Landscape Change In The South Prong Alafia River Basin

by

Kimberly Sarah Koenig

A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Arts
Department of Geography
College of Arts and Sciences
University of South Florida

Major Professor: Robert Brinkmann, Ph.D.
  Mark R. Hafen, Ph.D.
  Graham A. Tobin, Ph. D.

Date of Approval:
December 6, 2006

Keywords: phosphate mining, aerial photos, west-central Florida, Bone Valley, reclamation

© Copyright 2007, Kimberly Sarah Koenig
ACKNOWLEDGEMENTS

I would first like to thank Dr. Brinkmann for your constant support throughout this endeavor and for always providing positive energy in the department. Dr. Tobin, thank you for setting and adhering to high standards, and for your guidance in this thesis. Dr. Hafen, thank you for always providing help, support, and reality-checks when needed, in this thesis and throughout my graduate experience. The academic and moral support found in many of my fellow students has helped tremendously throughout graduate school. Sara, thank you for all of your help and friendship. Craig, thank you for your friendship, technical assistance, and help remaining sane through this journey. Clay, thank you for your friendship, moral support, and for taking me on the tour de phosphate that sparked my passion. Heather, your exceptional work and dedication serves as a shining light for many of us. April, Melissa, Dan, Grant, Erin, and Spencer – I have enjoyed your company and help throughout this experience. I would especially like to thank my family for their love and support throughout school and life. Thank you for being exceptional role models and for teaching me to live for what I believe in. A special thank you must go to John, Jordin, Rosalie, Matt, Pete, Sabrina, Jenny, and Darrell for your friendship, encouragement, and humor. And Kellan, your constant love and support has made the challenges of life and school seem minor. The dedication and excellence that you maintain in your work has served as a constant reminder of the capabilities of an individual. Thank you for everything.
# TABLE OF CONTENTS

List of Tables iii

List of Figures iv

Abstract v

Chapter 1 – Background 1
  Introduction 1
  Literature Review 2
    The Drainage Basin 4
    Landscape Alteration 5
      Land Use/Cover Change Analyses 7
    Florida Geology, Geomorphology, and Hydrology 8
      Florida Geology 8
      Florida Geomorphology 10
      Florida Hydrology 11
    Landscape Alteration in Florida 13
      Environmental Pressures 13
      Land Use 15
    Phosphate in Florida 16
      Formation 16
      Mining 18
      Landscape Alteration 19

Chapter 2 – Study Area 24
  Physical Geography 24
  Human Geography 26
  The Alafia River and Phosphate Mining 28
  The South Prong Alafia River 29

Chapter 3 – Data and Methodology 32
  Data 33
  Landscape Classification 35
  Analysis 41

Chapter 4 – Results and Discussion 45
  Landscape Composition 45
    Composition: 1940 Group 45
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition: 1970 Group</td>
<td>47</td>
</tr>
<tr>
<td>Composition: 2004 Group</td>
<td>47</td>
</tr>
<tr>
<td>Surface Hydrology</td>
<td>52</td>
</tr>
<tr>
<td>Surface Hydrology: 1940 Group</td>
<td>53</td>
</tr>
<tr>
<td>Surface Hydrology: 1970 Group</td>
<td>55</td>
</tr>
<tr>
<td>Surface Hydrology: 2004 Group</td>
<td>57</td>
</tr>
<tr>
<td>Phosphate Mining</td>
<td>59</td>
</tr>
<tr>
<td>Phosphate Mining: 1940 Group</td>
<td>59</td>
</tr>
<tr>
<td>Phosphate Mining: 1970 Group</td>
<td>61</td>
</tr>
<tr>
<td>Phosphate Mining: 2004 Group</td>
<td>63</td>
</tr>
<tr>
<td>Landscape Change</td>
<td>65</td>
</tr>
<tr>
<td>Composition</td>
<td>66</td>
</tr>
<tr>
<td>Surface Hydrology</td>
<td>81</td>
</tr>
<tr>
<td>Chapter 5 – Conclusion</td>
<td>91</td>
</tr>
<tr>
<td>Conclusions</td>
<td>91</td>
</tr>
<tr>
<td>Limitations</td>
<td>93</td>
</tr>
<tr>
<td>Implications</td>
<td>95</td>
</tr>
<tr>
<td>Future Research</td>
<td>97</td>
</tr>
<tr>
<td>References Cited</td>
<td>99</td>
</tr>
<tr>
<td>Appendix</td>
<td>107</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1. Aerial Photo Set Information. 34
Table 2. Georeferencing Data. 35
Table 3. Mining Feature Classes and Background Information. 37
Table 4. Landscape Classes and Background Information. 38
Table 5. Study Period Rainfall Information. 39
Table 6. 1940 Landscape Composition. 46
Table 7. 1970 Landscape Composition. 48
Table 8. 2004 Landscape Composition. 50
Table 9. 1940 Surface Hydrology. 53
Table 10. 1970 Surface Hydrology. 55
Table 11. 2004 Surface Hydrology. 57
Table 12. 1940 Phosphate Mining. 59
Table 13. 1970 Phosphate Mining. 62
Table 14. 2004 Phosphate Mining. 63
Table 15. General Landscape Change. 66
Table 16. Results of Difference Between 2 Proportions Tests, Anthropogenic Activity. 74
Table 17. Results of Difference Between 2 Proportions Test, Phosphate Mining Activity. 76
Table 18. Changes to Surface Hydrology. 81
Table 19. Length of Streams & Drainage Density, 1940, 1970, & 2004. 81
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Florida Geology</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>Bone Valley Phosphate Deposit</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Mandatory Reclamation Phosphate Lands</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>Alafia River Drainage Basin</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>Annual Rainfall Alafia Basin 1930 - 2005</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>Study Area</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>1940 General Landscape Composition Map</td>
<td>46</td>
</tr>
<tr>
<td>9</td>
<td>1940 Landscape Proportions</td>
<td>47</td>
</tr>
<tr>
<td>10</td>
<td>1970 General Landscape Composition Map</td>
<td>48</td>
</tr>
<tr>
<td>11</td>
<td>1970 Landscape Proportion</td>
<td>49</td>
</tr>
<tr>
<td>12</td>
<td>2004 General Landscape Map</td>
<td>51</td>
</tr>
<tr>
<td>13</td>
<td>2004 Landscape Proportion</td>
<td>52</td>
</tr>
<tr>
<td>14</td>
<td>1940 Surface Hydrology Map</td>
<td>53</td>
</tr>
<tr>
<td>15</td>
<td>1970 Surface Hydrology Map</td>
<td>56</td>
</tr>
<tr>
<td>16</td>
<td>2004 Surface Hydrology Map</td>
<td>58</td>
</tr>
<tr>
<td>17</td>
<td>1940 Phosphate Mining Map</td>
<td>60</td>
</tr>
<tr>
<td>18</td>
<td>1970 Phosphate Mining Map</td>
<td>62</td>
</tr>
<tr>
<td>19</td>
<td>2004 Phosphate Mining Map</td>
<td>64</td>
</tr>
<tr>
<td>20</td>
<td>General Landscape Change</td>
<td>67</td>
</tr>
<tr>
<td>21</td>
<td>Mining 1940, 1970, &amp; 2004</td>
<td>68</td>
</tr>
<tr>
<td>22</td>
<td>Water 1940, 1970, &amp; 2004</td>
<td>69</td>
</tr>
<tr>
<td>23</td>
<td>Urban 1940, 1970, &amp; 2004</td>
<td>70</td>
</tr>
<tr>
<td>24</td>
<td>Agriculture 1940, 1970, &amp; 2004</td>
<td>71</td>
</tr>
<tr>
<td>25</td>
<td>Undisturbed / Other 1940, 1970, &amp; 2004</td>
<td>72</td>
</tr>
<tr>
<td>26</td>
<td>Natural Lands Lost to Anthropogenic Activity 1970 - 2004 &amp; 1940 - 2004</td>
<td>73</td>
</tr>
<tr>
<td>27</td>
<td>Natural Lands Lost to Phosphate Mining 1970 - 2004 &amp; 1940 - 2004</td>
<td>75</td>
</tr>
<tr>
<td>28</td>
<td>1940 Landscape Evolution Example</td>
<td>78</td>
</tr>
<tr>
<td>29</td>
<td>1970 Landscape Evolution Example</td>
<td>79</td>
</tr>
<tr>
<td>30</td>
<td>2004 Landscape Evolution Example</td>
<td>80</td>
</tr>
<tr>
<td>31</td>
<td>Surface Hydrology 1940, 1970, &amp; 2004</td>
<td>82</td>
</tr>
<tr>
<td>32</td>
<td>1940 Hooker's Prairie Landscape Change Example</td>
<td>85</td>
</tr>
<tr>
<td>33</td>
<td>1970 Hooker's Prairie Landscape Change Example</td>
<td>86</td>
</tr>
<tr>
<td>34</td>
<td>2004 Hooker's Prairie Landscape Change Example</td>
<td>87</td>
</tr>
<tr>
<td>36</td>
<td>Surface Hydrology Lost to Phosphate Mining 1940 - 2004 &amp; 1970 - 2004</td>
<td>90</td>
</tr>
</tbody>
</table>
Landscape Change in the South Prong Alafia River Drainage Basin

Kimberly Koenig

ABSTRACT

West-central Florida has supplied much of the national and global demand for phosphate for over 100 years. The two main tributaries of the Alafia River, the North and South Prongs, have been extensively modified by the strip mining, benefaction, and chemical processing activities associated with the phosphate mining industry. Using aerial photos, an analysis of landscape change in the South Prong Alafia River drainage basin (357.4 km$^2$) between 1940, 1970, and 2004 was conducted. A modified Florida Land Use, Land Cover, and Forms Classification System code (FLUCCS) was used to classify and measure change through the study period. Change in the study area is characterized by a dramatic decline in the area covered by natural lands and an increase in the area covered by anthropogenic activity. Increasing 43.8 km$^2$ from 1940 – 1970 and 199.96 km$^2$ from 1970 – 2004, phosphate mining activity is the primary force of landscape alteration in the study area. The historic headwaters of the main stream, Hooker’s Prairie, is completely replaced by mining-induced landforms in 2004. Net change in landscape composition from 1940 – 2004 is 1) phosphate mining (+243.76 km$^2$), 2) surface hydrology (-113.13 km$^2$), 3) urban (+2.42 km$^2$), agriculture (+19.76 km$^2$), and undisturbed / other (-139.66 km$^2$). The results of this study indicate that the regional environment and hydrology have been heavily impacted by phosphate mining
activity. The critical management of the industry’s environmental impacts and reclamation practices is essential for the current and future health of the local environment and its inhabitants.
CHAPTER 1: BACKGROUND

Introduction

The largest reserves of phosphate in the world are located in central Florida (PCBOCC, 2006). Over 120 years of open-pit phosphate mining has caused great landscape disturbance, particularly in the west-central portion of the state. A primary concern related to the industry is the effect of mining activities on local hydrology (Brown, 2005). The management and reclamation of phosphate-disturbed lands is a critical issue for the future of Florida’s natural environment as well as for population sustainability.

This research project focuses on analyzing the spatial and temporal rates of landscape changes due to phosphate mining in the drainage basin of the South Prong Alafia Drainage Basin of west-central Florida. Details of landscape composition, before and after modification from phosphate mining, can guide restoration and reclamation efforts. Additionally, the examination of pre- and post-phosphate disturbed lands may provide insight into the effects of the industry on local ecological and hydrological functions.

The research objectives are:

- To understand landscape composition, with an emphasis on phosphate mining and surface hydrology, in 1940, 1970, and 2004.
- To understand landscape change, with an emphasis on phosphate mining and surface hydrology, in 1940, 1970, and 2004.
This research was driven by the following research questions:

- How has the landscape composition of the drainage basin of the South Prong Alafia River changed from 1940 – 2004?
- How has the surface hydrology of the study area changed from 1940 – 2004?
- How has phosphate mining altered the landscape of the study area from 1940 – 2004?

These research questions were addressed through aerial photointerpretation and GIS analysis. Aerial photos sets used in this analysis include a 1940 Group (1938 & 1941), a 1970 Group (1968 & 1973), and a 2004 Group (2004). The final product of this research is 1) a geodatabase, for each group of photos, of landscape composition, surface hydrology, and phosphate mining activity, 2) a morphometric and qualitative description of the features mapped in each group of photos, and 3) an analysis of landscape change throughout the study period.

**Literature Review**

Global history has seen an exponential increase in population, development, and technological innovations. Turner and others (2001) identify two important trends related to land use throughout history: the total land area dedicated to human uses has grown tremendously, and the use and control of the land has intensified as a result of increased production of goods and services. A burgeoning world population both contributes to and exacerbates these trends. Land use activities such as development, agriculture, and mining activities dramatically alter natural landscapes. Given the increase in land altered
by human use, there is heightened concern for the effects of land use on the natural
environment.

Water is a vital and increasingly scare resource. World wide, natural hydrologic
features are polluted, altered, and even lost. A large and growing world population
coupled with the increased area affected by human use places water resources under great
pressure. Public and private entities as well as scientists from a variety of disciplines are
concerned with the protection and integrity of hydrologic features of the natural
landscape. Globally, water resource issues are in the forefront.

The natural environment of Florida is one of the many places in which intensive
and extensive human use has resulted in a significantly altered landscape. Florida’s
natural hydrologic regime has undergone substantial modification. Federal, state, and
local governments are actively planning and conducting restoration efforts throughout
Florida. Also, there is a strong focus regarding water resource management throughout
Florida focused on conservation, reclamation, and restoration. There is an overall need
for more data to aid in these efforts.

A major issue related to Florida’s water resource and land management is the
phosphate mining industry (Brown, 2005). Florida is the nation’s leading producer of
phosphate (FIPR, 2004). Phosphate mining in Florida is extremely land-intensive (BMR,
2004). The rate of land disturbed by phosphate throughout the state is 4,000-6,000 acres
per year (FIPR, 2004). The natural landscape of the state has been and continues to be
severely modified by phosphate mining activities. The natural hydrologic regime of
phosphate mined areas is one of the primary issues related to the quality and functionality
of the post-mined landscape (Brown, 2005). This research seeks to add to the existing
knowledge regarding landscape composition before and after alteration from phosphate 
mining activity. Additionally, this research seeks to provide insight into the rate and 
extent of landscape modification from phosphate mining activity in the South Prong 
Alafia River Drainage Basin.

