Master Thesis

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Water Traces In The Phoenix Metropolitan Area

Robert Bruno Johann Bizaj

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This thesis is submitted as partial fulfillment of the requirements of the degree of

Master of Science (Geographical Information Science & Systems) - MSc (GISc)

Supervisors:

Ao. Univ.-Prof. Dr. Josef Strobl

Prof. Dr. Matthias Möller

Salzburg - Klagenfurt, April 23, 2009

Preface

All people listed below helped me directly or indirectly writing my thesis respectively gave me a lot of input for that work. To all of them I want so say a heartily - "Thank you very much for everything".

I am very grateful to **Ao. Univ.-Prof Dr. Josef Strobl** for his inputs during my work and constructive feedbacks to my application form. Mr. Strobl may be congratulated to an extraordinarily qualified UNIGIS team which was very cooperative during the whole time.

The idea for this master thesis based on an idea from **Prof. Dr. Matthias Möller**. He was also very open for all my questions regarding remote sensing. Mr. Möller supported me with much background information about the environment around Arizona and the Hohokam history. He worked also as middle-man between University Salzburg and the **Arizona State University (ASU)** which provided the dataset (built ESRI dataset of the Hohokam water traces) and satellite images.

During our study-time course leader **Mag. Michael Fally** and supervisor **Mag. Julia Moser** were always reachable for requests and problems. Special thanks apply to Mr. Fally for the assistance getting Leica ERDAS Imagine 8.x license and additional information about the UNIGIS study program (e.g. partner workshops).

A live without some good friends is not a real one. Beside the family friends belong to one of the most important things in my live. On this place I'd like to mention **DI (FH) Harald Kraxner** who went along with me since my first study. Some years ago he was the first person who indicated the UNIGIS study program to me. In the last two years I worked very intensive with **Gerald Jahrer**. We got friends, learned together many hours on modules and lections and motivated each other.

Of course I do not want to forget to thank **Mag. Astrid Mohrherr**, **DI Martina Bizaj** and **B.Sc. Mag. Jeff Mark Zimmerman B.A.** for the proofreading my thesis.

At last I would like to mention my family - my parents **Christine Bizaj** and **Johann Bizaj** and my younger sister Martina. I'm very thankful for their assistance, patient and helpfulness during the whole time in my life.

" . . . Everything should be made as simple

as possible, but not simpler . . ."

Albert Einstein

1879-1955

German Physicist and Nobel laureate

(http://www.quoteworld.org)

Declaration of Originality

I certify that this thesis and the research to which it refers are the product of my own work and that any ideas or quotations from the work of other people, published or otherwise, are fully acknowledged in accordance with the standard referencing practices of the discipline.

The work has not been presented previously for any degree, nor is it at present under consideration by any other degree awarding body.

Klagenfurt, April 23, 2009 Personal Signature

NOTE:

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Abstract

The idea for this thesis topic was presented by Professor Dr. Matthias Möller in November of 2007 during the UNIGIS study days in Salzburg. In several personal conversations the extent was discussed and reads as follows.

The examination area, the metropolitan area to Phoenix (Arizona, U.S.) lies within the more than 300,000 square kilometers large Sonoran Desert. With more than 300 sunny days a year, this area belongs to an arid climate zone. The summer temperatures greater than 38 °C are not uncommon.

During the period from about 300 before Christ until about 1500 AD Arizona was mainly inhabited by the Hohokam Indians. The survival and the development of this culture were only possible because of the use of complex water canals which were created and expanded by their inhabitants.

The Master's Thesis will explore whether the influences of historical water use on today's urban water regimes in the region can be derived. For this two different data sources are used. On the one hand, remote sensing data in form from satellite images and on the other hand reconstructed historic canals which were evaluated by the Arizona State University (ASU), were used. For the work the last set of data was provided in ESRI Shape format. Remote sensing data from the satellites of the study area were provided for the years from 1973, 1985, 1995 and 2003.

For this work the two GIS software products ERDAS Imagine 8.7 and ESRI ArcGIS 9.2 were used.

Kurzbeschreibung

Die Idee zu diesem Master Thesis Thema wurde von Herrn Professor Dr. Matthias Möller im November 2007 im Rahmen der UNIGIS Studientage in Salzburg vorgestellt. In mehreren persönlichen Gesprächen wurde das Thema abgegrenzt und der Umfang konkretisiert.

Das Untersuchungsgebiet, der Großraum um Phoenix (Arizona, US), liegt innerhalb der über 300.000 Quadratkilometer großen Sonora Wüste. Mit über 300 Sonnentagen im Jahr ist diese Gegend durch arides Klima geprägt, im Sommer sind Temperaturen über 38 °C keine Seltenheit.

In der Zeit von etwa 300 vor Christi bis ca. 1500 nach Christi wurden weite Teile Arizonas maßgeblich durch die Hohokam Indianer geprägt. Die Kultur wurde erst durch die Nutzung von komplexen Wasserkanälen möglich, die von ihren Einwohnern erstellt und ausgebaut wurden.

In dieser Master Thesis wird untersucht, ob die Einflüsse der historischen Wassernutzung sich auf das heutige urbane Wasserregime der Region ableiten lassen. Dazu werden zwei verschiedene Datenquellen verwendet: einerseits Satelliten Fernerkundungsdaten und andererseits rekonstruierte Verläufe der historischen Kanäle die durch die Arizona State University (ASU) erhoben worden sind und im Shape Format vorliegen. Satelliten Fernerkundungsdaten des Untersuchungsgebietes liegen für die Jahre 1973, 1985, 1995 und 2003 vor.

Diese Arbeit wurde unter Zuhilfenahme der beiden GIS-Softwareprodukte ERDAS Imagine 8.7 und ESRI ArcGIS 9.2 erstellt.

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Glossary & Abbreviations

AD = Anno Domini

AOI = Area of Interest; the same like POI but this syntax is used in ERDAS Imagine

ASI = Archaeological Survey of India

ASTER = Advanced Spaceborne Thermal Emission and Reflection Radiometer

ASU = Arizona State University

BC = before Christ

BU = Boston University

CAD = Computer Aided Design

CCD = Charge Coupled Device

DEM = Digital Elevation Model

DTM = Digital Terrain Model

e.g. = exempli gratia

ESRI = Environmental Systems Research Institute

etc. = etcetera

FIR = far infrared

GIS = Geographic Information System

GNSS = Global Navigation Satellite System

GPR = Ground Penetrating Radar

GPS = Global Positioning System

IR = infrared

ISPRS = International Society for Photogrammetry and Remote Sensing

KML = Keyhole Markup Language

LULC = Land Use Land Cover

MRB = Multiple Ring Buffer; analysis in ArcGIS with specialized buffers

MRI = Magnetic Resonance Imaging

MS = Microsoft Corperation

MSS = Multispectral Scanner System; NASA Landsat remote sensing satellite

MT = Master Thesis

NAD = North American Datum

NASA = National Aeronautics and Space Administration

NDVI = Normalized Differenced Vegetation Index

OBIA = Object Based Image Analysis

PDF = Portable Document Format; file format developed by Adobe Systems Inc.

POI = Points of Interest

RBV = Return Beam Vidicon; Landsat 1 senor technology also → MSS

RIT = Rochester Institute of Technology

RS = Remote Sensing

TM = Thematic Mapper; NASA Landsat remote sensing satellite

ULF = Ultra Low Frequency

URL = Uniform Resource Locator

UTM = Universal Transverse Mercator

VI = Vegetation Index; more common → NDVI

WGS84 = World Geodetic System 1984

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1. Introduction

Arizona is the forty-eighth state of the United States of America, located in the southwest of the United States and covers an area of approximately 295,000 square kilometer. The largest city is Phoenix with over 1.5 million inhabitants and an area of 1,230 square kilometer.

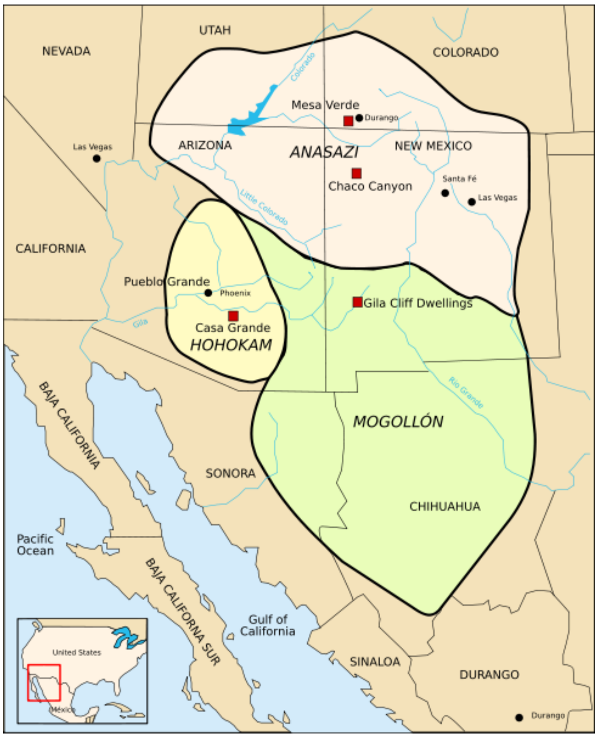


Image 1 - Arizona and the Hohokam

(http://en.wikipedia.org/wiki/Image:Anasazi-en.svg; April 19, 2009)

Large parts of Arizona and the northern parts of Mexico are covered by the Sonoran Desert. There is an arid climate with dry, hot summers where temperatures often rise to 50° Celsius even through frost-free winters. The native vegetation is a variety of cacti, agaves and other desert plants. About 300 BC the colonization of the area around Phoenix and its largest river, the Salt River, began and in time it was prepared for agricultural use. Due to the harsh climate the cultivation of plants was only possible with great efforts. Mainly corn, beans, cotton and various types of pumpkins were cultivated successfully. The survival of the inhabitants (the Hohokam Indian) was decisively assisted by the Salt River and its water. Another reason was the sophisticated irrigation traces for their water. Today it is estimated that the waterways have a length from 200 to 600 km (A Thematic Mapper Analysis of the prehistoric Hohokam Canal System, Phoenix - Arizona; Pamela Sands Showalter).

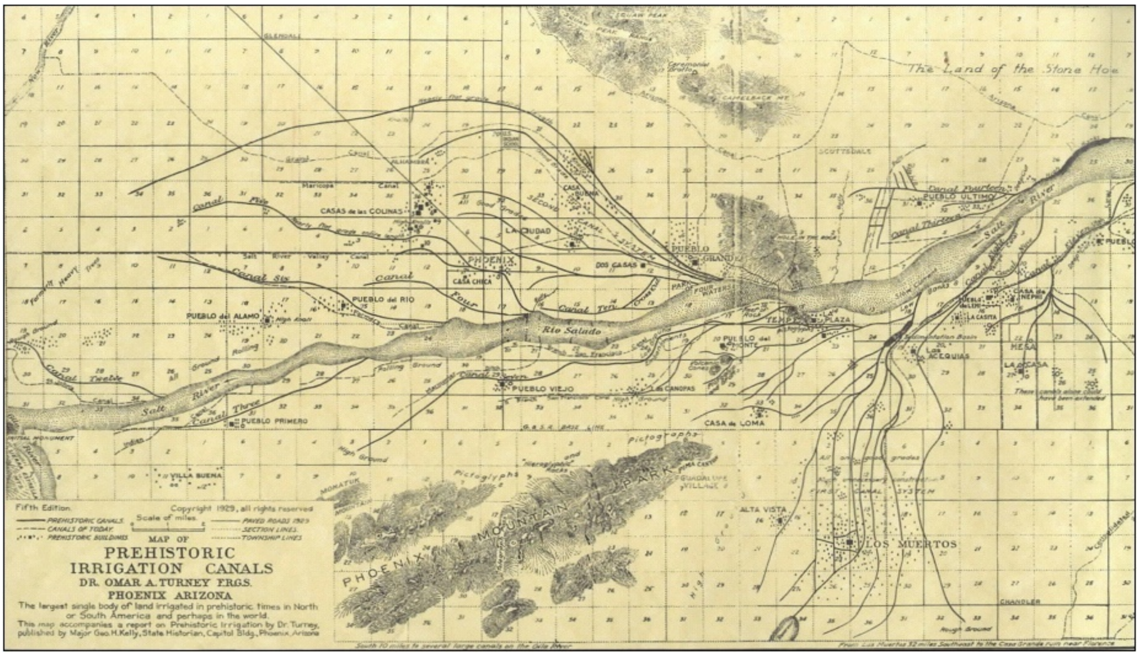


Image 2 - Prehistoric water traces constructed by Dr. Omar Turney from 1929 (http://archaeology.asu.edu/vm/Education/stanley/pages/hohokam.html; April 19, 2009)

The canals have a width of 15 to 26 meters and they are about 6 meters deep. Absolutely essential for a proper function was a regular maintenance of the irrigation canals. It is assumed that different groups or communities of the Hohokam people settled down along the canals to maintain waterways and prepare their lands for planting.

Image 3 - Overgrown and empty dried out canals, Arizona State University (http://archaeology.asu.edu/vm/Education/stanley/pages/hohokam.html; April 19, 2009)

A livestock was not raised by the Hohokam culture; the necessary meat was hunted (deer, rabbit and quail). They used the water canals not only for irrigation. They also used them for breeding crabs and clams. After about 1450 AD the Hohokam culture vanished. It is supposed that they disbanded into many smaller groups, but their history is not completely resolved. For archaeologists there are still many mysteries about this civilization that still need to be answered.

1.1 Motivation

In order to be able to understand why I have chosen this topic, I have to expand a little bit. The first time I have seen and worked with a so-called "virtual globe" was in the year 2000 in a Microsoft Encarta World Atlas implementation. Although the implemented datasets were for today's standards relatively easy with a low resolution and the display options were also perfective, I was fascinated from the first day about the possibilities of these globes. Since June, 2005, Google Earth was available on the internet for everybody and the usability has been continuously improved (satellite data and navigation tools). Other developers such as NASA (World Wind) and Microsoft (MapPoint Service, Virtual Earth, maps.live.com) have also recognized the potential of spatial information and brought their products onto the market. Meanwhile the resolutions in these virtual globes achieve accuracies about less than 50 centimeter per pixel (Microsoft UNIGIS partner workshop; Salzburg - February, 2008). With every newly launched remote sensing satellite more detailed images can be expected.

I am working in the IT department of an Austrian telecommunications provider working as a computer engineer. In this position I do not work very much with the geodata. As Professor Dr. Matthias Möller presented this topic as a possible master thesis during the UNIGIS study days on November 22, 2007, in Salzburg, this topic immediately sparked interests in me. What I really enjoy about this topic is to process a concrete archaeological GIS question with "real" remote sensing data (Landsat, ASTER) and other tools. I am also able to answer a question I asked myself - that is interesting and fascinating at the same time. In what extent analysis of remote sensing data in archeology and other near disciplines can be helpful.

1.2 Nature of Assignment

In the first step it should be investigated whether with the help of remote sensing data (satellite) and reconstructed plans of the Hohokam canal system, the water canals of the prehistoric Hohokam Indians can be detected.

As second step should be researched whether through the historic water utilization/ influences on the current usage can be observed.

The Phoenix metropolitan area as a possible study area should be resized to a suitable smaller test area.

1.3 Solution

1.3.1 Theory

Light is emitted from the sun in the form of electromagnetic waves. When these rays reach objects on our earth or particles inside our atmosphere four different interactions can occur: Scientists are talking about “transmittance”, “reflectance”, “scattering” or “absorption” (→ Image 4). Reflected and scattered light in the visible range from about 0.4 to 0.7 micrometer of the electromagnetic spectrum human can perceive these as different hues, above 0.7 micrometer range for the infrared begins.

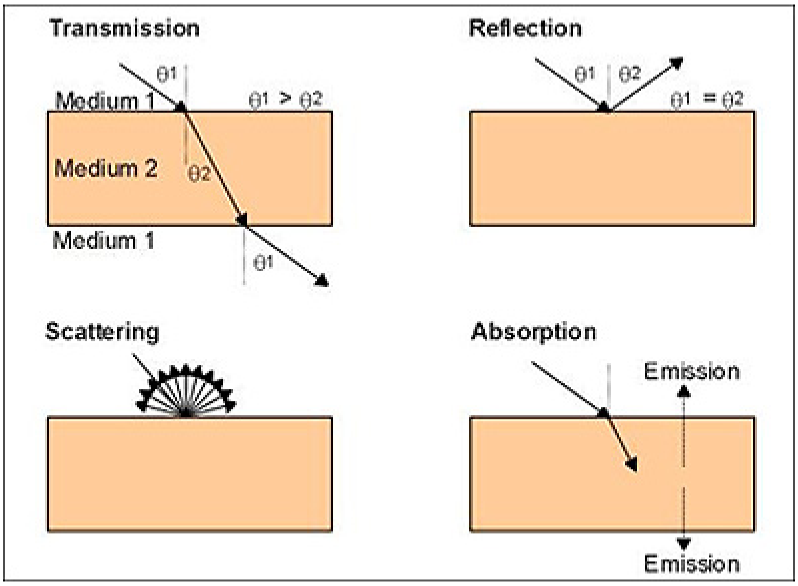


Image 4 - Transmittance, Reflectance, Scattering and Absorption of Light (http://rst.gsfc.nasa.gov/Intro/Part2_3.html; April 19, 2009)

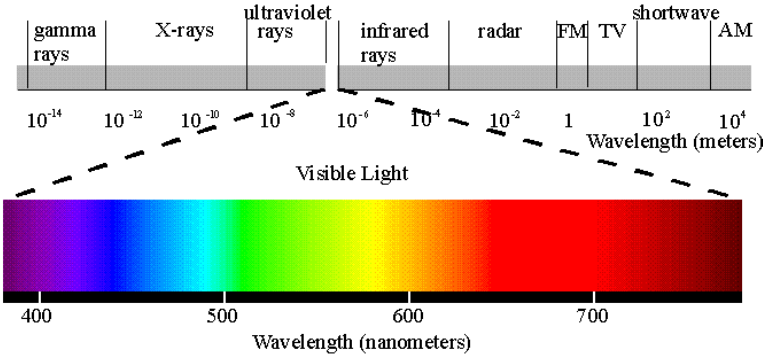


Image 5 - Visible Electromagnetic Spectrum, York University (http://www.yorku.ca/eye/spectru.htm; April 19, 2009)

In satellites the reflected light is converted into electronic signals. In most cases this is handled with so-called CCD (charge coupled device) devices. These are light sensitive semiconductors. In remote sensing satellites different elements of these are built in. It depends on the satellite owner and what purpose the satellite was built for. In addition to the visible light there are the sensors for different infrared sensitive areas for "visible near infrared (IR)", "short wave infrared" and "thermal infrared". Depending on the satellite operator the ranges of the wavelength varies a little bit. The data from the CCD elements are placed in separate bands which are stored in raster image files. With special GIS software tools called raster GIS such images can be loaded. By manipulating (setting active, switching on/off, etc.) the selected band, the user can perform analysis and the results to its questions can be answered.

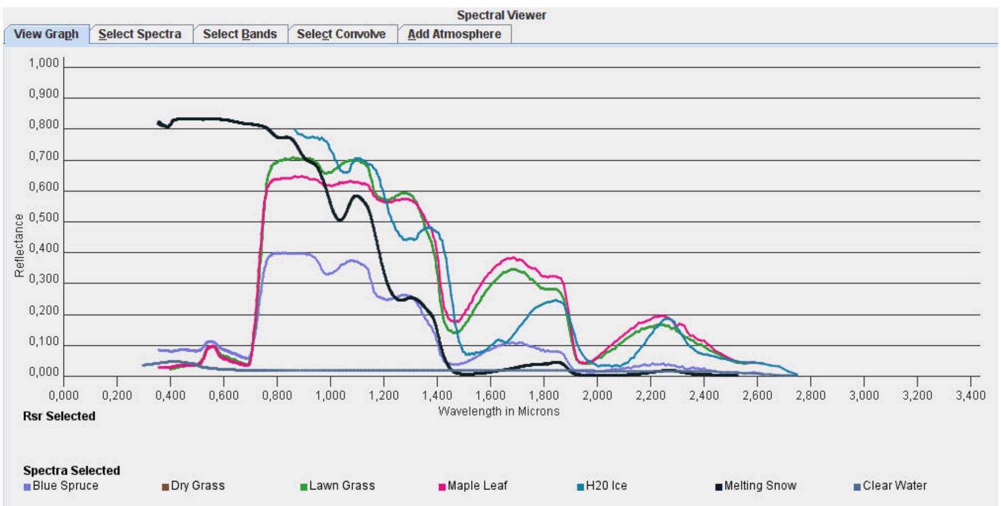


Image 6 - Some spectral characteristics of our environment (http://landsat.usgs.gov/tools_spectralViewer.php; April 19, 2009)

Scientist found out that objects have a different high of reflectance of wavelength over the whole spectrum. Because of that it is possible to differentiate objects into many "classes", e.g. water, moisture (on the ground and in the atmosphere), snow, ice, deciduous and coniferous forests, sand, rockets, etc. The discipline of study which uses these effects made from satellites is called remote sensing. It became a very cheap possibility to explore large areas and areas which are difficult to reach in scientific way. Over the last years it became more and more popular to use remote sensing technologies for many open questions concerning our environment. On this position a few projects where GI systems have helped in the archeology field will be introduced:

- GIS and Remote Sensing for Archaeology: Burgundy, France

A guided study lasting over two decades by American researchers (University of North Carolina / Rutgers University / International Space University) in the region Arroux Valley and Burgundy was very interdisciplinary. A period of time over 2000 years up to now is being researched. The main question is to understand the interactions between the different cultures and the physical environment in the region. This is significantly helped by remote sensing data.

(http://www.informatics.org/france/index.html; April 19, 2009)

- The use of satellite remote sensing for the management of cultural heritage sites in Cyprus

In this project IKONOS (1 m resolution) and Quickbird (0.62 m resolution) data are used in the area around Paphos (Greece) to investigate possible land use changes near archaeological heritage sites.

(http://cipa.icomos.org/fileadmin/papers/Torino2005/356.pdf; April 19, 2009)

- Ortho-rectification of IKONOS scenes as the basis for GIS data collection in the area of the Nasca Pampa / Peru

Nasca Pampa in Peru has one of the most fascinating ground drawings seen on our planet. There are still a lot of questions about the strange shapes from the scientists which are not answered yet. Therefore, remote sensing technologies are important for the research of this area because entering respectively driving across would destroy the drawings. The University of Applied Sciences Dresden has been known for their work in this research-field for a long time. There is a master thesis which was written by DI (FH) Christiane Richter in the year 2007 during their UNIGIS MSc program.

(http://www.unigis.ac.at/club/bibliothek/pdf/1232.pdf; April 19, 2009)

- Archiving Aerial Photography and Remote Sensing Data

It is an interesting introduction about aerial photos and remote sensing used in the archeology created by the University of York (Archeology Data Service / Department of Archeology).

(http://ads.ahds.ac.uk/project/goodguides/apandrs; April 19, 2009)

1.3.2 Method

In the raster image processing there are a number of different technologies of image manipulation and editing. During the classification process of images three typical steps are involved: the feature extraction, training and labeling. Under the “feature extraction” is known the transformation of the multispectral satellite picture to a feature image by a spatial/spectral transformation. Such a step is optional and the multispectral image may be used directly in the second step. The “training” includes the “unsupervised” or “supervised” classification. Working with the unsupervised method means to separate the raster image in a certain number of classes. Similar colors are summarized into the same classes. The unsupervised classification has only a few parameters that can be changed. An extension to the unsupervised classification is the supervised classification. Before the actual calculation is performed so-called user training areas are selected by the editors. The operator assigns special reflectance values to particular classes. Based on the user knowledge similar values can be combined into the same classes. In this master thesis the supervised classification was chosen because of their better possibility of defining the areas of interest (training areas). If a supervised classification was performed the features are already “labeled”. After an unsupervised classification the feature has to be labeled by the operator (Remote Sensing, Schowengert Robert A, page 388). As additional work the datasets are investigated with help of the vegetation index (VI). The mostly used vegetation index is the normalized differenced vegetation index (NDVI). Therefore, the “red” and “infrared” canals are used.

1.3.3 Tools

Because of their importance this chapter is be separated into two further chapters. This helps to understand better which tools were used and how.

1.3.3.1 Software Tools

Below all software products which were used for creating/writing this thesis are listed:

- ERDAS Imagine 8.7
- ESRI ArcGIS 9.2 Single License
- Irfan View 4.20
- CorelDraw Graphics Suite 11
- Microsoft Office 2007 Enterprise SP1
- Adobe Acrobat 8.0 Professional
- Microsoft Encarta Premium 2009
- Google Earth v. 4.3.7284.3916 (beta)
- MapWindow Open Source GIS v. 4.6.602
- Shape2Earth for MapWindow v.1.45.02

1.3.3.2 Internet Resources

The internet is one of the most powerful tools for starting the investigation of a scientific work. That does not mean that libraries are not useful, but if you are looking for a special book or paper the internet can help you to find the required information names of books or papers as fast as possible. After the information is found online the way to a library is often indispensable. The following “serious” sources were used:

- Online literature archives, e.g. http://www.highbeam.com
- Reports or documents from universities and other educational institutions
- Online library catalogues
- UNIGIS library, http://www.unigis.ac.at/club/bibliothek/index.asp
- Museums
- Further geographic orientation
    - Google Earth, http://earth.google.com
    - Microsoft, http://maps.live.com
        - Aerial layer
        - Road layer

1.3.4 Testing areas and datasets

For processing this thesis the following datasets were received from Prof. Dr. Matthias Möller. Jerry B. Howard, an archaeologist student from Arizona State University (ASU), finished his master thesis in 1990. His work was titled “Paleohydraulics: Modeling the Operation and the Growth of Prehistoric Canal Systems”. Therefore, water traces were digitized by him from an archaeological paper. The ASU was so kind to provide the reconstructed water traces in ESRI Shape (.shp) format.

Sensor	Path Row	Recording date	Number of Canals	Projection Information Spheroid / Datum
Landsat MSS	39/37	May 5, 1973	4	UTM, Zone 12 Nord WGS 84 / WGS 84
Landsat TM 5	37/37	May 4, 1985	7	UTM, Zone 12 Nord Clarke 1866 / NAD27
Landsat TM 5	37/37	March 13, 1995	7	UTM, Zone 12 Nord WGS 84 / WGS 84
ASTER	-	March 20, 2003	14	UTM, Zone 12 Nord WGS 84 / WGS 84
Jerry B. Howard Shape	-	1990	-	UTM, Zone 12 Nord Clarke 1866 / NAD27

Table 1 - Provided geoinformations for this thesis

(Robert Bizaj; October 1, 2008)

Characteristics of the bands and their spectral range of all used satellites:

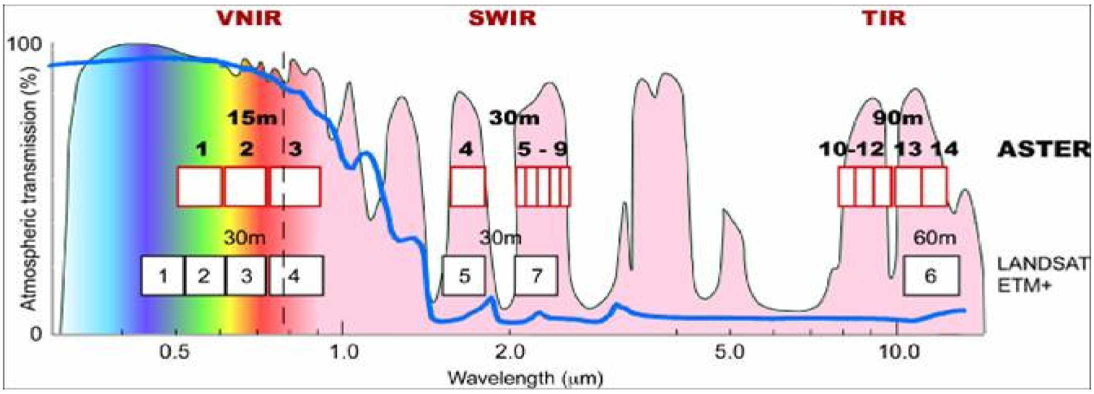


Image 7 - ASTER Instrument Characteristics

(http://asterweb.jpl.nasa.gov/images/spectrum.jpg; April 19, 2009)

Characteristic	VNIR	SWIR	TIR
Spectral Range	Band 1: 0.52 - 0.60 µm	Band 4: 1.600 - 1.700 µm	Band 10: 8.125 - 8.475 µm
	Band 2: 0.63 - 0.69 µm	Band 5: 2.145 - 2.185 µm	Band 11: 8.475 - 8.825 µm
	Band 3: 0.76 - 0.86 µm	Band 6: 2.185 - 2.225 µm	Band 12: 8.925 - 9.275 µm
		Band 7: 2.235 - 2.285 µm	Band 13: 10.25 - 10.95 µm
		Band 8: 2.295 - 2.365 µm	Band 14: 10.95 - 11.65 µm
		Band 9: 2.360 - 2.430 µm	
Ground Resolution	15 m	30 m	90 m

Table 2 - ASTER Instrument Characteristics (incomplete extract)

(http://asterweb.jpl.nasa.gov/characteristics.asp; April 19, 2009)

Band No.	Wavelength Interval (µm)	Spectral Response	Resolution (m)	Sensor
1	0.47 - 0.57	blue-green	80	Return Beam Vidicon (RBV)
2	0.58 - 0.68	orange-red	80	Return Beam Vidicon (RBV)
3	0.69 - 0.83	red to near-infrared	80	Return Beam Vidicon (RBV)
4	0.5 - 0.6	green	57 x 79	Multispectral Scanner (MSS)
5	0.6 - 0.7	red	57 x 79	Multispectral Scanner (MSS)
6	0.7 - 0.8	NIR	57 x 79	Multispectral Scanner (MSS)
7	0.8 - 1.1	NIR	57 x 79	Multispectral Scanner (MSS)

Table 3 - Overview Landsat Multispectral Scanner and Return Beam Vidicon

(http://landsat.usgs.gov/about_landsat1.php; April 19, 2009)

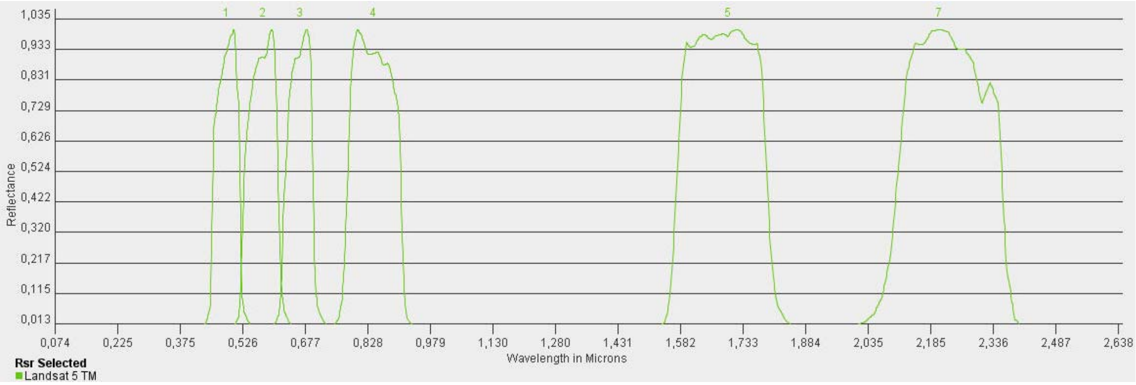


Image 8 - Overview Landsat Thematic Mapper 5 Bands

(http://landsat.usgs.gov/tools_viewer.php; April 19, 2009)

Band No.	Wavelength Interval (µm)	Spectral Response	Resolution (m)
1	0.45 - 0.52	blue-green	30
2	0.52 - 0.60	green	30
3	0.63 - 0.69	red	30
4	0.76 - 0.90	near IR	30
5	1.55 - 1.75	mid-IR	30
6	10.40 - 12.50	thermal IR	120
7	2.08 - 2.35	mid-IR	30

Table 4 - Overview Landsat Thematic Mapper (TM) Bands

(http://rst.gsfc.nasa.gov/Intro/Part2_20.html; April 19, 2009)

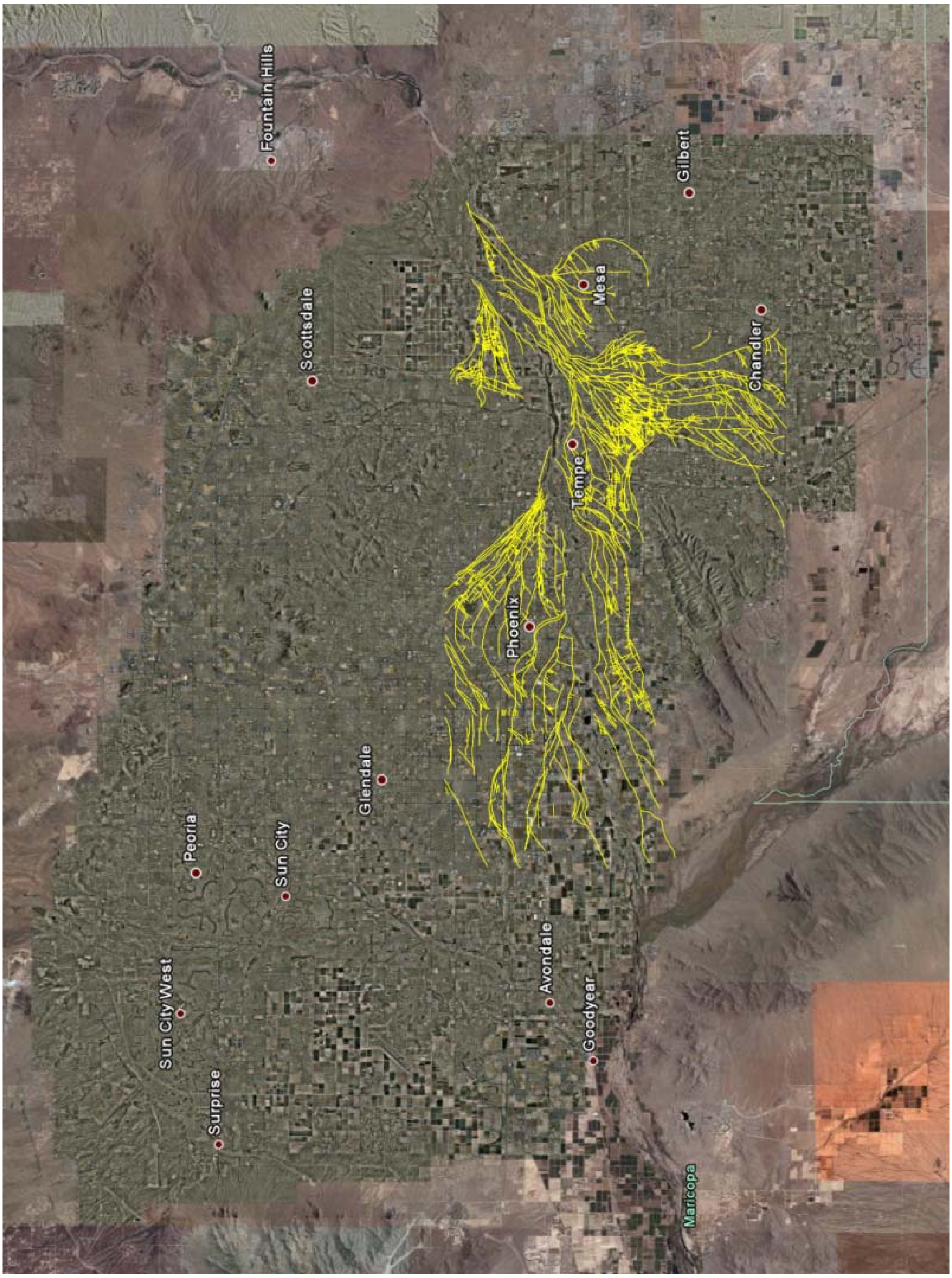


Image 9 - Hohokam water traces layer in yellow color over a Google Earth™

(KML-files created from the Shape-Files with Shape2Earth by Robert Bizaj; January 1, 2009)

1.4 Expected results

Through this thesis it should be investigated if the following hypothesis can be confirmed and verified for their accuracy:

1. The historic water irrigations can be extracted with the mentioned remote sensing data.

- All recorded datasets allow the same quality for the detection of structures.
- That overgrown vegetation routes (as well as dried out traces covered with more or less bare desert soil) can be detected in one step.

Successfully reached when:	- the extracted traces are connected and fit more or less exactly to the prehistoric water ways over a length of several hundred meters and more.

2. The influence of time between the years 1973 to 2003 on the city and their canals can be discovered.

- Due to the constantly increasing expansion of cities (during the study period) the existence of old canals structures are increasingly declining.

Successfully reached when:	- the number of recognized canals from 1973 until 2003 are decreasing in extreme ways (>20%) that would confirm this hypothesis.

3. It is possible today to determine the use of the traces (such as rain overflow canal, irrigation, swimming, green space [public parks], water reservoirs).

- Influences of prehistoric canals on the current water regime can be demonstrated.

Successfully reached when:	- within 500 m to both sides of the Hohokam canals one of the mentioned places are recognizable. The number should be greater than 15 units.

4. This approach or method is also adaptable for other places and analog questions.

Successfully reached when:	- it is plausibly explainable that the concepts/ideas of this thesis would work in other problem situations, too.

5. If it was not able to detect the Hohokam water traces in the points 1-4 above, maybe they can be recognized through the existence of water and humid areas around the prehistoric canals. If sufficient humid areas are trackable along the fragments (→ buffer zone) this could mean that the Hohokam water traces were in the closer surroundings.

Successfully reached when:	- connected humid areas over a length from several hundred meters or more within a buffer zone of 100 m, 300 m and 500 m to both sides of the Hohokam water traces can be found. - the increased occurrence of humid areas and vegetation within the buffer zones in contrast to the reference rectangle can be confirmed. It would be expected that the percentage of these areas within the buffer zones are substantial higher than in the reference area. Values greater than 15% difference can confirm the hypothesis. Below that percentage it would not show any relations between the Hohokam water traces and the humid areas.

1.5 Themes that are not covered

- The use of the water traces after the collapse of the Hohokam high culture after about 1450 AD will not be investigated.
- There is no intention to review the dataset (Hohokam shape file) from the master thesis of Jerry B. Howard. For this thesis it is supposed that the dataset is consistent, verified and correct.
- There are no intentions in this work for investigations within the meaning of "statistical methods".
- The direct differences between the supervised classification and the vegetation index will not be processed.

1.6 Expected audience

The primary target group should be an interested GIS user (layman). The work is designed to show the potential opportunities in the processing of geographic questions with the help of remote sensing methods. This document was created and basically no special skills are needed in GI systems to follow the content.

