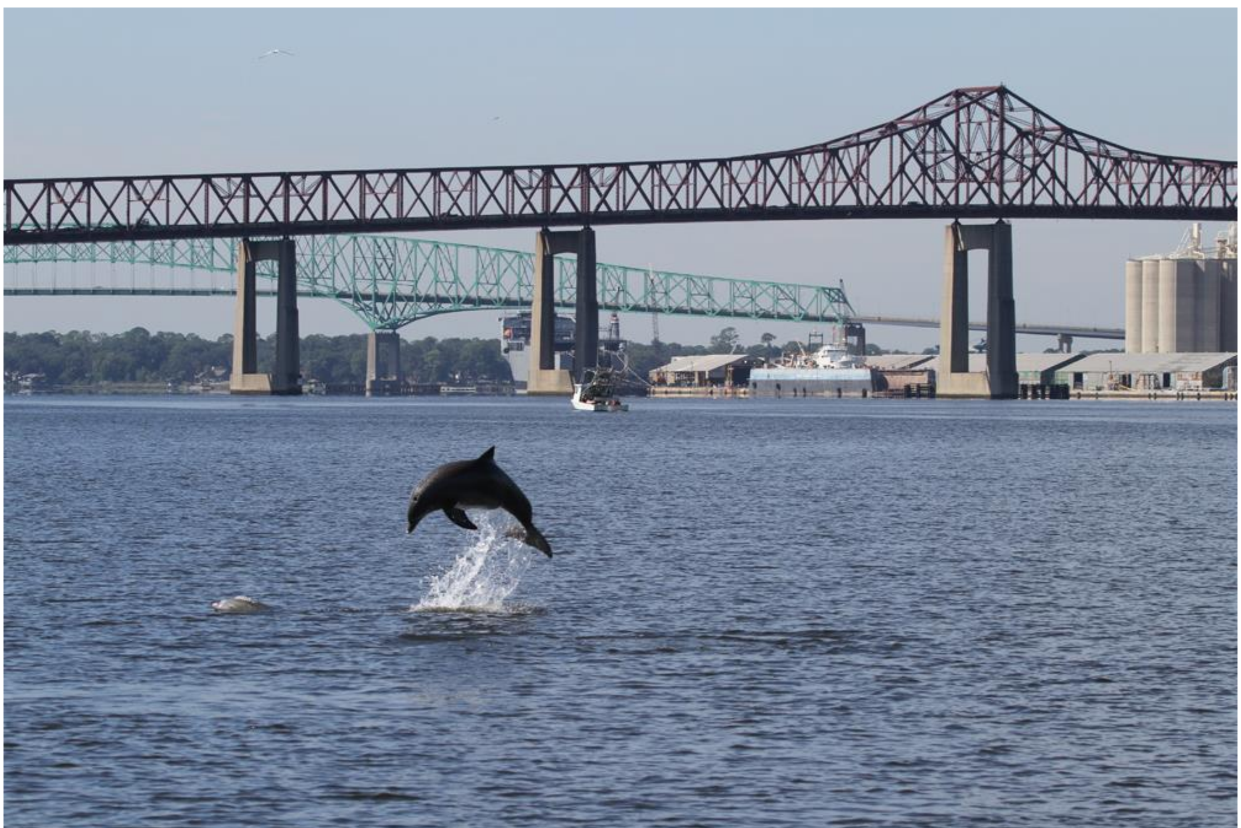
St. Johns River Economic Study

Edited by

Courtney T. Hackney
Director of Coastal Biology
University of North Florida
Jacksonville, Florida 32224
c.hackney@unf.edu



Cover Photo

Courtesy of Dr. Quincy Gibson showing the St. Johns River near Jacksonville, Florida with Dolphins in the foreground.

COASTAL BIOLOGY

UNIVERSITY OF NORTH FLORIDA

St. Johns River Economic Study

Edited by

Courtney T. Hackney
Director of Coastal Biology
University of North Florida
Jacksonville, Florida 32224
c.hackney@unf.edu

January 2015

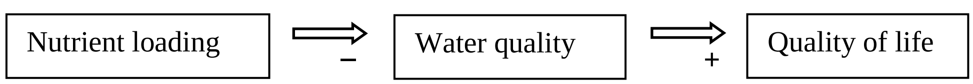
Report submitted to the St. Johns River Water Management District

under contract #27884

Executive Summary

Determining the economic value to society of a natural river system is inherently difficult. One approach (Ecological Services) relates ecological functions and processes to services provided by nature to people, and then calculates economic values of these services. Economic values obtained via this approach are usually based on the cost to replace those services. A workshop was held to determine if an Ecosystem Service approach was appropriate for the St. Johns River (SJR). Eleven economic priorities were set by in-state and out-of-state workshop participants using both an Ecosystem Service approach as well as other traditional economic analyses. Seven of the eleven priorities were funded with an appropriation from the Florida Legislature. Funded priorities included 1) a conceptual model connecting natural functions with economic values, 2) the value of the SJR wetlands in flood prevention, 3) the value of wetlands in the removal of phosphorus and nitrogen from water in the river, 4) the increase in value of real estate along or near the SJR in four counties, 5) value of surface water to consumers along the river, 6) the economic impact of recreation by Florida residents to the Florida Economy and 7) the potential for Ecotourism on the river. Many significant economic values of the river remain to be determined.

An important approach in understanding any complex issue is the development of a model that combines elements of knowledge in a way that allows various extensions of that knowledge to be evaluated or tested. Models thus represent selected aspects of reality or what we know. The concept of Ecosystem Services is an approach that allows economists and ecologists to combine what is known about the natural world and convert natural processes and products into monetary value. A conceptual model of the SJR was developed based on known or anticipated Ecosystem Services and shows linkages between Ecosystem Services and monetary value. The model is an envisioning and decision tool. A model can be as simple as:



where the model illustrates the fact that nutrient loading affects water quality, which subsequently affects quality of life for humans. The plus and minus signs indicate whether the effect is in the same (+) or opposite (–) direction. Various methods for assigning economic value are not suggested in these simple models, nor is a numeric economic value. Some examples of ecosystem services (clean water and flood protection) are linked to natural ecosystem components (wetlands, for example) that provide these “free” services. Economic analyses must be especially aware of feedback loops, which can either magnify or stabilize expected responses to change.

To develop an economic valuation of the wetlands as related to flood abatement and flood insurance rates required the integration of hydrologic and hydrodynamics models. A hydrologic model was used to describe infiltration and runoff for the entire drainage basin of the SJR. The model computed watershed runoff which was fed into a model that simulated tides, surge and flooding for the lower St. Johns River Basin. Results of the modeling included areal extent of flooding and water heights generated from scenario-based model runs, including historic events, Tropical Storm Fay, (an approximate 100-year rainfall event), and the same 100-year event, but with wetlands hypothetically converted to developed-type land cover/land use. The modeled extent of flooding and water heights were geospatially analyzed.

The economic value of total flood prevention is $3 billion dollars with an average decrease in residential property value of $15,156 from being in a flood zone.

Using geographic information systems (GIS) data, and data on wetland nitrogen (N) and phosphorus (P) accumulation in the SJR watershed and nearby areas (northern Everglades, southeastern Georgia), watershed-wide rates of wetland N and P removal were calculated. Wetlands in the SJR remove approximately 188,000 Metric Tons (MT) of N each year, half from burial and half from denitrification. The amount of P removed each year is nearly 2400 MT. The economic value of this watershed-wide nutrient removal was determined using the cost (per pound) of N and P removal by wastewater treatment plants and the cost (per pound) of N and P bought and sold in nutrient trading programs in the SJR watershed, Florida and nearby states. Based on wastewater treatment costs to remove N, including denitrification, wetlands of the SJR watershed provide 95 to 122 billion dollars in service each year to the state of Florida. Nitrogen removal using nutrient trading program costs values the SJR wetlands at 3.3 to 21.7 billion dollars each year. For P removal, the value of the SJR wetlands is 20 to 490 million dollars/year based on wastewater treatment costs and 360 million dollars/year based on nutrient trading programs. Uncertainty in these estimates results from limited data on these wetlands and the wide variety of wetlands (and their ability to remove N and P) in the watershed. Assuming a very conservative N/P removal cost of $1 per pound, the economic value for nutrient removal by SJR wetlands still exceeds 400 million dollars/year for N and 5.3 million dollars/year for P. The large economic value of the SJR wetlands underscores their importance in the maintenance and protection of water quality in eastern and northeastern Florida.

An econometric model was used to estimate the economic value of properties in the lower SJR basin (Duval, Clay, Putnam and St. Johns Counties) fronting or near the SJR. The model incorporated data on properties, demographics, water quality, and public awareness of harmful algal blooms for the past ten years to make estimates and used more than 20,000 property sales over the period 2003-2013. Riverfront properties in the four counties studied increased in value $944 million due solely to river frontage. Tributary frontage properties increased $117 million over properties that lack frontage, but were otherwise similar in property characteristics. The increased value attributable to the river carried to surrounding neighborhoods as well, with an $837 million value for proximity to the river. The increase in tax revenues for the four counties resulting from adjacency to the River and its tributaries is $136.54 million dollars over twenty years.

Health of the SJR measured as water clarity added significant value to waterfront properties. Waterfront properties with the highest water clarity enjoyed an increased value premium of close to 24% for river frontage, while properties with the lowest clarity saw this premium reduced to only 6% of sales price. If all riverfront properties were adjacent to the highest water quality, i.e. six feet clarity, the hypothetical improvement in economic value attributable to the water quality improvement alone would total $346.1 million. The property tax revenue associated with this increase in water quality would total $45.3 million over 20 years. Conversely, a decline in water quality could reduce property values and ultimately tax revenues.

A water-use valuation was completed for the major surface water and groundwater sources and uses of the SJR watershed. The evaluation used the “benefit-transfer” approach to value the annual surface and groundwater use in the watershed. Water use data was compiled from the United States Geological

Survey (USGS) and the SJR Water Management District (SJRWMD) for 2009 and 2010. The valuation data was collected from various literature sources as well as the JEA and the Orlando Utility Commission. Valuation estimates were normalized to the year 2010 using consumer price index data multipliers available from the Bureau of Labor Statistics and other similar entities. The water use data was sub-divided into discrete categories including public supply, commercial and industrial supply, agricultural irrigation supply, recreational water supply, and power generation. Overall the annual value of surface water used in the SJR Basin (in 2010 dollars) was about $70,000,000, while the value of groundwater used was greater than $420,000,000.