**The Drainage Basin**

This research was developed and conducted under the theoretical context of the 
*drainage basin system*. A systems approach focuses on objects, the origin and 
development of objects, and the interaction between objects (Thorn, 2005). In a system, 
everything is connected to varying degrees. Within physical sciences, such as 
geomorphology and hydrology, a systems approach has clarified the importance of and 
the interaction between form and process (Gardiner, 1975) and emphasized the 
importance of the total environment and the elements within that environment (Gregory 
and Walling, 1973).

The drainage basin is an open system in which there is the flow of mass and 
energy (Knighton, 1998; Wasserman, 1990); there is self-regulation and a tendency to 
promote equilibrium between the elements within the system (Wasserman, 1990). 
Within the drainage basin, it is well-established that “downstream consequences” have 
“upstream causes” (Knighton, 1998, p. 65). The behavior and characteristics of the 
fluvial system at any location are reflective of the collective effects of upstream controls; 
these controls include geology, land use, and basin physiography (Knighton, 1998). 
Thus, changes to these controls will result in modified behavior within the drainage basin 
system.
As a system, the drainage basin serves as an ideal setting for understanding hydrologic alterations. The extent of anthropogenic activities on the river channel and hydrologic functions is largely dependant on the nature of the activities as well as the proportion of the directly affected drainage basin (Park, 1977). Modifications to the fluvial environment result in changes to physical behavior and ecosystem dynamics (Levy and others, 2006; Poff and others, 1997).

Anthropogenic modifications in the hydrologic regime of a drainage basin are the result of either direct channel modifications or indirect channel modifications (Gregory, 1977; Park, 1977). Direct channel modifications include channelization, levee construction, dam and reservoir construction, irrigation diversions, and bank modification (Gregory, 1977). Indirect modifications include changes in land use such as urbanization, land clearing, and mining.

Through excavation and processing activities, phosphate mining results in both direct and indirect modification of Florida’s streams. The industry has impacted the state’s hydrology for over a century. The stress of the phosphate mining industry on the hydrologic system exacerbates the region’s water supply issues.

**Landscape Alteration**

The rate of land use and land cover change has rapidly increased in the last several decades. The area affected by such changes has greatly increased (Solecki, 2001; Rembold and others, 2000). The terms land use and land cover are closely related, but represent different phenomena. Land use refers to the ways in which humans utilize the land and its resources. Land cover refers to the habitat and/or vegetation present (Turner
and others, 2001). Worldwide, the rate of land cover alteration and land use change continues to accelerate.

Concern for land use and land cover changes has heightened in recent years (Park, 1977). Socio-economic and environmental issues related to land use and land cover change have been frequently highlighted in recent research (Rembold and others, 2002). Landscape alteration studies include analyses of both cultural and environmental changes and a combination of the two. Landscape alteration has recently included research themes such as the role of economics in land use and land cover change (for examples, see Solecki, 2001; Walker, 2001), socioeconomic activities, land use dynamics, and effects on land cover (for examples, see Rembold and others, 2000; Soini, 2005; and Hladnik, 2005), alterations to natural hydrology and subsequent changes in the hydrologic system and native land cover (for examples, see Merdonca-Santos and Claramunt, 2001; Maekawa and Nakagoshi, 1997; Ford and Brooks, 2002; Davies and others, 2005; White and Greer, 2006), as well as effects of mining activities on hydrology (for examples, see Kondolf and others, 2002; Graf, 1979; Rowan and others, 1995; Broring and Wiegleb, 2005).

Direct human use represents the principal factor in landscape alteration (Turner and others, 2001). Such activities include agriculture, livestock activities, silviculture, urbanization and development, and mining. The majority of the total open landscape area is affected by human use. Of the land area regularly affected by human use, nearly 65% is accounted for by agriculture, forestry, mineral extraction practices, transportation and urban development (Hladnik, 2005). Land use is directly linked to environmental quality (Redding and Perry, 1972; Solecki, 2001).
The concept of disturbance is a key to understanding landscape changes (Quattrochi and Pelletier, 1991). Disturbances can be natural (i.e. wildfire) or driven by human forces (i.e. drainage of wetlands). Disturbance refers to phenomena that disrupt the structure of ecosystems, communities, and/or population structures and change resources and/or the physical environment (Turner and Dale, 1991). Social, political, and economic forces largely dictate disturbances in landscapes that are dominated by human use (Dunn and others, 1991). Land and resource management activities should critically consider the causes, patterns, dynamics, and consequences of natural and human-induced disturbances (Turner and others, 2001).

As the growth of global population continues and associated changes in land use and land cover accelerate, there will be a continued increase in issues between water use, development, and environmental change (Herrmann and others, 1998).

Land Use/Cover Change Analyses

The study of land use and land cover changes is largely driven by applied problems and resource management needs (Turner and others, 2001). Landscapes are not static, but rather change over space and through time. Thus, space and time are critical elements for understanding change at the landscape scale (Wien, 2002; Merdonca-Santos and Claramunt, 2001).

Data for the analysis of landscape change are generally confined to three categories: 1) aerial photos, 2) satellite imagery, and 3) archival data. The current trend is towards the use of satellite-based imagery and automated raster analysis. However, aerial photos remain as prime source of landscape-scale data for a majority of the 20th century. Photointerpretation has some drawbacks which include quality and availability
of aerial photographs as well as the time involved in the process (Dunn and others, 1991). Digital remote sensing provides elaborate methods of analysis, but costs are relatively high and historical data are lacking. Archival data, such as census reports and historic soil surveys, can be used for qualitative analysis and can supplement aerial photointerpretation and digital remote sensing analyses (Dunn and others, 1991).

**Florida Geology, Geomorphology, and Hydrology**

Prior to discussing landscape alteration in Florida it is important to put the state in a geologic, geomorphic, and hydrologic context. Florida is frequently misunderstood as a flat, featureless plain. This is far from the truth. A variety of landforms occur throughout Florida. Florida has a rich geological history that has resulted in the diverse landscape present today.

*Florida Geology*

The state of Florida is located in the Coastal Plain physiographic province. The province is a region characterized by low relief that is underlain by unconsolidated to poorly consolidated sediments as well as hardened carbonate rocks (Berndt and others, 1998). Florida’s highest elevation is 345 feet above sea level in Walton County (FDEP, 2002). Most of the surface of Florida is covered by deposits of sand that overlie a thick sequence of limestone and dolomite (Berndt and others, 1998). Florida’s overall lack of natural exposures hinders geologic investigations in the state (Scott, 1992).

Surface sediments in Florida range in age from the Eocene to the Holocene epochs (Lane, 1994). Figure 1 depicts the surface geology of Florida. The surface of Florida is dominated by Pliocene to Holocene siliciclastic-bearing sediments that were deposited in response to late Tertiary and Quaternary Period fluctuations in sea level.
Figure 1. Florida Geology.
Precambrian – Cambrian igneous rocks, Ordovician - Devonian sedimentary rocks, and Triassic – Jurassic volcanic rocks occur thousands of feet below the surface of Florida and comprise what is known as the Florida Basement (Scott, 1992).

*Florida Geomorphology*

Peninsular Florida is the exposed portion of the Florida Platform. Florida is located on the eastern portion of the platform (Schmidt, 1997). The platform extends over 100 miles west of Tampa and only approximately 3 miles east of West Palm Beach (Lane, 1994). The Florida Platform was formed by a combination of volcanic activity and the deposition of marine sediments over 500 million years ago (FLMNH, 2006). Geological evidence indicates that Florida was first formed together with the northwest coast of Africa before they were separated by tectonic rifting (Lane, 1994).

Marine forces have dominated the geomorphologic history of Florida (Schmidt, 1997). Sea levels fluctuated numerous times since the formation of the Florida Platform (Lane, 1994). At times of higher sea levels, the platform was shaped by the shallow marine environment and associated erosional and depositional forces (Schmidt, 1997). Various relict shorelines can be observed throughout the state. The landscape of Florida continues to be modified through coastal, fluvial, chemical and aeolian forces.

Florida’s last documented emergence occurred approximately 35 million years ago (FLMNH, 2006). Florida was once separated from North America by the Gulf Trough. The trough was filled by siliciclastic sediments derived from the Appalachian Mountains during the Miocene Epoch (Lane, 1994). With time, these sediments covered the carbonate platform.
Florida Hydrology

Florida has a rich and diverse set of hydrological resources. Figure 2 is a simplified depiction of Florida’s surface hydrology. Average annual rainfall in the state is 53 inches; spatial and temporal variations in rainfall are present (Patton and Dehan, 1998). Freshwater is replenished by precipitation as well as inflow of ground- and surface water from Alabama and Georgia (Miller, 1997). With high amounts of rainfall, runoff, evapotranspiration, and groundwater levels, the landscape of Florida is dominated by hydrologic processes (Gross, 1991). The peninsula has over 1,190 miles of coastline, more than 7,700 lakes, greater than 1,700 streams, 3 million acres of wetlands, and 320 springs (Patton and Dehan, 1998).

The landscape of Florida is covered by highly permeable soil and rock at or near the surface (Miller, 1997). Karst terrain is present throughout much of the state (Lane, 1994). Manifestations of karst terrain throughout the state include a high occurrence of sinkholes and springs, the presence of caves, disappearing streams, and a well-established underground drainage network (FDEP, 2002). The high water table, low topographic relief, and proximity to sea level of Florida results in a higher number of streams than are generally present in karst areas (Mossa, 1998).

The hydrology of Florida includes a unique system of groundwater and surface water features. Combined, the surficial sands of Florida and the thick underlying limestone and dolomite form an extensive groundwater reservoir (Berndt and others, 1998). There are five principal aquifer systems in Florida that result in abundant groundwater resources (Miller, 1997). Statewide spring discharge exceeds 8 billion gallons per day (FDEP, 2002). The Floridan and Biscayne Aquifers represent the largest
Florida Hydrology

Note: Everglades information is not included in this map.

Data Source:
Florida Department of Environmental Protection
Florida Geographic Data Library

R. Sarah Koenig
2/12/06
sources of water for the state of Florida. A majority of lakes and streams interact with groundwater (FDEP, 2002).

**Landscape Alteration in Florida**

One of the state’s primary problems rests in the need for a sustainable relationship between the human environment and the natural environment (Winsberg, 1996b). Population growth and development characterizes much of the history of Florida (Fernald and May, 1996). The state’s most significant population boom was fully underway by the 1950s and it continues today (Winsberg, 1996a). Florida is currently home to over 17,000,000 people (USCB, 2006), with over 40,000,000 annual visitors (Winsberg, 1996b).

**Environmental Pressures**

Throughout the history of Florida, the state’s urbanization has frequently been at odds with the health of the natural environment (Fernald and May, 1996). The rate and scale of growth within the state threaten to destroy much of the beauty of Florida and to irreparably damage its ecology (Patton, 1996). Much of what attracted people has been altered and degraded by their presence. Widespread drainage of wetlands, miles of artificial waterfront, hazardous waste discharges, and unplanned urban sprawl are among some of the results of population growth with scant regard to the health of the natural environment (Patton, 1996). Florida’s species are among the most endangered in the nation, largely due to the destruction of habitats (Whitney and others, 2004), as well as habitat fragmentation (Kautz and others, 1998).
The natural hydrologic regime of Florida has been subjected to an exceptional amount of modification. Of Florida’s 51,858 miles of streams and rivers, approximately half are ditches and canals (FDEP, 2002). Extensive levee and canal construction began in the 1920s. Wetlands were drained on a large scale for flood control and to accommodate agriculture and development (Walker, 2001). Streams were channelized for navigation and development, altered by dams and reservoirs, and stressed by large withdrawals for various human uses. Floodplains were altered by development (Kautz and others, 1998). Florida’s coastline is heavily populated and its estuarine and marine habitats suffered greatly; many of the natural communities are not healthy (Whitney and others, 2004). Lakes were directly altered by land use change and urbanization as well as indirectly affected by groundwater withdrawals (Kautz and others, 1998). As the principal supply for public, domestic, and industrial water uses, groundwater is in high demand (Berndt and others, 1998).

The Federal, state, and local governments are actively undertaking projects to restore the natural functions of much of the state’s natural landscape (Patton and DeHan, 1998). The natural hydrology of Florida has undergone extensive alteration and many hydrologic features have been degraded, with some features lost altogether. The Florida Department of Environmental Protection identifies water quantity and quality issues to be of primary concern for the 21st century (FDEP, 2002). Two of the largest restoration efforts ever conducted, the Kissimmee River Restoration Project and the Comprehensive Everglades Restoration Plan, are currently being undertaken in the state. Both projects focus on restoring natural hydrologic functions.
Phosphate mining has been a major force of alteration in the state’s hydrologic and terrestrial landscape. The restoration of Florida’s phosphate-mined lands could potentially cover over 300,000 acres and is similar to the Everglades Restoration project in scale and complexity (Brown, 2005).

Land Use

Florida supported a large and growing population throughout most of the 20th century and into today. An expanding economy accompanied this explosive population (Patton, 1996). The rapid land use and land cover changes in Florida are driven by agricultural development, industrial purposes, commercial development, residential needs, and transportation (Solecki, 2001). Developing sustainable communities continues to be a challenge.

Florida’s three largest industries are tourism, agriculture, and mining (IMC phosphates, undated). The very nature of these industries causes them to alter the natural landscape of Florida. Florida is widely known for its ability to produce subtropical and out of season crops (Patton 1996) as well as its many tourist attractions, both constructed and natural. Although Florida ranked fifth nationwide in terms of non-fuel mineral production in 2003 (USGS, 2003), the mining industry of Florida is not as well-known as the tourism and agriculture industries.

The mineral industry of Florida is diverse in nature and is important to the state’s economy. Mining in Florida is undertaken exclusively by open-pit methods (Lane, 1994). Phosphate, cement, stone, sand, and gravel production represents approximately 88% of mining activities throughout the state (McClellan and Eades, 1997). Other mining activities include fuller’s earth, palygorskite clays, petroleum and natural gas, and
rutile (Campbell, 1985). All mining in Florida is subjected to reclamation requirements (BMR, 2004). Phosphate mining accounts for approximately 50% of Florida’s mineral value (McClellan and Eades, 1997) and represents the most land-intensive commodity mined in the state (BMR, 2004).

**Phosphate in Florida**

Of the four phosphate-producing states throughout the nation, Florida leads in production (USGS, 2003). Worldwide, only Morocco produces more phosphate than Florida (Livingston and others, 1998). The phosphate reserves of Florida contribute approximately 75% of the nation’s supply and approximately 25% of the world’s supply of phosphate (Brown, 2005; IMC Phosphates, undated). As the third largest industry in the state, phosphate mining and processing is of vital importance to the economy of Florida (IMC Phosphates, undated).