Another consideration is that the thesis might also be interesting for archaeologists, hydrologists and agronomists:

- Archeology: e.g. remote sensing of paths or settlements
- Hydrology: e.g. recovery of already forgotten water canals, rivers, etc.
- Agronomy: e.g. use of irrigation ditches; find areas of agricultural manner

1.7 Structure of the thesis

The structure of this work based on ideas which were presented from Dr. Adrijana Car in the form of a mind-map during the UNIGIS study days in November of 2007 in Salzburg. Her ideas were adapted for the requirements of this paper. The structure of the thesis will be:

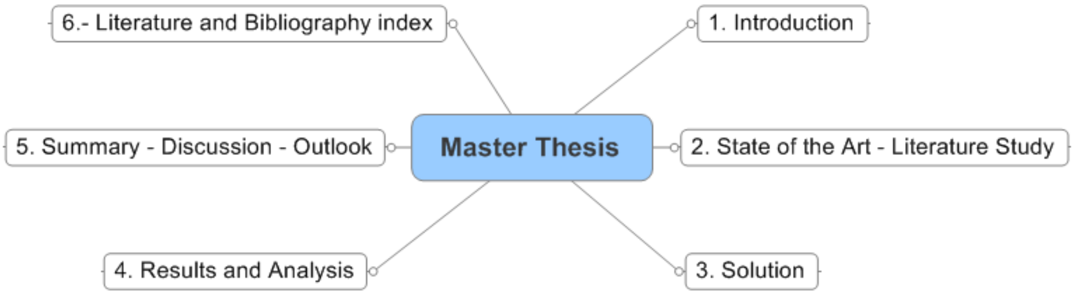


Image 10 - Structure of the Master Thesis

(Robert Bizaj; October 20, 2008)

2. State of the Art - Literature Study

This chapter is structured as follows. In chapter 2.1 the importance of remote sensing is described. The next chapter deals with projects in archeology and how remote sensing tools are successfully used in this field. The chapters 2.4 to 2.6 are dedicated to the basic thematic classification process of remote sensing images. For whom this work may be interesting is described in chapter 2.7. The importance of the mentioned sources is discussed in the last chapter.

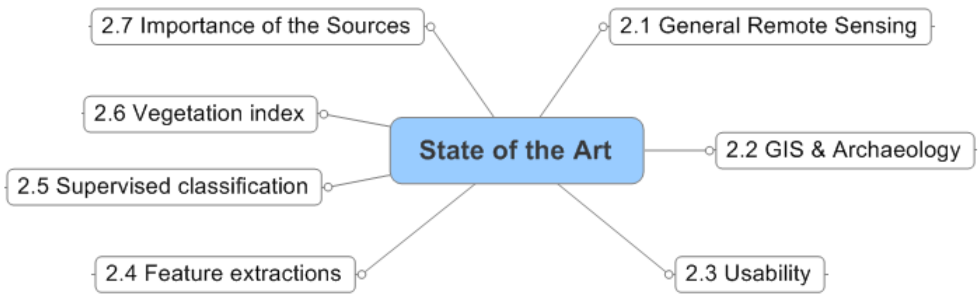


Image 11 - Roadmap about the literature study

(Robert Bizaj; October 28, 2008)

It was also a literature search done in the library online catalog (http://aleph.sbg.ac.at, University of Salzburg) with mentioned terms seen in the table 7. Special appropriate literature on this topic could not be found.

Further searches on the homepage of the digital book shop (http://www.ebooks.com) were done, that store has over 130,000 books in all fields and categories for online distribution. Three publications could be found which were bought for further study purposes:

- Practical applications of GIS for archaeologists; Taylor & Francis, Konnie L. Wescott & R. Joe Brandon; 2000
- Remote sensing: models and methods for image processing; Academic Press Elsevier | Sabre Foundation, Robert A. Schowengerdt; 2007
- Interpretation Remote Sensing Imagery; CRC Press LLC; Robert R. Hoffman & Arthur B. Markman; 2001

2.1 General Remote Sensing

2.1.1 What is remote sensing?

In GI science under remote sensing is understood as the measurement of different object properties from the surface of the earth by using an aircraft or a satellite. The measurements are done at a distance not in situ (Remote Sensing, Schowengerdt Robert A., page 2). It is possible to use many different sensors, one of the biggest differences are if they are working as an active or passive remote scanner.

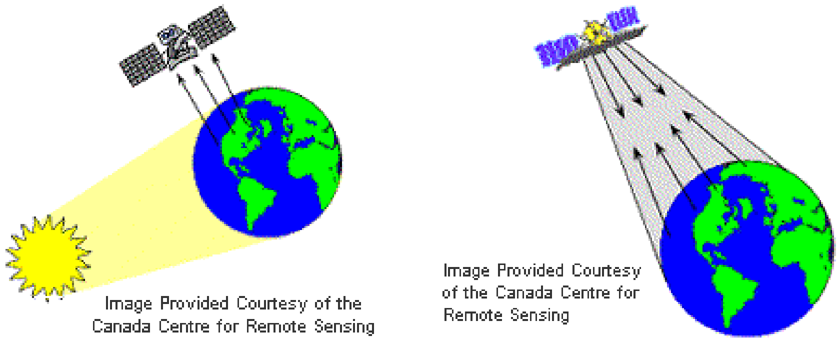


Image 12 - Passive (left side) and active (right side) remote satellite sensors (http://www.csc.noaa.gov/products/sccoasts/html/remote.htm; April 19, 2009)

Besides images from the visible range of the electromagnetic spectrum and the whole range of infrared also radar (radio detection and ranging), lidar (light detection and ranging) or laser (light amplification by stimulated emission of radiation) images can be used for recording. The quality and resolution depends largely from the requirement purpose and the hardware. It does not matter if an aircraft or a satellite is used; this is considered by both of them.

In the satellite technology two different systems were developed: geostationary on the one hand and on the other hand non-geostationary. For the geostationary satellites the flight altitude is around 36,000 km and they always retain the same position over the earth. In the most cases it is about communication or weather satellites. Non-geostationary satellites are often used for remote sensing because they can reach every point on earth in periodic intervals. Their altitude varies between a few hundred kilometers to some thousand (e.g. 450 km for Quickbird-2 or 681 km for GeoEye-1) (http://www.digitalglobe.com and http://www.geoeye.com; April 19, 2009).

Satellite	Operator	Type	Resolution	Revisit (days)
Landsat 5	Space Imaging	Multispectral	30	16
Landsat 7	US Government	Panchromatic Multispectral	15 30	16
IRS	India	Panchromatic Multispectral	6 23	5 24
SPOT	CNES/SPOT	Panchromatic Multispectral	10 20	1-4
RADARSAT	Canada	Radar	8-100	3-35
ERS	European Space Agency	Radar	30-50	3-35
JERS	Japan	Radar	15	4-45
IKONOS	Space Imaging	Panchromatic Multispectral	1 4	3-5
OrbView	Orbimage	Panchromatic Multispectral	1 4	3
Quickbird	EarthWatch	Panchromatic Multispectral	1 4	2-4
SPIN-2	Russia	Panchromatic Panchromatic	10 2	8

Table 5 - Some of well-known satellites assembled by James Madison University (http://maic.jmu.edu/sic/rs/image_formation_ctd.htm; April 19, 2009)

2.1.2 The first time when this technology was used

The first aerial photos of our earth were made by Gaspard-Felix Tournachon alias Nadar, a French photographer in the year 1858 when he flew over Paris. Therefore he used a balloon and his photographic stand camera. This was a rather primitive technique but this is known as the starting point for the modern remote sensing (Remote Sensing Tutorial Introduction - NASA, http://rst.gsfc.nasa.gov/Intro/Part2_7.html; April 19, 2009). Nadar became a famous pioneer in this technique.

The breakthrough of aerial photography began during World War I for military intelligence (surveillance and reconnaissance). Very early the military leaders and the politicians recognized the importance of photography and so the research was intensified by many countries. It reached the highest point during the Cold War (http://www.britannica.com/EBchecked/topic/457891/photogrammetry, Encyclopædia

Britannica; April 19, 2009). Combat aircrafts were equipped with a special platform for mounting the aerial camera. Both techniques were continuously improved since that time.

The Soviet Union launched their first satellite named Sputnik 1 on October 4, 1957. Over the next few years more and more artificial satellites were developed for various purposes and launched into space. The first remote sensing satellite was constructed by the United States of America in 1972 (Remote Sensing, Schowengerdt Robert A., page 1). It would be the first of six (originally seven but number six crashed during the start) satellites of the Landsat satellite program. The numbers of all active satellites in the year 2006 are estimated to 800 pieces (http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/satellites-types-orbits.html; April 19, 2009).

→ List about all launched remote sensing satellite missions from 1972 until 2008 can be found at: http://www.tbs-satellite.com/tse/online/mis_teledetection_res.html; April 19, 2009

2.1.3 What options (benefits) does this technology offer?

By the possibilities of the raster image analysis very large areas can be explored very cost effectively for scientific purposes. The other big advantages of this technology are that the locations can be discovered without entering a country's airspace and so there are no property violations. Problems can also come up from religious institutions for ethical issues. Likewise, mountainous and extreme climate regions can be a major challenge for normal investigation methods and can be very easy explored by means of remote sensing.

2.1.4 Why has this field of study increased so much over the last years?

During the last three decades countless satellites of various purposes have been sent into space and enormous amounts of information have been collected. The data from the different range of the electromagnetic spectrum can be provided for the diverse interesting clientele. The demand for spatial data (vector and grid) increases constantly as more and more new data is added every month, for instance 30-50 Tera-Bytes for

Microsoft's maps.live.com portal (Microsoft UNIGIS Partnerworkshop in Salzburg - February 25, 2008). Because of the forward movement of the technology the resolutions are getting better and better so new business models were possible. The spatial data have often been integrated in the workflow processes and are now a fixed component of them. In 2003 the German Ministry for Economic Affairs gave a study which says that in Germany alone there is a market for more than 8 billion Euros and already 15% are acquired. It may also be that about 13,000 new jobs can be created through it (E-Government Roadmap, initiative D21, page 40).

2.1.5 The current limitations of satellite remote sensing (civil, military use)

In an internet search four representative sources were selected for this paper:

QuickBird	60 cm panchromatic (2 ft); 2.4 meters multispectral (8 ft)
IKONOS	0.82 meter x 3.2 meters
GeoEye-1	0.41 meter x 0.41 meter, panchromatic 1.65 meters x 1.65 meters; multispectral
GeoEye-2	This is an 3th generation remote sensing satellite with an expected resolutions smaller than 25 cm

Table 6 - High resolution satellites for civil purposes

(http://www.ssd.itt.com/news/GeoEye-Contracts-with-ITT_18oct07.pdf, http://www.geoeye.com, http://www.digitalglobe.com; April 19, 2009)

During the work on this paper a lot of time was necessary for collecting information concerning the resolution of military remote sensing data. It is in the nature of matter that practically no information can be found. Since civilian satellites are already in the planning for the resolutions less than 25 centimeter per pixel (e.g. GeoEye-2 image specification) (http://www.satimagingcorp.com/satellite-sensors/geoeye-2.html; April 19, 2009), the author supposes that the actual resolutions of military surveillance satellites are already in sub decimeter range. It is not too far-fetched that real-time surveillance, like in the movie "Enemy of the State" by Jerry Bruckheimer and Buena Vista distribution from the year 1998 are already a reality for special military operations of e.g. the United States of America or other superpowers with their own defensives satellite programs.

Problems for the free market in the future could be that the civil use of high resolution (less than 50 centimeter) remote sensing data be prohibited by law of some countries and governments; currently this is happening in the USA. These data are reserved for their government and their designated allies (Mark Brender, GeoEye Inc., http://www.ssd.itt.com/news/GeoEye-Contracts-with-ITT_18oct07.pdf; April 19, 2009).

2.1.6 The main users of the remote sensing technology

The first users of the product were of course all kind of military organizations and intelligence services. At the California Institute of Technology from the NASA it is referred to the following possible field of sciences where remote sensing is able to help: land surface, climatology, vegetation and ecosystem dynamics, volcano monitoring, hazard monitoring, hydrology, geology and soils, land surface and land cover change (http://asterweb.jpl.nasa.gov/science.asp; April 19, 2009).

Remote sensing and photogrammetry technologies are used by the European Union and governments to control application from farmers to get their agrarian subvention (http://europa.eu/rapid/pressReleasesAction.do?reference=IP/04/953&format=PDF&aged=1&language=DE&guiLanguage=en, http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/04/273&format=PDF&aged=1&language=DE&guiLanguage=en; April 19, 2009)

More and more remote sensing data are integrated in huge public planning projects. Private people often use it in the form of WebGIS application (for instance maps.live.com, maps.google.com or the software Google Earth). Lawrence W. Fritz, President of the International Society for Photogrammetry and Remote Sensing (ISPRS) believes that there are many promising niches for the earth imaging industry. He points to the following markets: “disaster monitoring and assessment services; emergency services; tracking hazardous activities; fire and hazards detection; disease detection (agricultural); disease monitoring (agricultural & human); real estate appraisal, taxation and permitting; city and urban planning; financial and insurance services; retail marketing; facilities placement; facilities monitoring; peacekeeping and treaty monitoring; law enforcement; news services; environmental protection; global monitoring; resource assessment (natural & renewable); resource monitoring (natural &

renewable); archaeological & architectural site preservation; cadastral survey and land registration; trends analysis & prediction services; navigation safety; utilities management; reconnaissance, detection and surveillance; demographics; tourism and recreation entertainment" (http://www.isprs.org/publications/highlights/highlights0402/fritz.html; April 19, 2009).

2.1.7 The value of remote sensing data

All images are saved and multiple uses are possible. Further the dataset providers are able to construct orthorectified satellite images for refinement and increasing the value. Additionally, the following services are offered by many service providers: digital terrain models (DTM), image classification and land-use/land-cover (LULC) products. Practically every image selling company has such services for the customers on sale (http://www.digitalglobe.com/file.php/519/DG_Products_Ortho_Imagery_web.pdf and http://www.geoeye.com/CorpSite/products/services/Default.aspx; April 19, 2009).

Often the customers can order their requested dataset via a web shops where in most cases only rights to a license are sold. For an extra charge custom scenes with individual parameters are offered by most service providers. For scientific uses the possibility of sustainable exploration of our Earth's surface exists over the course of time.

There was no intention in the thesis to write about the recording mechanism of the satellites of geoinformation selling companies because this is not in direct context with the topic of this work.

2.2 GIS & Archeology

This chapter is divided into four parts. Chapter 2.2.1 contains what exactly is understood under the discipline of scientific archeology and how is it defined. Chapter 2.2.2 shows a number of technical achievements and describes how these are used in the archeology field. Chapter 2.2.3 is about geoinformation sciences and systems in archeology. Lastly, in chapter 2.2.4, the author will write about same archaeological projects which were supported with methods and techniques of the geoinformatics.

2.2.1 Characterization of the scientific field archeology

Archeology is described with the following words: “Archaeology, the scientific study of past human culture and behavior, from the origins of humans to the present. Archaeology studies past human behavior through the examination of material remains of previous human societies. These remains include the fossils (preserved bones) of humans, food remains, the ruins of buildings, and human artifacts - items such as tools, pottery, and jewelry. From their studies, archaeologists attempt to reconstruct past ways of life. Archaeology is an important field of anthropology, which is the broad study of human culture and biology. Archaeologists concentrate their studies on past societies and changes in those societies over extremely long periods of time”.

(http://encarta.msn.com/encyclopedia_761572159/Archaeology.html, Professor of Anthropology, University of California, Santa Barbara - Brian M. Fagan, B.A., M.A., Ph.D.; April 19, 2009)

2.2.2 New technologies used in archeology

In science and technology many innovative ideas and new methods of investigation were made and led to revolutionary technologies with unprecedented accuracy to be developed in recent decades. This also did not leave their marks in the archeology.

- The technique of age determination for organic material (carbon) was developed by Willard Frank Libby at the University of Chicago in 1949. Therefore he was awarded the Nobel Prize for Chemistry in the year 1960 (http://nobelprize.org/nobel_prizes/chemistry/laureates/1960/libby-bio.html, Willard Libby; April 19, 2009). Since this time it is considered a standard procedure for archaeologists to determine the age of investigation objects back to around 60,000 years BC.
- Also in the imaging diagnosis huge forward movements were made. Paul C. Lauterbur was responsible for this. In the year 1973 with the help of Sir Peter Mansfield they invented the magnetic resonance imaging (MRI) technology. These two inventors were honored for their achievements with a Nobel Prize in Physiology or Medicine. For scientists and physicians new discoveries on the inside of human and animal bodies were possible. In archeology it helps to explore mummies or other mortal remains (human, animal) without mechanical damage

(http://nobelprize.org/nobel_prizes/medicine/laureates/2003/lauterbur-cv.html, Paul C. Lauterbur; April 19, 2009).

- The endoscopy was initially developed for medical purposes. The fundamental part of this invention is a thin optic fiber using the total reflection inside the fiber for transferring images. A complex interplay of optical lenses, a fiber and a high resolution camera at the other end mounted in a suitable box can hold an endoscope. Pictures of cavities such as e.g. the abdomen or the knee in medicine and also from internal Egyptian mummies are possible.
- For measurements with a high need for accuracy, global navigation satellite system (GNSS) for instance the global positioning system [GPS] are used. The GPS technology is operated by the United States Department of Defense. In 1960 the United States Navy started their first test with satellite positioning called “Transit”. Over the years they improved their technology and many satellites were launched. GPS is considered to be the most reliable satellite navigation system (outside of war scenario). The accuracy depends very much on what method of measurement was chosen. The highest resolution is in the centimeter range. Archeologists take advantage of GPS to examine their excavations and POI’s before this data is inserted into GIS.

2.2.3 GIS used in archeology

In the geoinformatics for many years two imaging methods were used; they are called photogrammetry and remote sensing. Both technologies are equally used side by side for different work. These technologies originally were developed for another purpose (→ chapter 2.1.2). However, in recent years they were increasingly used for the investigation of archaeological projects from air and/or space. The resolution per pixel is getting better with every new satellite. The possibility to investigate the whole area with different spectral sensors is very interesting for the researchers in the archeology that is why this technology is used more and more.

For mapping and recording of investigative areas mainly vector GIS is deployed over raster image layers. Contrary to normal drawing programs, GIS applications offer a wide range of advantages; for instance, users are able to place points of interests (POI) in a georeferenced map and to compatibly work with different coordinate systems. GIS also has a more complex attribute handling when they are implemented in CAD software tools (http://www.ESRI.com/library/whitepapers/pdfs/gis_and_cad.pdf, GIS and CAD - The Right Tool for the Job, An ESRI White Paper - June 2002, November 17, 2008). Investigations (e.g. measurements) between the POI's as well as the surrounding environment can be carried out with a very high accuracy and, if needed, be simulated.

2.2.4 Archaeological projects which were supported by GIS

Nowadays it is really inconceivable that archaeological research takes place without GIS support. In recent years numerous interdisciplinary projects between archaeologists and geoinformatics were performed together. The author made an extensive online search with the Google™ (http://www.google.com) and HighBeam Research™ (http://www.highbeam.com) and different keywords on this theme.

archeology	GIS	Hohokam	irrigation traces	Phoenix	remote sensing
water traces	ASU	Salt River	Hohokam Indian	history	Sonoran desert

Table 7 - These key words were combined in different way for the internet search

(Robert Bizaj; January 18, 2009)

The author defined that only URLs from museums, municipalities and government agencies as well as from the university are intended as "serious links". Because of that the search results have been restricted but still a considerable number of results were displayed. Some of these projects and working groups the author would like to describe closer on the following pages. All of them are archeological projects which have a strong relation to remote sensing and their different methods.

The next table will give the reader an overview of all chosen projects. They will also notice that all selected projects have only an internet source. Only partially the articles appeared in specialized magazines (e.g. "Journal of Field Archeology"). References to specialized literature were not found. For the author the project descriptions were exclusively available in Adobe Acrobat PDF (portable document format) or as a web resource. He assumed the following possible causes:

- Projects are increasingly being presented exclusively on World Wide Web.
- High efforts and publishing costs for the production of printed documentation.
- Low outlet for printed works especially project summaries.
- Low number of professional customers.

Source	Subject
Source: University of Arkansas, High Beam^{TM} Author: Jesse Casana & Jackson Cothren Date: April 19, 2009 http://www.cast.uark.edu/assets/files/PDF/CasanaCothren_Proof.pdf http://www.highbeam.com/doc/1P3-1563801961.html	- Stereo analysis, DEM extraction and orthorectification of CORONA satellite imagery: archaeological applications from the Near East - New atlas to reveal landscape, undiscovered archeological sites in 3D
Source: Indian Academy of Sciences, High Beam^{TM} Found in: Current Science, 138 Vol. 93, No. 2, July 25, 2007 Date: April 19, 2009 http://www.ias.ac.in/currsci/jul252007/136.pdf http://www.highbeam.com/doc/1P3-1533075581.html	- CARTOSAT-1 views the Nalanda Buddhist ruins; Current Science, 138 Vol. 93, No. 2, July 25, 2007 - Excavation on to trace Nalanda varsity's main gateway
Source: Rochester Institute of Technology, Science Daily Author: Professor Bill Middleton Date: April 19, 2009 http://www.rit.edu/news/?r=46164 http://www.sciencedaily.com/releases/2008/05/080513112348.htm	Archaeologist uses satellite imagery to explore ancient Mexico
Source: Xinhua News Agency, GIS Development Date: April 19, 2009 http://www.highbeam.com/doc/1P2-18428403.html http://www.gisdevelopment.net/news/2001/nov/news301101.htm	China's 1st remote sensing archeology lab launched
Source: The Boston Globe, High BeamTM Author: David L. Chandler, Globe Staff Date: April 19, 2009 http://www.bu.edu/remotesensing/research/dry-rivers/index.html http://www.highbeam.com/doc/1P2-8220612.html	- Dry Rivers Project Summary - Traces reported found of a lost Mideast river
Source: University of Colorado at Boulder; NASA	- Prehistoric human footpaths in

Author: Payson Sheets, Jim Scott Date: April 19, 2009 http://www.colorado.edu/news/releases/2003/387.html http://weather.msfc.nasa.gov/archeology/arenal.html	Costa Rica indicate intimate ties with villages, cemeteries - Arenal Region, Costa Rica
Source: Journal of Field Archaeology 20; 77-90 Author: Pamela Sands Showalter Date: April 19, 2009 http://www.jstor.org/ http://www.bu.edu/jfa/Abstracts/S/ShowalterP_20_1.html	A thematic mapper analysis of the prehistoric Hohokam canal system, Phoenix, Arizona

Table 8 - Overview to GIS supported archeological projects

(Robert Bizaj; November 11, 2008)

2.2.4.1 Stereo analysis, DEM extraction and orthorectification of CORONA satellite imagery: archaeological applications from the Near East

Jesse Casana & Jackson Cothren work at the University of Arkansas with declassified images from the US government satellite program called CORONA from the years 1967 to 1972 to develop a 3D view of the landscape of the Middle East before the spread of cities and farmland began. Their opinion is that within the last forty years many archeological places as ancient roads, fields and water traces were destroyed because of the spread. This cannot be made retrogressive. The only possibility is to explore the data from the US reconnaissance satellite with his high resolution image scans. They believe that there are many hundred gigabytes of CORONA remote sensing data to deal with. Cothren developed a new mathematical model based on a model from the Ohio State University to correct so called “bowtie distortions”. When the scans are free from distortions it is possible to lay over them over new Google Earth images. After about a year scientific work it may be possible to find new archeological places with help of their three dimensional (stereo analysis) viewer.

2.2.4.2 CARTOSAT-1 views the Nalanda Buddhist ruins

The ruins of the 2,500 years old Nalanda University are located in the Northeast Indian part called Bihar (between 25°6'-25°10'N lat. and 85°24'-85°30'E long) and part of it are still standing only the main entrance is not found yet. It is spread over an area about 16 km². Today approximately 10 percent of the area has been excavated. Responsible therefore is a team of scientists from the Archaeological Survey of India (ASI). It is assumed that Nalanda was visited by Buddha many times. The Indian Space Research Organisation was asked for support and started their analysis in the year 2007. Images with a resolution of 2.5 meters (panchromatic) from their high resolution CARTOSAT-1 (IRS P5) satellite and IRS P6 LISS-IV with a spatial resolution of 5.8 meters were used to explore the whole Nalanda area. It exposed that many details (e.g. monasteries, temple, roads and tanks) on the satellite images can be found on the map which was made by the ASI. Three mounds can be identified also, they are 5-7 meters high and have perimeter of about 490-535 meters. CARTOSAT-1 offered a very good possibility to get an inventory of all assets of this area for further investigations. (http://www.highbeam.com/doc/1P3-1533075581.html, Excavation on to trace Nalanda varsity's main gateway; April 19, 2009)

2.2.4.3 Archaeologist uses satellite imagery to explore ancient Mexico

In this NASA funded project Professor Bill Middleton and his team from Rochester Institute of Technology will explore the ancient Mexican environment and where the Zapotecs culture lived from about 250 BC to 750 AD with help of satellite data.

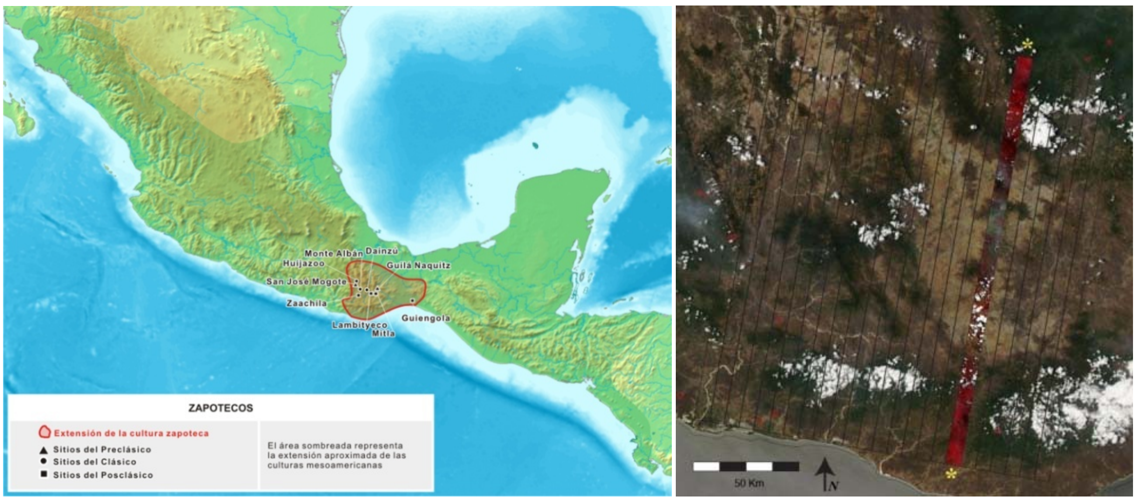


Image 13 - Southern Mesoamerica (left), Satellite scene of this area (right)

(http://en.wikipedia.org/wiki/Image:Zapotecos.png, The Zapotec civilization; April 19, 2009)

(http://www.sciencedaily.com/releases/2008/05/080513112348.htm, RIT - Rochester Institute of Technology; April 19, 2009)

Images from the Landsat and Earth Observing 1 satellites from an area of more than 30,000 km² are available for Professor Middleton. His team is going to use all kind of wavelengths of the spectrum (multispectral image analysis) which are contained in the datasets. Middleton says: "Today it's classified as semi-arid, and the dominant vegetation in the valley is thorn-scrub forest. Ten thousand years ago, it was a grassland and there were horses there". One goal of the project is to investigate the economy and environment and how it changed during the last 30 years. Because of the urban spread wide areas of the landscape changed. Middleton is very interested to compare the differences between the then-and-now images of the last decades.

2.2.4.4 China's 1st remote sensing archeology lab launched

The Chinese archaeologist recognized the capacity and potential which is in the remote sensing technology. That's why they build up a separate laboratory for remote sensing archeology which opened in November of 2001.

2.2.4.5 Traces reported found of a lost Mideast river

Dr. Farouk El-Baz started his career in Egypt and is now director of the Center for Remote Sensing at the Boston University (BU). Many of his projects refer to the locations in the Mideast e.g. Arabian countries like Iraq, Kuwait and Egypt. In his projects he engaged a lot about ground water potentials in arid climate areas (http://www.bu.edu/remotesensing/research/completed.html; April 19, 2009). He gave an interview for the Boston Globe on March 26, 1993 about a huge dried out water trace he found in the Arabian Peninsula area. Many thousand years ago there must be a mighty river (530 km long and up to 4.8 km wide). It flowed into a huge delta near Kuwait and southern Iraq, therefore El-Baz named the ancient water trace Kuwait River. He expects that cities and other human settlements may be found on the watersides too. The investigations were only possible with detailed analysis of remote sensing data. Previously some years ago in 1981 scientists of the BU already found another long-buried waterway. They used datasets from sand penetrating radar which were made onboard the US space shuttle Columbia. With this method it was possible to recognize the dried out watercourses. Dr. Farouk El-Baz believes that his research could help people to find ground water to support agriculture and help the region.

2.2.4.6 Prehistoric human footpaths in Costa Rica indicate intimate ties with villages, cemeteries

On the Homepage of the University of Colorado at Boulder is written the following project report from Professor Payson Sheets (from October 8, 2003. He and his team existing of a NASA remote sensing specialist Dan Irwin, NASA archeologist Tom Sever and his students Errin Weller, Michelle Butler and Devin White were working to discover prehistoric footpaths which were made by Costa Rican people about 1,500 years ago between their villages and cemeteries. The most paths are not visible on the ground, they only can be seen from space. For their recognition they used images from the IKONOS satellite and photogrammetry images which were shot by NASA aircrafts. The analyses were done in the infrared range of the electromagnetic spectrum with a special signature.

Image 14 - Color infrared (CIR) images of footpaths, Arenal Region

(http://weather.msfc.nasa.gov/archeology/arenal_cir.html, NASA; April 19, 2009)

"It appears these people may have had a much more complex network of social, economic and religious contact between isolated villages on both sides of the divide than we would have expected" said Professor Payson. Doctoral student Errin Weller believes that it is a great opportunity to work with remote sensing data in archeology.

2.2.4.7 A thematic mapper analysis of the prehistoric Hohokam canal system, Phoenix, Arizona

This project is about a feasibility study of the usability of Landsat Thematic Mapper satellite images for recognition of dried out water traces. Therefore the ancient Hohokam irrigation canals were chosen. The work was done by Pamela Sands Showalter in the year 1993 and published in the "Journal of Field Archaeology" - Volume 20, 1993. In the first part of their work Showalter is writing about the Hohokam history and the expansion of the water traces in combination to the human settlement and their cultivated agriculture. Also possibilities of different kinds of aerial photography technologies are mentioned.

In 1930 the Hohokam area was explored with aerial techniques by Neil Judd for archeological purposes for the first time. In a study with aerial images between the years 1973 to 1974, made by the Arizona Department of Transportation it was found out that many parts of the water traces has been eroded, leveled or has been destroyed in other kind. 1980 the area was investigated by Ebert and Lyon with Skylab III and Landsat MSS images and about 80 kilometers were able to be identified successfully. The report includes also a short overview about the Landsat TM and the methods and techniques of image processing to her work. During the test it was found out that major branches can be discerned. Nevertheless only 7% of the TM images correlate with the existing map. As a result of Pamela Sands Showalter study she suggests the Landsat Thematic Mapper datasets as very helpful tool for exploring prehistoric features in combination with classic mapping technologies.

2.3 Usability

It is very subjective detectably for whom the content of this work is interesting and who can take benefits of it. The investigation method is easily adjustable and similar issues and tasks can be adapted. The author is convinced that the content may be highly interested for people from the following disciplines or fields. Subsequent considerations were employed.

Hydrology & Agriculture	- To retrieve old canal structures (→ e.g. 2.2.4.1) - Use of natural irrigation traces
Archaeology	- Examine of paths and human settlements (→ e.g. 2.2.4.6) - Exploring water traces (→ e.g. 2.2.4.5)

Table 9 - Usability of this thesis

(Robert Bizaj, 22.01.2008)

And a further very farfetched idea:

Terraforming planets	For exploring of planets which are many light years away from Earth. For instance many years ago the NASA has born the idea to colonize our red planet - MARS sometime in the future. A terraforming is therefore absolutely essential. This means to create an oxygen based atmosphere were human can breath and live like we do on Earth. In the opinion of the author the methods used in this thesis could help to investigate the surface of the Mars by a remote sensing satellite in his orbit. Finding canal-structures are absolutely important for a possible water flow after the ice on Mars melted.

(http://quest.nasa.gov/mars/background/terra.html, Terraforming Mars; April 19, 2009)

(http://nssdc.gsfc.nasa.gov/planetary/mars/mars_colonize_terraform.html, Mars Exploration, Colonization and Terraforming Links; April 19, 2009)

2.4 Feature extraction

Remote sensing images are created as described in chapter 1.3.1. During this process a lot of interferences can occur, for instance in the atmosphere by means of clouds, vapor in the upper areas, scattering of light or the topographic relief of mountains. Other sources of errors are the satellite sensors themselves.

In the most cases the image information correlates strong between the different recorded bands which means, that there are a lot of redundant information. The idea of the feature extraction is to reduce the most unnecessary information in the image before the further classification process moves on. That can mean to switch of bands which are not useful for the next calculation process or to use a smoothing filter before for example (Remote Sensing, Schowengert Robert A, page 388-395)

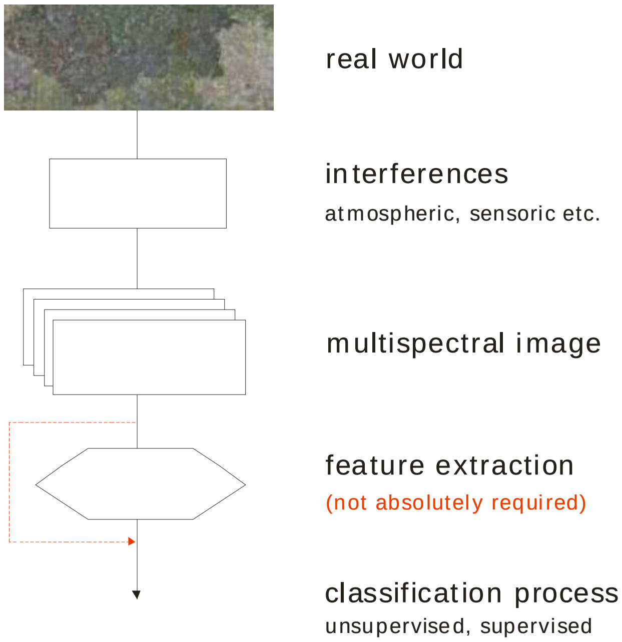


Image 15 - The real word to the classification process (simplified)

(Robert Bizaj; January 22, 2008)

2.5 Supervised classification

At first the user has to specify how many classes (water, streets, conifer forests, maize etc.) he will need for his classification. Afterwards training areas or better training pixels (also called prototype pixels) for each class have to be discovered. In step three the training areas are used to get a feeling how the parameters and properties need to be adjusted. With help of the training set the supervised classification can be performed. In the following step a summary of all occurred thematic classes has to be arranged by the operator. The last point is the labeling of the classes (Remote Sensing Digital Image Analysis, John A. Richards & Xuiping Jia - Springer, page 193; Remote Sensing, Schowengert Robert A, page 388-395).

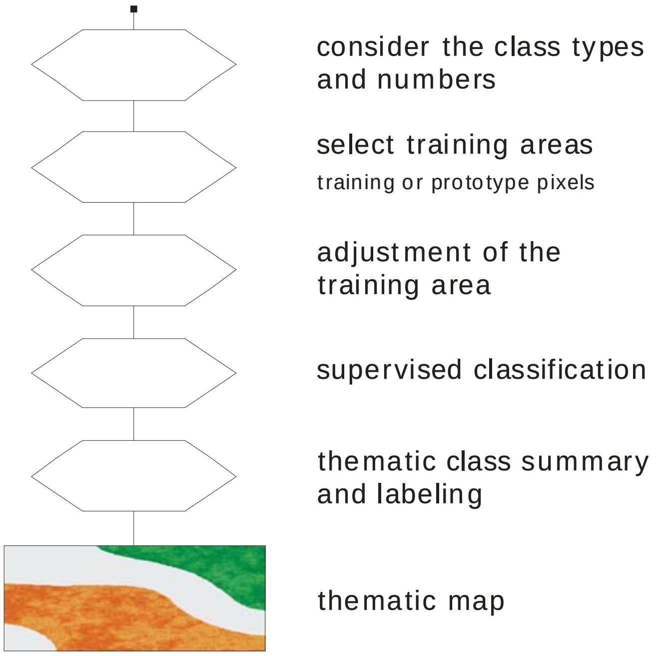


Image 16 - Creating a supervised classification (simplified)

(Robert Bizaj; January 22, 2008)

It was not described in this chapter that for a faster but imprecisely classification the unsupervised classification can be used and how it works.

2.6 Vegetation index (VI)

Vegetation indices are special parameters which can help to investigate many scientific questions around our earth and environment by remote sensing. The primary focus of these parameters is on the vegetation. Many different indices have been developed in the last years, the important indices are:

Abbreviation	Long expression	Explanation
NDVI	normalized differenced vegetation index	it is an indicator for the health of the vegetation
EVI	enhanced vegetation index	against the NDVI the spatial resolution is better and atmospheric haze can be corrected
SAVI	soil adjusted vegetation index	nearly the same like NDVI with an additional correction factor

Table 10 - Some important vegetation indices

(http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php, Normalized Difference Vegetation Index; April 19, 2009)

Nevertheless the NDVI established to one of the most common indices. It can be calculated with the “near infrared” and “red” canals from a dataset:

$$NDVI = \frac{NIR - red}{NIR + red}$$

Table 11 - Formula to calculate the NDVI

(Remote Sensing - Robert A. Schowengerdt, Vegetation Index, page 188 ff.)

Many actual remote sensing products (also ERDAS Imagine) support these indices in different forms. The outcome of a calculation is a panchromatic image. For instance white and very bright colors refer to healthy vegetation, black color interprets water.

Further information’s can be found the NASA Earth Observation homepage (http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php, Normalized Difference Vegetation Index; April 19, 2009) and in the book of Robert A. Schowengerdt (Remote Sensing - Robert A. Schowengerdt, Vegetation Index, page 188 ff.).

2.7 Importance of the Sources

The previously mentioned projects have a close relationship with the topic of this work. Every detailed described project has an archaeological question which could be supported and pushed with the help of remote sensing. The research suggests that many archaeologists increasingly use the ability of those in this relatively new field of scientific technology for their investigations. The author would like to take the opportunity to mention three works and why they are so significant for this work and why they were classified as very important:

- A work with a very big reference to this thesis is in the view of the author the study of Pamela Sands Showalter (at this time Ph.D. student) about “A thematic mapper analysis of the prehistoric Hohokam canal system, Phoenix, Arizona”. Very early (~1930) the investigations about this extensive area has began through aerial photography to map and for a closer research. Into Showalter's report it was referred to several such projects. Only through the possibilities of satellite remote sensing, in this case by a Landsat TM satellite (from 1982) and its various sensing systems, we owe it that the landscape was able to be explored in different wavelengths (multispectral). For this master's thesis similar datasets from Landsat MSS and TM of nearly the same region are available. That's why this project is set as very important.

- As second referred work the author wants to choose the project from Payson Sheets of "Prehistoric human footpaths in Costa Rica indicate intimate ties with villages, cemeteries". There are IKONOS multispectral data used for the analysis of paths and roads which are partially covered with rain forest. The relationship to this work is seen by the author in the detection of linear structures. In the present work linear water traces amongst urban area will be discovered, it is in a similar way a great challenge too. For Payson Sheets and his team it was possible to detect these structures very well for Costa Rica.
- The third work classified as important is the work of Professor Bill Middleton on "Archaeologist uses satellite imagery to explore ancient Mexico". He and his team used remote sensing data from the past thirty years for a multispectral research on the culture of the cities of the Zapotec culture. Also in this thesis old records from over thirty years are used. It can be assumed with high probability that even in Phoenix the spread of the city will play a large role in the detection of the water traces. Maybe more spread means less detected water traces?
- For the entire classification process the following two books were very important and useful for this work. These literatures contain many detailed information to understand these techniques better.
    - Remote Sensing Digital Image Analysis, John A. Richards & Xuiping Jia - Springer
    - Remote Sensing, Schowengert Robert A. - Academic Press / Elsevier

3. Solution

Before the solution can be worked out with using the method as described, some preparations must be made. In chapter 3.1 the preparation of the datasets e.g. resizing, natural colors and reprojections etc. are shown. A detailed investigation with eye and also with help of Google Earth™ is absolutely necessary (chapter 3.2) before classes can be defined in chapter 3.3. Supervised classifications are based on training areas which uses a specific spectral signature for each class (chapter 3.4). After finishing the preparation actually the supervised classification can be executed in chapter 3.5. All steps need to be done for all four satellite images (2003, 1995, 1985 and 1973).

