Fewer Wetlands More Connectivity: Implications of Land use-Land cover Change in an Agricultural Landscape

Stephanie Lawlor
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Fewer Wetlands, More Connectivity: Implications of Land use-Land cover Change in an Agricultural Landscape

by

Stephanie Lawlor

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy School of Geosciences College of Arts and Sciences University of South Florida

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DEDICATION

I dedicate this work to my family and friends. You all encouraged me to pursue my long-diverted dream to go to graduate school and championed me to the end. Thank you, without all of you, I would still be dreaming.
ACKNOWLEDGMENTS

Thank you, Drs. Mark and Kai Rains, for your steady competence and expert guidance. Dr. Landry, I appreciate your inciteful advice when GIS got the better of me.

My lab-mates, who commiserated, celebrated and encouraged me, I thank you for your company.

Also, a big thank-you to Eric Kastelic who helped me greatly with georeferencing the aerial photos.

There are many people who answered my questions, tracked down and donated files and data which kept the research moving forward. Especially, the St. Lucie County Environmental Management Team, and Claire Flannagan. I would not be able to do this research without them providing me their expertise and data.

Thank you to the Tharp Foundation for helping fund my research.
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ABSTRACT

St. Lucie County (SLC) is a 1,782 km² area in east-central Florida that drains to the Nationally Significant Indian River Lagoon (IRL). It is low lying and nearly level, with widespread non-floodplain wetlands (NFWs) and few natural channels. Since the early 20th century, SLC has undergone extensive land use-land cover (LULC) change and is now characterized by citrus farming in the interior and municipalities on its eastern coast on the Atlantic Ocean. This LULC change has been made possible by the construction of an extensive drainage network, which has altered the way water is stored within and transmitted through this landscape. The net effect in this case has been to greatly reduce wetland area, significantly increase drainage density, and decrease the distances between individual wetlands and channels. Key aspects of these changes were measured, by mapping the spatial distribution of wetlands and natural and artificial channels (1850, and 2004) before and after the most intense period of LULC change, and by calculating spatial metrics to quantify change. The reduction in wetland area and the increase in drainage density have been pronounced, resulting in a pronounced decrease in the distances between individual wetlands and channels. These results show that wetland water storage in the county has been decreased, with water instead being routed more efficiently to coastal waters. The loss of wetlands and enhanced hydrologic connectivity in SLC have implications for the IRL, where chronic and acute water-quality degradation and related harmful algal blooms (HABs) have become the norm. The author recommends that local LULC change be given careful consideration, armed with the measurements and structured data developed for this analysis, in ongoing efforts to address these growing threats to the ecological integrity of the IRL and similar coastal water.
INTRODUCTION

Between 1780 and 1980, the land mass now within the contiguous, continental United States lost nearly 53% of its wetlands. Florida lost 9.3 million wetland acres over those two centuries and is one of four states with the greatest wetland loss in acreage (Dahl, 1990). This means, in a two-hundred-year timespan, the United States lost over 60 acres of wetland every hour (Dahl, 1990). Wetland deterioration and losses are attributed to urban growth and agricultural practices which result in altered water flow, increased pollution, and habit fragmentation (Stedman and Dahl, 2013). However the majority of loss is due to draining for agricultural use (Dahl, 1990).

In order to remove excess water (from the ground surface) to facilitate growing crops, the most common methods of draining wetlands are with surface ditches and subsurface drains or “tiles” (Blann, Anderson, Sands, & Vondracek, 2009). Draining wetlands by ditching results in direct and indirect environmental impacts. Beyond the direct impacts of habitat loss due to conversion of wetlands, and loss of the beneficial functions wetlands provide, the indirect environmental impacts of agricultural ditching include the following: effects on water quality and aquatic habitats by sediment, phosphorus, nitrogen and other contaminants in agricultural runoff, caused by soil oxidation and nutrient mineralization, plus altered hydrology in terms of timing and volume of runoff, which leads to eutrophication and degradation of downstream waters (Blann et al., 2009; Wright, 2009). These effects are cumulative, interconnected, and likely to compound (Blann et al., 2009).

Wetlands have long been viewed as unproductive or marginal lands, and only when drained or transformed were they deemed economically beneficial lands (Butterfield, 1850; Dahl & Allord,
Yet, despite that common perception that pervaded two centuries, wetlands individually and as an integrated system represent some of the most valuable ecosystems, for they offer direct benefits to people and important long-term ecosystem services, such as preserving water quality and quantity, providing wildlife habitat, performing erosion control, and providing nutrient and carbon storage (Dahl & Stedman, 2013; Mitsch & Gosselink, 2015; Moreno-Mateos, Power, Comín, & Yockteng, 2012). Water stored by wetlands serves as habitat for fish, wildlife and plants, serves as a source of water during dry seasons, and is also a source of aquifer recharge. Wetlands are locations which gather and slow water as it moves from the land toward riverine systems and downstream water. This function provides flood damage protection, maintains stream flow, maintains salt-freshwater balance in estuaries, and sustains nutrient and energy flow to and from the surrounding environment. Other wetland benefits include sediment retention and nutrient or chemical sinks, which improve water quality in downstream waters. Wetlands provide habitats for rare and endangered species dependent on fluctuating water levels, and they are critical for conserving biodiversity (Tiner, Bergquest, DeAlessio, & Starr, 2002). Wetlands provide all these vital benefits, and the degradation of wetlands (to include changes in hydro-connectivity from draining wetlands) results in the loss of valuable and significant ecosystems, much to the detriment of society and the natural environment.

St. Lucie County, Florida (SLC) is a prime example of how such land use-land change has led to wetland loss and degradation from draining and ditching. Beginning in the late 19th century, St. Lucie county wetlands were considerably altered by agriculture (predominantly citrus farming) in the interior, and urban development on the coast (SFWMD, 2009). A 2009 analysis of St. Lucie’s wetlands determined that wetlands currently cover 8% of the county (Rains et al., 2011), whereas agriculture and urban coverage combined account for 59% of the total area of the county.
In the late 19th century in St. Lucie County, wetlands were converted for agriculture and development through the organization of drainage districts, which resulted in the development of a vast canal system that has greatly expanded the St. Lucie Estuary watershed, increasing water inflow (and the accompanying pollution and sedimentation) into the Indian River Lagoon (Barile, 2018; Lapointe, Herren, & Lynch, 2015).

The St. Lucie River Watershed is now 937 square-miles in size, and consists of a vast array of primary, secondary, and tertiary canals and ditches, which move water unidirectionally through a series of pumps and gates, toward the North Fork of the St. Lucie River or directly into the Indian River Lagoon (SFWMD, 2009). The C-23, C-24, and C-25 canals are three of the five major canal basins in the watershed and they each discharge approximately 130,000 acre-ft (median) of water annually into the St. Lucie River and St. Lucie Estuary, which both empty into the Indian River Lagoon (SFWMD, 2009).

