THE USE OF GEOSPATIAL TECHNOLOGIES TO EXAMINE SPATIAL AND TEMPORAL CHANGES OF AQUACULTURE COMPLEXES IN THE DELTA REGION OF MISSISSIPPI, 1984 TO 2001

By

John Storelli

A Thesis
Submitted to the Faculty of Mississippi State University In Partial Fulfillment of the Requirements for the Degree of Masters of Science in Geosciences in the Department of Geosciences

Mississippi State, Mississippi

May 2005
Name: John Storelli

Date of degree: May 7, 2005

Institution: Mississippi State University

Major Field: Geosciences

Major Professor: Dr. John Rodgers

Title of Study: THE USE OF GEOSPATIAL TECHNOLOGIES TO EXAMINE SPATIAL AND TEMPORAL CHANGES OF AQUACULTURE COMPLEXES IN THE DELTA REGION OF MISSISSIPPI, 1984 TO 2001

Pages in Study: 73

Candidate for the Degree of Masters of Science

This thesis used geographic information systems and remote sensing to measure expansion of aquaculture Northwest Mississippi. A feature extraction technique was used to identify aquaculture from satellite imagery. Variations in well water depth were examined in relation to the changes in aquaculture to explore its affects on the Mississippi River Valley Alluvial Aquifer (MRVA) aquifer. A soil moisture index was used to investigate preferential expansion of aquaculture onto soil moisture types. This study found that aquaculture expanded from 66,000 acres in 1984 to 142,000 acres in 2001. Total acreage of individual counties from the Feature Extraction is higher than estimates provided by the Mississippi Agriculture Statistics Service. It was found that aquaculture expansion covered more acres of wet soil classes than dry soil classes and the volumes of expansion onto moist soils depth time series were highly variable across the study area and showed no conclusive relationship to aquaculture expansion.
DEDICATION

I would like to dedicate this work to my parents; my father the late John Storelli Sr. and my mother Mary Storelli. Without their love and support this would have never been possible. I would also like to dedicate this project to my wife Suzanne. If it weren’t for her support/ coercion, I would never have had the will to continue, and for that I thank her.
ACKNOWLEDGMENTS

I would like to bestow my sincere gratitude to Mississippi State University’s Department of Geosciences for providing me with a teaching assistantship, without which, I would have not been able to attend graduate school. I would specifically like to thank my graduate advisor Dr. John Rodgers for all his help and support throughout my graduate studies and especially for his dedication helping me complete my thesis. I would also like to thank my graduate committee, Dr. William (Bill) Cooke and Dr. Scott Samson for their guidance throughout my graduate studies and their direction through completing my thesis. A second thanks goes out to Dr. Cooke for his role in providing me with a Feature Analyst license. Dr. John Mylroie deserves special thanks for providing assistance in getting me to MSU in the first place. I would like to thank Ducks Unlimited for providing me technical assistance and data necessary to complete my thesis the most inexpensive way possible. I would like to thank The Mississippi Department of Environmental Quality, most specifically Pat Phillips, for her role in providing me well data, answering my interview questions and graciously putting up with my pestering over the past year. I would like to thank Information Management Systems, with a special thanks to Gary Hennington for his support over the past year and for providing me with the tools and time necessary to complete this work.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
</tr>
<tr>
<td>CHAPTER</td>
</tr>
<tr>
<td>I. Introduction</td>
</tr>
<tr>
<td>II. Literature Review</td>
</tr>
<tr>
<td>2.1 History of Aquaculture</td>
</tr>
<tr>
<td>2.2 History of Aquaculture in the United States</td>
</tr>
<tr>
<td>2.3 Global Growth of the Aquaculture Industry</td>
</tr>
<tr>
<td>2.4 The Mississippi Delta</td>
</tr>
<tr>
<td>2.5 Aquaculture in the Delta</td>
</tr>
<tr>
<td>2.6 Geospatial Technology and Aquaculture</td>
</tr>
<tr>
<td>2.6.1 Remote Sensing</td>
</tr>
<tr>
<td>2.6.2 Feature Extraction</td>
</tr>
<tr>
<td>III. Study Area</td>
</tr>
<tr>
<td>3.1 Location</td>
</tr>
<tr>
<td>3.2 Climate of the Delta</td>
</tr>
<tr>
<td>3.3 Delta Geography</td>
</tr>
<tr>
<td>3.4 Delta Soils</td>
</tr>
<tr>
<td>IV. Methods</td>
</tr>
<tr>
<td>4.1 Data Acquisition and Preprocessing</td>
</tr>
<tr>
<td>4.1.1 Aquaculture Complexes</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Results of multiple means comparison test of difference in well depth from From 1984 to 2001 for selected Delta counties. Significance = 0.05….</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location map of the study area, the Mississippi Delta</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>Location of the Landsat scenes used to extract aquaculture complexes</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>An example section of the Soil Moisture Index</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>This is an illustration depicting the aquaculture complexes delineated from the feature extraction process from the 1984 satellite imagery</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>This is an illustration representing the aquaculture complexes delineated from the feature extraction process from the 1992 satellite imagery</td>
<td>43</td>
</tr>
<tr>
<td>6</td>
<td>This is an illustration representing the total change in aquaculture complex acreage by county from 1984 to 1992</td>
<td>44</td>
</tr>
<tr>
<td>7</td>
<td>This is an illustration of the aquaculture complexes as delineated from the feature extraction process from the 2001 satellite imagery</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>This is an illustration of the total change of aquaculture acreage from 1992 to 2001</td>
<td>47</td>
</tr>
<tr>
<td>9</td>
<td>This is an illustration of the total change of aquaculture acreage by county from 1984 to 2001</td>
<td>48</td>
</tr>
<tr>
<td>10</td>
<td>Comparison of aquaculture complex acreage values between estimates from using Feature Extraction of satellite imagery (FE, black-shaded bar and estimates provided by MASS (2005; MASS, grey-shaded bars)</td>
<td>50</td>
</tr>
<tr>
<td>FIGURE</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Mean differences between well water depths from 1984 to 2001. County values represent an average of six wells per county. Humphreys, Leflore, and Sunflower Counties have high amounts of aquaculture complexes. Bolivar, Quitman, and Tunica Counties have moderate to low amounts of aquaculture counties. Warren County has relatively no aquaculture complexes</td>
<td>51</td>
</tr>
<tr>
<td>12</td>
<td>Depth of water for selected individual wells from major aquaculture producing counties</td>
<td>55</td>
</tr>
<tr>
<td>13</td>
<td>Aquaculture complexes located on SMI moist soil classes, 1984, 1992 and 2001</td>
<td>57</td>
</tr>
<tr>
<td>14</td>
<td>Aquaculture complexes located on SMI dry soil classes, 1984, 1992, and 2001</td>
<td>57</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

This thesis uses geospatial techniques (remote sensing and geographic information systems, GIS) to quantify the expansion of aquaculture complexes in the Mississippi Delta from 1984 to 2001. Additionally this thesis investigates preferential expansion of aquaculture complexes onto moist soils and whether changes in aquaculture complex extent are associated with variations in well water depth.

Aquaculture is the rearing of aquatic species in a controlled or semi-controlled environment for harvesting as a food product (Landau, 1992). Several types of aquatic species such as salmon, mollusks, crayfish and shrimp are farmed around the world as food products, and the United States is no exception. In fact aquaculture has become one of the world’s fastest growing food-producing industries, and it is the fastest growing component of U.S. agriculture (Irwin and Geoghegan, 2001). In the Delta region of Mississippi the channel catfish has become the predominant aquaculture species. In Mississippi the channel catfish has become more than just a means of food production and economic stimulation. Not only are catfish a popular food item on most restaurant menus and outdoor venues, the catfish has become an integral part of Mississippi culture and lore. This is evidenced by the crowning of the Catfish Queen at the annual Catfish Festival held in Belzoni Mississippi. The cultural acceptance and embracement of the
catfish is further represented by Humphreys County Mississippi officially claiming to be the Catfish Capital of the World. Mississippi has become one of the world’s foremost producers of channel catfish and leads the nation in total acreage and production of channel catfish aquaculture (Landau, 1992). In the Delta region of Mississippi, channel catfish farmers predominantly use an open pond method for rearing fish (Merlo, 2003), which relies on large quantities of clean freshwater. Clean freshwater is necessary for the growth of a healthy stock of non-off flavor fish. In the Mississippi Delta, supplies of freshwater for agriculture are almost exclusively withdrawn from the Mississippi River Valley Alluvial Aquifer (Byrd, 2002).

The Delta of Mississippi is a major agricultural center in edition to being one of the largest areas of aquaculture complexes in the world. In edition, it is known that other forms of agriculture in the Delta also use large quantities of water for the production of crops such as rice. The amount of water required per pound of an aquaculture product is often much greater than that necessary for the production of other types of agricultural products (Yoo and Boyd, 1994). Thus, the expansion of channel catfish aquaculture in the Delta in conjunction with other forms of agriculture will lead to greater irrigation demands on the aquifer. This could potentially reduce the water levels in the MRVA and lower the groundwater table.

Prior to European colonization, the Delta was covered with vast acres of bottomland hardwood forests. These forests existed within hydric soil conditions. Bottomland hardwood forests are known to reduce flooding by slowing the flow of water and helping with groundwater recharge. These forests also have a high biodiversity and
are an important element of the Delta landscape. Any attempt to restore these bottomland hardwood forests would necessitate the use of areas with moist soil or hydric conditions. Therefore, expansion of aquaculture, especially if it is found to be occurring mostly on moist soil types, would potentially reduce the area of bottomland hardwood forest reforestation. Although many aquaculture complexes are built on existing agricultural lands, and that these same areas would still be agricultural even if aquaculture complexes did not exist, knowing that aquaculture expansion is preferential onto moist soils would be valuable information to managers and planners of Deltas natural areas.