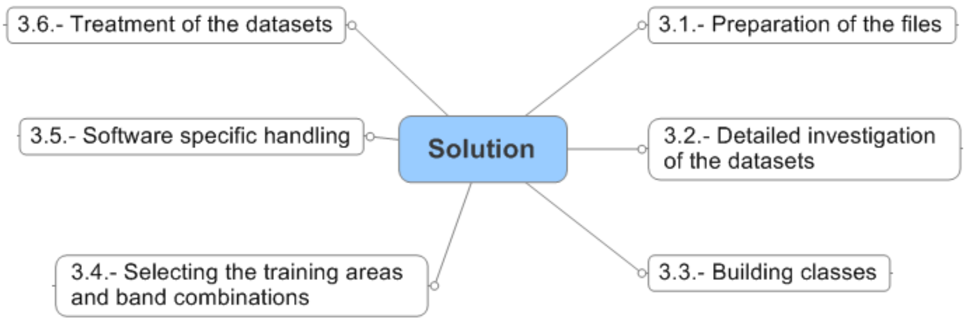


Image 17 - Single steps in the solution chapter

(Robert Bizaj; February 4, 2009)

3.1 Preparation of the datasets

3.1.1 Satellite images

The Phoenix metropolitan area consists of many cities e.g. Tempe, Scottsdale, Goodyear or Sun City to mention the most famous. All of them belong to the Maricopa County which is crossed by the Salt River from the east to the west. The Hohokam water traces extent this area about 9 km to the north and 16 km to the south. The east to west extend is about 45 km. All scenes mentioned in chapter 1.3.4 have a different size showing the area of Maricopa County and more. First of all they were resized to a common size. It was attempted to show the whole expansion of the cities (in order to get a better classification) and the Hohokam canal area. The projection type of all images is UTM with a WGS 84 spheroid and datum, the UTM zone is 12 North. The resize procedure was made:

- ERDAS Imagine → Data Preparation → Subset Image

With an "Inquire Box" these coordinates are used and applied to all images:

ULX: 372673.73	LRX: 429777.93
ULY: 3729393.20	LRY: 3682962.16

Table 12 - Coordinate of the resized datasets (ASTER, Landsat TM & MSS)

(ASTER satellite image; February 2, 2009)

For a better perception for human viewer the images were created in "natural colors" through the following steps (shown in image 18 & 19):

- ERDAS Imagine → Image Interpreter → Spectral Enhancement → Natural Color

Input band spectral range: Near infrared (3) - Red (1) - Green (2)

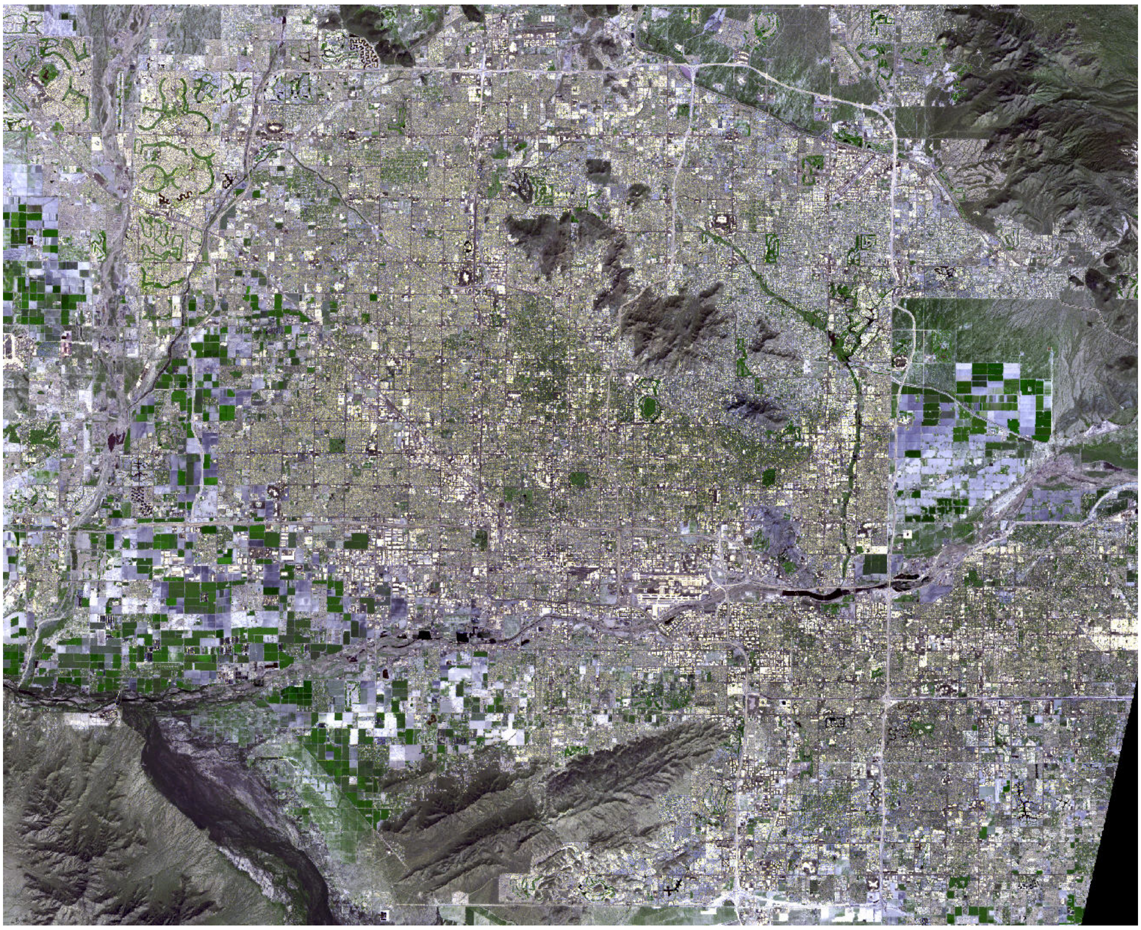


Image 18 - Extend of the cities in the Maricopa County and the Salt River

(ASTER scene from March 3, 2003 processed by Robert Bizaj; January 15, 2009)

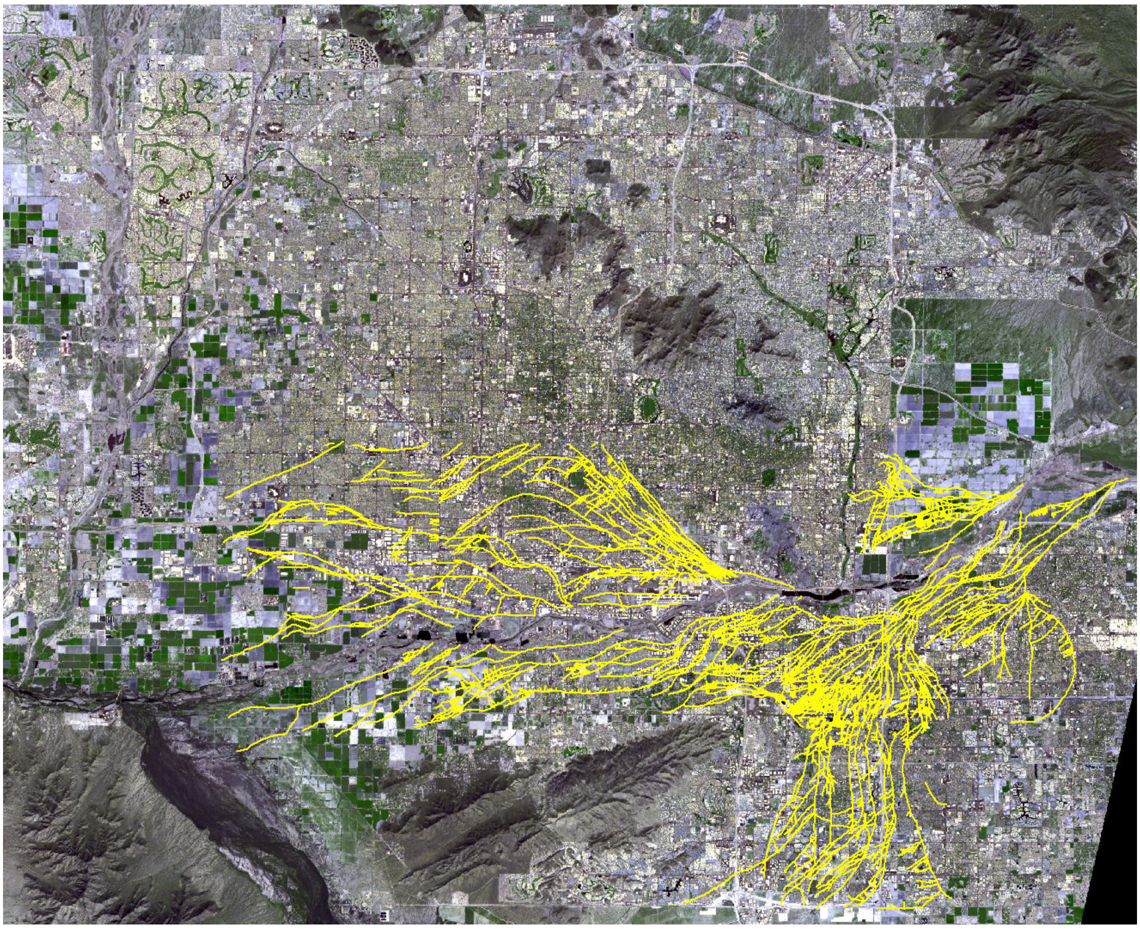


Image 19 - A view over the Maricopa County with the Hohokam canals overlay

(ASTER scene like before with a Hohokam canals shape overlay; January 15, 2009)

3.1.2 Hohokam shape file

The originally shape file was created by Jerry B. Howard with some different projection adjustments then all other satellite image had. To be in conform the shape file needs a reprojection. The ASU vector data had the following adjustments:

Projection Type: UTM	Spheroid Name: Clarke 1866	Datum Name: NAD27
UTM Zone: 12	North or South: North	Map Units: Meter

Table 13 - Shape file projection setting from Jerry B. Howard

(Hohokam canals shape; February 2, 2009)

To perform a reprojection the following steps needs to be done:

- ERDAS Imagine → Show Information for Top Raster, Vector or Annotations Layer → Projection → Edit → Add coverage projections → Meters → Edit Projection Parameters → Projection Type: UTM, Spheroid Name: WGS 84, Datum Name: WGS 84, UTM Zone: 12, NORTH or SOUTH: North → OK

The boundaries after the reprojection are:

Xmin: 383739	Ymin: 3.68363e+006
Xmax: 429295	Ymax: 3.70717e+006

Table 14 - Boundaries after the reprojection

(Hohokam canals shape; February 2, 2009)

3.1.3 Investigation areas

The idea is to create a huge reference rectangle over the whole Hohokam area and three buffer zones around the Hohokam water traces. Afterwards it will be compared how often (in percent) the occurrence of the classes of "water & wetlands", "vegetation" and "agriculture" (agriculture only in the supervised classification) are in the reference rectangle in comparison to the buffer zones.

3.1.3.1 Reference Rectangle

In ArcGIS a rectangle is created behind all Hohokam water traces. It has a length of approximately 47 kilometers and a high of about 25 kilometers, the whole area is 1,195.048 square kilometers.

Length_X	Length_Y	Shape_Area
46.977 m	25.435 m	1,195,048,316.52372 m²

Table 15 - Length and Area of the "Reference Rectangle"

(Robert Bizaj; April 15, 2009)

3.1.3.2 Creating Buffer Zones

First a “Personal Geodatabase” with the name “Hohokam Water Traces” was created and Jerry B. Howard’s shape File was imported into them. Four “Polylines” with the length of “0” were deleted (“Start Editing” → in the layer menu over the “Hohokam Water Traces” with the right mouse click “Open Attribute Table” → “Sort Ascending” to order the length of the canals from the smallest to the largest → the four with the length of “0” were deleted [OBJECTID: 512, 513, 514, 3533] because they cannot have a buffer zone around). A “Multiple Ring Buffer” (MRB) was chosen for the buffer zones. The advantage of this command is that in one step many buffers can be build. For this case buffers with 100 m, 300 m and 500 m around the canals were made.

- ArcMap → ArcToolbox → Analysis Tools → Multiple Ring Buffer

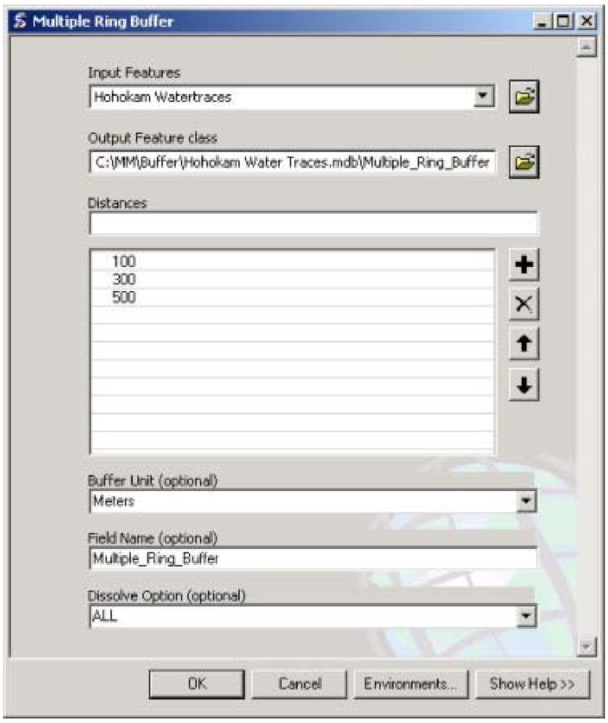


Image 20 - Creation of the “multiple ring buffer” in ArcGIS

(Robert Bizaj; April 15, 2009)

The “Dissolve Type” function was used with the parameter “all” to combine all buffer zones which are laying over each other to one buffer to reduce multiple usages of their areas. The outcome of the buffer calculation is:

Areas	area in m²	area in km²
Multiple Ring Buffer 100 (>0 to ≤100 meter)	222,997,140.84	222.99
Multiple Ring Buffer 300 (>100 to ≤300 meter)	201,111,804.84	201.11
Multiple Ring Buffer 500 (>300 to ≤500 meter)	103,042,535.58	103.04

Table 16 - Areas of the Buffer Zones

(Robert Bizaj; April 15, 2009)

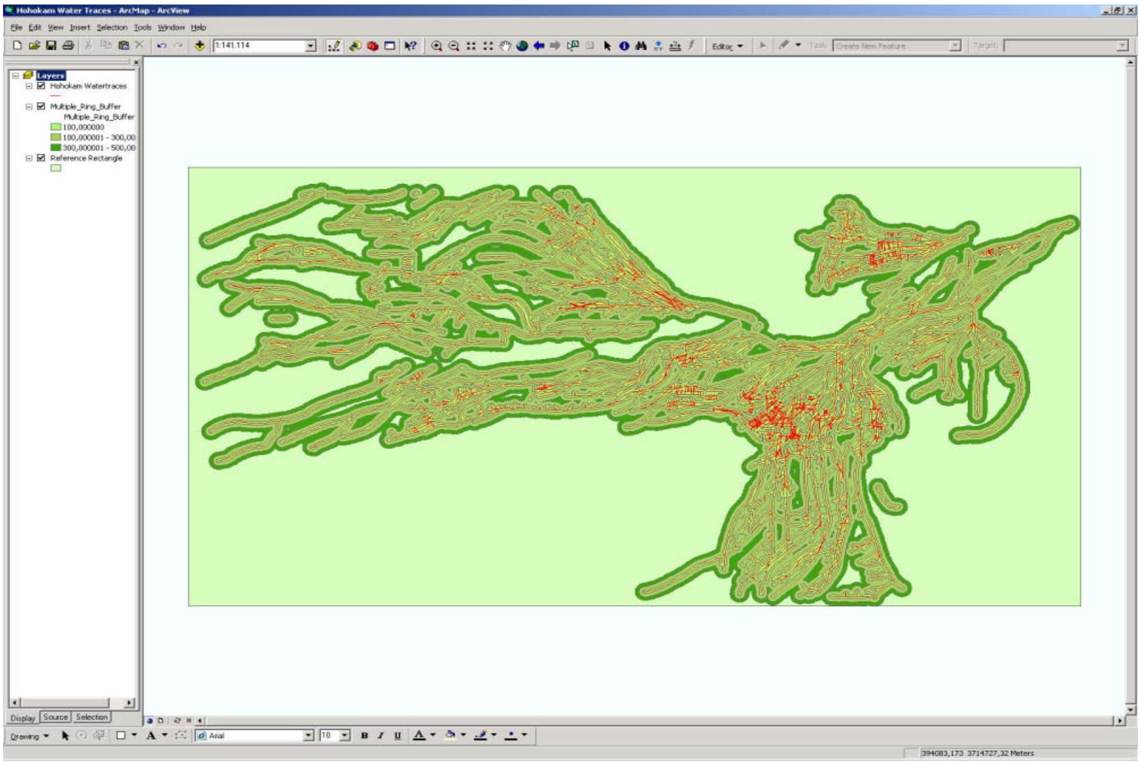


Table 17 - Reference area with the Hohokam traces and the Multi Ring Buffer

(Robert Bizaj; April 15, 2009)

3.1.4 Vegetation index

In ERDAS Imagine 8.7 the NVDI (Normalized Difference Vegetation Index) function is already implemented. Landsat MSS and TM datasets can be directly calculated without further preparations. The NVDI function can be found under:

- ERDAS Imagine 8.7 → Interpreter → Spectral Enhancement … → Indices …

ASTER Images needs a special preparation by clicking “Batch”. With this object based wizard from every satellite data (with the appropriate data) the NDVI can be calculated. Therefore the canals which represents the “NIR” and “red” spectrum has to be chosen a double click on “IR - Visible” and “IR + Visible”. The input file (“Input Raster”) and the output file (“Output Raster”) are also required. By pressing “Process” → “Run” in the menu bar the model calculates the prepared dataset. Afterwards the new created model with “aster_ndvi_model.gmd” was saved on the computer.

- “IR - Visible” → $n1_2003(3) - $n1_2003(2)
- “IR + Visible” → $n1_2003(3) + $n1_2003(2)

NIR	Canal 3
Red	Canal 2

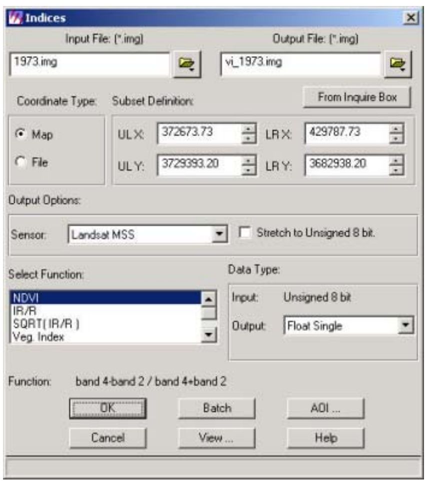
Table 18 - Used ASTER canals to calculate the NDVI

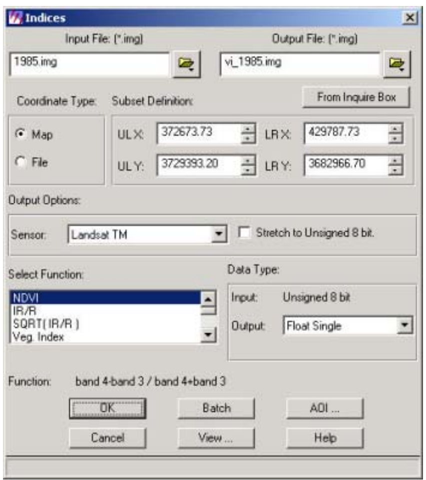
(Robert Bizaj; April 15, 2009)

$$NDVI = \frac{canal\ 3 - canal\ 2}{canal\ 3 + canal\ 2}$$

Table 19 - Formula to calculate the NDVI for ASTER images

(http://www.gisdevelopment.net/technology/rs/techrs0023pf.htm, Mapping surface cover types using ASTER data, Dr. Abdullah Mah; April 19, 2009))





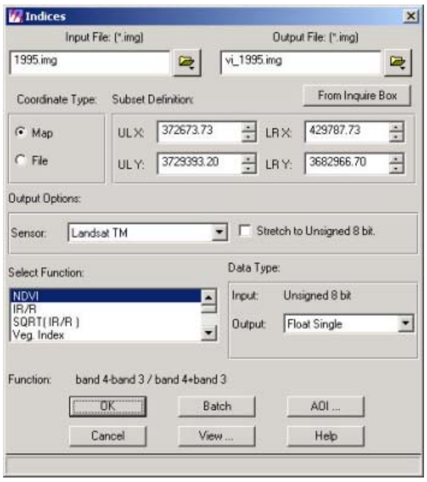


Image 21 - Calculation of the NDVI in ERDAS Imagine

(Robert Bizaj; April 12, 2009)

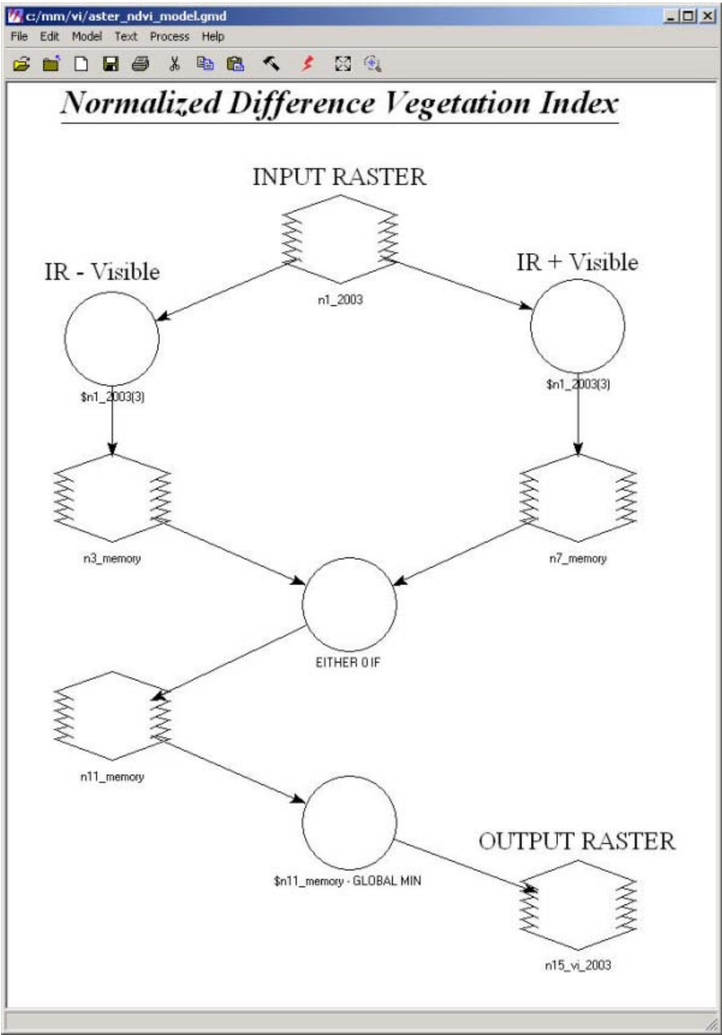


Image 22 - Diagram for the model to calculate the ASTER NDVI

(Robert Bizaj; April 12, 2009)

3.1.4.1 VI result for the year 2003

Image 23 - VI calculation from the ASTER 2003 image

(Robert Bizaj; April 13, 2009)

White Color	healthy vegetation
Black Color	all kind of water areas (rivers, lagoons etc.)

Table 20 - How to find healthy vegetation and water areas

(Robert Bizaj; April 13, 2009)

3.1.4.2 VI result for the year 1995

Image 24 - VI calculation from the Landsat TM 1995 image

(Robert Bizaj; April 13, 2009)

3.1.4.3 VI result for the year 1985

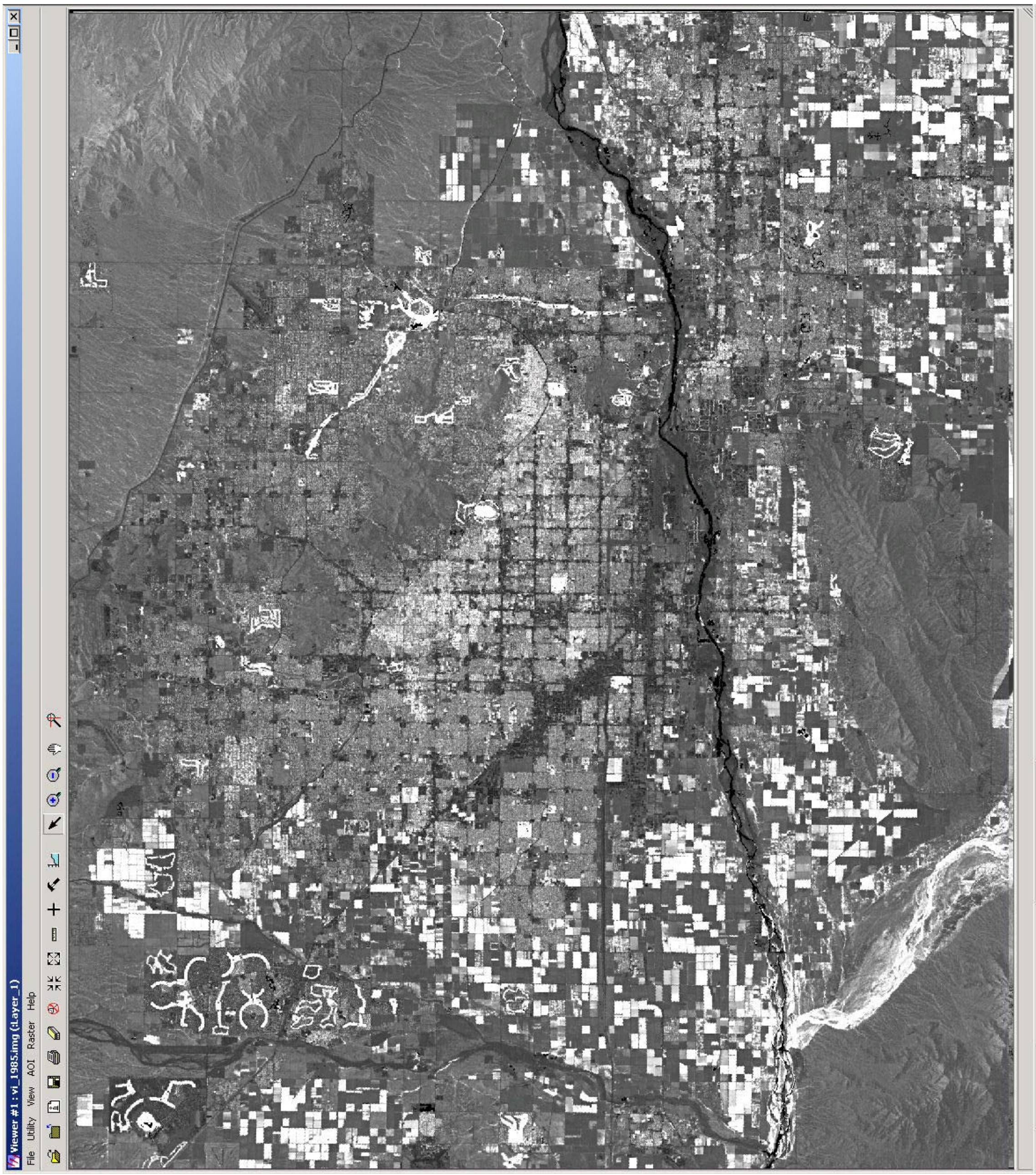


Image 25 - VI calculation from the Landsat TM 1985 image

(Robert Bizaj; April 13, 2009)

3.1.4.4 VI result for the year 1973

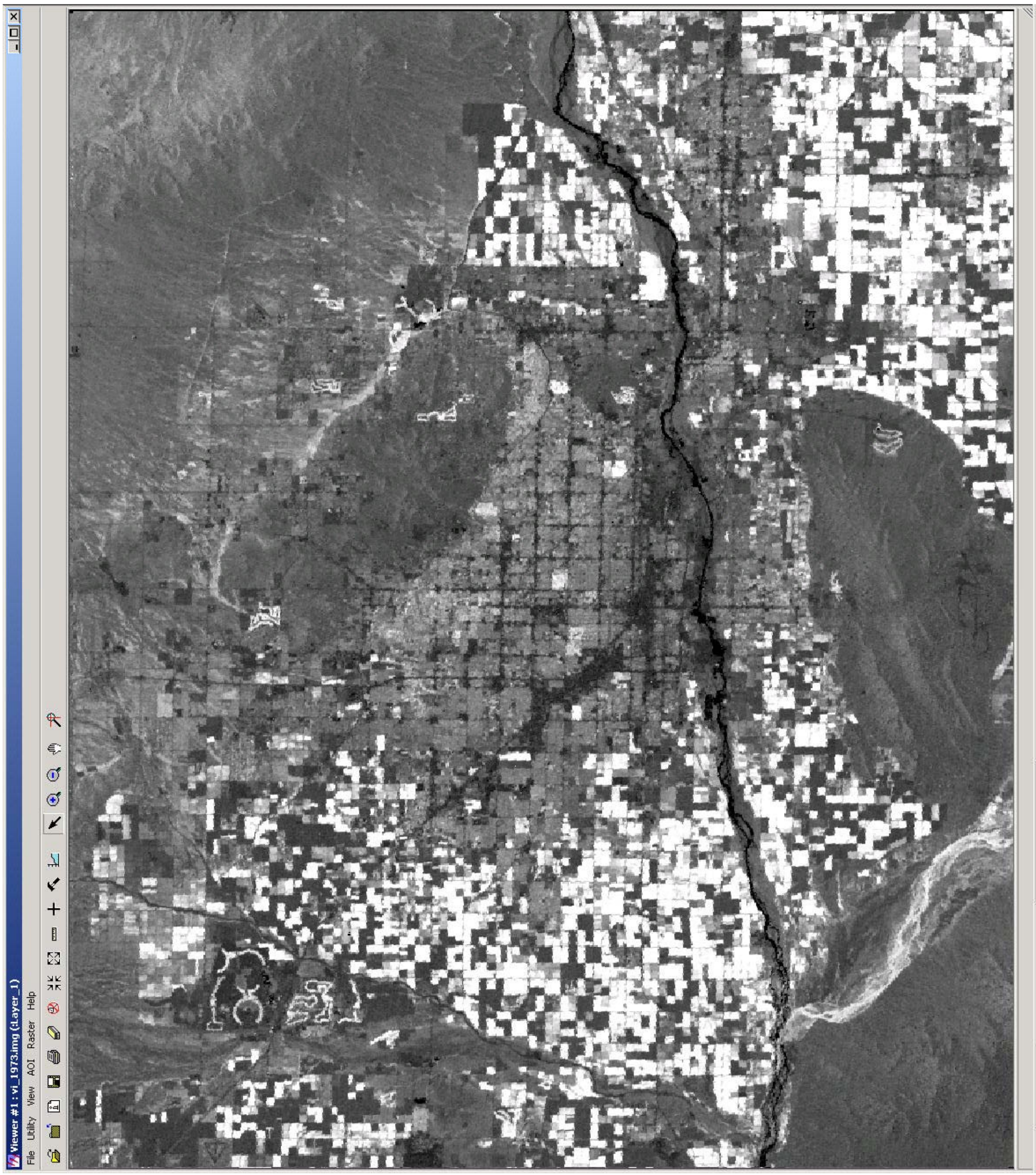


Image 26 - VI calculation from the Landsat MSS 1973 image

(Robert Bizaj; April 13, 2009)

3.2 Detailed investigation of the datasets

The investigation was performed in the following way. All raster datasets were opened in ERDAS Imagine one after the other. As an overlay (top layer) the Hohokam vector file was set. What's the cause to do that? The goal is to examine the area around the water traces which have been digitized and to get a better felling for the whole area. Finally the Phoenix metro area was also investigated with help of Google Earth™. Therefore the reprojected shape file was converted in a Google KML file with the software shape2earth. The results from the visual examination are:

- The whole metro area is strongly sealed with asphalt and concrete. For example streets, parking areas, highways etc.
- There is very rare natural vegetation. The most of the vegetation is made by human near their residential buildings (garden, bushes and trees).
- Because of the arid climate only a few water places can be found. The most of them is human-made and are swimming pool and small (!) lagoons (e.g. 33°20'16.84“N / 111°49'0.55“W; 33°21'10.60“N / 111°54'26.62“W).
- Huge regions in the east and west of Phoenix are used for agricultur. Without further investigations it may assumed that they are irrigated because of their hot and dry climate.
- Although an intensive search was executed over the whole canal area no fragments of the Hohokam irrigation canals could be found. Only in a few points human-made water ways (lagoons, rainwater canals) are crossed by the Hohokam canals but that is only a chance.

3.2.1 Critical event

Unfortunately no fragments from the Hohokam canals were trackable during the visual investigation with help of the human eyes. The attempt has to be to recognize the prehistoric canals “indirectly” over the existence of water and humid areas around the old canals. The idea is if sufficient humid areas (vegetation, water and agriculture) are trackable along the fragments within a buffer zone this could be a sign that Hohokam water traces were in the nearer surroundings.

3.3 Defining / Building classes

To run a supervised classification same preparation are necessary. In this chapter the classes are defined, in the following the signature file and the trainings areas are built. Therefore it is essential to write down possible classes, which were asserted during the investigation before. To find the possible Hohokam water traces not every class will be necessary, only a few have a significant meaning (humid areas, vegetation) for that thesis the other unimportant classes (surrounding, urban areas) were not further processed after the classification. After discovering the ASTER scene the following features are considered to be (actually) possible for the further recognition for this area:

1.	Agriculture	moist & dry fields
2.	Vegetations	trees, bushes, golf courses …
3.	Water & Wetlands	rivers, lakes, ponds, water traces (water-bearing) …
4.	Mountains, Desert	stones, rocks
5.	Sealed areas	streets, highways, parking areas, airfields …
6.	Buildings	residential buildings, industrial structures

Table 21 - Classes for the supervised classification extracted from the ASTER scene (Robert Bizaj; April 8, 2009)

Old Class	New Class	Old Name	New Name
1.	1.	Agriculture	Vegetations
2.		Vegetations	
3.	2.	Water & Wetlands	Humid Areas
4.	3.	Mountains, Desert	Surrounding
5.	4.	Sealed Areas	Urban Areas
6.		Buildings	

Table 22 - Simplified Classes for the supervised classification (Robert Bizaj; April 8, 2009)

The first two classes agriculture and vegetation are combined to one single class because for this work it does not matter if it is the one or the other class. Biomass can be found in both of them. The humid area class retained, also the surrounding which describes all features in our environment like stones, soil, mountains and the desert areas. The classes number five and six are merged again. The surrounding and urban areas will not be important after the reclassification process.

3.4 Selecting the band combinations and training areas

3.4.1 Band combinations

Remote sensing satellites have many different scanner devices, each of them has different spectral properties. For the feature classes (vegetation, agriculture + water and wetlands) which are interesting in this thesis, the visible near infrared spectrum (VNIR) is very suitable. The following table shows the band combinations from the available datasets. For the best investigation result of ASTER images the combination 3-2-1 is recommended (http://terra.nasa.gov/Brochure/Sect_4-2.html, ASTER; April 19, 2009).

Mr. James W. Quinn from the Portland State University writes that the standard false color image is a very common combination for vegetation studies, the 4-3-2 band from Landsat TM should be selected (http://web.pdx.edu/~emch/ip1/bandcombinations.html, Portland State University - James W. Quinn; April 19, 2009). The same false color image for Landsat MSS datasets can be made with the combination 4-2-1 [7-5-4] (http://academic.emporia.edu/aberjame/remote/landsat/landsat_interp.htm, Landsat Image Interpretation, Emporia State University - James S. Aber; April 19, 2009).

Satellite	RGB	Band Nr.	Wavelength Interval (µm)	Color
ASTER	(R)ed	3	0.76 - 0.86	near IR
	(G)reen	2	0.63 - 0.69	red
	(B)lue	1	0.52 - 0.60	green
Landsat TM5	(R)ed	4	0.76 - 0.90	near IR
	(G)reen	3	0.63 - 0.69	red
	(B)lue	2	0.52 - 0.60	green
Landsat MSS	(R)ed	4 [7]	0.70 - 0.80	NIR
	(G)reen	2 [5]	0.60 - 0.70	red
	(B)lue	1 [4]	0.50 - 0.60	green

Table 23 - Overview about the used satellite sensors

(http://asterweb.jpl.nasa.gov/characteristics.asp, http://landsat.usgs.gov/about_landsat1.php, http://rst.gsfc.nasa.gov/Intro/Part2_20.html, Excerpt by Robert Bizaj; April 19, 2009)

3.4.2 Positions of the AOI's

The supervised classification works with one or more AOI's for every class. All of them are created with polygons (the smaller AOIs) and in form of rectangles (mostly the greater areas). The idea was that writing down of all coordinates will be better than countless pages with screenshots. So it is very easy for everybody to verify all chosen area of interests and their position.

The points were collected in ERDAS Imagine in the viewer window, after pressing "CTRL" + "I" the "Inquire Cursor…" appears. The crosshair was moved to the AOI and the coordinate for the X and Y axis was read.