The economic value of recreation along the freshwater portion of the St. Johns River, the current level of ecotourism activities, and the potential for future ecotourism activities in St. Johns River Basin (SJRB) area were evaluated through (a) telephone survey of the general public (i.e. a random sample of residents from northeast, north-central, and central Florida), and (b) online survey of potential frequent visitors (i.e., a random sample of Florida freshwater fishing license holders and those belonging to organizations that use the river, e.g., Florida Professional Paddlesports Association). Sixteen percent of the general public surveyed had traveled to the SJRB to participate in inland outdoor recreation activities in the past 12 months, while 44% of the potential frequent users had traveled to the area. For the potential frequent users, the SJRB provided year-round recreation opportunities, while the general public visited the SJRB more often in the summer months. The top four most frequently reported activities for the general public were fishing (23%), swimming (17%), hiking (15%), and motorized boating (13%). Frequent users reported kayaking/canoeing (non-motorized boating, 27%), fishing (23%), motorized boating (12%), and hiking (12%). Most respondents considered the visited site as having “good” or “excellent” water quality.

Forty-one percent of the general public considered their home counties to have “moderate” to “severe” problems with surface water quality, as opposed to 60% of the frequent users. Only 20% of the respondents believed their counties to have “minor” problems with surface water quality. In addition, respondents were less concerned about water shortage problems in their home counties than water quality problems. Of the respondents, 56% of the general public sample believed water shortage was “likely” or “extremely likely” to occur in their home counties in the next 10 years; while only 34% of the frequent recreational user sample believed this to be true. Of the respondents, 69% of the frequent users had made donations for environmental causes in the past five years compared to 43% of the general public.

Survey responses were used to estimate a travel cost model (TCM) to determine the economic value of recreation along the freshwater portion of the St. Johns River. The value of the freshwater portion of the SJR to each household in Florida was calculated to be between $80.56 and $97.67 annually. Based on the United States Census Bureau (2013), the annual recreational benefit provided by the SJRB to Florida residents ranges from $89.8 million to $108.9 million. The estimated value from ecotourism activities could be around half of the recreational benefit provided by the SJRB. Note that the use of TCM provided a conservative estimate as we excluded non-residents of Florida from the analysis. Additionally, most visitors were from north and central Florida and undertook day trips to the SJR, thus their value could be underestimated because of shorter travel distance (i.e., smaller travel cost, which are likely below the total value assigned by the visitors to the recreational experiences).

Ecotourism opportunities in the SJRB were adequate for 50% of respondents that visited the SJR, but 43% indicated that there were not enough opportunities for nature-based recreation. Furthermore, while majority of the online and telephone respondents perceived the freshwater quality of their last visited site to be "good" or "excellent", lack of awareness of the recreational opportunities prevents Florida residents from enjoying the benefits offered by the SJR. Thus, market development strategies should be created to market the SJR with diverse and year-around recreational activities to the general public.

Economic values noted in this report were generated through various approaches, including an Ecosystem Services approach, which examined natural functions of the SJR that benefit people, e.g. flood storage, water supply and nutrient removal. It is important to recognize that these valued services are generated without costs to Society, but they are vulnerable to human disruption and can be lost, requiring replacement at high cost to State and local governments. Current levels of nutrient loading apparently exceed the ability of the SJR wetlands to remove phosphorus and nitrogen resulting in well-publicized algal blooms. The public, through purchase of river-associated properties, places a high value on water quality. Lower water quality leads to a reduced tax base for at least the four counties closest to the coast. The Public clearly values and uses the SJR environs generating significant economic activity.

It is tempting to summarize the economic values estimated in this report, but extreme caution should be used. Some chapters used multipliers that are standard in economic studies, while others reported actual replacement cost estimates if those natural functions had to be replaced, drastically underestimating the total value to the public. Also, note aspects of the SJR that were not included because of the lack of both funding and time required to generate the required analyses. Commercial fish harvest within the river is relatively small and only reflected here in the recreational and ecotourism components. The large commercial and recreational fishery associated with the coast of NE Florida is important to the economy of the region. The SJR clearly serves as a nursery for many coastal fish and shellfish species harvested outside the SJR basin. An accurate estimate of this Ecosystem Service component would be significant from an economic standpoint.

Much of the value that most residents associate with the SJR revolves around the river as a transportation corridor which drives Jacksonville's commercial and military ports, as well as upstream marinas that drive significant economic activity as far upstream as Green Cove Springs. Given the funding being provided by local, state and federal governments, it is clear that this component of the SJR's value to the economy of Florida is recognized, but not included here.

Table of Contents

Topic	Page Number
Executive Summary ……………………………………………………..	ii
Introduction to an Economic Study of the St. Johns River ……………..	1
Chapter 1 - A Conceptual Economic Model of the St. Johns River …..	7
Chapter 2 - Economic Valuation of Wetlands as Related to Flood Abatement and Flood Insurance Rates………………………..	35
Chapter 3 - Removal of Phosphorus and Nitrogen by Wetlands Along the St. Johns River: An Economic Perspective………..	145
Chapter 4 - Economic Impact of the St. Johns Water Quality on Property Values……………………………………………	169
Chapter 5 - Value of St. Johns River Surface Water and Groundwater …………………………………………….	205
Chapter 6 – Economic Value of Recreation along the Freshwater Portion of the St. Johns River…………………………………	225
Chapter 7 - An Estimate of the Current and Potential Value of Ecotourism in the St. Johns River………………….	263
Chapter 8 - What is a River Worth? Report Summary………………	269

Introduction to an Economic Study of the St. Johns River

By
Courtney T. Hackney
Director of Coastal Biology
Department of Biology
University of North Florida
Jacksonville, Florida 32224
c.hackney@unf.edu

Background

The Florida Legislature appropriated $400,000 in 2013 to assess the economic value of the St. Johns River (SJR) to the people of the state. Discussions among individuals and agencies interested in the St. Johns River led to the use of an "Ecological Services" approach, which bases economic value on the ecological function of the natural system itself. Not all functions of a natural system have direct value to people, but many do. Critical references to this approach of assigning economic values to the natural world are contained in Chapter 1 of this report. The use of an Ecological Services approach to economic valuation has several advantages. Chief among them is the direct relationship of natural function to a measure of human value. For example, if a river system removes a certain tonnage of nitrogen from the river, the cost of removing the same quantity via traditional water treatment facilities can be determined. Thus, the river saves tax payers and industry a quantity of capital that can be determined in dollars. Loss of that service, i.e. removing nitrogen, would require people to build and maintain a water treatment plant sufficient to remove the nitrogen removal capacity previously done for free by the river system if the river was to maintain the same level of nitrogen in its waters.

This valuation system assumes that society wants to maintain a healthy natural river. Not every potential economic value associated with the SJR can be directly assessed through an Ecological Services approach. Homes along the river are considered more desirable and thus generate higher prices and more tax base. No function of the river itself creates the value, but there is economic value generated by proximity to the river based on human perception of aesthetics and value that people associate with a view. That does not mean that the function of the river does not influence the human perception of value associated with living along the river. A degraded river caused by toxic algal blooms or fish kills caused by loss of function due to excess nutrient input into the river clearly alters the perception of value associated with living along the river, and hence tax revenues.

The question of how to proceed in determining the economic value of the SJR and which aspects to prioritize was determined at a Workshop, held April 8, 2014 at the University of North Florida. Five experts from outside Florida with expertise on valuing natural systems using the Ecological Services approach or with expertise in related disciplines were invited and attended to provide unbiased insight and advice on the process. The workshop was also attended by individuals from consulting companies, universities, agencies and NGOs with interest in the river or in developing economic assessments.

The Workshop began with morning presentations intended to engage participants on the concepts inherent in various ways humans can attach monetary values to the natural world, with the aim of extending these approaches to the environs of the SJR when possible. Human values and natural functions are not always in sync, which was also a presentation topic. The mixed audience was also introduced to the large data base for the St. Johns River that already resides with the St. Johns River Water Management District (SJRWMD) by their staff and how to access that data base. Understanding what data are available and how those data could be used in any Ecosystem Services economic study was essential for the afternoon discussion.

The afternoon discussion was led by a professional facilitator and oriented around three simplistic questions, each designed to challenge participants and elicit an exchange of information among attendees. Participants were put into small groups, which included a mix of disciplines, e.g. ecologist, economist and agency staffer, and asked to provide a collective answer to each question. Answers from each group were presented to the entire audience and discussed.

The first question was if there were important economic values of the SJR that could not be determined through an Ecosystem Services approach. Pre-workshop interviews with environmentalists and others suggested that important and significant value might exist that were not related to the natural function of the river that should be considered for funding. This question elicited significant input across subjects as varied as "aesthetic values" of the river to valuing the attractiveness of a river to a potential industry. This discussion provided some excellent thoughts that were useful concepts that appeared again later in the Workshop. One noteworthy idea was the concept that direct values had greater certainty than values linked to a service or use through several intermediate steps. Such a concept applies to both Ecosystem based services or more traditional economic connections. Direct connections are inherently more accepted by the public than those with less than clear connections.

Another concept that permeated the discussion was the variability of value placed on the river by people with different connections to the river. People living along different parts of the river, e.g. upstream versus downstream, or those who value the river because of some long, historic connection to the river might attach very different values to the same function or aspect of the river. Those with a long connection to the river who have always had use of the various river environs often do not value it as highly as a newcomer to the river basin or vice versa. Traditional use of the river might not produce the same economic output in dollars, but still be extremely valuable to those citizens using it in that historic manner. The GDP of the region may not be a measure of the value of the river to those with an intimate and long history with the river. In fact, it may be the exact opposite for this segment of the population. While economists may view the river in purely monetary terms, that may not be how the local population views the same resource.

A concept that emerged from this segment of the Workshop was the idea that the St. Johns River does not have a "Brand" associated with it that would raise its value in the public mind. The public values a product with a brand more than the same product without one. In the past, the SJR was viewed primarily as a part of the landscape that was used by industries, governments and individuals to generate economic value, but the river itself not valued. For the first two thirds of the 20th Century, the Everglades were viewed in the same way, but now the Everglades has a "Brand" and is valued in a far different way. This allows additional funds to be allocated for restoration of the Everglades than any systematic economic study would suggest. Is there a way to accomplish the same for the St. Johns River?

The second question asked of the Workshop participants was if there were significant data gaps that would prohibit a realistic evaluation of any Ecosystem Services valuation for different questions or segments of the river? The purpose of this question was to determine if data available at the SJRWMD was inadequate for answering specific questions. Discussions suggested that there was a lack of socio-economic data for people and communities living along the river in some cases. Subsequent to the meeting, several participants forwarded locations of these types of data that would provide information required for some of these important socio-economic questions. The SJRWMD is focused on environmental issues and does not routinely collect or maintain much of the social data that would be required to answer many of these socially-oriented questions, although they are related to the environment of the river. In general, there seems to be enough scientific data to answer most questions related to environmental issues that could lead to valid Ecosystem Services analyses, although they may not all reside with the SJRWMD.