Prior to these alterations, it is believed that rainfall pooled broadly in the county through a vast wetland system and moved relatively slowly toward the river and coastal lagoon (St. Lucie County, 2010). Historically, SLC wetlands were best characterized as depressional or flat wetlands, as suggested by the county’s relatively flat topography. Elevations range from 0 to 60 feet, although the vast majority of the county is about 20 feet in elevation (Raymond, 2002; St. Lucie County, 2010). The county has only one major natural riverine system, and a few smaller streams at its boundaries. Prior to settlement in the early 20th century, most of the county’s extensive wetlands were collectively named the Alpatiokee Swamp and most likely did not have a strong or permanent...
hydrological connection to the Atlantic Ocean or to Lake Okeechobee (SFWMD, 2009). Essentially, these non-floodplain wetlands (NFWs) were geographically isolated, having strong
internal hydrological connections and weak or no outflowing connections. They performed as a controlling element in the watershed by providing sink, lag and water storage functions to downstream waters and the Indian River Lagoon (Leibowitz, Mushet, & Newton, 2016).

Non-floodplain wetlands (or alternately named geographically isolated wetlands (GIWs)), are isolated spatially but have ephemeral or episodic flow connections to downstream waters, and these connections are important functional elements in the range of ecosystem service to the watershed through the restrictions they perform in hydrological connectivity, such as regulating flood control, and enhancing surface water quality (Cohen et al., 2016; Golden et al., 2017; Leibowitz et al., 2016; Rains et al., 2016). NFWs are an important element in the continuum of watershed functions, yet are vulnerable to filling and transformation by humans (Ameli & Creed, 2017). Until 2001, NFWs were protected under the Clean Water Act (CWA). However, two U.S. Supreme Court decisions created uncertainty in their jurisdictional protection. These decisions conferred federal protection only onto wetlands which had a significant nexus with navigable waters (Cohen, et al. 2016). Recent federal rule changes to the CWA regarding what constitutes a connection, have left wetlands and NFWs even more vulnerable to development.

Thus, the SLC historic wetland system in their isolated, non-floodplain position, provided water storage, nutrient and flow regulation, and other controlling functions within the watershed. Today, much of that watershed experiences rapid, large flow runoff from smaller canals into larger canals, and then to downstream waters, instead of a measured natural procession in which wetlands provide storage to facilitate evaporation, sedimentation and pollution control. Degrading agricultural land use practices, coupled with man-made modification and expansion of the historic watershed, have set the stage for the current impairment of the St. Lucie River watershed and the
consequent decline in the health of the downstream Indian River Lagoon (Lapointe, Herren, & Paule, 2017; SFWMD, 2009).

The Indian River Lagoon, which borders St. Lucie County has itself witnessed vast toxic algal blooms and reduced salinity in the past few years, which have led to fish die offs, stranded marine animals, and loss of sedimentary aquatic vegetation. (Audubon Florida, 2013; Lapointe et al., 2017). Most of Indian River Lagoon’s eutrophication and reduced salinity has been attributed to polluted freshwater overflow from Lake Okeechobee through the C-44 Canal (Voisinet, 2008). However, this explanation does not completely account for the recurring algal blooms, since the extensive system of citrus farm ditches and county-wide canals introduce highly polluted runoff into the estuarine system in greater amounts, than are produced from Lake Okeechobee (Lapointe et al., 2017; Middlebrook, 2018). Pollutant-carrying canal run-off delivered from the county to the Indian River Lagoon flows year-round, which is a steady disturbance that imperils the ecological health of the lagoon and sets up the Lagoon for seasonal algal blooms when polluted freshwater overflows from Lake Okeechobee are also flushed seasonally into the St. Lucie River (Middlebrook, 2018). The increased hydrological connectivity to the St. Lucie River and St. Lucie Estuary due to the county’s agricultural land transformation adds to the worsening water quality in the county and eutrophication of the Indian River Lagoon.

Restoring previously lost wetlands reestablishes their beneficial ecosystem services to society and to the environment, and understanding a watershed’s conditions before disturbances occurred, helps managers develop efficient and effective restoration and conservation strategies (Grossinger, Striplen, Askevold, Brewster, & Beller, 2007; Rhemtulla & Mladenoff, 2007; Stein et al., 2010). Anthropological legacies from the far past often become drivers of modern ecological processes, which are hidden from view in the current landscape (Rhemtulla & Mladenoff, 2007).
By constructing longer time-span ecological datasets of a landscape, historical reconstructions may inform the hidden drivers of contemporary landscape processes and patterns (Grossinger et al., 2007; Stein et al., 2010). Reconstructing the historical ecology of a wetland system can be difficult however, since very little quantitative information is normally available. Even when they are available, such historical reports customarily only contain narrative environmental descriptions, i.e., just qualitative data (Dahl, 1990). Nevertheless, even qualitative historical analysis is a worthwhile endeavor, beneficial not just for understanding what changes were wrought to the system over time (leading to the current conditions), but also for imparting an understanding to guide officials in restoring wetlands and their benefits to society and the environment.

The object of this study is to quantify the change in wetland area and channel length throughout the course of modern settlement in Florida, using St. Lucie County as a model system. This study hypothesizes that since the 1850s, wetland area has decreased and channel length increased in St. Lucie County, along with an associated increase in hydro-connectivity between wetlands and channels. The measurements, assessment, and methodologies developed in this study will improve understanding of wetland functions in the St. Lucie County watershed system, will benefit wetland conservation and restoration efforts in this and similar counties, and in turn contribute to the vitality of the St. Lucie River watershed.
METHODS

St. Lucie County

St. Lucie County, Florida presents a case well suited to historical mapping and comparison of lost wetlands, insofar as the landscape has been extensively altered by agriculture practices, namely citrus farming, resulting in extensive draining of the county’s wetlands. Moreover, the county is the subject of several resource management and planning efforts, which could be informed and enhanced with the results of this analysis.

The county is located along the east-central Florida coast as shown in Figure 1, and drains into the Nationally Significant Indian River Lagoon to the east. The county is bordered by Okeechobee County to the west, Martin County to the south, and Indian River County to the north. It is characterized by citrus farming in the interior, with two cities, Port St. Lucie and Fort Pierce (the county seat), on the coast. It has an area of 688 mi², which 572 mi² are terrestrial (containing the mainland and barrier islands), and 116 mi² are water (U.S. Gazetteer files, 2018). For this study, only the mainland portion of the county was assessed, for the barrier islands were not charted in the 1850 land surveys. According to the area of the SLCMainlandBoundary dataset by which all layers are clipped, the mainland portion of the county has an area of 361,369 acres or 565 mi².

The county’s climate is humid and subtropical, with a mean annual temperature of 73.5 °F, and a mean annual precipitation of 53 inches (Florida Climate Center, 2019; St. Lucie County, 2018). The landscape is low-lying and has a nearly level topography rising from sea level along the coastlines and the St. Lucie River to sixty feet above sea level along the Atlantic Coastal Ridge.
and in the southwestern corner (St. Lucie County, 2010; Watts & Stankey, 1980). The county contains widespread non-floodplain wetlands (NFWs) and few natural channels (St. Lucie County, 2010). The county is divided into three main physiographic sections: the Osceola Plain, the Eastern Valley and the Atlantic Coastal Ridge (Watts & Stankey, 1980). In the southwestern part of the county lies the Osceola Plain, which ranges in elevation from 30 feet to 60 feet above sea level. This area contains broad grassy sloughs, depressions and poorly defined drainageways. Vegetation on this plain is mostly flatwood pine and saw palmetto (Watts & Stankey, 1980).

The Eastern valley runs north to south across the entire length of the county and is situated between the Atlantic Ridge and the Osceola Plain. It contains the Allapattah Flats, the Green Ridge, St. Johns River Marsh and the Ten Mile Ridge, and has an elevation range from 15 to 30 feet above sea level. The predominant vegetation in this area includes cabbage palm hammocks, marsh grasses and clusters of cypress trees (Watts & Stankey, 1980).