All dataset's were reprojected before and have now the following projection data:

Projection Type: UTM	Spheroid Name: WGS 84	Datum Name: WGS 84
UTM Zone: 12	North or South: North	Map Units: Meter

Table 24 - Projection setting for the datasets

(Hohokam canals shape; February 2, 2009)

3.4.2.1 ASTER, 2003

Position		Vegetations	Humid Areas	Surrounding	Urban Areas
1.	AOI I	X: 373623.912569 Y: 3718673.27177	X: 381954.365340 Y: 3719632.80036	X: 375586.584688 Y: 3728181.32781	X: 393904.857798 Y: 3723165.61017
2.	AOI II	X: 380166.152965 Y: 3721202.93805	X: 414316.647835 Y: 3712523.56580	X: 423388.554519 Y: 3710866.19823	X: 394341.007158 Y: 3714137.31843
3.	AOI III	X: 405244.741152 Y: 3709252.44560	X: 414360.262771 Y: 3699569.92981	X: 386097.784258 Y: 3698654.01615	X: 412920.969884 Y: 3718237.12241
4.	AOI IV	X: 422516.255799 Y: 3711084.27291	X: 393861.242862 Y: 3697563.64275	X: 373580.297633 Y: 3720679.55882	X: 414840.027067 Y: 3694685.05698
5.	AOI V	X: 420684.428488 Y: 3683737.70805	X: 378072.636038 Y: 3707420.61829	X: 394733.541582 Y: 3690149.10364	X: 385574.405026 Y: 3705545.17604
6.	AOI VI	X: 386141.399194 Y: 3697781.71743	X: - Y: -	X: 390502.892792 Y: 3685220.61587	X: - Y: -

Table 25 - Positions of the AOI's from the ASTER 2003 (approximately)

(Robert Bizaj; March 8, 2009)

3.4.2.2 Landsat TM, 1995

Position		Vegetations	Humid Areas	Surrounding	Urban Areas
1.	AOI I	X: 374359.424832 Y: 3719861.60594	X: 381987.382410 Y: 3719643.66430	X: 374490.189819 Y: 3721474.37411	X: 393976.395073 Y: 3723348.04060
2.	AOI II	X: 380243.849249 Y: 3721212.84414	X: 414417.099199 Y: 3712495.17834	X: 421652.761816 Y: 3710925.99849	X: 393976.395073 Y: 3715152.58041
3.	AOI III	X: 405263.550105 Y: 3709443.99531	X: 414460.687528 Y: 3699636.62128	X: 418427.225469 Y: 3726966.50357	X: 385955.306375 Y: 3706390.41286
4.	AOI IV	X: 420955.348552 Y: 3711187.52847	X: 399030.419056 Y: 3697936.67644	X: 422960.411687 Y: 3689916.42391	X: 416557.503473 Y: 3704428.73356
5.	AOI V	X: 426229.536363 Y: 3687780.59578	X: 378020.844469 Y: 3705346.69238	X: 393712.642916 Y: 3686778.06422	X: 419303.854495 Y: 3690043.08535
6.	AOI VI	X: 381202.792487 Y: 3702469.86266	X: - Y: -	X: 380374.614236 Y: 380374.614236	X: 407141.442828 Y: 3720296.53946

Table 26 - Positions of the AOI's from the Landsat TM 1995 (approximately)

(Robert Bizaj; March 8, 2009)

3.4.2.3 Landsat TM, 1985

Position		Vegetations	Humid Areas	Surrounding	Urban Areas
1.	AOI I	X: 374400.720047 Y: 3720819.79877	X: 380894.832530 Y: 3719132.74799	X: 373435.253251 Y: 3718800.27629	X: 397135.950769 Y: 3723233.18453
2.	AOI II	X: 379886.626442 Y: 3720863.68602	X: 381898.235862 Y: 3719382.24287	X: 410698.016571 Y: 3727622.20259	X: 394326.979211 Y: 3713533.45462
3.	AOI III	X: 411309.898278 Y: 3705678.69711	X: 414338.961106 Y: 3712174.37545	X: 415833.167700 Y: 3725471.58374	X: 390771.874583 Y: 3704535.96760
4.	AOI IV	X: 424607.735381 Y: 3690537.59546	X: 416007.319797 Y: 3699741.67507	X: 419212.711605 Y: 3709319.99729	X: 414428.681921 Y: 3695801.82166
5.	AOI V	X: 383792.591796 Y: 3703879.31982	X: 399636.074018 Y: 3697684.79450	X: 420002.734856 Y: 3708529.97404	X: 424698.984179 Y: 3695626.26094
6.	AOI VI	X: 375936.773837 Y: 3696199.05086	X: 398699.050644 Y: 3697562.90528	X: 392132.470182 Y: 3685663.18995	X: 419344.382147 Y: 3688823.28295

Table 27 - Positions of the AOI's from the Landsat TM 1985 (approximately)

(Robert Bizaj; March 8, 2009)

3.4.2.4 Landsat MSS, 1973

Position		Vegetations	Humid Areas	Surrounding	Urban Areas
1.	AOI I	X: 373640.811221 Y: 3718946.45411	X: 381004.764355 Y: 3719584.23692	X: 373597.505878 Y: 3723924.47106	X: 397269.092030 Y: 3723363.10477
2.	AOI II	X: 380003.873806 Y: 3721370.47795	X: 382043.932990 Y: 3719815.16328	X: 410519.838786 Y: 3727647.00404	X: 394369.621457 Y: 3712847.11448
3.	AOI III	X: 411386.325332 Y: 3705700.89526	X: 414285.657031 Y: 3712064.30785	X: 415800.641383 Y: 3725309.59961	X: 390734.464320 Y: 3704711.28661
4.	AOI IV	X: 420000.267199 Y: 3708384.63594	X: 416017.067718 Y: 3699641.43617	X: 419176.892223 Y: 3709250.76549	X: 414449.537066 Y: 3695709.94513
5.	AOI V	X: 419827.122639 Y: 3688905.87292	X: 398183.537639 Y: 3697520.45808	X: 422899.425201 Y: 3689469.39838	X: 424619.321911 Y: 3695709.94513
6.	AOI VI	X: 383120.475889 Y: 3705181.46158	X: 395413.280539 Y: 3698039.88129	X: 384678.534277 Y: 3704229.67449	X: 401813.038450 Y: 3704148.70276

Table 28 - Positions of the AOI's from the Landsat MSS 1973 (approximately)

(Robert Bizaj; March 8, 2009)

3.5 ERDAS Imagine specific handling

3.5.1 Creating a signature file with AOI (areas of interest)

Once an image is opened the signature editor with the AOI tool menu (area of interest) can be used to define special regions with a unique spectral signature within the map to describe individual classes.

- ERDAS Imagine → Viewer → Open → Raster Layer
- ERDAS Imagine → Classifier → Signature Editor

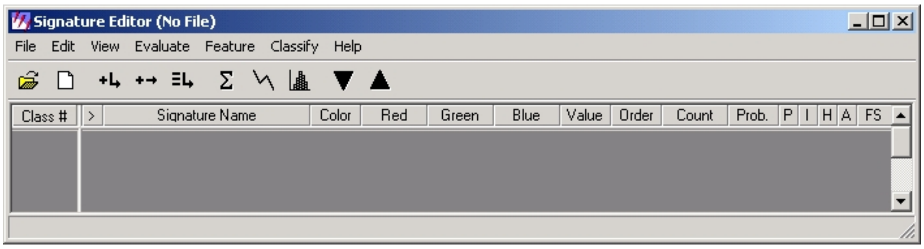


Image 27 - ERDAS Imagine 8.7 - Signature Editor

(Robert Bizaj; February 2, 2009)

- ERDAS Imagine → Viewer →AOI → Tools → Create Polygon AOI

Image 28 - ERDAS Imagine 8.7 - AOI tool box

(Robert Bizaj; February 9, 2009)

It was attempt to define areas of interests with exact the same quality in all four datasets. This was really difficult because of the different recording dates (March and May) and the use of different satellites and their divergent spatial and spectral resolutions. To validate the AOI's it is absolutely required to perform the "Contingency Report" which is described in chapter 7.

3.5.2 Supervised classification

To perform a supervised classification, two different ways are possible. The first way is direct over the main menu:

- ERDAS Imagine → Classification → Supervised Classification

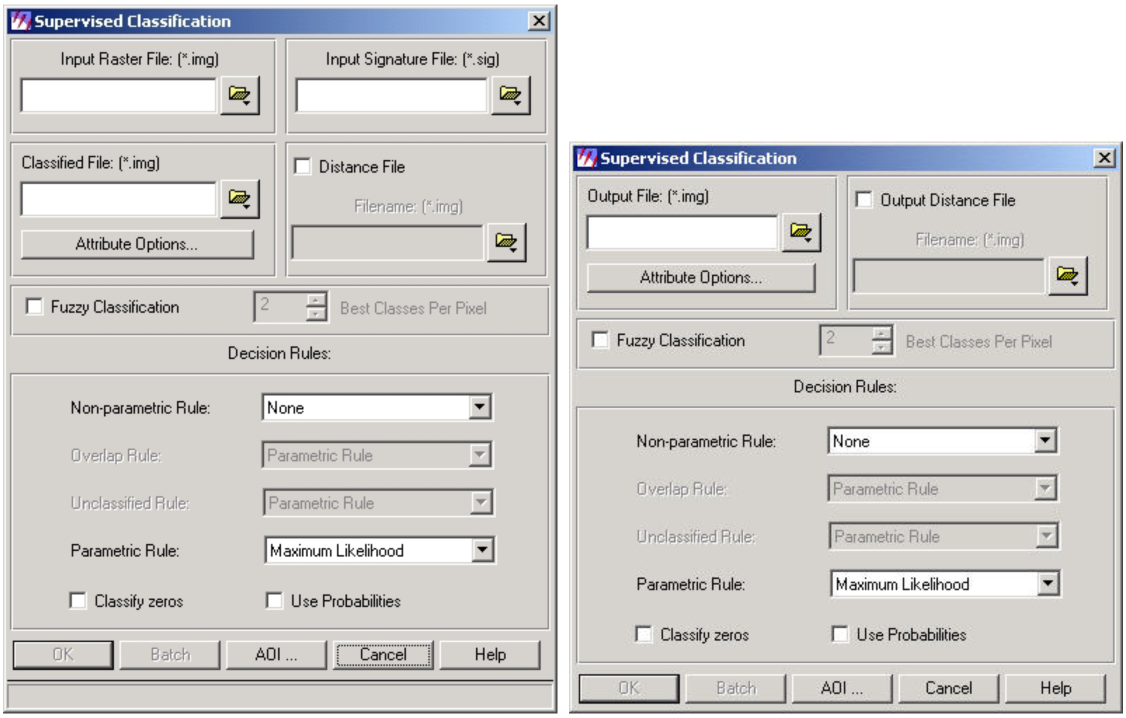


Image 29 - Started from main menu (left) and from signature editor (right)

(Robert Bizaj; February 9, 2009)

The second possibility is over the "Signature Editor" which was described on the last page. After the training areas were created with help of AOI's the "Supervised Classification" can be found under the following menu.

- ERDAS Imagine → Classification → Signature Editor → Classify → Supervised …

In both cases same adjustment are selectable which defines the decision rules of the method. For this work all adjustments were left default. For more information regarding that rules will be referred to the ERDAS Field guide (ERDAS Field Guide^{TM}, Classification [Chapter 7], Leica Geosystems GIS & Mapping, LLC, 2003).

3.6 Treatment of the datasets

3.6.1 Supervised classification

Nr.	Kind of work
1.	Load raster image with the defined band combinations
2.	Set up “Area of Interest”
3.	Create “Signature File”
4.	Verify the AOI with the “Contingency Matrix” → chapter 7
5.	Run the “Supervised Classification”
6.	“Grouping Tool” to color the classes
7.	Verify the classification with the “Accuracy Assessment” tool → chapter 7
8.	Create a documentation (screen shots, verbal description)

Table 29 - Rough sequence of the work for every dataset

(Robert Bizaj; March 6, 2009)

The first action was to load the raster image into the ERDAS Imagine Viewer with the appropriate band combinations. The areas of interests (AOI’s) were set up according to chapter 3.4 in the second step. After the AOI’s were placed the signature editor was started and the AOI’s were imported and labeled into them. Before the supervised classification was started the AOI’s were verified with the contingency matrix. In step five the supervised classification was started from signature editor. By the way all classification settings were left on default. After the classification finished the thematic image was opened with the grouping tool and the classes were colored with appropriate colors. In the next step the quality of the classification process was controlled with the accuracy assessment tool. These reports can be found on the last pages as additional. Afterwards the whole result data were documented, that means screen shots were made, resized and imported in this paper and also an explanatory description was formulated.

3.6.1.1 ASTER, 2003

Band combinations: R-G-B | 3-2-1

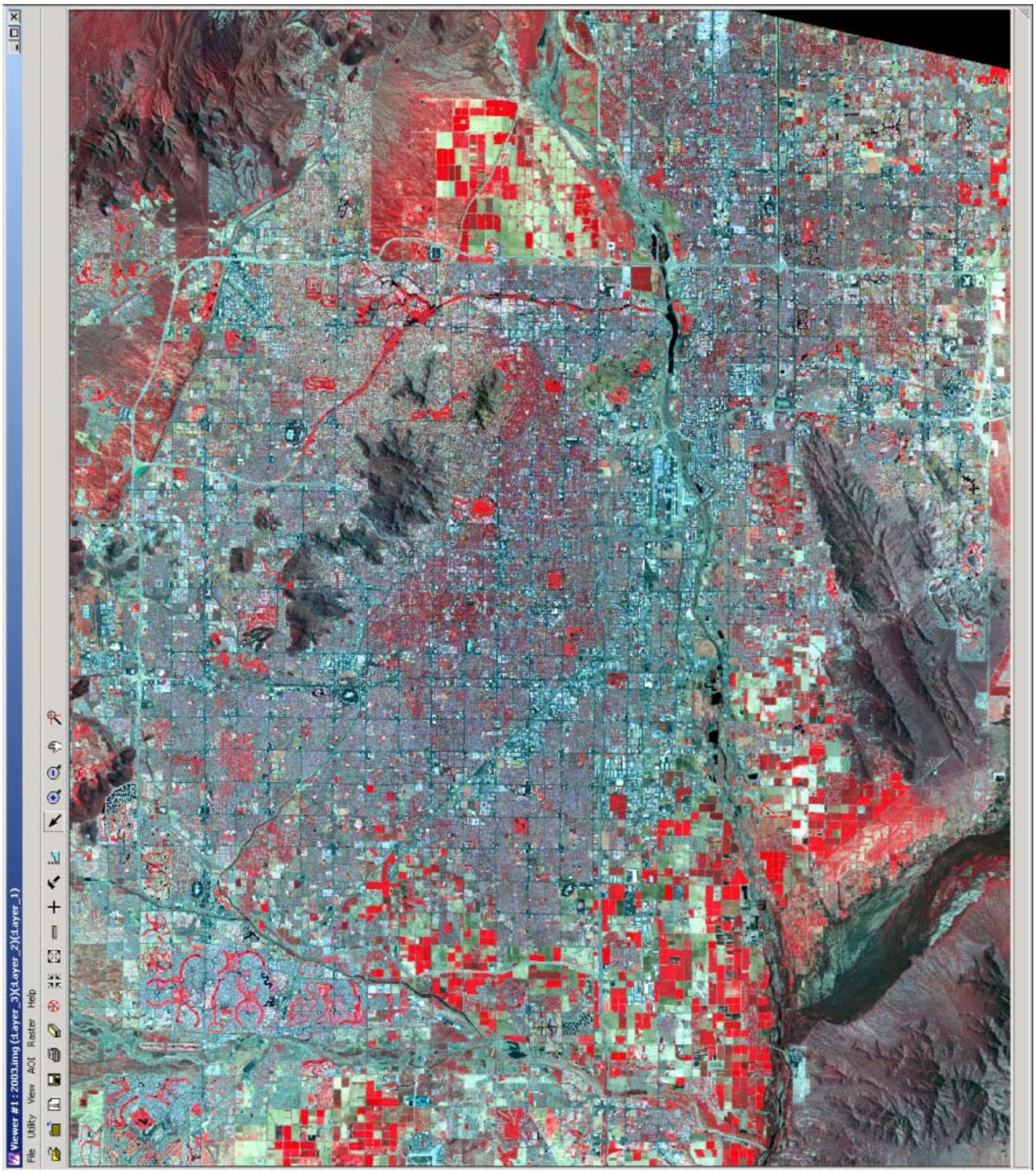
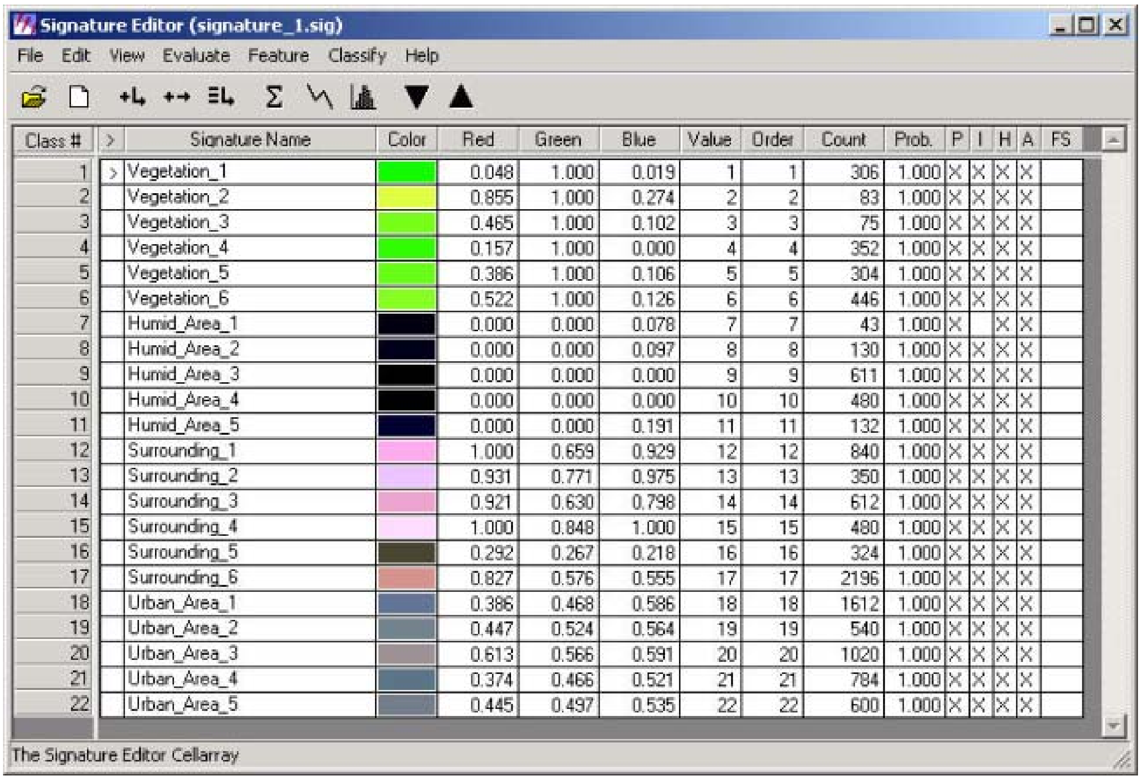


Image 30 - Phoenix metro area in the year 2003 from ASTER

(Robert Bizaj; March 8, 2009)

The ASTER ground resolutions were the best of all available datasets. Their spatial resolution of the first three bands is 15 meters. ASTER images have various numbers of sensors from the near infrared to the thermal infrared. That is why these datasets are very suitable to investigate all kind of questions regarding the environment.



Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation_1		0.048	1.000	0.019	1	1	306	1.000	X	X	X	X	
2		Vegetation_2		0.855	1.000	0.274	2	2	83	1.000	X	X	X	X	
3		Vegetation_3		0.465	1.000	0.102	3	3	75	1.000	X	X	X	X	
4		Vegetation_4		0.157	1.000	0.000	4	4	352	1.000	X	X	X	X	
5		Vegetation_5		0.386	1.000	0.106	5	5	304	1.000	X	X	X	X	
6		Vegetation_6		0.522	1.000	0.126	6	6	446	1.000	X	X	X	X	
7		Humid_Area_1		0.000	0.000	0.078	7	7	43	1.000	X		X	X	
8		Humid_Area_2		0.000	0.000	0.097	8	8	130	1.000	X	X	X	X	
9		Humid_Area_3		0.000	0.000	0.000	9	9	611	1.000	X	X	X	X	
10		Humid_Area_4		0.000	0.000	0.000	10	10	480	1.000	X	X	X	X	
11		Humid_Area_5		0.000	0.000	0.191	11	11	132	1.000	X	X	X	X	
12		Surrounding_1		1.000	0.659	0.929	12	12	840	1.000	X	X	X	X	
13		Surrounding_2		0.931	0.771	0.975	13	13	350	1.000	X	X	X	X	
14		Surrounding_3		0.921	0.630	0.798	14	14	612	1.000	X	X	X	X	
15		Surrounding_4		1.000	0.848	1.000	15	15	480	1.000	X	X	X	X	
16		Surrounding_5		0.292	0.267	0.218	16	16	324	1.000	X	X	X	X	
17		Surrounding_6		0.827	0.576	0.555	17	17	2196	1.000	X	X	X	X	
18		Urban_Area_1		0.386	0.468	0.586	18	18	1612	1.000	X	X	X	X	
19		Urban_Area_2		0.447	0.524	0.564	19	19	540	1.000	X	X	X	X	
20		Urban_Area_3		0.613	0.566	0.591	20	20	1020	1.000	X	X	X	X	
21		Urban_Area_4		0.374	0.466	0.521	21	21	784	1.000	X	X	X	X	
22		Urban_Area_5		0.445	0.497	0.535	22	22	600	1.000	X	X	X	X	

Image 31 - ASTER 2003, Signature Editor

(Robert Bizaj; March 8, 2009)

To reduce the number of classes they were reduced with the "Merge" function:

- ERDAS Imagine 8.7 → Classifier → Signature Editor … → Edit → Merge

Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation		0.336	1.000	0.076	23	23	1566	1.000	X	X		X	
2		Humid_Area		0.000	0.000	0.021	6	24	1396	1.000	X	X		X	
3		Surrounding		0.903	0.618	0.711	7	25	4802	1.000	X	X		X	
4		Urban_Area		0.450	0.500	0.567	1	26	4556	1.000	X	X		X	

Image 32 - ASTER 2003, Signature Editor

(Robert Bizaj; March 8, 2009)

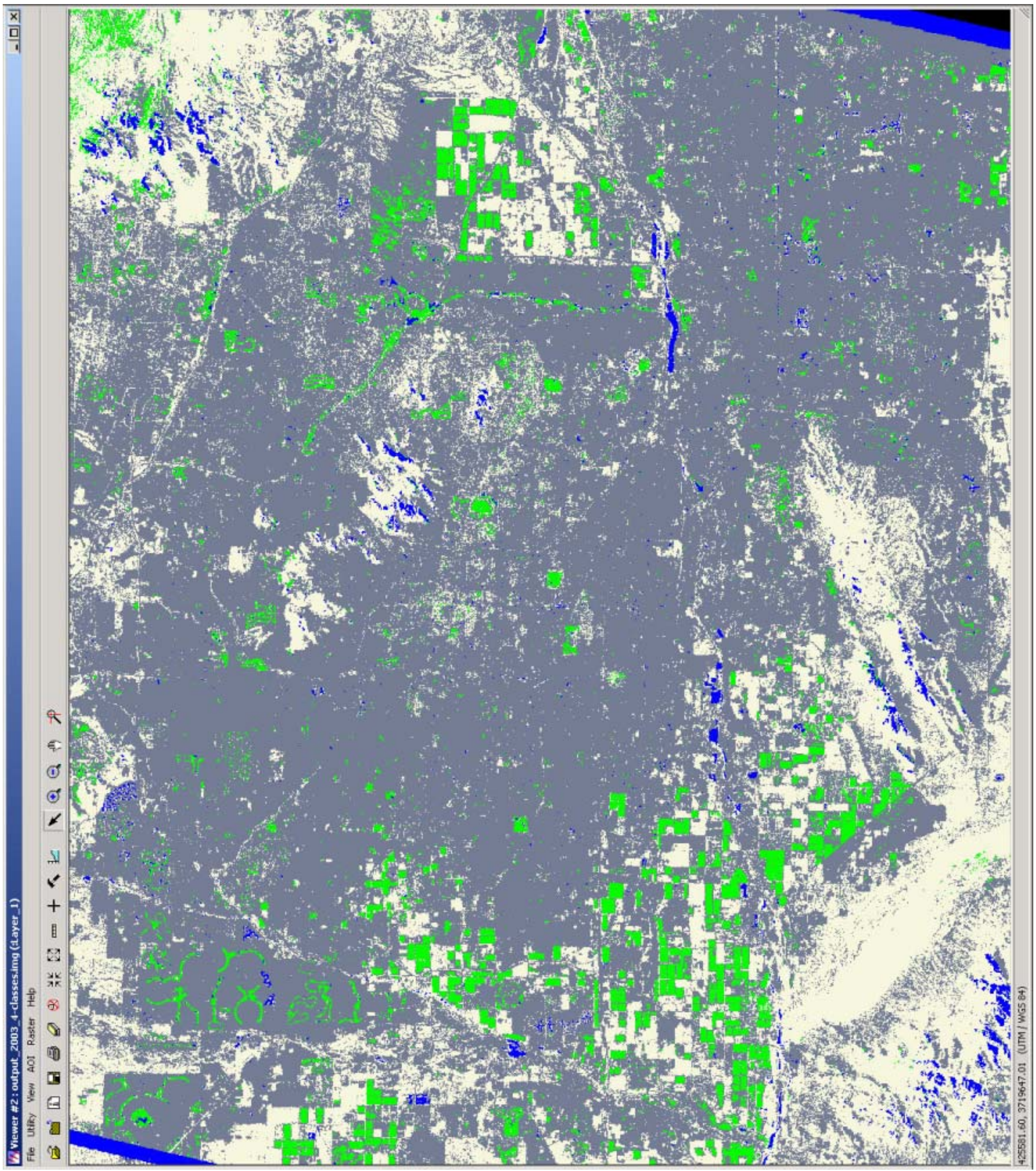


Image 33 - Classification result, ASTER 2003

(Robert Bizaj; March 8, 2009)

Class Number	Class Name
1	Urban Areas
6	Humid Areas
7	Surrounding
23	Vegetation

Table 30 - Class names and numbers after merging; ASTER 2003

(Robert Bizaj; March 8, 2009)

3.6.1.2 Landsat TM 5, 1995

Band combinations: R-G-B | 4-3-2

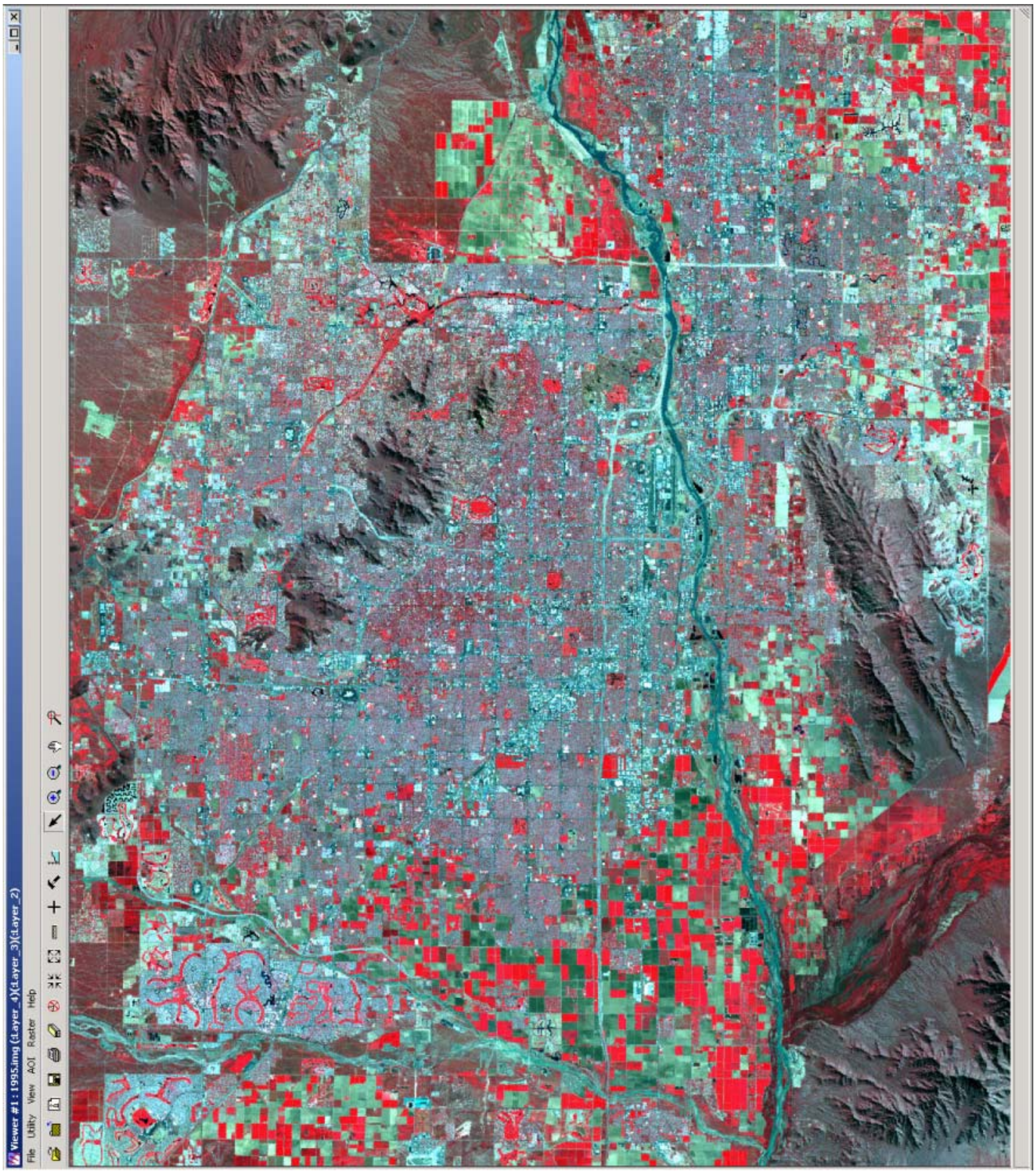
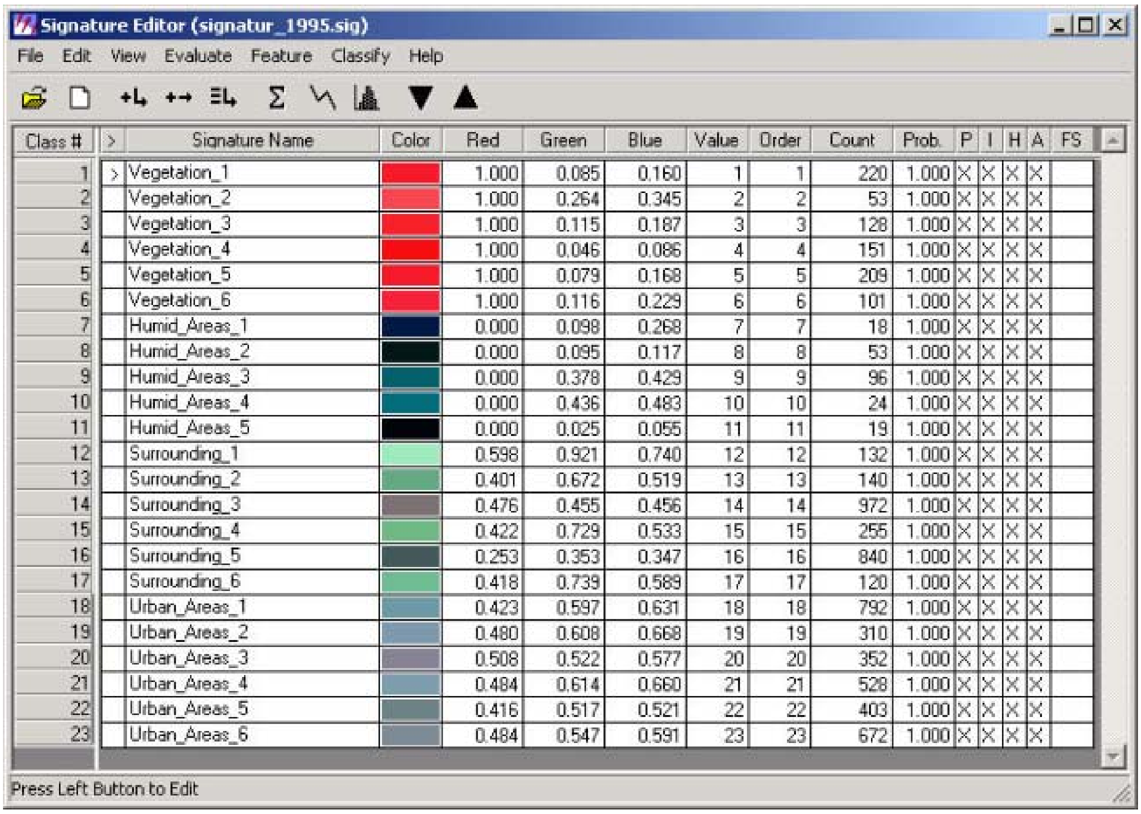


Image 34 - Phoenix metro area in the year 1995 from Landsat TM5

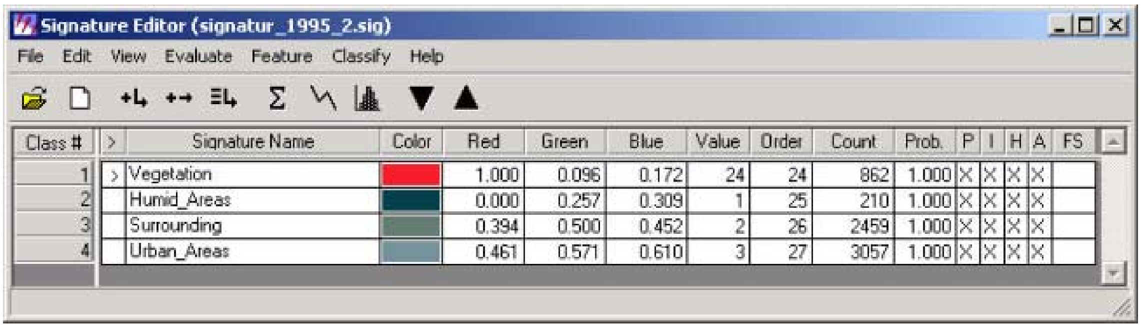
(Robert Bizaj; March 8, 2009)



Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation_1		1.000	0.085	0.160	1	1	220	1.000	X	X	X	X	
2		Vegetation_2		1.000	0.264	0.345	2	2	53	1.000	X	X	X	X	
3		Vegetation_3		1.000	0.115	0.187	3	3	128	1.000	X	X	X	X	
4		Vegetation_4		1.000	0.046	0.086	4	4	151	1.000	X	X	X	X	
5		Vegetation_5		1.000	0.079	0.168	5	5	209	1.000	X	X	X	X	
6		Vegetation_6		1.000	0.116	0.229	6	6	101	1.000	X	X	X	X	
7		Humid_Areas_1		0.000	0.098	0.268	7	7	18	1.000	X	X	X	X	
8		Humid_Areas_2		0.000	0.095	0.117	8	8	53	1.000	X	X	X	X	
9		Humid_Areas_3		0.000	0.378	0.429	9	9	96	1.000	X	X	X	X	
10		Humid_Areas_4		0.000	0.436	0.483	10	10	24	1.000	X	X	X	X	
11		Humid_Areas_5		0.000	0.025	0.055	11	11	19	1.000	X	X	X	X	
12		Surrounding_1		0.598	0.921	0.740	12	12	132	1.000	X	X	X	X	
13		Surrounding_2		0.401	0.672	0.519	13	13	140	1.000	X	X	X	X	
14		Surrounding_3		0.476	0.455	0.456	14	14	972	1.000	X	X	X	X	
15		Surrounding_4		0.422	0.729	0.533	15	15	255	1.000	X	X	X	X	
16		Surrounding_5		0.253	0.353	0.347	16	16	840	1.000	X	X	X	X	
17		Surrounding_6		0.418	0.739	0.589	17	17	120	1.000	X	X	X	X	
18		Urban_Areas_1		0.423	0.597	0.631	18	18	792	1.000	X	X	X	X	
19		Urban_Areas_2		0.480	0.608	0.668	19	19	310	1.000	X	X	X	X	
20		Urban_Areas_3		0.508	0.522	0.577	20	20	352	1.000	X	X	X	X	
21		Urban_Areas_4		0.484	0.614	0.660	21	21	528	1.000	X	X	X	X	
22		Urban_Areas_5		0.416	0.517	0.521	22	22	403	1.000	X	X	X	X	
23		Urban_Areas_6		0.484	0.547	0.591	23	23	672	1.000	X	X	X	X	

Image 35 - Landsat TM 5 - 1995, Signature Editor

(Robert Bizaj; March 8, 2009)



Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation		1.000	0.096	0.172	24	24	862	1.000	X	X	X	X	
2		Humid_Areas		0.000	0.257	0.309	1	25	210	1.000	X	X	X	X	
3		Surrounding		0.394	0.500	0.452	2	26	2459	1.000	X	X	X	X	
4		Urban_Areas		0.461	0.571	0.610	3	27	3057	1.000	X	X	X	X	

Image 36 - Landsat TM 5 - 1995, Signature Editor

(Robert Bizaj; March 8, 2009)

The spatial resolution compared to the ASTER image from the last classification decreased at the Landsat TM5 already to 30 meters. The older the image capture technology in the satellite is the more and more difficult for the GIS operator of the image to select the area of interest such as the river or other small features very precisely.

