accuracy, Producer’s and User’s Accuracy for data shown in Table 1.

<table>
<thead>
<tr>
<th>Overall Map Accuracy</th>
<th>Producer’s Accuracy</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Map Accuracy</td>
<td>E.N.F. = (15/19) = 78.94%</td>
<td>E.N.F. = (15/20) = 75%</td>
</tr>
<tr>
<td></td>
<td>Shrubland = (17/25) = 68%</td>
<td>Shrubland = (17/24) = 70.83%</td>
</tr>
<tr>
<td></td>
<td>Grassland = (19/32) = 59.35%</td>
<td>Grassland = (19/26) = 73.07%</td>
</tr>
<tr>
<td></td>
<td>Crop_veg = (12/18) = 66.66%</td>
<td>crop_veg = (12/21) = 57.14%</td>
</tr>
<tr>
<td></td>
<td>savanna = (18/22) = 81.81%</td>
<td>savanna = (18/25) = 72%</td>
</tr>
</tbody>
</table>

Overall Map Accuracy is a very general accuracy assessment. It is the sum of the major diagonal (the correctly classified sample points) divided by the total number of sample points in the entire confusion matrix. Producer’s Accuracy is computed by dividing the total number of correct sample points in one category by the total number
of sample points as indicated by the reference data. For example, the total number of correct sample points for evergreen needle-leaf forest is 15, that number is divided by the total number of evergreen needle leaf forest sample points as indicated by the reference data: 19. User’s Accuracy goes a step further by dividing the total number of correct sample units in the evergreen needle-leaf forest category (15), by the total number of sample points identified as evergreen needle leaf forest (20). What this information yields is that although 78.94% of the evergreen needle-leaf forest sample points have been correctly identified as evergreen needle leaf forest, only 75% of the areas called evergreen needle leaf forest on the map are actually evergreen needle leaf forest on the ground.

I expected that there would exist a difference in the results for map validation of the three land cover maps. This would have resulted in twelve confusion matrices, four per map. However, since there was no difference in the matrix results among the three land cover maps, there are only four resulting confusion matrices (Table 3). In other words, although there were differences in the results utilizing the two sources of reference data, there were not any differences in the results among the three land cover maps. The reasons for this are explored in the next chapter.
Table 3. Total data summary.
A. AAP as reference source for photointerpretation
   B. AAP as reference source for supervised classification
   C. TM as reference source for photointerpretation
   D. TM as reference source for supervised classification

A.

<table>
<thead>
<tr>
<th>Producer's Accuracy</th>
<th>User's Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENF = (15/19) = 78.94%</td>
<td>ENF = (15/20) = 75%</td>
</tr>
<tr>
<td>Shrubland = (17/25) = 68%</td>
<td>Shrubland = (17/24) = 70.83%</td>
</tr>
<tr>
<td>Grassland = (19/32) = 59.35%</td>
<td>Grassland = (19/26) = 73.07%</td>
</tr>
<tr>
<td>Crop_veg = (12/18) = 66.66%</td>
<td>crop_veg = (12/21) = 57.14%</td>
</tr>
<tr>
<td>savanna = (18/22) = 81.81%</td>
<td>savanna = (18/25) = 72%</td>
</tr>
</tbody>
</table>

**Overall Map Accuracy** = (15+17+19+12+18)/116 = 81/116 = 69.82%

B.

<table>
<thead>
<tr>
<th>Producer's Accuracy</th>
<th>User's Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENF = (12/17) = 70.58%</td>
<td>ENF = (12/20) = 60%</td>
</tr>
<tr>
<td>Shrubland = (16/22) = 72.72%</td>
<td>Shrubland = (16/24) = 66.67%</td>
</tr>
<tr>
<td>Grassland = (16/29) = 55.17%</td>
<td>Grassland = (16/26) = 61.54%</td>
</tr>
<tr>
<td>Crop_veg = (13/28) = 46.42%</td>
<td>crop_veg = (13/21) = 61.90%</td>
</tr>
<tr>
<td>savanna = (17/20) = 85%</td>
<td>savanna = (17/25) = 68%</td>
</tr>
</tbody>
</table>

**Overall Map Accuracy** = (12+16+16+13+17) = 74/116 = 63.79%

C.

<table>
<thead>
<tr>
<th>Producer's Accuracy</th>
<th>User's Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENF = (14/19) = 73.68%</td>
<td>ENF = (14/20) = 70%</td>
</tr>
<tr>
<td>Shrubland = (20/27) = 74.07%</td>
<td>Shrubland = (20/24) = 83.33%</td>
</tr>
<tr>
<td>Grassland = (21/29) = 72.41%</td>
<td>Grassland = (21/26) = 80.77%</td>
</tr>
<tr>
<td>Cropland_veg = (11/21) = 52.38%</td>
<td>Cropland_veg = (11/21) = 52.38%</td>
</tr>
<tr>
<td>Savanna = (19/20) = 95%</td>
<td>Savanna = (19/25) = 76%</td>
</tr>
</tbody>
</table>

**Overall Map Accuracy** = (14+20+21+11+19) = 85/116 = 73.27%
D.

<table>
<thead>
<tr>
<th>Producer's Accuracy</th>
<th>User's Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENF = (14/20) = 70%</td>
<td>ENF = (14/20) = 70%</td>
</tr>
<tr>
<td>Shrubland = (20/29) = 68.96%</td>
<td>Shrubland = (20/24) = 83.33%</td>
</tr>
<tr>
<td>Grassland = (21/31) = 67.74%</td>
<td>Grassland = (21/26) = 80.77%</td>
</tr>
<tr>
<td>Cropland veg = (10/20) = 50%</td>
<td>Cropland veg = (10/21) = 47.62%</td>
</tr>
<tr>
<td>Savanna = (16/16) = 100%</td>
<td>Savanna = (16/25) = 64%</td>
</tr>
<tr>
<td><strong>Overall Map Accuracy = (14+20+21+10+16) = 81/116 = 69.83%</strong></td>
<td><strong>Overall Map Accuracy = (14+20+21+10+16) = 81/116 = 69.83%</strong></td>
</tr>
</tbody>
</table>

These confusion matrix results did not, however, decisively address the question composed in the hypothesis: Can astronaut acquired photography validate land cover maps? To speak to this question, the following section yields the outcome from applying the Kappa and Z statistic to the results obtained from the confusion matrix.

4.3. Kappa and Z Statistic Summary

The numbers derived from the confusion matrix were utilized in the Kappa and Z statistic to conclusively answer the question in the hypothesis statement. The estimate of Kappa is the Khat value, which is a measure of agreement between the reference data and the remotely classified data. To prove or disprove the hypothesis, the results from the comparison between two types of reference data are shown below. The full, technical explanation of these statistics was illustrated in Chapter 3. There was one Khat result for each confusion matrix. Therefore, there are four resultant Khat values, summarized below.
Table 4. This table shows the Khat summary results.

<table>
<thead>
<tr>
<th>Reference Data Source</th>
<th>Khat Result</th>
<th>Agreement *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using AAP (P.I.) as reference data</td>
<td>0.599 or 59.9%</td>
<td>Moderate</td>
</tr>
<tr>
<td>Using AAP (C.I.) as reference data</td>
<td>0.5466 or 54.66%</td>
<td>Moderate</td>
</tr>
<tr>
<td>Using TM (P.I.) as reference data</td>
<td>0.6649 or 66.49%</td>
<td>Moderate</td>
</tr>
<tr>
<td>Using TM (C.I.) as reference data</td>
<td>0.4056 or 40.56%</td>
<td>Moderate to Poor</td>
</tr>
</tbody>
</table>

P.I. = Photointerpretation
C.I. = Supervised Image Classification

*According to Landis & Koch (1977)

Landis and Koch (1977) characterized the possible ranges of Khat into 3 groupings: a value greater than 0.80 (80%), represents strong agreement; a value between 0.40-0.80 represents moderate agreement, and a value below 0.40 represents poor agreement. Based on these groupings, the results above were categorized into strong, moderate or poor agreement between the remotely classified land cover map and the reference data. All of the results shown here were for moderate agreement. The Kappa statistic can yield Khat values describing agreement or disagreement between different sources of reference data. However, a specific application must to be employed to discover if there exists a significant difference between the Khat values for the two sources of reference data. This application is called the Z Statistic, and the results of this application are summarized in the following section.

4.3.1. Z Statistic Summary

The Z statistic is the final arithmetic step in the data processing of this dissertation research. The results of this statistic allow the user to generate a variance from the Khat value, apply the Z formula, and produce values that are either above or below
1.96, which indicates significant difference. The Z formula, see Chapter 3 for details, allows the user to combine two Khat values from two confusion matrices. Each confusion matrix utilized a different type of reference material. Therefore, the resulting Z value allows for a numerical decision as to whether there is was a significant difference between utilizing TM imagery versus AAP as a reference data source.

**Table 5.** The tables below show the results for the Z statistic for data shown in Table 4.

<table>
<thead>
<tr>
<th>Reference Data Source</th>
<th>Khat Result</th>
<th>Variance Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Using AAP (P.I.) as reference data</td>
<td>0.599</td>
<td>0.0029</td>
</tr>
<tr>
<td>2. Using AAP (C.I.) as reference data</td>
<td>0.5466</td>
<td>0.0032</td>
</tr>
<tr>
<td>3. Using TM (P.I.) as reference data</td>
<td>0.6649</td>
<td>0.0028</td>
</tr>
<tr>
<td>4. Using TM (C.I.) as reference data</td>
<td>0.4056</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Source Combination</th>
<th>Z Statistic Result</th>
<th>S/NS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2</td>
<td>0.2543 NS</td>
<td></td>
</tr>
<tr>
<td>1, 3</td>
<td>0.453 NS</td>
<td></td>
</tr>
<tr>
<td>1, 4</td>
<td>2.68 S</td>
<td></td>
</tr>
<tr>
<td>2, 3</td>
<td>0.667 NS</td>
<td></td>
</tr>
<tr>
<td>2, 4</td>
<td>2.45 S</td>
<td></td>
</tr>
<tr>
<td>3, 4</td>
<td>2.81 S</td>
<td></td>
</tr>
</tbody>
</table>

**NS** = Not Significant  
**S** = Significant

In summary, there was the least amount of difference between using AAP as either an unprocessed photograph or a classified image (1, 2) to determine the vegetation type at each sample point. The most significant difference occurred between utilizing classified Landsat TM data as the reference source and every other type of reference...
data. These differences are indicated in red. The classified TM data performed the worst as a reference data source than any other data type in this research. This is reflected in its low Khat results, low variance and high Z values. Therefore using TM classified images as a source of reference data for validating land cover maps containing savanna, grassland, shrubland, cropland/vegetation mosaic, and evergreen needle leaf forest is the poorest choice in terms of accuracy assessment and agreement. A thorough discussion of these results is contained in the following chapter.
Chapter 5

Analysis and Discussion of Results

This chapter is partitioned into three main sections. The first section is an analysis of the results including those values derived from the confusion matrix, Kappa and Z statistic. The second section consists of a discussion of the significance of the results. Based on the significance of the results, the third section examines the research benefits for future applications of the research completed here.

5.1. Analysis of Results

All analyses, using both types of reference data as well as both types of sample point interpretation (photointerpretation versus supervised classification) had moderate agreement between the reference data and the remotely classified data, according to the ranges set forth by Landis and Koch (1977). It is interesting to note, however, that the confusion matrix which yielded the worst results in terms of agreement, was that of the TM imagery as the reference data in the supervised classification yielding a 40% Kappa statistic. This reflects poor agreement between the reference data and the classified remotely sensed data.

According to the Z-statistic of each matrix, all confusion matrices scored well above the required 1.96 value indicating that the results were all significantly better than random. Taking the Z-statistic further, it was then possible to show that both confusion matrices generated using the AAP were not significantly different from
using TM as reference data for photointerpretation. However, the Khat statistic for the confusion matrix showing agreement between TM as (supervised classification) reference data for the remotely sensed classified data and every other confusion matrix result did show significant difference, because the result for the Khat value was so low for that matrix. In other words, using a supervised classification of a Landsat scene to distinguish the different types of vegetation on the landscape, at least for the five classes in this study, did not have a very successful outcome as a source of reference data.

The foremost reason for the much lower Khat score using the classified TM imagery was largely due to the misclassified pixels in the cropland/vegetation mosaic land cover class. All of the results were completed several times to insure accuracy and that no mistakes had been made. In the cropland/vegetation mosaic class, however, it is not insignificant that AAP, as both a photointerpretation reference as well as a supervised classification reference, scored better in terms of accuracy in the cropland/vegetation mosaic class than did the TM scenes falling over those same sample points for that class. This is one of the classes where scale became an issue. Although the AAP’s were resampled to be as close as possible to 30-meter spatial resolution, the AAP generally had finer spatial resolution than did the TM images. In other words, it was less difficult to tell what was on the ground when doing photointerpretation using the AAP’s.
Savanna and evergreen needle leaf forest tended to have the highest agreement scores throughout all the confusion matrices, probably because in the southwestern United States, these two classes tend to exist in very large, homogeneous stands across the region. There was a tendency for there to be confusion between shrubland and grassland and there was also a propensity for cropland/vegetation mosaic to be classified as grassland. This took place both during photointerpretation as well as when operating the automated classifier. In both cases, there was almost certainly a problem with definition of true class boundaries. For example, when some areas of shrubland were adjacent to areas of open grassland, there was usually no distinct boundary between them. A similar situation arose with the cropland/vegetation mosaic being classified as grassland. The gradual transition however, had more to do with cropland/vegetation being overgrown into areas of grassland. Many conversations with local university botany departments confirmed that farmers had a tendency to allow once very productive cropland fields to become fallow after about one year of reduced harvest from that field. Thus, the transition from cropland to fallow field became a transition from cropland to grassland.

These transitions cause confusion in photointerpretation as well as using the automated classifier. Transition fields are generally difficult to photo-interpret since they are usually half grassland and residual cropland. Having access to view and combine different bands was helpful in both AAP (RGB) and the TM images (bands 1-7). However, in the automated classification, training sites also incorporated the
mixed pixels from elsewhere in the images. Incorporating these pixels could have potentially helped in generalizing the areas classified as both grassland and cropland/vegetation mosaic. However in this study, it lowered the classification accuracy and Khat value for the automated classification of TM imagery as a reference source.

Mixed pixels and confusion delineating boundaries among different land cover classes are not the only potential sources of error that can affect accuracy assessments. There were also issues involving the creation of the land cover maps that were used in this study, and some that could potentially limit the reliability of the results found here. These limitations are discussed at length in Chapter 2. There are also issues concerning the TM data quality as well as astronaut acquired data quality that could also possibly affect the results completed in this study. These concerns are addressed in Chapter 3.

In summary, there was no significant difference between utilizing TM imagery versus AAP in terms of validating the land cover maps used in this research. The implication of these findings is described in the next section.