The Atlantic Coastal Ridge formed from relic beach ridges and is an elongated ridge that extends the entire length of the county along the mainland. Its elevation ranges from sea level up to 60 feet above sea level, and its vegetation coverage is cabbage palm, sand pine, scrub oak, saw palmetto, and shrubs (Watts & Stankey, 1980).

The county’s surface soils are predominantly marine terrace sands and shelly sands (Rupert & Florida Geological Survey, 1992; U.S. Army Corps of Engineers, 2001). The hydrogeology of the county comprises the Floridan Aquifer, which underlies several unconfined shallow, surficial aquifers, (U.S. Army Corps of Engineers, 2001). These aquifers are separated by a continuous, intermediate confining unit of slowly permeable clay and sand (Reese, 2004; Watts & Stankey, 1980). The Floridan Aquifer is unsuitable as a source for drinking water or for agriculture use, because of its high mineral content (Watts & Stankey, 1980). Drinking water in St. Lucie County
is sourced from surface water or the surficial aquifers, which at some points have as their upper limit, the water table that varies with surface topography. The surficial aquifers produce water flows ranging from a few gallons per minute (gpm) to greater than 2000 gpm (U.S. Army Corps of Engineers, 2001), and they are recharged mostly through local precipitation (Rupert & Florida Geological Survey, 1992).

Figure 3: Location of the Study Area, St. Lucie County, Florida. This shows the major land use cover in the county as agriculture, and urban areas with the two main cities, Fort Pierce and Port St. Lucie along the coast.
Overall Approach

This research project was accomplished in four steps:

1. data collection,
2. mapping 1850s wetlands,
3. wetland change analysis, and
4. drainage density and connectivity change analysis.

The first phase involved collecting geospatial information systems (GIS) data, maps, and historical physiographic descriptions of the area for additional support analyzing historical conditions. The second phase was synthesizing data sources into a composite picture of the county in the 1850s, then delineating wetlands, streams and open waters from the resulting map. In the third phase, wetlands from the 1850s maps were analyzed, and then compared with data from 2004 Florida Land Use, Cover and Forms Classification System (FLUCCs) and from a 2011 wetland survey, to determine change in structure and class of the wetlands between the 1850s and 2004. The final phase consisted of determining the drainage density and connectivity of wetlands to streams and/or artificial channels, to gauge the level of hydro-connectivity change from 1850 to 2004. The following paragraphs expand on each step with more detailed overviews. GIS model flowcharts of each layer created during analysis are in Appendix A.
Data Collection

Table 1: Primary GIS Data Layers used for this research.

<table>
<thead>
<tr>
<th>Content</th>
<th>Layer Acquired</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850s Land Surveys</td>
<td>18 PLSS Land Surveys</td>
<td>Bureau of Land Management, General Land Office (GLO) Record portal</td>
</tr>
<tr>
<td>PLSS Township and Division</td>
<td>FL_cadNSDI_V2.gdb</td>
<td>Bureau of Land Management, Catalog.data.gov website</td>
</tr>
<tr>
<td>SLC Image Basemap</td>
<td>True Color: 2009</td>
<td>Florida Department of Transportation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>delivered by County</td>
</tr>
<tr>
<td>County Boundary</td>
<td>SLCMainlandBoundary</td>
<td>St. Lucie County’s GIS Division</td>
</tr>
<tr>
<td>FLUCCS2004</td>
<td>Florida Land Use, Land Cover Classification System 2004-05 (FLUCCS2004)</td>
<td>South Florida Water Management District (SFWMD)</td>
</tr>
<tr>
<td>Wetlands2004_only</td>
<td>FLUCC_Wetland_HGM_Association</td>
<td>2009_Final.mxd from 2011 St. Lucie County Wetland Inventory and Evaluation Report</td>
</tr>
<tr>
<td>Contemporary Streams/Channels</td>
<td>County Drainage System</td>
<td>Claire Flannagen</td>
</tr>
<tr>
<td>OpenWater2004_only</td>
<td>FLUCC_Wetland_HGM_Association</td>
<td>2009_Final.mxd from 2011 St. Lucie County Wetland Inventory and Evaluation Report</td>
</tr>
</tbody>
</table>

Government Land Office (GLO) PLSSI land surveys were obtained from the Bureau of Land Management (BLM). These land surveys represent the best authoritative source depicting the county’s landscape and land cover before major landscape changes and canal construction started in the early 1900’s. The historical baseline period of the 1850s was chosen as the earliest time period with suitable maps available for this county. GLO Public Land Survey System (PLSS) datasets were used to georeference and rectify the 1850s land surveys, and to estimate 1850s wetland coverage for analysis. (The survey maps used for this study are actually dated from the years 1844 – 1887, with the majority of the land surveys dated 1853). However, for convenience,
this study refers collectively to the historical period as “the 1850s”, while acknowledging some data was incorporated from few years before and after that specific decade.)

Current conditions for comparison to the 1850s wetlands were selected from the year 2004, in order to take advantage of the Wetland Inventory and Evaluation Report (Rains et al., 2011), which used the 2004 FLUCC dataset as the base layer to depict conditions of contemporary wetlands. A crosswalk was used in that report to reclassify wetland and open water polygons as Probable Wetlands, Open Waters, and Probable Non-Wetlands (Table 2). A contemporary Drainage System Dataset created by Claire Flannagen (unpublished data) was used to determine current drainage density and connectivity for comparison with 1850s drainage conditions.

<table>
<thead>
<tr>
<th>Level I FLUCCS2004 Land Use and Cover Class Code</th>
<th>Assigned Wetland or Open Water Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>5250, 5430, 6000-6990</td>
<td>Probable Wetland</td>
</tr>
<tr>
<td>5000-5240, 5260-5990, 8360</td>
<td>Open Water</td>
</tr>
<tr>
<td>1000-4990, 7000-7990, 8000-8990</td>
<td>Probable Non-Wetland</td>
</tr>
</tbody>
</table>

Other layers used in this study’s wetland change analysis were from a dataset entitled FLUCC_HGM_Wetland_Association from the Rains et al, 2011 report. A 2009 SLC image basemap was used to facilitate comparing structures in the map, and a county boundary layer was used to define the study area, corresponding to the confines of the county’s political boundaries. The primary GIS data layers used for this research are described in Table 1.

In addition to the GIS datasets and map documents, several historical narratives and other maps were also used to corroborate the historical landcover and vegetation descriptions of the
1850s wetland map. The historical narratives include surveyor field notes, military charts, and narrations of the landscape and vegetation circa 1850. Table 3 lists these supporting documents.

Table 3: Cartographical and descriptive historical documentation used to interpret land surveys and delineate wetland area for 1850s map.

**Historical Reference Material**

Ives, J.C., 1856. *Memoir to accompany a military map of the peninsula of Florida, south of Tampa Bay.*


Moore, J.M., 1851. *To The Surveyor General of Oregon; Being A Manual for Field Operations*

Zahina, J.G. et al. 2007. *Pre-Development Vegetation Communities of Southern Florida: Technical Publication HESM-02*

Unk., 1884. *Report of the Superintendent U.S. Coast and Geodetic Survey showing the Progress of the Work during the Fiscal Year ending with June, 1883*

Butterfield, J., 1850. *Instructions to the surveyors general of public lands of the United States*

Colonna, B.A., 1883. *Descriptive Report, Topographic Sheet N. 1652, Locality: South End of Indian River*

Unk. MAP of the State of Florida, Showing the Progress of Surveys. 1856,

Ives. J.C., MAP, Military, of the Peninsula of Florida, south of Tampa Bay. 1856.