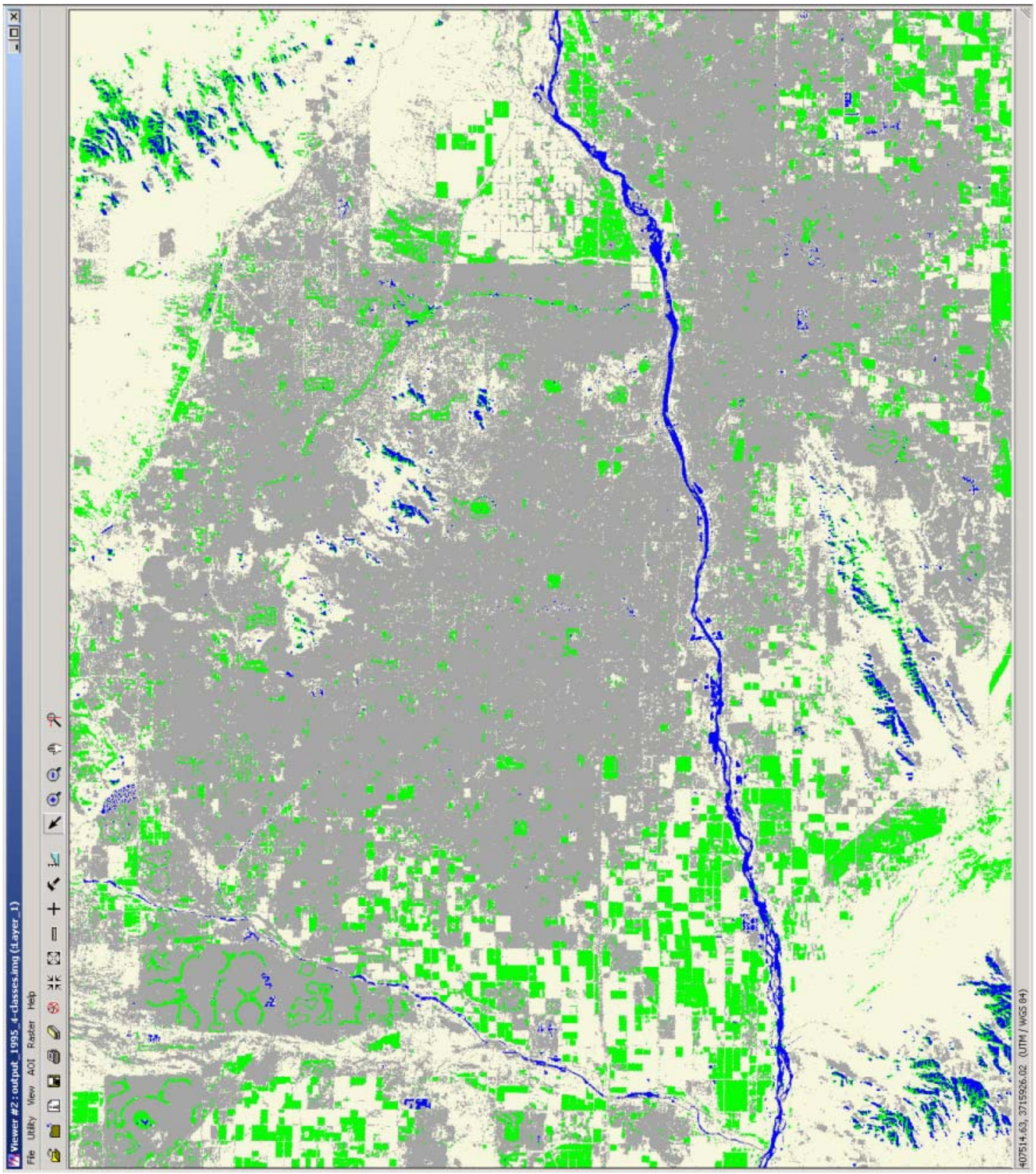


Image 37 - Classification result, Landsat TM5 1995

(Robert Bizaj; March 8, 2009)

Class Number	Class Name
3	Urban Areas
1	Humid Areas
2	Surrounding
24	Vegetation

Table 31 - Class names and numbers after merging; Landsat TM 1995

(Robert Bizaj; March 8, 2009)

3.6.1.3 Landsat TM 5, 1985

Band combinations: R-G-B | 4-3-2

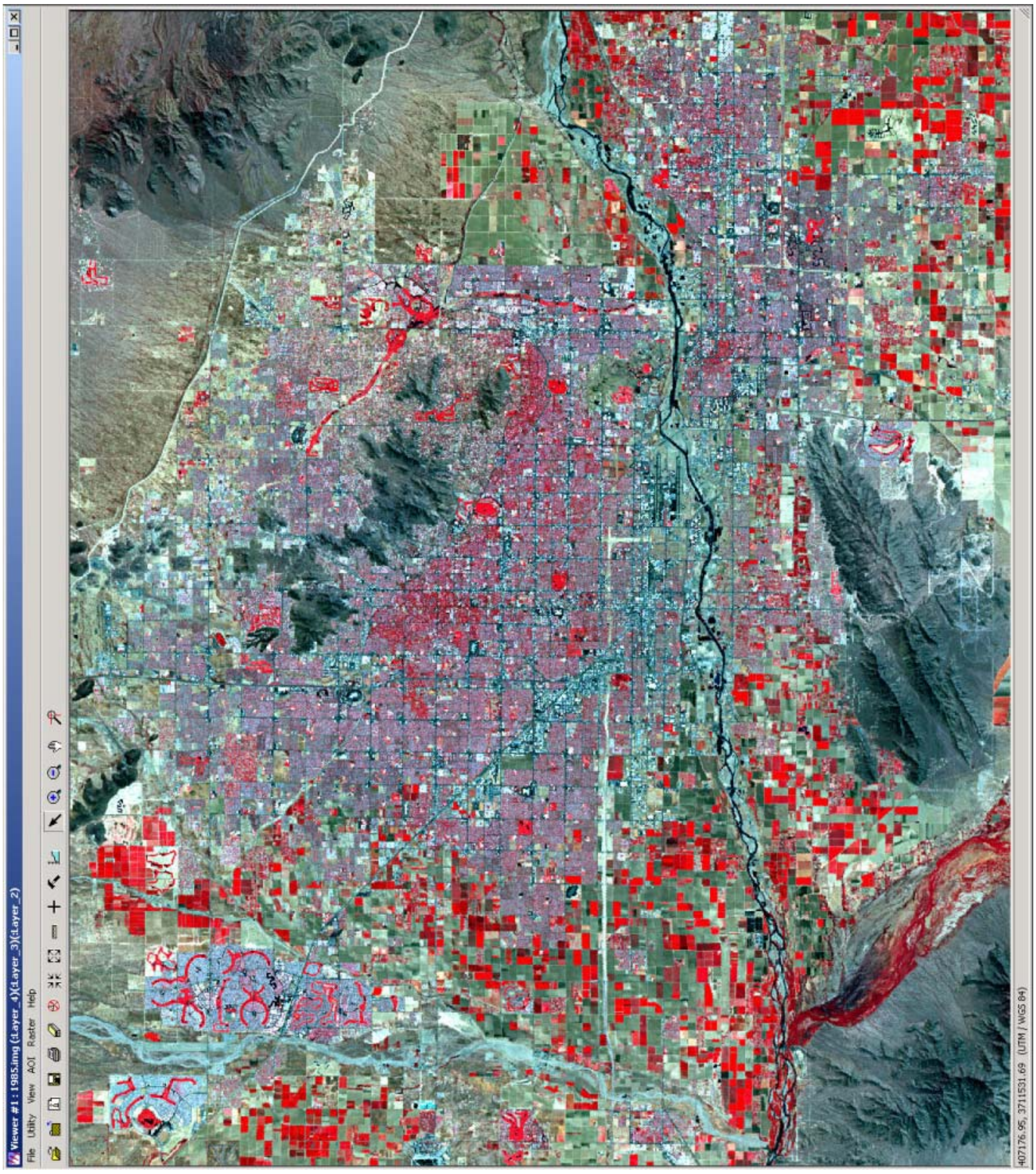
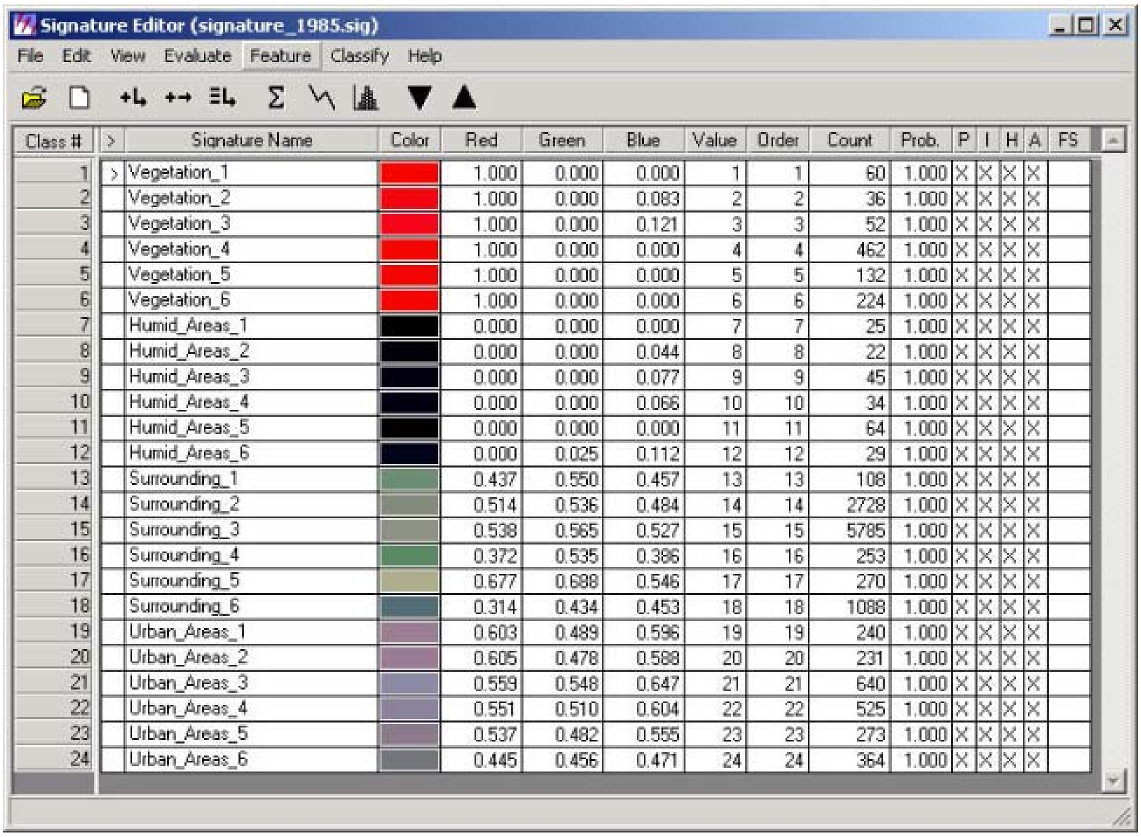


Image 38 - Phoenix metro area in the year 1975 from Landsat TM5

(Robert Bizaj; March 8, 2009)



Signature Editor (signature_1985.sig)

File Edit View Evaluate Feature Classify Help

Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation_1		1.000	0.000	0.000	1	1	60	1.000	X	X	X	X	
2		Vegetation_2		1.000	0.000	0.083	2	2	36	1.000	X	X	X	X	
3		Vegetation_3		1.000	0.000	0.121	3	3	52	1.000	X	X	X	X	
4		Vegetation_4		1.000	0.000	0.000	4	4	462	1.000	X	X	X	X	
5		Vegetation_5		1.000	0.000	0.000	5	5	132	1.000	X	X	X	X	
6		Vegetation_6		1.000	0.000	0.000	6	6	224	1.000	X	X	X	X	
7		Humid_Areas_1		0.000	0.000	0.000	7	7	25	1.000	X	X	X	X	
8		Humid_Areas_2		0.000	0.000	0.044	8	8	22	1.000	X	X	X	X	
9		Humid_Areas_3		0.000	0.000	0.077	9	9	45	1.000	X	X	X	X	
10		Humid_Areas_4		0.000	0.000	0.066	10	10	34	1.000	X	X	X	X	
11		Humid_Areas_5		0.000	0.000	0.000	11	11	64	1.000	X	X	X	X	
12		Humid_Areas_6		0.000	0.025	0.112	12	12	29	1.000	X	X	X	X	
13		Surrounding_1		0.437	0.550	0.457	13	13	108	1.000	X	X	X	X	
14		Surrounding_2		0.514	0.536	0.484	14	14	2728	1.000	X	X	X	X	
15		Surrounding_3		0.538	0.565	0.527	15	15	5785	1.000	X	X	X	X	
16		Surrounding_4		0.372	0.535	0.386	16	16	253	1.000	X	X	X	X	
17		Surrounding_5		0.677	0.688	0.546	17	17	270	1.000	X	X	X	X	
18		Surrounding_6		0.314	0.434	0.453	18	18	1088	1.000	X	X	X	X	
19		Urban_Areas_1		0.603	0.489	0.596	19	19	240	1.000	X	X	X	X	
20		Urban_Areas_2		0.605	0.478	0.588	20	20	231	1.000	X	X	X	X	
21		Urban_Areas_3		0.559	0.548	0.647	21	21	640	1.000	X	X	X	X	
22		Urban_Areas_4		0.551	0.510	0.604	22	22	525	1.000	X	X	X	X	
23		Urban_Areas_5		0.537	0.482	0.555	23	23	273	1.000	X	X	X	X	
24		Urban_Areas_6		0.445	0.456	0.471	24	24	364	1.000	X	X	X	X	

Image 39 - Landsat TM 5 - 1985, Signature Editor

(Robert Bizaj; March 8, 2009)

Signature Editor (signature_1985_1.sig)

File Edit View Evaluate Feature Classify Help

Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation		1.000	0.000	0.000	25	25	966	1.000	X	X	X	X	
2		Humid_Areas		0.000	0.000	0.000	1	26	219	1.000	X	X	X	X	
3		Surrounding		0.506	0.546	0.504	2	27	10232	1.000	X	X	X	X	
4		Urban_Areas		0.546	0.503	0.587	3	28	2273	1.000	X	X	X	X	

Press Left Button to Place Marker

Image 40 - Landsat TM 5 - 1985, Signature Editor

(Robert Bizaj; March 8, 2009)

For the training areas it was always very difficult to get a spectrally pure and very clean AOI. Contaminated AOI with other spectral influences have as a consequence a very bad classification. Features appear on locations where they should not be recognized - the whole results are poor and in the most cases unusable for an exactly evaluation.

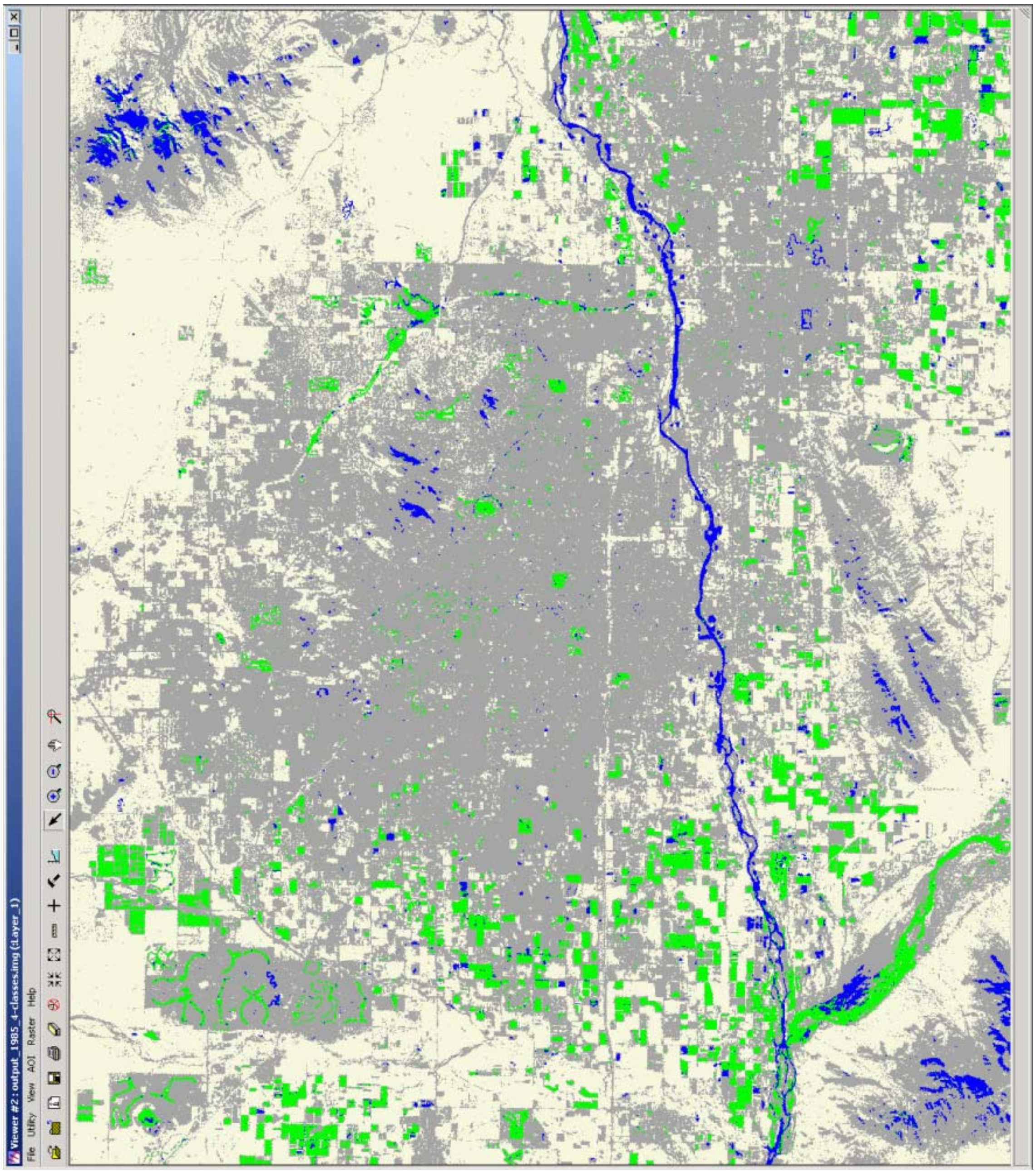


Image 41 - Classification result, Landsat TM5 1985

(Robert Bizaj; March 8, 2009)

Class Number	Class Name
3	Urban Areas
1	Humid Areas
2	Surrounding
25	Vegetation

Table 32 - Class names and numbers after merging; Landsat TM 1985

(Robert Bizaj; March 8, 2009)

3.6.1.4 Landsat MSS, 1973

Band combinations: R-G-B | 4-2-1

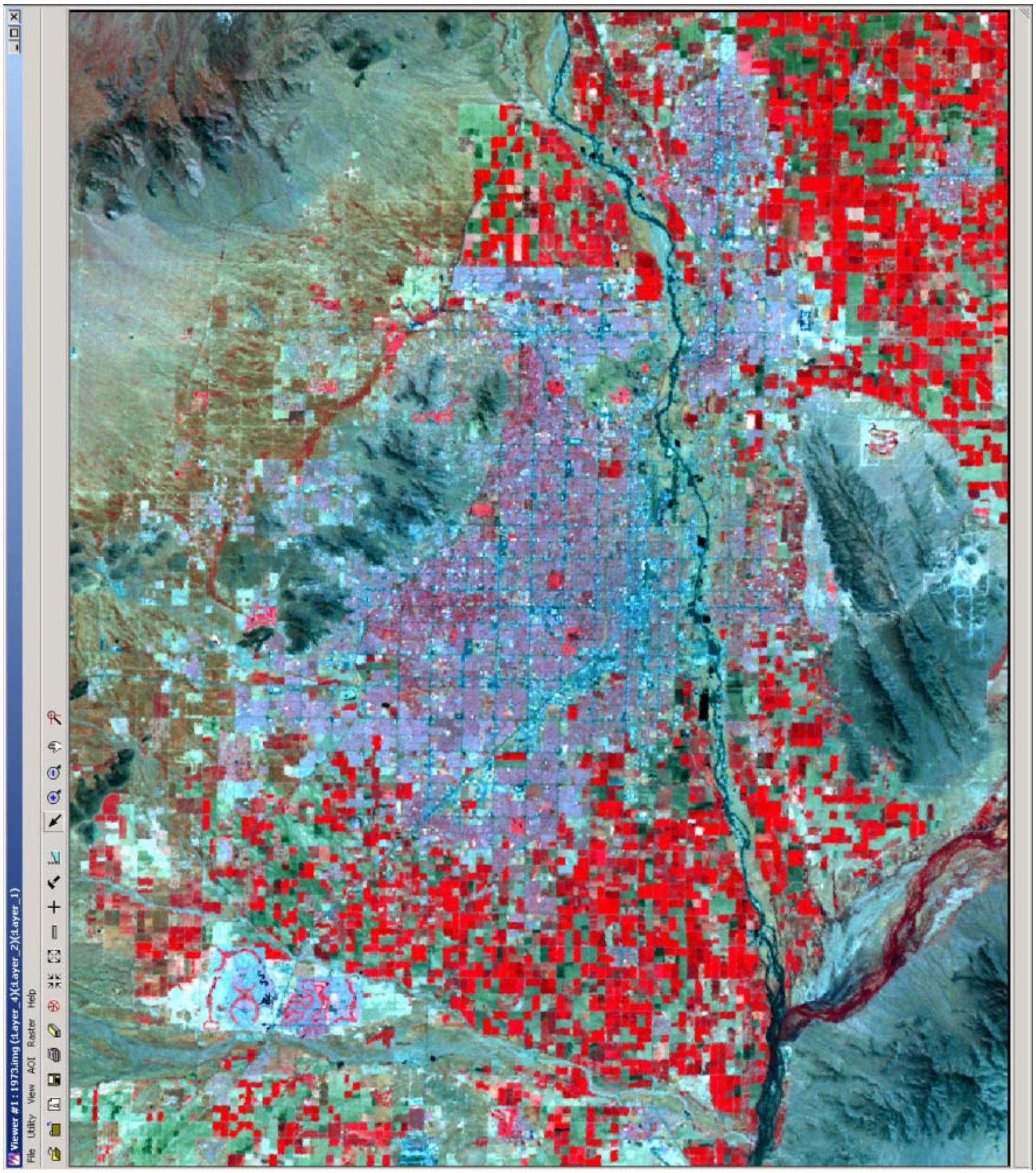
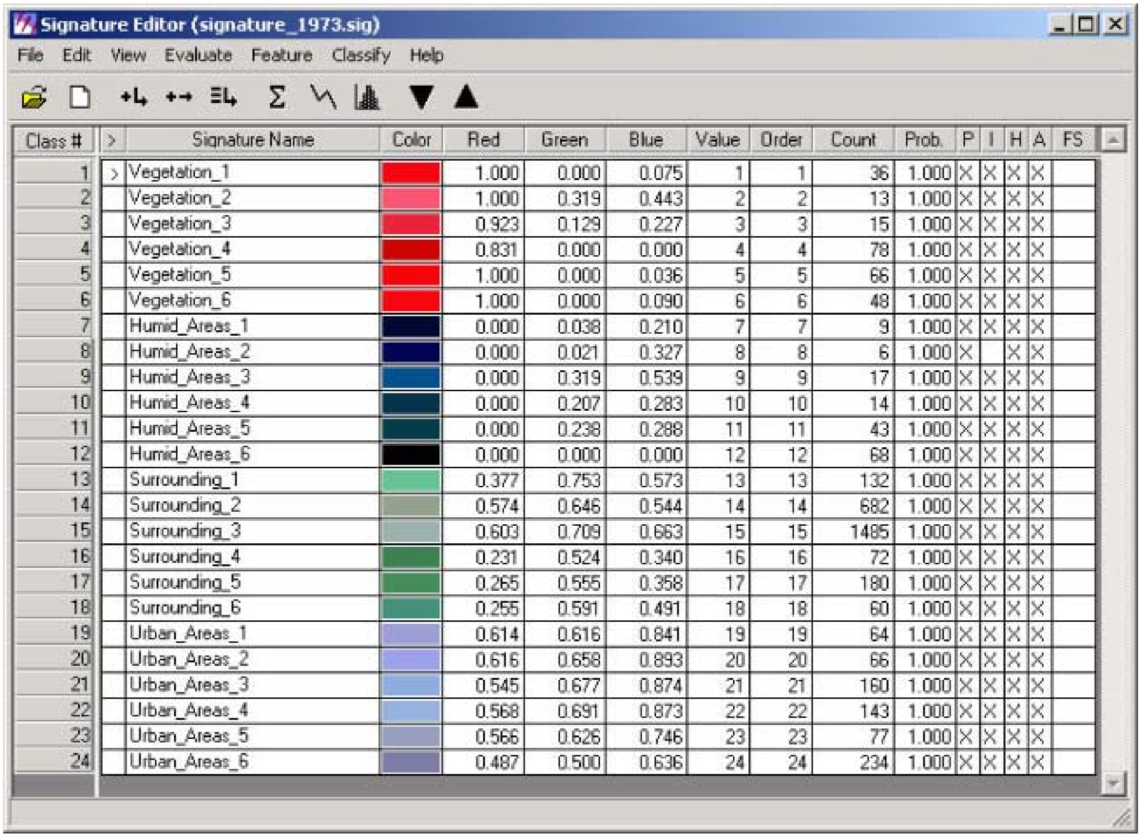


Image 42 - Phoenix metro area in the year 1973 from Landsat MSS

(Robert Bizaj; March 8, 2009)


Signature Editor (signature_1973.sig)

File Edit View Evaluate Feature Classify Help

Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation_1		1.000	0.000	0.075	1	1	36	1.000	X	X	X	X	
2		Vegetation_2		1.000	0.319	0.443	2	2	13	1.000	X	X	X	X	
3		Vegetation_3		0.923	0.129	0.227	3	3	15	1.000	X	X	X	X	
4		Vegetation_4		0.831	0.000	0.000	4	4	78	1.000	X	X	X	X	
5		Vegetation_5		1.000	0.000	0.036	5	5	66	1.000	X	X	X	X	
6		Vegetation_6		1.000	0.000	0.090	6	6	48	1.000	X	X	X	X	
7		Humid_Areas_1		0.000	0.038	0.210	7	7	9	1.000	X	X	X	X	
8		Humid_Areas_2		0.000	0.021	0.327	8	8	6	1.000	X		X	X	
9		Humid_Areas_3		0.000	0.319	0.539	9	9	17	1.000	X	X	X	X	
10		Humid_Areas_4		0.000	0.207	0.283	10	10	14	1.000	X	X	X	X	
11		Humid_Areas_5		0.000	0.238	0.288	11	11	43	1.000	X	X	X	X	
12		Humid_Areas_6		0.000	0.000	0.000	12	12	68	1.000	X	X	X	X	
13		Surrounding_1		0.377	0.753	0.573	13	13	132	1.000	X	X	X	X	
14		Surrounding_2		0.574	0.646	0.544	14	14	682	1.000	X	X	X	X	
15		Surrounding_3		0.603	0.709	0.663	15	15	1485	1.000	X	X	X	X	
16		Surrounding_4		0.231	0.524	0.340	16	16	72	1.000	X	X	X	X	
17		Surrounding_5		0.265	0.555	0.358	17	17	180	1.000	X	X	X	X	
18		Surrounding_6		0.255	0.591	0.491	18	18	60	1.000	X	X	X	X	
19		Urban_Areas_1		0.614	0.616	0.841	19	19	64	1.000	X	X	X	X	
20		Urban_Areas_2		0.616	0.658	0.893	20	20	66	1.000	X	X	X	X	
21		Urban_Areas_3		0.545	0.677	0.874	21	21	160	1.000	X	X	X	X	
22		Urban_Areas_4		0.568	0.691	0.873	22	22	143	1.000	X	X	X	X	
23		Urban_Areas_5		0.566	0.626	0.746	23	23	77	1.000	X	X	X	X	
24		Urban_Areas_6		0.487	0.500	0.636	24	24	234	1.000	X	X	X	X	

Image 43 - Landsat MSS - 1973, Signature Editor

(Robert Bizaj; March 8, 2009)


Signature Editor (signature_1973_1.sig)

File Edit View Evaluate Feature Classify Help

Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	>	Vegetation		1.000	0.000	0.071	25	25	256	1.000	X	X	X	X	
2		Humid_Areas		0.000	0.049	0.128	1	26	157	1.000	X	X	X	X	
3		Surrounding		0.542	0.676	0.594	2	27	2611	1.000	X	X	X	X	
4		Urban_Areas		0.545	0.612	0.785	3	28	744	1.000	X	X	X	X	

Image 44 - Landsat MSS - 1973, Signature Editor

(Robert Bizaj; March 8, 2009)

According to the United States Geological Survey the Landsat MSS sensors have a pixel size of 57 meters x 79 meters (http://landsat.usgs.gov/about_landsat1.php; April 19, 2009).

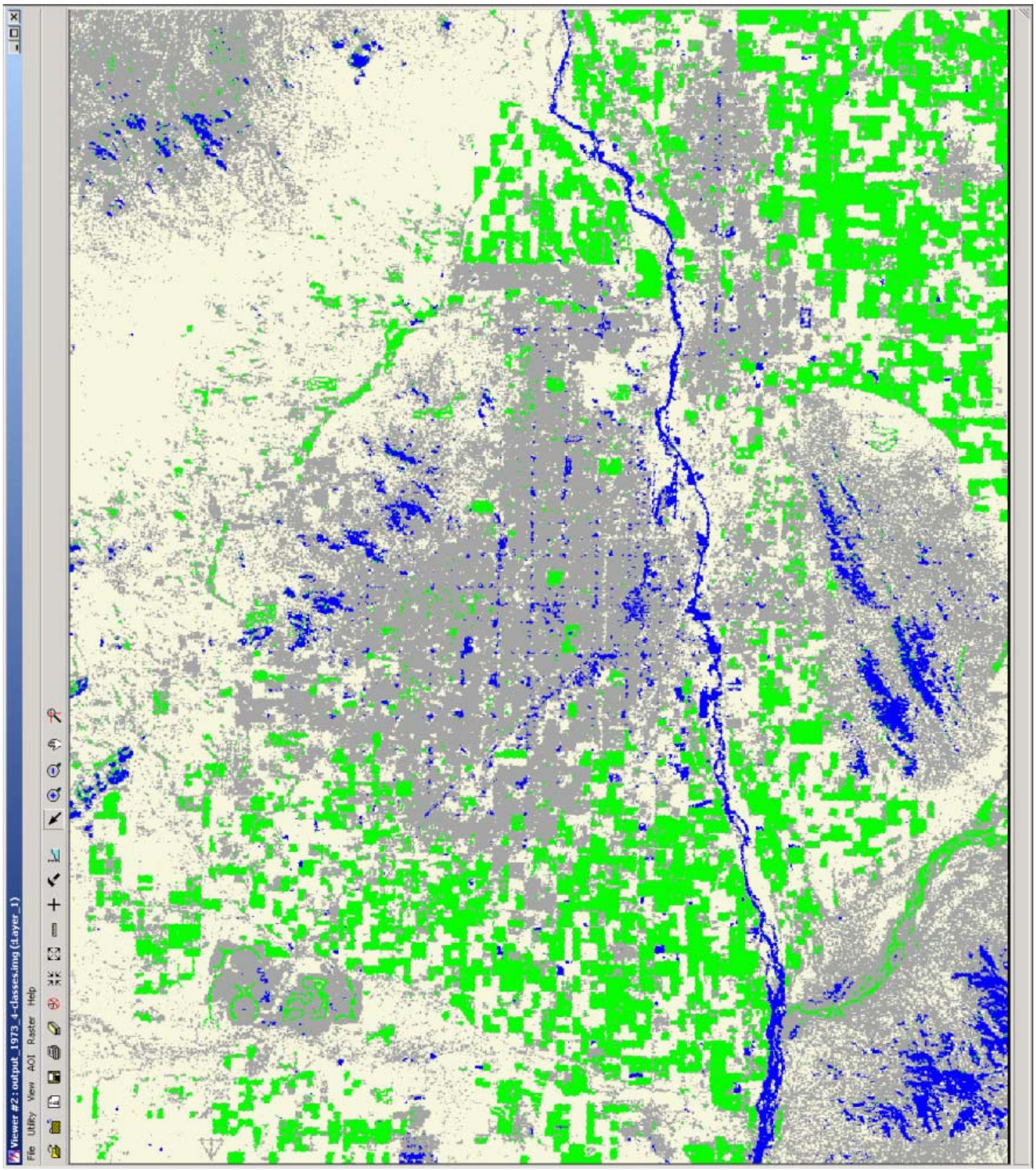


Image 45 - Classification result, Landsat MSS 1973

(Robert Bizaj; March 8, 2009)

Class Number	Class Name
3	Urban Areas
1	Humid Areas
2	Surrounding
25	Vegetation

Table 33 - Class names and numbers after merging; Landsat MSS 1973

(Robert Bizaj; March 8, 2009)

3.6.1.5 Quality Validation

For this reason two reports, the “Contingency Matrix” and the “Accuracy Assessment” reports were generated which are shown in chapter 7. The outcome of these reports was that the classification was performed with a quality which is acceptable for this work.

Dataset	Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
ASTER 2003	Unclassified	0	0	0	---	---
	Urban_Area	133	169	131	98.50%	77.51%
	Humid_Area	12	9	9	75.00%	100.00%
	Surrounding	73	48	45	61.64%	93.75%
	Vegetation	38	30	30	78.95%	100.00%
	Totals	256	256	215		
	Overall Classification Accuracy = 83.98%					
Landsat TM 1995	Unclassified	0	0	0	---	---
	Humid_Areas	14	13	13	92.86%	100.00%
	Surrounding	88	83	78	88.64%	93.98%
	Urban_Areas	117	127	114	97.44%	89.76%
	Vegetation	37	33	32	86.49%	96.97%
	Totals	256	256	237		
	Overall Classification Accuracy = 92.58%					
Landsat TM 1985	Unclassified	0	0	0	---	---
	Humid_Areas	9	10	9	100.00%	90.00%
	Surrounding	115	95	87	75.65%	91.58%
	Urban_Areas	100	135	94	94.00%	69.63%
	Vegetation	31	16	16	51.61%	100.00%
	Totals	255	256	206		
	Overall Classification Accuracy = 80.47%					
Landsat MSS 1973	Unclassified	0	0	0	---	---
	Humid_Areas	17	17	17	100.00%	100.00%
	Surrounding	126	115	102	80.95%	88.70%
	Urban_Areas	66	81	55	83.33%	67.90%
	Vegetation	47	43	42	89.36%	97.67%
	Totals	256	256	216		
	Overall Classification Accuracy = 84.38%					

Table 34 - Excerpt from the Accuracy Assessment Reports of each dataset

(Robert Bizaj; March 8, 2009)

3.6.1.6 Calculation of the area and percentage

The following steps were performed to calculate the areas and percentages of the humid and vegetation areas from the supervised classification:

Nr.	Program	Kind of work
1.	ArcGIS	The multi ring buffer and the reference rectangle were created.
2.	ERDAS	The satellite datasets were classified with a supervised classification with about 24 and later merged to 4 classes.
3.	ArcGIS	First the supervised classification was made with maximal 24 classes. After they were merged, finally remained only four. Nevertheless the originally 20 classes remained "empty" in the image file. That's why a reclassify was made in ArcGIS to remove all unimportant data. The new classes were named with "1" for the humid areas and "2" for the vegetation areas.
4.	ArcGIS	With "Raster to Polygon" they were imported into ArcGIS as a vector data.
5.	ArcGIS	An "Intersect" between the reference rectangle and the polygons were made. The result was that only the humid and vegetation areas within the rectangle remained.
6.	ArcGIS	An "Intersect" between the multi ring buffer and the polygons were made. The result was that only the humid and vegetation areas within the rectangle remained.
7.	ArcGIS	With help of the "Attribute Table" and the "Select by Attributes" function the areas were calculated: e.g.:"[Multiple_Ring_Buffer] = 100 AND [GRIDCODE] = 1" Multi Ring Buffer: 100, 300, 500 Gridcode: 1 (humid areas), 2 (vegetation areas) With the "Statistics" function on the right mouse click the selected items in the column for "Shape_Area" was summarized.
8.	Excel	Afterward a Microsoft Excel was filled with that data and the percentage was calculated (→ next tables): area_reference_rectangle….................................100% humid_areas_(within_the_reference_rectangle)…..….? area_reference_rectangle………………………...100% vegetation_(within_the_reference_rectangle)…..…….?

Table 35 - Working steps to get the areas & percentage of the interesting classes

(Robert Bizaj; March 6, 2009)

SC	Humid areas (class 1)				Vegetation (class 2)			
in km²	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500
2003	9.76	1.15	1.32	0.91	47.47	6.53	6.79	5.50
1995	20.96	1.11	2.55	3.18	121.24	18.46	19.57	12.27
1985	21.92	2.41	3.58	2.75	72.22	10.35	11.78	6.35
1973	45.45	6.11	7.23	5.28	263.74	47.47	47.82	27.33

Table 36 - Calculated areas with the Supervised Classification in km²

(Robert Bizaj; March 6, 2009)

SC	Humid areas (class 1)				Vegetation (class 2)			
in %	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500
2003	0.82	0.51	0.66	0.89	3.97	2.93	3.38	5.34
1995	1.75	0.50	1.27	3.09	10.14	8.28	9.73	11.91
1985	1.83	1.08	1.78	2.67	6.04	4.64	5.86	6.16
1973	3.80	2.74	3.59	5.13	22.07	21.29	23.78	26.52

Table 37 - Calculated areas with the Supervised Classification in percentage

(Robert Bizaj; March 6, 2009)

What do these data mean?

- By looking to the horizontal lines of each class for instance the green or red bordered rectangle in the last table it is recognizable that the differences in percent are very low and always lower than 5%.
- By comparing the values from the reference rectangles and every column of the multiple ring buffers it can be noticed, that there are no significant differences in nearer area around the Hohokam water traces. In other words there is no more "vegetation" or "humid areas" in the buffer areas than to the reference rectangle.
- There may be a trend recognizable where the humid areas and vegetation areas with ongoing years dramatically decrease (without statistical evidence).
- With help of the supervised classification the existence of the Hohokam water traces in these areas may not be confirmed nowadays.