5.2. Discussion of Research

This study was one of the first quantitative comparisons between TM and AAP data. It was the first time AAP has been utilized in the process of map validation. The
results showed that there were no negative significant differences between utilizing TM versus AAP as a reference data source. This fact demonstrates several significant findings. These findings are described in the following sections.

5.2.1. AAP Affordable Alternative to TM Data

The first significant factor supporting the import behind the Z statistic results showing that there is no significant difference between using TM imagery versus AAP for map validation is an important factor of cost. Based on this research, it has been proven that one can use AAP in lieu of TM imagery to obtain similar results in map validation exercises. Although the federal government is making an effort to reduce the cost of Landsat imagery, the cost per scene is still several hundred dollars. The cost per AAP is twenty dollars per photograph. On average, it takes three AAP's to cover the same area as one TM scene. Cost is a central issue for scientists interested in completing land cover change analyses over time or any study that requires a large number of images. One of the major reasons for the lack of mapping validation efforts is the prohibitive costs and time involved in planning and managing such an endeavor.

5.2.2. Rapid and Efficient Evaluation of Land Cover Products

Cost is not the only potentially prohibitive issue; time management is also fundamental to planning research projects. The IGBP DISCover validation endeavor, for example, was completed six years after the original data were collected to create
the Seasonal Land Cover Characteristics Database. This effort, using the same baseline dataset, was completed in only two years. This is still an extremely long time from data collection to completed validation results. It is however, an improvement. The advantage of using the methodology described in this study is it requires less time, less money and less computational power than did the IGBP DISCover validation. The statistics are very basic and not difficult to implement. The application of the confusion matrix, Kappa and Z statistic reveals a quick and computationally efficient way of assessing the accuracy of land cover maps.

5.2.3. The Human is Still Important

Not only are time and cost issues of this research central to planning map validation, but there is an additional factor that has been a central theme throughout this dissertation: the inclusion of the human behind the camera. Fundamentally, this research proves that using astronaut acquired photography can benefit the users of the Earth observing data in many aspects. In the past, utilizing the Space Shuttle camera systems, astronauts have captured ephemeral events, and documented land cover change over time in a multitude of areas around the world. An increasing number of AAP users are completing scientific studies with this enormous archive of data.

In addition to a distinguished history, AAP has a promising future. With the work concluded here, it will be possible to make land cover interpretation more accurate by the astronauts obtaining the photographs as well as for the users of the data. There
are many future applications of this research, and they are detailed in the following sections.

5.3. **Global Applications of Research for Future Use**

This study was conducted in a regional area of the southwestern United States. However, due to several factors, it is possible to apply these findings and methods to future global endeavors. The fact that the study area contains a great deal of climatic variety in terms of temperature, moisture, seasonality and elevation lends the results of this research to applications elsewhere in the world. Based on the research done here, there are several potential applications for increasing the efficiency of astronauts acquiring photographs. Because of constant communication with Johnson Space Center’s Earth Science Office, it is hoped that the suggestions outlined in the following sections will be applied to the Johnson Space Center Astronaut Protocols.

5.3.1. **Prioritization and Standardization of Future AAP**

There are a large number of requests for astronaut acquired photography. A considerable percentage of those requests originate from people who have no idea what kind of preparations the astronauts require to obtain Earth observing photographs. Until recently, one of the only ways to obtain an astronaut acquired image was through an EarthKam mission. These missions allow grade school children to make photographic requests of astronauts. This is the quickest way for a layperson to obtain an almost real-time Earth observation. However, this option was
not open to anyone above grade school age, and this program is extremely selective. EarthKam will be taken to the International Space Station (ISS) within this year (2001).

Based on this information, the suggestion now is to place a methodology on the NASA data acquisition website to help requesters understand better what details are needed from the astronauts’ viewpoint. This is to insure that the astronauts obtain the best photograph possible. The first several processes require a small amount of research on the part of the requester. The first step in the process is for the requester to define their area of interest. It is important to describe what event is occurring, if an episodic event, or what feature of the landscape or ocean is desired. The geographic coordinates, boundaries, and any identifying characteristics in the area of interest are all essential pieces of information for the astronaut. The next step is to view images from the DISCover dataset, for example, and high quality, previously acquired AAP that show the feature of interest.

When looking at and comparing these two sources of data, it would be extremely useful for the astronaut (or scientist preparing information for the astronaut, more likely) to determine the land cover class proportions shown in the area of interest. It would be even more useful to actually delineate those different classes by colored boundaries and label those polygons so astronauts can use these images as reference data on the fly as they as look for the feature from orbit. As these classes are
delineated, it is important to have some scale in terms of the ease or difficulty in interpreting what exactly the feature is from space. Thus, these delineated polygons would have a legend and associated labels titled: easy, medium and hard coupled with each class polygon. A second scale is also useful to those interested in doing quantitative analysis as well: an expected quantification scale with labels of low, medium and high. This type of scale defines how much processing it is probably going to take to get this image or photograph into a format that can be quantitatively studied. Therefore, with all this information, those scheduling the astronauts’ time can assess the requests in the following way, for example: Important Event + Easy Class + Low Quantification = High Priority. This web-based application is shown in a flowchart on the following page.
What event is occurring?
Or
What feature of the land/ocean is desired?

What are the geographic coordinates of the event occurrence?
AND
What are the boundaries of the event occurrence?
AND
Are there any identifying characteristics that might help astronauts to locate this feature?

Take DISCover dataset and clip out Area Of Interest (AOI)
AND
Determine the class variability proportions
(Grass = 40%, Forest = 30%, Wetland = 30%) through histograms of AOI

Access high quality, previously acquired AAP of AOI

Use AAP and DISCover TM image
AND
Evaluate ease of interpretation as easy, medium or hard

Assign level of quantification expected as low, medium or high

Prioritization and quantification standards are now in place:
Important Event + Easy Class + Low Quantification = High Priority
This flowchart, embedded into a photographic request site at Johnson Space Center, would enable future users of these photographs to become more familiar with the many preparations the astronauts have to manage to train for this type of data acquisition. In addition to recommending a more user-friendly interface for future users of AAP, there is another future application of this dissertation research that could aid astronauts in land cover identification around the world.

5.3.2. Ease of Interpretation Maps

The map validation completed in this research yielded accuracy assessments of agreement between reference data and remotely sensed land cover classification maps. These accuracy assessments are based on results from a confusion matrix. The confusion matrix yields by-class accuracy of each land cover type validated in the land cover map. If a vegetation class has a low accuracy, this can be directly correlated to the difficulty at which that land cover class is identified correctly. If a vegetation class has a high accuracy, this can be directly correlated to the ease at which that class is identified correctly. From by-class accuracy results found in this study, it is possible to create interpretation maps. For example, Figure 16 is a map that was derived from the results of the overall confusion matrices for the land cover maps. The different colors correlate to different levels of interpretation. The reason that photointerpretation is so important for documenting landscape features is the astronauts need to be able to recognize the type of land cover the users request. If
this type of map were available, the astronaut could prepare for the more difficult locations with additional ancillary data.

**Figure 16.** Ease of interpretation map for study area

Since the results from this research can be used not only for regional but also global applications, it is possible to extrapolate from the results obtained above and create a global "Ease of Interpretation Map". Using the IGBP data set (Figure 17) a global map (Figure 18) was made with 3 categories of interpretation: Easy, Moderate, and Difficult. The 17 different land cover classes of the IGBP DISCover land cover map were evaluated for ease of interpretation. Therefore, Figure 18 represents
interpretability applied to a 17-class land cover class land cover characterization map.

**Figure 17.** IGBP DISCover dataset.
Figure 18. Ease of interpretation based on the IGBP classification.

<table>
<thead>
<tr>
<th>Red</th>
<th>Easy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>Moderate</td>
</tr>
<tr>
<td>Yellow</td>
<td>Difficult</td>
</tr>
</tbody>
</table>

Given that a mapping system currently exists within the Space Shuttle, and the ISS, it would be possible to incorporate these interpretation maps into the system software.

5.3.3. Hotlinks to Previous Photographs of AOI

Prior to taking a photograph, the Shuttle astronauts prepare by viewing maps. Approximately forty-five minutes before the photograph is actually taken, the astronauts are prompted to get ready. This prompt allows them time to prepare and mount the camera system. During this period, they also prepare to identify the landscape feature of interest. The ease of interpretation maps are helpful, but in
addition to those maps, there could also be links to previously acquired AAP or IGBP DISCover validation images (see examples in Figure 19 and 20).

**Figure 19.** The ease of interpretation map below has hot-linked images associated with areas of interest.
Figure 20. The ease of interpretation map below has hot-linked images associated with areas of interest.

These proposed additions to the mapping system would allow for examples of the event or land cover class to be portrayed for the astronauts during the most crucial part of photographic acquisition, that is, immediately before.

With these future applications of the work shown in this chapter, it will be possible to make land cover interpretation more accurate by the astronauts obtaining the
photographs and thus also for the users of the data. The technique presented in this
dissertation offers an efficient method for validating current maps to assess the
accuracy of the land cover classes they contain. With this information, it is possible
to create regional and global maps derived from those results that statistically show
how difficult or easy any given class may be to interpret from space. Depending on
the difficulty level shown by these maps, additional ancillary data can be hot-linked
to the software systems already in place onboard the Space Shuttle and ISS. All of
these recommended preparations will increase the efficiency and accuracy of the
astronauts as they acquire Earth observing photography.
Chapter 6

Conclusions and Recommendations

This chapter is separated into two main sections. The first section discusses how the hypothesis of this research was addressed with the science objectives achieved. The second section gives recommendations for anyone aspiring to complete a map validation in the future.

6.1. Hypothesis and Science Objectives

The hypothesis of this dissertation was: Can astronaut acquired photography be utilized to validate land cover maps? The results reveal that the method and resources presented in this dissertation can be applied to map validation in an efficient and statistically significant manner. In addition, the results demonstrate that photointerpretation is still a competitive map validation method compared to machine-assisted classification of images and photographs. Finally, it is clear that AAP can perform equally well in comparison to Landsat TM as a data source for validation of land cover maps.

Using a set of robust statistics the hypothesis of this research was addressed. The hypothesis was addressed via the application of several key science objectives, listed below.
(1) Assess and document the accuracy of three land cover maps used in global change and other fundamental and applied research with the results of this analysis.

(2) Determine whether and which individual land cover maps (of the three used for this study) are more appropriate for validation employing photography acquired by astronauts.

(3) Determine whether and which land cover classes on each individual land cover map have the highest accuracy for validation purposes.

The results pertaining to the first objective, in terms of the accuracy of the three land cover maps, showed no difference in their accuracy assessments according to the 5 land cover classes chosen for this study. The difference lay in the agreement between the reference data and the remotely classified data for each type of validation (photointerpretation versus supervised classification). For future research however, it seems likely that there would be different results if the study were based on a much larger number of sample points as well as a much larger number of classes to be validated.

In terms of the second objective, all three maps were easily validated largely because the classes were not particularly heterogeneous, meaning they were generally not mixed with other classes. Therefore, the mixed pixel problem was minor, except in some cases such as the cropland/vegetation mosaic. Thus, because of the
homogeneity of the classes in this validation exercise, both AAP and TM did almost equally well as sources of reference data. The more heterogeneous the landscape however, the better the AAP performed than the TM data, as a rule. This is evident in the results for the cropland/vegetation mosaic class. There are several explanations for this. The first is that generally the AAP spatial resolution was anywhere from 20-30 meters, after being resampled in the point-to-point registration to the TM imagery. However, visually interpreting the AAP was generally easier than with the TM images. In areas where there were several hundred kilometers of savanna, for example, the resolution was not much of an issue. However, in areas where there were mixed pixels or a different class adjacent to the sample point, resolution became more of an issue for the TM data than for the AAP data.

From these observations, the conclusion is that AAP is generally more appropriate when there exist small changes in a heterogeneous landscape. Conversely, in some cases TM was a better reference source because there were more bands to choose from and different types of vegetation became spectrally more distinct when switching among bands to create different combinations. Overall, when the landscape was quite homogeneous, like in large areas of Texas, there was no significant difference between the two types of reference data. When the landscape was heterogeneous, it was easier to discern features utilizing AAP because of the finer spatial resolution. Therefore, the AAP would be more appropriate for validation of Olson’s Global Map because it has such a high number of classes, whereas the
IGBP land cover classification system could use either AAP or TM imagery with no significant difference between the two types of reference data in the resulting validation statistics. Thus, the recommendation based on these results, is for a validation exercise of a land cover map with a large number of classes, using a reference data source like AAP would be more appropriate because of the higher resolution of that data source. This makes for easier interpretation of land cover classes that appear similar and exist in similar or the same environments. The other advantage of using AAP in validation of a land cover map with a high number of classes is that various look angles are obtained when capturing photographs over any given area. These various look angles of the same area can provide additional information about that area and the type of landscape that defines it.

The third objective was to determine which land cover classes had the highest accuracy for validation purposes. To summarize, when using AAP as the reference data, savanna scored the highest overall whereas grassland and the cropland/vegetation classes had the lowest score. When using TM imagery as the reference data, the cropland/vegetation class scored the worst in both user’s and producer’s accuracy whereas there was some fluctuation among the other classes when comparing user’s and producer’s accuracy. Overall, using both types of reference data, it was evident that savanna and evergreen needle leaf forest had the highest level of accuracy for validation purposes. Based on the results derived from
the science objectives, there are a number of recommendations for those interested in effecting a map validation in the future.

6.2. Recommendations

First, it is important to have a clear understanding of the definitions of the different land cover classes being validated. This is important because when one land cover class transitions into another land cover class there may be very different definitions of both classes, or the transition class may be defined as a seasonal version of that class. This situation can be made even more complicated when mixed classes are adjacent to homogeneous stands of completely different classes. A dendogram, which was used in this research, is essential to fully understanding how each land cover class is defined. Background literature is also extremely important in understanding how the land cover classification was derived, and perhaps the agenda supporting the classification.

A second recommendation for photointerpretation as well as automated classification is to have access to an abundance of ancillary information associated with all areas surrounding the sample points to be analyzed. For example, high altitude aerial photographs, atlases, local maps, and journal articles describing the sample point areas are all valuable. Personal communications with universities, botany or environmental science departments, state park rangers, and naturalists can also be extremely helpful when there is an area of uncertainty. With these types ancillary
information on hand to aid interpretation, fewer errors will be incorporated into the accuracy assessment of the research area.

A technical recommendation is also important to note. If there are a large number of sample points to be validated, this requires a large number of images and photographs to be incorporated into a computer system. Both Landsat TM images and, to a lesser extent, photographs, can be quite large. For example, after completing the data processing for each TM image, each scene was approximately 300-450 megabytes in size. After processing the AAP's, each was approximately 75-150 megabytes in size. When preparing a grant proposal to do a map validation, it is important to include an abundance of computing power.