Some serious concerns were raised that related to how any economic analysis would be bounded: Should the entire watershed be evaluated or just the river itself? The productivity of the near shore ocean is intimately connected with the river, which delivers nutrients and provides nursery habitat for many commercial and non-commercial species of fish, shrimp and crabs. The SJRWMD is focused on the river, but data on near shore and river fisheries might be available from the Florida Fish and Game Commission or the Department of Environmental Protection. The value of fisheries associated with the St. Johns River is not just how many pounds of these stocks are landed, but magnified by the importance of recreational fishing by both Florida residents and those from out-of state.

The St. Johns River has a much greater connectivity to aquifers that discharge into the river along its 310 mile length than many rivers. It was not clear if there was enough information to understand the importance of these riparian springs to the river to allow certain economic valuation to be made. How important are these springs to river flow and subsequent water quality issues during droughts? Is there a point in the removal of groundwater where the river provides aquifer recharge instead of discharge? Groundwater is the source of drinking water for most communities in the St. Johns Watershed making the question of linkage of subsurface waters to the river very important. Currently, the cost of water to industry and the public in general is relatively inexpensive. That could change in the near future as demand for withdrawals directly from the river increases. Any decrease in downstream flow has the potential to increase nutrient loading from both point and non-point sources, since the residence time increases decreasing the dilution factor. This could lead to increased algal blooms and the need for additional regulations and/or projects to retrofit septic tanks, tertiary sewage treatment, etc. Any decrease in downstream flow could also lead to an upstream movement of the freshwater/saltwater interface with associated economic and ecological impacts. While there is concern that upstream removal was an issue, a rising ocean level would also be an issue in the future. Can costs and benefits be determined? Are there thresholds for water removal that are based on economic as well as ecological metrics? Are there tradeoffs that the public is willing to accept?

Many of the questions raised by workshop participants related to "policy objectives". What does the public want from the river and what are they willing to give up or pay for? Does the public understand the tradeoffs involved with different policies? The way the public views the value of the river is likely to change with time and along the length of the river as different communities value the river differently. To answer many economic questions will require the integration of scientific data with both public policy and population perception of the value of the river.

The third question of the afternoon was designed to force attendees to focus on the "most important" economic question based on the perspectives of the group. Some of the suggested priorities ranged outside the primary goal of the question, but are included here because they reflect a valued view of the river by individual participants. These ideas will constitute the prime areas of focus for funding, once integrated with earlier discussions and any post-workshop information provided by participants. The following is a summary, in no particular order, of potential funding priorities; assess

1) increased property values and tax assessments associates with the river (direct and indirect river contact) including how a change in water quality impacts property values,
2) flood protection (including insurance costs),
3) water supply (both directly from the river and related to aquifer/river interaction),
4) recreational benefits (fishing, boating, swimming, etc.),
5) ecotourism,
6) water-dependent industries (marinas, shipping seafood,
7) human welfare related to the condition of the river (e.g. impact of toxic algal blooms,
8) importance of public lands purchased by agencies and others to protect river function or health,
9) develop internet and/or direct survey using fishing licensees as the data source to develop an understanding of how the public values the river along its length,
10) what are the Ecosystem Services associated with specific habitats and hydrological state of the river,
11) how is the water supply related to the Ecosystem Services of the river, especially in light of proposal to remove surface water for human consumption,
12) what is the aesthetic value of the river to citizens (related to property values), develop a team to write a proposal for an NSF program that incorporates the measured environmental components of the SJR with the economic needs of the region and finally,
13) how will the decision be made to decide who gets what from the SJR ecosystem; will it be based on traditional uses, maximizing economic values or on preserving natural attributes of the river ecosystem.

From these questions the following priorities were developed.

1) Using models of river flows and natural processes, develop a simple conceptual model that can be used to show where value is generated within the river and its connected environs. This is intentionally being poorly defined to allow generation of different approaches by those interested in developing what will likely be the opening chapter in

the final report. The SJRWMD does have complex models available, but there is no requirement to use any specific model as a starting point.

2) What is the value of riparian wetlands, upstream and downstream, in terms of flood abatement? Does their presence impact flood insurance rates and if so, what are the values of these wetlands based on insurance relief? What would flood zones look like without riparian wetlands? How would this alter flood insurance rates?

3) What is the economic value of riparian wetlands in reducing nutrient loading (primarily nitrogen and phosphorus) along the entire river? Note that a portion of these wetlands are tidal and others non-tidal.

4) Property values (and the tax revenues produced) along the river are higher than those for property not associated with the river. What is the increase in tax revenues associated with proximity to the St. Johns River to counties and municipalities? Include values associated with development that provides access to the river via docks, boat ramps, parks, etc. Include any aesthetic component of property along or connected to the river that enhances property values. Remember that industries may also pay high tax premiums for their access to the river. Does lower water quality, e.g. toxic algal blooms, impact property (and tax) values?

5) The St. Johns River is a source of water for industry and increasingly, for domestic use as well. How much economic value does that bring to the region and state? Does reduced water quality increase costs to those using water from the river? Is there a cost-benefit from upstream efforts to reduce nutrient inputs to the river? Does upstream use of water and discharge have downstream cost-associated impacts? Can these be determined for the entire basin?

6) What is the economic value of recreation along the freshwater portions of the St. Johns River, river and lakes? Boating, fishing, skiing and sightseeing are all obvious uses by the public.

7) Ecotourism is a growing industry in Florida, but relatively limited in the SJR. There is great potential given the manatee, dolphin and other wildlife in and on the river. What is the current value of ecotourism and what is the potential economic value to the region if ecotourism is fully developed for the SJR? Are there potential limits to development of this industry because of water quality issues?

8) There are already estimates for the value of JaxPort to the region with and without deepening the river. What is the economic impact of other water dependent industries along the river? Besides marinas, ship repair, and other vessel related activities, is there increased economic activity from river-associated restaurants, festivals or other non-traditional water associated uses?

9) Is there an economic cost from direct impacts to human health from decreased water quality? Toxic algal blooms, contaminated seafood or contact with water-borne diseases all have potential economic costs associated with them. Is there a way to calculate the current economic cost as well as future costs given a variety of scenarios? Will demographic changes along the river increase demand and increase costs to maintain the status quo with respect to major environmental events?

10) The lower SJR is nursery habitat for a large number of marine fish, shrimp and crabs. To a small degree, these species are harvested commercially within the river (primarily blue crabs), but the vast majority of these species are either caught in the nearby coastal waters or form the base of coastal food chains that fuel a large commercial and recreational

fishery. Can these values be calculated based on primary productivity within the river, assuming associated multipliers for recreational and commercial fishing? Much of this occurs outside of the river itself, but would not exist without the river.

11) Generate an overall conceptual model of economic output from the SJR. How do different components of the river ecosystems generate economic values to local, regional and state economies? Using estimates from other rivers and regions, can an economic skeleton of the river be developed that can provide some scale of potential value to the economy for the SJR?

Unfortunately, funds appropriated and time required to develop answers to these did not allow all of these priorities to be funded. The final chapter in this document shows the potential values associated with the SJR and actual values assessed by the chapters within this report. It also indicated economic values of the river that could not be funded.

All or portions of priorities 1-7 above were funded. Results can be found in the following chapters.

Chapter 1

A Conceptual Economic Model of the St. Johns River

By

Robert W. Virnstein[1] and Clay L. Montague[2]

[1]Seagrass Ecosystems Analysts *and*
St. Johns River Institute, Inc
142 Elgin Road
East Palatka, FL 32131
seagrass3@gmail.com

[2]Associate Professor Emeritus, UF
245 Deerwood Creek Estates Road
Waverly, GA 31565
montague@ufl.edu

Abstract

All models represent some aspects of reality and ignore others in order to accomplish a given purpose. The intention of this document is to show linkages between ecosystem services and monetary value. "Ecosystem services" are those that are already provided "free" by natural ecosystems. Examples of ecosystem services are provided, with linkages to the local economy. A conceptual model of a natural or economic system is one in which primary linkages between key components are proposed in concept without dollar values ascribed to them. It is an envisioning and decision tool. Complex systems experience change through time. A conceptual model can also reveal critical feedback loops, which can automatically amplify or moderate expected responses to change. Economic analyses must be especially aware of feedback loops. We provide background about the enormously diverse St. Johns River and its basin and divide it into nine segments. We provide examples of conceptual economic models using various components of, and feedback between, the natural ecosystem and social system. We suggest various methods for assigning economic value. Subsequent chapters provide specific details of valuation.

Purpose of this document

This document shows linkages between ecosystem services and monetary value. These concepts are very closely related. The term "ecosystem services" arises from a rational theory of value, namely that people do not have to pay for services that are being done for them already by the natural world. Humans enjoy those services for free until humans alter the natural world such that those services are no longer generated. At such a point, society can choose to pay to protect or restore those services by protecting or restoring the ecosystems that produce them. People could rationally be willing to pay to protect these naturally-provided services, but often do not appreciate the economic value they have received for "free".

A major purpose of an economic valuation of ecosystem services is to provide a rational understanding of the connection between ecosystem services and economic values. First, however, people need to recognize those services. We will provide some examples of ecosystem services that are apparent for the St. Johns River. We hope these examples will stimulate additional economic valuation of the St. Johns River or in similar rivers. Through this method a more exhaustive list of ecosystem services can be developed.

Several types of economic valuation methods have been applied to ecosystem services. We will provide a brief overview of some of these. Subsequent chapters provide detailed analyses and valuation based on more complex models generated through these simplistic approaches. The list of methods provided is introductory.

One important feature of ecosystem services is that they depend on the perpetuation of a complex system of living organisms. The service can disappear if the appropriate environmental conditions change enough to alter the balance between organisms and their environment. This is sometimes called the tipping point. Even before the tipping point, the level of service fluctuates, as the various species respond in their own way to each dynamic condition. Major physical influences include light, temperature, salinity, water level, water movement, nutrients, and toxins.

One ecosystem can perform several functions simultaneously: habitat for wildlife, soil stabilization, nutrient conversion, water aeration, food production, pollutant sequestration, etc. A suitable environment is needed for these functions to persist. Any given environmental factor can be overwhelmed by human or natural change. Natural systems have evolved within natural variations of the physical environment, but humans often introduce changes that exceed these natural changes.