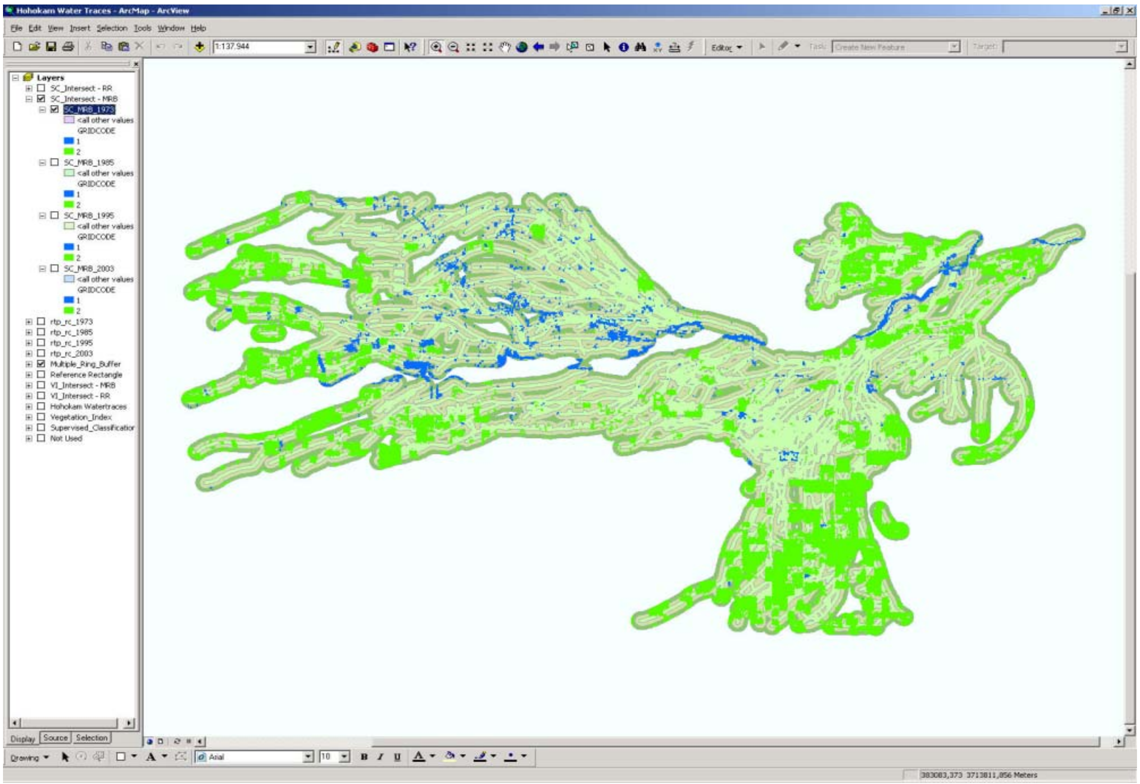


Image 46 - Intersect between MRB and investigation file, Landsat MSS 1973

(Robert Bizaj; April 14, 2009)

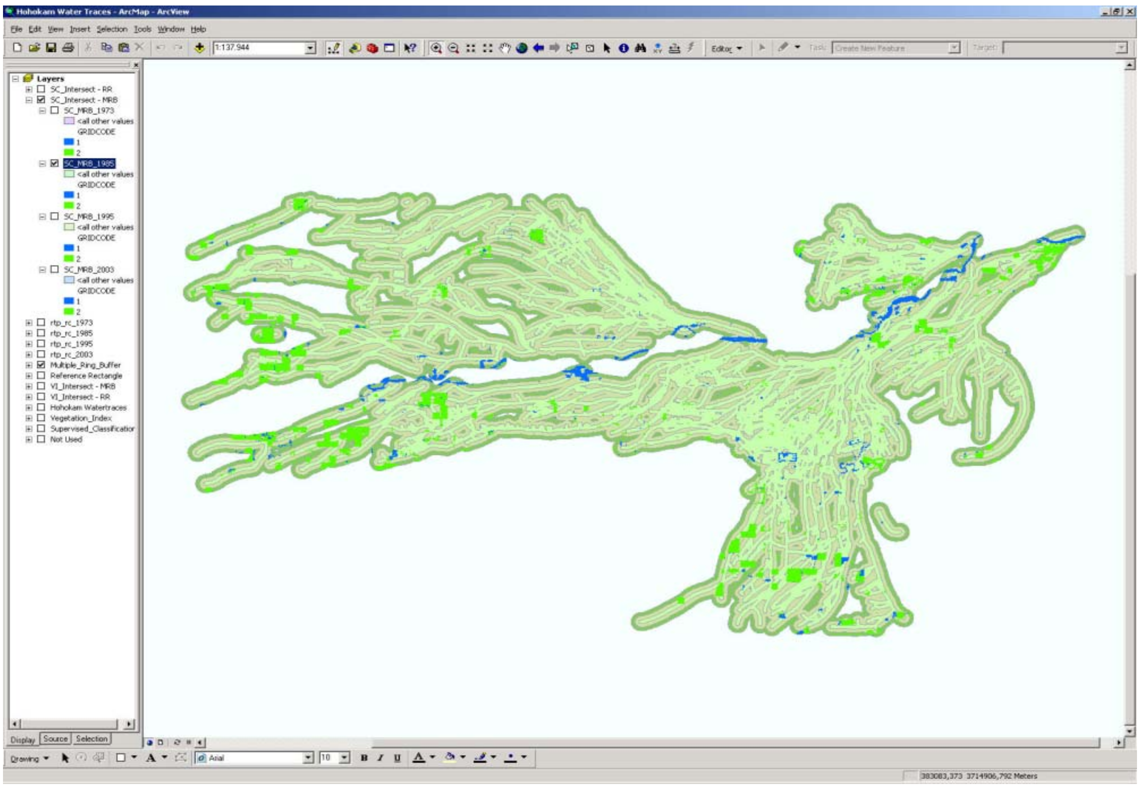


Image 47 - Intersect between MRB and investigation file, Landsat MT 1985

(Robert Bizaj; April 14, 2009)

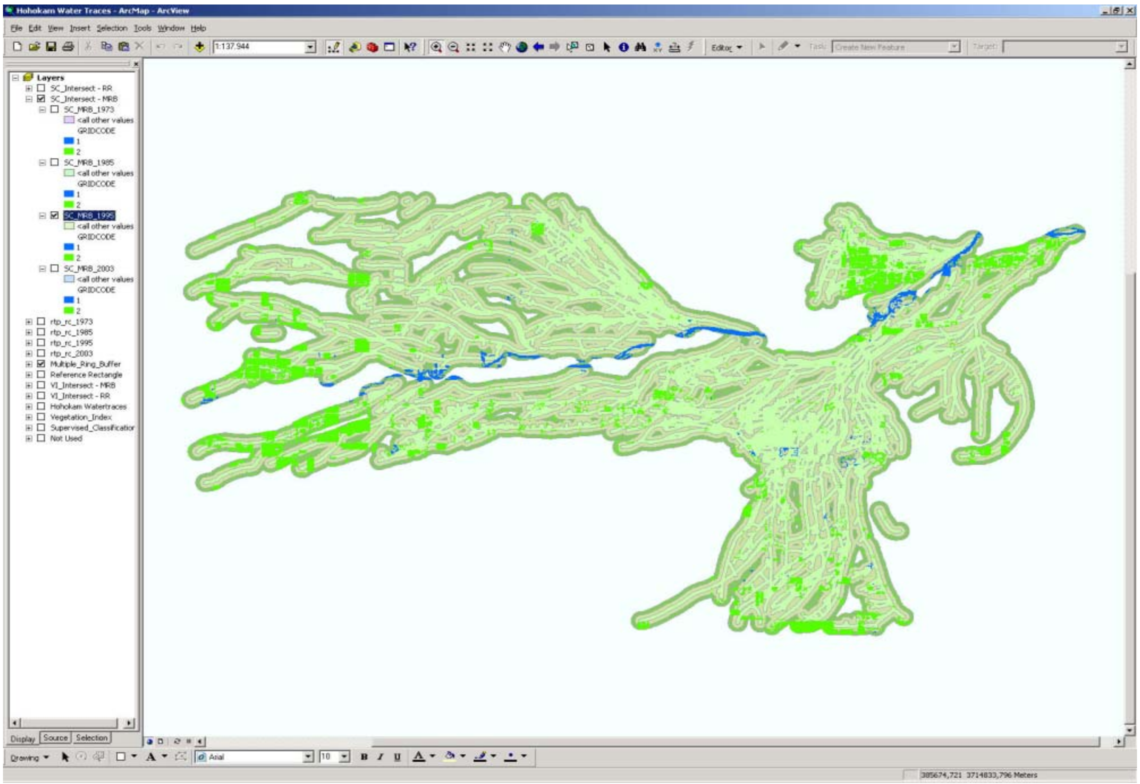


Image 48 - Intersect between MRB and investigation file, Landsat MT 1995

(Robert Bizaj; April 14, 2009)

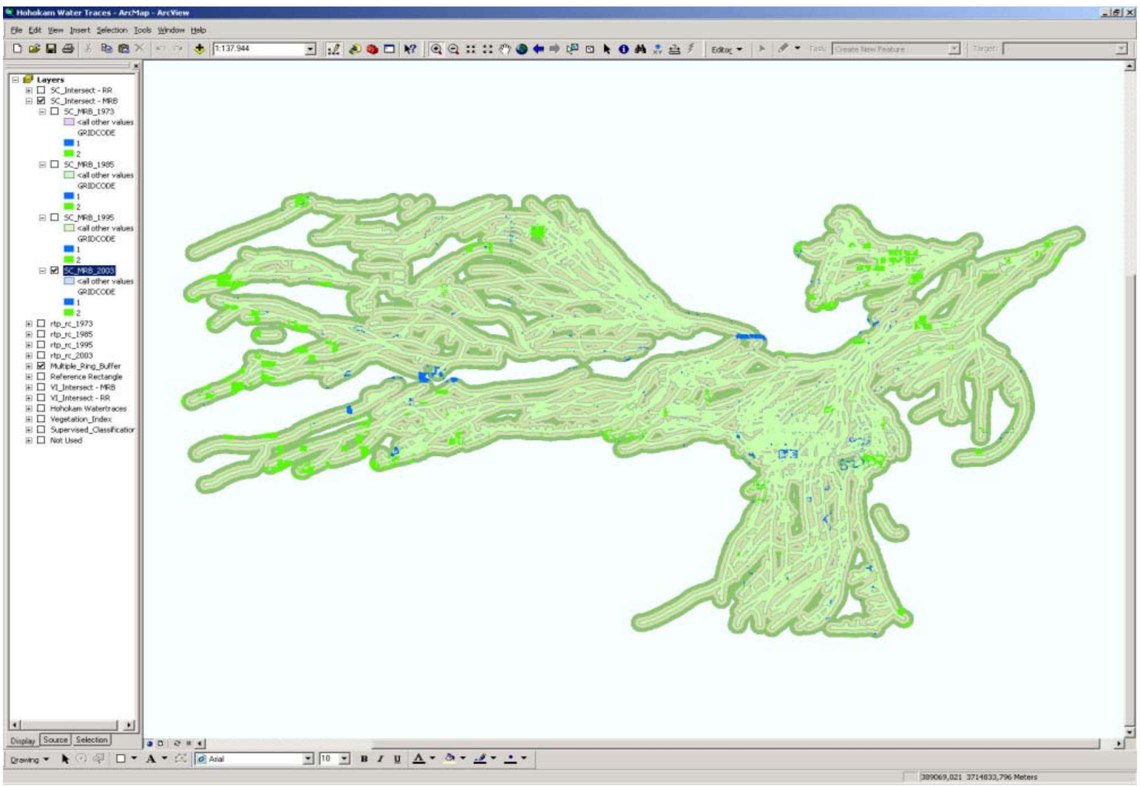


Image 49 - Intersect between MRB and investigation file, ASTER 2003

(Robert Bizaj; April 14, 2009)

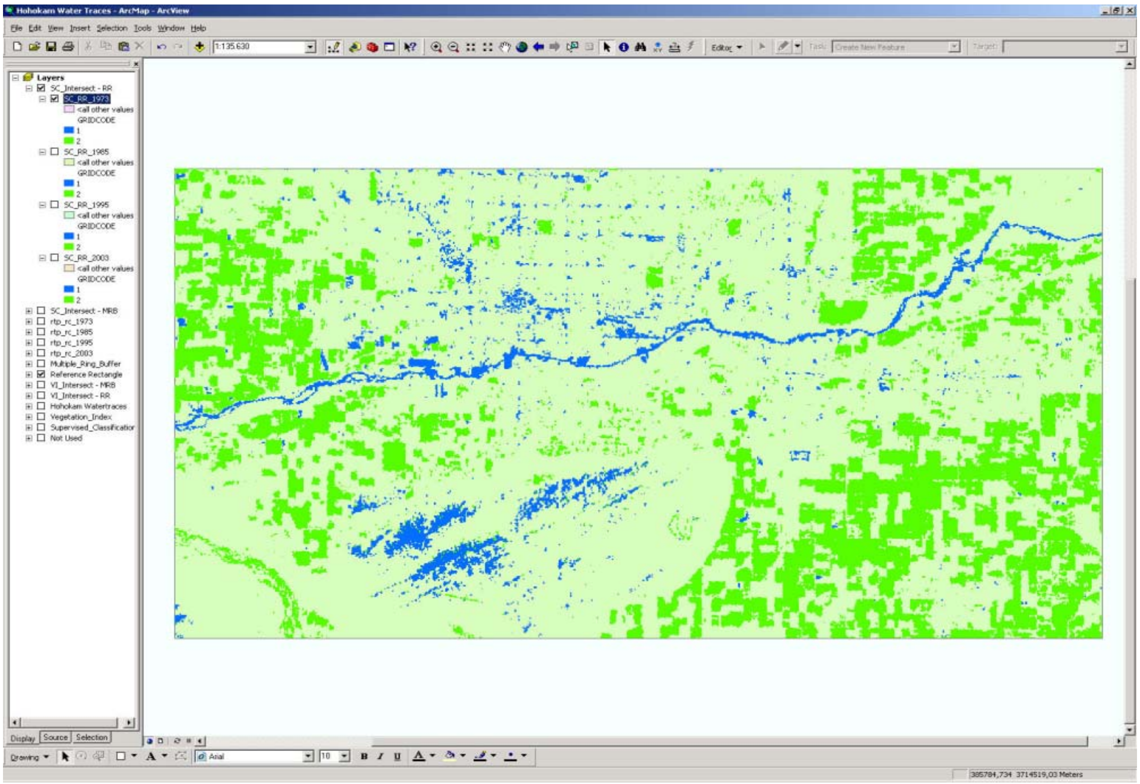


Image 50 - Intersect between rectangle and the investigation file, Landsat MSS 1973

(Robert Bizaj; April 14, 2009)

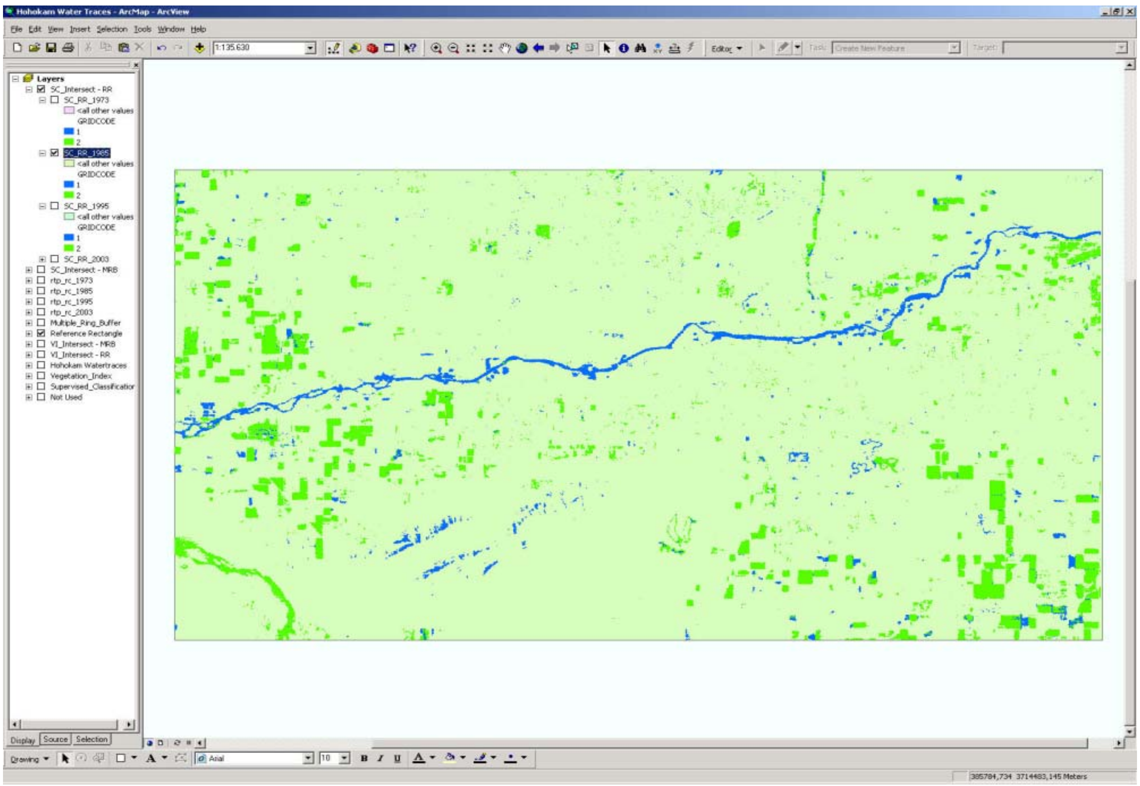


Image 51 - Intersect between rectangle and the investigation file, Landsat TM 1985

(Robert Bizaj; April 14, 2009)

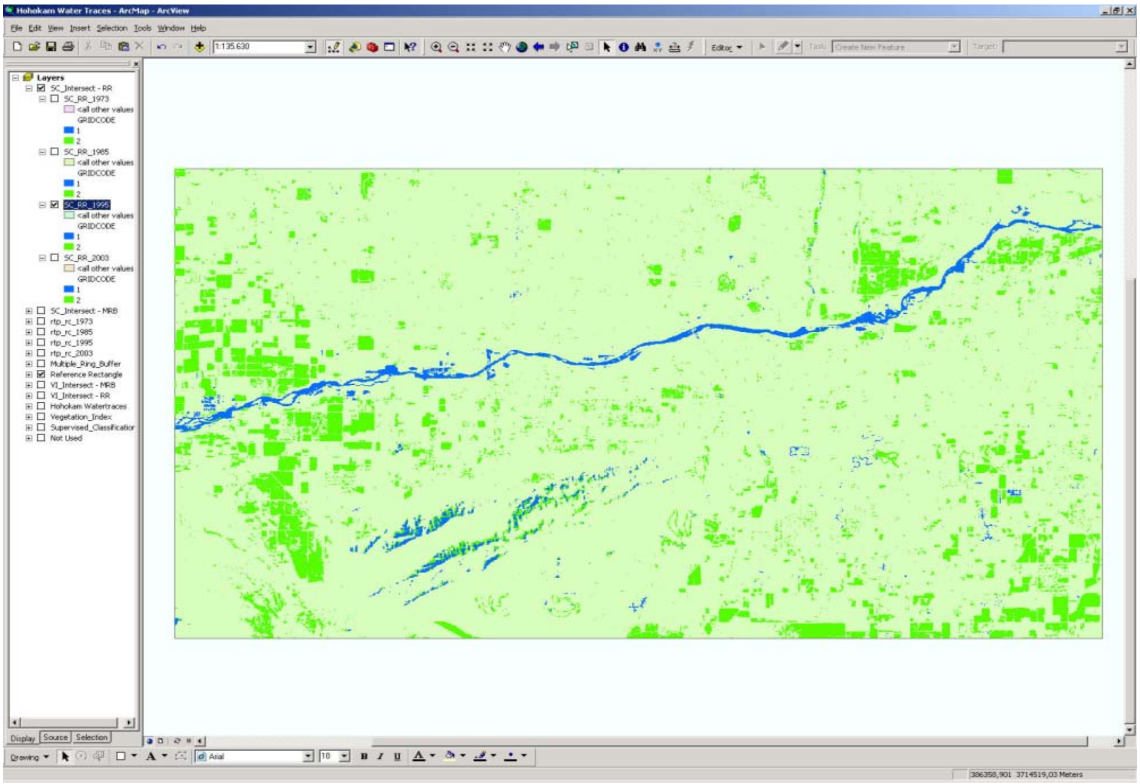


Image 52 - Intersect between rectangle and the investigation file, Landsat TM 1995

(Robert Bizaj; April 14, 2009)

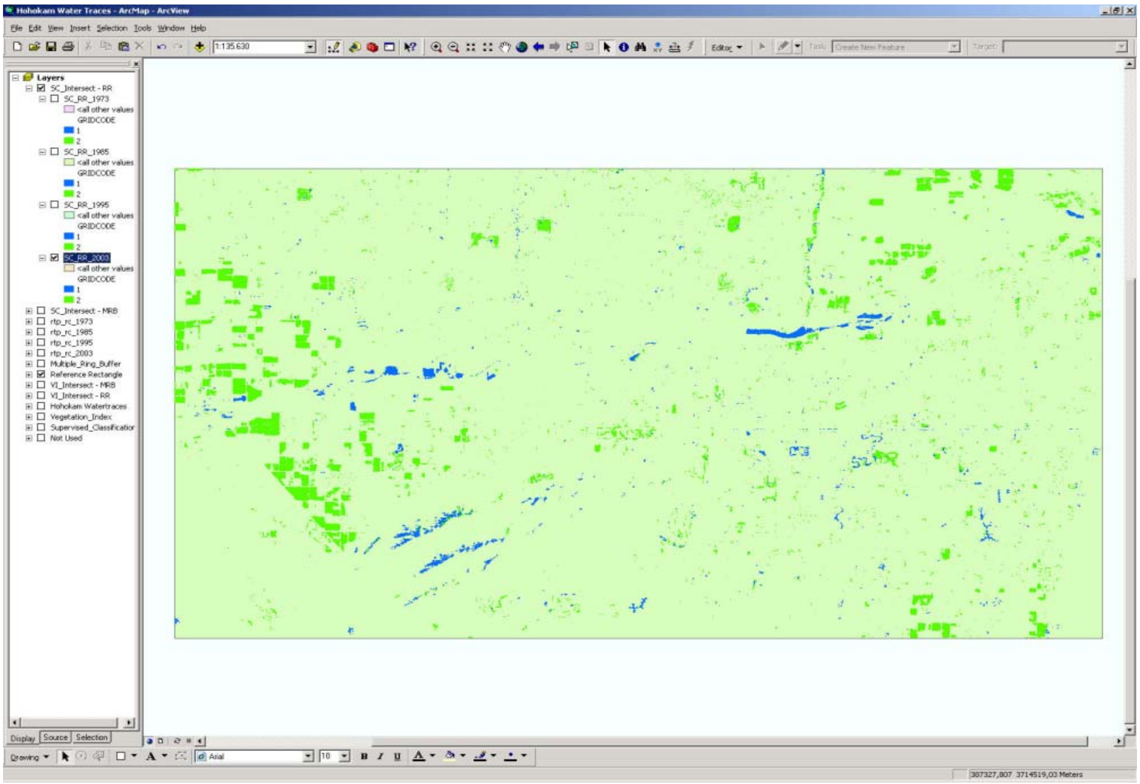


Image 53 - Intersect between rectangle and the investigation file, ASTER 2003

(Robert Bizaj; April 14, 2009)

3.6.2 Vegetation index

Nearly the same steps like in the supervised classification were made to calculate the areas and percentages from the vegetation index out.

Nr.	Program	Kind of work
1.	ArcGIS	The multi ring buffer and the reference rectangle were created.
2.	ERDAS	From all datasets the VI was calculated (already shown before).
3.	ERDAS	The panchromatic images were classified with an unsupervised classification with 20 classes.
4.	ArcGIS	They were reclassified, so all unimportant classes disappeared, only the “water & wetlands” and “vegetation” remained.
5.	ArcGIS	This dataset was still a raster images, with “Raster to Polygon” they were imported into ArcGIS to a vector file.
6.	ArcGIS	An “Intersect” between the reference rectangle and the vectorized files were made. The result was that only the humid and vegetation areas within the rectangle remained. The red color represents the class “1” which stands for water & wetlands on the other hand the bright greens are the classes “19” and “20” and stands for vegetation.
7.	ArcGIS	An “Intersect” between the multiple ring buffer and the vectorized files were made. The result was that only the humid and vegetation areas within the ring buffer remained. The red color represents the class “1” which is water & wetlands on the other hand the bright greens are the classes “19” and “20” and stands for vegetation.
8.	ArcGIS	With help of the “Attribute Table” and the “Select by Attributes” function the areas were calculated: e.g.: “[Multiple_Ring_Buffer] = 100 AND [GRIDCODE] = 1” or “Multiple_Ring_Buffer] = 300 AND [GRIDCODE] ≥ 19” Multi Ring Buffer: 100, 300, 500 Gridcode: 1 (humid areas), 2 (vegetation areas) With the “Statistics” function on the right mouse click the selected items in the column for “Shape_Area” was summarized.
9.	Excel	Afterward a Microsoft Excel was filled with that data and the percentage was calculated (→ next tables): area_reference_rectangle….................................100% humid_areas_(within_the_reference_rectangle)…….? area_reference_rectangle………………………...100% vegetation_(within_the_reference_rectangle)…..…….?

Table 38 - Working steps to get the areas (percentage) of the interesting classes

(Robert Bizaj; April 14, 2009)

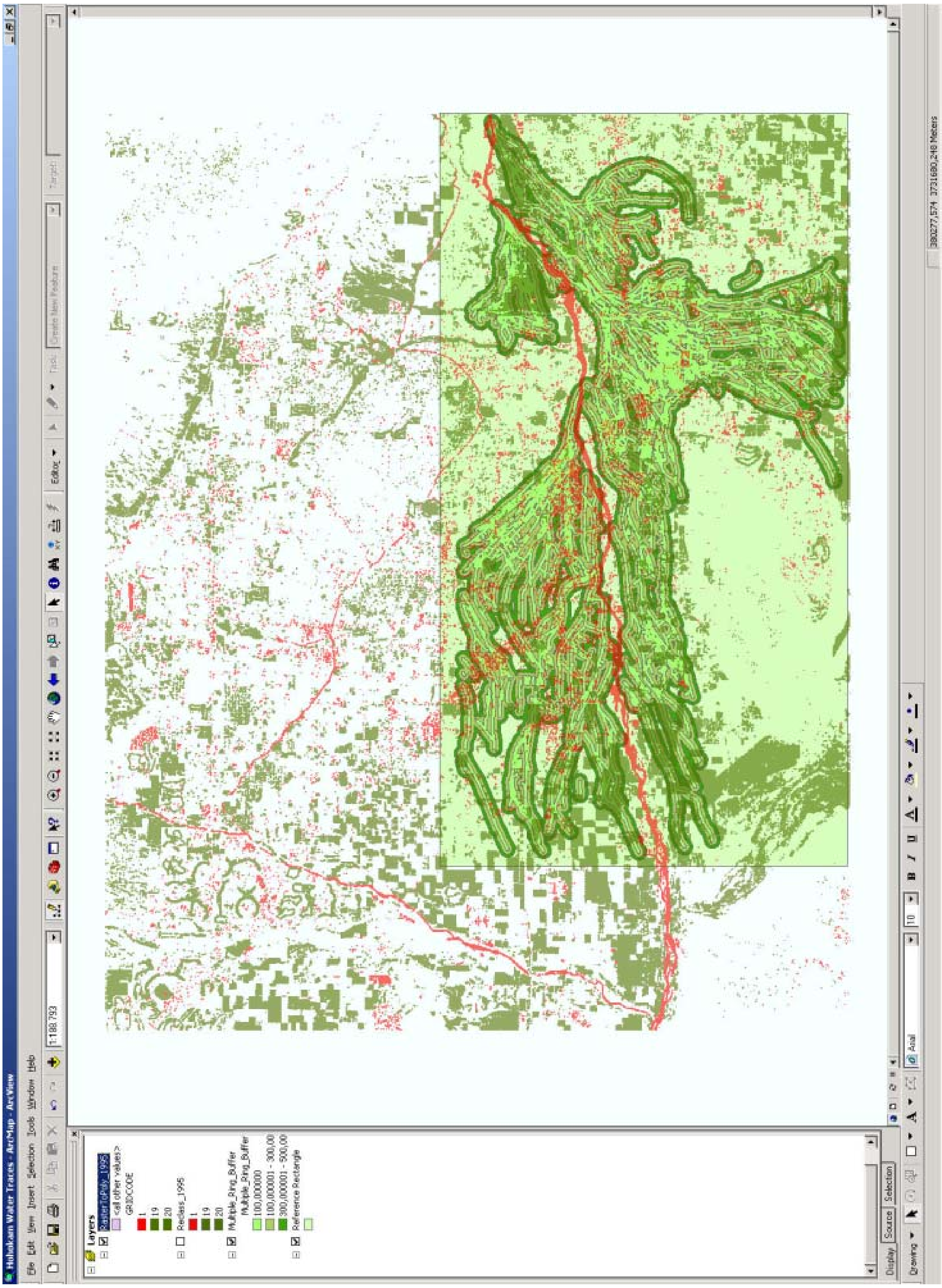


Image 54 - Overview over the work with the VI; Landsat TM 1995

(Robert Bizaj; April 14, 2009)

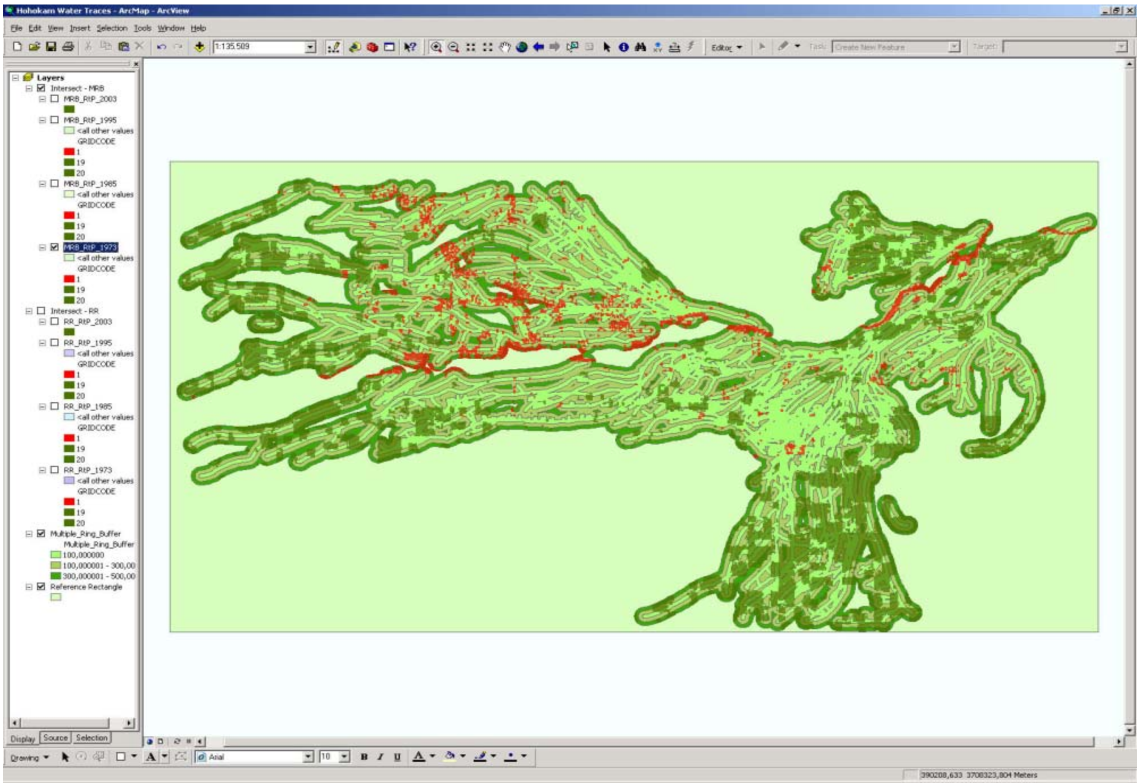


Image 55 - Intersect between MRB and investigation file, Landsat MSS 1973

(Robert Bizaj; April 14, 2009)

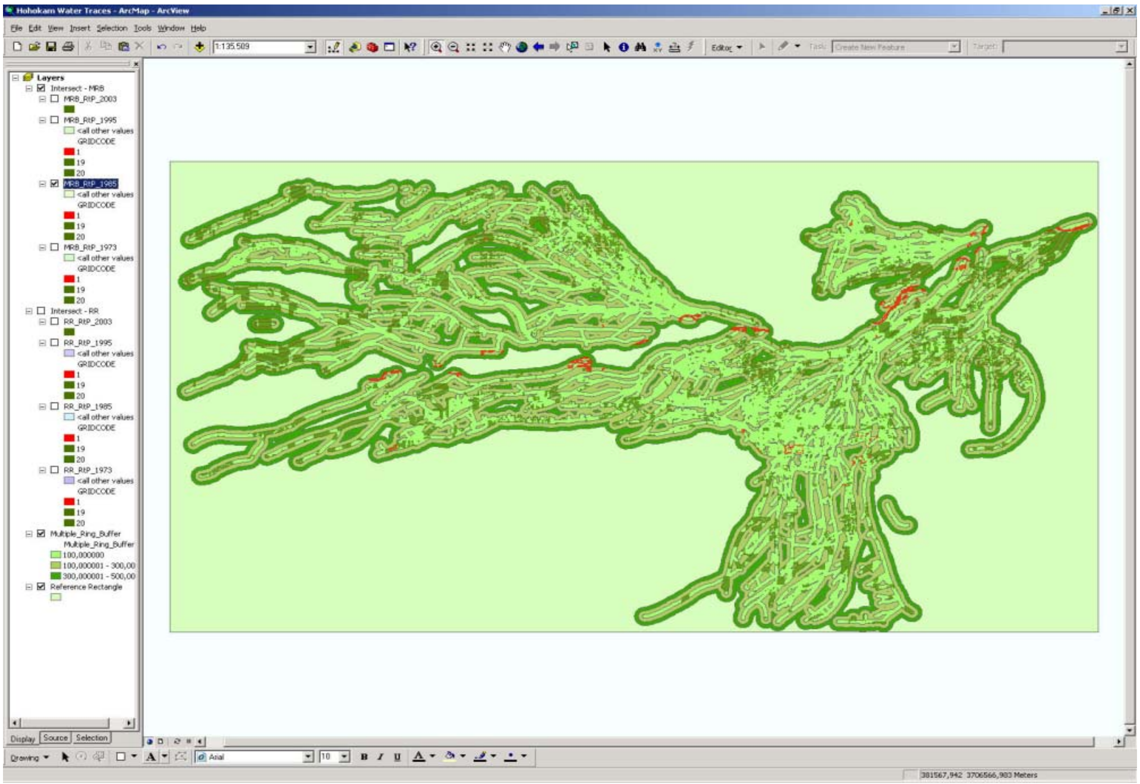


Image 56 - Intersect between MRB and investigation file, Landsat TM 1985

(Robert Bizaj; April 14, 2009)

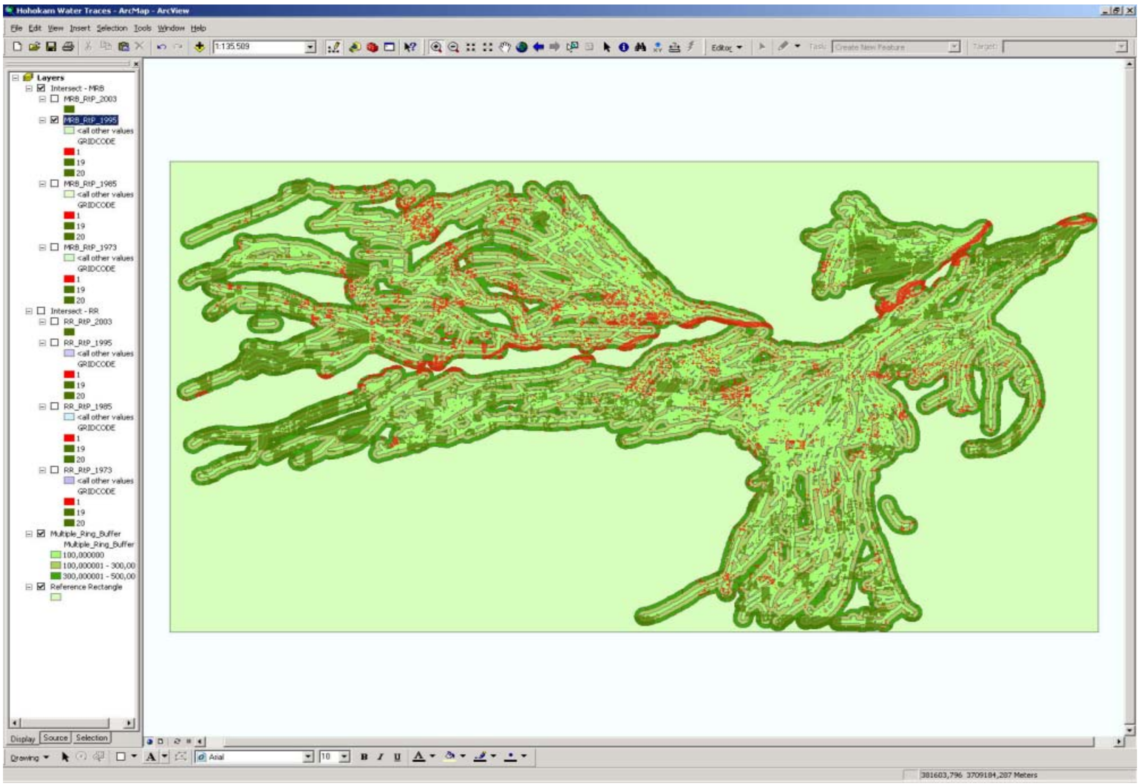


Image 57 - Intersect between MRB and investigation file, Landsat TM 1995

(Robert Bizaj; April 14, 2009)

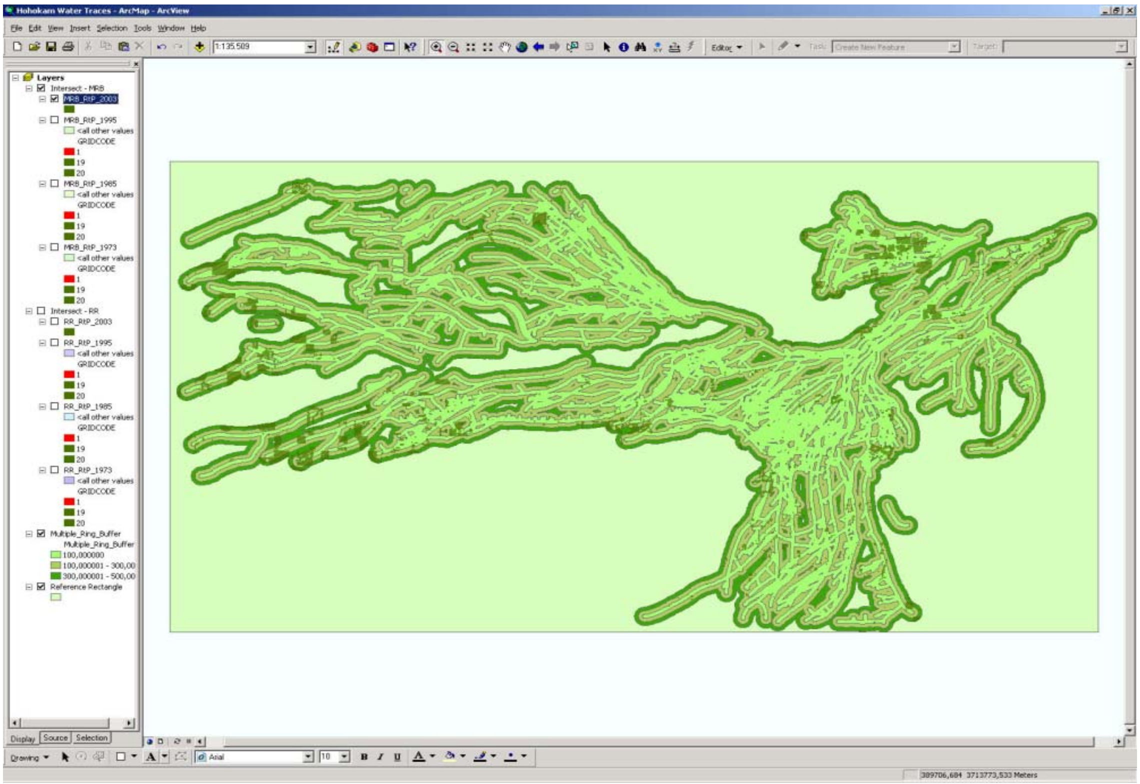


Image 58 - Intersect between MRB and investigation file, ASTER 2003

(Robert Bizaj; April 14, 2009)

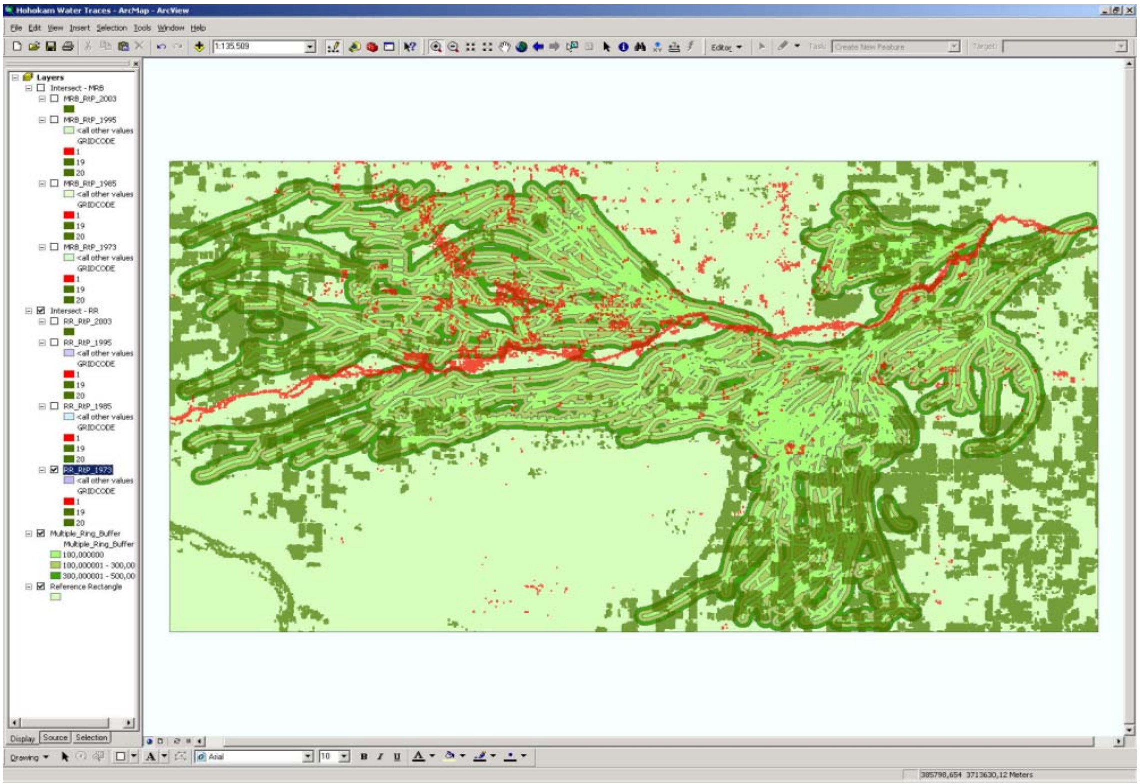


Image 59 - Intersect between the rectangle and the polygons, Landsat MSS 1973

(Robert Bizaj; April 14, 2009)