Phosphate is a limited, non-renewable resource (FIPR, 2004; Slansky, 1986). A majority (90%) of phosphate mined in Florida is used in the production of fertilizer. Phosphorus is one of the three primary plant nutrients essential for growth (FIPR, 2004; Slansky, 1986). There are no substitutes for phosphorus in agriculture (Jasinski, 2005; Slansky, 1986). With a rising world population and the need for dependable food supplies, global phosphate demand is expected to increase (Jasinski, 2006; Slansky, 1986). Phosphate is also used in a variety of products such as plastic, food preservatives, animal feed, soft drinks, toothpaste, and vitamins (Lane, 1994; Campbell, 1985).

**Formation**

Phosphorite is a term used to describe sedimentary rocks that contain an economic amount of phosphorus (Compton, 1997). Large, economic phosphorite deposits, such as
those found in Florida, are rare due to the strict conditions necessary for their formation (Compton, 1997; Riggs, 1980). The formation of such deposits requires a sufficient fluctuation of organic matter to provide the phosphorus necessary to form phosphorite. Once formed, a physical process to remove organic matter and fine-grained sediments is necessary to yield concentrated phosphorite (Compton, 1997).

The origin of the phosphorite reserves of Florida lies in Miocene marine sedimentation (Compton, 1997; Riggs, 1980). Phosphorite-bearing sediments of Florida, for the most part, belong to the Hawthorn Group and the Bone Valley Member (Compton, 1997). Fluctuations in sea level during the Miocene provided the shallow-water coastal and shelf marine environmental conditions necessary for the formation of Florida’s phosphate reserves (Riggs, 1980; Scott, 1997). Re-working of these reserves during the Pliocene high-stand resulted in the high concentrations of phosphorus present in much of Florida’s phosphate deposits today (Slansky, 1986). A majority of the phosphorus in Florida’s phosphorite derives from francolite. Crandallite and wavellite contribute a minor portion of the phosphorus in the phosphorite reserves of Florida; these minerals form from extensively weathered francolite (Compton, 1997).

The topography of Florida guided the Miocene sedimentation of phosphate, and thus, the distribution of the state’s current reserves (Compton, 1997). Low-lying areas were submerged, providing the necessary marine environment, and the topographic highs of the state provided structural guidance for the sedimentation and subsequent concentration. Topographic highs of greatest influence during this process were the Ocala Upland and the Sanford High (Riggs, 1980). Other influential positive features
included the St. Johns Platform, the Central Florida Platform, and the Brevard Platform (Compton, 1997).

**Mining**

Over 300,000 acres in Florida are dominated by phosphate mining activities (Brown, 2005). Phosphate mining has taken place in Florida for nearly 120 years. The discovery of high-grade hard rock phosphate ore near Dunnellon in 1889 triggered a phosphate boom. By 1892, there were over 215 phosphate mining companies operating in the state (FIPR, 2004). Currently, three companies mine land pebble phosphate in the state. Land pebble is favored for mining because of the large size of the deposits as well as the ease in mining and low benefaction costs (Campbell, 1985).

The Bone Valley Deposit in Central Florida is the largest phosphate deposit in the world (PCBOCC, 2006). This deposit encompasses approximately 500,000 acres throughout Polk, Hillsborough, Manatee, and Hardee Counties and has been the primary source of phosphate in the state (Jasinski, 2005). The location of the Bone Valley Deposit is depicted in Figure 3. The Hawthorn Formation is also being mined in Hamilton County in north Florida and areas adjacent to the Bone Valley Deposit (FIPR, 2004).

Phosphate mining in Florida takes the form of open pit mining, utilizing large draglines and buckets to remove vegetation and the overburden, which is typically 30 feet thick (Brown, 2005). The buckets, which are large enough to hold a truck or van, are also used to mine the phosphate matrix (FIPR, 2004). The pits created in the phosphate
extraction are generally 200-300 feet wide and several thousand feet in length (Yon, 1983). The phosphate ore zone is generally 5 to 50 feet thick and is a combination of clay, quartz sand, and phosphate (Yon, 1983). After excavation, high pressure water is utilized to slurry the phosphate matrix for transport to the benefaction plant. The phosphate is then separated from the matrix through benefaction and shipped to chemical processing facilities for the production of fertilizer (FIPR, 2004).

**Landscape Alteration**

Phosphate mining activity results in a landscape that is “severely modified” (Brown, 2005, p. 324). Annually, phosphate mining disturbs 4,000-6,000 acres (FIPR,
Mining for phosphate alters the topography, the stratigraphy of geology and soils, and the hydrologic regime of the natural landscape of Florida (Riekert and others, 1991).

The nature of landscape alteration from phosphate mining results from excavation as well as processing. In fact, some of the primary issues associated with phosphate mining are its waste products. The two main waste products from phosphate mining are clay settling areas and phosphogypsum. The following is a brief summary of these waste products.

- **Clay Settling Areas (CSAs)** – produced through benefaction; typically occupy 40 – 60% of the post-mined landscape (Brown, 2005). High-pressured water is utilized to separate the phosphate matrix and results in clay by-products that occupies a much larger area post-processing. CSAs shift and settle over time, resulting in increased depression storage and evaporation and decreased runoff (Lewelling and others, 1998). Additionally, CSAs hinder groundwater recharge (Lewelling and others, 1998).

- **Phosphogypsum Stacks** – phosphogypsum is produced from chemical ‘wet processing’ of phosphoric acid at a rate of 30 million tons/year (FIPR, 2004). Approximately 5 tons of phosphogypsum results from the production of 1 ton of phosphoric acid (Long and Orne, 1990). Phosphogypsum contains radium, fluoride, and acids and is required to be stored in giant ‘gyp stacks’ (Dooris and others, 2000). Over 1 billion tons of phosphogypsum is currently stored in 25 stacks in Florida (FIPR, 2004). Gyp stacks can reach 200 feet high and cover 400 – 600 acres; the smallest stack weighs approximately 5 million tons (Dooris and others, 2000).
The hydrologic regime is particularly affected by phosphate mining activities. In 1998, the regional water demand for the industry was 200 million gallons/day (SWFWMD, 1998). Approximately 25-30% of lands annually disturbed by phosphate extraction activities are wetlands (FIPR, 2004). In addition to the wetlands directly destroyed by mining, other wetlands are affected due to disconnection from natural systems, altered hydrology, and increased turbidity (HCEPC, 2006). Streams have been relocated to allow phosphate mining (Robertson, 1987). Effects of phosphate mining on the hydrology of Florida include the reduction or elimination of base flow, reduced surface runoff, lowered water levels in the Upper Floridan aquifer, and replacement of natural surface drainage by modified topography and reclaimed ditches and swales (Lewelling and others, 1998).

The landscape that remains after phosphate mining takes place is “virtually barren” (Brown, 2005, p. 326). Reclamation of phosphate mined lands is mandatory for all lands mined after July 1, 1975. Lands mined prior to July 1, 1975 were reclaimed on a voluntary basis; a majority of mined land in rural central Florida was not reclaimed (FIPR, 2004). The location of ‘Mandatory Reclamation’ phosphate lands is depicted in Figure 4.

Reclamation research is considered a top priority related to the industry in Florida (FIPR, 2004). It is estimated that without human intervention, the post-mined landscape will take approximately 500 years to undergo natural restoration (Brown, 2005). It is important to note that reclamation does not mean the restoration of the natural communities that were in existence prior to mining activity. Reclamation entails returning lands to a beneficial use, whereas restoration entails restoring ecological and
Figure 3. Mandatory Reclamation Phosphate Lands.
hydrological functions (Brown, 2005). Alternative ecosystems, differing significantly from the original ecosystems, usually result from reclamation activities (Pratt and others, 1985).

Phosphate mining is frequently promoted as a ‘temporary land use’ by the industry (Mosaic, 2005). However, finding productive uses for reclaimed phosphate land often presents a major problem (PC and UFIFAS, 1994). Public concern and debate has often surrounded the effects of phosphate mining on Florida’s wetlands, rivers, and natural landscape (Pratt and others, 1985). There is currently a large public concern regarding the industry’s intentions to move south as the Bone Valley deposit is mined out. The ecological and hydrological health of the Peace River is a major focus of public resistance to additional mining.

For over a century, phosphate mining has been a significant force of landscape modification and resource consumption in the region. Critical management of this industry is necessary for future sustainability of the region. A greater understanding of the role of phosphate mining in land use/land cover change and environmental health is essential for the current and future task of regulation and management of Florida’s phosphate industry.
CHAPTER 2: STUDY AREA

This project focuses on a sub-basin of the Alafia River, which has been heavily impacted by phosphate mining activities. The South Prong of the Alafia River was chosen for this analysis due to the scale of impacts from mining on this sub-basin. The following sections explore geography of the Alafia River and highlight the interaction of the phosphate industry with the Alafia River watershed. The final section specifically examines the South Prong Alafia River sub-basin.

Physical Geography

The Alafia River drains approximately 1,093 square kilometers in Hillsborough and Polk Counties (Kelly and others, 2005). The location of the Alafia River Drainage Basin is depicted in Figure 5. The Alafia River is formed by the confluence of its two main tributaries, the North and South Prong Alafia Rivers, in eastern Hillsborough County. It flows 38.6 kilometers west into lower Hillsborough Bay (SWFWMD, 2001). The Alafia River watershed is surrounded by the Peace River watershed to the east, the Little Manatee River watershed to the south, and the Hillsborough River watershed to the north (Kelly and others, 2005).

The climate of this area is humid subtropical, with a mean annual temperature of 72.2°F (SWFWMD, 2001). Mean annual rainfall is 52 inches, with a majority of precipitation occurring as convective thunderstorms from June – September (Kelly and others, 2005). Figure 6 is a graph of annual rainfall of the basin from 1930 – 2004.
Annual evapotranspiration for the Alafia River drainage basin is 39 inches (SWFWMD, 2001).

Land cover in the Alafia River watershed was historically a variety of coastal, wetlands, and upland habitats (SWFWMD, 2001). The lower portion of the Alafia River drains part of the Gulf Coastal Lowlands, while the remainder of the river flows through the Polk Upland (Kelly and others, 2005). Primary soil groups in the Alafia River watershed include the Myakka-Basinger-Holopaw association, the Candler-Lake association, and the Winder-Chobee-St. Johns (SWFWMD, 2001). The soils of the Polk County portion of the watershed are dominated by Arents-Haplaquents-Quartzipsamments, a man-made soil type that is the result of phosphate mining (Kelly and others, 2005).
The water level of the Alafia River is often below the potentiometric surface of the underlying aquifers, resulting in numerous springs and seeps along the river and floodplain (Dames and Moore, 1975). Two second-magnitude springs, Lithia and Buckhorn Springs, contribute approximately 35 million gallons/day to the Alafia River (Champion and Starks, 2001). Approximately 14% of the combined flow of Lithia and Buckhorn Springs is diverted to phosphate chemical processing facilities (SWFWMD, 2001).

**Human Geography**

The Alafia River is located within the large and rapidly developing urban area of Tampa Bay. Urban areas within the watershed include parts of Lakeland, Plant City, Mulberry, and Brandon (Kelly and others, 2005). Watershed population in 2000 was
estimated to be 232,227 (SWFWMD, 2006). Agriculture and phosphate mining are major economic activities in the watershed. Rates of habitat destruction within the watershed have been high since the 1920s and 1930s (SWFWMD, 2001). The current area covered by natural systems is declining, habitats are being fragmented, and changes in hydrology and degraded water quality are leading to damage in areas not directly altered by anthropogenic activity (PESI, 2002).

The Alafia River watershed is a major water source for public supply, industrial uses, agriculture, and phosphate mining (SWFWMD, 2001). Both surface and ground water are used for water supply. For example, approximately 99.6 million gallons/day were withdrawn from the watershed in 1998. Of these withdrawals, agriculture accounted for 30% and phosphate mining accounted for 28% (SWFWMD, 2001). Additionally, the recently completed C.W. ‘Bill’ Young Reservoir utilizes the Alafia River as a primary source of water (TBW, 2006).

As urbanization and industrial growth continue in the drainage basin and surrounding areas, pressures on water supply are expected to increase (SWFWMD, 2001). This is especially important given the history of water supply shortages in the Tampa Bay region. For over 40 years, the region has experienced political battles over water resource supply and demands (Rand, 2003). Water quality and quantity continue to be an issue in the region.

PESI (2002) identifies the following as the primary sources of pollutant loading to the Alafia River: 1) phosphate mining and processing, 2) nitrate loading from Lithia and Buckhorn Springs, 3) periodic spills from phosphate CSAs and gypsum stacks, 4) urbanization, 5) agriculture, and 6) sewage disposal.
The Alafia River and Phosphate Mining

The Alafia is home to both phosphate mining and processing and is thus impacted by the land disturbance, clay and phosphogypsum waste, and water quality issues associated with the industry. Phosphate mining activity has been an “inherently intrusive and destructive practice” with respect to the natural habitat within the watershed (SWFWMD, 2001, p. 6-15). In 1999, mining activity accounted for at least 35.9% of the total land area within the drainage basin (Kelly and others, 2005). A majority of the mining activity is concentrated in the eastern half of the watershed, particularly in the North and South Prongs of the river (SWFWMD, 2001).

The headwaters of both the river and its two main tributaries are located in the phosphate mining district of Hillsborough and Polk counties (Dames and Moore, 1975). The mouth of the river was dramatically altered by dredge and fill activities associated with the need for shipping access from a phosphate mining facility to the main shipping channel in Tampa Bay. The historic mouth of the river has since been reduced to a small tidal creek with minimal to no connection to the river (PESI, 2002).

Widespread changes to the physiography and drainage patterns of the basin have resulted from phosphate mining as natural lands have been cleared, excavated, and partially reclaimed (SWFWMD, 2001). The origin of many of the ‘open water systems’ in the eastern portion of the basin lies in phosphate mining activity (Kelly and others, 2005). The largest wetland in the basin, Hooker’s Prairie (Dames and Moore, 1975), has undergone near total modification by phosphate mining. Phosphate reclamation efforts within the basin have yielded mixed results (SWFWMD, 2001).
Phosphate mining activity accounts for a majority of the water quality issues that the watershed has experienced (HCEPC, 1998), and represents both point and non-point sources of pollution (SWFWMD, 2001). Pollutants that result from the mining process include strong acids, phosphates, fluorides, sulfates, ammonia, and radionuclides (PESI, 2002).