Studying the spatial and temporal relationship of aquaculture using traditional means of surveying and agronomy would be a daunting task. Geospatial tools, including geographic information systems (GIS) and remote sensing (RS), assist an educated analyst to examine changes in the landscape with increased proficiency, potentially reducing the number of man hours, staff and monetary expenditures. GIS and RS have many capabilities that aid the study of spatial and temporal relationships. RS is defined as “the art and science of obtaining information about an object without being in direct physical contact with the object. It is a scientific technology that can be used to measure and monitor important biophysical characteristics and human activities on Earth” (Jenson, 2000). GIS is defined as “A system for entering, storing, manipulating, analyzing, and displaying geographic or spatial data” (Lyon and McCarthy, 1995). Given these definitions, remote sensing offers the ability to quantify changes in the landscape over time and to examine the factors of change across time, while GIS offers the ability to quantitatively analyze these relationships.
This study used both GIS and RS to investigate the growth and spatial distributions of aquaculture complexes in the Delta from 1984 to 2001. The main objectives of this study are (1) to measure aquaculture complexes throughout the study time period, (2) to examine variations in well water data in relation to aquaculture expansion, and (3) to determine if aquaculture occurs preferentially onto moist soil types. The specific objectives of this study are to first measure the acreage of aquaculture complexes from the available satellite imagery dates of 1984, 1992, and 2001. These measurements were then used to calculate expansion of the aquaculture complexes over time. Water well depth from each county of the study area (part of the MRVA aquifer) were examined to determine if major variations in the water table coeval with aquaculture expansion. Aquaculture complexes were then compared to a soil moisture index to test if expansion was preferential within moist soil types. The three main hypotheses of this thesis are:

1) Aquaculture complexes in the Delta have greatly expanded from 1984 to 2001, and this expansion can be successfully quantified using Feature Extraction techniques.

2) The expansion of aquaculture has resulted in greater aquifer depletion for wells located within the Delta.

3) Aquaculture has expanded preferentially onto moist soil types.
CHAPTER II
LITTERATURE REVIEW

2.1 History of Aquaculture

Aquaculture, the practice of rearing aquatic organisms under controlled or semi-controlled environments, is a form of agriculture (Landau, 1992). This form of agriculture has been used by mankind for over 2000 years to grow food in an organized fashion. It is not known who first developed or practiced aquaculture, however, an Egyptian bas-relief on the tomb of Aktihep (2500 B.C.) shows what scholars believe to be men harvesting fish from a pond (Landau, 1992). There are several other historical accounts of aquaculture being practiced throughout the world. In China it is well documented that aquaculture, specifically carp, were spawned and reared around the same time that the Egyptians were raising Tilapia, circa 2500 B.C. However, it is believed that in China aquaculture was twice that old (Landau, 1992). The Romans are also known to have practiced aquaculture off the coast of Italy, a skill thought to have been passed down from the Egyptians by way of the Phoenicians and Etruscans (Landau, 1992). The Hawaiians are known to have started farming fish around 1000 A.D. They used ponds to catch, store and grow brackish organisms such as shrimp, mullet and milkfish (Landau, 1992). The Germans and French are known for their perfection of trout
hatcheries during the 1700’s and 1800’s as a response to increased sport fishing (Landau, 1992).

2.2 History of Aquaculture in the United States

Aquaculture in the United States began around 1853 with the first experimental fish farm near Cleveland Ohio (Landau, 1992). However, aquaculture did not establish itself in the United States until 1871 when Spencer F. Baird became the first U.S. Commissioner of Fish and Fisheries (Landau, 1992). Just a little over a decade later the first marine fish hatchery was established near Woods Hole, Massachusetts by the U.S. Fish Commission. By 1917 three U.S. fish hatcheries produced nearly three billion fish per year, mostly of the species Pollack, Flounder, Cod and Haddock (Landau, 1992).

Aquaculture has dramatically increased in number of species grown and volume produced since its inception in the United States. It was estimated that in 1987 aquaculture production in the U.S. reached 13.1 million metric tons, which translates to nearly 13% of the world’s aquaculture harvest (Landau, 1992). Aquaculture in the United States has been experiencing rapid growth as a science and an industry, with an estimated 15% annual growth rate since 1980 (McVey, et al., 1992).

In the United States, aquaculture has been a growing industry throughout the last three decades. There were 987 operating catfish farms in 1982, however that figure has risen to 2003 by 1988 (Landau, 1992). The United States has experienced a 600% increase in production of aquaculture since 1980, and in 1985 the United States was
among the top five aquaculture producing countries in the world. These included China, Japan, Korea, and the Philippines (Landau, 1992).

In the United States, channel catfish is the predominant species reared in aquaculture. It is estimated that there are more catfish grown in the United States than all other species combined (Landau, 1992). Early research and development in the catfish industry, from 1955 through 1970, occurred in Arkansas where the Buffalo fish culture was established and about 10,000 acres of ponds were devoted to channel catfish production (Tucker and Robinson, 1990). Mississippi ranks first in total U.S. catfish production, contributing more than 75% of all channel catfish consumed nationwide (Humphreys County, 2003). Channel catfish has grown as an industry in the Delta over the last two decades, experiencing a growth rate of up to 10% annually, (Robinson and Avery, 2000) and by 1990 Mississippi already represented 75% of the total channel catfish industry (Tucker and Robinson, 1990).

2.3 Global Growth of the Aquaculture Industry

Throughout history fish have been valuable sources of nutrients, most notably protein. It is estimated that fish make up about 16% of animal protein intake and this is expected to rise especially in developing countries (Bardach, 1997). The world has increased its demand for fish as can be deduced from the world fish catch records. The world’s fish catch increased nearly 25 fold from an estimated catch of 4 million metric Tons in 1900 to an estimated catch of 100 million metric Tons in 1995 (Bardach, 1997).
It is not surprising that many of the world’s fisheries are no longer productive and some have even been capped with moratoriums and quotas. The moratorium on the fisheries industry off the coast of Newfoundland Canada is one example of the ecological destruction of a natural resource caused by unsustainable management practices or the lack of management practices altogether (Beltempo, 2003). The increased demand for fish protein due to human population stress coupled with the decrease in fisheries production leads directly to the conclusion that the world’s consumable fish demands will have to be met through aquaculture. It is estimated that aquaculture production will have to increase sevenfold from the current 11 million metric Tons, to approximately 77 million metric Tons by the year 2025 to meet the demands of the global population (Irwin and Geoghegan, 2001).

2.4 The Mississippi Delta

The Delta of Mississippi is not a typical delta in the geologic sense of the term, which in general refers to a triangular shaped alluvial deposit at the mouth of a river. The Delta is actually the flood plain of the Mississippi River in Northwest Mississippi. In these terms the Delta is a geographical region not a geological formation.

The Delta has rich alluvial soils as well as a rich cultural history. The cotton industry was initially attracted to this area for its deep dark nutrient rich soils. The Mississippi River had naturally deposited rich nutrients throughout the Delta allowing a
build up of alluvial soils over time. Cotton farmers were interested in manipulating the nutrient laden soils for cotton production and profit.

This area however, was covered with an extensive thick forest filled with many species of flora and fauna. Early settlers and explorers described the area as wild and jungle like. William Faulkner (a renowned writer from Mississippi) describes his impression of the Deltas wilderness.

The rich, deep, black alluvial soil which would grow cotton taller than the head of a man on a horse, already one jungle, one brake, one impassable density of briar and cane and vine interlocking the soar of gum and cypress and hickory and pin oak and ash, printed now by the tracks of unalien shapes, bear and deer and panthers and hogs and wolves and alligators and a myriad of smaller beasts, and unalien man to name them, too, perhaps in the trackless infested forest (As quoted by William Faulkner, Delta Land Trust, 2003).

Although early cotton plantations were scattered throughout the Delta in the Antebellum South, the Delta still held many of its natural characteristics. A local inhabitant of the 1930’s describes them as “On the Mississippi River front and along the smaller streams and lakes there were great cotton plantations and some beautiful and wealthy homes. However for each plantation there were miles of “wild lands” inhabited only by wild animals” (Lowery, 1937).

Delta forests are in large part bottomland hardwood forests. This type of forest is well adapted to the annual flooding of the Mississippi River and they play a vital role in reducing massive flooding by temporarily storing large volumes of water and slowing the rate of speed at which water flows over land. Bottomland forests also recharge groundwater and reduce soil erosion (Delta Land Trust, 2003).
The Delta held most of its wild characteristics until the passage of the Swamp Lands Act of 1849 and 1859, which the federal government deeded to the states over 20 million acres of swamp lands for regional settlement (Delta Lands Trust, 2003). After the Swamplands Act of 1849 and 1859 were passed, thousands of farmers moved west into the Delta. As the population grew, farmers cleared forests, drained swamps and cultivated row crops consisting mostly of cotton (National Parks Service, 2003).

After the Civil War the cotton plantation system was gone but agriculture in the Delta remained. The timber industry boomed during the late 19th century in response to demands for timber and to clear more land for agriculture. By the early 20th century Midwest timber companies exploited the Delta's forests to near extinction and virtually depleted cypress forests from the region (National Parks Service, 2003). Bottomland hardwood forests were exhausted as well. The Delta Land Trust (2003) state that the Delta initially had approximately 24 million acres of bottomland hardwood forested wetlands, by 1937 only about 12 million acres remained. Since that time another 6.5 million acres have been cleared leaving less than 5.2 million acres in bottomland hardwoods. Approximately 20% of the original acreage of bottomland hardwood forests remains today (Delta Land Trust, 2003).

In much of the early 20th century, cotton was the predominant crop grown in the Delta, although some corn, rice and wheat were also grown. After the 1950’s soybeans overtook cotton as the dominant cash crop. In 1977, more acreage of soybeans were grown than the combination of the four other major crops of cotton, wheat, rice and corn (Delta Land Trust, 2003). Soybeans were an integral part of the agricultural landscape of
the Delta but wouldn’t remain; increased production costs mixed with volatile prices and decreasing profits drove many Delta farmers out of the soybean business (Merlo, 2003). With the traditional agricultural system failing, many Delta farmers began looking toward aquaculture as a potential solution.

2.5 Aquaculture in the Delta

Aquaculture came to the Delta in 1965 when J.B. Williamson dug his first catfish pond in Humphreys County Mississippi (Humphreys County, 2003). In 1976 Governor Cliff Finch proclaimed Humphreys County Mississippi to be “The Catfish Capital of the World”. At that time Humphreys County Mississippi had 6000 acres of channel catfish ponds, more than any other county in the nation. Humphreys County claimed over 35,000 acres of channel catfish ponds in 2003, still more than any other county in the nation (Humphreys County, 2003).