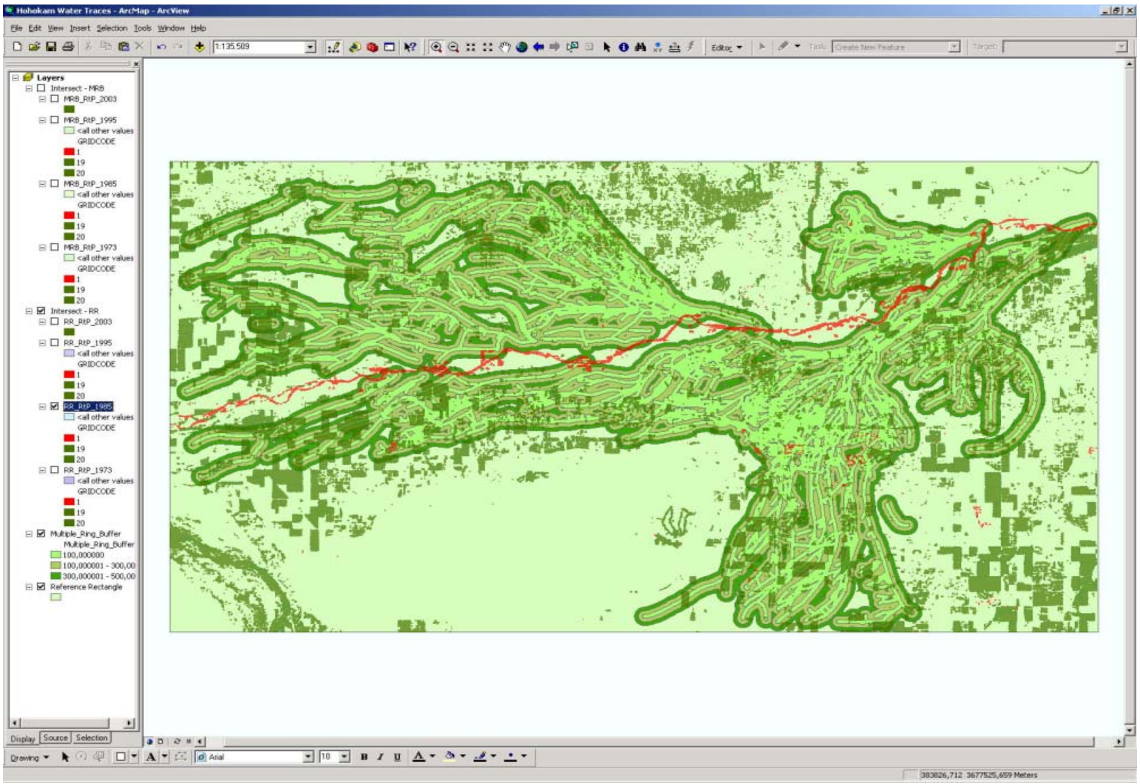


Image 60 - Intersect between the rectangle and the polygons, Landsat TM 1985

(Robert Bizaj; April 14, 2009)

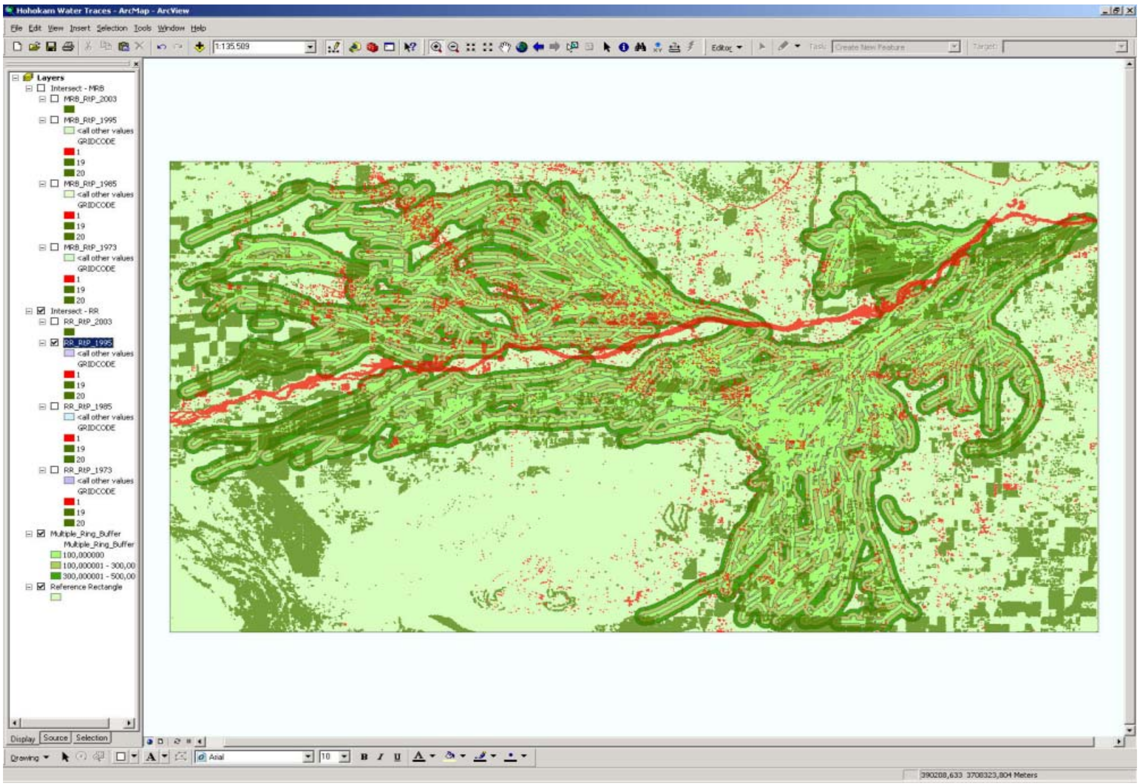


Image 61 - Intersect between rectangle and the investigation file, Landsat TM 1995

(Robert Bizaj; April 14, 2009)

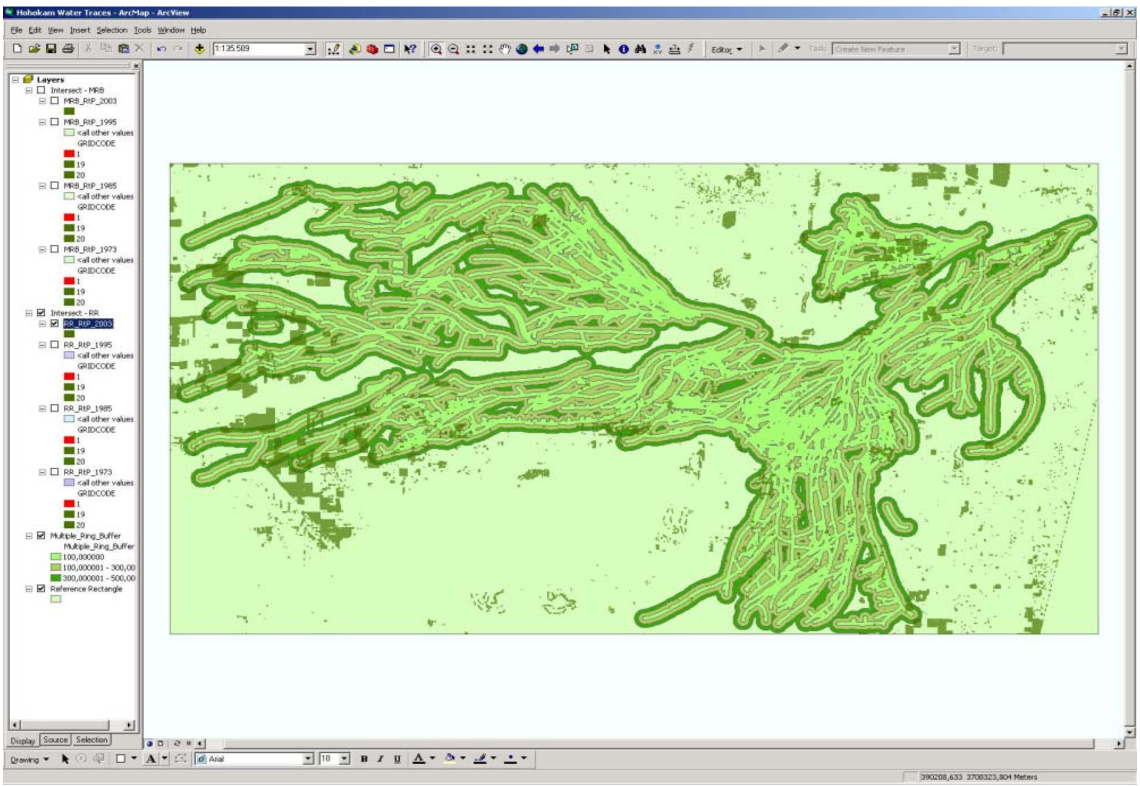


Image 62 - Intersect between rectangle and the investigation file, ASTER 2003

(Robert Bizaj; April 14, 2009)

VI	Humid areas (class 1)				Vegetation (class 19, 20)			
in km²	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500
2003	-	-	-	-	40.91	5.22	5.70	4.75
1995	29.28	4.77	6.09	4.93	149.94	22.91	23.87	14.43
1985	6.89	0.64	1.52	1.18	141.54	23.00	23.30	11.85
1973	27.67	4.92	6.54	5.56	225.29	40.82	40.53	23.66

Table 39 - Areas of the vegetation index in km²

(Robert Bizaj; April 14, 2009)

VI	Humid areas (class 1)				Vegetation (class 19, 20)			
in %	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500	Reference Rectangle	Buffer 100	Buffer 300	Buffer 500
2003	-	-	-	-	3.42	2.34	2.83	4.61
1995	2.45	2.14	3.03	4.78	12.55	10.27	11.87	14.01
1985	0.58	0.29	0.76	1.14	11.84	10.32	11.58	11.50
1973	2.32	2.21	3.25	5.39	18.85	18.31	20.15	22.97

Table 40 - Areas of the vegetation index in percentage

(Robert Bizaj; April 14, 2009)

What do these data mean?

- By comparing of the values from the reference rectangles and every column of the buffers it can be noticed, that there are no significant differences in nearer area around the water traces which means there is no more "vegetation" or "humid areas" in the buffer areas than to the reference rectangle.
- After the vegetation index was calculated from ASTER 2003, the class "vegetation" was extracted with a good quality also the black colored "humid areas" can be seen very well (→ see chapter 3.1.4.1). But it was not possible to extract this class after the unsupervised classification in a good quality. It were always more humid areas calculated than really exist. That's why no plausible data are available.
- By looking to the horizontal lines of each class for instance the green or red bordered rectangle in the last table it is recognizable that the differences in percent are very low and always lower than 5%.

4. Results and Analysis

In chapter 1.4 the hypothesis were defined. For a better understanding these points are described here again. Below each point to the table was added one row to comment the results which were found out during the investigations. All scientific questions will be commented if the expected result in the table row above were reached, the word “yes”, “no” or “partially” will be used for an easier understanding.

1. The historic water irrigations can be extracted with the mentioned remote sensing data.

- All recorded datasets allow the same quality for the detection of structures.
- That overgrown vegetation routes (as well as dried out traces covered with more or less bare desert soil) can be detected in one step.

Successfully reached when:	- the extracted traces are connected and fit more or less exactly to the prehistoric water ways over a length of several hundred meters and more.
Results of this work:	Through the circumstances that it was not possible to assign areas of interests to a class called “Hohokam water traces” (chapter 3.3) the theoretical idea has to be changed. It was necessary to dodge to concept to try to recognize water and wetland within a defined buffer zone around the Hohokam canals (chapter 3.2.1). The supervised classifications were designed to find water and wetlands, vegetations and agriculture, therefore false color image are selected (chapter 3.4.1). All things which have an “environmental green” background. By comparing the results of the thematic images from all four years (2003, 1995, 1985, 1973) no potential matches could be found with the Hohokam shape file. With the help of the reference rectangle and the multi ring buffer it was also not possible to get a better result. The differences are not greater than 5% between the buffers and the rectangle which means that a causal relation cannot be confirmed with help of the supervised classification (chapter 3.6.1.5) and the vegetation index (chapter 3.6.2). In cause of that knowledge the two sub points of that hypothesis cannot be answered in a positive way either.
	No, there were no corresponding segments of the historic water traces to the Hohokam shape with the method of feature extraction, supervised classification found. The vegetation index didn’t help to get the necessary information’s either.

2. The influence of time between the years 1973 to 2003 on the city and their canals can be discovered.

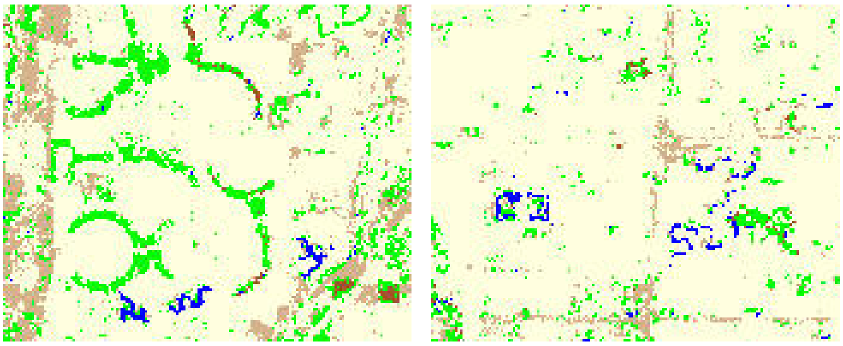
- Due to the constantly increasing expansion of cities (during the study period) the existence of old canals structures are increasingly declining.

Successfully reached when:	- the number of recognized canals from 1973 until 2003 are decreasing in extreme ways (>20%) that would confirm this hypothesis.
Results of this work:	At the time when the hypothesis were formulated such bad results were not expected (not even in the worst case). Nevertheless all statements were carefully studied. Basically in all four datasets the same classes and their according AOIs were used. In a few cases the AOI are located in a little distance away from the original position because the AOI's got too small for instance (happened with water and wetlands, vegetation [golf courses]). The results obviously show that the agricultural use decrease continuously since the year 1973 and were replaced by residential areas. Mainly the agricultural areas in the Southeast and West of the Phoenix metro area decreased. Anyway the investigations brought the results that the urban expansion greatly increased since that time. This circumstance is also very good recognizable with the vegetation index. No comments are possible to the hypothesis about the decreasing status of the Hohokam irrigation traces.
	Partially, the urban expansion takes place evidently. Decreasing agriculture area is replaced with sealed and residential areas. But it was not possible to find any water traces (according to the first question), that is why this hypothesis has to be answered negative.

3. It is possible today to determine the use of the traces (such as rain overflow canal, irrigation, swimming, green space [public parks], water reservoirs).

- Influences of prehistoric canals on the current water regime can be demonstrated.

Successfully reached when:	- within 500 m to both sides of the Hohokam canals one of the mentioned places are recognizable. The number should be greater than 15 units.
Results of this work:	Yes it is possible to assign many significant areas to their appropriate classes. For instance for the class "vegetation" the green round shapes in the middle of the thematic layers can be assigned to golf courses or in the upper left corner the semicircular shaped areas are green areas and separators between different residential areas. Also in the same area the class "water & wetlands" shows wormlike blue shapes which represents small lagoon from the high society residential. These

	lagoons can also be found in Southeast (ASTER 2003, Landsat TM 1985). The same figures appear in the vegetation index without further refinements.  **Image 63 - ASTER 2003, Phoenix Northwest (left), Southeast (right)** **(Robert Bizaj; March 17, 2009)**
	No, with both classification methods (supervised classification, vegetation index) no Hohokam water traces were assignable to a specific purpose which is mentioned above.

4. This approach or method is also adaptable for other places and analog questions.

Successfully reached when:	- it is plausibly explainable that the concepts/ideas of this thesis would work in other problem situations, too.
Results of this work:	It seems those primary problems are the missing natural vegetation and the few wetlands areas. There is no contrast between the different features (e.g. Hohokam canal, desert sand, river banks and nearer surrounding). Wherever the Hohokam canals exist they may go down in their environment because of the so little contrast (there is a too little spectral difference) between them.
	Yes, linear feature are extractable with methods of the remote sensing (e.g. Salt River in many classification results). Therefore the supervised classification can be used and also the calculation of the vegetation index, both methods work. Some examples are listed in chapter 2.2.3. Countries with more natural vegetation would develop more forests and bushes. If on both sides of rivers would grow bushes and trees that would be easier to recognize with a supervised classification even there is no water in the river (not reviewed with other locations).

5. If it was not able to detect the Hohokam water traces in the points 1-4 above, maybe they can be recognized through the existence of water and humid areas around the prehistoric canals. If sufficient humid areas are trackable along the fragments (→ buffer zone) this could mean that the Hohokam water traces were in the closer surroundings.

Successfully reached when:	- connected humid areas over a length from several hundred meters and within a buffer zone of 100 m, 300 m and 500 m to both sides of the Hohokam water traces can be found. - the increased occurrence of humid areas and vegetation within the buffer zones in contrast to the reference rectangle can be confirmed. It would be expected that the percentage of these areas within the buffer zones are substantial higher than in the reference area. Values greater than 15% difference can confirm the hypothesis. Below that percentage it would not show any relations between the Hohokam water traces and the humid areas.
Results of this work:	This question was already investigated in the questions 1-4 because it was not possible to find any training areas (chapter 3.2.1) to assign them to an area of interest and a class named "Hohokam water traces" for the supervised classification. A detailed work with buffer zones (in this case multi ring buffers) around the Hohokam shape and a reference rectangle was performed to the supervised classification and VI datasets. Nevertheless not even the smallest segment could be found. One cause could be that there are no more ancient Hohokam water traces trackable nowadays from space with remote sensing technologies. That would be one plausible reason, why nowhere segments from the Hohokam irrigation canals could be found.
	No, this theory did not apply.

5. Summary - Discussion - Outlook

5.1 Summary - what was done in this thesis?

In the current work was investigated if it is possible to extract the ancient Hohokam irrigation canals in the greater Phoenix metropolitan area with the methods of the supervised classification and help of the vegetation index and the satellite data from ASTER (2003), Landsat TM5 (1995, 1985) and Landsat MSS (1973). The results were not satisfactory, no such canals were found. Two possible reasons could be the strong expansion in the last decades and the dry climate of the area. All classification results have shown that natural vegetation is only sparsely available in the Hohokam area, and the human made greenswards and agriculture areas cannot flourish without irrigation.

5.2 Discussion - technical and personal review from the author

In a very early state of the work it was evident that it will be a challenge to search for ancient water traces in the heavily populated area around the Phoenix metropolitan area and in the desert zone. The first idea was to perform a supervised classification to extract the Hohokam canals. This failed because it was not possible to find same water traces. The second idea was to investigate the water & wetlands and vegetation around the Hohokam area. If some old canals already exist nowadays they may grow up in the nearer surrounding (less than 500 meter) of the Hohokam water traces. It was explored with the supervised classification and the vegetation index. Because too less vegetation grow in the nearer space this method failed also.

In the opinion of the author the main difficulties are that the scant rainfall in this area evaporates or seeps before the water can be stored in very little natural vegetation that exists in the study area. So there is no possibility for the vegetation to receive some water and they cannot grow up, this makes detection from the air/sky impossible. Beside this challenge the idea of a multidisciplinary treatment between two completely different sciences (archaeology and geoinformatic) was very interesting.

From a technical view there were no difficulties with the software ERDAS Imagine. It was possible to perform all tasks stable and expected speed. For the processing of raster images the author can recommend highly the use of this software every GIS user.

5.3 An outlook to the future

5.3.1 Possible scenarios for continuing the work

5.3.1.1 Theory 1 - Ground Penetrating Radar

Future writers of scientific works in this field could try to work with data of the ground penetrating satellites (ground penetrating radar - GPR). The use of satellite sensors with active radar components with very long-electromagnetic radiation (ultra low frequencies) enables the enforcement of the earth in suitable depths, where the potential water resources can be presumed (https://www.soils.org/press/releases/2008/0317/10/, Using Ground Penetrating Radar to Observe Hidden Underground Water Processes; March 14, 2009). If the work would show signs of water in nearer the underground the results can be compared with Jerry B. Howard Hohokam shape file for compliance. This possibility of remote sensing could help to get a closer look of Hohokam area and their ancient water traces.

Kind of spectrum	Range	Example	Penetrating the soil
far infrared (FIR)	1 mm - 1,000 µm	3 GHz ↔ 1 mm	only a few µm
ultra low frequency (ULF)	300 - 3,000 Hz	1,700 Hz ↔ 176.5 m	~ 10 meters

Table 41 - Wavelengths and their effect on the earth for GPR with RS

(Robert Bizaj; February 19, 2009)

5.3.1.2 Theory 2 - Pipes placed in the Hohokam water traces

Another promising possibility for handling this issue could be the analysis of existing documentation of the water or sewage pipes in the archives of the office of civil engineering located in the city hall and also in the city history/chronicle. The following hypothesis can be: At the beginning of the expansion in the cities in the Phoenix metro area several decades ago, the current used pipes could be placed into the historic Hohokam water traces (as described in the first chapter their depth was up to 6 meters). Afterwards they were buried with soil and desert sand so nobody would find them again after some years. A scientific work might verify these facts.

5.3.1.3 Theory 3 - Investigation with “Definiens eCognition”

The available dataset could be processed with the software Definiens eCognition. A fully developed image analysis algorithm for object detection (object based image analysis - OBIA) is able to recognize and extract very unclear images (http://www.definiens.com/image-analysis-in-earth-sciences_165_36_37.html, Image analysis in earth sciences; April 19, 2009). The idea of the object based analysis should be examined, maybe it is a better way to get results of Hohokam irrigation canals.

5.3.2 Generalization of the presented solution

One way to verify the general applicability / usability of the solution is to apply the same method of feature extraction, supervised classification and vegetation index with satellite data of the same quality (the same year just so the same provider) in a region with a temperate climate and increased vegetation. Suitable areas are in the northern parts of the United States or in the large spaces of Canada and Europe. It is not known if there are somewhere else remnants of earlier civilizations with similar irrigation canals. An alternative to water canals could be the use of historic trade routes or road connections between cities of earlier settlers. For instance the Roman Empire had an expanded network of such connections. In small investigation areas it could be possible to find ancient roads nowadays.

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7. Additional Content

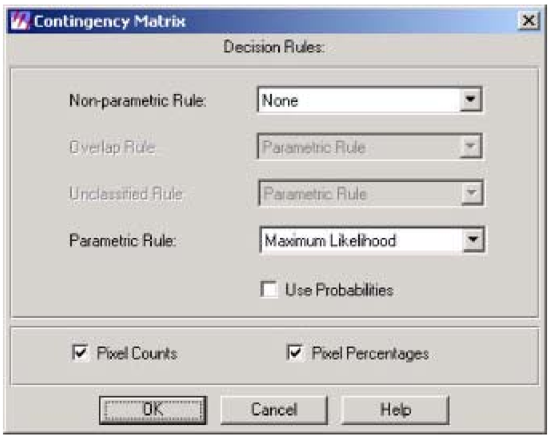
Nr.	Kind of work
1.	ERDAS Imagine 8.7 → Signature Editor … → Evaluate → Contingency …
2.	The following setting were used: 
3.	Finally the results were saved as an ASCII text file.

Table 42 - How to perform a "Contingency Matrix Evaluation Reports"?

(Robert Bizaj; April 18, 2009)

Nr.	Kind of work
1.	ERDAS Imagine 8.7 → Classifier → Accuracy Assessment …
2.	Open a viewer with a thematic file
3.	Select the viewer with the opened file as default Accuracy Assessment → View → Select Viewer …
4.	"Edit" → "Import User-defined Points" For the verification process a prepared ASCII text file of 256 random points which were calculated before in this tool were used for every dataset of the supervised classification.
5.	Show all points in the viewer window and change their color to yellow Accuracy Assessment → View → Show All Accuracy Assessment → View → Change Colors …
6.	Show all classes in the accuracy assessment tool Accuracy Assessment → Show Class Values
7.	Verify every point if the class was classified correctly or not
8.	After all point were verified the test was executed Accuracy Assessment → Report → Accuracy Report …

Table 43 - How to perform an "Accuracy Assessment" test?

(Robert Bizaj; April 18, 2009)

2003		1995, 1985, 1973	
1	Humid Areas	1	Humid Areas
6	Surroundings	2	Surroundings
7	Urban Areas	3	Urban Areas
23	Vegetation	25	Vegetation

Table 44 - Class description in ERDAS Imagine from the supervised classification

(Robert Bizaj; April 18, 2009)

7.1 Supervised Classification - Contingency Matrix Evaluation

7.1.1 ASTER 2003

```
ERROR MATRIX
-------------

                          Reference Data
                          --------------
Classified
      Data   Vegetation   Humid_Area   Surroundin   Urban_Area
----------   ----------   ----------   ----------   ----------
Vegetation         1563            0            0            0
Humid_Area            0         1396            0            0
Surroundin            0            0         4785          160
Urban_Area            3            0           17         4396

Column Total       1566         1396         4802         4556


             ----- End of Error Matrix -----
```

```
ERROR MATRIX
-------------

                          Reference Data
                          --------------
Classified
      Data   Vegetation   Humid_Area   Surroundin   Urban_Area
----------   ----------   ----------   ----------   ----------
Vegetation        99.81         0.00         0.00         0.00
Humid_Area         0.00       100.00         0.00         0.00
Surroundin         0.00         0.00        99.65         3.51
Urban_Area         0.19         0.00         0.35        96.49

Column Total       1566         1396         4802         4556


             ----- End of Error Matrix -----
```

7.1.2 Landsat TM 1995

ERROR MATRIX

Reference Data

Classified Data	Vegetation	Humid_Area	Surroundin	Urban_Area
Vegetation	862	0	0	0
Humid_Area	0	210	0	0
Surroundin	0	0	2459	0
Urban_Area	0	0	0	3057
Column Total	862	210	2459	3057

----- End of Error Matrix -----

ERROR MATRIX

Reference Data

Classified Data	Vegetation	Humid_Area	Surroundin	Urban_Area
Vegetation	100.00	0.00	0.00	0.00
Humid_Area	0.00	100.00	0.00	0.00
Surroundin	0.00	0.00	100.00	0.00
Urban_Area	0.00	0.00	0.00	100.00
Column Total	862	210	2459	3057

----- End of Error Matrix -----

7.1.3 Landsat TM 1985

ERROR MATRIX

Reference Data

Classified Data	Vegetation	Humid_Area	Surroundin	Urban_Area
Vegetation	966	0	0	0
Humid_Area	0	219	0	0
Surroundin	0	0	10174	29
Urban_Area	0	0	58	2244
Column Total	966	219	10232	2273

----- End of Error Matrix -----

ERROR MATRIX

Reference Data

Classified Data	Vegetation	Humid_Area	Surroundin	Urban_Area
Vegetation	100.00	0.00	0.00	0.00
Humid_Area	0.00	100.00	0.00	0.00
Surroundin	0.00	0.00	99.43	1.28
Urban_Area	0.00	0.00	0.57	98.72
Column Total	966	219	10232	2273

----- End of Error Matrix -----

7.1.4 Landsat MSS 1973

ERROR MATRIX

Reference Data

Classified Data	Vegetation	Humid_Area	Surroundin	Urban_Area
Vegetation	256	0	0	0
Humid_Area	0	155	0	0
Surroundin	0	0	2590	19
Urban_Area	0	2	21	725
Column Total	256	157	2611	744

----- End of Error Matrix -----

ERROR MATRIX

Reference Data

Classified Data	Vegetation	Humid_Area	Surroundin	Urban_Area
Vegetation	100.00	0.00	0.00	0.00
Humid_Area	0.00	98.73	0.00	0.00
Surroundin	0.00	0.00	99.20	2.55
Urban_Area	0.00	1.27	0.80	97.45
Column Total	256	157	2611	744

----- End of Error Matrix -----

7.2 Supervised Classification - Accuracy Assessment Files

7.2.1 ASTER 2003

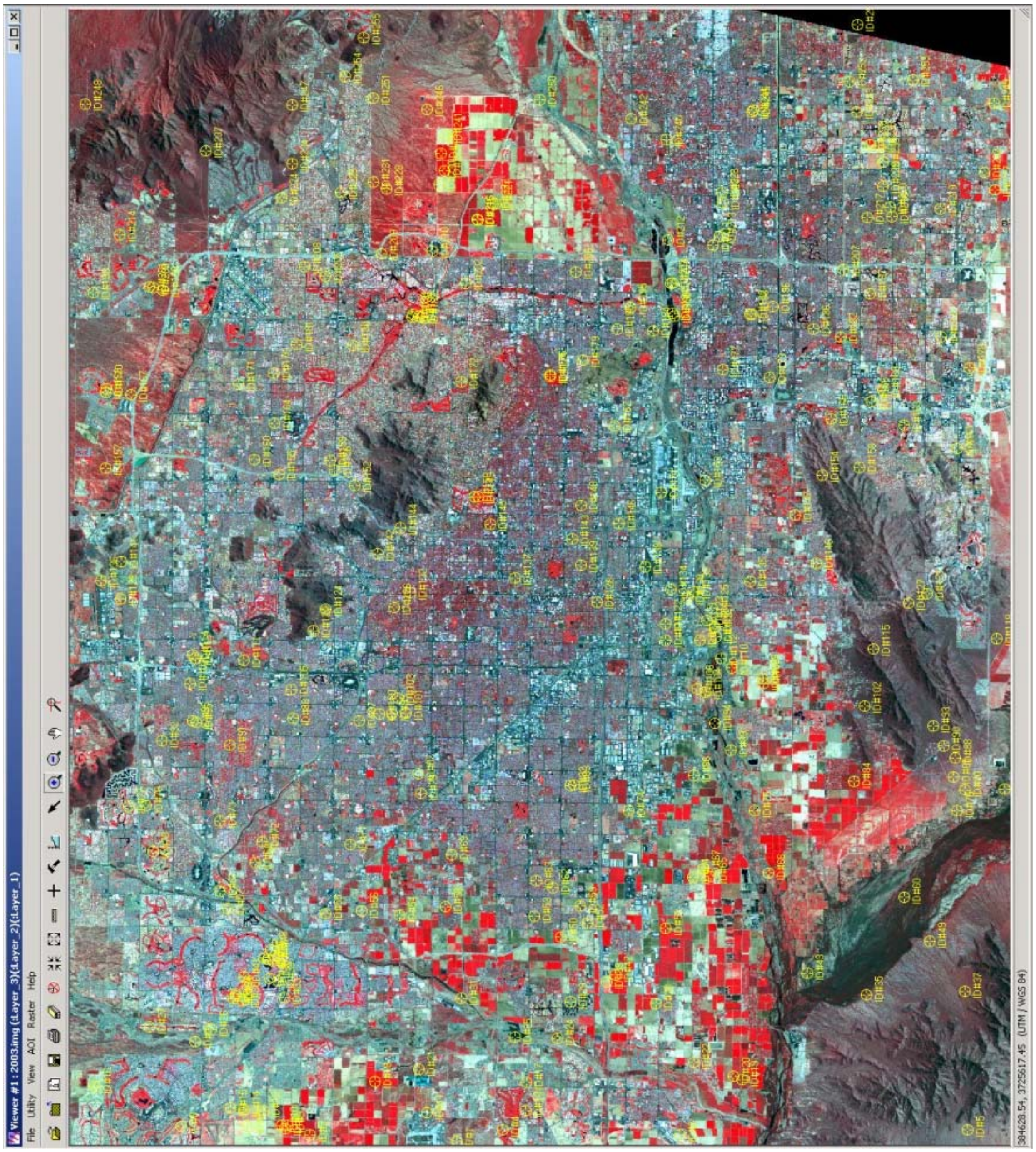


Image 64 - Random points from Accuracy Assessment from ASTER 2003

(Robert Bizaj; April 18, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/classification_iv/2003/output_2003_4-classes.img
User Name : Robert Bizaj
Date : Sat Apr 18 15:01:39 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Urban_Area	----------	----------
Unclassified	0	0	0	0
Urban_Area	0	131	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Humid_Area	0	0	0	0
Surrounding	0	2	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	133	0	0

Reference Data

Classified Data	----------	----------	Humid_Area	Surroundin
Unclassified	0	0	0	0
Urban_Area	0	0	2	28
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Humid_Area	0	0	9	0
Surrounding	0	0	1	45
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	12	73

Reference Data

Classified Data				
Unclassified	0	0	0	0
Urban_Area	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Humid_Area	0	0	0	0
Surrounding	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Urban_Area	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Humid_Area	0	0	0	0
Surrounding	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Urban_Area	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Humid_Area	0	0	0	0
Surrounding	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				Vegetation
Unclassified	0	0	0	0
Urban_Area	0	0	0	8
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Humid_Area	0	0	0	0
Surrounding	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	30
Column Total	0	0	0	38

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
Urban_Area	133	169	131	98.50%	77.51%
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Humid_Area	12	9	9	75.00%	100.00%
Surrounding	73	48	45	61.64%	93.75%
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Vegetation	38	30	30	78.95%	100.00%
Totals	256	256	215		

Overall Classification Accuracy = 83.98%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7260

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	0.0000
Urban_Area	0.5320
	0.0000
	0.0000
	0.0000
	0.0000
Humid_Area	1.0000
Surrounding	0.9126
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000

```
                                              0.0000
                                              0.0000
                          Vegetation          1.0000

          ----- End of Kappa Statistics -----
```

7.2.2 Landsat TM 1995

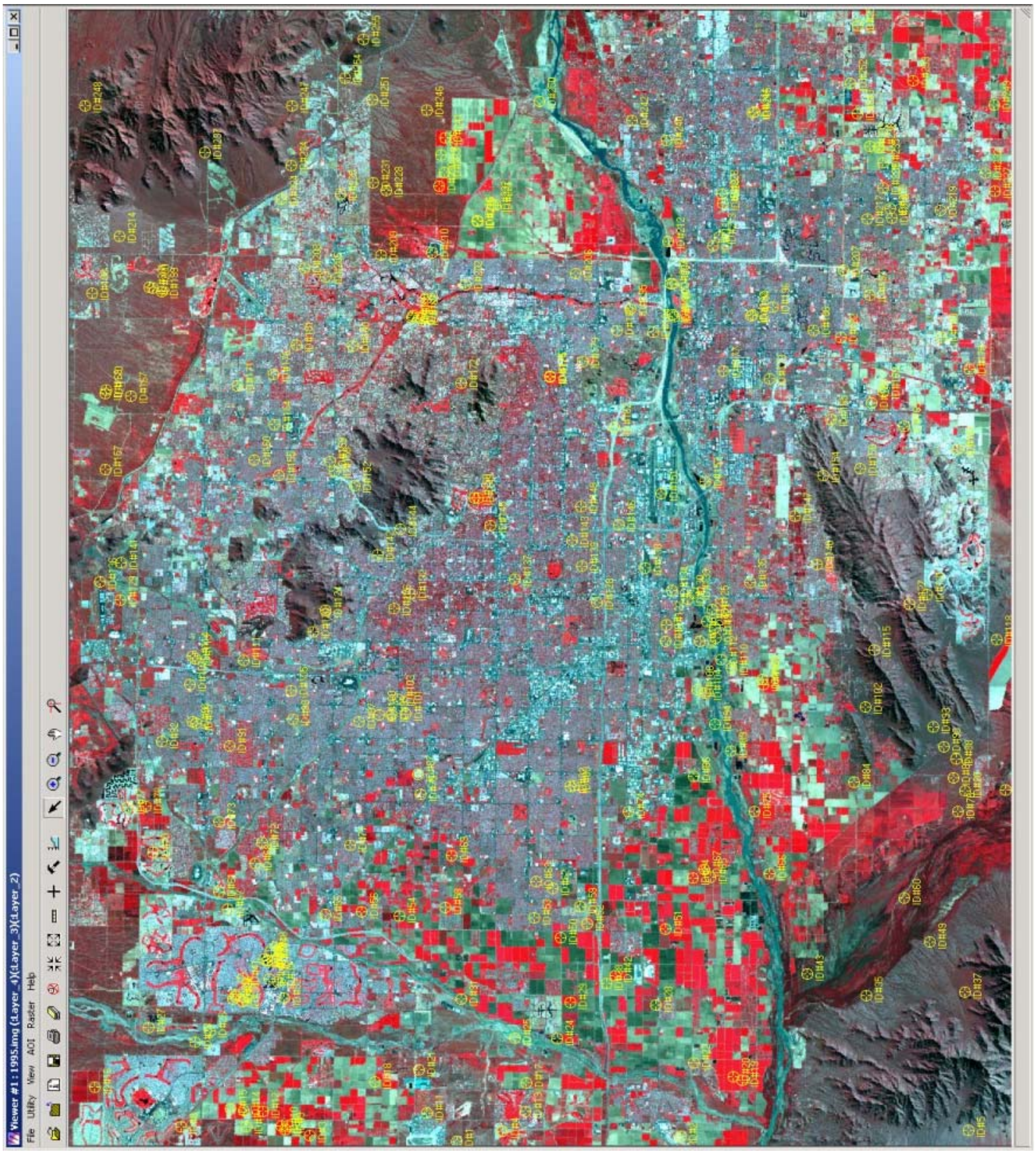


Image 65 - Random points from Accuracy Assessment from Landsat 1995

(Robert Bizaj; April 18, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/classification_iv/1995/output_1995_4-classes.img
User Name : Robert Bizaj
Date : Sat Apr 18 15:53:48 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Humid_Area	Surroundin	Urban_Area
Unclassified	0	0	0	0
Humid_Areas	0	13	0	0
Surrounding	0	1	78	3
Urban_Areas	0	0	9	114
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	1	0
Column Total	0	14	88	117

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0

Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data	Vegetation	Row Total
Unclassified	0	0
Humid_Areas	0	13
Surrounding	1	83
Urban_Areas	4	127
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
Vegetation	32	33
Column Total	37	256

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
Humid_Areas	14	13	13	92.86%	100.00%
Surrounding	88	83	78	88.64%	93.98%
Urban_Areas	117	127	114	97.44%	89.76%
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Vegetation	37	33	32	86.49%	96.97%

Totals	256	256	237

Overall Classification Accuracy = 92.58%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.8841

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	0.0000
Humid_Areas	1.0000
Surrounding	0.9082
Urban_Areas	0.8115
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
Vegetation	0.9646