6.3. Conclusions
It is clear that astronaut acquired photography can be utilized to validate land cover maps. What is also apparent is that much more research needs to be done to insure that this vast resource does not remain relatively undiscovered and unused. The methodology presented here is not difficult to implement. Based on that ease of implementation, it is important to consider future mapping endeavors such as the validation of maps produced from camera and sensor systems in the International Space Station (ISS) as well as maps created from Moderate Resolution Imaging Spectrometer (MODIS) imaging systems. This methodology can be utilized to validate maps derived from these types of imaging systems in the future.
A second important aspect of these research results is that they provide evidence that these types of photographs can be utilized not only for quantitative land cover map validation, but also to capture episodic events, as well as potentially assess land cover change over time. More research on both of these topics using this resource is needed.

These results also underline the need for more map validation to take place. The maps that were validated had average accuracy. Maps derived from the SLCC database are being utilized in global environmental models, regional studies and other varied research around the world. The more accurate the baseline data, the more accurate models of the Earth can become. Studies based on the assumption that SLCC maps are 100% correct are flawed, and such assumptions can be disastrous for scientific research.

In conclusion, it is clear that much more research is needed on this subject. This study, however, provides a first step in future mapping validation efforts. This research offers an easily implemented methodology, as well as recommendations for Johnson Space Center to streamline technology and increase accuracy of future land cover maps.
REFERENCES


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Appendix A

USGS, IGBP, and Olson’s Land Cover Class Value & Description

Table 1. USGS Land Use/Land Cover System Classes (Modified Level 2)

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Urban and Built-Up Land</td>
</tr>
<tr>
<td>2</td>
<td>Dryland Cropland and Pasture</td>
</tr>
<tr>
<td>3</td>
<td>Irrigated Cropland and Pasture</td>
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<td>Mixed Dryland/Irrigated Cropland and Pasture</td>
</tr>
<tr>
<td>5</td>
<td>Cropland/Grassland Mosaic</td>
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<td>Cropland/Woodland Mosaic</td>
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<td>7</td>
<td>Grassland</td>
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<td>8</td>
<td>Shrubland</td>
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<td>9</td>
<td>Mixed Shrubland/Grassland</td>
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<td>Savanna</td>
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<td>11</td>
<td>Deciduous Broadleaf Forest</td>
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<td>12</td>
<td>Deciduous Needleleaf Forest</td>
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<td>13</td>
<td>Evergreen Broadleaf Forest</td>
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<tr>
<td>14</td>
<td>Evergreen Needleleaf Forest</td>
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<td>15</td>
<td>Mixed Forest</td>
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<td>16</td>
<td>Water Bodies</td>
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<td>17</td>
<td>Herbaceous Wetland</td>
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<tr>
<td>Value</td>
<td>Description</td>
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<tr>
<td>1</td>
<td>Evergreen Needleleaf Forest</td>
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<tr>
<td>2</td>
<td>Evergreen Broadleaf Forest</td>
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<tr>
<td>3</td>
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<td>7</td>
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<td>8</td>
<td>Woody Savannas</td>
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<td>9</td>
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</tr>
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<td>11</td>
<td>Permanent Wetlands</td>
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Table 2. The International Geosphere Biosphere Programme Land Cover Classes
12  Croplands
13  Urban and Built-Up
14  Cropland/Natural Vegetation Mosaic
15  Snow and Ice
16  Barren or Sparsely Vegetated
17  Water Bodies

Table 3. Olson’s Global Ecosystems Classes

<table>
<thead>
<tr>
<th>Value</th>
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<td>6</td>
<td>Evergreen Broadleaf Forests</td>
</tr>
<tr>
<td>7</td>
<td>Tall Grasses and Shrubs</td>
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<tr>
<td>8</td>
<td>Bare Desert</td>
</tr>
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<td>9</td>
<td>Upland Tundra</td>
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<td>10</td>
<td>Irrigated Grassland</td>
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<tr>
<td>11</td>
<td>Semi Desert</td>
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<tr>
<td>12</td>
<td>Glacier Ice</td>
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<td>13</td>
<td>Wooded Wet Swamp</td>
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<td>14</td>
<td>Inland Water</td>
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137
15  Sea Water
16  Shrub Evergreen
17  Shrub Deciduous
18  Mixed Forest and Field
19  Evergreen Forest and Fields
20  Cool Rain Forest
21  Conifer Boreal Forest
22  Cool Conifer Forest
23  Cool Mixed Forest
24  Mixed Forest
25  Cool Broadleaf Forest
26  Deciduous Broadleaf Forest
27  Conifer Forest
28  Montane Tropical Forests
29  Seasonal Tropical Forest
30  Cool Crops and Towns
31  Crops and Town
32  Dry Tropical Woods
33  Tropical Rainforest
34  Tropical Degraded Forest
35  Corn and Beans Cropland
36  Rice Paddy and Field
37  Hot Irrigated Cropland
38  Cool Irrigated Cropland
39  Cold Irrigated Cropland
40  Cool Grasses and Shrubs
41  Hot and Mild Grasses and Shrubs
42  Cold Grassland
43  Savanna (Woods)
44  Mire, Bog, Fen
45  Marsh Wetland
46  Mediterranean Scrub
47  Dry Woody Scrub
48  Dry Evergreen Woods
49  Volcanic Rock
50  Sand Desert
51  Semi Desert Shrubs
52  Semi Desert Sage
53  Barren Tundra
54  Cool Southern Hemisphere Mixed Forests
55  Cool Fields and Woods
56  Forest and Field
57  Cool Forest and Field
58  Fields and Woody Savanna
59  Succulent and Thorn Scrub
60  Small Leaf Mixed Woods
61  Deciduous and Mixed Boreal Forest
62  Narrow Conifers
63  Wooded Tundra
64  Heath Scrub
65  Coastal Wetland, NW
66  Coastal Wetland, NE
67  Coastal Wetland, SE
68  Coastal Wetland, SW
69  Polar and Alpine Desert
70  Glacier Rock
71  Salt Playas
72  Mangrove
73  Water and Island Fringe
74  Land, Water, and Shore (see Note 1)
75  Land and Water, Rivers (see Note 1)
76  Crop and Water Mixtures
77  Southern Hemisphere Conifers
78  Southern Hemisphere Mixed Forest
79  Wet Sclerophylic Forest
80  Coastline Fringe
81 Beaches and Dunes
82 Sparse Dunes and Ridges
83 Bare Coastal Dunes
84 Residual Dunes and Beaches
85 Compound Coastlines
86 Rocky Cliffs and Slopes
87 Sandy Grassland and Shrubs
88 Bamboo
89 Moist Eucalyptus
90 Rain Green Tropical Forest
91 Woody Savanna
92 Broadleaf Crops
93 Grass Crops
94 Crops, Grass, Shrubs
Appendix B

The Details of Different Missions in the Early Age of Space Travel

THE MERCURY PROGRAM:

Unmanned missions:

LJ-1 Little Joe 1
BJ-1 Big Joe 1
LJ-6 Little Joe 6
LJ-1A Little Joe 1A
LJ-2 Little Joe 2
LJ-1B Little Joe 1B
BA-1 Beach Abort
MA-1 Mercury-Atlas 1
LJ-5 Little Joe 5
MR-1 Mercury-Redstone 1
MR-1A Mercury-Redstone 1A
MR-2 Mercury-Redstone 2
MA-2 Mercury-Atlas 2
LJ-5A Little Joe 5A
MR-BD Mercury BD
MA-3 Mercury-Atlas 3
LJ-5B Little Joe 5B
MA-4 Mercury-Atlas 4
MS-1 Mercury-Scout 1
MA-5 Mercury-Atlas 5

The missions that were staffed by U.S. astronauts during this period are listed as follows:

MR-3 Freedom 7
MR-4 Liberty Bell 7
MA-6 Friendship 7
MA-7 Aurora 7
MA-8 Sigma 7
MA-9 Faith 7

The Gemini Program

Manned missions:

GT-03 Gemini 3
GT-04 Gemini IV
GT-05 Gemini V
GT-07 Gemini VII
GT-06 Gemini VI-A
GT-08 Gemini VIII
GT-09 Gemini IX-A
GT-10 Gemini X
GT-11 Gemini XI
GT-12 Gemini XII

Geology

Mt. Godwin-Austen (K-2) (S65-45648)
The Nile (S65-34780)
Rub-al-Khali, Arabia (S65-34765)
Cordillera Blanca, Peru (S66-38298)
Medina, Saudi Arabia (S65-34665)
Arabian Peninsula & Gulf of Oman (S65-34661)
Eastern Sahara (S66-54525)
Air-Au-Azbine Mountains, Niger (S65-63158)
Algerian Sahara (S65-63829)
Baja California (S65-45586)
Sinai & Middle East (S66-54893)

Oceanography

Bahamas (S65-45760)
Texas-Louisiana Gulf Coast (S66-63032)
Taiwan & Formosa Strait (S66-45868)
Florida Keys (S65-34766)

Weather

Sunset over Andes (S65-63780)
Southern tip of India (S66-54676)
Namib Desert and Atlantic Coast (S65-45579)
Circular Feature in Sahara (S65-34670)
Vortex off Moroccan Coast (S65-45665)

Water Resources

Cape Canaveral, Florida (S65-45599)
Ethiopian Lakes (S65-63162)
Colorado River (S65-34673)
South-central Iran (S65-45720)
Yangtze River, China (S65-45713)
Nile Delta (S65-34776)
South Yemen (S65-34658)
Oued Saoura, Algerian Sahara (S65-63830)
Cairo and Nile Delta (S65-45778)
Edwards Plateau (S65-34704)

THE APOLLO PROGRAM

The Unmanned Apollo Flights included:

Earth Orbiting Missions:

SA-6
AS-203
Apollo 4
Apollo 5
Apollo 6

Apollo Suborbital Flights:

AS-201
AS-202

The Crewed Apollo Flights included:

Apollo Crewed Earth Orbiting Missions

Apollo 7
Apollo 9

The Crewed Moon Missions included:

Apollo 8
Apollo 10 (Charlie Brown and Snoopy)
Apollo 11 (Columbia and Eagle)
Apollo 12 (Yankee Clipper and Intrepid)
Apollo 13 (Odyssey and Aquarius)
Apollo 14 (Kitty Hawk and Antares)
Apollo 15 (Endeavor and Falcon)
Apollo 16 (Casper and Orion)
Apollo 17 (America and Challenger)
Appendix C

Dendograms Courtesy Of Dr. Thomas Loveland – Eros Data Center

The Seasonal Land Cover Database Translated into the Olson Land Cover System


<table>
<thead>
<tr>
<th>SLCR</th>
<th>OLSON_CODE OLSON</th>
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<tbody>
<tr>
<td>CROPLAND (SMALL GRAINS AND PASTURE) WITH GRASSLANDS</td>
<td>30 COOL CROPS AND TOWNS</td>
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<tr>
<td>CROPLAND (SMALL GRAINS) WITH GRASSLANDS</td>
<td>30 COOL CROPS AND TOWNS</td>
</tr>
<tr>
<td>CROPLAND (COFFEE, SUGAR CANE, MIXED CROPS)</td>
<td>93 GRASS CROPS</td>
</tr>
<tr>
<td>CROPLAND</td>
<td>92 BROADLEAF CROPS</td>
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<tr>
<td>CROPLAND (SMALL GRAINS, PASTURE) WITH DECIDUOUS WOODLANDS</td>
<td>30 COOL CROPS AND TOWNS</td>
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<td>CROPLAND (SMALL GRAINS, ROW CROPS)</td>
<td>30 COOL CROPS AND TOWNS</td>
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<tr>
<td>CROPLAND (WINTER WHEAT)</td>
<td>31 CROPS AND TOWN</td>
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<tr>
<td>CROPLAND (CORN AND SOYBEANS)</td>
<td>35 CORN AND BEANS</td>
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<td>CROPLAND (CORN AND OTHER ROW CROPS, FORAGE CROPS)</td>
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<td>CROPLAND (TRUCK CROPS) WITH DECIDUOUS WOODLANDS (OAK)</td>
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<td>CROPLAND (CORN AND SOYBEANS)</td>
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<tr>
<td>CROPLAND (SMALL GRAINS, HAY, PASTURE) WITH WETLANDS</td>
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<td>CROPLAND (MIXED ROW CROPS) WITH WOODLAND</td>
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<td>CROPLAND (GRASS SEED, SMALL GRAINS) WITH MIXED WOODLANDS</td>
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<td>CROPLAND (CULTIVATED GRASSLAND)</td>
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<tr>
<td>CROPLAND (WINTER WHEAT)</td>
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<td>CROPLAND (SUGAR CANE)</td>
<td>93 GRASS CROPS</td>
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<td>CROPLAND (COTTON, SOYBEANS, RICE)</td>
<td>35 CORN AND BEANS</td>
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<td>CROPLAND (SUGAR CANE)</td>
<td>93 GRASS CROPS</td>
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<tr>
<td>CROPLAND (CULTIVATED GRASSES)</td>
<td>93 GRASS CROPS</td>
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</table>
WITH WOODLAND
CROPLAND (CULTIVATED GRASSES) WITH SAVANNA
CROPLAND (CORN, SOYBEANS, COTTON, RICE) WITH WOODLANDS
CROPLAND WITH SAVANNA
CROPLAND
CROPLAND WITH GRASSLAND
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
CROPLAND/DECIDUOUS FOREST (ASPEN) MOSAIC
CROPLAND, WOODLAND, URBAN MOSAIC
CROPLAND/WOODLAND (MAPLE, BEECH, BIRCH) MOSAIC
CROPLAND (CORN, SOYBEANS, ALFALFA)/WOODLANDS MOSAIC
CROPLAND (CORN, SOYBEANS, PASTURE)/WOODLAND (MAPLE, ELM) MOSAIC
CROPLAND (CORN, SMALL GRAINS)/DECIDUOUS FOREST (OAK, HICKORY) MOSAIC
CROPLAND (CORN, SOYBEANS, PASTURE)/WOODLAND (OAK, HICKORY) MOSAIC
CROPLAND/DECIDUOUS FOREST MOSAIC
93 GRASS CROPS
92 BROADLEAF CROPS
93 GRASS CROPS
92 BROADLEAF CROPS
92 BROADLEAF CROPS
93 GRASS CROPS
38 COOL IRRIGATED CROPLAND
37 HOT IRRIGATED CROPLAND
38 COOL IRRIGATED CROPLAND
38 COOL IRRIGATED CROPLAND
37 HOT IRRIGATED CROPLAND
38 COOL IRRIGATED CROPLAND
37 HOT IRRIGATED CROPLAND
37 HOT IRRIGATED CROPLAND
37 HOT IRRIGATED CROPLAND
57 COOL FOREST AND FIELD
55 COOL FIELDS AND WOODS
57 COOL FOREST AND FIELD
55 COOL FIELDS AND WOODS
55 COOL FIELDS AND WOODS
57 COOL FOREST AND FIELD
56 FOREST AND FIELD
CROPLAND/WOODLAND
CROPLAND (CORN, COTTON, SOYBEANS) / EVERGREEN NEEDLELEAF FOREST (SLASH PINE) MOSAIC
GRASSLAND, CROPLAND (SMALL GRAINS), FALLOW MOSAIC
CROPLAND (SMALL GRAINS, PASTURE) / GRASSLAND MOSAIC
GRASSLAND/CROPLAND (WHEAT, CORN) MOSAIC
CROPLAND (ROW CROPS, SMALL GRAINS) / GRASSLAND MOSAIC
CROPLAND (SMALL GRAINS, ROW CROPS) / GRASSLAND
CROPLAND (CORN, SORGHUM, SMALL GRAINS) / GRASSLAND MOSAIC
CROPLAND / GRASSLAND
CROPLAND (CORN, COTTON, SORGHUM, PASTURE) / GRASSLAND MOSAIC
CROPLAND (PASTURE) / GRASSLAND MOSAIC
WET HERBACEOUS MEADOWS
GRASSLAND (SHORT- MID GRASS PRAIRIE)
GRASSLAND (SHORT GRASS PRAIRIE)
GRASSLAND WITH CROPLAND (SMALL GRAINS)
MIXED RANGELAND (GRASSLAND/SHRUBLAND)
GRASSLAND