There are several reasons why channel catfish aquaculture came to the South and particularly the Mississippi Delta. Channel catfish are generally a hardy species that can adapt well to a wide range of temperatures (Aquaculture.com, 2003). They are also tolerant to crowding allowing many fish per pond, and adapt well to a variety of rearing techniques. They are easy to spawn and large numbers of fry (juvenile catfish) are easily obtained for subsequent harvests. Additionally channel catfish have a high feed conversion value, which makes them more profitable than some of the other species of catfish (Aquaculture.com, 2003). Perhaps one of the most marketable characteristics of
the channel catfish is that the flesh of the channel catfish is firm and white with few intramuscular bones and a mild flavor (Aquaculture.com, 2003).

The second criterion of the successful aquaculture industry in the Delta is geographic in nature. The lay of the land, infrastructure and the widely available natural resources made the Delta the perfect location for catfish farming. Farmers in the Delta had already established the basis of large scale farming from their previous agricultural endeavors (Tucker and Robinson, 1990). This infrastructure allowed an easy transition into aquaculture from traditional row crop agriculture. The flat topography and clay-based soils in the Delta of Mississippi are a perfect combination for inland pond style aquaculture. The fact that the Delta area of Mississippi had an abundant supply of groundwater only added to the prospect of profitability in aquaculture. The variables of flat land, clay based soils and abundant water supply coupled with the intact agricultural infrastructure made the Delta region of Mississippi the perfect location for channel catfish aquaculture.

These near perfect conditions for aquaculture have led to a booming industry in the Delta. Unfortunately they have also enabled the Delta to remain devoid of much of its original ecology, due to its deforestation and continual use in the agriculture and aquaculture industries. A sustainable balance between the food production needs of the population and the ecological protection needs of the environment are imperative to the sustainability of the industry, the natural resources and the people dependent upon them (FAO, 1991). In 1991 the Food and Agriculture Organization (FAO, 1991) defined sustainable development as the following,
The management and conservation of the natural resource base, and the orientation of technical and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generation. Such sustainable development conserves land, water, plant and animal genetic resources, is economically viable and socially acceptable.

Growth of the aquaculture industry in the Delta should be monitored to ensure sustainable development and management practices. The rapid growth of aquaculture worldwide has raised questions about aquaculture’s sustainability. Technical assistance organizations and governmental agencies have considerable interest in the sustainability of aquaculture in developing nations that are still developing an aquaculture industry, and in developed nations with well established aquaculture industries (Nath, et al, 2000). The sustainability of any industry using natural resources should be monitored to ensure proper use of the resource and to protect the natural environment from destruction. The aquaculture industry should also have considerable interest in sustainability as to ensure its own future market and profitability.

2.6 Geospatial Technology and Aquaculture

Geospatial technology, including geographic information systems (GIS) and remote sensing (RS), may be the best approach for quantifying the expansion of the aquaculture industry and measuring its effect on the environment. GIS is an organized collection of computer hardware, software, geographic data, procedures and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (Lyon and McCarthy, 1995). Additionally, GIS
can be thought of as the concept of using spatially referenced geographic information arranged in overlapping layers to help users better understand spatial relationships between features and their surroundings on the landscape. Each layer of a GIS contains a different type of spatial data, e.g. roads, rivers, soils, or political boundaries. When these layers are laid over one another, the relationships between features can be identified, manipulated, and analyzed. A very simple example might be that a user wants to know the location of bridges in a particular county. GIS can answer this question by using a roads layer overlaid with the rivers layer. One can easily deduce that bridges will be located where roads cross rivers.

2.6.1 Remote Sensing

Remote Sensing (RS) is the ability to obtain information about an object using a sensing device without that device being in direct contact with that object. One common type of RS involves the interpretation of satellite imagery. Images from satellites provide the ability to gather information about landscape changes at a regional scale. For example, Yang and Lo (1999) used satellite imagery to quantify landscape changes in the rapidly developing Atlanta, GA area. Similarly, Seto (2002) was able to use satellite imagery to measure changes in land use along the Pear River Delta. By using brightness, wetness, and greenness values, as interpreted from satellite images spanning multiple time periods, Seto developed a map showing areas that either converted from agriculture or natural vegetation into urban areas. His results indicate that the area of study
experienced an urbanized growth of over 300% between 1988 and 1996. A comparison of computer output and field studies tested, showed an accuracy of this land use change to be 93.5%. This high accuracy shows that remote sensing can be an effective method for quantifying land use land cover changes.

2.6.2 Feature Extraction

Feature extraction is a type of RS technique that has great potential for delineating aquaculture complexes. Feature extraction uses specified algorithms to determine how spatial and spectral pattern recognition of particular features is associated with their surroundings on the landscape. (Visual Learning Systems, 2005) Feature Analyst then makes decisions on that feature based on parameters set by the user. These techniques generally have a two-step operation. In the first step, useful information is separated from the noise and in the second step the dimensionality of the data is reduced in order to simplify calculations performed by the classifier (Swain, 1978). The Nature Conservancy (2003) used feature extraction to help develop their Wyoming Chapters landscape-level conservation plan. They compared standard image processing techniques such as texture algorithms and convolution filtering using ERDAS Imagine, with the ArcGIS extension Feature Analyst created by Visual Learning Systems. The main objective of this study was to develop a risk assessment for two study areas, while comparing high and low resolution imagery as well as comparing the two feature extraction techniques. The study determined that the standard remote sensing techniques worked best, especially when
using edge detection algorithms in open areas. Areas with rough terrain and forested areas are found to more difficult to extract target features using both systems. A feature extraction technique should work well in detecting aquaculture complexes on the landscape of the Mississippi Delta because the relatively flat terrain will not project shadows that distort the analysis and the catfish ponds should be easily distinguishable from the other agricultural features on the Delta landscape.

Geospatial techniques have been used to monitor several features on the landscape, and are perhaps the best media for measuring spatial changes over time. Two questions in particular can be answered with these geospatial tools: where are land-use changes likely to take place (location of change) and at what rates are changes likely to progress (quantity of change). This information can then be applied to developing sustainable management practices and environmental protection (Xiuwan, 2002). In addition several assessments on biophysical process, land degradation, ecosystem stability and diversity among others can also be determined (Veldkamp, 2001). In a similar manner to how they have been used elsewhere, GIS and RS technologies could be combined to provide general planning for aquaculture development as well as to identify and rank individual locations best suited for aquaculture development (Kapetsky, 1987).

The benefits of GIS and RS have yet to be fully applied to the aquaculture industry, however, Salam and Ross (1999) used GIS to detect suitable locations for aquaculture in Bangladesh. In this study the authors used Landsat TM data to identify water bodies, the extent of brackish water, and the type of land use. A GIS database was then created that contained locations of proximal cities, roads and processing plants to the
conditions described above. The authors theorized that locations with features including water availability, well-maintained infrastructure, good growth performance, and land availability would be critical factors contributing to the success of aquaculture. Areas that exhibited these attributes were then identified and used in computer generated models in conjunction with elevation data to determine the best locations.
CHAPTER III

STUDY AREA

3.1 Location

The Mississippi Delta is part of the greater Mississippi Alluvial Valley which extends from southern Illinois to the north, and southward through southeastern Louisiana where it exits into the Gulf of Mexico (USDA and Ducks Unlimited, 2001). The Mississippi Delta however, is located in the northwest portion of the state and is bordered by the Mississippi River to the West and the bluff hills to the east. Specifically, it extends in area from the northern boundary of Mississippi south to Vicksburg, and from Greenwood east to Greenville. Although the Delta spans 19 counties, portions of some counties are outside the study area. This is important with respect to aquaculture, in that preliminary research showed no significant amount of catfish ponds are in these areas. Areas west of the study area are bordered by the Mississippi River levee.

Areas between the levee and the river were not considered for analysis because these areas are frequently flooded. Catfish would be swept away with the rising waters in these areas. Therefore, they are considered to be out of the scope of this project. Counties east of the study area are considered outside the scope of this study as the bluff hills are commonly considered to be the border of the Delta. The general Delta general, the
hydrography, major transportation routs and governmental boundaries of the area are shown in Figure 1.

Figure 1: Location map of the study area, the Mississippi Delta
According to studying the analysis of the Delta’s geospatial data, the area comprises approximately 4,202,483 acres or 6,566 square miles, and is nearly 180 miles long and 65 miles wide at its greatest extents. Through studying topographic maps of the region it is evident that the area is a flat lying floodplain formed by the meandering Mississippi River. Review of regional topographic maps also reveals that elevation in the Delta is primarily consistent with few measurable changes however; the highest elevation reaches greater than 210 feet above mean sea level at the Northern end with the lowest point just below 100 feet above mean sea level at the southern end. This dip in elevation suggests that the Delta has a general slope southward, which follows the flow direction of the Mississippi River towards the Gulf of Mexico.

3.2 Climate of The Delta

The Delta climate is described by Mississippi Information (Mississippi Information, 2005). The Delta has a warm, humid climate with long hot summers and short mild winters. Temperatures average about 28°C (~ 82°F) in July and about 9°C (~ 48°F) in January. This area receives approximately 1,270 mm (~ 50 in.) in yearly precipitation. Although it rarely snows in the Delta small amounts have been known to precipitate in the area during the coldest months of the year. The Delta is subject to tornadoes that strike most often between February and May (Mississippi Information, 2003).
3.3 Delta Geography

Further reviews of topographic maps of the area reveal major geographic features of the area to include one of the most famous rivers in the world, the Mississippi River. Other river systems in the Delta include the Yazoo River, Bogue Phalia River, Sunflower River, Coldwater River, Tallahatchie River and Yalobusha River. Oxbow lakes left behind from the continuous meanderings of these rivers are common in the Delta.

3.4 Delta Soils

The following soils information of the Delta is described by A Soil Moisture Index for the Mississippi Alluvial Valley Using Landsat ETM+ (USDA and Ducks Unlimited, 2001). The soils of the Delta are a result of the deposits of the Mississippi River and its secondary streams or tributaries. These soils are made up of a mixture of sediments washed down from several types of parent materials consisting of soils, rocks and unconsolidated sediments. Natural levees were formed by the sandy and loamy deposits settling out first followed by finer materials such as silts and clay. This is the result of the natural deposition of heavier sediments depositing during higher flows, while finer materials settled out during times of slower flow. In the areas further from the river channels, water was able to stand as backwater. In these areas fine materials settled creating clayey beds. The major soil type in the Delta consists of the Sharkey series. Sharkey soils are generally defined as consisting of very fine materials which are poorly
drained. These soils have a slope gradient no greater that five percent and are usually
dark in color ranging from dark grey, yellow to red (USDA and Ducks Unlimited 2001).
CHAPTER IV
METHODS

4.1 Data Acquisition and Preprocessing

This section will describe the type of data used in the research, the data sources, and how the data were preprocessed for analysis with GIS and remote sensing. Specifically it will describe the methods used to process the satellite imagery including the use of Feature Analyst and the derivation of aquaculture data thereof. Soils data will also be discussed as derived from a soil moisture index. Well depth information from Mississippi Department of Environmental Quality’s Semi Annual Survey will also be covered.