Both phosphogypsum and clay settling area failures have occurred numerous times on the Alafia River, often with ecologically devastating results. These spills can threaten human health, wildlife, and ecosystems (SWFWMD, 2001). An example of such spills occurred on December 7, 1997 when the dike of a gypsum stack failed and released approximately 50 million gallons of acidic process water into a tributary of the North Prong of the Alafia River (HCEPC, 1998). The spill resulted in the death of most of the aquatic life (ranging from alligators to fish to microscopic plankton) for the remaining length of the river (HCEPC, 1998).

*The South Prong Alafia River*

The South Prong Alafia River, one of the two main tributaries of the Alafia River, drains approximately 357 square kilometers (88,303 acres) (Kelly and others, 2005). The location of the South Prong Alafia River Drainage Basin is depicted in Figure 7. The channel of the South Prong is poorly defined, flowing through marsh and swamp areas (SWFWMD, 2001). The headwaters of this stream are in Hooker’s Prairie, northeast of Brewster in Polk County (Dames and Moore, 1975).

Watershed land use in 1999 (utilizing the FLUCCS code) was dominated by phosphate mining activity (65%) and agriculture (17.3%), with small amounts of wetlands (10.9%), uplands (5.5%), open water (1.5%), and urban usage (2.3%) (Kelly

Over half of the mined land in the Alafia River watershed is located in the South Prong sub-basin (Kelly and others, 2005). Topographic maps indicate that much of the area within the basin is ‘barren land,’ a result of extensive phosphate mining activity (SWFWMD Exec Summary). Phosphate mining is considered the major pollutant source for the South Prong drainage basin (SWFWMD, 2001). The headwaters of the South Prong Alafia River (Hooker’s Prairie) have been greatly impacted by phosphate mining activity. A sawgrass reclamation project in the Hooker’s Prairie area won the Bureau of Mine Reclamation’s Outstanding Wetland Project award in 2000 (Mosaic, 2005).
However, the mining tract that covers the Hooker’s Prairie area was not yet released by FDEP in 2003.

There is a lack of understanding regarding the impacts of anthropogenic activity, and particularly phosphate mining, on the Alafia River Drainage Basin. This research seeks to contribute to the knowledge regarding the impacts of phosphate mining on the South Prong Alafia River Drainage Basin. Additionally, this research seeks to enhance the understanding of the dynamics of landscape change in the region and the associated implications for population and environmental sustainability.
CHAPTER 3: DATA AND METHODOLOGY

This research seeks to understand landscape change to the drainage basin of the South Prong of the Alafia River, utilizing the earliest comprehensive data set available. The objectives of this research are:

- To understand landscape composition, with an emphasis on phosphate mining and surface hydrology, in 1940, 1970, and 2004.
- To understand landscape change, with an emphasis on phosphate mining and surface hydrology, in 1940, 1970, and 2004.

This research was driven by the following research questions:

- How has the landscape composition of the drainage basin of the South Prong Alafia River changed from 1940 – 2004?
- How has the surface hydrology of the study area changed from 1940 – 2004?
- How has phosphate mining altered the landscape of the study area from 1940 – 2004?

These research questions were addressed through the interpretation of sequential aerial photographs. Given that aerial photographs provide a holistic view of the landscape (Lo, 1976) and represent the only comprehensive source of data for the early 20th century, aerial photos were ideal for this study. Analysis of archival data, such as historic soil surveys and topographic maps, was utilized to enhance the quality of the aerial photointerpretation and resulting data. The utilization of multi-temporal sets of
aerial photos allowed for the exploration of the spatial and temporal dynamics related to phosphate mining in the study area.

Data

The two-county nature of the drainage basin provided a challenge to the acquisition of comprehensive sets of aerial photographs for the years of interest. Photos were taken in different, but near, years in each of the two counties. In order to utilize the earliest photos available for the study area, 1938 Hillsborough County and 1941 Polk County aerial photos were acquired. This group of photos will be referred to as the 1940 Group. Table 1 outlines information for each set of photos used in this analysis. 1968 Polk County and 1973 Hillsborough County photos were chosen for analysis in order to gain a better understanding of the temporal dynamics associated with change in the study area. This group of photos will be referred to as the 1970 Group. The final photos, taken in 2004, were chosen for analysis in order to understand the contemporary composition of the study area. This group of photos will be referred to as the 2004 Group. While the multi-year groupings are not desirable, they provided the only way to capture full drainage basin characteristics during particular time periods.

Due to the non-static nature of drainage basin boundaries and many issues associated with delineating them, spatial data were acquired from the SWFWMD regarding the current South Prong Alafia River drainage basin. This basin boundary was used in each year of analysis. In many places, the basin boundary is defined by anthropogenic features. County Road 555 forms the entire eastern boundary of the basin and State Highway 674 forms part of the southern boundary. Additionally, many parts of
the basin boundary are formed by phosphate mining features that include clay settling areas of various ages and stages of reclamation and gypsum stacks.

Table 1. Aerial Photo Set Information.

<table>
<thead>
<tr>
<th>Photo Group</th>
<th>Photo Set</th>
<th>Data Source</th>
<th>Date</th>
<th>Additional Info</th>
<th>Required Georeferencing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940 Group</td>
<td>1938 Hillsborough</td>
<td>Florida Center for Community Design and Research (FCCDR), University of South Florida</td>
<td>November 1938 – January 1939</td>
<td>Georeferenced by FCCDR under a grant from Hillsborough County</td>
<td>No</td>
</tr>
<tr>
<td>1941 Polk</td>
<td>University of Florida</td>
<td>March 1941</td>
<td>Originally taken by the Department of Agriculture</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>1970 Group</td>
<td>1968 Polk</td>
<td>University of Florida</td>
<td>January – February 1968</td>
<td>Originally taken by the Department of Agriculture</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>1973 Hillsborough</td>
<td>Environmental Protection Commission of Hillsborough County</td>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>2004 Group</td>
<td>2004 Polk &amp; Hillsborough</td>
<td>FDEP’s Land and Boundary Information System (LABINS)</td>
<td>December 2003 – April 2004</td>
<td>Orthophotos</td>
<td>No</td>
</tr>
</tbody>
</table>

All analysis was conducted within the Albers Equal Area Conical Projection in order to preserve areal integrity of the data. Where needed, georeferencing was conducted within ArcGIS. Due to the rural nature of the study area in the early photos and the extent of landscape alteration over the study period, an array of spatial data were utilized to ensure quality georeferencing. Table 2 outlines the data that were utilized in the georeferencing process.
### Table 2. Georeferencing Data.

<table>
<thead>
<tr>
<th>Data</th>
<th>Information</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographic Maps</td>
<td>USGS 7.5 minute; created 1987</td>
<td>LABINS</td>
</tr>
<tr>
<td>Roads</td>
<td>1: 24,000 roads; created 1998</td>
<td>Florida Geographic Data Library</td>
</tr>
<tr>
<td>Hydrography</td>
<td>1: 100,000 surface hydrology; created 2003</td>
<td>Florida Geographic Data Library</td>
</tr>
<tr>
<td>Gypsum Stacks</td>
<td>Phosphogypsum stack locations; created 2003</td>
<td>FDEP</td>
</tr>
<tr>
<td>Mandatory, Non-Mandatory, and Hybrid CSAs</td>
<td>Compilation of all data regarding clay settling areas; created 2003</td>
<td>FDEP</td>
</tr>
</tbody>
</table>

**Landscape Classification**

Data analysis was conducted within ArcGIS. All data were managed within a geodatabase. The three groups of photo sets provided the basis for the creation of the database. The features of interest were for each study period and subsequently analyzed landscape changes. A classification system was created and uniformly applied to each set of photos. The creation of this classification system was guided by a review of the nature of phosphate mining in central Florida as well as the Florida Land Use, Cover, and Classification System (FLUCCS) Handbook. The FLUCCS code was developed by the Florida Department of Transportation to provide a uniform basis for land cover and land use classification.

The identification of features of interest was performed through the utilization of the fundamental principles of image interpretation. These are size, shape, location, shadow, tone and color, texture, pattern, height and depth, site, situation, and association (Jensen, 2000). An inherent challenge to quantifying landscape change is the notion that
“the landscape is a continuum rather than a series of discrete landscape classes and problems arise in landscape classification regardless of the survey methodology employed” (Taylor and others, p. 2749,1999). I attempted to best account for this challenge through the utilization of a variety of archival data and constant data quality and assurance monitoring. To assure quality landscape classification, historic and contemporary soil surveys, topographic maps, and the pertinent available spatial data were used to guide interpretation of the photos.

A pilot study, covering 50 sq km in Polk County, was conducted April – May 2006. This study area was chosen because of the existence of both mining and natural features in the historic landscape. The goal of the pilot study was to test and fully develop the methods and classification scheme proposed for this study. The pilot study was successful in this regard. Minor modifications in the classification scheme were made as a result of this study. The study area was successfully mapped by land use.

The landscape classes and specific features utilized in this analysis were chosen to fully embrace the nature of landscape alteration from phosphate mining as well as to meet the goals of this study. Tables 3 and 4 outline the landscape features and basic criteria for their identification used in this analysis.

Special attention was placed on wetland delineation. A wetland is defined as “an area that is periodically inundated or saturated by surface or ground water on an annual or seasonal basis, that displays hydric soils, and that typically supports or is capable of supporting wetland hydrophytic vegetation” (Black, 1991, p. 133). However, true wetland delineation was in this case difficult due to the inability to test soils, water, and vegetation.
Table 3. Mining Feature Classes and Background Information.

<table>
<thead>
<tr>
<th>LU/LC Category</th>
<th>Feature ID</th>
<th>Feature Type</th>
<th>Classification</th>
</tr>
</thead>
</table>
| Mining         | 110       | Mining Facilities | • Industrial facilities on mining land  
|                |           |              | • Processing began in 1950s (Long & Orne, 1990) |
|                | 120       | Gypsum Stacks  | • A by-product of processing, gypsum stacks are located near processing facilities  
|                |           |              | • FDEP shapefiles used as guidance in case of discrepancy |
|                | 130       | Open Pits – Active  | • Adjacent pits and steep-sloped piles  
|                |           |              | • Mine pits are easily observable on aerial photos (SWFWMD, 2001) |
|                | 140       | Clay Settling Areas  | • CSAs that retained shape were placed under this classification  
|                |           |              | • CSAs easily observable on aerial photos (SWFWMD, 2001)  
|                |           |              | • FDEP shapefiles were used as guidance in case of discrepancy |
|                | 150       | Old Clay Settling Areas  | • CSAs that have not retained their shape and/or were heavily vegetated were placed under this classification  
|                |           |              | • FDEP shapefiles were heavily utilized as guidance for this feature classification |
|                | 160       | Tailings/ Spoil Piles  | • Generally located in areas of recent and active mining  
|                |           |              | • Tailings now utilized in reclamation efforts; represent a temporary landscape feature in current photos |
|                | 170       | Mining Lakes & Ponds  | • Region has many water-filled former mine pits (SWFWMD, 2006)  
|                |           |              | • Water bodies on mined land not falling into other categories were placed under this classification |
|                | 180       | Disturbed Mining Land  | • Mining scars apparent and/or documented from earlier photo sets  
|                |           |              | • Mining land not falling into other terrestrial mining classes was placed under this classification |
|                | 190       | Reclaimed Land/Converted to other Land Uses  | • Mined land in areas of mandatory reclamation and classified as ‘released’ by FDEP was placed under this classification  
|                |           |              | • Mined land that was converted to other uses (agriculture & urban) and observed through the interpretation of earlier photos was placed under this classification |
Table 4. Landscape Classes and Background Information.

<table>
<thead>
<tr>
<th>LU/LC Category</th>
<th>Feature ID</th>
<th>Feature Type</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>210</td>
<td>Streams</td>
<td>• Much of the channel is undefined, flowing through marsh and swamp (Dames and Moore, 1975)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Topographic maps and FDEP shapefiles were used for guidance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Streams were combined with wetlands for areal measurements</td>
</tr>
<tr>
<td></td>
<td>220</td>
<td>Wetlands</td>
<td>• Natural wetland systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Topographic maps and soil surveys were used for guidance</td>
</tr>
<tr>
<td></td>
<td>230</td>
<td>Lakes and Ponds</td>
<td>• Natural lakes and ponds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Water bodies placed under this classification have little to no vegetation</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>Karst Depressions</td>
<td>• Mapped only in areas not classified as wetlands</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• These features have little to no water</td>
</tr>
<tr>
<td>Urban</td>
<td>300</td>
<td>Urban</td>
<td>• Urban or Built Up</td>
</tr>
<tr>
<td>Agriculture</td>
<td>400</td>
<td>Agriculture</td>
<td>• Agricultural activity apparent</td>
</tr>
<tr>
<td>Undisturbed / Other</td>
<td>500</td>
<td>Undisturbed / Other</td>
<td>• All lands not falling into the above categories were placed under this classification. Although most of these lands were undisturbed, some rangeland was likely placed into this category due to its general lack of distinctive landforms and/or borders</td>
</tr>
</tbody>
</table>

at each site for each year of analysis. To compensate for this difficulty, soil surveys and topographic maps were used for guidance. The complications associated with identifying wetlands from aerial photos may have led to the inclusion of some undisturbed land in this land use category. Data quality checking and assurance was conducted after the completion of each year of landscape classification as well once all years were completed.
Due to the dynamic nature of the precipitation regime and hydrological system, it is likely that features mapped as ‘karst depressions’ in drier conditions may be mapped as ‘lakes/ponds’ in wetter conditions, and vice versa. The stream floodplains are densely vegetated and the streams often disappear in the aerial photos. To ensure accurate measurements in landscape coverage, streams and wetlands were combined for areal calculations.

Streams were digitized as line files in order to determine total stream length and drainage density. These parameters were examined to provide a general understanding of the defined drainage in the study area throughout the study period. The fine scale of analysis necessary for accurate hydrologic modeling was unattainable due to the large size of the study area and difficulties encountered in stream definition.

Understanding changes to surface hydrology is difficult due to the dynamic nature of the hydrologic regime. This challenge was additionally given special consideration due to the time between the photo sets used for the 1940 Group (1938 & 1941) and the 1970 Group (1968 & 1973). Table 4 provides summary data regarding annual basin rainfall during the study period.

Table 5. Study Period Rainfall Information. (Data Source: SWFWMD, CWM, 2006).