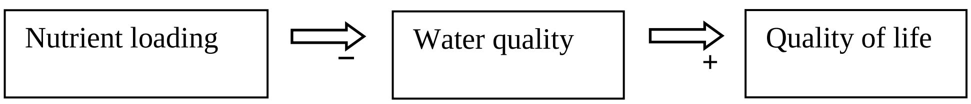
SAV (submersed aquatic vegetation) beds offer a robust example easily illustrated by a conceptual model. A steady, but low supply of nutrients is necessary for the SAV to provide their maximum services, which include fish production, pollutant sequestration, erosion protection, and sediment stabilization (protection from channel infill). Too much nutrient input means that phytoplankton in the water column multiplies, light is absorbed, and SAV reduce growth or die. Death of SAV releases nutrients and sediments that increase turbidity and decrease light further – a positive (amplification) feedback loop that drives SAV density down, isolating them to shallower and shallower waters until they disappear.

Why a Conceptual Economic Model?

Models are representations of real systems. They simplify reality for a given purpose. A model ship may show visual details in exquisite detail that can be examined at arm's length, but it cannot navigate the ocean. Its purpose is to stimulate understanding. A fashion model shows how clothes can look, but only on one size and shape of person. The purpose is to sell clothes. All models represent some aspects of reality and ignore others in order to accomplish a given purpose. To fairly evaluate a model, that purpose must be recognized. Although few people look like a fashion model, we can quantify the success of the model in the sales of clothing. In our conceptual economic model we highlight some of the ecosystem processes and products that have economic value within and along the St. Johns River. We can quantify the success of such a model through funds saved by recognizing and protecting valuable ecosystem services performed by nature for free.

Use of a Conceptual Model:

A highly simplistic model, with only three components and two linkages could be as simple as:



This simplistic model says that nutrient loading affects water quality, which subsequently affects quality of life. In addition, the negative sign on the first arrow indicates that increased nutrient loading reduces water quality. As water quality declines, so does quality of life (a positive influence, i.e., in the same direction, regardless of perceived value). Individual influences may be positive or negative, and effects of a string of influences on the economy may similarly be positive or negative, and economic loss or gain assigned. The relevance of a model is how accurately the components and links capture reality and stimulate further investigation.

A conceptual model can also reveal critical feedback loops. Examples below expand the simplistic model above to illustrate general feedbacks between ecosystems and society. Some loops are negative, which means that in whichever direction a change occurs, that change is eventually opposed. For example, when quality of life *declines* because of deteriorating ecosystem services, people *increase* their efforts in environmental protection, which *restores* those services and the quality of life they provide. To maintain quality of life, while increasing the output of dangerous byproducts, people must be willing to continuously pay increasing costs.

In a positive loop, a change anywhere in the loop is reinforced or amplified. Quality of life in Jacksonville, for example, attracts more people and industry, which increases the costs to manage the pollution load on the environment necessary to maintain an attractive quality of life, possible as long as people are willing to pay the cost of environmental protection. In this manner, pollution control creates the conditions that increase and continue the need for pollution control. A local community can decide to create a positive feedback loop. For example, improved environmental quality may increase property values and industry, which stimulates a local tax base. Local decisions can be made to use taxes in a campaign to protect and promote the quality of the environment in an effort to maintain the quality of life and further stimulate population and industrial growth.

Feedback can automatically amplify or moderate expected responses to change, although not all significant economic connections will involve feedbacks. When such feedback loops are involved, the consequences of lost ecosystem services may be much greater and generate unexpected outcomes. Feedback loops account for amplification of influence, vicious and virtuous cycles, stabilization, oscillation, instability, and other characteristics that an ecological-economic system may exhibit through time. Economic analyses must be especially aware of feedback effects and how to incorporate them into economic models.

For many purposes, it would be easy to use snippets of conceptual models, such as the examples above, to show the relationship of just a few important components. Subsequent researchers, such as those involved in the following chapters, will focus on particular components and ecosystem linkages that impact an economic system.

A conceptual model of a natural or economic system may also experience change through time. Such a model is one in which primary linkages between key components are proposed in concept without quantities ascribed to them. It is an envisioning and decision tool. The linkages themselves can help explain responses to previous actions, or can suggest reasons for expecting a certain pattern of change in the future. Conceptual models are useful for education and public outreach, to guide further research and economic analysis, and to frame ways to address environmental or economic problems.

The focus of this introductory chapter is twofold: first, to suggest some major economic connections to ecosystems that planners and the public may wish to recognize enough to seek funding for professional economic valuations; and second, to stimulate imagination and discussion, so that a more complete list of worthwhile economic connections can be developed and evaluated.

Examples of Conceptual Models

Figures 1-1 through 1-4 are *examples* of conceptual models that illustrate feedback processes involved in the free services provided by ecosystems to an economy. Each arrow represents an influence that takes some time to occur. The arrow is numbered for reference and contains a plus (+) or minus (-) sign at its head. The direction of influence is from cause to effect, or stimulus to response.

For example, Figure 1-1 is the simplest. It looks at a bigger picture in less detail, but illustrates an important single feedback that permeates all environmental protection issues. Key among these is the initial condition for society, which is a high quality of life, allowed by favorable environments for free ecosystem services (Influence 1 of Figure 1-1).

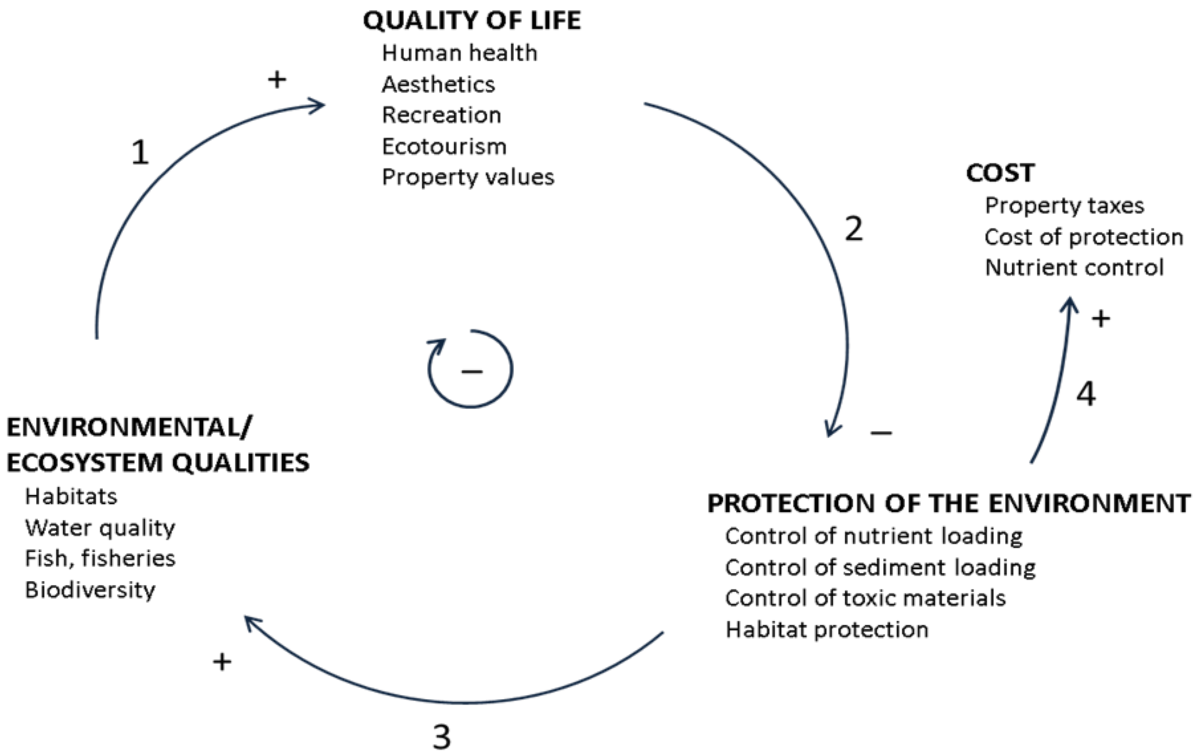


Figure 1-1. Influence diagram of feedback between ecosystem services, quality of life, and cost of environmental protection that enhances environmental quality and quality of life. The negative feedback creates a tradeoff between quality of life and the cost of environmental protection.

Other influences on quality of life, such as job opportunities are not illustrated. The model focuses on one feedback loop to illustrate a point. Although many conceptual models are vastly complex, none consider all possible influences. Influences are selected to make certain points, or to account for specific observed patterns. In this case, the pattern to point out is the increase in environmental protection that occurs when the quality of life declines (Influence 2). Quality of life declines when the environment fails to support certain ecosystem services, but increases again with sufficient environmental protection (Influence 3), as long as the cost of environmental protection is tolerated (Influence 4).

The feedback loop of Figure 1-1 is negative. It has one negative influence (an odd number). Any change started in this loop results in the opposite effect on that same variable, a stabilizing governor. When quality of life declines, demand for environmental protection increases and lost ecosystem services return, restoring quality of life to a higher level. On the other hand, when quality of life is high, environmental protection relaxes, and the system becomes vulnerable to losing some of its environmental qualities and quality of life. A balance may occur among tradeoffs of ecosystem services, quality of life, environmental protection, and cost.

Figure 1-2 illustrates a concomitant feedback that is positive. Starting with Influence 1 of Figure 1-2, pollution control enhances quality of life, which enhances the attractiveness of the region. This stimulates population and industrial growth, which creates a need for greater pollution control if quality of life is to be maintained. Costs of pollution control continue to rise in order to maintain an attractive quality of life. In reverse, this feedback loop would drive down industrial growth like the loops that drive down SAV.