Unk. MAP of the State of Florida, 1784.

Unk. MAP of St. Lucie County, 1919.
Figure 4: Flowchart of mapping historical wetlands and open waters area and PLSS intersect portions of historical wetlands and open waters.
Mapping Wetland Area 1850s and 2004

In the United States, public land has described and subdivided by the Public Land Survey System, (PLSS). The PLSS divides land into 36 sq. mile plots called townships, which are further subdivided into 36 one-mile-square sections, called divisions. The surveys were created by the surveyor walking, mapping and measuring the division lines, laying a 100-link chain (which measured 66-feet long), as he went. Features crossing this chain were noted with detail in the surveyor’s notes. For example, vegetation cover, timber, possible ore sources and water features were noted, with water features being measured and drawn in the surveyor’s logbooks. These land surveys were used in this study to determine wetland and open water coverage, because they were standardized and spatially coordinated maps, which allows them and their map features to be digitally delineated and analyzed quantitatively. Because the surveyors physically walked and measured these lines, we can be confident the features were accurately noted in their logs and drawn on the surveys. Information about the surveyors, who surveyed what area and when in St. Lucie County, is presented in Table 4, sorted by Township and Range number. Figure 5 shows an example of the land surveys used to create the 1850s map of St. Lucie County and Figure 6 shows the mosaicked land surveys with each survey labeled in position on the map.
Table 4: List of PLSS Land Surveys for St. Lucie County with Township and Range numbers, dates of survey and which surveyor conducted the survey or section of survey. The position of each block in the table corresponds with the survey’s position in the 1850s map.

<table>
<thead>
<tr>
<th>Township</th>
<th>Surveyor</th>
<th>Date of Survey</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS34R37E</td>
<td>George Houston</td>
<td>1844</td>
<td>Surveyed all Township boundaries.</td>
</tr>
<tr>
<td>TS34R38E</td>
<td>George Houston</td>
<td>1844</td>
<td>Surveyed all Township boundaries.</td>
</tr>
<tr>
<td>TS34R39E</td>
<td>George Houston</td>
<td>1844</td>
<td>(2nd Quarter of Year) Surveyed all Township boundaries.</td>
</tr>
<tr>
<td>TS34R40E</td>
<td>George Houston</td>
<td>1844</td>
<td>(4th Quarter of the Year) Surveyed all Township boundaries.</td>
</tr>
<tr>
<td>TS35R37E</td>
<td>Charles F Hopkins</td>
<td>1853</td>
<td>Surveyed North Township boundary.</td>
</tr>
<tr>
<td>TS35R38E</td>
<td>Charles F Hopkins</td>
<td>1853</td>
<td>(June) Surveyed all Township boundaries and Section lines.</td>
</tr>
<tr>
<td>TS35R39E</td>
<td>Charles F Hopkins</td>
<td>1853</td>
<td>(May and June) Surveyed all Township boundaries and Section lines.</td>
</tr>
<tr>
<td>TS35R40E</td>
<td>Charles F Hopkins</td>
<td>1853</td>
<td>(May) Resurveyed all township boundaries and section lines.</td>
</tr>
<tr>
<td>TS36R37E</td>
<td>Charles F Hopkins</td>
<td>1853</td>
<td>Surveyed North Township boundary.</td>
</tr>
<tr>
<td>TS36R38E</td>
<td>Charles F Hopkins</td>
<td>1853</td>
<td>(June) Surveyed North, East and West Township boundaries and Section lines.</td>
</tr>
<tr>
<td>TS36R39E</td>
<td>A.H. Jones</td>
<td>1845</td>
<td>Surveyed the East boundary.</td>
</tr>
<tr>
<td>TS36R40E</td>
<td>A.H. Jones</td>
<td>1845</td>
<td>Surveyed the West boundary.</td>
</tr>
<tr>
<td>TS36R41E</td>
<td>George Houston</td>
<td>1845</td>
<td>Surveyed the West boundary.</td>
</tr>
<tr>
<td>TS37R37E</td>
<td>Marcellus A. Williams</td>
<td>1853</td>
<td>Surveyed North boundary.</td>
</tr>
<tr>
<td>TS37R38E</td>
<td>Marcellus A. Williams</td>
<td>1853</td>
<td>Surveyed the East boundary.</td>
</tr>
<tr>
<td>TS37R39E</td>
<td>G. Houston</td>
<td>1845</td>
<td>Surveyed East Township boundary.</td>
</tr>
<tr>
<td>TS37R40E</td>
<td>G. Houston</td>
<td>1845</td>
<td>(1st Quarter of Year) Surveyed Township boundaries.</td>
</tr>
<tr>
<td>TS34R41E</td>
<td>George Houston</td>
<td>1845</td>
<td>(1st Quarter of Year) Surveyed Township boundaries.</td>
</tr>
</tbody>
</table>
Figure 5: Survey T37S R37E from the 1850s map of St. Lucie County. The box (bottom center), details when the survey was conducted, by whom, and how much they were paid. The paragraph on the right (in red box), notifies of other surveys done in this section and by whom.
The historical 1850s wetland map was fashioned from 18 PLSS land surveys of St. Lucie County from the 1850s. Using the software application ArcGIS 10.6, the land surveys were digitally clipped to remove non-map features and georeferenced to township and range grid coordinates on the PLSS Township dataset. The land surveys were then photo-mosaicked into one map using the “Add Raster to Mosaic Dataset” tool. The pond, marsh and swamp, and wet prairie areas in the map were digitized using an ArcGIS drawing toolset at a scale of 1:5,000 and were then exported as individual shapefile polygon layers into the map. These different wetland layers were combined into one layer to create the **Prob_1850Wetland** dataset to spatially define the
1850s wetlands as one polygon as the historical layer for wetland change analysis. The county’s historical stream system prior to development was delineated by digitizing in the same manner and at the same scale as the historical wetlands and then exported as a single shapefile polyline layer, labeled as **SLRiver**, to the map. The stream delineations were used as a determinant of drainage density and connectivity levels between wetlands and channels in the 1850s.

Historical narratives describing vegetation and topographical features in the area were researched and used to confirm landcover classifications for delineation of wetlands and streams in the 1850s. The 1850s areal extent of wetlands and open water was obtained from tabular statistic query, and then compared to 2004 wetland and open water areal extent, which were obtained from a 2004 probable wetland dataset.

In addition to defining total extent by area, a map was created to show the proportion of PLSS grid that was overlapped by wetland or open water features in the 1850s. The proportional length of all wetland types was summed to obtain a proportional coverage extent of wetlands and open waters in the county in the 1850s. The proportional method of determining area of wetlands and open water in the county was used to check the accuracy of wetland area maps created by the delineation of wetlands and open waters in 1850s. Normally area accuracy is checked by ground truthing the delineated wetland area. For obvious reasons, this could not be done for delineation of historical wetland and open water areas. However, since Township- and Range lines are demarcated by the surveyors’ walking paths across the land in a well-defined and standardized manner, these lines and the portions of the wetland area and open water area along these lines (which are described in detail), are essentially ground-truthed by the surveyors of the land surveys.