4.1.1 Aquaculture Complexes

Aquaculture complex data is a derived dataset created to calculate the acreage of catfish ponds in the Delta given the time period of the study. The aquaculture complexes were derived using remote sensing and GIS techniques of feature extraction. Landsat Satellite Imagery was used as the base map for the aquaculture complex feature delineation process. This process was enhanced with the aid of Visual Learning Systems, Feature Analyst software extension to Environmental Systems Research Institutes (ESRI)
ArcView 3.2a, geographic information systems software package. Feature Analyst was developed to assist NASA’s Earth Enterprise Mission. It was an important part of that operation to quickly but accurately identify and classify important features from the landscape (NASA, 2003). Feature Analyst was used to quickly identify and delineate the aquaculture complexes on the Deltas landscape, while GIS was used to quantify acreage change over the time period of this study.

4.1.2 Satellite Imagery

Satellite imagery was used with this project as the source data for extracting catfish pond features. This data was acquired from Ducks Unlimited with permission to use the data for this project. Six scenes were used in this project spanning the time period from 09/20/84, 05/05/92 and 09/11/01. Each Landsat scene encompasses a greater region than the study area, therefore each scene was subset to the study area to reduce size and increase manageability of the data. Each date requires both scenes of path 23, row 36 and of path 23, row 37 to encompass the study area. The Landsat images correspond with the swath of path 23, row 36 to cover the northern sections and path 23, row 37 to cover the southern portion of study area. Figure 2 shows the satellite scene footprints used in this study.

Preprocessing involved creating a polygon data layer of the study area using the software package ERDAS Imagine (Leica Geosystems, ERDAS Imagine, 2005). The satellite imagery was then subset to the study area polygon using the same software.
The earliest image taken in 1984 originated from the Landsat 5 satellite which used the Thematic Mapper (TM) sensor. Imagery from 1992 and 2001 originated from Landsat 7, which used the Enhanced Thematic Mapper plus (ETM+) sensor. It was scanned on September 20th, 1984. The mid-range image was obtained on May 5th, 1992 and the latest image was obtained on September 11th, 2001. These dates were chosen because they are clear, cloud free images. It is necessary to mention that there is a significant difference between the seasons of May and September. However, aquaculture is mostly permanent, year-round structures that are not affected by seasonal differences in land-cover. Channel catfish ponds hold water irrespective of season, therefore differences in the dates of imagery is not considered to have affected the analysis of the project. The satellite images are referenced to the Universal Transverse Mercator projection and the North American Datum of 1927.
Figure 2: Location of the Landsat scenes used to extract aquaculture complexes.
4.1.3 Soil Moisture Index

The following information on the soil moisture index (SMI) used in this study is from USDA and Ducks Unlimited (2001). The SMI is a classification of surface soil moisture content during leaf-off precipitation free conditions in the Mississippi Alluvial Valley. It was developed by Ducks Unlimited Southern Regional Office in Ridgeland Mississippi. Satellite imagery from the drought winter of 1999 – 2000 was used in creating the SMI because of the lack of precipitation and the leaf off conditions of the trees. Precipitation free imagery was used in creating the SMI to minimize confusion between the spectral responses of moist soils, and spectral responses of soils that had recently been precipitated on. The soils in the SMI are exposed soils and bare ground, and they do not include soils under forest or active croplands (USDA and Ducks Unlimited, 2001).

Solar radiation striking the soil will be both absorbed and reflected. The specific electromagnetic radiation wavelengths and the amount of wavelength absorption or reflection by the soil is based on mineral composition, soil moisture, organic matter content, and soil texture (Lillesand and Kiefer, 1987). Estimates for the SMI were made on reflectance of near infrared energy (USDA and Ducks Unlimited, 2001). Soils with higher moisture will absorb more solar energy, especially in the near infrared range, and this can be distinguished from drier soils by satellite sensors (Dwivedi et al., 1999).

The unsupervised classification algorithm (ISODATA) was used with Landsat 7 ETM+ 30 meter pixel resolution satellite imagery to create 220 clustered pixel classes (USDA and Ducks Unlimited, 2001). Classes representing wettest to driest surface soil
moisture were created by individually evaluating each clustered pixel class. The SMI contains seven soil characteristic classifications ranging from 0 to 6. Zero represents areas where a soil reading could not be obtained. Class one represents very wet soils, class two represents wet soils, class three represents intermediate soils, class four represents dry soils, class five represents very dry soils and class six represents water. For the purposes of this study classes one and two were combined to represent moist soils while classes four and five were combined to represent dry soils. Classes zero, three and six were combined to represent all other soils conditions. Satellite resolution merge products, aerial photos, topographic maps and spectral profiles were used to refine each moisture class. Field investigation of the data was performed by Ducks Unlimited in the winter of 2001 in Western Tennessee and Leflore County Mississippi (USDA and Ducks Unlimited, 2001). The SMI is a raster dataset and is projected to the Universal Transverse Mercator (UTM) zone 15 projection with the North American Datum (NAD) of 1927.

There are some accuracy issues that are important to understand when using the SMI. Field investigations indicate that the severe drought experienced in the winter of 1999 caused the wet soil classes to be underestimated and the dry soil classes to be overly inclusive (USDA and Ducks Unlimited, 2001). Also, the reflectance of clay soils in some areas will increase during a severe drought and can actually exceed the reflectance of coarser sandy soils. Ducks Unlimited compared the SMI to the Soil Survey Geographic Database (SSURGO) created by the Natural Resources Conservation Service (NRCS) to determine an agreement assessment. SSURGO data agreement assessment was based on map agreement which is not a measure of accuracy, but rather a relative
measure of agreement between the SMI and related datasets. The assessment of the SMI compared to SSURGO by Ducks Unlimited shows an agreement of the data to be 79% (USDA and Ducks Unlimited, 2001). The conservative nature of the SMI dataset insures that those areas that are classified as “wet” are almost certainly wet in any year (USDA and Ducks Unlimited, 2001). “Therefore, maximum benefit of the SMI will be in applications where the user is locating moist soils, rather than dry areas that may have been classified as a wetter class under more average climatological conditions” (USDA and Ducks Unlimited, 2001).

The original SMI data was obtained in grid format and included the entire Mississippi Alluvial valley. The data were subset to the study area. The previously digitized area of interest was used to clip the data to the study area. A new SMI dataset was created that coincides with the spatial extents of the study area. The raster data was converted to vector polygons that are easily managed and manipulated. Figure 3 shows a portion of the SMI in Northwest Mississippi. This section clearly depicts each classification of the SMI.
Figure 3: An example section of the Soil Moisture Index
4.1.4 Water Well Data

The Mississippi Department of Environmental Quality (MDEQ) provided well data for the study area. This data is taken from the semi-annual survey conducted in spring and fall of each year. The semi-annual survey measures depth to water in feet, of wells in the Mississippi River Valley Alluvial Aquifer (MRVA). This aquifer is a bountiful source of water in the area and is the most intensely developed in the state (Byrd, 2002). The measurements in this survey are gathered twice per year, once in the spring prior to irrigation and once in the fall after irrigation. The same wells are measured each survey barring closure or access restrictions. Approximately 400 wells are measured in the survey each year (Byrd, 2002).

The well data was obtained as separate spreadsheets for each county in the Delta. The separate spreadsheets were then aggregated. Each of the study area county well data was reviewed to ensure a complete record of well information existed throughout the projects timeframe. Six well data tables from each county were then selected to be used for analysis. The selection was based on those tables that had complete spring and fall information and those that most closely matched the time period of the study.

4.2 Analysis

4.2.1 Feature Extraction

The previously subsetted Landsat 5 and 7 imagery were used as the base map for analysis. Feature Analyst extension to ESRI’s ArcView 3.2a was used to extract the
aquaculture complexes from the imagery. The first step in the extraction process consisted of creating a new feature layer, which is the information the software uses during the extraction process. A feature layer in this sense is a dataset designed by the user that the software uses to extract the desired feature from the landscape. Examples of aquaculture complexes were selected or digitized over the imagery as samples for the software to use in the extraction process. Once the target landscape features were successfully selected, the learning process was better designed. The software uses these examples to determine which features to extract from the imagery based on shape and spectral signature. After several trial iterations, it was concluded that the “one button learning process” works better than other options of the software. The parameters executed on the “one button learning process” include selection of non natural or man made features and selection of features greater than five meters. The results are a polygon dataset of the learner’s first attempt to extract the target feature. After a visual inspection of the initial results, it was determined that most of the target features had been extracted correctly. It was also evident that there were several areas where the feature extraction was overly inclusive in areas where target features were lacking.

The next step in the learning process involved creating additive and subtractive cluster layers. This process involves selecting areas that were initially incorrectly extracted that should or should not be part of the target feature. The additive layer includes features that were not initially selected as the target feature, while the subtractive layer includes features originally excluded. After the additive and subtractive polygons were selected and reviewed, the second iteration of the one button learning was
processed. The resulting polygon dataset successfully captured the aquaculture complexes over the study area. However, it also captured the rivers, streams and lakes.

Several trial sessions using different configurations were run to improve the learning process of selecting only aquaculture water features. Each trial session used different techniques using differing combinations of settings choices and the input representation, while setting up the learning process to determine the best technique for running the process on the entire data set. The results of these sessions concluded that too many aquaculture features were sacrificed in order to exclude the natural water features. It was determined that the learning process was more successful when leaving those unwanted water features in the selection and removing them later. This problem was overcome by masking the natural water features out of the imagery after the learning process was complete.