GRASSLAND (WARM SEASON GRASSES)
GRASSLAND WITH CROPLAND (SMALL GRAINS, PASTURE)
MIXED RANGELAND (GRASSLAND AND SHRUBLAND)
GRASSLAND WITH WOODLAND AND WETLANDS
GRASSLAND WITH CROPLAND

GRASSLAND (TALL GRASS PRAIRIE)
GRASSLAND WITH CROPLAND

SAVANNA

56 FOREST AND FIELD
56 FOREST AND FIELD
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
94 CROPS, GRASS, SHRUBS
42 COLD GRASSLAND
40 COOL GRASSES AND SHRUBS
2 LOW SPARSE GRASSLAND
40 COOL GRASSES AND SHRUBS
40 COOL GRASSES AND SHRUBS
41 HOT AND MILD GRASSES AND SHRUBS
41 HOT AND MILD GRASSES AND SHRUBS
41 HOT AND MILD GRASSES AND SHRUBS
40 COOL GRASSES AND SHRUBS
40 COOL GRASSES AND SHRUBS
41 HOT AND MILD GRASSES AND SHRUBS
7 TALL GRASSES AND SHRUBS
41 HOT AND MILD GRASSES AND SHRUBS
43 SAVANNA (WOODS)
GRASSLAND
MIXED RANGELAND (NEEDLEGRASS, BIG SAGE, RABBITBRUSH)
MIXED RANGELAND (SALTBUSH, SAND SAGE, RABBITBRUSH)
MIXED RANGELAND (SHRUBS AND GRASSES)
MIXED RANGELAND (GRASSLAND, SHRUBLAND) WITH CROPS, FALLOW SPARSELY VEGETATED DESERT SHRUBLANDS
DESERT SHRUBLANDS (CREOSOTE, SALTBUSH, SAND SAGE) - SONORAN TALL SHRUBS (WILLOW, BIRCH, ALDER)
DESERT SHRUBLAND (CREOSOTE, SALTBUSH, MESQUITE, SAND SAGE)
DESERT SHRUBLAND (CREOSOTE, SALTBUSH, SAND SAGE, MESQUITE) - CHIHUAHAN TALL/LOW SHRUBS (WILLOW, ALDER) AND WET HERBACEOUS DESERT SHRUBLAND/GRASSLAND (CREASOTE, SALTBUSH, MESQUITE, SAND SAGE)
TALL/LOW SHRUBS, TUNDRA, SPRUCE DESERT SHRUBLANDS (CREOSOTE, SALTBUSH, MESQUITE, SAND SAGE)
TALL/LOW SHRUBS, TUNDRA, SPRUCE DESERT SHRUBLAND (CREOSOTE, SALTBUSH, MESQUITE, CACTUS) WITH GRASSES
TALL SHRUBS (WILLOW, BIRCH, ALDER) AND WET HERBACEOUS MEADOWS CHAPARRAL

41 HOT AND MILD GRASSES AND SHRUBS
52 SEMI DESERT SAGE
60 SMALL LEAF MIXED WOODS
41 HOT AND MILD GRASSES AND SHRUBS
40 COOL GRASSES AND SHRUBS
52 SEMI DESERT SAGE
51 SEMI DESERT SHRUBS
17 SHRUB DECIDUOUS
51 SEMI DESERT SHRUBS
51 SEMI DESERT SHRUBS
17 SHRUB DECIDUOUS
51 SEMI DESERT SHRUBS
17 SHRUB DECIDUOUS
52 SEMI DESERT SAGE
17 SHRUB DECIDUOUS
51 SEMI DESERT SHRUBS
17 SHRUB DECIDUOUS
46 MEDITERRANEAN SCRUB
43 SAVANNA (WOODS)
91 WOODY SAVANNA
91 WOODY SAVANNA
91 WOODY SAVANNA
91 WOODY SAVANNA
149
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<th>60 Small Leaf Mixed Woods</th>
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<td>Open Mixed Forest (Aspen, Birch, White Spruce, Black Spruce)</td>
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<td>Mixed Forest (Aspen, Birch, Balsam Poplar, Black and White Spruce)</td>
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<td>Deciduous Forest (Aspen) with Pasture</td>
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<td>Deciduous Woodland (Oak, Populus) with Conifer Species</td>
<td>25 Cool Broadleaf Forest</td>
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<td>Mixed Forest (Black and White Spruce, Aspen, Birch)</td>
<td>5 Deciduous Broadleaf Forest</td>
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<td>Deciduous Forest (Aspen)</td>
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<td>Deciduous Woodlands (Aspen)/Shrublands (Mountain Mahogany)</td>
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<td>Mixed Forest (Aspen, Birch, Spruce, Balsam Fir)</td>
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<td>Deciduous Forest (Maple, Beech, Birch) with Cropland (Pasture, Hay)</td>
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<td>Deciduous Dry Forest</td>
<td>32 Dry Tropical Woods</td>
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<td>Deciduous Forest (Oak)</td>
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<td>Deciduous Forest (Maple, Beech, Birch, Oak, Hickory) with Pasture Tropical Dry Forest</td>
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<td>Deciduous Forest (Oak, Hickory, Sweet Gum, Southern Pines) with Cropland and Pasture Semi-Deciduous Tropical Forest</td>
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<td>Montane Tropical Broadleaf Forest</td>
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WESTERN RED CEDAR)
EVERGREEN NEEDLELEAF FOREST
(DOUGLAS FIR, LODGEPOLE PINE,
LARCH, WESTERN RED CEDAR)
OPEN NEEDLELEAF FOREST
(PONDEROSA PINE AND LODGEPOLE
PINE)
MIXED BOREAL FOREST (ASPEN,
BIRCH, SPRUCE, PINE)
NEEDLELEAF FOREST (LODGEPOLE
PINE, PONDEROSA PINE, ENGLEMANN
SPRUCE, SUBALPINE FIR)
NEEDLELEAF FOREST (SITKA SPRUCE,
WESTERN HEMLOCK)
NEEDLELEAF FOREST (RED PINE, JACK
PINE, SPRUCE, ASPEN, BIRCH,
TAMARACK)
NEEDLELEAF FOREST (WESTERN RED
CEDAR, LODGEPOLE PINE, DOUGLAS
FIR, LARCH, PONDEROSA PINE)
NEEDLELEAF FOREST (PONDEROSA,
LODGEPOLE AND WHITE PINE,
DOUGLAS FIR)
PONDEROSA PINE FOREST
NEEDLELEAF FOREST (DOUGLAS FIR,
LODGEPOLE PINE, WESTERN WHITE
PINE)
EVERGREEN NEEDLELEAF FOREST
(CHIHUAHUA PINE, APACHE PINE)
EVERGREEN NEEDLELEAF FOREST
(DOUGLAS FIR, PONDEROSA, JEFFREY
PINE)
NEEDLELEAF FOREST (PONDEROSA
PINE)
EVERGREEN NEEDLELEAF FOREST
(SPRUCE, BALSAM FIR, EASTERN
WHITE PINE, EASTERN HEMLOCK)
NEEDLELEAF FOREST (DOUGLAS FIR)
WITH MIXED HARDWOODS
OPEN NEEDLELEAF FOREST
(PONDEROSA PINE, PINYON-JUNIPER)
EVERGREEN NEEDLELEAF FOREST
(PINE SPECIES)
NEEDLELEAF FOREST (DOUGLAS FIR)
NEEDLELEAF FOREST (WESTERN
HEMLOCK, SITKA SPRUCE, DOUGLAS
FIR)
EVERGREEN NEEDLELEAF FOREST
(LOBLOLLY, SLASH PINE) WITH HARDWOODS (GUM, CYPRESS)
EVERGREEN NEEDLELEAF FOREST (DOUGLAS FIR, WESTERN HEMLOCK, PONDEROSA PINE)
EVERGREEN NEEDLELEAF FOREST (DOUGLAS FIR, PONDEROSA PINE, REDWOODS)
EVERGREEN NEEDLELEAF FOREST (LONGLEAF, SLASH PINE)
CARIBBEAN MONTANE PINE FOREST
OPEN MIXED FOREST (SPRUCE AND ASPEN)
MIXED FOREST (BALSAM FIR, JACK PINE, BLACK AND WHITE SPRUCE, JACK PINE, ASPEN, BIRCH)
MIXED FOREST (PINE AND OAK)
MIXED FOREST (PINE AND OAK)
MIXED FOREST (ASPEN, MAPLE, OAK, JACK PINE, RED PINE, SPRUCE)
MIXED FOREST (PINE, OAK)
MIXED FOREST (PINE, OAK)
MIXED FOREST (OAK, PINE SPECIES)
DECIDUOUS SHRUBLANDS (OAK) WITH PINYON JUNIPER
DECIDUOUS TROPICAL DRYLAND WOODLAND
SPRUCE WOODLANDS AND SHRUB BOGS
BLACK SPRUCE WOODLANDS, BOGS
SUBALPINE TRANSITIONAL FOREST
WHITE SPRUCE AND BLACK SPRUCE FENS
OPEN SPRUCE FOREST WITH TALL SHRUBS (WILLOW, BIRCH, ALDER)
BLACK SPRUCE, TAMARACK, LICHEN WOODLAND
JUNIPER WOODLAND
PINYON-JUNIPER WOODLAND
SPRUCE WOODLANDS WITH LOW/TALL SHRUBS
PONDEROSA/LODGEPOLE PINE WOODLAND
PINYON JUNIPER WOODLAND
PINYON-JUNIPER WOODLAND
NORTHERN MIXED FOREST (MAPLE, BEECH, BIRCH, PINE)
SHRUB FENS AND BOGS (WILLOW, 47 DRY WOODY SCRUB
47 DRY WOODY SCRUB
47 DRY WOODY SCRUB
23 COOL MIXED FOREST
44 MIRE, BOG, FEN
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<td>11 Semi Desert Trees and Shrubs</td>
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<td>8 Bare Desert</td>
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The Seasonal Land Cover Data Base Translated into the International Geosphere Biosphere Program (IGBP) Land Cover System


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CROPLAND (CORN, COTTON, SORGHUM, PASTURE)/GRASSLAND MOSAIC
CROPLAND (PASTURE)/GRASSLAND MOSAIC
CROPLAND (PASTURE)/GRASSLAND MOSAIC
WET HERBACEOUS MEADOWS
GRASSLAND (SHORT- MID GRASS PRAIRIE)
GRASSLAND (SHORT GRASS PRAIRIE)
GRASSLAND WITH CROPLAND (SMALL GRAINS)
MIXED Rangeland (GRASSLAND/SHRUBLAND)
GRASSLAND
GRASSLAND (WARM SEASON GRASSES)
GRASSLAND WITH CROPLAND (SMALL GRAINS, PASTURE)
MIXED Rangeland (GRASSLAND AND SHRUBLAND)
GRASSLAND WITH WOODLAND AND WETLANDS
GRASSLAND WITH CROPLAND
GRASSLAND (TALL GRASS PRAIRIE)
GRASSLAND WITH CROPLAND
SAVANNA
GRASSLAND
MIXED Rangeland (NEEDLEGRASS, BIG SAGE, RABBITBRUSH)
MIXED Rangeland (SALTBUSH, SAND SAGE, RABBITBRUSH)
MIXED Rangeland (SHRUBS AND GRASSES)
MIXED Rangeland (GRASSLAND, SHRUBLAND) WITH CROPS, FALLOW SPARSELY VEGETATED DESERT SHRUBLANDS
DESERT SHRUBLANDS (CREOSOTE, SALTBUSH, SAND SAGE) - SONORAN TALL SHRUBS (WILLOW, BIRCH, ALDER)
DESSERT SHRUBLAND (CREOSOTE, SALTBUSH, MESQUITE, SAND SAGE)
DESSERT SHRUBLAND (CREOSOTE, SALTBUSH, SAND SAGE, MESQUITE) - CHIHUAHAN TALL/LOW SHRUBS (WILLOW, ALDER) AND WET HERBACEOUS
DESSERT SHRUBLAND/GRASSLAND

MOSAIC
14 CROP/VEG MOSAIC
14 CROP/VEG MOSAIC
10 GRASSLANDS MOSAIC
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9 SAVANNAS
10 GRASSLANDS
7 OPEN SHRUBLANDS
7 OPEN SHRUBLANDS
10 GRASSLANDS
10 GRASSLANDS
7 OPEN SHRUBLANDS
10 GRASSLANDS
7 OPEN SHRUBLANDS
6 CLOSED SHRUBLANDS
7 OPEN SHRUBLANDS
7 OPEN SHRUBLANDS
7 OPEN SHRUBLANDS
6 CLOSED SHRUBLANDS
7 OPEN SHRUBLANDS
7 OPEN SHRUBLANDS
(CREASEOTE, SALTBUSS, MESQUITE, SAND SAGE)
TALL/LOW SHRUBS, TUNDRA, SPRUCE

DESERT SHRUBLANDS (CREASEOTE, SALTBUSS, MESQUITE, SAND SAGE)
TALL/LOW SHRUBS, TUNDRA, SPRUCE

DESERT SHRUBLAND (CREASEOTE, SALTBUSS, MESQUITE, CACTUS) WITH GRASSES
TALL SHRUBS (WILLOW, BIRCH, ALDER) AND WET HERBACEOUS MEADOWS
CHAPPARRAL

OAK SAVANNA
DECIDUOUS DRY FOREST WITH SAVANNA PATCHES
WOODY SAVANNA
OAK WOODLANDS
GRASSLAND/WOODLAND (OAK) MOSAIC WITH CROPLAND
GRASSLAND/FOREST
DECIDUOUS FOREST AND TALL SHRUBS (WILLOW, BIRCH, ALDER)
MIXED FOREST (ASPEN, BIRCH, SPRUCE)
DECIDUOUS FOREST (ASPEN)