To produce this proportional map, a grid polyline feature was digitized directly from the PLSS Division level lines on the 1850s map, to accurately match the survey lines walked and
drawn by the surveyors, which in turn more aptly depicted the wetland features crossing the PLSS lines. A combined proportional wetland feature dataset was created to spatially define the extent of 1850 wetlands in St. Lucie County.

The 2004 probable wetlands and open water polygons were tabular selected from the “wetland” field in the SLC_FLUCCS_Wetland_HGM_Association layer (modified from the original by clipping to county mainland border) and exported into the working map as the ProbWet2004A layer and as OpenWater2004_only layer. The Open Water layer was used to determine the coverage of open water in 2004 to compare with open water area of 1850s. The created 2004 wetland layer was used in wetland change, drainage density, and connectivity analysis, and to create maps showing the 2004 wetland coverage of St. Lucie County.

**Wetland Change Analysis**

The digitized and delineated historic wetland features were analyzed to describe changes to wetland area and class between the 1850s and 2004.

**Wetland Loss**

The difference between the historical wetland layer (1850s) and the existing wetland (2004) inventory identifies those St. Lucie County wetlands lost between 1850 and 2004. To determine the land-use/land-cover change which resulted in wetland loss, an intersection between the historical wetland layer (1850s) and Flucc_Wetland_HGM_Association layer was performed to categorize and determine into which LULC level 1 classification the 1850 wetlands were transformed by 2004. In the resulting intersection layer, the features were dissolved according to
LCCODE field in the attribute table, and then were identified by tabular selection and exported into the working map as **Wetland1850_Assoc_LOSS**. This dataset describes the increases and decreases in areal extent and location of each LULC class, summed over the county.

![Flowchart of Wetland Change Analysis](image)

**Figure 7: Flowchart of Wetland Change Analysis**
Wetlands Remaining

To determine how much wetland still remained in 2004 from the 1850s, the 2004 wetland layer was intersected with the historical layer, thus creating a dataset displaying wetlands from the 1850s still present in 2004, called **Wetland1850_STILL_LCcode**. The **Wetland1850_STILL_LCcode** layer was then modified by dissolving the attributes according to the LCCODE field, in order to categorize the types of wetlands from the 1850s as defined by LEVEL 1 land-cover categories. Classifying the remaining wetlands in this manner helps to understand how the historical wetland areas may have been structured with regard to landcover categories, prior to development in the county.

Wetland New

The **Wetland_NEW** layer was fashioned by erasing the **Wetland1850_STILL_LCcode** layer from the **Probwet2004A** dataset, to identify the historical wetlands that were not captured in the mapping of the 1850s wetlands, or which were newly created wetlands since the 1850s. The attributes of this layer were aggregated to differentiate new wetlands by descriptions of level 1 FLUCCS codes, which resulted in the **Wetland_NEW_LCcode** layer. Table 3 and Figure 6 show the newly mapped wetlands (i.e., those that appeared after the 1850s, as created wetlands or remnant wetland, wetlands not captured in 1850s mapping process) in the county according to FLUCCS landcover categories.
Drainage Density and Connectivity Analysis

Drainage Density

Drainage density was calculated according to the formula where drainage density was defined as the total length of all streams or channels in a drainage basin divided by the total area of the drainage basin (Horton, 1945). Thus, the equation for drainage density is:

\[ Dd = \frac{Ls}{Aw} \]
Where Dd is drainage density, Ls is the total length of streams and channels in a watershed, and Aw is the area of the watershed. For the purpose of this study, the drainage basin area is defined as the complete mainland area of St. Lucie County.

Wetland Connectivity

Connectivity between wetlands and channels was determined by intersecting each time period’s (1850s and 2004) Probable Wetland layer with its corresponding stream/channel system buffered to 328-ft, creating separate datasets of the areal scope of wetlands that are directly connected or are located within 328-feet of a stream/channel. When intersected, the wetland area is clipped to the buffered channel area thus only the wetland area directly within 328-feet of a channel was captured and measured for connectivity analysis. A buffer of 328-feet was set for the streams or channels, because other research has shown that land-use/land-cover characteristics within 328-feet (100m) of wetlands are strongly correlated with the function and structure of peninsular Florida wetlands (Brown & Vivas, 2005; Rains, Landry, Rains, Seidel, & Crisman, 2013).

Additionally, a Generate Near Table (Analysis) was performed to calculate the mean distance between 1850s wetlands (edge) and the nearest stream (in the 1850s), and also with 2004 wetland (edge) and the nearest channel (in 2004), to determine the change in the mean distance between wetlands and nearest channel.
RESULTS

Mapping Wetland Area, 1850s and 2004

Wetland and open water landcover were measured by calculating total area (ac) of wetlands and open water in the county and by determining the proportion of wetlands and open water polygons overlapping the PLSS Grid. Coverage results were similar in both methods.

In the 1850s, as measured by total area, there were a total of 178,137 acres of wetlands and 4,973 acres of open water with a combined coverage of 183,110 acres, or 50% of the county area (Table 5, Figure 9). The open water category consisted of the St. Lucie River and the portion of the St. Lucie Estuary falling within the borders of the county. As measured by the proportion of probable wetlands and open water overlapping the PLSS grid, the combined coverage was 48.4% of the County (Table 6). The proportional measurement of wetland area is similar to the amount of total wetland and open water area (ac), which verifies the total wetland area in acres. Since the total wetland area was verified by this secondary measurement method, the follow on analysis of wetland change and connectivity change analysis were conducted using data from the total wetland area method, in order to facilitate comparing historical polygon data with contemporary wetland polygon area data in the wetland change and connectivity change analysis (Figure 11 &12).

In 2004, there were a total of 32,087 acres of wetlands and 11,457 acres of open water, compromising 9% and 3% of the county land area, respectively. The 2004 open water consisted of the the St. Lucie River and a portion of the St. Lucie Estuary within the borders of the county, plus 9,143 acres of artificial canals and reseviors (Table 5, Figure 10).
### Table 5: St. Lucie County Wetland and Open Water total area in 1850s and 2004

<table>
<thead>
<tr>
<th>Landcover</th>
<th>Area Total (ac)</th>
<th>Area Total (ha)</th>
<th>% of County Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1850</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probable Wetlands</td>
<td>178,137</td>
<td>72,089</td>
<td>49%</td>
</tr>
<tr>
<td>Open Water</td>
<td>4,973</td>
<td>2,012</td>
<td>1%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>183,110</strong></td>
<td><strong>74,102</strong></td>
<td><strong>50%</strong></td>
</tr>
<tr>
<td><strong>2004</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probable Wetlands</td>
<td>32,087</td>
<td>12,985</td>
<td>9%</td>
</tr>
<tr>
<td>Open Water</td>
<td>11,457</td>
<td>4,636</td>
<td>3%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>43,532</strong></td>
<td><strong>17,617</strong></td>
<td><strong>12%</strong></td>
</tr>
</tbody>
</table>

### Table 6: Proportion of Wetland and Open Water Area which overlaps PLSS lines. Total Proportion of wetland and open water length which overlaps with PLSS lines is similar to the percent of county covered by wetland and open water area.