The natural water features mask was also created using Feature Analyst. For the creation of the mask, the one button learning was designed with the parameters that the features are linear and not man made. The first feature layer was created by digitizing polygons of the target features. The one button learner was then implemented and the resulting polygons represented most of the natural water features on the landscape. These features were not as overly inclusive as the aquaculture feature layer. It was determined that with manual deletion of extraneous pixel clusters that this layer could be used as a successful mask. Both the mask and aquaculture datasets were assigned unique record numbers in the attribute tables. The aquaculture and mask layers were then merged within the GIS. The resulting dataset contained the tabular information for both datasets. The
unique record number corresponding to the mask data were then selected and removed from the dataset. This process resulted in a dataset containing only aquaculture polygons.

After review of the masked extracted aquaculture features layers, it was determined that some of the selected features did not meet the initial criteria of this study. The criteria were that only aquaculture complexes should be extracted, not individual ponds. The selected features included smaller individual ponds or clusters of up to four individual ponds. This problem was overcome by using Feature Analyst to aggregating the polygon datasets. The aggregate function was designed to exclude polygon features that were created with fifty or less pixel clusters from the imagery. A cluster of fifty pixels was determined to be the average size of less than four individual catfish ponds. This operation successfully removed the smaller ponds. The final operation on the aquaculture polygons was to run a smoothing function. The purpose of the smoothing process was to create a more aesthetic dataset. The smoothing function removed every other node or approximately half the vertices of each polygon. The resulting polygon dataset contained aquaculture complexes greater than fifty pixels with smooth edges that excluded natural water features. The software automatically creates a vector dataset created from a raster base-map. Once the parameters that yielded the most positive response were established, the process was completed for each of the three differing dates of imagery.

Once the aquaculture complex features were successfully extracted, the polygon datasets could be measured for acreage. This was accomplished using the Arc macro language script Calcacre to be run with ArcView 3.2a. This script will calculate area,
perimeter and acreage for designated polygon datasets. This is accomplished by first opening the text of the script in its original programming language in ArcView. Then the script is compiled to enable it to be executed within ArcView. Once the script was successfully compiled, a button was created and assigned to the Calcacre script in the ArcView interface to run the commands of the script. Each of the aquaculture polygon datasets were assigned to run through the Calcacre script. The resulting polygon attribute tables were updated with new columns for area, perimeter and acreage and each column value was automatically calculated for each polygon in each of the datasets. The attribute tables of each of the polygon datasets was then summarized to determine the total acreage for each dataset.

4.2.2 Spatial-Temporal Changes in Aquaculture Complexes

One of the most important aspects of this study was to calculate the growth of the aquaculture industry from 1984 through 2001. This was accomplished using the attribute tables of each of the dates of aquaculture data. The aquaculture data corresponding to 1984 was the first to be measured. This was accomplished by adding a column in the attribute table and establishing a unique record number corresponding to the year of data. This unique record number would be used when comparing datasets. The remaining datasets were also manipulated to have a new column containing unique record numbers corresponding to their respective dates. The 1984 imagery data of aquaculture was then merged with the 1992 aquaculture data for comparison. This was done using the Union
function of the Geoprocessing Wizard in ArcView 3.2a. The resulting polygon dataset contained the spatial extent and attribute information from both datasets. The 1992 and 2001 aquaculture datasets were combined using the Union function of the Geoprocessing Wizard in ArcView 3.2a. The unique record numbers could then be used to extract areas of aquaculture that have either expanded or retracted from 1984 to 1992 and from 1992 to 2001.

Calculation of areas with no change was accomplished by comparing the unique record numbers of each date of data in the attribute table. Areas that were unchanged share the same row in the unique record column. This was accomplished by querying the data with an expression that allows for the unique record number of the earlier data and later data to both exist in the same row.

To calculate aquaculture complexes that expanded in area, the unique record number was used to look for data that were lacking in the earlier date of aquaculture data. A query was designed so that the unique record number of the earlier image was lacking, while the unique record number of the later image existed. The resulting polygon datasets contained information for aquaculture complexes that existed in the most recent images but were lacking in older images. This information was used to establish aquaculture complexes that have either expanded over time or have been newly created.

The calculation of aquaculture complexes that have reduced in size, or did not exist in the same spatial location was calculated using a query of the attribute tables in the same way as the previous two examples. A query was developed to establish areas where the record number of the earliest date of data existed, but that of that latter date did not.
This established areas where aquaculture complexes existed in past imagery but was lacking in more recent imagery. The acreage of no change, expansion and retraction could then be calculated and compared for analysis.

4.2.3 Soil Moisture Index

The Soil Moisture Index was created using ERDAS Imagine and was maintained as a raster .IMG file format. The first step was to convert the file from an .IMG file to an ESRI Grid file format. The data was converted to an ERSI Grid file using ArcGIS 8.1 ArcCatalog export command. This command allows raster data to be converted to other vector formats. Once the data was in the ESRI Grid file format it was clipped to the study area. This was done using the Mila Grid Utilities extension for ArcView 3.2a. This extension allows raster data to be clipped with vector data. The resulting raster data consisted of all the SMI information with the spatial extent of the specified study area. The new SMI grid was then converted to vector format to be used with the aquaculture vector files.

Acreage values for wet and dry soil classes were then calculated. These classes were then compared to the aquaculture complex polygons. This was done using the clip function of the Goeprocessing wizard in ArcView 3.2a. The SMI was the input theme and aquaculture complexes were the clipping theme. The resulting SMI polygons contained the attribute information of the SMI with the spatial extent of the aquaculture complexes. Acreage values were then calculated for the wet and dry classes. The resulting values
correspond to wet and dry classes of the SMI polygons that are under aquaculture complexes. The acreage values of the moisture classes were then used to determine preferential expansion of aquaculture complexes onto soil classes. This was done by comparing the moist and dry soil acreage values across the different imagery dates. The process was accomplished using the clip function of the Geoprocessing wizard in ArcView 3.2a. The SMI was clipped to each date of aquaculture data. Acreage values were then calculated for each of the three resulting SMI themes. With this information any expansion or retraction of aquaculture complexes onto moist soil classes could be calculated.

4.2.4 Well Data

From the entire well database, six individual wells were sampled from each of six counties. The six counties included three counties in high aquaculture areas (Humphreys, Sunflower, and Leflore Counties) and three counties in moderate to low aquaculture areas (Bolivar, Quitman, and Tunica Counties). The average depth to water of the spring and fall readings was calculated for each well for each year from 1984 to 2001. Well locations within the counties were chosen at random. The difference between the 1984 and 2001 depth values was calculated and used in the following statistical analysis. Analysis of Variance was used to test for significant differences among the well depths (2001 minus 1984) among the six counties and between the high aquaculture and moderate to low aquaculture county groups. Afterwards a post-hoc multiple means
comparison test was used to examine significant differences in well depths among each of the six counties.

In addition to the statistical analysis, six individual wells from major aquaculture counties were examined for changes over the 1984 to 2001 time period. Inflection points of the water well depth time series were compared to aquaculture expansion values in nearby areas. It is worth noting that this study did not directly measure the amount of water extracted from the MRVA to be used in aquaculture. Also, multiple factors may be related to variations in well water depth (climate, terrestrial agriculture, and urban development). However it is suggested that if major changes in water level that occurred at the same time with aquaculture expansion for nearby areas, this would be suggestive that aquaculture is related to water well depth variability.
5.1 Expansion of Aquaculture Complexes in the Mississippi Delta

The Feature Extraction analysis successfully identified multiple aquaculture complexes (AC) within the Mississippi Delta. Insignificant amounts of AC were found on the bluffs of Mississippi Delta counties that border the study area, thus the results presented below will only be for portions of Mississippi within the Delta proper (i.e. the study area, Figure 1). Most (13) of the Delta counties fall either entirely within this boundary or have significant portions of their area within the Delta boundary. Six counties, including Desoto, Tate, Panola, Grenada, Carroll, and Warren, only have minute portions of their area within the Delta. It is recognized the six bordering counties of the Delta have much less land area within the study area. Given this, though the results of the feature extraction process will be presented at the county level as a matter of convenience.

The feature extraction process identified close to 66,000 acres of AC from the 1984 imagery (Figure 4, Table 1). As can be seen on figure 4, these complexes were not divided evenly among the 19 counties, but were highly clustered within the study area (Figure 4). As expected, Humphreys County had the highest acreage (23,690.01 acres), followed by the next highest county Sunflower (14,001.01 acres). Collectively both these
two counties comprised 57% of the total AC in the Delta. Washington County, Leflore County, and Yazoo County occupied the middle tier, and they collectively represent about 28% of the Delta AC.

Figure 4. This is an illustration depicting the aquaculture complexes delineated from the feature extraction process from the 1984 satellite imagery.
The remaining 14 counties individually had less than 3000 acres and collectively represented only 15% of the AC. It is worth noting that several counties on the periphery of the Delta, including Warren, Carroll, Grenada, Panola, and Tate Counties showed no AC in 1984.

From the 1992 satellite imagery, feature extraction helped identify 115,350.88 total acres of AC (Table 1, Figure 5). This represents a total of 175% increase from the 1984 imagery. Aquaculture greatly expanded within the counties that already had AC and it spread into three new counties where AC had not been previously. New to AC in 1992 were Panola, Quitman, and Carroll Counties. Humphreys and Sunflower Counties again had the highest acreage of AC, with 34,576.14 and 29,214.76 acres respectively. Collectively these counties represent 55% of the AC from 1992. Sunflower County experienced a 200% increase in AC and Humphreys AC expanded by approximately 150% (Figure 6). Given these substantial increases in total acreage, however, these two counties did not experience the greatest percentage of increase. This distinction was obtained by the two counties Coahoma, which had an 835% increase from 86 acres to 750 acres, and Leflore which increased by 280% from 6,647 acres to 18,605 acres (Figure 6). Because both Coahoma and Leflore counties are largely contained within the study area, a comparison of rate of expansion per area shows that Leflore actually had the greatest increase. Leflore increased by 7.6 acres whereas Coahoma increased by only 0.43 acres. Besides Humphreys and Coahoma, the counties of Leflore, Washington, Yazoo, and Sharkey all had AC values close to 5000 acres or higher and collectively represent 34% of the total AC. It should be pointed out that the counties with the greatest
overall increases (Humphreys, Sunflower, and Leflore) also had high AC acreage values in the 1984 image. Desoto and Tallahatchie Counties were unique in that they were the only two counties to have a decrease in AC acres. Grenada County, Tate County, and Warren County still were devoid of AC in the 1992 imagery.