OPEN MIXED FOREST (ASPEN, BIRCH, WHITE SPRUCE, BLACK SPRUCE)
MIXED FOREST (ASPEN, BIRCH, BALSAM POPULAR, BLACK AND WHITE SPRUCE)
DECIDUOUS FOREST (ASPEN) WITH PASTURE
DECIDUOUS WOODLAND (OAK, POPULUS) WITH CONIFER SPECIES
MIXED FOREST (BLACK AND WHITE SPRUCE, ASPEN, BIRCH)
DECIDUOUS FOREST (ASPEN)

DECIDUOUS WOODLANDS (ASPEN)/SHRUBLANDS (MOUNTAIN MAHOGANY)
MIXED FOREST (ASPEN, BIRCH, SPRUCE, BALSAM FIR)
DECIDUOUS FOREST (MAPLE, BEECH, BIRCH) WITH CROPLAND (PASTURE, HAY)
DECIDUOUS DRY FOREST
DECIDUOUS FOREST (OAK)

DECIDUOUS FOREST (MAPLE, BEECH, BIRCH, OAK, HICKORY) WITH PASTURE TROPICAL DRY FOREST

DECIDUOUS FOREST (OAK, HICKORY, SWEET GUM, SOUTHERN PINES) WITH CROPLAND AND PASTURE SEMI-DECIDUOUS TROPICAL FOREST

SEMI-DECIDUOUS DRY FOREST

SEMI-DECIDUOUS TROPICAL FOREST

MONTANE TROPICAL BROADLEAF FOREST

TROPICAL BROADLEAF FOREST

TROPICAL BROADLEAF FOREST

DEGRADED TROPICAL FOREST

DEGRADED TROPICAL FOREST

EVERGREEN BROADLEAF TROPICAL FOREST

SUBALPINE FOREST (ENGLERMANN SPRUCE, SUBALPINE FIR, DOUGLAS FIR)

EVERGREEN NEEDLELEAF FOREST (BALSAM FIR, WHITE SPRUCE, BLACK SPRUCE)

WHITE, BLACK SPRUCE FOREST

SPRUCE FOREST

PONDEROSA, LODGEPOLE PINE FOREST

EVERGREEN NEEDLELEAF FOREST (BALSAM FIR, BLACK SPRUCE, WHITE SPRUCE)

EVERGREEN NEEDLELEAF FOREST AND WOODLAND (BLACK AND WHITE SPRUCE)

BROADLEAF FOREST

4 DECIDUOUS BROADLEAF FOREST

4 DECIDUOUS BROADLEAF FOREST

2 EVERGREEN BROADLEAF FOREST

4 DECIDUOUS BROADLEAF FOREST

2 EVERGREEN BROADLEAF FOREST

2 EVERGREEN BROADLEAF FOREST

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2 EVERGREEN BROADLEAF FOREST

2 EVERGREEN BROADLEAF FOREST

5 MIXED FORESTS

1 EVERGREEN NEEDLELEAF FOREST

1 EVERGREEN NEEDLELEAF FOREST

1 EVERGREEN NEEDLELEAF FOREST

1 EVERGREEN NEEDLELEAF FOREST

5 MIXED FORESTS

1 EVERGREEN NEEDLELEAF FOREST
EVERGREEN NEEDLELEAF FOREST
(Lodgepole Pine and Douglas Fir)

NEEDLELEAF FOREST (Englemann Spruce, Lodgepole Pine, Douglas Fir)

OPEN BLACK SPRUCE WITH BALSAM FIR, ASPEN, BIRCH

NEEDLELEAF BOREAL FOREST (Black and White Spruce, Tamarack, Aspen)

NEEDLELEAF BOREAL FOREST (Black and White Spruce, Aspen, Birch)

OPEN EVERGREEN NEEDLELEAF FOREST (Ponderosa Pine)

EVERGREEN NEEDLELEAF FOREST (Lodgepole Pine, Englemann Spruce, Ponderosa Pine)
NEEDLELEAF FOREST (Douglas Fir, Spruce, Western Red Cedar)

SPRUCE AND PINE FOREST

NEEDLELEAF FOREST (Spruce, Jack Pine, Aspen, Birch, Tamarack)

NEEDLELEAF FOREST (Hemlock, Spruce, Douglas Fir)

EVERGREEN NEEDLELEAF FOREST (Ponderosa Pine, Douglas Fir, Western Red Cedar)
EVERGREEN NEEDLELEAF FOREST (Douglas Fir, Lodgepole Pine, Larch, Western Red Cedar)
OPEN NEEDLELEAF FOREST (Ponderosa Pine and Lodgepole Pine)

MIXED BOREAL FOREST (Aspen, Birch, Spruce, Pine)

NEEDLELEAF FOREST (Lodgepole Pine, Ponderosa Pine, Englemann Spruce, Subalpine Fir)
NEEDLELEAF FOREST (SITKA SPRUCE, WESTERN HEMLOCK)   1 EVERGREEN NEEDLELEAF FOREST

NEEDLELEAF FOREST (RED PINE, JACK PINE, SPRUCE, ASPEN, BIRCH, TAMARACK)   5 MIXED FORESTS

NEEDLELEAF FOREST (WESTERN RED CEDAR, LODGEPOLE PINE, DOUGLAS FIR, LARCH, PONDEROSA PINE)   1 EVERGREEN NEEDLELEAF FOREST

NEEDLELEAF FOREST (PONDEROSA, LODGEPOLE AND WHITE PINE, DOUGLAS FIR)   1 EVERGREEN NEEDLELEAF FOREST

PONDEROSA PINE FOREST   1 EVERGREEN NEEDLELEAF FOREST

NEEDLELEAF FOREST (DOUGLAS FIR, LODGEPOLE PINE, WESTERN WHITE PINE)   1 EVERGREEN NEEDLELEAF FOREST

EVERGREEN NEEDLELEAF FOREST (CHIHUAHUA PINE, APACHE PINE)   1 EVERGREEN NEEDLELEAF FOREST

EVERGREEN NEEDLELEAF FOREST (DOUGLAS FIR, PONDEROSA, JEFFREY PINE)   1 EVERGREEN NEEDLELEAF FOREST

NEEDLELEAF FOREST (PONDEROSA PINE)   1 EVERGREEN NEEDLELEAF FOREST

EVERGREEN NEEDLELEAF FOREST (SPRUCE, BALSAM FIR, EASTERN WHITE PINE, EASTERN HEMLOCK)   1 EVERGREEN NEEDLELEAF FOREST

NEEDLELEAF FOREST (DOUGLAS FIR) WITH MIXED HARDWOODS   1 EVERGREEN NEEDLELEAF FOREST

OPEN NEEDLELEAF FOREST (PONDEROSA PINE, PINYON-JUNIPER)   1 EVERGREEN NEEDLELEAF FOREST

EVERGREEN NEEDLELEAF FOREST (PINE SPECIES)   1 EVERGREEN NEEDLELEAF FOREST

NEEDLELEAF FOREST (DOUGLAS FIR)   1 EVERGREEN NEEDLELEAF FOREST

NEEDLELEAF FOREST (WESTERN HEMLOCK, SITKA SPRUCE, DOUGLAS FIR)   1 EVERGREEN NEEDLELEAF FOREST

EVERGREEN NEEDLELEAF FOREST (LOBLOLLY, SLASH PINE) WITH HARDWOODS (GUM, CYPRESS)   1 EVERGREEN NEEDLELEAF FOREST

EVERGREEN NEEDLELEAF FOREST   1 EVERGREEN
(DOUGLAS FIR, WESTERN HEMLOCK, PONDEROSA PINE) NEEDLELEAF FOREST
EVERGREEN NEEDLELEAF FOREST 1 EVERGREEN
(DOUGLAS FIR, PONDEROSA PINE, REDWOODS) NEEDLELEAF FOREST
EVERGREEN NEEDLELEAF FOREST 1 EVERGREEN
(LONGLEAF, SLASH PINE) NEEDLELEAF FOREST
CARIBBEAN MONTANE PINE FOREST 1 EVERGREEN

OPEN MIXED FOREST (SPRUCE AND ASPEN) 5 MIXED FORESTS
MIXED FOREST (BALSAM FIR, JACK PINE, BLACK AND WHITE SPRUCE, JACK PINE, ASPEN, BIRCH) 5 MIXED FORESTS
MIXED FOREST (PINE AND OAK) 5 MIXED FORESTS
MIXED FOREST (PINE AND OAK) 5 MIXED FORESTS
MIXED FOREST (ASPEN, MAPLE, OAK, JACK PINE, RED PINE, SPRUCE) 5 MIXED FORESTS
MIXED FOREST (PINE, OAK) 5 MIXED FORESTS
MIXED FOREST (PINE, OAK) 5 MIXED FORESTS
MIXED FOREST (OAK, PINE SPECIES) 5 MIXED FORESTS
DECIDUOUS SHRUBLANDS (OAK) WITH PINYON JUNIPER 6 CLOSED
DECIDUOUS TROPICAL DRYLAND SHRUBLANDS
WOODLAND 4 DECIDUOUS BROADLEAF FOREST

SPRUCE WOODLANDS AND SHRUB BOGS 5 MIXED FORESTS
BLACK SPRUCE WOODLANDS, BOGS 5 MIXED FORESTS
SUBALPINE TRANSITIONAL FOREST 5 MIXED FORESTS
WHITE SPRUCE AND BLACK SPRUCE FENS 8 WOODY SAVANNAS
OPEN SPRUCE FOREST WITH TALL SHRUBS (WILLOW, BIRCH, ALDER) 5 MIXED FORESTS
BLACK SPRUCE, TAMARACK, LICHEN WOODLAND 5 MIXED FORESTS

JUNIPER WOODLAND 8 WOODY SAVANNA
PINYON-JUNIPER WOODLAND 8 WOODY SAVANNA
SPRUCE WOODLANDS WITH LOW/TALL SHRUBS 5 MIXED FORESTS

PONDEROSA/Lodgepole Pine WOODLAND 1 EVERGREEN

PINYON JUNIPER WOODLAND 8 WOODY SAVANNA
PINYON-JUNIPER WOODLAND 8 WOODY SAVANNA
NORTHERN MIXED FOREST (MAPLE, BEECH, BIRCH, PINE) 5 MIXED FORESTS

SHRUB FENS AND BOGS (WILLOW, ALDER, 11 PERMANENT
| BIRCH, BLACK SPRUCE | WETLANDS |
| MIXED WETLANDS; HERBACEOUS AND WOODY (MANGROVE) | 11 PERMANENT WETLANDS |
| SPARSELY VEGETATED ARCTIC TUNDRA | 16 BARREN OR SPARSELY VEGETATED |
| HERBACEOUS ALPINE TUNDRA WITH LOW/DWARF SHRUBS | 7 OPEN SHRUBLANDS |
| HERBACEOUS ARCTIC TUNDRA | 16 BARREN OR SPARSELY VEGETATED |
| HERBACEOUS ALPINE TUNDRA | 7 OPEN SHRUBLANDS |
| HERBACEOUS ARCTIC TUNDRA | 16 BARREN OR SPARSELY VEGETATED |
| SPARSELY VEGETATED ALPINE SHRUBLANDS | 7 OPEN SHRUBLANDS |
| WOODY ALPINE TUNDRA | 8 WOODY SAVANNAS |
| HERBACEOUS ARCTIC TUNDRA WITH LOW/DWARF SHRUBS | 16 BARREN OR SPARSELY VEGETATED |
| WOODY ARCTIC TUNDRA WITH LICHEN | 8 WOODY SAVANNAS |
| HERBACEOUS ALPINE TUNDRA WITH LOW/DWARF SHRUBS | 7 OPEN SHRUBLANDS |
| HERBACEOUS ARCTIC TUNDRA | 16 BARREN OR SPARSELY VEGETATED |
| WOODY ARCTIC TUNDRA (DWARF/LOW SHRUBS) | 8 WOODY SAVANNAS |
| WOODY ARCTIC TUNDRA, TALL, LOW, AND DWARF SHRUBLANDS | 15 SNOW AND ICE |
| ICE AND SNOW | 7 OPEN SHRUBLANDS |
| BARREN OR SPARSELY VEGETATED BARREN | 16 BARREN OR SPARSELY VEGETATED |
| WATER | 17 WATER BODIES |
The Seasonal Land Cover Data Base Translated into the USGS Land Cover System


SLCR  USGS_CODE USGS
CROPLAND (SMALL GRAINS AND PASTURE) WITH GRASSLANDS 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (SMALL GRAINS) WITH GRASSLANDS 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (COFFEE, SUGAR CANE, MIXED CROPS) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (SMALL GRAINS, PASTURE) WITH DECIDUOUS WOODLANDS 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (SMALL GRAINS, ROW CROPS) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (WINTER WHEAT) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (CORN AND SOYBEANS) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (CORN AND OTHER ROW CROPS, FORAGE CROPS) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (TRUCK CROPS) WITH DECIDUOUS WOODLANDS (OAK) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (CORN AND SOYBEANS) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (CORN AND SOYBEANS) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (SMALL GRAINS, HAY, PASTURE) WITH WETLANDS 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (MIXED ROW CROPS) WITH WOODLAND 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (GRASS SEED, SMALL GRAINS) WITH MIXED WOODLANDS 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (CULTIVATED GRASSLAND) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (WINTER WHEAT) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (SUGAR CANE) 211 DRYLAND CROPLAND AND PASTURE
CROPLAND (COTTON, SOYBEANS, RICE) 211 DRYLAND CROPLAND
CROPLAND (SUGAR CANE)
CROPLAND (CULTIVATED GRASSES) WITH WOODLAND
CROPLAND (CULTIVATED GRASSES) WITH SAVANNA
CROPLAND (CORN, SOYBEANS, COTTON, RICE) WITH WOODLANDS
CROPLAND WITH SAVANNA

CROPLAND
CROPLAND

CROPLAND WITH GRASSLAND
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE
IRRIGATED AGRICULTURE

CROPLAND/DECIDUOUS FOREST (ASPEN) MOSAIC
CROPLAND, WOODLAND. URBAN MOSAIC

CROPLAND/WOODLAND (MAPLE, BEECH, BIRCH) MOSAIC
CROPLAND (CORN, SOYBEANS, ALFALFA)/WOODLANDS MOSAIC
CROPLAND (CORN, SOYBEANS, PASTURE)/WOODLAND (MAPLE, ELM) MOSAIC

AND PASTURE
211 DRYLAND CROPLAND AND PASTURE
211 DRYLAND CROPLAND AND PASTURE
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212 IRRIGATED CROP AND PASTURE
212 IRRIGATED CROP AND PASTURE
290 CROPLAND/ WOODLAND MOSAIC
280 CROPLAND/ GRASSLAND MOSAIC
290 CROPLAND/ WOODLAND MOSAIC
280 CROPLAND/ GRASSLAND MOSAIC
280 CROPLAND/ GRASSLAND MOSAIC
280 CROPLAND/ GRASSLAND MOSAIC
CROPLAND (CORN, SMALL GRAINS)/DECIDUOUS FOREST (OAK, HICKORY) MOSAIC
CROPLAND (CORN, SOYBEANS, PASTURE)/WOODLAND (OAK, HICKORY) MOSAIC
CROPLAND/DECIDUOUS FOREST MOSAIC