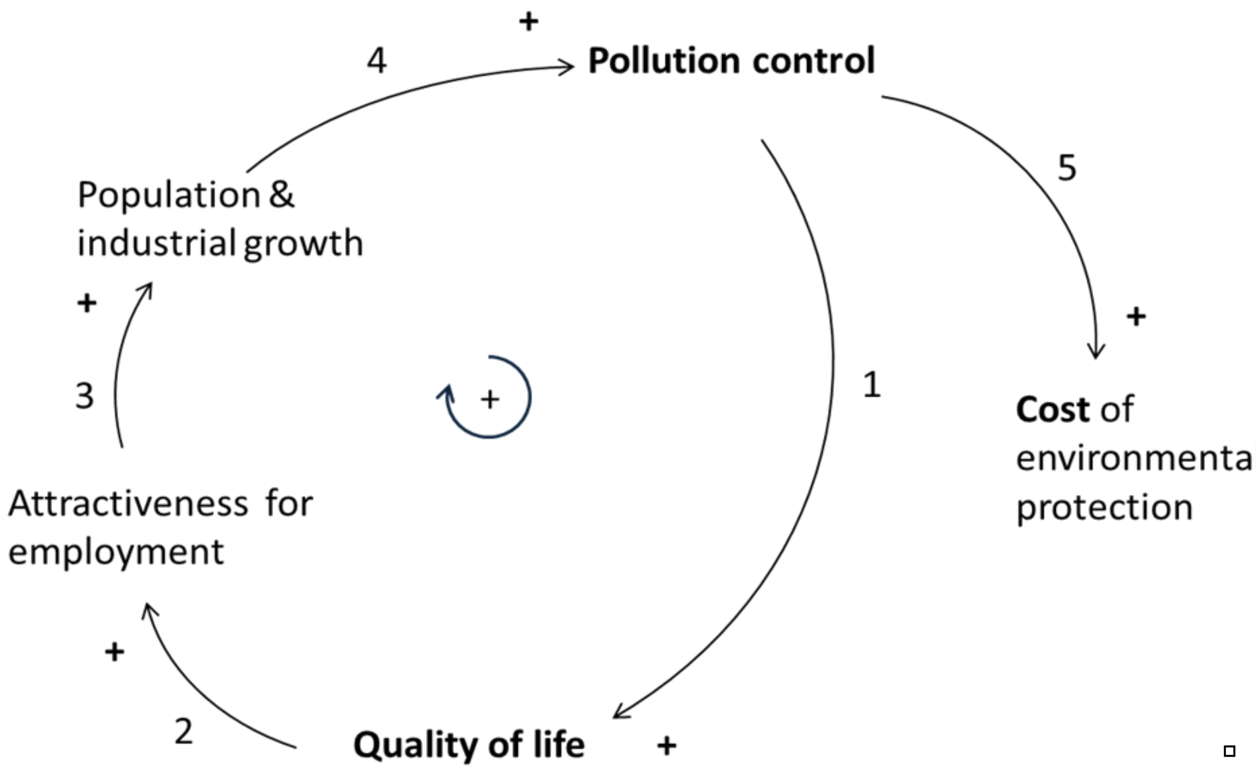


Figure 1-2. Influence diagram of feedback between pollution control, quality of life, and attractiveness that causes population and industrial growth in the St. Johns River watershed. The positive feedback creates a perpetual and growing cost of pollution control as growth continues.

Figure 1-3 illustrates the interconnection of three positive feedback loops. For example, in Influence 1 of Figure 1-3, sewage discharge positively influences nutrient loading into the water of the St. Johns River. The positive arrow sign indicates that more sewage discharge means more nutrient loading, and that less discharge means less loading. A positive influence occurs when the affected variable changes in the same direction as the causal variable. Influence 2 likewise shows the stimulating influence of nutrient loading on phytoplankton growth, and Influence 3 describes the increase of turbidity (cloudiness of the water, or decrease of visibility) that follows.

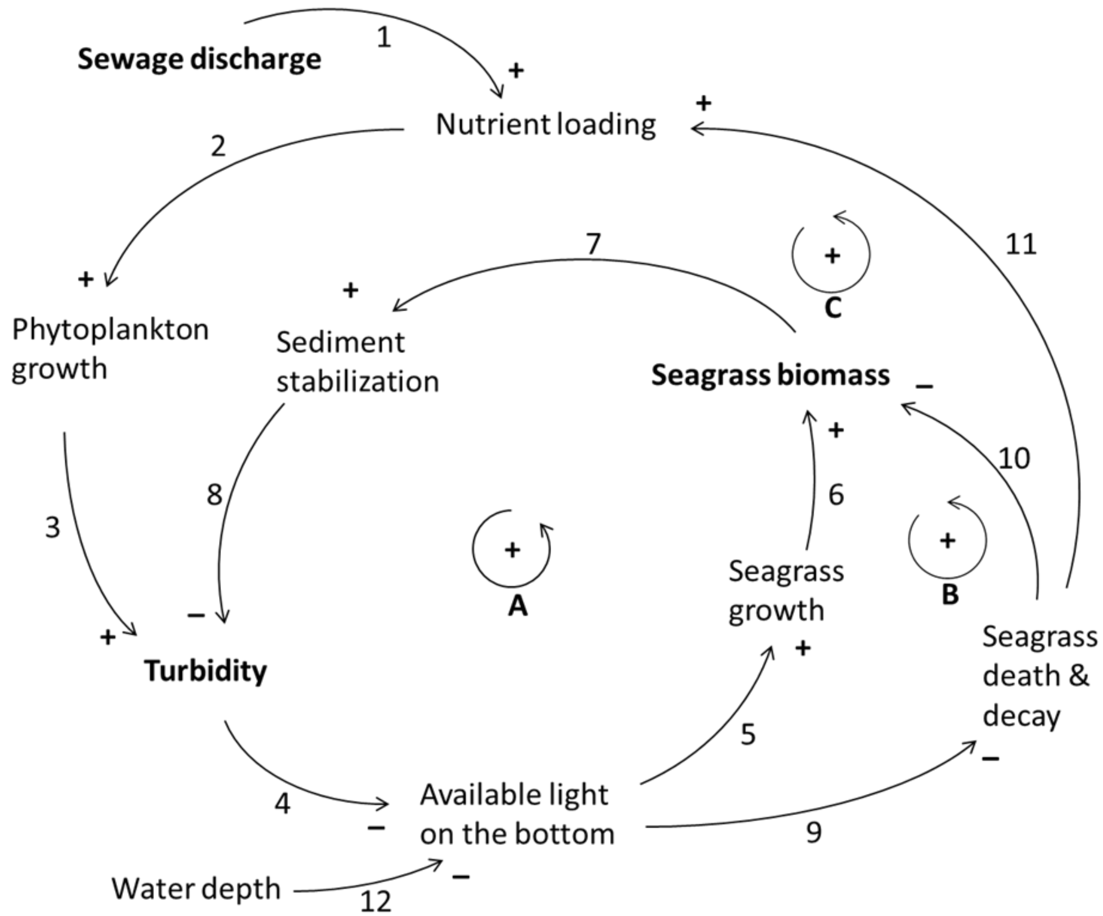


Figure 1-3. Influence diagram illustrating the effect of sewage discharge on the feedback between seagrasses, nutrients, light, and sediments in waters of the St. Johns River. The positive loops can rapidly cause disappearance of seagrasses and the ecological services they provide. Influences and loops are labeled for reference in accompanying text.

Influence 4, however, is negative. An increase of turbidity means a decrease in light penetrating to the bottom where the SAV is. Conversely if turbidity were to somehow decline, light on the bottom would increase. When the effect of one variable causes an opposite effect on another, the influence is negative.

When light on the bottom decreases, SAV growth also declines, as illustrated in the positive Influence 5. SAV growth positively influences SAV biomass, so when growth declines, eventually so does biomass, as normal decay processes continue with the decreased growth. But SAV have roots that stabilize the sediment on the bottom, the positive Influence 7. When sediment becomes destabilized, sediments are re-suspended from the bottom into the water, causing an increase in turbidity. The negative Influence 8 illustrates the phenomenon that sediment stabilization decreases turbidity, and likewise when sediment destabilization occurs, turbidity increases.

A feedback loop has now been described that involves light, SAV, and sediment via Influences 4, 5, 6, 7, 8, and back to 4, indicated as Loop A in Figure 1-3. The feedback is positive, because a change in any one of those variables will result in a reinforcement or amplification of that change when the loop of influences closes back on that same variable. For example, if light on the bottom increases, SAV growth will increase, followed by biomass, which will enhance sediment stability. That would then decrease turbidity, which in turn would increase light on the bottom. Thus, the initial increase in light resulted in even more light, a characteristic of a positive feedback loop. On the other hand, had light initially decreased, the same loop would have driven SAV biomass down, destabilized sediment and reduced light even more. Hence, positive loops can create either virtuous or vicious cycles, and can thus destabilize a system.

A rapid way to identify the sign of a loop is to note the number of negative influences within it. The loop is negative when an odd number of negative influences occur, but positive otherwise (zero or an even number of negative influences). Loop A in Figure 1-3 has two negative influences, and was already shown to have the required characteristic of change reinforcement by a positive loop.

Two additional feedback loops are illustrated in Figure 1-3. Both are also positive. Loop B involves two negative influences: one in which more light decreases the rate of death and decay of SAV biomass (Influence 9), and the second thereby allowing greater biomass (Influence 10). In other words, with less light, not only does growth decrease (Influence 5), but the rate of SAV death and decay increases (Influence 9). The rest of Loop B is also part of Loop A.

The positive feedback Loop C of Figure 1-3 illustrates yet another driver of SAV demise as SAV death and decay increase. Decaying SAV releases otherwise sequestered nutrients to the water, enhancing nutrient loading (Influence 11). That then closes yet another positive loop that results in decreased light on the bottom, and more death and decay of SAV, and yet additional nutrient loading. It is now evident how positive feedback unwittingly started by sewage discharge can lead to the disappearance of SAV. Feedback identification is a significant value of this conceptual model. Because SAV have many habitat and water quality improvement values, it pays to keep such loops from reaching a tipping point, illustrated by the feedback loops in Figure 1-3.

Finally, Figure 1-4 illustrates, in some detail, two negative feedback loops that account for a series of costs that are controlled by a particular ecosystem service. In this conceptual model, wetlands and SAV are shown to enhance the safety of St. Johns River waters for fish and people by controlling waterborne disease created by harmful algal blooms and septic conditions in the water. Loop A in Figure 1-4 is started by the increase in nutrient loading caused by greater population in the St. Johns River watershed (Influence 1). Greater nutrient loading increases nutrients such as nitrogen, phosphorus, and organic matter, which creates a suitable environment for harmful algal blooms and survival of human pathogens (Influences 2, 3, and 4). The treatment of waterborne diseases and fielding complaints about them are costs to society (Influence 5). The presence of disease then creates incentives for policies to control nutrient loading (Influence 6), policies that cost time and money to create (Influence 7). These policies result in the engineering of nutrient control measures and monitoring that adds more costs (Influences 8 and 9). However, these measures decrease the nutrient loading, and if they are effective enough and the costs are paid, they allow the coexistence of greater population in the watershed.