<table>
<thead>
<tr>
<th>Class</th>
<th>Length Total (ft)</th>
<th>Length Total (m)</th>
<th>% of overlap with PLSS lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLSS Grid</td>
<td>6,624,622</td>
<td>2,019,185</td>
<td>----</td>
</tr>
<tr>
<td><strong>Probable Wetlands’ overlap length with PLSS lines</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marshes &amp; Swamps</td>
<td>681,081</td>
<td>207,593</td>
<td>10%</td>
</tr>
<tr>
<td>Ponds</td>
<td>482,624</td>
<td>147,104</td>
<td>7%</td>
</tr>
<tr>
<td>Wet Prairies</td>
<td>2,013,678</td>
<td>613,769</td>
<td>31%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3,177,383</strong></td>
<td><strong>968,466</strong></td>
<td><strong>48%</strong></td>
</tr>
<tr>
<td><strong>Open Waters’ overlap length with PLSS lines</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Lucie Estuary</td>
<td>3,974</td>
<td>1,211</td>
<td>0.06%</td>
</tr>
<tr>
<td>St. Lucie River</td>
<td>23,694</td>
<td>7,222</td>
<td>0.3%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>27,668</strong></td>
<td><strong>8,433</strong></td>
<td><strong>&gt;1%</strong></td>
</tr>
</tbody>
</table>
Figure 9: 1850s Wetland and Open Water area in St. Lucie County.
Figure 10: 2004 Wetland and Open Water area in St. Lucie County.
Figure 11: Wetland and Open Water area and overlaid Division Lines grid which when intersected and measured, make up the 1850s Proportional Wetland and Open Water Area.
Figure 12: Proportional sections lengths of wetlands and open water area which intersect with the overlaid PLSS division lines creating Proportional Area of 1850s Wetland and Open Water in St. Lucie County.
Wetland Change Analysis

Wetland Loss between 1850 and 2004

St. Lucie County wetlands coverage decreased by 82%, from 178,137 acres in the 1850s to 32,087 acres in 2004. During that same time span, the county’s open waters increased from 4,973 acres in 1850 to 11,457 acres in 2004, a 130% increase. The gross amount of wetland loss was primarily due to direct land use conversion by agricultural LULC, which accounted for 76% of the lost wetlands between 1850 and 2004. Other direct replacements had smaller impacts on wetland loss, with a distant second contributor, urban LULC, accounting for 5% of the wetland loss. Drying and channelization also contributed to wetland loss by conversion to upland forest/and water LLUC (in the form of canals and reservoirs), contributing 3% and 2% respectively, to wetland area loss. However, there are 19,476 acres of wetlands still remaining from the 1850s wetlands. (Tables 7 & 8, Figures 13 & 14).

Table 7: Totals of Wetland Change, 1850s to 2004

<table>
<thead>
<tr>
<th>Wetland Coverage Change</th>
<th>Total Area (ac)</th>
<th>Total Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850s Wetland Total</td>
<td>178,137</td>
<td>72,089</td>
</tr>
<tr>
<td>1850s Wetland STILL in 2004</td>
<td>19,476</td>
<td>7,882</td>
</tr>
<tr>
<td>Wetland newly mapped since 1850s</td>
<td>12,611</td>
<td>5,103</td>
</tr>
<tr>
<td>2004 Wetland Total</td>
<td>32087</td>
<td>12,985</td>
</tr>
<tr>
<td><strong>NET Wetland LOSS</strong></td>
<td><strong>146,050</strong></td>
<td><strong>59,104</strong></td>
</tr>
</tbody>
</table>
Table 8: Wetland Conversion to Land use-Land cover in St. Lucie County, based on the 1000 Level Landcover category of the Florida Land Use, Cover and Forms Classification System (Florida Department of Transportation, 2004).

<table>
<thead>
<tr>
<th>Land Use-Land Cover</th>
<th>Total Area (ac)</th>
<th>Total Area (ha)</th>
<th>Percent Area (%) of 1850s Wetlands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural</td>
<td>134,495</td>
<td>54,428</td>
<td>76%</td>
</tr>
<tr>
<td>Wetlands</td>
<td>19,476</td>
<td>7,882</td>
<td>11%</td>
</tr>
<tr>
<td>Urban</td>
<td>9,175</td>
<td>3,713</td>
<td>5%</td>
</tr>
<tr>
<td>Upland Forests</td>
<td>4785</td>
<td>1,936</td>
<td>3%</td>
</tr>
<tr>
<td>Rangeland</td>
<td>4480</td>
<td>1,813</td>
<td>2%</td>
</tr>
<tr>
<td>Water</td>
<td>4364</td>
<td>1,766</td>
<td>2%</td>
</tr>
<tr>
<td>Transportation, Comm. &amp; Utilities</td>
<td>1100</td>
<td>445</td>
<td>1%</td>
</tr>
<tr>
<td>Barren Lands</td>
<td>258</td>
<td>104</td>
<td>&lt;1%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>178,132</strong></td>
<td><strong>72,087</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Wetlands Remaining from the 1850s

Of the current 2004 wetlands in St. Lucie County, 61% or 19,476 acres, remain from and appear to have originated from the historical 1850s wetlands. These 1850s remaining wetland areas are primarily in the less developed and agricultural areas of the county, and likely have undergone the least amount of disturbance since the 1850s. They therefore present the least complicated potential conservation opportunities within the county’s highly modified landscape (Figure 15).
Figure 13: Lost 1850s wetlands area, still remaining wetlands area and new wetlands area in 2004
Figure 14: 1850s Wetland Conversion by Level 1 Landcover categories.
Figure 15: 1850s wetlands area which still remain in 2004
Newly Mapped Wetlands

Of the total area of 2004 wetlands, 40% (or 12,611 acres) are wetlands that were not mapped in the 1850s. The majority type of wetlands in this group, when classified according to LCcodes, are freshwater marshes or wet prairies (Table 9).

This new wetlands portion of the 2004 wetlands area, may represent a gain of wetland area in the county. However, that designation can not be conclusively determined from this study. The source of these wetland areas may be new functional wetlands, such as from a restoration wetland creation project, or they may be wetland-appearing-areas, (e.g., non-functional wetlands) such as a stormwater pond or roadside ditch in an urban setting. Or they may be remnants from the 1850s which were not captured when wetlands were delineated from the 1850s land surveys, and thus may be the result of “undermapping.” To illustrate this point, the study notes a major portion of these wetlands are present within modern urban settings and resemble artificially created retention ponds, golf course fairways, electrical transmission lines and roadway ditches when assessed at close resolution (1:10,000) on the St. Lucie County satellite basemap, yet some of the ‘new’ wetlands are in less developed areas or county parks.

Alternatively, some of these wetlands may be remnants from the 1850s, which were not captured in the mapping process of the 1850s map. This undermapping may have occurred for several reasons. Variations may have occurred because of imprecise map terminology (e.g., a “hammock” could be hydric, mesic or xeric), differences in effective mapping scale (e.g., upland-wetland mosaics may have been too small to individually map), limitations of survey methods (e.g., surveyors measured and noted features along the division lines, not the interiors of the division sections), or because of shifting map projection (e.g., incomplete overlap between the 1850s an 2000s wetlands layers could result in slivers of “new” wetlands on some boundaries).
An example of undermapping due to imprecise map terminology is shown in Figure 16. In the southwest corner of the county, (circled in red in the map), is a complex of ‘new’ wetlands. The same spatially defined area in the 1850s land survey map (Figure 17), depicts an area of “hammocks” which was not delineated as a wetland area because the word “hammocks” could represent either a ‘dry’ (e.g., mesic pine forest) or a ‘wet’ (e.g., hydric hardwood forest) landcover. The distinction between different types of hammock areas was not detailed on the 1850s land surveys. Therefore, any area defined as “hammock” on the surveys was not mapped as wetlands in the 1850s wetland map. However, it is possible that this area was part of an upland wetland forest mosaic in the 1850s, but is now designated as a “new” wetland (even though it may have been a wetland pre-development) because it was not delineated as a wetland.