CROPLAND/WOODLAND

CROPLAND (CORN, COTTON, SOYBEANS)/EVERGREEN NEEDLELEAF FOREST (SLASH PINE) MOSAIC
GRASSLAND, CROPLAND (SMALL GRAINS), FALLOW MOSAIC
CROPLAND (SMALL GRAINS, PASTURE)/GRASSLAND MOSAIC
GRASSLAND/CROPLAND (WHEAT, CORN) MOSAIC
CROPLAND (ROW CROPS, SMALL GRAINS)/GRASSLAND MOSAIC
CROPLAND (SMALL GRAINS, ROW CROPS)/GRASSLAND
CROPLAND (CORN, SORGHUM, SMALL GRAINS)/GRASSLAND MOSAIC
CROPLAND/GRASSLAND

CROPLAND (CORN, COTTON, SORGHUM, PASTURE)/GRASSLAND MOSAIC
CROPLAND (PASTURE)/GRASSLAND MOSAIC
WET HERBACEOUS MEADOWS
GRASSLAND (SHORT- MID GRASS PRAIRIE)
GRASSLAND (SHORT GRASS PRAIRIE)
GRASSLAND WITH CROPLAND (SMALL GRAINS)
MIXED RANGELAND
(GRASSLAND/SHRUBLAND)
GRASSLAND
GRASSLAND (WARM SEASON GRASSES)
GRASSLAND WITH CROPLAND (SMALL GRAINS, PASTURE)
MIXED RANGELAND (GRASSLAND AND SHRUBLAND)
GRASSLAND WITH WOODLAND AND WETLANDS
GRASSLAND WITH CROPLAND

280 CROPLAND/
GRASSLAND MOSAIC
290 CROPLAND/
WOODLAND MOSAIC
290 CROPLAND/
WOODLAND MOSAIC
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280 CROPLAND/
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<td>GRASSLAND WITH CROPLAND</td>
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<td>GRASSLAND</td>
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<tr>
<td>SPARSELY VEGETATED DESERT SHRUBLANDS</td>
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<td>DESERT SHRUBLANDS (CREOSOTE, SALTBUSS, SAND SAGE) - SONORAN</td>
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<tr>
<td>TALL SHRUBS (WILLOW, BIRCH, ALDER)</td>
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<td>DESERT SHRUBLAND (CREOSOTE, SALTBUSS, MESQUITE, SAND SAGE)</td>
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<tr>
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<td>TALL/LOW SHRUBS (WILLOW, ALDER)</td>
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<td>DECIDUOUS DRY FOREST WITH SAVANNA Patches</td>
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<td>OAK WOODLANDS</td>
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<td>GRASSLAND/WOODLAND (OAK) MOSAIC WITH CROPLAND</td>
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<td>GRASSLAND/FOREST</td>
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<td>DECIDUOUS FOREST AND TALL SHRUBS (WILLOW, BIRCH, ALDER)</td>
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<td>(WILLOW, BIRCH, ALDER)</td>
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<td>BROADLEAF FOREST</td>
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MIXED FOREST (ASPEN, BIRCH, SPRUCE)

DECIDUOUS FOREST (ASPEN)

OPEN MIXED FOREST (ASPEN, BIRCH, WHITE SPRUCE, BLACK SPRUCE)

MIXED FOREST (ASPEN, BIRCH, BALSAM POPLAR, BLACK AND WHITE SPRUCE)

DECIDUOUS FOREST (ASPEN) WITH PASTURE

DECIDUOUS WOODLAND (OAK, POPULUS) WITH CONIFER SPECIES

MIXED FOREST (BLACK AND WHITE SPRUCE, ASPEN, BIRCH)

DECIDUOUS FOREST (ASPEN)

DECIDUOUS WOODLANDS (ASPEN)/SHRUBLANDS (MOUNTAIN MAHOGANY)

MIXED FOREST (ASPEN, BIRCH, SPRUCE, BALSAM FIR)

DECIDUOUS FOREST (MAPLE, BEECH, BIRCH) WITH CROPLAND (PASTURE, HAY)

DECIDUOUS DRY FOREST

DECIDUOUS FOREST (OAK)

DECIDUOUS FOREST (MAPLE, BEECH, BIRCH, OAK, HICKORY) WITH PASTURE

TROPICAL DRY FOREST

DECIDUOUS FOREST (OAK, HICKORY, SWEET GUM, SOUTHERN PINES) WITH CROPLAND AND PASTURE

SEMI-DECIDUOUS TROPICAL FOREST

SEMI-DECIDUOUS DRY FOREST

SEMI-DECIDUOUS TROPICAL FOREST

MONTANE TROPICAL BROADLEAF FOREST

TROPICAL BROADLEAF FOREST

TROPICAL BROADLEAF FOREST

DEGRADED TROPICAL FOREST

411 DECIDUOUS BROADLEAF FOREST

411 DECIDUOUS BROADLEAF FOREST

411 DECIDUOUS BROADLEAF FOREST

411 DECIDUOUS BROADLEAF FOREST

411 DECIDUOUS BROADLEAF FOREST

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411 DECIDUOUS BROADLEAF FOREST

411 DECIDUOUS BROADLEAF FOREST

411 DECIDUOUS BROADLEAF FOREST
DEGRADED TROPICAL FOREST

EVERGREEN BROADLEAF TROPICAL FOREST
SUBALPINE FOREST (ENGLEMANN SPRUCE, SUBALPINE FIR, DOUGLAS FIR)
EVERGREEN NEEDLELEAF FOREST (BALSAM FIR, WHITE SPRUCE, BLACK SPRUCE)
WHITE, BLACK SPRUCE FOREST

SPRUCE FOREST

PONDEROSA, LODGEPOLE PINE FOREST

EVERGREEN NEEDLELEAF FOREST (BALSAM FIR, BLACK SPRUCE, WHITE SPRUCE)
EVERGREEN NEEDLELEAF FOREST AND WOODLAND (BLACK AND WHITE SPRUCE)
EVERGREEN NEEDLELEAF FOREST (Lodgepole Pine AND Douglas Fir)
NEEDLELEAF FOREST (ENGLEMANN SPRUCE, LODGEPOLE PINE, DOUGLAS FIR)
OPEN BLACK SPRUCE WITH BALSAM FIR, ASPEN, BIRCH
NEEDLELEAF BOREAL FOREST (BLACK AND WHITE SPRUCE, TARMARACK, ASPEN)
NEEDLELEAF BOREAL FOREST (BLACK AND WHITE SPRUCE, ASPEN, BIRCH)
OPEN EVERGREEN NEEDLELEAF FOREST (PONDEROSA PINE)
EVERGREEN NEEDLELEAF FOREST (Lodgepole Pine, Englemann Spruce, Ponderosa Pine)
NEEDLELEAF FOREST (DOUGLAND FIR, SPRUCE, WESTERN RED CEDAR)
SPRUCE AND PINE FOREST

NEEDLELEAF FOREST (SPRUCE, JACK PINE, ASPEN, BIRCH, TARMARACK)
NEEDLELEAF FOREST (HEMLOCK, SPRUCE, DOUGLAS FIR)
EVERGREEN NEEDLELEAF FOREST (PONDEROSA PINE, DOUGLAS FIR, WESTERN RED CEDAR)
EVERGREEN NEEDLELEAF FOREST (DOUGLAS FIR, LODGEPOLE PINE, LARCH)
WESTERN RED CEDAR
OPEN NEEDLELEAF FOREST (PONDEROSA PINE AND LODGEPOLE PINE)
MIXED BOREAL FOREST (ASPEN, BIRCH, SPRUCE, PINE)
NEEDLELEAF FOREST (LODGEPOLE PINE, PONDEROSA PINE, ENGLEMANN SPRUCE, SUBALPINE FIR)
NEEDLELEAF FOREST (SITKA SPRUCE, WESTERN HEMLOCK)
NEEDLELEAF FOREST (RED PINE, JACK PINE, SPRUCE, ASPEN, BIRCH, TAMARACK)
NEEDLELEAF FOREST (WESTERN RED CEDAR, LODGEPOLE PINE, DOUGLAS FIR, LARCH, PONDEROSA PINE)
NEEDLELEAF FOREST (PONDEROSA, LODGEPOLE AND WHITE PINE, DOUGLAS FIR)
PONDEROSA PINE FOREST
NEEDLELEAF FOREST (DOUGLAS FIR, LODGEPOLE PINE, WESTERN WHITE PINE)
EVERGREEN NEEDLELEAF FOREST (CHIHUAHUA PINE, APACHE PINE)
EVERGREEN NEEDLELEAF FOREST (DOUGLAS FIR, PONDEROSA, JEFFREY PINE)
NEEDLELEAF FOREST (PONDEROSA PINE)

EVERGREEN NEEDLELEAF FOREST (SPRUCE, BALSAM FIR, EASTERN WHITE PINE, EASTERN HEMLOCK)
NEEDLELEAF FOREST (DOUGLAS FIR) WITH MIXED HARDWOODS
OPEN NEEDLELEAF FOREST (PONDEROSA PINE, PINYON-JUNIPER)
EVERGREEN NEEDLELEAF FOREST (PINE SPECIES)
NEEDLELEAF FOREST (DOUGLAS FIR)

NEEDLELEAF FOREST (WESTERN HEMLOCK, SITKA SPRUCE, DOUGLAS FIR)
EVERGREEN NEEDLELEAF FOREST (LOBLOLLY, SLASH PINE) WITH HARDWOODS (GUM, CYPRESS)
EVERGREEN NEEDLELEAF FOREST (DOUGLAS FIR, WESTERN HEMLOCK, PONDEROSA PINE)
EVERGREEN NEEDLELEAF FOREST (DOUGLAS FIR, PONDEROSA PINE, REDWOODS)
EVERGREEN NEEDLELEAF FOREST (LONGLEAF, SLASH PINE)
CARIBBEAN MONTANE PINE FOREST
OPEN MIXED FOREST (SPRUCE AND ASPEN)
MIXED FOREST (BALSAM FIR, JACK PINE, BLACK AND WHITE SPRUCE, JACK PINE, ASPEN, BIRCH)
MIXED FOREST (PINE AND OAK)
MIXED FOREST (PINE AND OAK)
MIXED FOREST (ASPEN, MAPLE, OAK, JACK PINE, RED PINE, SPRUCE)
MIXED FOREST (PINE, OAK)
MIXED FOREST (PINE, OAK)
MIXED FOREST (OAK, PINE SPECIES)
DECIDUOUS SHRUBLANDS (OAK) WITH PINYON JUNIPER
DECIDUOUS TROPICAL DRYLAND WOODLAND
SPRUCE WOODLANDS AND SHRUB BOGS
BLACK SPRUCE WOODLANDS, BOGS
SUBALPINE TRANSITIONAL FOREST
WHITE SPRUCE AND BLACK SPRUCE FENS
OPEN SPRUCE FOREST WITH TALL SHRUBS (WILLOW, BIRCH, ALDER)
BLACK SPRUCE, TAMARACK, LICHEN WOODLAND
JUNIPER WOODLAND
PINYON-JUNIPER WOODLAND
SPRUCE WOODLANDS WITH LOW/TALL SHRUBS
PONDEROSA/Lodgepole PINE WOODLAND
PINYON JUNIPER WOODLAND
PINYON-JUNIPER WOODLAND
NORTHERN MIXED FOREST (MAPLE, BEECH, BIRCH, PINE)
SHRUB FENS AND BOGS (WILLOW, ALDER, BIRCH, BLACK SPRUCE)
MIXED WETLANDS; HERBACEOUS AND WOODY (MANGROVE)
SPARSELY VEGETATED ARCTIC TUNDRA
HERBACEOUS ALPINE TUNDRA WITH LOW/DWARF SHRUBS

422 EVERGREEN NEEDLELEAF FOREST
422 EVERGREEN NEEDLELEAF FOREST
422 EVERGREEN NEEDLELEAF FOREST
430 MIXED FOREST
430 MIXED FOREST
430 MIXED FOREST
430 MIXED FOREST
430 MIXED FOREST
320 SHRUBLAND
411 DECIDUOUS BROADLEAF FOREST
430 MIXED FOREST
430 MIXED FOREST
430 MIXED FOREST
820 WOODED TUNDRA
430 MIXED FOREST
430 MIXED FOREST
320 SHRUBLAND
320 SHRUBLAND
430 MIXED FOREST
422 EVERGREEN NEEDLELEAF FOREST
320 SHRUBLAND
320 SHRUBLAND
430 MIXED FOREST
620 WOODED WETLANDS
620 WOODED WETLANDS
830 MIXED TUNDRA
820 WOODED TUNDRA
HERBACEOUS ARCTIC TUNDRA
HERBACEOUS ALPINE TUNDRA
HERBACEOUS ARCTIC TUNDRA
SPARSELY VEGETATED ALPINE SHRUBLANDS
WOODY ALPINE TUNDRA
HERBACEOUS ARCTIC TUNDRA WITH LOW/DWARF SHRUBS
WOODY ARCTIC TUNDRA WITH LICHEN
HERBACEOUS ALPINE TUNDRA WITH LOW/DWARF SHRUBS
HERBACEOUS ARCTIC TUNDRA
WOODY ARCTIC TUNDRA (DWARF/LOW SHRUBS)
WOODY ARCTIC TUNDRA, TALL, LOW, AND DWARF SHRUBLANDS
ICE AND SNOW
BARREN OR SPARSELY VEGETATED
BARREN
WATER

830 MIXED TUNDRA
820 WOODED TUNDRA
830 MIXED TUNDRA
820 WOODED TUNDRA
830 MIXED TUNDRA
820 WOODED TUNDRA
820 WOODED TUNDRA
830 MIXED TUNDRA
820 WOODED TUNDRA
820 WOODED TUNDRA
900 SNOW AND ICE
331 MIXED SHRUBLAND/GRASSLAND
770 BARREN OR SPARSELY VEGETATED
500 WATER BODIES
Appendix D

The Avenue Program Used To Complete The Stratified Random Sampling
For Data Points In ArcView – Courtesy Of Suzanne P. Wechsler

' Unc.RanSel
' Checks whether active theme is a point or grid theme.
' If its a grid, the program converts the grid to points.
' n random points are selected and saved to a shapefile (v_fname.shp).
' The unselected points can be saved to another file (n_fname.shp).
' Randomly selected values can be used in other programs such as
' semivariogram analysis or for interpolation/validation.
' Author: Suzanne P. Wechsler
' Created: 11/2/98
' Last Revised: 11/22/98
'

' Get the View

theProject = av.GetProject
theView = av.GetActiveDoc
theActiveThemes = theview.GetActiveThemes
wkdir = av.GetProject.GetWorkDir
theT=" Random Selection Tool"