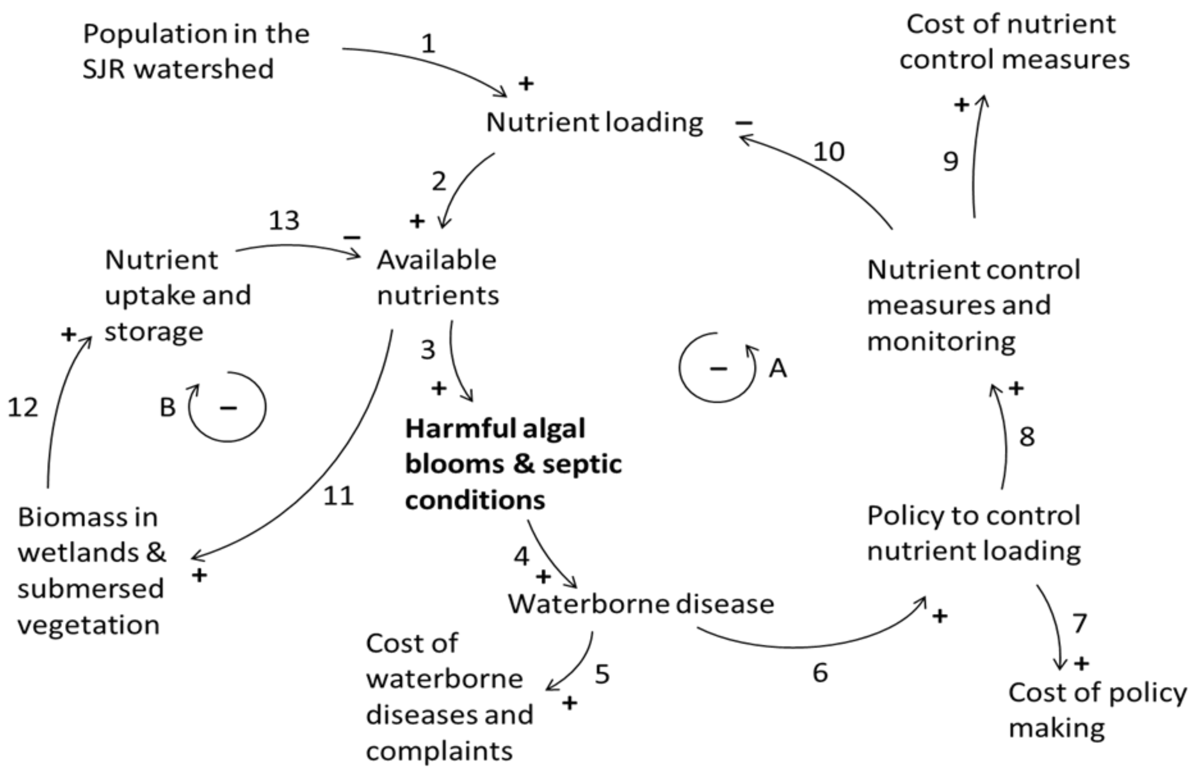


Figure 1-4. Influence diagram of feedback involved between waterborne diseases, their costs and the costs of managing them, and the role of natural ecosystems in disease control. Loops A and B illustrate a way of valuing ecosystem services in the economy of population and industrial development in the St. Johns River watershed. Loop A has multiple costs. Loop B is free.

Loop B of Figure 1-4 shows the free process that does the same thing without cost. In this loop, available nutrients are taken up and stored by wetlands and submersed vegetation (Influences 11, 12, and 13), which reduces the nutrients available to stimulate harmful algae blooms and septic conditions. Loop B illustrates a free service of nature. The value of this service to society is in the cost savings from a reduction in waterborne disease. It can be quantified by evaluating each relationship and then comparing the costs of the control effect of Loop A with the control effect of Loop B given different test amounts of wetlands and submersed vegetation in the watershed.

Cautions about Use of Models

It is oft-stated that a model is only as good as the data and assumptions put in it. In fact, by forcing the modeler to consider and describe connections, a model can actually be better than just data-in, data-out when it reveals a solution to a problem unforeseen before the data and assumptions are put together. A model can also mislead. Proper use of a model is a huge responsibility for both modelers and users.

Model validation is an essential process to help distinguish among the range of possibilities. Those who contract for modeling work should be aware of model validation and sensitivity testing.

Models designed to reveal the economic values of ecosystem services involve two phases, each with its own need for evaluation. One phase is more familiar. It involves the careful inventory of the ecosystems present in a landscape, often using techniques of remote sensing and GIS tools. The less familiar phase is the method by which a given type of ecosystem is evaluated for its services. The "Economic Valuation of Ecosystem Services" section of this chapter (below) lists different general approaches to this evaluation.

The simplest evaluation tools apply a constant coefficient of value to each type of service attributed to each kind of ecosystem present in a landscape. Such constants have been determined through one or more of the general approaches used. At the other extreme, tools may involve complex dynamic models of each coefficient, treating each as a variable in which the values change according to the environment, the health of an ecosystem, and relationships among adjacent ecosystems and land uses.

For both phases of an ecosystem services evaluation, and with any type of coefficient determination, model validation is important. Models with a track record of providing helpful results can be taken as valid for similar applications. Proven utility is itself a type of validation. The best validation involves testing to be certain that a model successfully predicts something that is already known to be true (as long as the model was not previously fed that truth). This would be strong validation evidence that the model is highly capable. The more such tests the model passes, the better the confidence will be in the model. However, such validation is often impractical to perform, causing the risk of being misled to increase when applying model results.

Regardless of the status of validation, any model can undergo simple sensitivity testing and uncertainty evaluation that can eliminate an obviously incorrect model, and can pinpoint those aspects that need first attention for making improvements. Over time and through continued work, models will converge on a useful result, thereby moving a model from being obviously incorrect to being useful, independently tested, and highly reliable.

A simple sensitivity test produces a ranking of model constants by the model's sensitivity to a standardized alteration. Regardless of complexity, all numerical models have some constant coefficients. Sensitivity testing involves altering these coefficients and watching the effect on the conclusions one would draw from the model. A common method is to halve and double each constant, one at a time (note: to produce a fair ranking of impact, a consistent change such as halving and doubling is more important than whether a halved or doubled value is reasonable). A model with 10 coefficients, for example, would require 20 reruns to accomplish this sensitivity evaluation. The set of reruns is then examined to rank the impact of each coefficient on conclusions.

The ranking of constants by relative sensitivity can then be compared to a ranking by relative uncertainty in the original values assigned to the constants. For a given constant, the multiple of rank times uncertainty and rank times sensitivity produces a priority ranking for the necessary work to improve the model. A constant of high sensitivity and high uncertainty needs more attention than one of lower rank.

Because models can only represent a few chosen aspects of reality, readers are advised to be cautious in their acceptance of interpretations and conclusions drawn from models, and to ask questions about model validation and sensitivity. One need not be overly convinced or overly suspicious of transparently-presented and well-tested models. We next look at various ecosystem services and how they might be evaluated.

A Partial List of Ecosystem Services

Most primary services of the St. Johns River are based on the key ecosystem service of primary production, mainly photosynthesis. Services of photosynthesis range from producing food, clothing, and shelter, to carbon sequestration and pleasing scenery production. Lumber, food, and fiber production rely on photosynthesis as a free service of nature. Such services may be disrupted by pollution, sea level rise, and climate change.

Some of the ecosystem services that currently support the economy of the people and communities along the St. Johns River include:

1) **Storm protection:** Expanses of submersed aquatic vegetation (SAV) and emergent marsh plants significantly reduce wave energy and current velocity, and dissipate storm tidal energy and wave and wind energy, thereby reducing flood and wind damage to structures and roadways from hurricanes and nor'easters.
2) **Buffer of the flow and supply of water:** Wetlands provide stormwater flood protection, drought protection, and water recharge. Perched wetlands and river swamps store water during rain and floods, and subsequently add water to the River and watershed during drought. The amplitude of River fluctuations is thereby reduced, which limits both flood damage and the effects of drought.
3) **Water purification:** Healthy aquatic ecosystems are self-protecting, and self-cleansing. We benefit because these cleansing processes also keep our environment clean. They protect the health of swimmers, the quality of agricultural irrigation water, and lower the costs of drinking water purification. They convert active chemicals to more benign forms through processes such as plant uptake and microbial metabolism. Such processes can decompose organic toxins, weakening their effects as mutagens, carcinogens, and agents affecting larval or fetal development. They sequester pollutants in biomass. Long term sequestering can occur through peat formation and biologically-mediated sediment-forming processes.
4) **Fishery and wildlife production:** A variety of ecosystems at various scales and locations work together to produce the necessary range of foods and cover for the various life stages of juvenile and adult wildlife, including most of the important fishery species, several species of special management concern, and various forage organisms. The key is variety. No single ecosystem provides all of the required habitats for even one commercially important species or for any other widely ranging species. Even sedentary oysters have a mobile planktonic stage, as do blue crabs, shrimp, and all the commercially important finfish! A mixture of ecosystems is needed to maintain most individual species as well as the overall diversity of fish and wildlife.

5) **Education and research:** A variety of ecosystems creates an outdoor learning laboratory for students at all levels, and a wealth of natural processes and products with undiscovered benefits.

6) **Arts, scenery, and recreation:** Healthy ecosystems have long been an upbeat inspiration of poetry, paintings, photography, music, and dance. In addition, healthy aquatic ecosystems create the value and safety of the River for recreational activities that involve swimming, nature watching, and fishing.

7) **Job creation:** Protecting the health of ecosystems is itself an industry that involves many technical and professional jobs in the environmental realm. The ratio of human work to natural work is a key variable. Greater development per acre of natural ecosystems, for example, means that greater protection and remediation measures are needed per remaining acre. Greater development per acre also means greater expense in managing the health and safety problems that require adequate water supply and treatment.

Economic Valuation of Ecosystem Services

Although we do not provide economic valuations in this introductory chapter, we describe some general approaches. Some of the various economic methods that have been used to value natural resources include:

1) Mass communication surveys of willingness to pay to use, protect, or restore the ecosystem services provided by a river. These are usually performed by questionnaire and interview methods. In addition, willingness to pay has been evaluated from the voluntary contributions to wildlife protection associated with tax payments and license plates, and contributions to nonprofit organizations with protection and restoration missions for ecosystems, fish, wildlife, and rivers. Voting to spend tax money can also be used to evaluate willingness to pay. Results are highly dependent on public perception. They may over- or under-estimate value depending on local attitudes and beliefs, which can be influenced by educational and promotional efforts to change public perceptions. However, when methods used to calculate willingness to pay are timely, they can be defensible as a basis for political decisions.

2) Assessments of the amounts provided in legal settlements of environmental lawsuits when ecosystems and natural resources are damaged or destroyed. These methods research case studies of court decisions and public settlements, and are based on the assumption that the courts are well-informed and fair. They may underestimate to the degree that some values may not have been known or suspected at the time the case was resolved.

3) Costs to replace or restore destroyed or damaged ecosystems. Those more inclusive evaluations will consider the lost opportunity for ecosystem services that occurs during their absence before restoration is completed. In other words, both a certain amount of funds and time are needed to restore a system, but until the restoration is complete and the ecosystem matures, some ecosystem services will be temporarily absent.