<table>
<thead>
<tr>
<th>Group</th>
<th>Year</th>
<th>Rainfall (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940 Group</td>
<td>1938</td>
<td>48.63</td>
</tr>
<tr>
<td></td>
<td>1941</td>
<td>57.55</td>
</tr>
<tr>
<td>1970 Group</td>
<td>1968</td>
<td>50.44</td>
</tr>
<tr>
<td></td>
<td>1973</td>
<td>55.28</td>
</tr>
<tr>
<td>2004 Group</td>
<td>2004</td>
<td>68.80</td>
</tr>
<tr>
<td>Mean</td>
<td>1930 - 2005</td>
<td>52.32</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1930 - 2005</td>
<td>8.76</td>
</tr>
</tbody>
</table>
The land use category of undisturbed / other served as a catch-all for lands not falling in any of the anthropogenic land use categories or lands with no clearly identifiable hydrological characteristics. Most of these lands are likely undisturbed uplands. However, there is a possibility that some rangelands were included in this classification category due to the frequent lack of physical evidence associated with historic cattle farming.

The available spatial data regarding phosphate mining landforms were used as guidance in classification. Phosphate mining-associated data are generally limited to post-1975, when reclamation became mandatory. However, there has been a considerable effort by various state agencies to compile spatial information regarding clay settling areas that were present prior to mandatory reclamation. These data were especially helpful due to the sometimes unclearly defined boundaries of clay settling areas in the historic photos.

Consistent with the need to clearly define landscape classes and specific feature classes, specifications were developed as to what lands would be included in the ‘reclaimed land’ category. Spatial data regarding reclamation status are available on a scale that is consistent with individual mining operations, which modernly cover broad expanses. Most of the study area is contemporarily mined out; nearly all of the mined land in the study area is classified by FDEP as ‘under reclamation.’ Land was classified as ‘reclaimed’ only if 1) the mining tract was officially released by FDEP according to the 2003 shapefile, or 2) conversion to other land uses (i.e. urban or agriculture) was observed in the aerial photos through the study period.
Analysis

In 1940, missing and/or poor quality photos led to the classification of 14.5 sq km of the basin as ‘no data.’ This area represents 4.5% of the basin. To ensure a consistent study area, these areas were treated as exclusion layers in the subsequent years. All results and maps are based on the basin with the appropriate areas excluded. However, information regarding all available data is also presented in the results tables for each step of analysis for the 1970 and 2004 groups.

The area of each feature was calculated within ArcGIS. These figures were used in calculating the total extent of each landscape class and feature class. General landscape composition is analyzed based on the five broad landscape classes generated for this analysis (mining, water, urban, agriculture, and undisturbed / other). For the purpose of understanding the role of anthropogenic activity in the landscape change dynamics, the five landscape classes were grouped into the categories of natural and anthropogenic land uses. Anthropogenic land uses include mining, urban, and agricultural lands. Natural lands include water and undisturbed / other.

After the examination of general landscape composition, surface hydrology and phosphate mining activity were analyzed in greater detail based on the specific feature classes generated for this analysis (Table 4). Areal calculations were used to gain an understanding of the role of each feature within surface hydrology and phosphate mining. Additionally, landscape organization was visually examined for patterns.

Areal calculations were then used to explore land use change from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004. To explore landscape evolution, land use maps were generated for each general landscape class for 1940, 1970, and 2004. To
further examine the role of anthropogenic activity in the loss of natural lands, layers of natural and anthropogenic land uses were generated for each 1940, 1970, and 2004. The intersect function in ArcGIS was then used to determine which natural lands present in 1940 were replaced with anthropogenic lands in 1970. This operation was subsequently repeated to determine natural lands lost to anthropogenic activity from 1970 – 2004, and overall from 1940 – 2004.

The significance of the change in the proportion of the basin covered by anthropogenic activity was statistically explored through the Difference Between Proportions Two Sample Z-test. This statistic tests for a significance different between two proportions from different populations, at the desired level of significance (McGrew and Monroe, 2000). The standardized test statistic for the Difference Between Proportions Two Sample z-test is:

\[
    z = \frac{\text{Observed diff} - \text{Hypothesized difference}}{\text{Standard Error}}
\]

\[
    z = \frac{(\hat{p}_1 - \hat{p}_2) - (p_1 - p_2)}{\sqrt{\bar{p} \bar{q} \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}},
\]

Where:

\( \hat{p}_1 \) = the number of successes (proportion of the total study area) accounted for by the variable of interest in the population 1

\( \hat{p}_2 \) = the number of successes (proportion of the total study area) accounted for by the variable of interest in population 2

\( n_1 \) = the total population 1 (study area)

\( n_2 \) = the total population 2 (study area)
\[ \bar{p} = \frac{\text{the amount of the variable of interest in population 1} + \text{the amount of the variable of interest in population 2}}{\text{the total study area of population 1} + \text{the total study area of population 2}} \]

\[ \bar{q} = 1 - \bar{p} \]

(McGrew and Monroe, 2000)

To further examine the role of phosphate mining activity in the loss of natural lands, layers of phosphate mining activity were generated for each data set in 1940, 1970, and 2004. The intersect function in ArcGIS was then used to determine which natural lands present in 1940 were replaced with phosphate mining activity in 1970. This operation was subsequently repeated to determine natural lands lost to phosphate mining activity from 1970 – 2004, and overall from 1940 – 2004. The Difference Between Proportions Two Sample Z-test was again used to explore the significance of the change in the proportion of the basin covered by phosphate activity from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004.

Areal calculations were then used to explore changes to surface hydrology from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004. Change in total stream length and drainage density were also explored. To understand hydrological evolution in the study area, land use maps were generated for the specific surface hydrological features for 1940, 1970, and 2004.

The role of anthropogenic activity in the loss of surface hydrology was explored using the intersect function in ArcGIS. The intersect function was first used to determine the area of surface hydrology in 1940 that is replaced by anthropogenic
activity in 1970. This operation was subsequently repeated to determine the area covered
by surface hydrology lost to anthropogenic activity from 1970 – 2004, and overall from
1940 – 2004. The role of phosphate mining in the loss of surface hydrological features
was examined using the intersect function described above.
CHAPTER 4: RESULTS & DISCUSSION

Landscape Composition

It is well documented that the landscape of the South Prong Alafia River drainage basin has been dramatically altered by intensive land use activity, most notably phosphate mining and processing. However, detailed data regarding the spatial and temporal dynamics of this alteration are lacking.

A total of 1717 landscape features were delineated for this analysis. The following information is the result of the digitization of the 1940 Group, 1970 Group, and 2004 Group aerial photographs.

Composition: 1940 Group

The general land use map generated for the 1940 Group is located in Figure 8. A total of 14.5 sq km, representing 4.05% of the study area, was treated as ‘no data’ in the 1940 classification due to missing and/or poor quality photos. Table 6 summarizes the spatial extent and landscape proportion for the general landscape classes in 1940. Minimal anthropogenic activity was observed in the 1940, and thus this photo set provided a basis for understanding landscape composition in the study area under ‘natural’ conditions. Figure 9 represents proportional landscape composition for the 1940 Group.

Anthropogenic activities accounted for 10.89% of the study area in 1940. Agriculture, covering a mere 27.25 sq km, was the major activity present. Small patches of agricultural land uses were located adjacent to wetlands throughout the study area.
Table 6. 1940 Landscape Composition.

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>Area (square km)</th>
<th>% of study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>11.55</td>
<td>3.23</td>
</tr>
<tr>
<td>Water</td>
<td>152.26</td>
<td>42.57</td>
</tr>
<tr>
<td>Urban</td>
<td>0.19</td>
<td>0.05</td>
</tr>
<tr>
<td>Agriculture</td>
<td>27.25</td>
<td>7.61</td>
</tr>
<tr>
<td>Undisturbed / Other</td>
<td>151.96</td>
<td>42.49</td>
</tr>
<tr>
<td>Exclusion / No Data</td>
<td>14.50</td>
<td>4.05</td>
</tr>
<tr>
<td>Total</td>
<td>357.1</td>
<td>100</td>
</tr>
</tbody>
</table>

Urban activity, covering 0.19 km sq, occurred as a small group of structures adjacent to agricultural activity. Phosphate mining activity, which occurred in small groups on the periphery of the eastern portion of the basin, accounted for 11.55 sq km.

Figure 7. 1940 General Landscape Composition Map.
A majority of the study area (85.06%) was covered by natural landscape classes. Water features, including streams, wetlands, lakes and ponds, and karst features, covered 152.26 sq km. Undisturbed / other lands covered 151.96 sq km. These landscape classes were interspersed and occurred ubiquitously throughout the study area.

Figure 8. 1940 Landscape Proportions.

Table 7 summarizes the spatial extent and landscape proportion for the general landscape classes in 1970. The data for the entire study area, without the exclusion are also listed in Table 7. To ensure a consistent study area throughout the period of analysis, all results are based on the study area with the appropriate areas excluded from the data. The general landscape map generated for the 1970 Group is located in Figure 10. Figure 11 represents proportional landscape composition for the 1970 Group.

Composition: 1970 Group

Table 7 summarizes the spatial extent and landscape proportion for the general landscape classes in 1970. The data for the entire study area, without the exclusion are also listed in Table 7. To ensure a consistent study area throughout the period of analysis, all results are based on the study area with the appropriate areas excluded from the data. The general landscape map generated for the 1970 Group is located in Figure 10. Figure 11 represents proportional landscape composition for the 1970 Group.
Table 7. 1970 Landscape Composition.

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>All Available Data</th>
<th>With Appropriate Area Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (square km)</td>
<td>% of study area</td>
</tr>
<tr>
<td>Mining</td>
<td>55.35</td>
<td>15.48</td>
</tr>
<tr>
<td>Water</td>
<td>122.15</td>
<td>34.15</td>
</tr>
<tr>
<td>Urban</td>
<td>2.69</td>
<td>0.75</td>
</tr>
<tr>
<td>Agriculture</td>
<td>67.47</td>
<td>18.86</td>
</tr>
<tr>
<td>Undisturbed / Other</td>
<td>110.00</td>
<td>30.76</td>
</tr>
<tr>
<td>Exclusion / No Data</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>357.6</td>
<td>100</td>
</tr>
</tbody>
</table>

Figure 9. 1970 General Landscape Composition Map.

Anthropogenic activities accounted for 34.15% of the study area in 1970. Agriculture, covering 65.65 sq km, accounted for the largest area of anthropogenic activity. Agriculture occurred throughout the basin, but was concentrated largely in the western portion of the basin. The size of the agricultural patches of land varied, with the
largest patch covering 10.22 sq km. With a spatial extent of 53.91 sq km, phosphate mining activity accounted for a large portion of the anthropogenic activity. A majority of the phosphate mining activity occurred in the eastern portion of the basin. A large cluster of mining activity, covering 25.25 sq km, was present on the southeast border of the basin. Phosphate mining activity was minimal in the western portion of the basin, with the largest patch covering 4.55 sq km. Covering only 2.60 sq km, urban activity occurred primarily in one cluster in the east central portion of the basin. This urban area was the mining town of Bradley Junction.

Figure 10. 1970 Landscape Proportion.

A majority of the study area (61.79 %) was covered by natural landscape classes. The dominant natural landscape class was water, covering 115.12 sq km of the study area. Covering 105.88 sq km, undisturbed / other lands occurred throughout the basin.
Together, these landscape classes formed a network of natural lands that extends throughout the basin.

**Composition: 2004 Group**

Table 8 summarizes the spatial extent and landscape proportion for the general landscape classes in 2004. The data for the entire study area, without the exclusion, are also listed in Table 8. Again, to ensure a consistent study area throughout the period of analysis, all results are based on the study area with the appropriate areas excluded from the data. The general landscape map generated for the 2004 Group is located in Figure 12. Figure 13 represents proportional landscape composition for the 2004 Group.

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>Area (square km)</th>
<th>% of study area</th>
<th>Area (square km)</th>
<th>% of study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>255.31</td>
<td>71.38</td>
<td>245.06</td>
<td>68.51</td>
</tr>
<tr>
<td>Water</td>
<td>39.12</td>
<td>10.94</td>
<td>37.32</td>
<td>10.43</td>
</tr>
<tr>
<td>Urban</td>
<td>1.52</td>
<td>0.42</td>
<td>1.52</td>
<td>0.42</td>
</tr>
<tr>
<td>Agriculture</td>
<td>47.58</td>
<td>13.30</td>
<td>46.99</td>
<td>13.14</td>
</tr>
<tr>
<td>Undisturbed / Other</td>
<td>14.15</td>
<td>3.96</td>
<td>12.30</td>
<td>3.44</td>
</tr>
<tr>
<td>Exclusion / No data</td>
<td>--</td>
<td>--</td>
<td>14.50</td>
<td>4.05</td>
</tr>
<tr>
<td>Total</td>
<td>357.6</td>
<td>100</td>
<td>357.6</td>
<td>99.99</td>
</tr>
</tbody>
</table>

Anthropogenic activities accounted for 82.08 % of the study area in 2004. Phosphate mining was the major land use, covering 245.06 sq km. Spatially dominating the basin, phosphate mining activity occurred throughout. Some agricultural activity was present, covering 46.99 sq km. Agricultural land use primarily occurred in large clusters in the west-southwest portion of the study area and in the northwest portion of the study area, near the basin outlet. Urban usage covered 1.52 sq km of the basin. Encapsulated by mining activity, the urban area of Bradley Junction is present. Small patches of urban
areas also occurred adjacent to agriculture activity in the northwestern portion of the study area.

**Figure 11. 2004 General Landscape Map.**

![2004 General Land Use Diagram]

Natural land use accounted for 13.87% of the study area. Natural lands occurred relatively infrequently and were found primarily in the western portion of the basin. Covering 37.32 sq km, water accounted for a majority of the natural land in the basin. Water features occurred primarily along major streams segments and were frequently surrounded by anthropogenic activity, of which phosphate mining is the major factor. Undisturbed / other lands cover for 12.30 sq km and occur in small patches, mostly in the western portion of the basin. Some of these patches occur amidst vast expanses of phosphate mining activity; these patches exhibited no obvious signs of mining activity,
were not mined in either of the historic data sets, and were heavily vegetated. There is a possibility that these lands were mined and reclaimed, but lack of evidence led these lands to be classified as other / undisturbed.

**Figure 12, 2004 Landscape Proportion.**

![2004 General Landscape Composition](image)

**Surface Hydrology**

A focus of this analysis was to understand surface hydrology of the study area in 1940, 1970, and 2004. The landscape class (200) of surface hydrology is subdivided into four major categories: streams (210), wetlands (220), lakes (230), and karst depressions (240) (Table 4).
Surface Hydrology: 1940 Group

The map of surface hydrology generated for the 1940 Group is located in Figure 14. In 1940, water features covered 42.57% of the landscape. Table 9 summarizes the spatial extent and proportion of study area for each water feature class.

Figure 13. 1940 Surface Hydrology Map.