Table 9: New Wetlands in St. Lucie County sorted by Level 1 Landcover codes and descriptions.

<table>
<thead>
<tr>
<th>FLUCCS Landcover Class</th>
<th>Total Area (ac)</th>
<th>Percent of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6400-Freshwater marsh, wet prairie</td>
<td>6,620</td>
<td>53%</td>
</tr>
<tr>
<td>6100-Wet Hardword forest</td>
<td>3,716</td>
<td>29%</td>
</tr>
<tr>
<td>6200-Wet Coniferous Forest</td>
<td>1,766</td>
<td>14%</td>
</tr>
<tr>
<td>6300-Wetland forested mixed</td>
<td>508</td>
<td>4%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>12,610</td>
<td>100%</td>
</tr>
</tbody>
</table>
Figure 16: Wetlands which are classified as ‘New’ wetlands in 2004, because they have been created since the 1850s, or were not captured during the process of delineating wetlands from the 1850s map. The red oval is the close-up area shown in Figure 17.
Figure 17: Close-up of 1850s Map showing New Wetland (from 2004, in red and circled) overlaying area designated ‘hammock’ in 1850s land survey map. This hammock area was not delineated as wetland in mapping 1850s wetlands and therefore presents as ‘New’ wetland. This area is located in southwest corner of St. Lucie County

**Drainage Density and Connectivity Analysis**

**Drainage Density, 1850s and 2004**

Channel drainage density throughout the county increased from 0.33 ft/acre in the 1850s, to 331 ft/acre in 2004 (Table 10). The difference in drainage channel length is easily seen in the comparison of the map of the 1850s drainage channel system with the map of the 2004 drainage channel system (Figure 18 and 19). A close-up of the 2004 channels can be seen in Figure 20. The
change in drainage density is a three-order of magnitude change. Drainage density intensification was not however, uniform throughout the county. Changes in drainage density were greatest in agricultural areas (with a 2004 density of 443 ft/acre), while the next largest LULC coverage class, urban, had a density in 2004 of 114 ft/acre. Measurement of channel drainage density is important to highlight, because drainage density plays an important role in runoff processes, influences the strength of potential floods, and it affects the concentration of nutrient- and sediment loading in a drainage basin (Zävoianu, 1985).

The drainage channel GIS layer used for this analysis was not 100% accurate. It is only approximately 90% accurate when compared to the 2009 St. Lucie County basemap, which is a 2009 satellite image of the county. This rough accuracy rating is based on a random sample test comparison, using 100 random points generated by the ArcGIS program to fall within channel areas, and 100 random points outside the county’s channel areas. A truer accuracy measurement for the drainage channel GIS layer would also depend upon the lateral resolution difference between it and the 2009 St. Lucie County satellite basemap. Although the drainage channel GIS layer may not be an exact replica of the exact landscape, the three orders of magnitude difference in change between the 1850s and 2004 is such a vast transformation, that 90% accuracy is acceptable for showcasing drainage density- and wetland to channel hydro-connectivity changes in St. Lucie County, for the purposes of this study.

Table 10: Drainage Density for 1850 and 2004 in St. Lucie County. (Total area for County is 361,369 acres)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Drainage Channel Total Length</th>
<th>Drainage Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850s</td>
<td>117,655 ft</td>
<td>.33 ft/ac</td>
</tr>
<tr>
<td>2004</td>
<td>119,723,885 ft</td>
<td>331 ft/ac</td>
</tr>
</tbody>
</table>
Wetland Connectivity to Channels, 1850s and 2004

Paralleling the increase in drainage density, connectivity also increased considerably over the same time period. The study specifically identified the change affecting areas of hydrologic connectivity through contiguous surface-water connections between wetlands and channels. In the 1850s there were 3,256 acres of wetland within 328 feet of streams in the county, thus 2% of the county’s 1850s wetlands were connected to channels. By 2004 this increased to 18,933 acres, or 60% of St. Lucie’s wetlands within 328 feet of a stream or channel (Table 11).

Additionally, when the polylines representing the county’s channels are buffered to 328-feet to create polygons, the total buffered area of the channels increased from the 1850s to 2004. They increased from 2% of the county surface area in the 1850s to 85% of the county surface in 2004.

The mean distance between 1850s wetlands (from polygon edge) and the nearest 1850s stream as determined by running a Near Analysis in ArcGIS was 17,823 feet or almost 5.5 km. whereas the mean distance between 2004 wetlands (from polygon edge) and the nearest 2004 channel was 127 feet.

This is another indication of the magnitude of increased hydro-connectivity experienced in the county. The study also notes, in 2004 the majority of channels in the county were artificial canals or ditches, whereas in the 1850s all the channels were natural streams and rivers.

Table 11: Connectivity Analysis—Amount of Wetland Area in 1850s and 2004, within 328 feet of a channel

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Total area of wetlands (ac)</th>
<th>wetlands area within 328 feet of a channel (ac)</th>
<th>wetlands area within 328 feet of a channel (ha)</th>
<th>% of total wetland area within 328 ft of a channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850s</td>
<td>178,134</td>
<td>3,256</td>
<td>1,318</td>
<td>2%</td>
</tr>
<tr>
<td>2004</td>
<td>32,075</td>
<td>18,933</td>
<td>7,662</td>
<td>60%</td>
</tr>
</tbody>
</table>
Figure 18: St. Lucie County’s drainage channel system in 1850s.
Figure 19: St. Lucie County’s drainage channel system in 2004. The blue area and lines are canals, drains, or agricultural ditches.
Figure 20: Close-up view of 2004 Drainage channel system
DISCUSSION

This research spanning the course of modern settlement in St. Lucie County, is a novel approach in historical wetland analysis in Florida, addressing both loss of wetlands and increase in hydro-connectivity of wetlands to channels. This study reveals that St. Lucie’s historical wetland loss was considerable, and the hydro-connectivity of the remaining wetlands has substantively increased. The extensive wetland loss in St. Lucie County resulting from conversion to agriculture, plus increased connectivity driven by the creation of an extensive drainage system, are likely contributors to the current, impaired condition of the St. Lucie Estuary and the Indian River Lagoon.