4) Costs to provide equally good services using various treatment facilities or agricultural substitutes (useful for evaluating the lost opportunity for ecosystem services during their absence).
5) Evaluation of services and products using various complex network analysis tools, such as input-output flow analysis and energy analysis, which are based on specific flow theories of value that translate ecological work into monetary terms. Some such analyses include estimates of both known and unknown services by assuming that most if not all ecological work has some value to our life support system whether it has been discovered yet or not (Odum 1996). Therefore, such techniques can provide an upper bound to the potential value of ecological services if sufficient ecological productivity measurements are available.

All of these quantitative methods depend on first conceptualizing the relationship between ecosystem services and the economy. A conceptual economic model records current understanding of these relationships, and sets the stage for quantitative evaluation.

Ecosystem Service Evaluation Tools

A variety of tools have been developed in recent years to organize the process of valuing ecosystem services within a landscape such as the St. Johns River watershed. An excellent review and comparison of 17 such tools is given by Bagstad et al. (2013). This review also identifies the major steps and data resources required to assess ecosystem services, regardless of the tool used. Careful reading of this one article can better prepare all involved for the process, even if none of the tools reviewed will be used in a given application.

Eight criteria of ecosystem service valuation tools were examined by Bagstad et al. (2013). These include:

1) Quantification of prevalence, value, and uncertainty of ecosystem services.
2) Time requirements for practical application of the tool.
3) Capacity for application by those other than the developers of the tool.
4) Level of development and documentation.
5) Scalability (useful at multiple temporal and spatial scales within the same system).
6) Generalizability (transferable to evaluate locations other than where developed).
7) Able to include non-monetary and cultural perspectives.
8) Affordability, insights, and integration with existing environmental assessment (gives new insight while working with established environmental management and planning data types and programs).

From among the tools evaluated by Bagstad et al. (2013), we list some ecosystem services evaluated by three example tools below. Additional service evaluations are possible and may be forthcoming with any given tool. Three tools are cited to illustrate a broad range of ecosystem services that have been evaluated, and to note that each tool has strengths and limits. By citing these, we are not recommending a given tool for the St. Johns River through this comparison. These three and others are continually being expanded and improved.

Ecosystem Service	InVEST	ARIES	LUCI
Biodiversity and habitat risk and connectivity	Yes		Yes
Carbon sequestration and storage	Yes	Yes	Yes
Flood regulation and vulnerability along rivers and coasts	Yes	Yes	Yes
Freshwater supply	Yes	Yes	
Nutrient retention	Yes		
Marine water quality	Yes		
Sediment regulation and retention	Yes	Yes	Yes
Erosion protection	Yes		
Agriculture			Yes
Crop pollination	Yes		
Timber production	Yes		
Marine fish aquaculture	Yes		
Subsistence fisheries	Yes	Yes	
Fisheries and recreation overlap	Yes		
Recreation	Yes	Yes	
Aesthetic quality and viewsheds	Yes	Yes	
Wave and wind energy protection	Yes		
Hydroelectric power production	Yes		

InVEST, ARIES, and LUCI are three ecosystem valuation tools reviewed by Bagstad et al. (2013). The overall purpose of these tools is to help decision makers visualize the role of local and nearby ecosystems in a local or regional economy. Such tools combine existing mapping data of ecosystems with service valuations for those ecosystems and allow alternative land management scenarios to be compared. Some advantages of these three example tools is that they have been usefully applied in a variety of settings, are open source, and can be a focal point for decision makers who want to address ecosystem service valuation in policy and planning. The three are presented here primarily to illustrate a range of ecosystem services involved, but not to recommend a particular tool. A careful reading of Bagstad et al. (2013) is helpful before choosing an economic valuation tool. However, any of these can facilitate policy decisions that include ecosystem services.

InVEST - Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is a broadly applied, public domain tool from the Natural Capital Project, a project headed by scientists, economists, and policy analysts collaborating from Stanford, The World Wildlife Fund, The Nature Conservancy, and the University of Minnesota (http://www.naturalcapitalproject.org). InVEST is a GIS mapping and value analysis tool for ecosystems that allows different values of the same ecosystem derived from different sources to be integrated (Holzman 2012). It is integrated with ArcGIS software. The practice of using this and other such tools by the Natural Capital Project has led to a general framework for conducting ecosystem service valuations with decision makers (Rosenthal et al. 2014).

ARIES - Artificial Intelligence for Ecosystem Services (ARIES) is a web-based set of tools for mapping and visualizing the impact of ecosystem services on a local economy (http://www.ariesonline.org). It has been broadly applied. The ARIES project is headed by a team of researchers from the US Geological Survey, Earth Economics, Conservation International, and the United Nations Environment Programme World Conservation Monitoring Centre and other international environmental organizations. A description of the ARIES approach is given by Villa et al. (2014).

LUCI - Land Utilisation and Capability Indicator (LUCI) is a second generation tool originally developed as Polyscape. Stakeholder engagement is emphasized (Jackson et al. 2013). The focus of applications has been on the impact of land management decisions and tradeoffs on ecosystem services in flood prevention, nutrient sequestration, farm production, and biodiversity. It is an evolving GIS toolbox for ArcGIS software that requires elevation data, land cover, and soils information (http://www.lucitools.org/). New modules are under development. The LUCI project is led by Victoria University of Wellington, New Zealand, and includes collaboration with the Centre for Ecology and Hydrology of the Natural Environment Research Council in Wales, UK. The first-generation Polyscape is described in detail by Jackson et al. (2013). LUCI has been applied primarily in Great Britain and New Zealand.

Ecosystem services evaluations have been performed enough to identify a general sequence of steps in any such process. Potential steps identified by Bagstad et al. (2013) include:

1) Impact screening of ecosystem services (cooperating with well-informed stakeholders and experts to identify the types, extent, and relative importance in the local community of various ecosystem services in a given region, such as a watershed).
2) Landscape scale modeling and mapping (to evaluate landscape-scale ecosystem services tradeoffs, such as might be created by converting natural land to timber production, timberland to residences, costs of wetland loss, costs of pollution).
3) Site scale modeling if needed to engage and inform stakeholders and decision makers in understanding the effect of ecosystem services at a particular location.
4) Both monetary and non-monetary evaluations to determine per unit costs associated with converting from one landscape type to another. Costs include social costs, market costs, costs avoided, and replacement costs.

Table 1-1. Table of ecosystems and ecosystem services applicable to the St. Johns River, Florida. As services values are determined, they can be entered in the blanks. Values would arise from the multiple of the annual value per unit (such as an acre) and the number of units (acres) in the watershed.

SERVICE → / **ECO-SYSTEM ↓**	Storm protection	Water level buffer & flood regulation.	Water purification. & nutrient retention	Fish and wildlife production	Carbon sequestration	Sediment & erosion control	Agriculture & timber production	Arts, scenery, & recreation	Education & research	Job creation
Tidal marsh & mudflats										
Submersed vegetation beds										
Freshwater wetlands & floodplains										
Estuary*										
River, stream, & lake*										
Springs†										
Forests & timberland										
Cropland										
Grassland & rangeland										
Aquaculture										
Urban & roadway										

*Includes the whole system of neuston, plankton, nekton & non-vegetated submersed benthos. Wetlands and submersed vegetation beds are listed separately.

†Springs are listed separately because of their large size, number, and unique ecology in the St. Johns River watershed.

Table 1-1 is a starting point for valuing ecosystem services in the St. Johns River watershed. It includes broad categories of ecosystems and types of service. Depending on the analysis tools and unit values chosen, each blank may have more than one value determination. A completed table may include the mean and range of values found for each blank. Biodiversity might also be added to the list, but we know of no current method to evaluate it.

Table 1-2. Some widely quoted values of ecosystem services listed by Costanza et al. (2014) based on de Groot et al. (2012). This table is presented only to show example values, not necessarily applicable to the St. Johns River. These values were determined using a specific method of evaluation. Values produced by other methods will differ.

Ecosystem	**2007 $/ha/yr** (x 0.4 = $/acre/yr)
Marine	$1,368
Coastal	$8,944
Estuaries	$28,916
SAV/Algae Beds	$28,916
Terrestrial	$4,901
Forest	$3,800
Grass/Rangelands	$4,166
Wetlands	$140,174
Tidal Marsh/Mangroves	$193,843
Swamps/Floodplains	$25,681
Lakes/Rivers	$12,512
Cropland	$5,567
Urban	$6,661

We do not have the expertise to critique these numbers nor to present the method by which they arose. A wide range of values has been attributed to specific ecosystems. For example, using his Emergy synthesis methodology, H.T. Odum (1996) evaluated northwestern Florida salt marshes at $648 per ha per year (based on the solar equivalent work done in 1990 dollars). Bell and Linne (1997) valued them at less than $75.22 per ha per year (marginal value in 1984 dollars). Note that the value in Table 1-2 for salt marshes is about $194,000 per ha per year (2007 dollars). This difference cannot be explained by inflation. The infancy of this type of method is to blame, along with the growing understanding of the number and type of ecosystem services provided.

Basic data needed for ecosystem valuations at the landscape scale include elevation, slope, hydrography, detailed land cover, and coefficients or decision rules for converting land cover by type to an ecosystem service value. Although such coefficients and decision rules may be dynamic, complex, and interdependent, or they may be poorly developed and incompletely supported by scientific validation, the use of simple coefficients and rules may be necessary and justified based on a "better-than-nothing" criterion. However, such coefficients can be replaced by better ones over time as they become available. Furthermore, the sensitivity of model results to variation in coefficients can easily be tested and reported in a model validation exercise. Thus, results of a sensitivity analysis can be used to prioritize model improvements.