<table>
<thead>
<tr>
<th>Water Feature</th>
<th>total #</th>
<th>area (sq km)</th>
<th>% of study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands</td>
<td>--</td>
<td>148.08</td>
<td>41.40</td>
</tr>
<tr>
<td>Ponds/lakes</td>
<td>147</td>
<td>3.02</td>
<td>0.85</td>
</tr>
<tr>
<td>Karst Depressions</td>
<td>76</td>
<td>1.16</td>
<td>0.32</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>--</td>
<td><strong>152.26</strong></td>
<td><strong>42.57</strong></td>
</tr>
</tbody>
</table>
The study area was dominated by hydrological features in 1940. Wetlands are present throughout as well as ponds, lakes, and karst depressions. A total of 147 lakes / ponds were mapped, covering 3.02 sq km. Lakes / ponds had an average size of 0.02 sq km. The minimum and maximum size of these features was 0.0012 sq km and 0.1717 sq km, respectively. These ponds and lakes were concentrated in the eastern portion of the basin, but were found throughout. A majority of these features are circular in shape and are likely karstic in origin.

A total of 76 karst depressions are present were 1940, covering 1.16 sq km. Mean size of karst depressions is 0.015 sq km. The minimum and maximum size of these features was 0.0011 sq km and 0.1105 sq km, respectively. Many of these features likely function as intermittent lakes. The features were found mostly in the eastern portion of the basin.

Covering 148.08 sq km, wetlands dominated the surface hydrology in the study area in 1940. A network of wetlands covered the basin. Hooker’s Prairie, a major wetland system that serves as the headwaters of the South Prong Alafia River, was present in the south-southeast portion of the basin. In the western portion of the basin, wetlands occurred largely along the floodplain of streams. Modifications from agriculture, such as drainage channels adjacent to agricultural activity, were present in some of the wetlands.

Channelized flow occurred mostly in the western portion of the basin. Total stream length in 1940 was 166.09 km and drainage density is 0.464. The streams flowed through sometimes wide areas of wooded and non-wooded wetlands. Many streams
flowed as poorly defined channels, originating in wetlands. Vegetation islands occurred in many streams.

**Surface Hydrology: 1970 Group**

In 1970, water features cover 32.19% of the landscape. Table a0 summarizes the spatial extent and proportion of study area for each water feature class. The data for water features in the entire study area, without the exclusion is also listed in Table 10. All results are based on the study area with the appropriate areas excluded from the data. The surface hydrology map generated for the 1970 Group is located in Figure 15.

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>All Available Data</th>
<th>With Appropriate Area Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total #</td>
<td>Area km²</td>
</tr>
<tr>
<td>Wetlands</td>
<td>--</td>
<td>117.98</td>
</tr>
<tr>
<td>Ponds/lakes</td>
<td>25</td>
<td>0.18</td>
</tr>
<tr>
<td>Karst Depressions</td>
<td>56</td>
<td>1.63</td>
</tr>
<tr>
<td>Total</td>
<td>--</td>
<td>119.79</td>
</tr>
</tbody>
</table>

Surface hydrological features were present throughout the study area in 1970. Ponds/Lakes and karst features were present throughout the study area, but were largely concentrated in the eastern portion of the basin. Karst depressions covered 0.99 sq km and ponds and lakes cover 0.17 sq km of the basin. A total of 56 karst depressions were present. The mean size for karst depressions is 0.0106 sq km, with a maximum size of 0.165 sq km and a minimum size of 0.001 sq km. A total of 25 lakes / ponds were present. The mean size of lakes and ponds was 0.007 sq km, with a maximum size of 0.072 sq km and a minimum size of 0.001 sq km. A majority of the lakes and ponds were circular in nature.
Covering 113.96 sq km, wetlands spatially dominated the surface hydrology of the study area in 1970. Various networks of wetland systems were found throughout the study area. Some of these wetland systems have straight edges, characteristic of anthropogenic modification. Hooker’s Prairie was present in a reduced size in the south-southeast area of the basin. In the western portion of the basin, wetlands were located primarily at the headwaters and fringes of streams.

Channelized flow occurred primarily within the western portion of the basin. Total stream length in 1970 was 162.33 km. Numerous tributaries flowed into the main stream. Drainage density in 1970 was 0.454. The streams meandered through areas of
wooded and non-wooded wetlands. Vegetation islands were present along much of the main stream.

Surface Hydrology: 2004 Group

The map of surface hydrology generated for 2004 is located in Figure 16. In 2004, water features cover 10.94% of the landscape. Table 11 summarizes the spatial extent and proportion of study area covered for each water feature class. The data for water features in the entire study area, without the exclusion, is also listed in Table 11.

Table 11. 2004 Surface Hydrology.

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>Total #</th>
<th>All Data Area (km²)</th>
<th>% of study area</th>
<th>With Appropriate Area Excluded Total #</th>
<th>Area (km²)</th>
<th>% of study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands</td>
<td>--</td>
<td>38.6</td>
<td>10.82</td>
<td>--</td>
<td>36.92</td>
<td>10.32</td>
</tr>
<tr>
<td>Ponds/lakes</td>
<td>23</td>
<td>0.43</td>
<td>0.12</td>
<td>22</td>
<td>0.41</td>
<td>0.11</td>
</tr>
<tr>
<td>Karst Depressions</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>--</td>
<td>39.12</td>
<td>10.94</td>
<td>--</td>
<td>37.33</td>
<td>10.43</td>
</tr>
</tbody>
</table>

Surface hydrological features are confined to the western portion of the basin. The entire eastern portion of the basin is void of natural surface hydrology. Lakes and ponds are present in close proximity to channelized flow and amongst agricultural activity in the western portion of the basin. A total of 22 lakes / ponds are present, covering 0.41 sq km. Mean size of ponds / lakes is 0.034 sq km. The maximum and minimum size of ponds / lakes is .092 sq km and 0.0001 sq km, respectively. Most of these features do not exhibit natural form. No karst depressions were mapped in 2004. Above average rainfall from 2002-2004 may have led to the filling of any karst depressions present, and the subsequent classification of these features as lakes / ponds in this analysis.
Wetlands are present along streams in the western portion of the basin. Although dominating the surface hydrology of 2004, wetlands cover only 36.92 sq km. Nearly all of these wetlands are bordered by anthropogenic activity. Hooker’s Prairie, historically the headwaters for the main channel, is no longer present.

Channelized flow is present in the eastern portion of the basin. Total stream length in 2004 is 118.85 km. Many of the streams are fragmented by anthropogenic activity. Drainage density is 0.332. The main channel flows through thin areas of wooded and non-wooded wetlands as well as through mining activity. Near the outlet of the basin, where agriculture is the dominant land use, the stream flows through a wide area of wetlands.
Phosphate Mining

Another focus of this thesis was to understand phosphate mining activity in the study area in 1940, 1970, and 2004. The general landscape class of (100) phosphate mining activity was subdivided into nine major categories: mining facilities (110), gypsum stacks (120), active / open pits (130), clay settling areas (140), old clay settling areas (150), sand tailings / spoil piles (160), mining lakes (170), disturbed mined land (180), and reclaimed mined land (190) (Table 3).

Phosphate Mining: 1940 Group

The map of phosphate mining in 1940 is located in Figure 17. In 1940, phosphate mining activity accounted for 3.23% of the study area. Table 12 summarizes the spatial extent and proportion of study area covered by each mining feature.

Table 12. 1940 Phosphate Mining.

<table>
<thead>
<tr>
<th>Mining Feature</th>
<th>area (sq km)</th>
<th>% of study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities</td>
<td>0.58</td>
<td>0.16</td>
</tr>
<tr>
<td>Gyp Stacks</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Open &amp; Active Pits</td>
<td>0.63</td>
<td>0.18</td>
</tr>
<tr>
<td>Clay Settling Area</td>
<td>1.44</td>
<td>0.40</td>
</tr>
<tr>
<td>Old Clay Settling Area</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tailings &amp; Spoil Piles</td>
<td>2.02</td>
<td>0.56</td>
</tr>
<tr>
<td>Mining Lake</td>
<td>0.94</td>
<td>0.26</td>
</tr>
<tr>
<td>Disturbed Mined Land</td>
<td>5.93</td>
<td>1.66</td>
</tr>
<tr>
<td>Reclaimed Land</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11.55</strong></td>
<td><strong>3.23</strong></td>
</tr>
</tbody>
</table>

A majority of the mining land in 1940 is classified under the broad category of ‘disturbed mined land,’ covering 5.93 sq km. This is likely the result of two factors: reclamation was not yet mandatory and the benefaction capabilities of the industry were limited. Although some of the mining activity that was present in 1940 is obviously
Figure 16. 1940 Phosphate Mining Map.

Phosphate mining activity was limited to two small clusters in the eastern portion of the basin in 1940. These clusters were located along the southern border and northeastern border of the study area. One of the areas excluded due to poor quality photos traverses mining activity.

The cluster in the northeast was a mix of features resulting from prior mining activity. There was also a processing facility in this group of mining features. This is likely a benefaction plant (chemical processing had not yet begun). Numerous flooded historic, the mined land is filled with sharp features. The industry’s capability to separate the phosphate ore from the matrix was not efficient in 1940, resulting in larger amounts of the matrix discarded as waste.
pits were present here as well as two clay settling areas, some tailings and spoil piles, and
disturbed mined land.

Active and recent mining activity was present in the cluster located along the southern border of the western portion of the basin. There was a series of active pits and the associated spoil piles. There was also a group of mining facilities present along with clay settling areas and disturbed mined land in this cluster.

Some mining features are absent from the study area in 1940. There are no gypsum stacks, old clay settling areas, or reclaimed mined land. Gypsum stacks are not present because the chemical production of phosphoric acid had not yet begun in 1940. The absence of old clay settling areas and reclaimed land can likely be attributed to the relatively early stage of mining in the area.

**Phosphate Mining: 1970 Group**

Table 13 summarizes the spatial extent and landscape proportion in for each mining feature class in 1970. The data for the entire study area, without the exclusion are also listed in Table 13. All results are based on the study area with the appropriate areas excluded from the data. The map of phosphate mining features generated for the 1970 Group is located in Figure 18.

Phosphate mining covered 53.91 sq km in 1970, accounting for 15.07% of the basin. Both active mining and relic mining features were present in 1970. A majority of the phosphate mining activity was located in the eastern portion of the basin. Mining activity in the western portion of the study area was limited to a large area of active mining pits, a gypsum stack, and a small mix of disturbed mined land and mining lakes. All mining features used in this analysis were found in the eastern portion of the basin.
Table 13. 1970 Phosphate Mining.

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>1970 All Data</th>
<th></th>
<th>1970 With Appropriate Area Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area $km^2$</td>
<td>% of study area</td>
<td>Area $km^2$</td>
</tr>
<tr>
<td>Facilities</td>
<td>2.91</td>
<td>0.81</td>
<td>2.87</td>
</tr>
<tr>
<td>Gyp Stacks</td>
<td>8.70</td>
<td>2.43</td>
<td>8.70</td>
</tr>
<tr>
<td>Open &amp; Active Pits</td>
<td>14.94</td>
<td>4.18</td>
<td>14.66</td>
</tr>
<tr>
<td>Clay Settling Area</td>
<td>4.16</td>
<td>1.16</td>
<td>4.16</td>
</tr>
<tr>
<td>Old Clay Settling Area</td>
<td>2.24</td>
<td>0.63</td>
<td>2.24</td>
</tr>
<tr>
<td>Tailings &amp; Spoil Piles</td>
<td>1.38</td>
<td>0.39</td>
<td>1.38</td>
</tr>
<tr>
<td>Mining Lake</td>
<td>2.42</td>
<td>0.68</td>
<td>2.37</td>
</tr>
<tr>
<td>Disturbed Mined Land</td>
<td>17.53</td>
<td>4.90</td>
<td>16.48</td>
</tr>
<tr>
<td>Reclaimed Land</td>
<td>1.07</td>
<td>0.30</td>
<td>1.05</td>
</tr>
<tr>
<td>Total</td>
<td>55.35</td>
<td>15.48</td>
<td>53.91</td>
</tr>
</tbody>
</table>

Figure 17. 1970 Phosphate Mining Map.

Mining activity was spatially dominated by disturbed mined land and active pits, covering 16.48 sq km and 14.66 sq km, respectively. There are a number of mining facilities; this category is likely comprised of both benefaction and chemical processing.
facilities. There were four gypsum stacks present, ranging in size from 2.72 sq km to 0.19 sq km, covering 2.43% of the basin. Covering 6.40 sq km, three clay settling areas, one old and two new, were present. There were some small mining lakes, many in the rectilinear shapes of old pits, located amongst disturbed mined land and adjacent to active mining activity.

There was a small portion of agricultural activity taking place on land that was mined in the past. Reclaimed land covered 1.05 sq km in 1970. This reclaimed land is located along the northern border of the study area in the eastern portion of the county.

**Phosphate Mining: 2004 Group**

Table 14 summarizes the spatial extent and landscape proportion in for each mining feature class in 2004. The data for the entire study area, without the exclusion is also listed in Table 1r. All results are based on the study area with the appropriate areas excluded from the data. The map of phosphate mining features generated for the 2004 Group is located in Figure 19.

<table>
<thead>
<tr>
<th>Land Use Class</th>
<th>2004 All Data</th>
<th></th>
<th>2004 With Appropriate Area Excluded</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (km²)</td>
<td>% of study area</td>
<td>Area (km²)</td>
<td>% of study area</td>
</tr>
<tr>
<td>Facilities</td>
<td>0.59</td>
<td>0.16</td>
<td>0.59</td>
<td>0.16</td>
</tr>
<tr>
<td>Gyp Stacks</td>
<td>6.80</td>
<td>1.90</td>
<td>6.81</td>
<td>1.90</td>
</tr>
<tr>
<td>Open &amp; Active Pits</td>
<td>1.65</td>
<td>0.46</td>
<td>1.65</td>
<td>0.46</td>
</tr>
<tr>
<td>Clay Settling Area</td>
<td>11.00</td>
<td>3.07</td>
<td>11.00</td>
<td>3.08</td>
</tr>
<tr>
<td>Old Clay Settling Area</td>
<td>32.56</td>
<td>9.10</td>
<td>31.98</td>
<td>8.94</td>
</tr>
<tr>
<td>Tailings &amp; Spoil Piles</td>
<td>5.18</td>
<td>1.45</td>
<td>5.18</td>
<td>1.45</td>
</tr>
<tr>
<td>Mining Lake</td>
<td>35.76</td>
<td>9.99</td>
<td>33.63</td>
<td>9.40</td>
</tr>
<tr>
<td>Disturbed Mined Land</td>
<td>154.28</td>
<td>43.13</td>
<td>146.73</td>
<td>41.03</td>
</tr>
<tr>
<td>Reclaimed Land</td>
<td>7.47</td>
<td>2.09</td>
<td>7.47</td>
<td>2.09</td>
</tr>
<tr>
<td>Total</td>
<td>255.31</td>
<td>71.38</td>
<td>245.05</td>
<td>68.51</td>
</tr>
</tbody>
</table>

Phosphate mining dominates the study area in 2004. The entire eastern portion of the basin is covered by mining activity that also extends into the western portion of the
basin. A network of features associated with phosphate mining activity blankets the study area. Little active mining is present in the study area. Nearly all of the mining features present are relic in nature and/or associated with phosphate processing.