This research indicates that of the 178,132 acres of wetlands in St. Lucie County present in the 1850s, only 32,075 acres remained in 2004 (Table 3), representing a net loss of 82% of the county’s wetlands. It is not surprising that the majority of loss was due to agricultural conversion (Table 6), given that citrus farms are the predominant industry in the County. Prior to the county’s anthropogenic alterations, wetlands pooled across the width of SLC (Figure 5) yet were only marginally connected to the watershed. Today, runoff from the county’s expanded drainage system flows quickly from residential and agricultural canals into larger canals, and finally surges into coastal waters. In the past, water would flow slowly as sheet-flow across the county, through multiple evaporation and biogeochemical cycles. These would filter out nutrients and sediments, and recharge the surficial groundwater (Byrne & Patino, 2004). St. Lucie’s heightened hydro-connectivity is evident by the amplification of the drainage density determined in this study, i.e., from .33 ft/acre to 331 ft/acre (Table 9). It is also made evident by the increase in wetland area
within 328-ft of a channel (from 3,256 acres to 18,933 acres, as measured in this study). Moreover, the amount of wetland area within 328-feet of a channel increased despite the sharp decrease in overall wetland area. St. Lucie now has far fewer wetlands, but they are situated significantly closer to channels, than was long the case before development. Such loss of wetlands combined with increased hydro-connectivity, has implications for water quality management in St. Lucie County, especially regarding water quality in the Indian River Lagoon. Because of the large flow of nutrients and fresh water discharging into the Indian River Lagoon from the county, the Lagoon now suffers from chronic and acute water-quality degradation and related harmful algal blooms (HABs) (Barile, 2018; Lapointe et al., 2015).

The extensive rise in this county’s connectivity started with modification in the early twentieth century, when canals and levees were built in part to lower the risk of flood and reduce water borne diseases, but mostly to reclaim the land for agriculture or development (Barile, 2018; Lapointe et al., 2015). However, St. Lucie County’s canals yielded the same aftermath of unintended consequences as seen in other wetland landscapes: wetland loss and lowered water tables, depleted natural storage areas, water delivered in pulses instead of slow flows, dry-down in shallow aquatic habitats during dry season, habitats opened up to exotic species, and sediments and nutrients deposited to downstream waters (Harvey, Loftus, Rehage, & Mazzotti, 2010).

The overall loss of wetlands in St. Lucie County, as measured and modeled in this research effort as 82%, is substantial and greater than previously estimated (e.g., 46% for Florida, as extrapolated by Dahl and Stedman (2013)). St. Lucie County’s greater loss rate can in part be ascribed to the large proportion of wetlands transformed specifically for agricultural land use. A majority of the county’s 1850s wetland areas were arrayed on what would later become the largest land-use category by a hefty margin (59% of the county area is agricultural). This is because
wetland areas are the easiest to transform (by ditching), for they have level, or mostly level
topography, and usually have fertile soils. In other words, a substantial portion of the historical
wetlands were transformed by agriculture, either into croplands or as grazing land for cattle,
because the greatest concentration of wetlands was in the area later developed for agriculture.
Additionally, the drivers of wetland loss in St. Lucie County, i.e., ditches and channels to drain
wetlands for agriculture and flood control, were common practice in the state in the early 20th
century. With regard to land-use conversion percentages, (77% of the county’s historical wetlands
were converted to agriculture), comparable portions of wetlands transformed to agriculture lands
have been reported in other areas of Florida, mostly by draining with ditches and canals. (Fretwell,
Williams, & Redman, 1996).

The primary purpose of this research project is to assess and quantify the change in
wetlands over more than a century in St. Lucie County. However, the methods were not optimized
for absolute measurements of historical wetlands’ number, or for use to study individual wetlands.
This research is instead designed for use at the landscape scale, to provide a quantitative overview
of wetland loss and change in connectivity, across a broad temporal and spatial scale. Although
accuracy of wetland area mapping was validated by a frequency analysis, - using proportional
wetland area intersecting PLSS division lines which arrived at similar wetland area, - there is
uncertainty in historical mapping and interpretation of historical data when determining historical
wetland area. Limitations in mapping precision and quality may arise from several components in
the mapping process, and thereby limit the utility of these results as absolute measures. These
errors can compound to limit precision and increase errors in the data.

Deviations in wetland mapping accuracy and precision arise from several sources, and one
source is in the creation of the 1850s land surveys. Individual surveyors’ abilities to correctly
measure and record landcover features are not uniform and some people may work more precisely than others. Additionally, there is a temporal variance in mapping precision due to the span of time between sectional surveys, plus seasonal variation in precipitation and thus soil saturation levels on the landscape, which generates discrepancies in identification of wet areas by surveyors. Other deviations result from variations in cartographic production quality. Consider that GLO survey maps were hand drawn, and based on field note descriptions and measurements, often by different surveyors covering the same area at different time scales (Zahina, 2007). Likewise, errors can occur in the interpretation of map records (see “new” wetlands in Results), because of distortions from converting paper maps to electronic image formats, and with the projection distortion between GIS layers and in the rectifying process in the ArcGIS program. Lastly, there are difficulties in resolving and delineating wetland structures, due to limitations of cartographic resolution or lack of definition of important landscape features. However, given the magnitude of change in wetland loss, channel intensification, and wetland to channel connectivity determined in this study, it is unlikely that such limitations in the data or methods could significantly change the overall results.

This study’s quantitative analysis describing the change in extent, and structure of St. Lucie County’s wetlands, along with the change in connectivity analysis across a century-plus timespan, represents a valuable tool for management and restoration efforts in their efforts to reestablish ecosystem functions in the St. Lucie County watershed and the Indian River Lagoon system. The study produced structured baseline data, which enables more accurate and compelling analysis for investing resources toward developing and managing environmental conservation and restoration programs in the county. Regional assessments of historical and contemporary land use-land cover change, as well as historical wetland inventories, are essential to wetland resource management
for they illuminate possible remnants from the past, which can present superior sources for restoration or conservation opportunities within substantially modified landscapes. Also, deeper understanding of how and where transformations to natural states have occurred, allows managers to more effectively and efficiently reverse hidden anthropological changes to fully restore wetlands and their ecosystem services to the benefit of society and the environment.

Next steps for this research will address wetland extent and connectivity in the interval between 1850 and 2004, focusing on the temporal mid-range of the 1950s. Aerial photographs from the U.S. War Department, from 1944 (October to February) and 1952 (January to April) have been rectified and georeferenced using ArcMap 10.6 and 10.7, to the same 2009 aerial image basemap of the county as used in this research. The photos from each year were collected in a catalog dataset and then mosaicked together in ArcGIS into two digitized feature layers, for 1944 and 1952 respectfully. These two layers collectively will form the midpoint historical wetland dataset of St. Lucie County. For this analysis, the streams and wetlands will be delineated in a random sampling format in the midpoint dataset using a randomly generated circle (1 km in diameter) sampling system, to sample 15% of the county. This sampling protocol has also been developed and tested against the historical 1850s and contemporary 2004 datasets. The sampling protocol consists of 256 points randomly scattered across the county and then buffered to one kilometer. Wetlands and channels will be delineated within the buffered polygons by photo-interpreting the historic wetland and channel boundaries. Finally, extent and connectivity analysis will be completed for these polygons. This future research will thus provide an even more comprehensive set of structured data and quantified assessments, with which to understand the details of St. Lucie County’s great wetlands loss, enhanced connectivity, and prospects for restoration or conservation of the county’s wetlands.
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APPENDIX A

Model A1: Wetland 2004_only GIS layer

Model A2: Wetland Loss and Classification Analysis GIS layers
APPENDIX A (Continued)

Model A3: New wetlands and derivatives GIS layers

Model A4: Wetland_STILL and derivatives GIS layers
APPENDIX A (Continued)

Model A5: Connectivity Analysis, 1850s and 2004 wetland intersect with buffered channels GIS layers