' Check if there are any active themes in the view
if ((theActiveThemes = Nil) Or (theActiveThemes.Count = 0)) then
MsgBox.Error("There is no active theme in the current view.", theT)
return Nil
end

' Select the theme.
' If a grid theme is active, convert it to a shapefile.
' If a point theme (shapefile) is active, proceed.

if (theActiveThemes.count = 0) then
    messagebox.error("No active themes found.", " Selection Error")
    exit
end
if (theActiveThemes.count > 1) then
    messagebox.error("Only one active theme allowed.", " Selection Error")
    exit
end
if (theActiveThemes.count = 1) then
  gfound = false
  ffound = false
  for each activetheme in theactivethemes
    if (activetheme.getclass.getclassname = "gtheme") then
      gridGTheme = activetheme
      gname = gridGtheme.GetSrcName
      gfound = true
    end 'if
    if (activetheme.getclass.getclassname = "ftheme") then
      theftheme = activetheme
      ffound = true
      FThemeSrcName = theftheme.GetSrcName.AsString
    end 'if
  end 'for each
end

' If it's a grid theme, convert it to point theme.

if (gfound = TRUE) then

  convertpoints = MsgBox.YesNoCancel("You have selected a
grid." + NL + "Convert " + gname.AsString + " to points?", "Grid to Point Conversion", TRUE)
  if (convertpoints = NIL) then
    MsgBox.Info("Program Has been Canceled.", "Exiting Program...")
    exit
  elseif (convertpoints = FALSE) then
    MsgBox.Info("Select another feature.", "Exiting Program...")
    exit
  elseif (convertpoints = TRUE) then
    MsgBox.Info("Converting grid to point theme...", "Commence Grid to Point Conversion.")
  end 'if convertpoints

  theGrid = gridGtheme.Clone.GetGrid.Clone
  thePrj = Prj.MakeNull

  'Create output theme
  rep = 0
  fName = FileName.Make(wkdir.AsString).MakeTmp("grid", "shp")
  while (rep = 0)
    outFileName = FileDialog.Put(fName, "*.shp", "Out theme")
  end 'while

end
if (outFileName = NIL) then
  exit
elseif (outFileName.GetBaseName.AsTokens( "." ).Get(0).Contains( " " )) then
  MsgBox.Warning("Output theme name not specified, re-enter", "Warning")
else
  rep = 1
end
end

theTab = Ftab.MakeNew(outFileName, Point)
theFTheme = FTheme.Make(theTab)
outFields = List.Make
outFields = List.Make
outFields.Add( Field.Make("X", #FIELD_LONG, 11, 0) )
outFields.Add( Field.Make("Y", #FIELD_LONG, 11, 0) )
outFields.Add( Field.Make("Z", #FIELD_LONG, 11, 0) )
theTab.AddFields(outFields)

' Set field alias

XField = theTab.FindField("X")
YField = theTab.FindField("Y")
ZField = theTab.FindField("Z")
shapefield = theTab.FindField("shape")

' Export ascii and read it

tempOutFileName = (outFileName.AsString.Left(outFileName.AsString.Count-3)+"asc").AsFileName
theGrid.SaveAsASCIITempOutFileName
theTextFile = TextFile.Make(tempOutFileName, #FILE_PERM_READ)
theText = theTextFile.Read(theTextFile.GetSize)
theTextFile.Close

theRows = theText.AsTokens(NL)

count = 0
numOfRows = theGrid.GetNumRowsAndCols.Get(0)
numOfCols = theGrid.GetNumRowsAndCols.Get(1)
cellSize = theGrid.GetCellSize
theStartPoint = theGrid.GetExtent.AsMultiPoint.AsList.Get(0)

X = theStartPoint.GetX+(cellSize/2)
Y = theStartPoint.GetY+(cellSize/2)
XCount = 0
YCount = 1
theValues = theRows.Get(theRows.Count-1).AsTokens(" ")

av.ShowMsg("Exporting grid...")
av.SetStatus(0)
av.ShowStopButton
sstatus = (numOfCols*numOfRows)
while (ccount<>(numOfCols*numOfRows))
ccount = ccount+1
'MessageBox.ListBoxAsText(theValues,"","")
ppoint = point.Make(X,Y)
Z = theValues.Get(XCount).AsNumber
XCount = XCount+1
if (XCount = numOfCols) then
    X = theStartPointGetX+(cellSize/2)
    Y = Y+cellsize
    XCount = 0
    YCount = YCount+1
    theValues = theRows.Get(theRows.Count-YCount).AsTokens(" ")
else
    X = X+cellSize
end
if (Z<>"-.9999".AsNumber) then
    newrec = theFtab.AddRecord
    theFtab.SetValue(shapefield,newrec,ppoint)
    theFtab.SetValue(XField,newrec,X)
    theFtab.SetValue(YField,newrec,Y)
    theFtab.SetValue(ZField,newrec,Z)
end
proceed = av.SetStatus((ccount/sstatus)*100)
if (proceed.Not) then
    av.ClearStatus
    av.ShowMsg("Stopped")
    exit
end

'Reset arcview

theFtab.Flush
theFtab.Refresh
theFTheme.StopEditing(TRUE)
FthemeSrcName=theFTheme.GetSrcname
av.ClearStatus
av.ClearMsg
'Add theme to view
  theView.AddTheme(theFTheme)
  theView.FindTheme(FthemeSrcName.AsString)
  theFTheme.Select

  theFtab = thefTheme.GetFtab
  theShapeF = theFTab.FindField("Shape")
  theValue = theFTab.ReturnValue(theShapeF, 0)
  if ((theValue.GetDimension = 0).Not) then
    MsgBox.Error("The active theme is not a point theme!"+NL+"Requires a point/multi-point theme.", theT)
    return Nil
  end 'if

end 'if gfound = TRUE  'End convert grid to points

if (ffound = TRUE) then
  theFTheme = theActivethemes.Get(0)
  FthemeSrcName=theFTheme.GetSrcname
  theFtab = thefTheme.GetFtab
  theShapeF = theFTab.FindField("Shape")
  theValue = theFTab.ReturnValue(theShapeF, 0)
  if ((theValue.GetDimension = 0).Not) then
    MsgBox.Error("The active theme is not a point theme!"+NL+"Requires a point/multi-point theme.", theT)
    return Nil
  end 'if

end 'if ffound or gfound = true

'Activate the point theme for random point selection

fthemeselect=MsgBox.YesNo("You have selected: "+FthemeSrcName.AsString, " Is this the correct theme?", TRUE)
if (ftemeselect=FALSE) then
  MsgBox.Error("Try your feature selection again.", " Exiting Program...")
  exit
end 'if

TotalRecs = theFtab.GetNumRecords
TotalRecs.SetFormat("d")

'User enters number of features to be selected
NumberofRanString = MsgBox.Input("Enter number of random features to be selected: ", "Select Random Sample from: "+fthemeSrcName.asString,"10")
NumberofRan=NumberofRanString.AsNumber
if ((NumberofRanString = NIL) or (NumberofRanString.IsNumber.Not)) then exit end
if (NumberofRanString.AsNumber < 1) then
    MsgBox.Error("You must enter a number > 0.","Exiting Program...")
    exit
end

'Create a list of n unique random numbers
'Use random numbers to select records from the ftheme

'MsgBox.Info("Total Records in: "+fthemeSrcName.AsString+" = "+totalrecs.asString, "Total Records")

RanNumList=List.Make
RanNumListClone=List.Make

theBitMap = theFtab.GetSelection
theBitMap.ClearAll

while ((RanNumList.Count)<(NumberofRan) = TRUE)
    j=number.makerandom(0,(totalrecs-1))
    j.setformat("d")
    RanNumList.Add(j)
    RanNumList.RemoveDuplicates
    theBitMap.set(j,clone)
end 'while

RanNumListCount=RanNumList.Count
'MsgBox.ListAsString(RanNumList, RanNumListCount.AsString+" Unique Random Numbers", "Random Number List")
theValidBitmapCount=theBitMap.Count
'MsgBox.Info("Number of BitMap objects = "+theValidBitmapCount.AsString, ")
'theValidBitmapList=theValidBitmap.AsList
'MsgBox.ListAsString(theValidBitmapList, "Valid Bitmap List", ")

'Export randomly selected points to a new Ftab

DirString = theProject.GetWorkDir.AsString
'velidshapename="v_"+fthemesrcname.AsString+".shp"
validshapename="v_"+NumberofRanString+"_"+fthemesrcname.asstring
ValidationFtab=theFtab.Export(validshapename.AsFilename, Shape, TRUE)
ValidationFtheme=ftheme.Make(ValidationFtab)
ValidationCount=ValidationFtab.GetNumRecords
ValidationCount.SetFormat("d")
theview.AddTheme(ValidationFtheme)

'Ask User if NOT selected points should be saved to another file
unsel=totalrecs-NumofRan
saveunsel=MsgBox.YesNo("Save "+unsel.asstring+" unselected points to a shapefile?", "Points to Random Points", TRUE)

'Export unselected points to a different file
'This part doesn't work - generated shapefile is empty

if (saveunsel=TRUE) then
  theBitmap.Not

  theFtab.UpdateSelection
  theNOTBitmapCount=theBitmap.Count
  'MsgBox.Info("Number of NOT BitMap objects = "+theNOTBitmapCount.AsString, ")

  NOTvalidshapename="n_"+unsel.asstring+"_"+fthemesrcname.asstring
  NOTValidationFtab=theFtab.Export(NOTvalidshapename.AsFilename, shape, TRUE)
  NOTValidationFtheme=ftheme.Make(NOTValidationFtab)
  NOTValidationCount=theFtab.GetNumRecords
  NOTValidationCount.SetFormat("d")

elseif (saveunsel=FALSE) then
  MsgBox.Info(" Program Completed.", theT)
  exit
end 'if

theview.AddTheme(NOTValidationFtheme)
thebitmap.clearall
theFtab.updateSelection
theview.invalidate
RanNumList.Empty
av.purgeobjects

'Ask User if point theme will be used for interpolation.
Appendix E

Point To Point Rectification Steps In Imagine

1. Open two viewers, one with AAP.jpg displayed and one with the TM scene displayed.
2. Go to Raster (button), scroll down to Geometric Correction.
3. Polynomial, 2nd order, apply, then close.
4. Existing viewer, click in TM scene viewer.
5. Projection "unknown" is ok.
6. Click on pointer (up arrow button) and can move Area Of Interest (AOI) box around and can zoom in and out of image
7. Go to Ground Control Point (GCP) tool and select button \( \oplus \) on the bottom rectangular display.
8. Select a point in the AAP FIRST, because this is the image you're going to warp to Imagine coordinate system, order is important.
9. Select same point in TM scene.
10. Pick around 40-60 points that match between each scene.
11. Keep an eye on the Root Mean Squared (RMS) error shown for the whole image and also for each individual point you add. Keep it 0.10 or lower.
12. Make sure to uniformly distributed set of points all over the image, too many in one place and too few in another will cause problems and errors later.
13. After you have selected all the points, save inputs as filename.gcc and make sure you save this file in the same folder as the finished AAP image.
14. Click on the button \( \square \) and this will start the rectification process.
15. Sampling method: \( \mathcal{C} \) cubic convolution, check "ignore zero" all else leave to default values.
16. Select output filename and place to put file, the file should be in the same folder as the filename.gcc file. The file will be created with an *.img extension, this will show up in ArcView with no trouble and will overlay with the TM scene you rectified it to.
Appendix F

Astronaut Acquired Photography Used

Sample Points – Suitable Matches in SSEOP Database:

class: #29, called: Evergreen needleleaf forest

1) SSEOP Database Photograph Information
   STS090-705-5.JPG
   PHASE II PROJECT
   Identification

Mission: STS090 Roll: 705 Frame: 5 Mission ID on the Film: STS90
Country or Geographic Name: USA-CA
Features: MONTEREY BAY, SALINAS
Center Point Latitude: 37.0 Center Point Longitude: -122.0
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North: Top
ONC Map ID: G-18 JNC Map ID: 28
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: South
Camera: HB: Hasselblad
Film: 5069 : Kodak Elite 100S, E6 Reversal, Replaces Lumiere, Warmer in tone vs. Lumiere.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19980417 (YYYYMMDD) GMT Time: 225937 (HHMMSS)
Nadir Point Latitude: 37.6, Longitude: -122.1 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 247 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 140 nautical miles
Sun Elevation Angle: 43 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 4
*This point matches with point: x_coord: -121.95693, y_coord: 37.07217 in the class: #29, called: Evergreen needleleaf forest

2) A) Images STS068-205-38.JPG
Identification
Mission: STS068 Roll: 205 Frame: 38 Mission ID on the Film: STS68
Country or Geographic Name: USA-CA
Features: NEAR LEMOORE NAS
Center Point Latitude: 36.5 Center Point Longitude: -120.0 (Negative numbers indicate south for latitude and west for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-18 JNC Map ID: 28
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North West
Camera: HB: Hasselblad
Film: 2443 : Kodak, color infrared, Aerochrome 2443, thin base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19941010 (YYYYMMDD) GMT Time: 184324 (HHMMSS)
Nadir Point Latitude: 35.9, Longitude: -119.6 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 158 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 111 nautical miles
Sun Elevation Angle: 45 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 168
Matches with point: x_coord: -120.18173, y_coord: 36.71959, class #29
2) B) Matches with point: x_coord: -120.18173, y_coord: 36.71959, class #29
STS068-258-6.JPG
Identification
Mission: STS068 Roll: 258 Frame: 6 Mission ID on the Film: STS68
Country or Geographic Name: USA-CA
Features: AGR..SMALL CITIES
Center Point Latitude: 36.5 Center Point Longitude: -120.0 (Negative numbers indicate south for latitude and west for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-18 JNC Map ID: 28
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North West
Camera: HB: Hasselblad
Film: 5046 : Kodak, natural color positive, Lumiere 100/5046, ASA 100, standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19941009 (YYYYMMDD) GMT Time: 190627 (HHMMSS)
Nadir Point Latitude: 35.7, Longitude: -119.3 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 166 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 111 nautical miles
Sun Elevation Angle: 47 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 152

2) C) Matches with point: x_coord: -120.18173, y_coord: 36.71959, class #29

STS073-742-66.jpg
Identification
Mission: STS073 Roll: 742 Frame: 66 Mission ID on the Film: STS73
Country or Geographic Name: USA-CA
Features: SAN JOAQUIN V, AGR, CITIES
Center Point Latitude: 36.5 Center Point Longitude: -120.0 (Negative numbers indicate south for latitude and west for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-18 JNC Map ID: 28
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North West
Camera: HB: Hasselblad
Film: 2443 : Kodak, color infrared, Aerochrome 2443, thin base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19951026 (YYYYMMDD) GMT Time: 182220 (HHMMSS)
Nadir Point Latitude: 36.0, Longitude: -119.4 (Negative numbers indicate south for
latitude and west for
longitude)
Sun Azimuth: 155 (Clockwise angle in degrees from north to the sun measured
at the nadir point)
Spacecraft Altitude: 144 nautical miles
Sun Elevation Angle: 38 (Angle in degrees between the horizon and the sun,
measured at the nadir point)
Orbit Number: 101