Figure 18. 2004 Phosphate Mining Map.

Most numerous are mining lakes, many of which exhibit the rectilinear form of old phosphate mining pits. Old and new clay settling areas cover 31.98 sq km and 11.00 sq km, respectively, and account for 11.02% of the study area. Sand tailings and spoil piles, covering 5.18 sq km, likely represent a temporary landform due to their contemporary use in reclamation practices. Three gypsum stacks are present, ranging in size from 1.95 sq km to 3.15 sq km, and account for 1.90% of the study area.
Reclaimed land covers 7.47 sq km and accounts for 2.09% of the basin. Lands that have been reclaimed and officially released by FDEP occur in a large cluster on the eastern border of the basin. Covering 4.14 sq km, this land has been reclaimed to mimic natural systems such as wetlands. Two other areas were considered reclaimed in this analysis because of their conversion to other land uses. Urban activity, covering 1.99 sq km, occurs in a previously mined land in the northeastern portion of the basin. Agricultural activity, covering 1.32 sq km, occurs on previously mined land in one area adjacent to the main stream of the basin.

Disturbed mined land dominates phosphate mining activity as well as all features used in this analysis in 2004. Occurring throughout the study area, disturbed mined land covers 146.73 sq km and accounts for 43.03% of the basin. Phosphate extraction is nearly exhausted in the basin in 2004, and reclamation of mined land is required. Most of the land included in the disturbed mined land category in this analysis was classified as ‘under reclamation’ by FDEP. It is possible that some areas classified in this analysis as disturbed mined land may have already been reclaimed but not officially released by the FDEP.

**Landscape Change**

The second objective of this research is to understand landscape change in the study area between 1940, 1970, and 2004. Consistent with land use and land cover change throughout the state, the study area has undergone extensive landscape modification from the early 20th century to the present. The unique physical and social context of the study area has led to a particular mode of landscape alteration found only in this region of the state.
Composition

Landscape evolution in the study area from 1940 – 2004 is characterized by an increase in lands dominated by anthropogenic activity, and a loss of natural lands. Table 15 summarizes the total change in the landscape, based on general landscape class, between the periods of 1940 -1970 and 1970 - 2004 as well as net change from 1940 – 2004. The data for the entire study area, without the exclusion is also listed in Table 15. Figure 20 is a graphical representation of the general landscape changes from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004. All results are based on the study area with the appropriate areas excluded from the data. Figures 21 – 25 represent the area covered by each land use category in 1940, 1970, and 2004.

Table 15. General Landscape Change.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>+43.80</td>
<td>+199.96</td>
<td>+243.76</td>
<td>+42.36</td>
<td>+191.15</td>
<td>+233.51</td>
</tr>
<tr>
<td>Water</td>
<td>-30.10</td>
<td>-83.03</td>
<td>-113.13</td>
<td>-37.13</td>
<td>-77.81</td>
<td>-114.94</td>
</tr>
<tr>
<td>Urban</td>
<td>+2.52</td>
<td>-1.18</td>
<td>+1.34</td>
<td>+2.42</td>
<td>-1.08</td>
<td>+1.34</td>
</tr>
<tr>
<td>Agriculture</td>
<td>+40.24</td>
<td>-19.89</td>
<td>+20.35</td>
<td>+38.42</td>
<td>-18.66</td>
<td>+19.76</td>
</tr>
<tr>
<td>Undisturbed / Other</td>
<td>-41.96</td>
<td>-95.86</td>
<td>-137.81</td>
<td>-46.08</td>
<td>-93.58</td>
<td>-139.66</td>
</tr>
</tbody>
</table>

From 1940 to 1970, landscape change is driven by anthropogenic usage. All three anthropogenic land uses increase and the two natural landscape classes decrease. The largest increase in land use from 1940 to 1970 occurs with phosphate mining. Accounting for just 3.23% of the study area in 1940, mining land increases by 42.36 sq km, resulting in the coverage of 15.07% of the basin in 1970. The increase in agricultural lands from 1940 to 1970 is 38.42 sq km, resulting in the coverage of 18.86% of the study area.
Natural lands declined from 1940 – 1970, but account for a majority of the basin in both 1940 and 1970. The largest loss in natural land from 1940 to 1970 occurs in the undisturbed / other category. Covering 42.49% percent of the basin in 1940, undisturbed / other lands decrease by 46.08 sq km, resulting in the coverage of 29.06% of the study area. A large decline (-37.13 sq km) in the area covered by natural water features also occurred from 1940 to 1970.

The only land use category to gain in area from 1970 to 2004 is phosphate mining activity. Covering 15.07% of the study area in 1970, the area covered by phosphate mining activity increases by 191.15 sq km, resulting in the coverage of 68.51% of the study area in 2004. The loss of natural lands from anthropogenic activity is depicted in Figure 26. All other land use categories experience a decline in this period. Agricultural
Figure 20. Mining 1940, 1970, & 2004
Figure 22. Urban 1940, 1970, & 2004.
Figure 23. Agriculture 1940, 1970, & 2004.
Figure 24. Undisturbed / Other 1940, 1970, & 2004.
Figure 25. Natural Lands Lost to Anthropogenic Activity 1970 - 2004 & 1940 - 2004.
lands decrease by 18.66 sq km from 1970 – 2004. A minimal land use throughout the study period, urban lands decrease by 1.08 sq km, resulting in the coverage of 0.42% of the study area in 2004. A majority of spatial loss from 1970 to 2004 occurs in the natural lands category, with the largest decrease occurring in the undisturbed / other category. The areas covered by both water and undisturbed / other lands shrink dramatically from 1970 – 2004, with a loss of 77.81 sq km and 93.58 sq km, respectively.

A Difference Between Proportions Two Sample Z-test was used to investigate the significance of the change in the proportion of the study area covered by anthropogenic activity from 1940 – 1970 and 1970 – 2004, as well as overall change from 1940 – 2004. In order to maintain a consistent study area for the change comparisons, this test was conducted only on the study area with the appropriate exclusions. The following hypothesis was developed based on the land use maps and associated data generated for each time period studied: 1) The proportion of the study area covered by anthropogenic activity significantly increases through time. The results of this statistical analysis are outlined in Table 16. For each time period examined, z critical falls in the rejection region at the .01 significance level. Therefore, there is enough evidence to support the alternative hypotheses that there is a significant increase in the proportion of anthropogenic lands from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004.

Table 16. Results of Difference Between 2 Proportions Tests, Anthropogenic Activity.

<table>
<thead>
<tr>
<th>Anthro p1</th>
<th>p2</th>
<th>Claim</th>
<th>Null</th>
<th>Critical z-values (α = .01)</th>
<th>z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940 vs. 1970</td>
<td>p1&lt;p2</td>
<td>p1=p2</td>
<td></td>
<td>-2.33</td>
<td>-6.36</td>
</tr>
<tr>
<td>1970 vs. 2004</td>
<td>p1&lt;p2</td>
<td>p1=p2</td>
<td></td>
<td>-2.33</td>
<td>-14.10</td>
</tr>
<tr>
<td>1940 vs. 2004</td>
<td>p1&lt;p2</td>
<td>p1=p2</td>
<td></td>
<td>-2.33</td>
<td>-18.66</td>
</tr>
</tbody>
</table>
Figure 26. Natural Lands Lost to Phosphate Mining 1970 - 2004 & 1940 - 2004.

Natural Lands Lost to Phosphate Mining

1970 - 2004

1940 - 2004

Exclusion / No data

K. Sarah Koenig
10/26/06
Albers Equal Area Conical Projection

0  1.5  3  6  9  12 Kilometers
Phosphate mining activity experiences the largest spatial increase from 1940 – 1970 and 1970-2004 as well as from 1940 – 2004. Natural land lost to phosphate mining activity is depicted in Figure 27. To further investigate the role of phosphate mining activity in land use change, the Difference Between Proportions Two Sample Z-test was applied to the proportion of the study area covered by phosphate mining activity from 1940 – 1970 and 1970 – 2004, as well as overall change from 1940 – 2004. Again, in order to maintain a consistent study area for the change comparisons, this test was conducted only on the study area with the appropriate exclusions. The following hypothesis was developed based on the land use maps and associated data generated for each time period studied: 1) The proportion of the study area covered by phosphate mining significantly increases through time. The results of this statistical analysis is outlined in Table 17. For each time period examined, z critical falls in the rejection region at the .01 significance level. Therefore, there is enough evidence to support the alternative hypotheses that there is a significant increase in the proportion of phosphate mining from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004. A comparison of Figures 26 and 27 illustrates the dominant role that phosphate mining played in the loss of natural lands throughout the study period.

Table 17. Results of Difference Between 2 Proportions Test, Phosphate Mining Activity.

<table>
<thead>
<tr>
<th>Mining</th>
<th>Claim</th>
<th>Null</th>
<th>Critical z-values (α = .01)</th>
<th>z-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>p1 vs. p2</td>
<td>p1&lt;p2</td>
<td>p1=p2</td>
<td>-2.33</td>
<td>-5.28</td>
</tr>
<tr>
<td>1940 vs. 1970</td>
<td>p1&lt;p2</td>
<td>p1=p2</td>
<td>-2.33</td>
<td>-14.12</td>
</tr>
<tr>
<td>1940 vs. 2004</td>
<td>p1&lt;p2</td>
<td>p1=p2</td>
<td>-2.33</td>
<td>-17.68</td>
</tr>
</tbody>
</table>

Through the study period, phosphate mining played an increasingly dominant role in the spatial pattern of landscape composition in the basin. For example, agricultural
lands occurred as dispersed patches throughout the basin in the 1940 Group and are pushed to the extreme western portion of the basin by 2004 (Figure 24). A comparison of Figure 24 and Figure 21 illustrates phosphate mining’s influence on the geography of agriculture in the basin. The same pattern emerges through time regarding the location and extent of the surface hydrologic features (Figure 22), undisturbed / other lands (Figure 25), and urban lands (Figure 23).

Net change from 1940 to 2004 was:

- mining: +233.51 sq km
- water: -114.94 sq km
- urban: +1.34 sq km
- agriculture: +19.76 sq km
- undisturbed / other: -139.66 sq km.

In 1940, a network of natural lands covers the basin. In 2004, the natural lands are replaced with phosphate mining activity and some agriculture. Figures 28 – 30 provide an example of landscape evolution from 1940 – 1970 – 2004. This is an area of the main channel that experienced relatively little change in comparison to other parts of the basin. An evolution in the surrounding area is evident.
Figure 27. 1940 Landscape Evolution Example.
Figure 28. 1970 Landscape Evolution Example.
Figure 29. 2004 Landscape Evolution Example.
Surface Hydrology

The third objective of this research is to explore changes to surface hydrology from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004. Throughout the study period, natural surface hydrologic features declined. This trend is consistent with the overall decline in natural lands observed throughout the study period. Figure 31 illustrates the extent and specific features of surface hydrology present in 1940, 1970, and 2004. Change to surface hydrology in the study area from 1940 – 2004 is characterized by a decrease in the number of features and their spatial extent.

Table 18 summarizes the changes to the coverage in surface hydrological features between the periods of 1940 -1970 and 1970 - 2004 as well as net change from 1940 – 2004. The data for the entire study area, without the exclusion is also listed in Table 18. Total stream length and drainage density for 1940, 1970, and 2004 is listed in Table 19. All results are based on the study area with the appropriate areas excluded from the data.

Table 18. Changes to Surface Hydrology.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands</td>
<td>-27.73</td>
<td>-81.34</td>
<td>-109.07</td>
<td>-34.12</td>
<td>-76.75</td>
<td>-110.87</td>
</tr>
<tr>
<td>Lakes / Ponds</td>
<td>-2.84</td>
<td>-0.06</td>
<td>-2.90</td>
<td>-2.85</td>
<td>-0.06</td>
<td>-2.91</td>
</tr>
<tr>
<td>Karst</td>
<td>0.47</td>
<td>-1.63</td>
<td>-1.16</td>
<td>-0.99</td>
<td>-0.99</td>
<td>-1.16</td>
</tr>
<tr>
<td>Total</td>
<td>-30.10</td>
<td>-83.03</td>
<td>-113.13</td>
<td>-37.13</td>
<td>-77.81</td>
<td>-114.94</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Streams and Drainage Density (km)</th>
<th>All Data</th>
<th>With Appropriate Area Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Stream Length</td>
<td>166.09</td>
<td>162.33</td>
</tr>
<tr>
<td>Drainage Density</td>
<td>0.464</td>
<td>0.454</td>
</tr>
</tbody>
</table>


Figure 30. Surface Hydrology 1940, 1970, & 2004.

Surface Hydrology

1940
Total Stream Length: 166.09 km
Drainage Density: 0.454

1970
Total Stream Length: 162.33 km
Drainage Density: 0.454

2004
Total Stream Length: 118.85 km
Drainage Density: 0.332

Albers Equal Area Conical Projection
S. Koeng 10/23/05

Legend:
- Stream
- Wetlands
- Lakes and Ponds
- Karst Depressions
- Exclusion / No data
From 1940 – 1970, the total area covered by natural surface hydrological features declines by 37.13 sq km. A majority of the change does not include the direct alteration of defined drainage. Total stream length declines by 3.76 km and drainage density is reduced from 0.464 to 0.454. Some wetlands that remain in 1970 show signs of anthropogenic modification such as the construction of canals through wetland areas. Phosphate mining encroaches on Hooker’s Prairie from the west, replacing areas of the wetland system with phosphate mining activity. Additionally, many of the areas of Hooker’s Prairie that remain in 1970 show signs of modification.

The area covered by surface hydrological features declines by 77.81 sq km from 1970 - 2004, nearly double the decline that occurs from 1940 – 1970. These changes occur throughout the basin, affecting streams, wetlands, lakes / ponds, and karst depressions. The entire eastern portion of the basin is void of natural surface hydrologic features in 2004. The length of streams declines by 43.48 km and drainage density declines from 0.454 to 0.332.