Figure 5. This is an illustration representing the aquaculture complexes delineated from the feature extraction process from the 1992 satellite imagery.
Figure 6. This is an illustration representing the total change in aquaculture complex acreage by county from 1984 to 1992
The feature extraction results from the 2001 imagery recognized 141681.2 acres of AC (Figure 7).

Figure 7. This is an illustration of the aquaculture complexes as delineated from the feature extraction process from the 2001 satellite imagery
This represents a 215% increase from the 1984 imagery and a 123% increase from 1992 imagery. Similar to the other two sets of imagery, Humphreys and Sunflower Counties comprised over 50% of the total AC acreage. In 2001 however, Sunflower County had the greatest total number of AC (39,387.15 acres) followed by Humphreys County (38,130.54 acres) and Leflore (26,700.97 acres). The middle tier of AC counties from the 2001 image include Bolivar, Issaquena, Tunica, Sharkey, Washington, and Yazoo, and collectively these counties represent 23% of AC. Even though they were in the middle tier, Bolivar and Washington Counties actually experienced a reduction in acreage from the 1992 results (Figure 8). AC in 2001 from Bolivar County was only 76% of the acres of AC from 1992 imagery. AC in 2001 from Washington County was 98% of the 1992 AC acreage. Holmes County and Tallahatchie County also showed substantial decreases in AC acreage, -55.35 (93% reduction) acres and -663.14 acres (30% reduction) respectively (Table 1). Loss of AC in Desoto County may be the most profound. No AC was identified at all in Desoto County in 2001, representing a loss of -660.7 acres from the 1992 imagery. Warren County, Tate County, and Grenada County once again did not have any AC identified in the 2001 imagery by Feature Extraction. Coahoma County again had the highest percentage of increase (ca. 168%) going from 750 acres to 1457 acres.
Figure 8. This is an illustration of the total change of aquaculture acreage from 1992 to 2001.
Throughout the study period (1984 – 2001), Humphreys, Sunflower, Leflore, and Sharkey Counties experienced the highest overall AC expansion (Figure 9).

Figure 9. This is an illustration of the total change of aquaculture acreage by county from 1984 to 2001.
Washington, Issaquena, and Yazoo Counties had the second highest overall expansion (Figure 9). Holmes, Carroll, Bolivar, Coahoma, Quitman, Panola, and Tunica Counties experienced moderate to low expansion. Tallahatchie County, on the other hand, showed the greatest decline in AC over the 18 year period, experiencing a reduction of 663 total acres (Table 1, Figure 9).

Validation of the feature extraction results is difficult because AC acreage values per county are not readily available for all counties in the study area throughout the 1984–2001 time periods. Estimates for the dominant catfish counties in recent years, however, are reported by the Mississippi Agricultural Statistics Service (MASS, 2005). These estimates are acquired through an annual census of registered catfish farmers including telephone interviews and individual meetings with land-owners (Cindy Casey, Mississippi Agricultural Statistics Service, personal communication, 03/10/05). In general, the AC acreage values per county generated by feature extraction are greater than those reported by MASS (2005; Figure 10). The seven counties reported by MASS (2005) show a total value of 96,000 acres whereas the AC acreage values for these same counties was found to be 130915.80 acres. This is a difference of 34915.8 acres. The main catfish-producing counties, Humphreys, Leflore, and Sunflower, show the greatest differences between the two estimates. The remaining four counties show overestimates by the feature extraction, but these differences are not as substantial (Figure 10).
Figure 10: Comparison of aquiculture complex acreage values between estimates from using Feature Extraction of satellite imagery (FE, black-shaded bar and estimates provided by MASS (2005; MASS, grey-shaded bars).
5.2 MRVA Well Data

Well depths generally decreased across the Delta from 1984 to 2001 (Figure 11). Counties with huge amounts of AC, including Humphreys, Sunflower, and Leflore, showed major increases in the depth to the well water. However, counties with moderate to very low AC throughout the study period, such as Bolivar, Quitman, and Tunica, also experienced increase depth to well water (Figure 11). Furthermore, Warren County had no AC in any of the time periods and it also experienced an increase in well water depth from 1984 – 2001.

Figure 11: Mean differences between well water depths from 1984 to 2001. County values represent an average of six wells per county. Humphreys, Leflore, and Sunflower Counties have high amounts of aquaculture complexes. Bolivar, Quitman, and Tunica Counties have moderate to low amounts of aquaculture counties. Warren County has relatively no aquaculture complexes.
The results of the analysis of variance comparing differences in well depth from 1984 to 2001 showed no significant differences between counties with high amounts of AC and counties of moderate to low amounts of AC (p = 0.126). Individual counties were significantly different from one another (p = 0.02), but multiple means comparison tests reveal no clear grouping of high and low AC counties (Table 1).
<table>
<thead>
<tr>
<th>(l) county</th>
<th>(j) county</th>
<th>Mean Difference (l-j)</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>95% Confidence Interval</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOLIV</td>
<td>HUMPH</td>
<td>2.5450</td>
<td>1.97028</td>
<td>.851</td>
<td>-3.6140</td>
<td>5.7040</td>
<td></td>
</tr>
<tr>
<td>LEFLOR</td>
<td></td>
<td>-7.083</td>
<td>1.97028</td>
<td>1.000</td>
<td>-6.8673</td>
<td></td>
<td>1.3346</td>
</tr>
<tr>
<td>QUIT</td>
<td></td>
<td>5.1283</td>
<td>1.97028</td>
<td>.156</td>
<td>-1.0306</td>
<td>11.2873</td>
<td></td>
</tr>
<tr>
<td>SUNFLOW</td>
<td></td>
<td>-2.3967</td>
<td>1.97028</td>
<td>.883</td>
<td>-8.5566</td>
<td>3.7623</td>
<td></td>
</tr>
<tr>
<td>TUNICA</td>
<td></td>
<td>2.2500</td>
<td>1.97028</td>
<td>1.000</td>
<td>-5.9050</td>
<td>6.4050</td>
<td></td>
</tr>
<tr>
<td>WARREN</td>
<td></td>
<td>5.4467</td>
<td>1.97028</td>
<td>.112</td>
<td>-.7123</td>
<td>11.6056</td>
<td></td>
</tr>
<tr>
<td>HUMPH</td>
<td>BOLIV</td>
<td>-2.5450</td>
<td>1.97028</td>
<td>.851</td>
<td>-8.7040</td>
<td>3.6140</td>
<td></td>
</tr>
<tr>
<td>LEFLOR</td>
<td></td>
<td>-3.2533</td>
<td>1.97028</td>
<td>.651</td>
<td>-9.4123</td>
<td>2.9056</td>
<td></td>
</tr>
<tr>
<td>QUIT</td>
<td></td>
<td>2.5833</td>
<td>1.97028</td>
<td>.842</td>
<td>-3.5756</td>
<td>8.7423</td>
<td></td>
</tr>
<tr>
<td>SUNFLOW</td>
<td></td>
<td>-4.9417</td>
<td>1.97028</td>
<td>.817</td>
<td>-11.1006</td>
<td>1.2173</td>
<td></td>
</tr>
<tr>
<td>TUNICA</td>
<td></td>
<td>-2.2950</td>
<td>1.97028</td>
<td>.902</td>
<td>-8.4540</td>
<td>3.8640</td>
<td></td>
</tr>
<tr>
<td>WARREN</td>
<td></td>
<td>2.9017</td>
<td>1.97028</td>
<td>.758</td>
<td>-3.2573</td>
<td>9.0606</td>
<td></td>
</tr>
<tr>
<td>LEFLOR</td>
<td>BOLIV</td>
<td>.7083</td>
<td>1.97028</td>
<td>1.000</td>
<td>-5.4506</td>
<td>6.8573</td>
<td></td>
</tr>
<tr>
<td>HUMPH</td>
<td></td>
<td>3.2533</td>
<td>1.97028</td>
<td>.651</td>
<td>-2.9056</td>
<td>9.4123</td>
<td></td>
</tr>
<tr>
<td>QUIT</td>
<td></td>
<td>5.8367</td>
<td>1.97028</td>
<td>.073</td>
<td>-.3223</td>
<td>11.9956</td>
<td></td>
</tr>
<tr>
<td>SUNFLOW</td>
<td></td>
<td>-1.6683</td>
<td>1.97028</td>
<td>.977</td>
<td>-7.8473</td>
<td>4.4706</td>
<td></td>
</tr>
<tr>
<td>TUNICA</td>
<td></td>
<td>-.9583</td>
<td>1.97028</td>
<td>.999</td>
<td>-5.2006</td>
<td>7.1173</td>
<td></td>
</tr>
<tr>
<td>WARREN</td>
<td></td>
<td>6.1550</td>
<td>1.97028</td>
<td>.050</td>
<td>-.0040</td>
<td>12.3140</td>
<td></td>
</tr>
<tr>
<td>QUIT</td>
<td>BOLIV</td>
<td>-5.1283</td>
<td>1.97028</td>
<td>.156</td>
<td>-11.2873</td>
<td>1.0306</td>
<td></td>
</tr>
<tr>
<td>HUMPH</td>
<td></td>
<td>-2.5533</td>
<td>1.97028</td>
<td>.842</td>
<td>-8.7423</td>
<td>3.5756</td>
<td></td>
</tr>
<tr>
<td>LEFLOR</td>
<td></td>
<td>-5.8367</td>
<td>1.97028</td>
<td>.073</td>
<td>-11.9956</td>
<td>.3223</td>
<td></td>
</tr>
<tr>
<td>SUNFLOW</td>
<td></td>
<td>-7.5250*</td>
<td>1.97028</td>
<td>.009</td>
<td>-13.6840</td>
<td>-1.3680</td>
<td></td>
</tr>
<tr>
<td>TUNICA</td>
<td></td>
<td>-4.8783</td>
<td>1.97028</td>
<td>.199</td>
<td>-11.0373</td>
<td>1.2806</td>
<td></td>
</tr>
<tr>
<td>WARREN</td>
<td></td>
<td>3.193</td>
<td>1.97028</td>
<td>1.000</td>
<td>-5.8408</td>
<td>6.4773</td>
<td></td>
</tr>
<tr>
<td>SUNFLOW</td>
<td>BOLIV</td>
<td>2.3067</td>
<td>1.97028</td>
<td>.883</td>
<td>-3.7623</td>
<td>8.5556</td>
<td></td>
</tr>
<tr>
<td>HUMPH</td>
<td></td>
<td>4.9417</td>
<td>1.97028</td>
<td>.187</td>
<td>-1.2173</td>
<td>11.1006</td>
<td></td>
</tr>
<tr>
<td>LEFLOR</td>
<td></td>
<td>1.6883</td>
<td>1.97028</td>
<td>.977</td>
<td>-4.4706</td>
<td>7.8473</td>
<td></td>
</tr>
<tr>
<td>QUIT</td>
<td></td>
<td>7.5250*</td>
<td>1.97028</td>
<td>.009</td>
<td>1.3660</td>
<td>13.6840</td>
<td></td>
</tr>
<tr>
<td>TUNICA</td>
<td></td>
<td>2.6467</td>
<td>1.97028</td>
<td>.827</td>
<td>-3.5123</td>
<td>8.8056</td>
<td></td>
</tr>
<tr>
<td>WARREN</td>
<td></td>
<td>7.8433*</td>
<td>1.97028</td>
<td>.006</td>
<td>1.6944</td>
<td>14.0023</td>
<td></td>
</tr>
<tr>
<td>TUNICA</td>
<td>BOLIV</td>
<td>-2.5000</td>
<td>1.97028</td>
<td>1.000</td>
<td>-6.4090</td>
<td>5.9090</td>
<td></td>
</tr>
<tr>
<td>HUMPH</td>
<td></td>
<td>2.2950</td>
<td>1.97028</td>
<td>.902</td>
<td>-3.8640</td>
<td>8.4540</td>
<td></td>
</tr>
<tr>
<td>LEFLOR</td>
<td></td>
<td>-9.583</td>
<td>1.97028</td>
<td>.999</td>
<td>-7.1173</td>
<td>5.2006</td>
<td></td>
</tr>
<tr>
<td>QUIT</td>
<td></td>
<td>4.8783</td>
<td>1.97028</td>
<td>.199</td>
<td>-1.2806</td>
<td>11.0373</td>
<td></td>
</tr>
<tr>
<td>SUNFLOW</td>
<td></td>
<td>-2.6467</td>
<td>1.97028</td>
<td>.827</td>
<td>-8.8056</td>
<td>3.5123</td>
<td></td>
</tr>
<tr>
<td>WARREN</td>
<td></td>
<td>5.1687</td>
<td>1.97028</td>
<td>.146</td>
<td>-9.9233</td>
<td>11.3585</td>
<td></td>
</tr>
<tr>
<td>WARREN</td>
<td>BOLIV</td>
<td>-5.4467</td>
<td>1.97028</td>
<td>.112</td>
<td>-11.056</td>
<td>7.123</td>
<td></td>
</tr>
<tr>
<td>HUMPH</td>
<td></td>
<td>-2.9017</td>
<td>1.97028</td>
<td>.758</td>
<td>-9.0606</td>
<td>3.2573</td>
<td></td>
</tr>
<tr>
<td>LEFLOR</td>
<td></td>
<td>-6.1550</td>
<td>1.97028</td>
<td>.050</td>
<td>-12.3140</td>
<td>.0040</td>
<td></td>
</tr>
<tr>
<td>QUIT</td>
<td></td>
<td>-3.183</td>
<td>1.97028</td>
<td>1.000</td>
<td>-6.4773</td>
<td>5.8406</td>
<td></td>
</tr>
<tr>
<td>SUNFLOW</td>
<td></td>
<td>-7.8433*</td>
<td>1.97028</td>
<td>.006</td>
<td>-14.0023</td>
<td>-1.6844</td>
<td></td>
</tr>
<tr>
<td>TUNICA</td>
<td></td>
<td>-5.1967</td>
<td>1.97028</td>
<td>.146</td>
<td>-11.3556</td>
<td>.9623</td>
<td></td>
</tr>
</tbody>
</table>