3) A) Matches with point: x_coord: -118.58686, y_coord: 36.98940, class #29
STS048-603-23.jpg
Identification
Mission: STS048 Roll: 603 Frame: 23 Mission ID on the Film: STS48
Country or Geographic Name: USA-CA
Features: OWENS R., SIERRA NEVADAS
Center Point Latitude: 37.0 Center Point Longitude: -118.5 (Negative numbers
indicate south for latitude and west
for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-18 JNC Map ID:
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: East
Camera: RX: Roloflex
Film: 5017 : Kodak, natural color positive, Ektachrome, X Professional, ASA
64, standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19910918 (YYYYMMDD) GMT Time: 004300 (HHMMSS)
Nadir Point Latitude: 36.4, Longitude: -119.8 (Negative numbers indicate south for
latitude and west for
longitude)
Sun Azimuth: 340 (Clockwise angle in degrees from north to the sun measured
at the nadir point)
Spacecraft Altitude: 307 nautical miles
Sun Elevation Angle: -33 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 77

3) B) Matches with point: x_coord:-118.58686, y_coord: 36.98940, class #29
STS059-154-161.JPG
Identification
Country or Geographic Name: USA-CA
Features: KINAS R, SIERRA NEVADA, V.
Center Point Latitude: 37.0 Center Point Longitude: -118.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-18 JNC Map ID: 28
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: South West
Camera: LH: Linhoff
Film: 5046: Kodak, natural color positive, Lumiere 100/5046, ASA 100, standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 5
Nadir
Date: 19940411 (YYYYMMDD) GMT Time: 211937 (HHMMSS)
Nadir Point Latitude: 37.8, Longitude: -117.6 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 220 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 119 nautical miles
Sun Elevation Angle: 55 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 40

4) matches with point: x_coord:-116.54503 y_coord: 33.38869
STS059-232-37.JPG
Identification
Country or Geographic Name: USA-CA
Features: SAN DIEGO AREA COAST
Center Point Latitude: 33.0 Center Point Longitude: -116.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-18 JNC Map ID: 28
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 40mm
Camera Look Direction: North
Camera: HB: Hasselblad
Film: 5046 : Kodak, natural color positive, Lumiere 100/5046, ASA 100, standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 5
Nadir
Date: 19940418 (YYYYMMDD) GMT Time: 185836 (HHMMSS)
Nadir Point Latitude: 32.2, Longitude: -116.5 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 150 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 113 nautical miles
Sun Elevation Angle: 66 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 152

5) both images match with x_coord: -112.24101  y_coord: 38.94059
SSEOP Database Photograph Information
STS040-80-20.JPG
Mission: STS040 Roll: 80 Frame: 20 Mission ID on the Film: STS40
Country or Geographic Name: USA-UT
Features: AREA AROUND BEAVER
Center Point Latitude: 38.5 Center Point Longitude: -112.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: JNC Map ID:
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 100mm
Camera Look Direction: South West
Camera: HB: Hasselblad
Film: 5017 : Kodak, natural color positive, Ektachrome, X Professional, ASA 64, standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19910610 (YYYYMMDD) GMT Time: 165233 (HHMMSS)
Nadir Point Latitude: 38.7, Longitude: -112.2 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 103 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 153 nautical miles
Sun Elevation Angle: 53 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 83

6) matches class 29 x_coord: -110.76784 y_coord: 33.29449
STS077-151-92.JPG
Identification
Mission: STS077 Roll: 151 Frame: 92 Mission ID on the Film: STS77
Country or Geographic Name: USA-AZ
Features: SAN CARLOS LAKE, MINES
Center Point Latitude: 33.5 Center Point Longitude: -110.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-19 JNC Map ID: 43
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: South
Camera: LH: Linhoff
Film: 5046 : Kodak, natural color positive, Lumiere 100/5046, ASA 100, standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19960521 (YYYYMMDD) GMT Time: 165425 (HHMMSS)
Nadir Point Latitude: 33.9, Longitude: -110.4 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 104 (Clockwise angle in degrees from north to the sun measured
at the nadir point)
Spacecraft Altitude: 152 nautical miles
Sun Elevation Angle: 55 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 37

7) A) matches with class 29 x_coord: -110.79119 y_coord: 31.56647

STS062-83-134.JPG
Identification
Country or Geographic Name: USA-AZ
Features: FT. HUACHUCA, SAN PEDRO R
Center Point Latitude: 31.5 Center Point Longitude: -110.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: H-22 JNC Map ID: 43
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North West
Camera: HB: Hasselblad
Film: 5046 : Kodak, natural color positive, Lumiere 100/5046, ASA 100, standard base.
Film Exposure: Normal
Percentage of Cloud Cover: 5
Nadir
Date: 19940309 (YYYYMMDD) GMT Time: 192047 (HHMMSS)
Nadir Point Latitude: 30.7, Longitude: -109.8 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 176 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 162 nautical miles
Sun Elevation Angle: 55 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 84

8) A) matches with class 29 x_coord: -98.75192 y_coord: 29.78262
Mission: STS050 Roll: 71 Frame: 96 Mission ID on the Film: STS50
Country or Geographic Name: USA-TX
Features: SAN ANTONIO AREA
Center Point Latitude: 29.5 Center Point Longitude: -98.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: H-23 JNC Map ID: 44
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North
Camera: HB: Hasselblad
Film: 5017 : Kodak,natural color positive,Ektachrome,X Professional,ASA 64,standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19920625 (YYYYMMDD) GMT Time: 174838 (HHMMSS)
Nadir Point Latitude: 28.5, Longitude: -98.7 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 112 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 163 nautical miles
Sun Elevation Angle: 78 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 2

8) B) matches with class 29 x_coord: -98.75192 y_coord: 29.78262
SSEOP Database Photograph Information
STS050-71-97.JPG
Identification
Mission: STS050 Roll: 71 Frame: 97 Mission ID on the Film: STS50
Country or Geographic Name: USA-TX
Features: SAN ANTONIO AREA
Center Point Latitude: 29.5 Center Point Longitude: -98.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: H-23 JNC Map ID: 44
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North
Camera: HB: Hasselblad
Film: 5017 : Kodak,natural color positive,Ektachrome,X Professional,ASA 64,standard base.
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19920625 (YYMMDD) GMT Time: 174845 (HHMMSS)
Nadir Point Latitude: 28.5, Longitude: -98.2 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 113 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 163 nautical miles
Sun Elevation Angle: 78 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 2

9) (A&B) matches with _29 xcoord: -106.52865 y_coord: 36.14679
STS040-614-63.JPG
Mission: STS040 Roll: 614 Frame: 63 Mission ID on the Film: STS40
Country or Geographic Name: USA-NM
Features: VALLES CALDERA
Center Point Latitude: 36.0 Center Point Longitude: -106.5 (Negative numbers indicate south for latitude and west for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: JNC Map ID:
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction:
Camera: RX: Roloflex
Film: 5017 : Kodak,natural color positive,Ektachrome,X Professional,ASA 64,standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: (YYMMDD) GMT Time: (HHMMSS)
Nadir Point Latitude: , Longitude: (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: nautical miles
Sun Elevation Angle: (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number:

10) matches with point x_coord: -103.15751 y_coord: 33.14201
STS61A-41-80.JPG
Identification
Mission: STS61A Roll: 41 Frame: 80 Mission ID on the Film: 61-A
Country or Geographic Name: USA-TX
Features: SEMINOLE
Center Point Latitude: 33.0 Center Point Longitude: -103.0 (Negative numbers indicate south for latitude and west for longitude)
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North:
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North
Camera: HB: Hasselblad
Film: 5017 : Kodak.natural color positive,Ektachrome,X Professional,ASA 64,standard base.
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19851104 (YYYYMMDD)GMT Time: 165807 (HHMMSS)
Nadir Point Latitude: 32.3, Longitude: -102.9 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 150 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 177 nautical miles
Sun Elevation Angle: 36 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 80

11) matches with class 29 x_coord: -94.96805 y_coord: 34.43508
STS068-204-48.JPG
Mission: STS068 Roll: 204 Frame: 48 Mission ID on the Film: STS68
Country or Geographic Name: USA-OK
Features: BROKEN BOW LAKE
Center Point Latitude: 34.0 Center Point Longitude: -95.0 (Negative numbers indicate south for latitude and west for longitude)
Stereo: No (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: G-20 JNC Map ID: 44
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North
Camera: HB: Hasselblad
Film: 2443 : Kodak, color infrared, Aerochrome 2443, thin base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19941009 (YYYYMMDD) GMT Time: 173822 (HHMMSS)
Nadir Point Latitude: 33.9, Longitude: -95.0 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 169 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 111 nautical miles
Sun Elevation Angle: 49 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 151

12) matches with  class 29 x_coord: -94.99225 y_coord: 30.02901
STS61A-48-74.JPG
Mission: STS61A Roll: 48 Frame: 74 Mission ID on the Film: 61-A
Country or Geographic Name: USA-TX
Features: HOUSTON
Center Point Latitude: 30.0 Center Point Longitude: -95.0 (Negative numbers indicate south for latitude and west for longitude)
Stereo: Yes (Yes indicates there is an adjacent picture of the same area)
North:
ONC Map ID: JNC Map ID:
Camera
Camera Tilt: Near Vertical
Camera Focal Length: 250mm
Camera Look Direction: North East
Camera: HB: Hasselblad
Film: 5017 : Kodak,natural color positive,Ektachrome,X Professional,ASA 64,standard base.
Quality
Film Exposure: Normal
Percentage of Cloud Cover: 0
Nadir
Date: 19851103 (YYYYMMDD) GMT Time: 164042 (HHMMSS)
Nadir Point Latitude: 29.9, Longitude: -95.2 (Negative numbers indicate south for latitude and west for longitude)
Sun Azimuth: 152 (Clockwise angle in degrees from north to the sun measured at the nadir point)
Spacecraft Altitude: 177 nautical miles
Sun Elevation Angle: 40 (Angle in degrees between the horizon and the sun, measured at the nadir point)
Orbit Number: 64
Appendix G
Landsat Thematic Mapper Scenes Used

**BOLD = MEXICO**

**SHRUBLAND**

1) LT5036041009224910 (ID)
   Baja Mexico
   Path : 36
   Row : 41
   DCT Availability : Y DCT's are available

2) LT5037038009333810
   Sonora/Arizona Border
   Path : 37
   Row : 38
   DCT Availability : Y DCT's are available

3) LT5039037009314410
   San Diego area, California
   Path : 39
   Row : 37
   DCT Availability : Y DCT's are available

4) LT5039036009228610
   Palm Springs, So, California area
   Path : 39
   Row : 36
   DCT Availability : Y DCT's are available

5) LT5041035009314210
   Bakersfield, California area
   Path : 41
   Row : 35
   DCT Availability : Y DCT's are available

6) LT5037034009330610
   Arizona/Utah Border
   Path : 37
   Row : 34
DCT Availability: Y DCT's are available

7) LT5040034009323110
   Nevada
   Path: 40
   Row: 34
   DCT Availability: Y DCT's are available

SAVANNA

1) LT5035039009327610
   Sonora, Mexico
   Path: 35
   Row: 39
   DCT Availability: Y DCT's are available

2) LT50333039009315010
   Chihuahua, Mexico
   Path: 33
   Row: 39
   DCT Availability: Y DCT's are available

3) LT5035038009310010
   Arizona, Sonora Border
   Path: 35
   Row: 38
   DCT Availability: Y DCT's are available

4) LT5036037009323510
   Arizona
   Path: 36
   Row: 37
   DCT Availability: Y DCT's are available

5) LT5036036009317110
   Arizona
   Path: 36
   Row: 36
   DCT Availability: Y DCT's are available

6) LT503303509329410
   New Mexico
   Path: 33
   Row: 35
DCT Availability : Y DCT's are available

7) LT5041036009317410
   Los Angeles area, California
   Path : 41
   Row : 36
   DCT Availability : Y DCT's are available

GRASSLAND

1) LT5028041009306710
   Tamaulipas/Texas Border Mexico/TX
   Path : 28
   Row : 41
   DCT Availability : Y DCT's are available

2) LT5028040009306710
   Southern Texas
   Path : 28
   Row : 40
   DCT Availability : Y DCT's are available

3) LT5029040009234410
   Coahuila/Texas Border
   Path : 29
   Row : 40
   DCT Availability : Y DCT's are available

4) LT5028038009322710
   Texas
   Path : 28
   Row : 38
   DCT Availability : Y DCT's are available

5) LT5030038009219110
   Texas
   Path : 30
   Row : 38
   DCT Availability : Y DCT's are available

6) LT5030036009325710
   Texas
   Path : 30
   Row : 36
DCT Availability: Y DCT's are available

7) LT5030034009325710
   Oklahoma/Kansas border
   Path: 30
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   DCT Availability: Y DCT's are available

EVERGREEN NEED LEAF FOREST

1) LT5027039009229810
   Texas
   Path: 27
   Row: 39
   DCT Availability: Y DCT's are available

2) LT5025039009215610
   Texas
   Path: 25
   Row: 39
   DCT Availability: Y DCT's are available

3) LT5024038009211710
   LA, TX Border
   Path: 24
   Row: 38
   DCT Availability: Y DCT's are available

4) LT5025037009218810
   LA, TX, Arkansas Border
   Path: 25
   Row: 37
   DCT Availability: Y DCT's are available

5) LT5031037009326410
   New Mexico/Texas Border
   Path: 31
   Row: 37
   DCT Availability: Y DCT's are available

6) LT5042035009216310
   California
   Path: 42
Rol : 35
DCT Availability: Y DCT's are available

7) LT5034033009226710
   Colorado
   Path: 34
   Row: 33
   DCT Availability: Y DCT's are available

CROPLAND/VEGETATION MOSAIC

1) LT5029037009221610
   Texas
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   Row: 37
   DCT Availability: Y DCT's are available

2) LT5023035009320810
   Tennessee/Arkansas Border
   Path: 23
   Row: 35
   DCT Availability: Y DCT's are available

3) LT5024033009331110
   Illinois/Missouri Border
   Path: 24
   Row: 33
   DCT Availability: Y DCT's are available

4) LT5024033009216510
   Illinois/Missouri Border
   Path: 24
   Row: 33
   DCT Availability: Y DCT's are available
Appendix H

Complete Confusion Matrix Results

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Appendix I

Sample Header File Format for Landsat TM Imagery

Nrows     6845
Ncolumns  7633
Nbands    7
Nbits     8
Layout    BSQ
Ulymap    3615810
Ulxmap    494340
Ydim      30
Xdim      30
Skipbyte  120