Many streams are lost to anthropogenic activity, most notably phosphate mining. Many streams that remain in 2004 are fragmented. Figures 32 - 34 provide an example of landscape change and the fragmentation of surface hydrological features. Wetlands decline by 76.75 sq km. Together, lakes/ponds and karst depressions experience a 3.01 sq km decrease in spatial extent. This change may be best understood together due to the unique hydrologic landscape of Florida and the seasonal and annual fluctuations of water levels. The area covered by wetlands declines by 34.12 sq km.
An important change occurs in the nature of the lakes/ponds in this time period. Most of the lakes in 1970 exhibit natural form, including characteristics such as undisturbed and/or circular shorelines. In 2004, many of the lakes that remain are encapsulated by anthropogenic activities and exhibit unnatural form such as straight shorelines. Nearly all of the wetlands that remain in 2004 are present as narrow strips adjacent to remaining streams.

Hooker’s Prairie is no longer present in 2004, replaced by phosphate mining activity. Figures 32 - 34 show the evolution of a portion of Hooker’s Prairie throughout the study period. A small tract (1.10 sq km) of undisturbed land remains amongst mining activity in what was historically Hooker’s Prairie. However, this tract of land exhibits no verifiable signs of water and was classified as undisturbed / other. Much of the area that was once Hooker’s Prairie appears to be reclaimed. However, this mining complex is listed as ‘under reclamation’ by FDEP, resulting in the classification of this area as disturbed mined land.

Overall, from 1940 – 2004, there is a major decrease in the number and extent of natural surface hydrological features. Covering 152.26 sq km in 1940, the extent of natural water features declines by 114.94 sq km, resulting in the coverage of just 37.33 sq km of the basin in 2004. In 1940, the landscape is covered by a network of natural lands, of which surface hydrological features account for approximately half. The 1940 network of natural lands is replaced in 2004 by a network of anthropogenic land uses, of which phosphate mining is the dominant landscape class.
Figure 31. 1940 Hooker's Prairie Landscape Change Example.
Figure 32. 1970 Hooker's Prairie Landscape Change Example.
Figure 33. 2004 Hooker's Prairie Landscape Change Example.
The changes observed in surface hydrology are consistent with the overall decline in natural lands and increase in anthropogenic lands in the basin. Figure 35 illustrates spatial loss of natural surface hydrologic features to anthropogenic activity from 1970 – 2004 and overall from 1940 – 2004. It is important to note that phosphate mining activity is the only landscape class that experiences an increase in the period of 1970 – 2004. Figure 36 illustrates spatial loss of natural surface hydrologic features to phosphate mining activity from 1970 – 2004 and overall from 1940 – 2004.
Natural Surface Hydrology
Lost to Anthropogenic Activity

1940 - 2004

1970 - 2004

K. Sarah Koenig
11/05/06
Albers Equal Area Conical Projection
Figure 35. Surface Hydrology Lost to Phosphate Mining 1940 - 2004 & 1970 - 2004.

Natural Surface Hydrology
Lost to Phosphate Mining

1940 - 2004

1970 - 2004
CHAPTER 5: CONCLUSION

Conclusions

The results of this study have provided new information regarding the spatial and temporal dynamics of landscape alteration in the South Prong Alafia River Drainage Basin. The detailed mapping of landscape characteristics on the 1940 Group and 1970 Group historic aerial photos and 2004 aerial photos was a useful exercise in understanding landscape change in the South Prong Alafia River Drainage Basin. The approach utilized in this analysis has provided a general understanding of the effects of phosphate extraction and processing on the local landscape, and particularly on the South Prong Alafia River basin.

Landscape change in the study period is characterized by a loss of natural lands and an increase in anthropogenic lands. The proportion of the study area covered by anthropogenic activity significantly increased, at a confidence level of .01, from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004. This trend is first apparent from 1940 – 1970, where the area covered by water features and undisturbed / other lands declines by a total of 83.21 sq km. The loss of these features was replaced by an increase in phosphate mining activity (42.36 sq km), agriculture (38.42 sq km), and urban lands (2.42 sq km). Despite the spatial loss of water and undisturbed / other lands, a network of natural lands continues to span the basin in 1970. Natural lands account for 61.79% of the basin in 1970.
The loss of natural lands to anthropogenic activity increases tremendously from 1970 – 2004. The total decline in the area covered by natural lands is -171.39 sq km. The area covered by agriculture and urban usages decline as well, with a change of -18.66 sq km and -1.08 sq km, respectively. The increase in anthropogenic activity is attributed entirely to phosphate mining activity, with a change of +191.15 sq km. Natural lands account for 13.87% of the basin in 2004.

Overall from 1940 – 2004, the landscape of the basin is transformed from an area dominated by natural lands to an area dominated by anthropogenic activity, of which phosphate mining is the primary land use. The natural lands that remain in 2004 are confined to the western portion of the basin and are fragmented by anthropogenic land uses.

An important aspect of the loss of natural lands throughout the study period is the dramatic alteration of surface hydrological features. From 1940 – 1970, the number of and area covered by wetlands, lake / ponds, and karst depressions decline. The area covered by hydrological features declined by 37.13 sq km in this time period. Defined drainage is also impacted, with the loss of 3.76 km of streams and a decline in drainage density from 0.464 to 0.454.

From 1970 – 2004, the number of features and area covered by wetlands, lakes / ponds, and karst depressions dramatically declined. The area covered by hydrological features decreased by 77.81 sq km. Wetlands are confined to thin areas surrounding the remaining streams. Most lakes that are present in 2004 occur in areas of agricultural activity and do not exhibit natural form. Total stream length declined by 43.48 km and drainage density declines from 0.454 to 0.332. Many streams were lost to phosphate
mining activity. Hooker’s Prairie, the headwaters of the main stream, was replaced by phosphate mining activity.

The nature of the surface hydrology in the basin was radically altered from 1940 – 2004. Accounting for 42.57% of the basin in 1940, water features cover just 10.43% of the basin in 2004. A number of streams were lost, with a total decline in stream length of 47.24 km. Many streams that remained in 2004 are fragmented by anthropogenic activity. Hydrological features in 2004 are surrounded by anthropogenic activity. The entire eastern portion of the basin is void of natural surface hydrological features.

The primary force in landscape alteration throughout the study period is phosphate mining activity. The proportion of the study area covered by phosphate mining activity significantly increased, at a confidence level of .01, from 1940 – 1970, 1970 – 2004, and overall from 1940 – 2004. The largest increase in land area observed from 1940 – 1970 is in phosphate mining activity. The only increase in land area observed from 1970 – 2004 is in phosphate mining activity. Many natural features were lost to phosphate mining, including wetlands, ponds / lakes, karst depressions, and undisturbed / other lands. Perhaps most striking is the erasure of Hooker’s Prairie, a critical source of flow for the South Prong Alafia River. Additionally, phosphate mining activity replaced agricultural areas and small areas of the mining town of Bradley Junction. Phosphate mining activity dominates the study area in 2004, forming a network of mining-induced anthropogenic landforms throughout the basin.

**Limitations**

It should be mentioned that there were some limitations associated with this research. Landscapes are not static and lack clearly defined boundaries. Thus, it is
inherently difficult to draw boundaries around a natural landscape. To best account for this limitation, landscape class delineation was guided by a review of the literature regarding the physical and human geography of the basin, the utilization of available spatial data, and regular data quality monitoring. The manual methods used in this analysis provided the capability to make educated judgments regarding landscape composition when necessary.

The historic aerial photosets presented an additional limitation. Aerial photos are most accurate in the center of the image; this was considered when layering the georeferenced photos. Some spatial accuracy can be lost in the various stages of data management and with aging of the photos. Additionally, the aerial photos used to assemble the 1940 and 1970 Groups were taken in different, but near years. Although the difference in years is not ideal, these photosets provided the only way to capture landscape characteristics for the entire basin for the period of interest.

The results and conclusions of this thesis provide a general understanding of landscape composition and change in the South Prong Alafia River drainage basin. Details regarding the consequences of these changes can be obtained only through more detailed modeling. There is, however, a well-established body of literature regarding 1) the effects of phosphate mining on the natural landscape of Florida and 2) the effects of land use change on the behavior of the drainage basin system. The results of this thesis are briefly explored below through the context of this literature.
Implications

The natural landscape of the South Prong Alafia River drainage basin has been radically altered by anthropogenic activity, particularly phosphate excavation, benefaction, and processing. These activities have been especially robust over the last 35 years. The implications associated with the landscape modification documented in this research transverse a variety of scales. From the hydrological and ecological effects of the erasure of a single karst lake to the importance of the Alafia River as a source of freshwater to the residents of Tampa Bay, the consequences associated with the alteration of the South Prong Alafia River drainage basin are many.

At least 68.5% of the basin has been directly modified by phosphate mining activity. The consequences of these alterations potentially extend throughout the system, beyond the directly modified areas. The erasure of vast areas of undisturbed land, wetlands, streams, lakes, ponds, and karst depressions indicates that hydrological and ecological functions within the basin have been altered and likely degraded. Additionally, the replacement of these natural lands with phosphate mining and agricultural activity further indicates that hydrological and ecological functioning within the basin have been corrupt.

The common practice of reclaiming the land to ‘beneficial uses’ does not necessarily restore hydrologic and ecologic functioning. The quality of reclamation practices in the basin should be critically considered and closely monitored to ensure an optimal recovery to the basin system.

The nature of phosphate extraction, benefaction, and processing results in the transformation of a many physical parameters that influence functioning within the
drainage basin system. The removal of native land cover, alteration of soil stratigraphy and composition, modification of topography and natural drainage patterns, alteration and destruction of critical flow sources, and water consumption associated with phosphate mining activity inevitably alters hydrologic behavior.

The dominant and long-lasting influence of the phosphate activity in the South Prong Basin may indicate that the hydrologic system present prior to phosphate activity no longer exists. The nature of phosphate mining activities, the proportion of the basin affected, the rapid rate of landscape alteration, and the fragmentation of the remaining natural landscape are evidence of a destroyed system. The possibility of future phosphatic waste clay storage in the basin has the potential to further modify the physiography and functions throughout the basin system.

Many natural habitats have been destroyed and the remaining natural lands within the basin are fragmented as a result of phosphate mining activity. The erasure of and disturbance to natural lands associated with the industry disrupts ecosystem functions and health. Mining discharges and accidental spills have impacted water and environmental quality throughout the basin system. The possibility of spills remains. The extent of the basin that has been altered, and the rate at which these alterations occurred, indicates that environmental health has been degraded by the industry’s presence.

The role of the South Prong Alafia River as one of the two main tributaries that form the Alafia River additionally denotes the significance of the modifications documented in this research. As a subsystem of the Alafia River drainage basin, the landscape alteration in the South Prong Alafia River basin likely damaged ecological and
hydrological functioning in the Alafia River basin and Tampa Bay. The Alafia River is important to the sustainability of the local population and environment.

The multitude and duration of the negative impacts of phosphate mining on the Alafia River should be a critical concern for local water and land management. The documented effects of phosphate mining within the Alafia River drainage basin should inform the public and private debate regarding the phosphate industry and its impact on the local environment.

**Future Research**

As a system whose landscape has been severely modified but will not undergo any further phosphate excavation, the South Prong Alafia River drainage basin presents a unique research opportunity. Modeling of hydrologic and ecologic response to reclamation activities within the basin would be beneficial to future and current reclamation efforts, both within and beyond the basin. The variety of mining landforms and range in the age of these features present an ideal landscape for a more detailed analysis of the effects of phosphate mining activity on the natural environment.

The extent of the landscape modification that occurred in the basin indicates that the success of reclamation activities should be closely monitored. In particular, the success of the reclamation of Hooker’s Prairie should be monitored for an extended period of time. The significance of this wetland system and its eventual destruction necessitates proper management and restoration.

Raster-based analysis may be a useful tool in understanding the spatial and temporal dynamics of landscape change in the basin and regionally that have occurred more recently or in the future. This would be especially helpful in understanding the
increasingly dominant role of phosphate mining in the landscape pattern of the basin as well as the region. Additionally, this would be useful to monitor the efficiency of reclamation practices and the associated environmental responses. Additionally, an examination of basin landscape composition in the future would provide insight into the dynamics of landscape and environmental change post-phosphate extraction.
REFERENCES CITED


Florida Department of Environmental Protection (FDEP). Undated website. Land and Boundary Information System (LABINS). data.labins.org


Polk County Board of County Commissioners (PCBOCC), 2006. About Polk County. www.polk-county.net


United States Census Bureau (USCB), 2006, State and County Quick Facts – Florida, quickfacts.census.gov/qfd/states/12000.html


Appendix
Appendix

Figure A-1. 1940 Aerial photo of wetlands, lakes / ponds, and undisturbed / other. The circular form of the lakes / ponds is characteristic of many of these features in both 1940 and 1970. These are likely karstic in origin.
A-2. 1940 Aerial photo of wetlands and stream, undisturbed / other, and small agricultural patches amongst wetlands. The placement and size of this agricultural activity is characteristic of much of the agricultural activity in 1940.
Figure A-3. Aerial photo of open phosphate pits in 1970. There is also a small group of processing facilities in the southwest corner of the photograph.
Figure A-4. Aerial Photo of clay settling area in 1970.
Figure A-5. 1970 Aerial photo of stream amongst wetlands. The densely vegetated nature of the floodplain, when undisturbed, is characteristic of this feature in 1940, 1970, and 2004.
Appendix (Continued)

Figure A-6. 1970 Aerial photo of straight-edged wetlands, an indicator of anthropogenic modification. Also note the large patch of open pits and spoil piles in the west and small patch of agriculture in the east.
Appendix (Continued)

Figure A-7. 2004 Aerial photo of gyp stack, mining lakes, tailings, and disturbed mined land. The rectilinear form of the mining lakes indicates that these are old phosphate pits, a characteristic of many mining lakes present throughout the study period. Gypsum stacks are easily identified due to their significant height and location near processing facilities.
Appendix (Continued)

Figure A-8. 2004 Aerial photo of a clay settling area, mining lakes, and disturbed mined land. The disturbed mined land appears to be in the process of reclamation.
Appendix (Continued)

Figure A-9. 2004 Aerial photo of a stream and wetlands fragmented by mining activity.
Appendix (Continued)

Figure A-10. 2004 Aerial photo of agriculture, a pond, and a small patch of undisturbed / other land in the eastern portion of the photograph. The unnatural form of the pond is characteristic of many of these features in 2004.