Based on observed means.
* The mean difference is significant at the .05 level.

Table 1: Results of multiple means comparison test of difference in well depth from 1984 to 2001 for selected Delta counties. Significance = 0.05
Individual wells from each of the six major AC counties show a high degree of complexity (Figure 12). The Sunflower County and Leflore County wells show a continuous decline (decrease in well depth) throughout the study period. The rate of change from 1984 to 1992 is not much different from the rate of change from 1992 to 2001 (almost linear) even though the expansion of AC varied, slowing from 1992 to 2001, between these time periods. The Humphreys County well (Figure 12) shows a precipitous drop in well depth from 1984 to 1989, but increases again throughout the 1990s. The Washington County well shows both increases and decreases of well depth throughout the 1980s and through the mid-1990s. Well depth increases continuously, though, after 1995. This time period corresponds to a period when Washington County actually decreased in AC acreage. Wells from Sharkey and Yazoo Counties fluctuate over the study period, but no major changes occur in the overall time series.
5.3 Aquaculture and Soil Moisture Index

The SMI for the Delta contains a total of 4,205,066 acres of exposed or bare soil in 1999. From this data, dry soils (class 1 and class 2) accounted for 1,226,489 acres (29%) and wet soil classes (class 4 and class 5) accounted for 683,429 acres (16%). Collectively, soils that had no reflectance (class 0), intermediate soils (class 3), and water (class 6) comprised the remaining 55% of the SMI Delta area.
Comparing the SMI index to the 1984 AC data reveals that aquaculture was predominantly found on moist soil. This pattern was true for all counties that had AC. Moist soils totaled 5760.73 acres whereas dry soils totaled only 413.71 acres. A similar trend occurs with the 1992 AC data. There were 7441.09 acres of AC on moist soils compared to only 451.85 acres of dry soil. From 1984 to 1992, AC on moist soils across all counties increased by 129% compared to a 109% increase for dry soils. In 2001, moist soils contained substantially more acres of AC (8398.63 acres) than dry soils (921.42 acres). Given this difference, AC actually showed greater increases on dry soil classes (204%) than wet soil classes (113%).

At the county level, expansion of AC on moist soils occurs continuously throughout the study period for Humphreys and Leflore Counties (Figures 13 and 14). Washington County shows a marked decline of AC on moist and dry soils from 1992 to 2001 (Figures 13 and 14). There was relatively no AC on dry soils in 1984 and 1992 for Carroll, Coahoma, Panola, Quitman, and Sharkey Counties. In contrast, all counties with AC had acreage values on moist soils (Figures 13 and 14).
Figure 13: Aquiculture complexes located on SMI moist soil classes, 1984, 1992, and 2001.

Figure 14: Aquiculture complexes located on SMI dry soil classes, 1984, 1992, and 2001.
6.1 Expansion of Aquaculture in the Delta

This study shows that aquaculture complexes have generally increased from 1984 to 2001. Humphreys County, Sunflower County, and Leflore County in particular had the highest acreage values and experienced the greatest overall growth. These are the central most counties within the study area. The counties on the periphery of the Delta, however, showed the least expansion. There are at least two possible explanations for these results. First, Humphreys County has long since embraced aquaculture, and its prominence as the “Catfish Capital of the World” (www.searchus.com), being the largest producer of catfish in the United States (MASS, 2005), and containing the headquarters of The Catfish Institute (TCI, 2005) speaks volumes about the role of catfish in this county. Acreage values for Humphreys were consistently within the top rank, especially in the earliest time period (1984), and this county may have the longest record of aquaculture in Mississippi. Sunflower County has also had traditionally high aquaculture values throughout the study period, and their acreage values consistently ranked within the top one or two. Because catfish industry and catfish culture have long been embedded within the community, it stands to reason that these counties would continue to associate success and community recognition with catfish production. Thus there would
be incentives to continue and expand aquaculture activities. Counties that have recently
developed aquaculture (e.g. Carroll and Coahoma Counties) may still be assimilating
catfish culture and may not have experienced the full economic boom. So, their growth
may be slower initially. Perhaps these other counties will one day match the aquaculture
production within the Delta core.

 Counties that are proximal to the catfish core (Humphreys and Sunflower
Counties) would be expected to show the greatest increase in aquaculture complexes
because they would experience the quickest diffusion of catfish economic and cultural
principles. Leflore County, for example, had aquaculture values less than half of its
neighboring counties Humphreys and Sunflower in 1984. By 2001, however, aquaculture
values in Leflore were comparable to the catfish core. Washington County also borders
both Humphreys and Sunflower, and it showed substantial growth of aquaculture from
1984 to 2001. Perhaps results from Washington and Leflore Counties illustrate the
influence of the core counties on their surrounding neighbors.

 A second explanation for the higher aquaculture values in the center of the Delta
may be the presence of catfish processing plants. Of the 16 processing plants nationwide
registered by the TCI, six are located in the Mississippi Delta (TCI, 2005). These include
plants in Itta Bena (Leflore County), Isola (Humphreys County), Indianola (Sunflower
County), Belzoni (Humphreys County), Tunica (Tunica County), and Yazoo City (Yazoo
County). Additionally, there is a catfish processing plant in Greenville (Washington
County). These plants may have initially located near major aquaculture complexes to
begin with. Once established, it would be more economical for additional aquaculture
complexes to cluster around the processing plants. In this case, aquaculture would not be expected to be evenly distributed as it would be difficult for catfish farms to manage and operate there industry. A clustered approach to aquaculture ensures a more manageable farm. One reason for greater manageability with a clustered approach ensures less expenditure on gasoline and employee salaries to feed the fish and haul them to market. It is much easier to export the product from a central location opposed to gathering a few at one location only to travel to another to gather more. The major decline in aquaculture in Tallahatchie County may be related to its distal location to the catfish processing centers.

6.2 MRVA Well Data

The lack of discernable difference in depth to water in counties with the greatest acreage of aquaculture could be attributed to two fundamental reasons. First, MRVA aquifer is a dynamic system with influences including the bluff hills to the east, the Mississippi River to the west and the general geology of the area. A full investigation of these factors was not part of the scope of this study. Further investigation could help parse better information from the data used to ascertain the results herein. The second potential reason that the well data reported no significant differences could be simply that AC has no affect on the recharge of the MRVA.
6.3 Aquaculture and Soil Moisture Index

The results show a strong relationship between moist soils and aquaculture complex locations. This could be attributed to the origins of aquaculture in Humphreys County. During the time aquaculture was being developed in the Delta, row crop and rice were the dominant industry. The crops being grown at the time could have necessitated better and dryer soils, and thus the wet soils may be the only ones available to be developed for aquaculture. Farmers would be less likely to turn productive cropland into aquaculture. Therefore, these moist soils would be ideal locations for aquaculture development. Additionally, the physical characteristics of the moist soils may be better suited for catfish production. The relationship between soil characteristics and aquaculture productivity is beyond the scope of this thesis, but it warrants further investigation.