----- End of Kappa Statistics -----

7.2.3 Landsat TM 1985

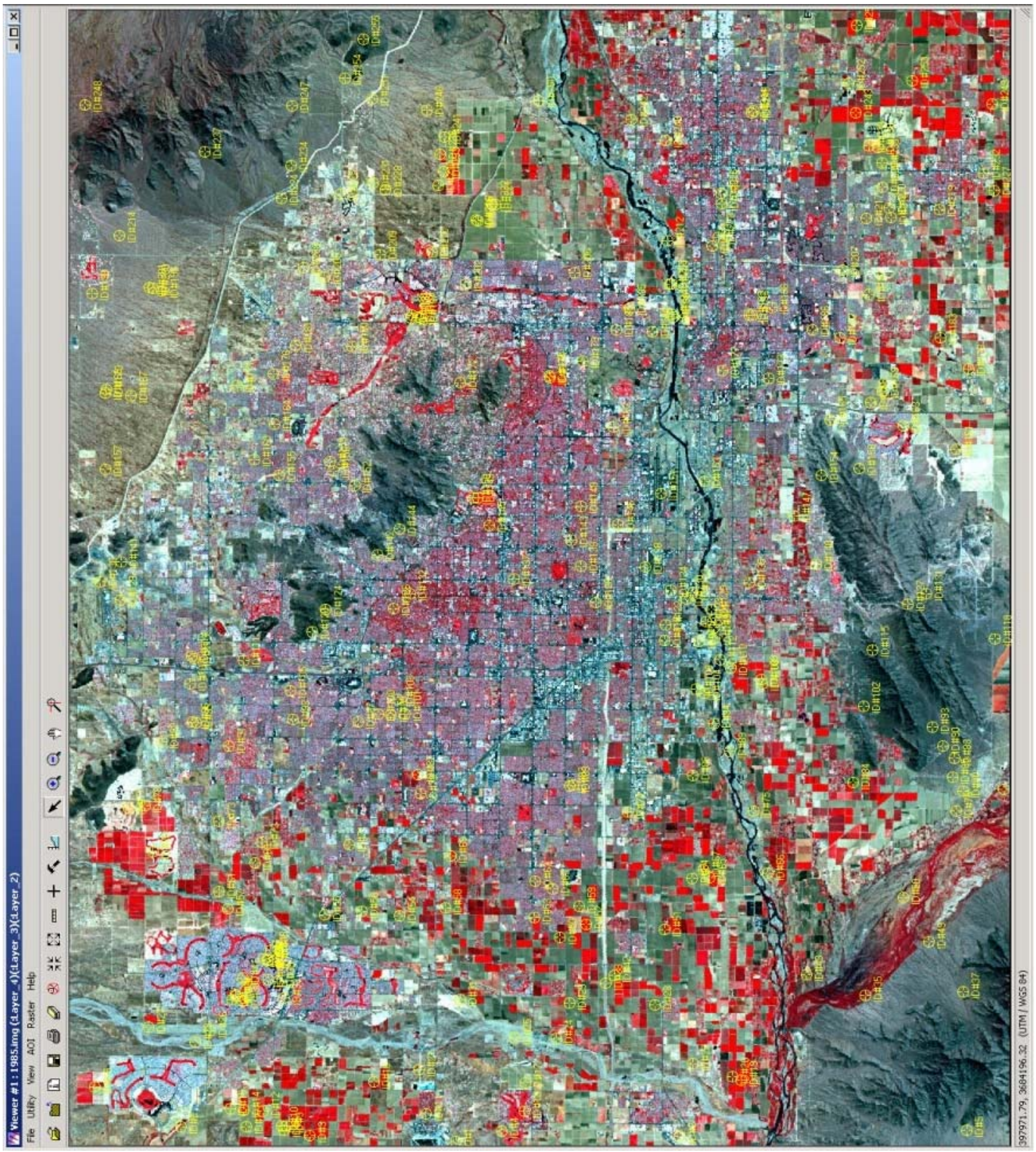


Image 66 - Random points from Accuracy Assessment from Landsat TM 1985

(Robert Bizaj; April 18, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/classification_iv/1985/output_1985_4-classes.img
User Name : Robert Bizaj
Date : Sat Apr 18 19:49:26 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Humid_Area	Surroundin	Urban_Area
Unclassified	0	0	0	0
Humid_Areas	0	9	1	0
Surrounding	0	0	87	6
Urban_Areas	0	0	27	94
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	9	115	100

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

Classified Data				
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data	----------	----------	----------	----------
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data	----------	----------	----------	----------
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

	Reference Data		
Classified Data		Vegetation	Row Total
Unclassified	0	0	0
Humid_Areas	0	0	10
Surrounding	0	2	95
Urban_Areas	0	13	134
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
Vegetation	0	16	16
Column Total	0	31	255

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
Humid_Areas	9	10	9	100.00%	90.00%
Surrounding	115	95	87	75.65%	91.58%
Urban_Areas	100	135	94	94.00%	69.63%
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---

	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Vegetation	31	16	16	51.61%	100.00%
Totals	255	256	206		

Overall Classification Accuracy = 80.47%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.6841

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	0.0000
Humid_Areas	0.8964
Surrounding	0.8471
Urban_Areas	0.5016
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
Vegetation	1.0000

----- End of Kappa Statistics -----

7.2.4 Landsat MSS 1973

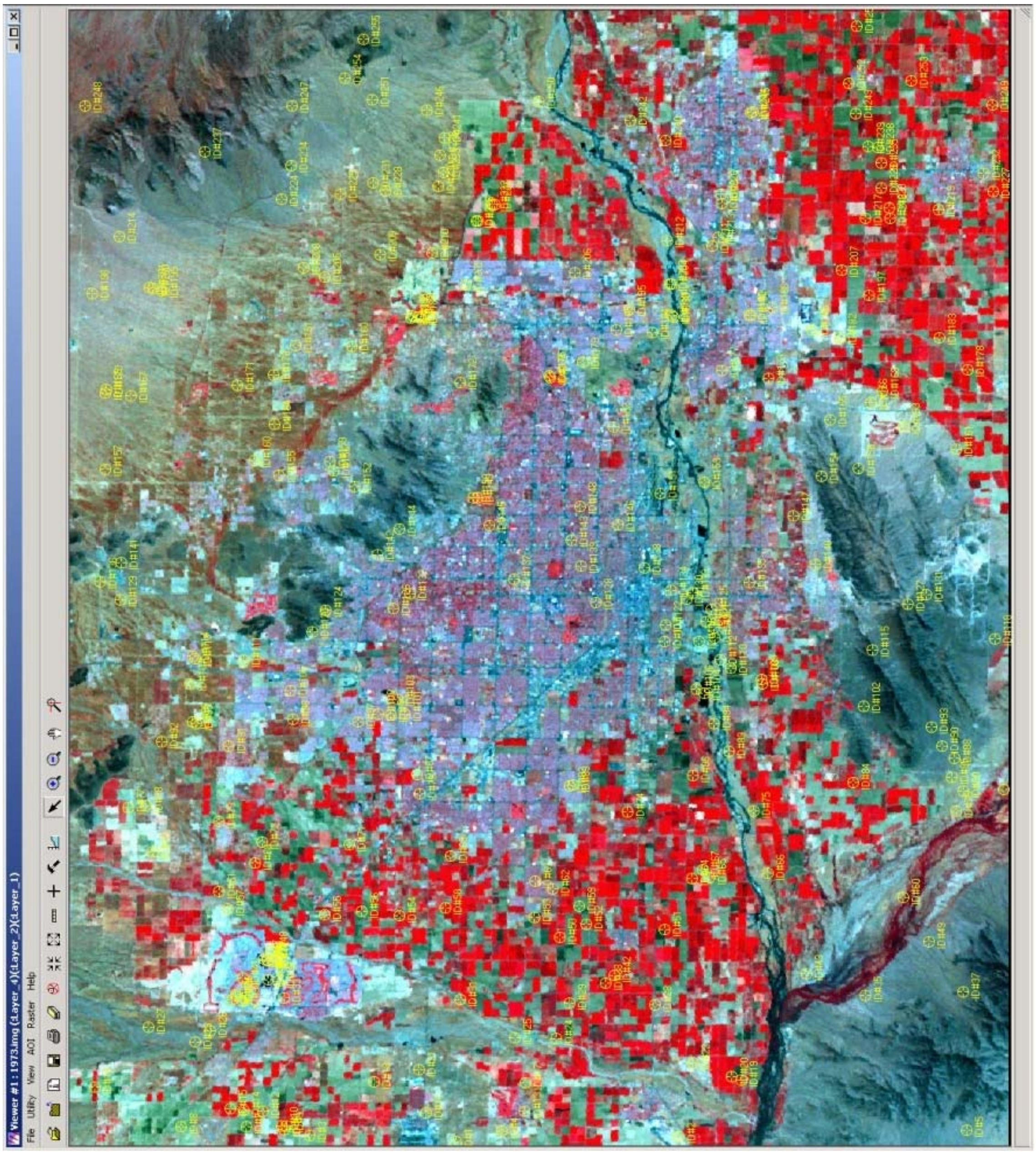


Image 67 - Random points from Accuracy Assessment from Landsat MSS 1973

(Robert Bizaj; April 18, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/classification_iv/1973/output_1973_4-classes.img
User Name : Robert Bizaj
Date   : Sat Apr 18 19:30:37 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Humid_Area	Surroundin	Urban_Area
Unclassified	0	0	0	0
Humid_Areas	0	17	0	0
Surrounding	0	0	102	10
Urban_Areas	0	0	24	55
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	1
Column Total	0	17	126	66

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data				
Unclassified	0	0	0	0
Humid_Areas	0	0	0	0
Surrounding	0	0	0	0
Urban_Areas	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0

	0	0	0	0
Vegetation	0	0	0	0
Column Total	0	0	0	0

Reference Data

Classified Data		Vegetation	Row Total
Unclassified	0	0	0
Humid_Areas	0	0	17
Surrounding	0	3	115
Urban_Areas	0	2	81
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0
Vegetation	0	42	43
Column Total	0	47	256

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
Humid_Areas	17	17	17	100.00%	100.00%
Surrounding	126	115	102	80.95%	88.70%
Urban_Areas	66	81	55	83.33%	67.90%
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---

	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
	0	0	0	---	---
Vegetation	47	43	42	89.36%	97.67%
Totals	256	256	216		

Overall Classification Accuracy = 84.38%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7640

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	0.0000
Humid_Areas	1.0000
Surrounding	0.7774
Urban_Areas	0.5675
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
	0.0000
Vegetation	0.9715

----- End of Kappa Statistics -----

7.3 Vegetation Index - Accuracy Assessment Files

7.3.1 ASTER 2003 - unsupclass_vi_2003.img

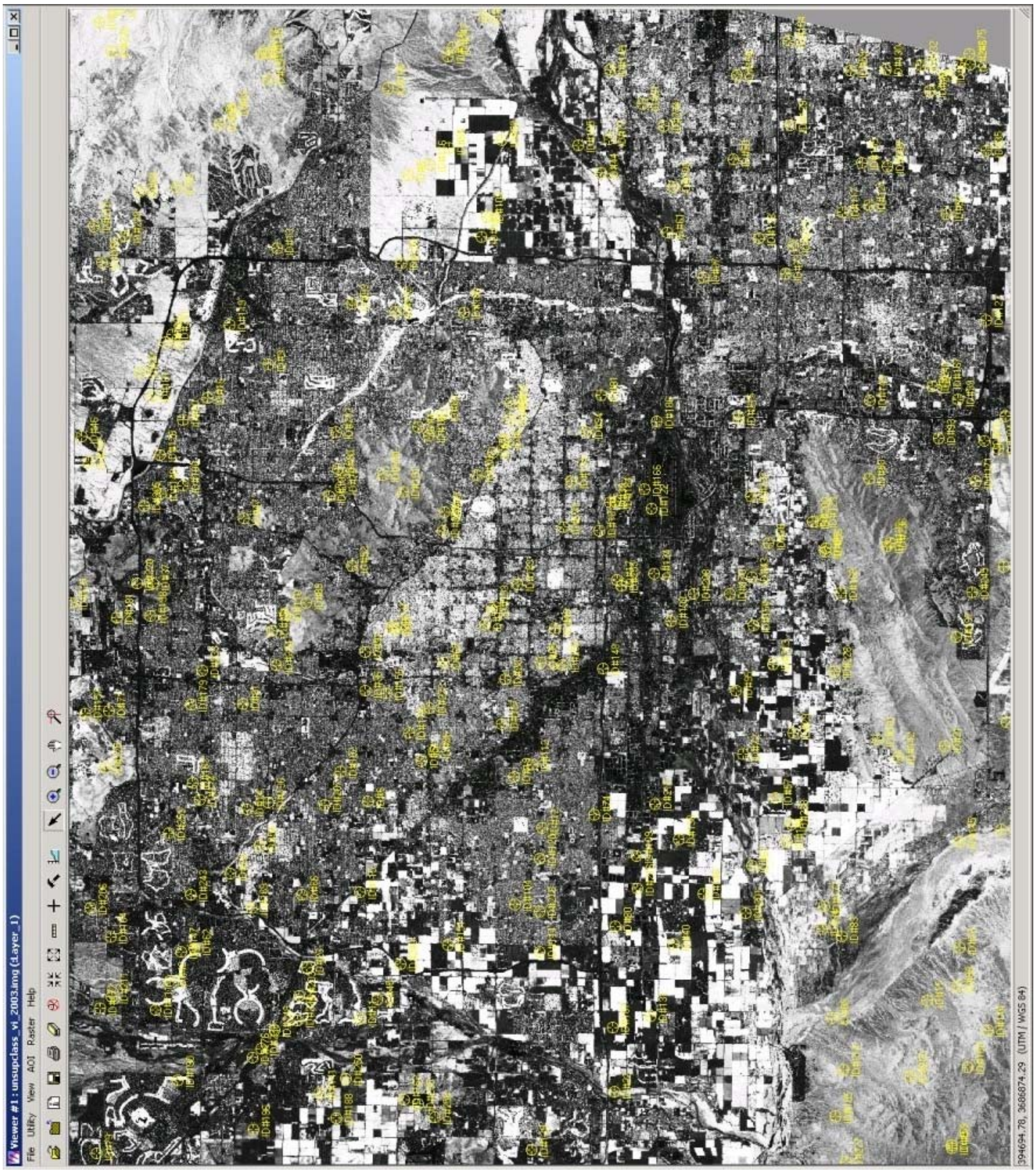


Image 68 - Random points from Accuracy Assessment from ASTER 2003

(Robert Bizaj; April 11, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/vi/unsupclass_vi_2003.img
User Name : Robert Bizaj
Date   : Mon Apr 11 14:26:44 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Class 1	Class 2	Class 3
Unclassified	0	0	0	0
Class 1	0	10	0	0
Class 2	0	6	39	0
Class 3	0	0	6	18
Class 4	0	0	0	2
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	0	16	45	20

Reference Data

Classified Data	Class 4	Class 5	Class 6	Class 7
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	5	0	0	0
Class 5	1	15	0	0
Class 6	0	2	1	0
Class 7	0	0	2	15
Class 8	0	0	0	4
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	6	17	3	19

Reference Data

Classified Data	Class 8	Class 9	Class 10	Class 11
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	8	0	0	0
Class 9	7	11	0	0
Class 10	0	1	4	0
Class 11	0	0	5	10
Class 12	0	0	0	1
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	15	12	9	11

Reference Data

Classified Data	Class 12	Class 13	Class 14	Class 15
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	2	0	0	0
Class 13	6	7	0	0
Class 14	0	1	4	0
Class 15	0	0	3	6
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	8	8	7	6

Reference Data

Classified Data	Class 16	Class 17	Class 18	Class 19
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0

Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	3	0	0	0
Class 17	1	10	0	0
Class 18	0	3	17	0
Class 19	0	0	3	7
Class 20	0	0	0	3
Column Total	4	13	20	10

	Reference Data	
Classified Data	Class 20	Row Total
Unclassified	0	0
Class 1	2	12
Class 2	0	45
Class 3	0	24
Class 4	0	7
Class 5	0	16
Class 6	0	3
Class 7	0	17
Class 8	0	12
Class 9	0	18
Class 10	0	5
Class 11	0	15
Class 12	0	3
Class 13	0	13
Class 14	0	5
Class 15	0	9
Class 16	0	3
Class 17	0	11
Class 18	0	20
Class 19	0	10
Class 20	5	8
Column Total	7	256

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
Class 1	16	12	10	62.50%	83.33%
Class 2	45	45	39	86.67%	86.67%
Class 3	20	24	18	90.00%	75.00%
Class 4	6	7	5	83.33%	71.43%
Class 5	17	16	15	88.24%	93.75%
Class 6	3	3	1	33.33%	33.33%
Class 7	19	17	15	78.95%	88.24%
Class 8	15	12	8	53.33%	66.67%
Class 9	12	18	11	91.67%	61.11%
Class 10	9	5	4	44.44%	80.00%
Class 11	11	15	10	90.91%	66.67%
Class 12	8	3	2	25.00%	66.67%
Class 13	8	13	7	87.50%	53.85%

Class 14	7	5	4	57.14%	80.00%
Class 15	6	9	6	100.00%	66.67%
Class 16	4	3	3	75.00%	100.00%
Class 17	13	11	10	76.92%	90.91%
Class 18	20	20	17	85.00%	85.00%
Class 19	10	10	7	70.00%	70.00%
Class 20	7	8	5	71.43%	62.50%
Totals	256	256	197		

Overall Classification Accuracy = 76.95%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7510

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	0.0000
Class 1	0.8222
Class 2	0.8382
Class 3	0.7288
Class 4	0.7074
Class 5	0.9331
Class 6	0.3254
Class 7	0.8729
Class 8	0.6459
Class 9	0.5920
Class 10	0.7927
Class 11	0.6517
Class 12	0.6559
Class 13	0.5236
Class 14	0.7944
Class 15	0.6587
Class 16	1.0000
Class 17	0.9042
Class 18	0.8373
Class 19	0.6878
Class 20	0.6145

----- End of Kappa Statistics -----

7.3.2 Landsat TM 1995 - unsupclass_vi_1995.img

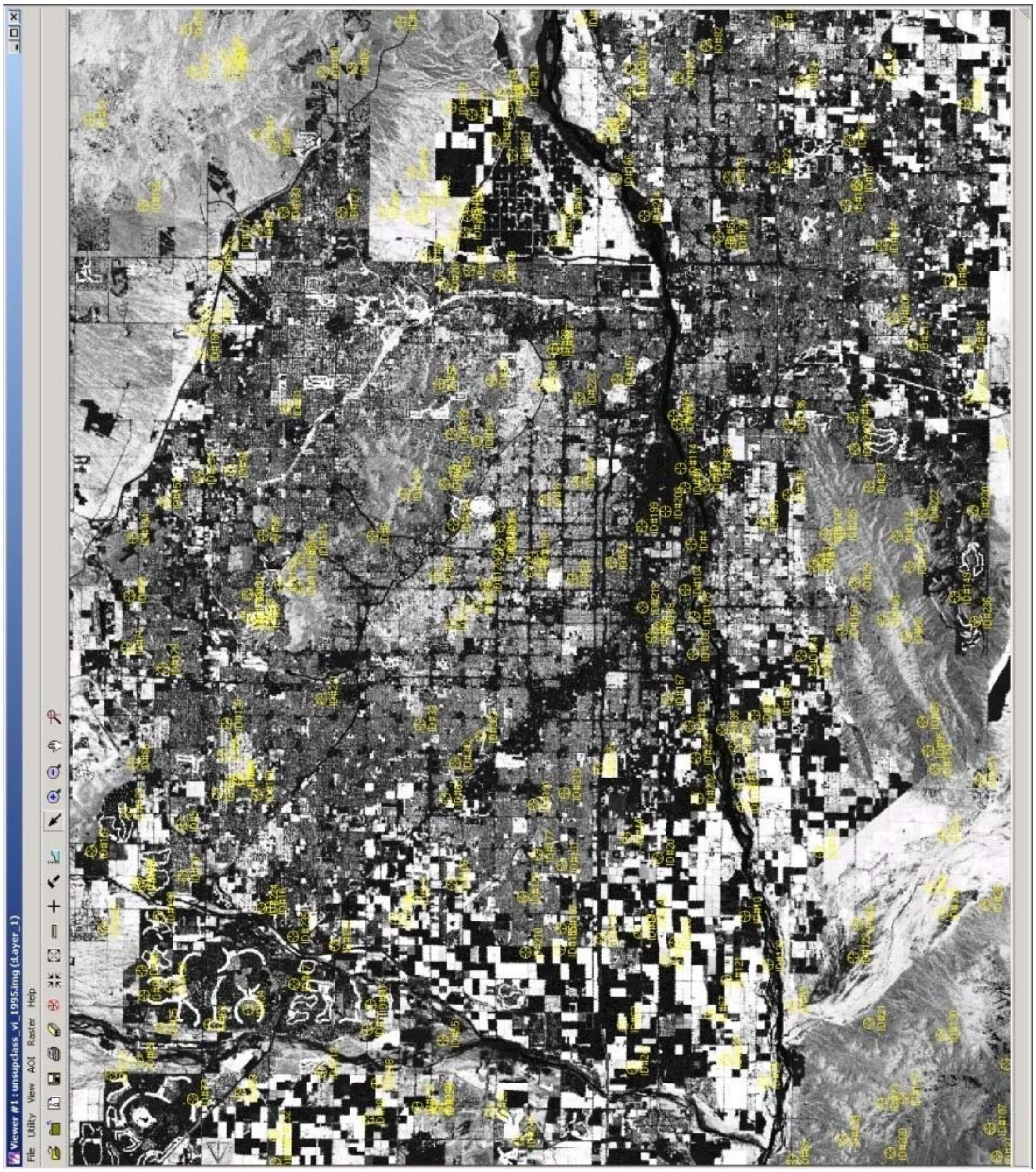


Image 69 - Random points from Accuracy Assessment from Landsat MT 1995

(Robert Bizaj; April 11, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/vi/unsupclass_vi_1995.img
User Name : Robert Bizaj
Date : Mon Apr 12 20:48:36 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Class 1	Class 2	Class 3
Unclassified	5	0	0	0
Class 1	0	2	0	0
Class 2	0	10	50	0
Class 3	0	0	8	19
Class 4	0	0	0	2
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	5	12	58	21

Reference Data

Classified Data	Class 4	Class 5	Class 6	Class 7
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	11	0	0	0
Class 5	2	8	0	0
Class 6	0	1	15	0
Class 7	0	0	4	10
Class 8	0	0	0	2
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	13	9	19	12

Reference Data

Classified Data	Class 8	Class 9	Class 10	Class 11
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	7	0	0	0
Class 9	2	4	0	0
Class 10	0	1	7	0
Class 11	0	0	1	6
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	9	5	8	6

Reference Data

Classified Data	Class 12	Class 13	Class 14	Class 15
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	8	0	0	0
Class 13	1	7	0	0
Class 14	0	1	1	0
Class 15	0	0	2	4
Class 16	0	0	0	3
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	9	8	3	7

Reference Data

Classified Data	Class 16	Class 17	Class 18	Class 19
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0

Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	3	0	0	0
Class 17	1	6	0	0
Class 18	0	4	5	0
Class 19	0	0	5	14
Class 20	0	0	0	1
Column Total	4	10	10	15

	Reference Data	
Classified Data	Class 20	Row Total
Unclassified	0	5
Class 1	0	2
Class 2	0	60
Class 3	0	27
Class 4	0	13
Class 5	0	10
Class 6	0	16
Class 7	0	14
Class 8	0	9
Class 9	0	6
Class 10	0	8
Class 11	0	7
Class 12	0	8
Class 13	0	8
Class 14	0	2
Class 15	0	6
Class 16	0	6
Class 17	0	7
Class 18	0	9
Class 19	0	19
Class 20	13	14
Column Total	13	256

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	5	5	5	---	---
Class 1	12	2	2	16.67%	100.00%
Class 2	58	60	50	86.21%	83.33%
Class 3	21	27	19	90.48%	70.37%
Class 4	13	13	11	84.62%	84.62%
Class 5	9	10	8	88.89%	80.00%
Class 6	19	16	15	78.95%	93.75%
Class 7	12	14	10	83.33%	71.43%
Class 8	9	9	7	77.78%	77.78%
Class 9	5	6	4	80.00%	66.67%
Class 10	8	8	7	87.50%	87.50%
Class 11	6	7	6	100.00%	85.71%
Class 12	9	8	8	88.89%	100.00%
Class 13	8	8	7	87.50%	87.50%

Class 14	3	2	1	33.33%	50.00%
Class 15	7	6	4	57.14%	66.67%
Class 16	4	6	3	75.00%	50.00%
Class 17	10	7	6	60.00%	85.71%
Class 18	10	9	5	50.00%	55.56%
Class 19	15	19	14	93.33%	73.68%
Class 20	13	14	13	100.00%	92.86%
Totals	256	256	205		

Overall Classification Accuracy = 80.08%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7811

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	1.0000
Class 1	1.0000
Class 2	0.7845
Class 3	0.6772
Class 4	0.8379
Class 5	0.7927
Class 6	0.9325
Class 7	0.7002
Class 8	0.7697
Class 9	0.6600
Class 10	0.8710
Class 11	0.8537
Class 12	1.0000
Class 13	0.8710
Class 14	0.4941
Class 15	0.6573
Class 16	0.4921
Class 17	0.8513
Class 18	0.5375
Class 19	0.7205
Class 20	0.9248

----- End of Kappa Statistics -----

7.3.3 Landsat TM 1985 - unsupclass_vi_1985.img

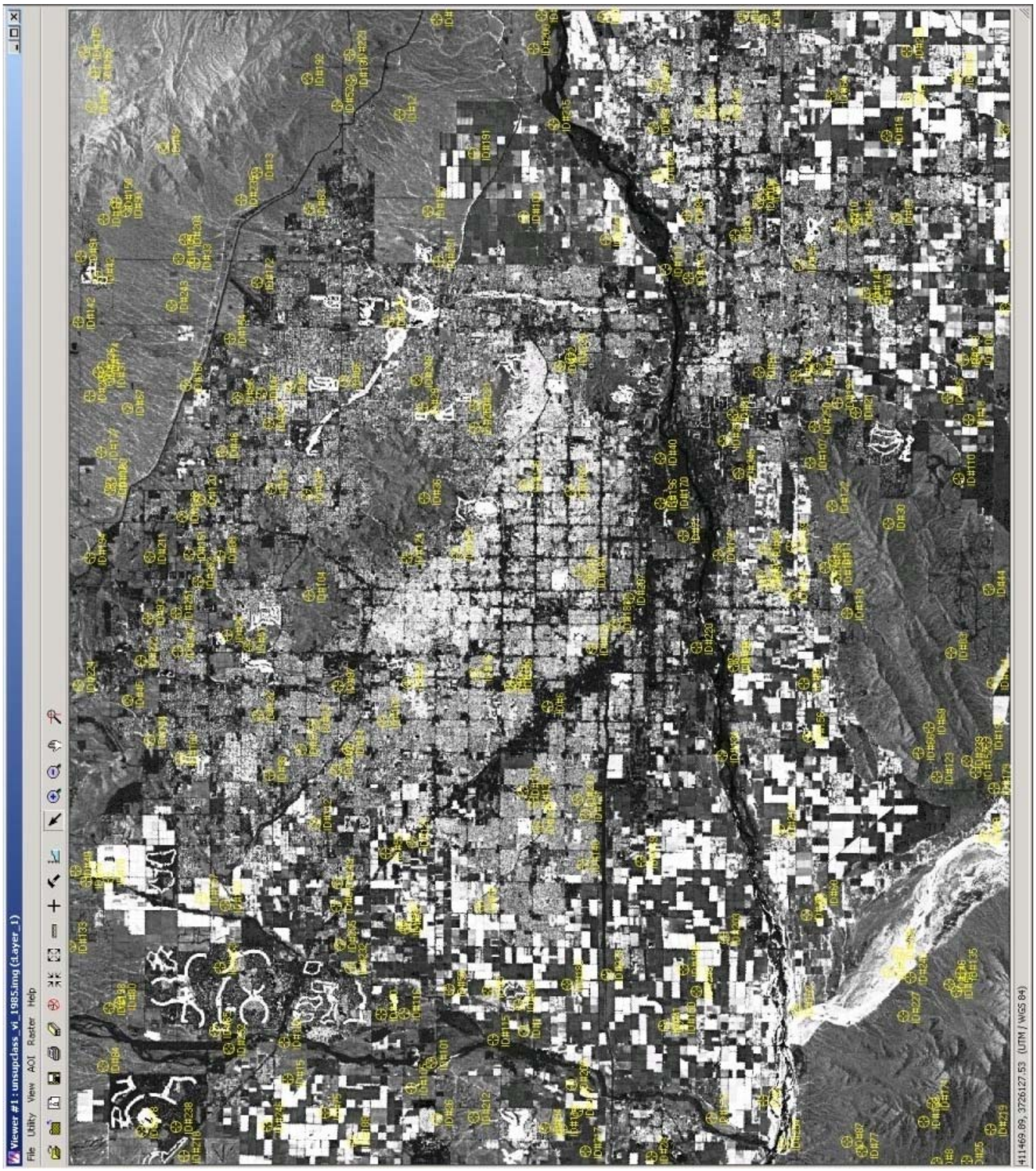


Image 70 - Random points from Accuracy Assessment from Landsat MT 1985

(Robert Bizaj; April 11, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/vi/unsupclass_vi_1985.img
User Name : Robert Bizaj
Date : Mon Apr 12 13:25:24 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Class 1	Class 2	Class 3
Unclassified	3	0	0	0
Class 1	0	1	0	0
Class 2	0	3	13	0
Class 3	0	0	3	18
Class 4	0	0	0	5
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	3	4	16	23

Reference Data

Classified Data	Class 4	Class 5	Class 6	Class 7
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	16	0	0	0
Class 5	5	7	0	0
Class 6	0	5	29	0
Class 7	0	0	3	25
Class 8	0	0	0	5
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	21	12	32	30

Reference Data

Classified Data	Class 8	Class 9	Class 10	Class 11
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	22	0	0	0
Class 9	4	16	0	0
Class 10	0	4	8	0
Class 11	0	0	0	8
Class 12	0	0	0	1
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	26	20	8	9

Reference Data

Classified Data	Class 12	Class 13	Class 14	Class 15
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	5	0	0	0
Class 13	1	6	0	0
Class 14	0	0	3	0
Class 15	0	0	0	1
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	6	6	3	1

Reference Data

Classified Data	Class 16	Class 17	Class 18	Class 19
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0

Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	3	0	0	0
Class 17	0	2	0	0
Class 18	0	1	5	0
Class 19	0	0	2	14
Class 20	0	0	0	1
Column Total	3	3	7	15

	Reference Data	
Classified Data	Class 20	Row Total
Unclassified	2	5
Class 1	0	1
Class 2	0	16
Class 3	0	21
Class 4	0	21
Class 5	0	12
Class 6	0	34
Class 7	0	28
Class 8	0	27
Class 9	0	20
Class 10	0	12
Class 11	0	8
Class 12	0	6
Class 13	0	7
Class 14	0	3
Class 15	0	1
Class 16	0	3
Class 17	0	2
Class 18	0	6
Class 19	0	16
Class 20	6	7
Column Total	8	256

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	3	5	3	---	---
Class 1	4	1	1	25.00%	100.00%
Class 2	16	16	13	81.25%	81.25%
Class 3	23	21	18	78.26%	85.71%
Class 4	21	21	16	76.19%	76.19%
Class 5	12	12	7	58.33%	58.33%
Class 6	32	34	29	90.63%	85.29%
Class 7	30	28	25	83.33%	89.29%
Class 8	26	27	22	84.62%	81.48%
Class 9	20	20	16	80.00%	80.00%
Class 10	8	12	8	100.00%	66.67%
Class 11	9	8	8	88.89%	100.00%
Class 12	6	6	5	83.33%	83.33%
Class 13	6	7	6	100.00%	85.71%

Class 14	3	3	3	100.00%	100.00%
Class 15	1	1	1	100.00%	100.00%
Class 16	3	3	3	100.00%	100.00%
Class 17	3	2	2	66.67%	100.00%
Class 18	7	6	5	71.43%	83.33%
Class 19	15	16	14	93.33%	87.50%
Class 20	8	7	6	75.00%	85.71%
Totals	256	256	211		

Overall Classification Accuracy = 82.42%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.8098

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	0.5953
Class 1	1.0000
Class 2	0.8000
Class 3	0.8430
Class 4	0.7406
Class 5	0.5628
Class 6	0.8319
Class 7	0.8786
Class 8	0.7939
Class 9	0.7831
Class 10	0.6559
Class 11	1.0000
Class 12	0.8293
Class 13	0.8537
Class 14	1.0000
Class 15	1.0000
Class 16	1.0000
Class 17	1.0000
Class 18	0.8286
Class 19	0.8672
Class 20	0.8525

----- End of Kappa Statistics -----

7.3.4 Landsat MSS 1973 - unsupclass_vi_1973.img

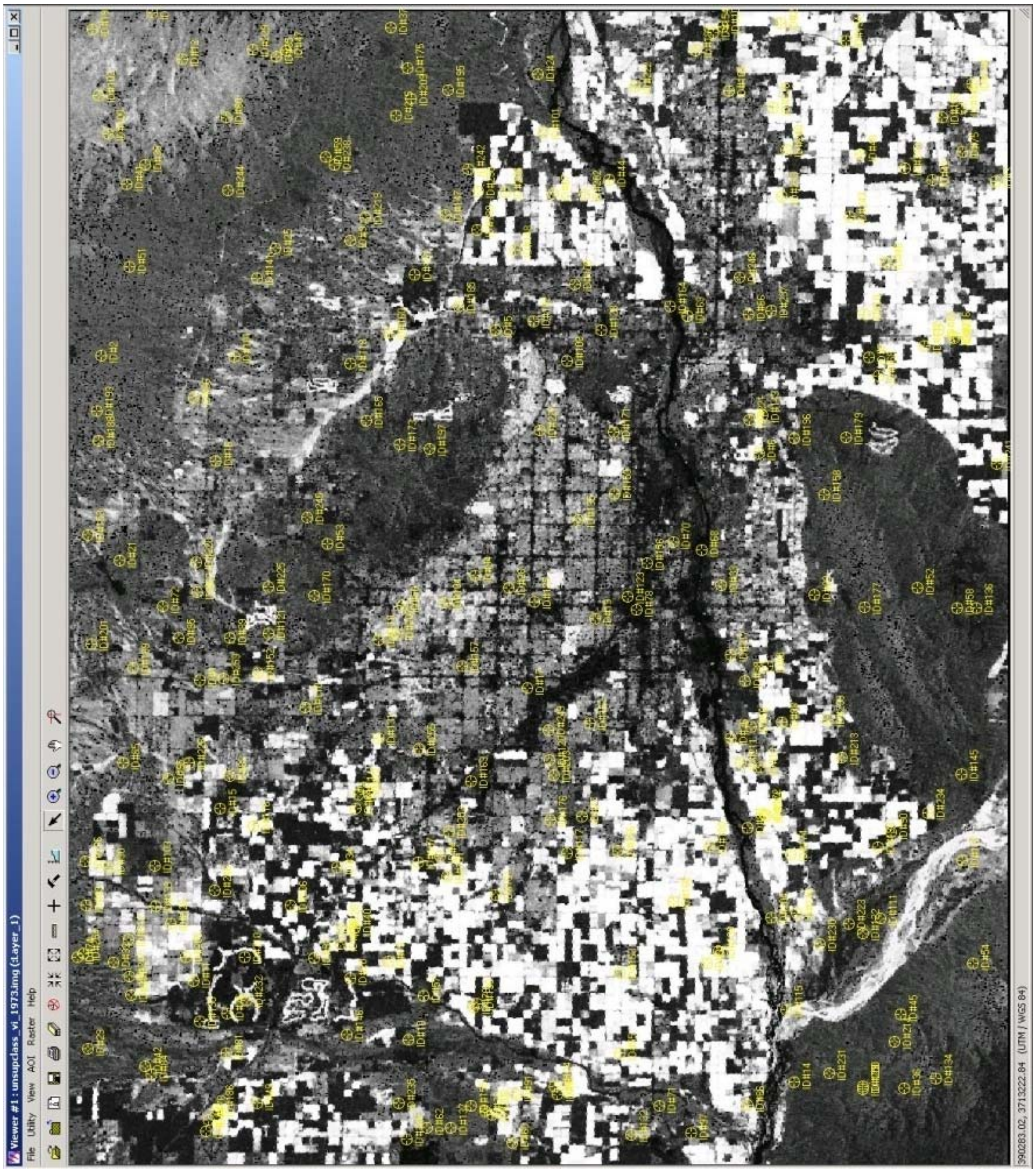


Image 71 - Random points from Accuracy Assessment from Landsat MSS 1973

(Robert Bizaj; April 11, 2009)

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : c:/mm/vi/unsupclass_vi_1973.img
User Name : Robert Bizaj
Date : Mon Apr 13 22:47:00 2009

ERROR MATRIX

Reference Data

Classified Data	Unclassifi	Class 1	Class 2	Class 3
Unclassified	9	0	0	0
Class 1	0	3	0	0
Class 2	0	3	24	0
Class 3	0	0	6	15
Class 4	0	0	0	1
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	9	6	30	16

Reference Data

Classified Data	Class 4	Class 5	Class 6	Class 7
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	14	0	0	0
Class 5	6	19	0	0
Class 6	0	4	20	0
Class 7	0	0	7	10
Class 8	0	0	0	5
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	20	23	27	15

Reference Data

Classified Data	Class 8	Class 9	Class 10	Class 11
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	13	0	0	0
Class 9	3	9	0	0
Class 10	0	4	6	0
Class 11	0	0	4	5
Class 12	0	0	0	1
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	16	13	10	6

Reference Data

Classified Data	Class 12	Class 13	Class 14	Class 15
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0
Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	0	0	0	0
Class 12	5	0	0	0
Class 13	2	7	0	0
Class 14	0	1	2	0
Class 15	0	0	0	2
Class 16	0	0	0	0
Class 17	0	0	0	0
Class 18	0	0	0	0
Class 19	0	0	0	0
Class 20	0	0	0	0
Column Total	7	8	2	2

Reference Data

Classified Data	Class 16	Class 17	Class 18	Class 19
Unclassified	0	0	0	0
Class 1	0	0	0	0
Class 2	0	0	0	0
Class 3	0	0	0	0
Class 4	0	0	0	0
Class 5	0	0	0	0
Class 6	0	0	0	0
Class 7	0	0	0	0
Class 8	0	0	0	0

Class 9	0	0	0	0
Class 10	0	0	0	0
Class 11	1	0	0	0
Class 12	0	0	0	0
Class 13	0	0	0	0
Class 14	0	0	0	0
Class 15	0	0	0	0
Class 16	1	0	0	0
Class 17	1	2	0	0
Class 18	0	0	3	0
Class 19	0	0	3	14
Class 20	0	0	0	2
Column Total	3	2	6	16

	Reference Data	
Classified Data	Class 20	Row Total
Unclassified	1	10
Class 1	1	4
Class 2	0	27
Class 3	0	21
Class 4	0	15
Class 5	0	25
Class 6	0	24
Class 7	0	17
Class 8	0	18
Class 9	0	12
Class 10	0	10
Class 11	0	10
Class 12	0	6
Class 13	0	9
Class 14	0	3
Class 15	0	2
Class 16	0	1
Class 17	0	3
Class 18	0	3
Class 19	0	17
Class 20	17	19
Column Total	19	256

----- End of Error Matrix -----

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	9	10	9	---	---
Class 1	6	4	3	50.00%	75.00%
Class 2	30	27	24	80.00%	88.89%
Class 3	16	21	15	93.75%	71.43%
Class 4	20	15	14	70.00%	93.33%
Class 5	23	25	19	82.61%	76.00%
Class 6	27	24	20	74.07%	83.33%
Class 7	15	17	10	66.67%	58.82%
Class 8	16	18	13	81.25%	72.22%
Class 9	13	12	9	69.23%	75.00%
Class 10	10	10	6	60.00%	60.00%
Class 11	6	10	5	83.33%	50.00%
Class 12	7	6	5	71.43%	83.33%
Class 13	8	9	7	87.50%	77.78%

Class 14	2	3	2	100.00%	66.67%
Class 15	2	2	2	100.00%	100.00%
Class 16	3	1	1	33.33%	100.00%
Class 17	2	3	2	100.00%	66.67%
Class 18	6	3	3	50.00%	100.00%
Class 19	16	17	14	87.50%	82.35%
Class 20	19	19	17	89.47%	89.47%
Totals	256	256	200		

Overall Classification Accuracy = 78.13%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.7654

Conditional Kappa for each Category.

Class Name	Kappa
Unclassified	0.8964
Class 1	0.7440
Class 2	0.8741
Class 3	0.6952
Class 4	0.9277
Class 5	0.7363
Class 6	0.8137
Class 7	0.5626
Class 8	0.7037
Class 9	0.7366
Class 10	0.5837
Class 11	0.4880
Class 12	0.8286
Class 13	0.7706
Class 14	0.6640
Class 15	1.0000
Class 16	1.0000
Class 17	0.6640
Class 18	1.0000
Class 19	0.8118
Class 20	0.8863

----- End of Kappa Statistics -----