6.4 Environmental Effects

Expanding aquaculture could hinder attempts by conservation groups to return Delta lands back to their natural habitat of bottomland hardwood forests. The Delta was once covered in thick vegetation harboring many species of flora and fauna. The passage of the Swamp Lands Acts of 1849 and 1859 opened the Delta for development. Since that time the Deltas has been transformed from predominately bottomland hardwood forest to an agricultural landscape. This type of change affects any landscape. With this type of alteration of the land use, problems such as soil loss through erosion, increased sediment
in perennial streams and nutrientation become typical. Also with the introduction of all types of livestock, biological impairments such as fecal contamination affect areas downstream. The lack of bottomland hardwood forests could have a long-term affect on flooding, soil fertilization and groundwater recharge. This type of forest is well adapted to the annual flooding of the Mississippi River and play a vital role in reducing massive flooding by temporarily storing large volumes of water and slowing the rate of speed at which water flows over land. They also act to recharge groundwater and reduce soil erosion (Delta Land Trust, 2003). The loss of this ecosystem results in a loss of natural flood control, fertilization and groundwater recharge of the area.

6.5 Accuracy Assessment of the Feature Extraction Results

Actual measurements of aquaculture acreage values are not readily available, thus it is difficult to compare the results of the feature extraction with “true” values. However there are other estimates of aquaculture acreage for the Delta on which a comparison can be made. For example, channel catfish aquaculture is reported to have grown in the Delta over the last two decades at a rate of 10% annually (Robinson and Avery, 2000). This correlates with the findings of this study. The results of the Feature Extraction show a growth rate of aquaculture from 1984 to 1992 to be 57%, or just a little less than 10% per year. Over the nine year period from 1992 to 2001, Feature Extraction showed that aquaculture complexes grew by 80%. Once again these results are on pace with Robinson and Avery’s (2000) 10% per year increase values. Close agreement of the
values from this current study and those of Robinson and Avery (2002) lend credence to the validity of the results derived from feature extraction.

The discrepancies between the feature extraction aquaculture acreage and the acreage values reported by MASS (2005) could originate from several sources. MASS’s estimates are based on surveys of registered catfish owners. It is possible that there may be aquaculture complexes identified in this study that are inactive. In these cases they would not be reported to MASS. The possibility of active unregistered aquaculture complexes is also possible.

Although great care was taken to separate local farm catfish ponds from major aquaculture complexes and all non-agricultural water bodies were masked, another reason for the higher values reported in this thesis may be from the Feature Extraction not distinguishing these other water bodies from aquaculture. Errors associated with the Feature Extraction analysis are described in the section below.

6.6 Complications and Sources of Error

6.6.1 Feature Extraction

The results of this study were closely related to what was expected. It was expected that aquaculture complexes were expanding and this study provides evidence and background literature to support that theory. The process used to quantify expansion was considered successful but not without the need for revision. One problem in particular that occurred due to the extraction process employed was sliver data. Sliver
data are small pieces of polygons left behind in the process of assessing the same area twice. Such an example exists while extracting identical aquaculture complex from different dates of imagery. Although the physical area might be the same, the pixel classification will be altered from one image to the next due to mixed pixels and missed registration. This leaves small pockets of data, some of which will be overly inclusive or exclusive depending on the calculation of are the ponds expanding or retracting. Once this problem was identified it was determined to simply exclude all sliver data rather than try to calculate the expansion versus retraction acreage. It was determined that the total amount of sliver data was not significant enough to skew the data one way or another and that those areas overly included or excluded would cancel each other out. Even with this problem the feature extraction process was successful in that the growth rate of aquaculture in the Delta was well correlated with expectations based on the literature.

6.6.2 Soil Moisture Index

This study resulted in an inconclusive outcome that preferential expansion of aquaculture complexes onto moist soil classes is occurring. The soil moisture index used in this study was not a standard or traditional data set. The SMI used in this study was created from a single date of satellite imagery captured during a severe drought. This dataset was used, as was the feature analyst process, to explore new or non traditional means of attaining information. Although the methodology was explained earlier, this data set did not employ traditionally excepted methods to determine soil moisture
content. More traditional methods typically use long term measurements in conjunction with computer models and other ancillary data such as rain gage or vegetative cover. In the study Operational Modeling of Soil Moisture at Local and Regional Scales, Peters-Lidard, et. al, used satellite imagery along with computer models and State Soil Geographic (STATSGO), Soil Survey Geographic (SSURGO) and Food and Agricultural Organization of United Nations (FAO) soils data sets. That study also used soil moisture data from the Monsoon ‘90 experiment which used six days of microwave brightness measurements to compute soil moisture.

6.6.3 Water Well Data

The well data used in this study was part of the Mississippi Department of Environmental Quality’s Semi Annul Survey capturing measurements in the spring and fall. Although these measurements are supposed to be collected twice per year there were some gaps. For instance one well might be missing the spring or fall measurement for any given year. Also the years of collection are not consistent. These gaps in the data could be a result of any individual well being put into or taken out of service at different times, or that access to the well was denied. These gaps in the data restricted the number of wells to be used in this study. It was important within the scope of this study to use data that was consistent throughout the studies time period. Therefore well data was selected on the basis of completeness rather than a random sample, or site selected. This study has concluded that the well data was sufficient to complete the parameters set forth for well
data however, a more precise dataset might determine an even greater relationship with aquaculture expansion and increased depth to water in MRVA wells. Also a more precise dataset might establish a relationship in some of the counties with less acreage of aquaculture complexes.

In the analysis of variance, it was assumed that wells within the area would be affected similarly by regional climate variables, and that differences in well depth between high aquaculture density and low aquaculture density would be the major contributing factor. The importance of local climate on well water depth may be masking any affects of aquaculture. Additionally, assessing the local variation in well depth due to terrestrial agricultural uses and natural fluctuations in well depth were beyond the scope of this study. Future investigations should consider these parameters when investigating the effects of aquaculture on MRVA.
CHAPTER VII
CONCLUSIONS

This study used feature extraction methods to quantify acreage of aquaculture complexes in the Delta region of Mississippi from satellite imagery for the dates 1984, 1992 and 2001. Preferential expansion of aquaculture complexes onto moist and dry soil types was examined. The relationship between expanding aquaculture complexes and increased depth to water in MRVA wells was investigated to determine if the expansion affected the water level. It was concluded that there was expansion of aquaculture complexes by 215% over the time period from 1984 through 2001. The counties in the core of the Delta that have had longer histories of aquaculture, such as Humphreys and Sunflower Counties, showed the greatest overall expansion. Proximal counties to these core counties also witnessed rapid growth of aquaculture (Leflore and Washington County), possibly indicating a diffusion of catfish economic and cultural principles. Peripheral Delta counties, such as Desoto, Tate, Tallahatchie, and Tunica Counties, experienced either moderate growth or decline of aquaculture. The location of major catfish producing plants may be responsible for continued high clustering of aquaculture complexes in core catfish counties. Aquaculture complexes distal to processing plants may endure higher shipping and transportation costs, making them less successful. Thus,
aquaculture in counties further away from the core would not be expected to expand at the same rate as those nearer to processing plants.

Aquaculture expansion was preferential on moist soils. Initial aquaculture complexes may have been built on wetter soil types because they may have been the only ones available. Well drained soils would be more productive for crops, and it would be counterintuitive to turn productive cropland into aquaculture. Over time, the expansion of aquaculture continued on moist soils, but the rate of expansion slowed. In contrast, aquaculture expansion onto drier soil types increased greatly in more recently times (1992 – 2001). By 2001 many of the available moist soil locations were already occupied by aquaculture, leading to speculation that further expansion had to continue on drier soils. Furthermore, once the economic boom of aquaculture is widely realized, then there may be more of an incentive for landowners to convert drier or marginally drier land into aquaculture.

The results of this study were based on the use of unique software procedures to extract aquaculture complexes from satellite imagery. Validation of these results with true measurements is difficult due to the lack of data and to the high numbers of aquaculture complexes throughout the Delta. Comparisons with other reported estimates yields mixed results. Aquaculture acreage estimates reported by Mississippi Agriculture Statistics Service (MASS) were much lower than the estimates reported in this thesis. Discrepancies may exist due to limitation of the methodology and data used in this research and to possible incompleteness of true reporting of catfish acreage. Given that the total acreage numbers are overestimated, the actual trend in aquaculture expansion
mirrors the same trends reported by MASS. Moreover, rates of aquaculture expansion from 1984 to 2001 match closely with other published values, such as those from Robinson and Avery (2000). Therefore, there are indications that extraction procedures used in the thesis are successful for monitoring trends in aquaculture. Future filed validations of actual acreage values with estimates from Feature Extraction, though, would greatly improve this relationship, and would provide more insight in to the expansion of aquaculture in the Delta.
BIBLIOGRAPHY


Robinson, E.H., Avery, J.L., Thad Cochran National Warmwater Aquaculture Center, Delta Branch Experiment Station. Farm-Raised Catfish, Fact Sheet 005, July 2000.


The following citations were obtained via internet:

http://iwarrior.uwaterloo.ca/?module=displaystory&story_id=832&format=html&edition_id

Aquaculture.com., Aquaculture information, education, commerce and more. 


Visual Learning Systems, The Feature Analyst Extension for ArcView and ArcGIS. 


The Catfish Capitol of the world, Humphreys County Mississippi. 

Merlo, C., Rural Cooperatives, Hooked on Catfish; The Mississippi Delta is catfish country, Where Delta Pride Catfish Inc. is the big fish in the big pond. 


Mississippi Information. Date Visited, April 7, 2005. 
http://www.valuecom.com/mississippi/info.htm

Visual Learning Systems, Feature Analyst Software. Date Visited, April 7, 2005. 
http://www.featureanalyst.com/
Leica Geosystems, ERDAS Imagine. Date Visited, April 7 2005. 
http://www.gis.leica-geosystems.com/