Basin Characteristics and Segmentation

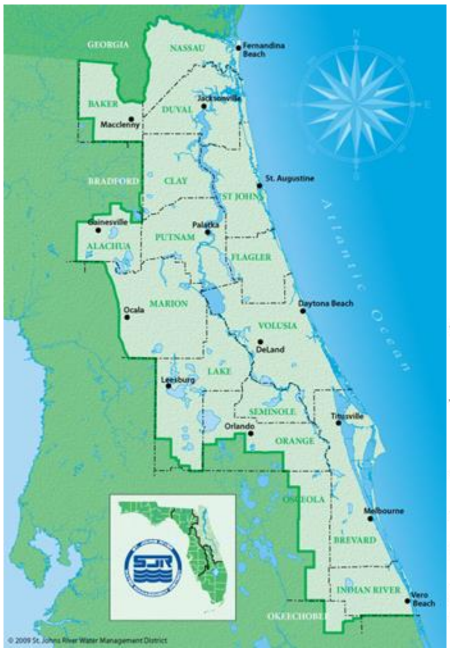
Figures 1-5 through 1-7, and Tables 1-1 and 1-2 provide a basic geographic foundation for the boundaries and landscapes involved in any evaluation of ecosystem services in the St. Johns River watershed. It is obvious that the St. Johns River and its drainage basin are big and complex. As examples, some basic facts and features of the St. Johns River include:

1) The main stem of the St. Johns River: 500 km (310 miles) long.
2) St. Johns River and floodplain area: 2,372 km^2 (916 mi^2)
3) St. Johns River drainage basin area: 16,581 km^2. (6,402 mi^2)
4) Ocklawaha River drainage basin area: 5,200 km^2. (2,008 mi^2)
5) Average rainfall: 130 cm (51 inches) (http://webapub.sjrwmd.com/agws10/hydroreport/).
6) Recent sea level rise: 2.4 mm per year (1.0 inch/decade) at Mayport.
7) Tide (mean range): 4.52 ft at Mayport; 0.42 ft at Welaka.
8) Net discharge of freshwater at the mouth: 8,246 cfs (= 5,330 mgd = 234 m^3/sec) (Sucsy et al. 2012).
9) Flow from Ocklawaha River: 2,200 cfs or about 27% (Wycoff 2010).

Figure 1-5 shows the counties involved in the St. Johns River watershed (panel A) and illustrates the unusually low change in elevation along this river (panel B). The St. Johns River flows north from its southern headwaters. It is a slow-moving, low-slope, shallow river. Most of the river is <10 feet deep (Figure 1-5B). Almost the entire lower half of the river is at sea level, from the mouth of the River at

Mayport to the south end of Lake George. Therefore, water level in this lower part of the river is predominantly driven by ocean water level, not rainfall, and is thus affected by sea-level rise. In the upper half, freshwater flow creates an elevated river surface, but the total rise of surface elevation is less than 20 feet in 150 miles.

A



B

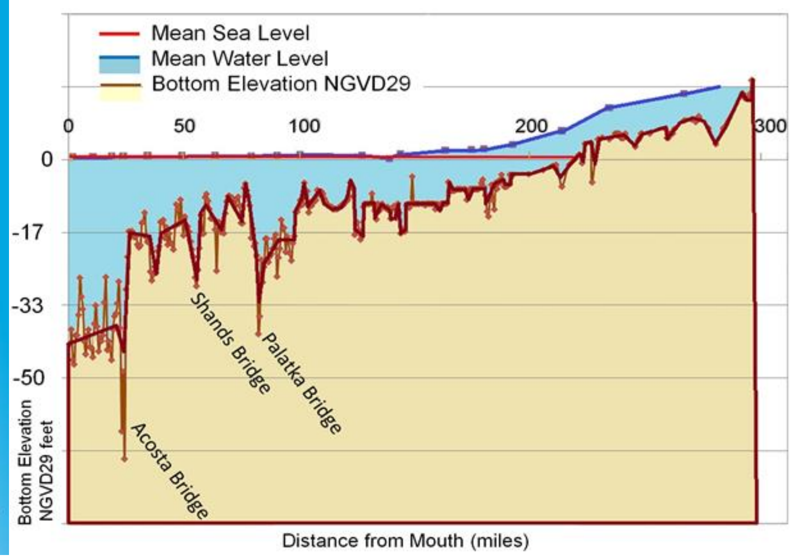


Figure 1-5. General geographic setting of the St. Johns River. A: The St. Johns River Water Management District boundary and the counties within the watershed. B: Elevation of the river bottom and water surface from the mouth at Mayport to the headwaters at Blue Cypress Lake. Note that most of the River is shallow (<10 feet) and that the first 125 River miles from the mouth to Astor at the south end of Lake George are at sea level. Source: St. Johns River Water Management District.

The St. Johns River is fortunate to have a lot of intact natural uplands and wetlands (Figure 1-6). For example, in the Upper Basin (the headwaters south of Titusville), 305,000 acres (477 square miles) of the wetlands have been restored, enhanced, or protected by the St. Johns River Water Management District. Also within the watershed are two large urban areas – all of Jacksonville and much of Orlando (Figure 1-6). Intermingling of the various natural and developed landscape features is an important factor to consider in economic analyses. Figure 1-6 illustrates some of the nature of this admixture, but more detailed land use and vegetation maps are necessary for an ecosystem services valuation.

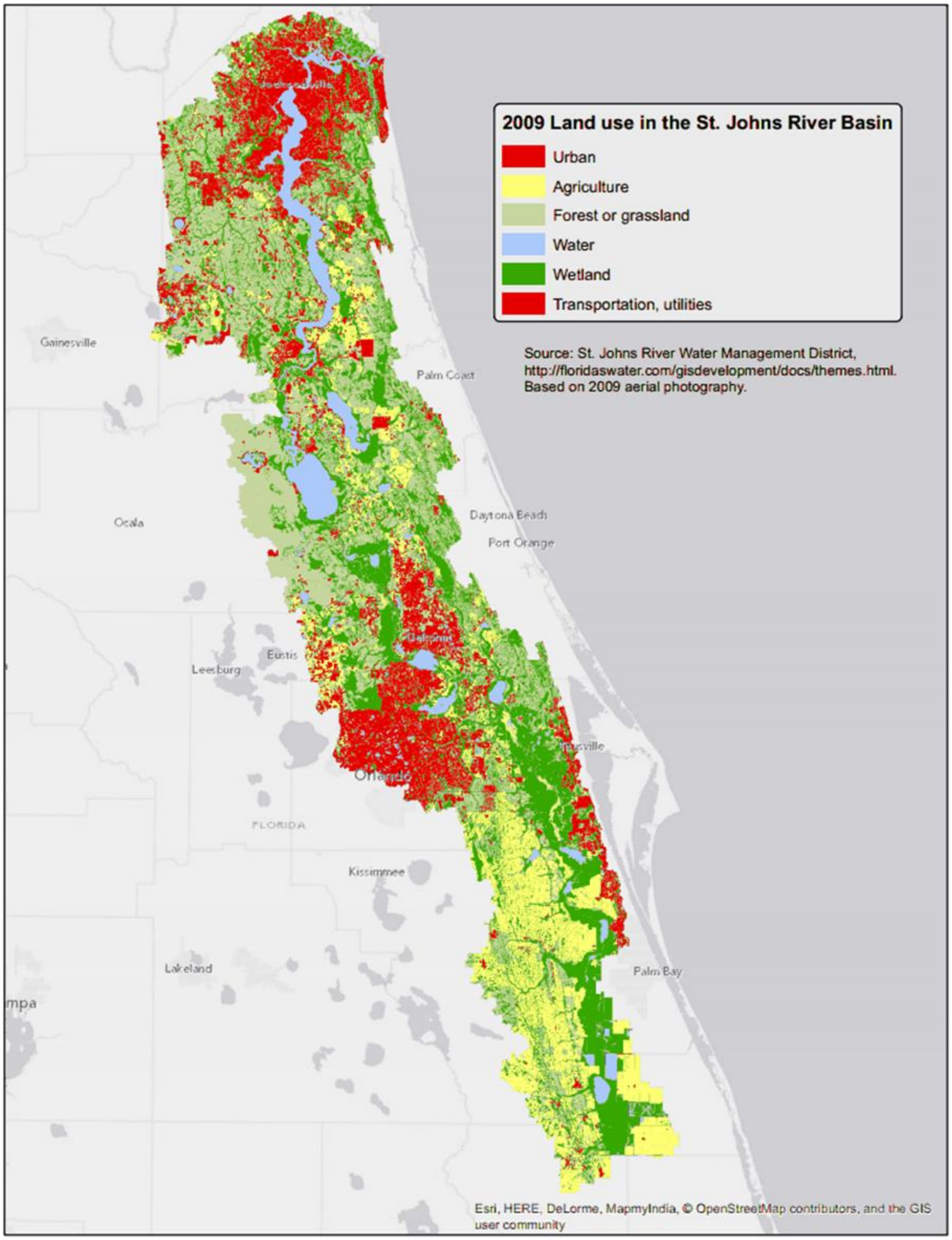


Figure 1-6. Land use in the St. Johns River basin. The proportion of the area in wetlands increases upstream (southward). Major urban centers occur around Jacksonville, Orlando, and Titusville and exhibit intense edge interfaces with natural wetlands, forests, and submersed vegetation. The Ocklawaha River basin is not included.

As illustrated in Figure 1-6, the St. Johns River is an enormously diverse system of ecosystems, with estuarine (brackish), lacustrine (lake-like), riverine (river-like), and wetland features intermixed with urban development and agriculture. The wetlands of the River exhibit a strong geographical pattern. Downstream, tidally driven salt marshes occur only near the mouth of the River. Further upstream is a long segment containing few floodplain wetlands, which then transitions into a reach extending to Lake Monroe, along which hardwood swamps are the characteristic wetland type. Moving further south, and especially upstream from SR46 at River kilometer (RK) 310 (= River mile 192), various types of herbaceous wetlands dominate the landscape. Although less prevalent, hardwood swamps associated with tributary streams frequently encroach into the herbaceous wetlands of the floodplain.

For study purposes, the River has recently been divided into nine, relatively homogeneous segments illustrated in Figure 7. We list these segments here by River kilometer (RK) (from Kinser et al. 2012):

1) Mayport to Fuller Warren Bridge (Mill Cove), RK 0-40 (x 0.62 = River mile 0-25)
2) Fuller Warren Bridge to Flemming Island (Doctor’s Lake), RK 40-65
3) Flemming Island to Little Lake George (Deep Creek), RK 65-163
4) Little Lake George to Astor (Lake George), RK 163-204
5) Astor to the Wekiva River (Lake Woodruff), RK 204-254
6) Wekiva River to St. Road 46 (Central Lakes: Lakes Monroe, Jesup, and Harney), RK 254-310
7) State Road 46 to State Road 520 (Anastomosing Channels: St. Road 50), RK 310-378
8) State Road 520 to Three Forks Marsh (Chain-of-Lakes: Lakes Poinsett, Winder, Washington, Sawgrass, and Helen Blazes); RK 378-443 and
9) Three Forks Marsh to Fort Drum Creek (Blue Cypress Lake), RK 443 to approximately 50 km south of the headwaters.

Among the 9 segments, basin characteristics vary widely, as summarized in Tables 1-3 and 1-4. For example, urban land varies from 2% to 40% cover; agriculture varies from 2% to 51%; and forested land varies from 3% to 49% (Table 1-3). There is also a wide variation in floodplain characteristics among the segments (Table 1-4). For example, average floodplain width (= floodplain area divided by segment length) varies from 2.7 km to 7.2 km, and the proportion of the floodplain that is wetlands varies from 14% to 87%.

Table 1-3. General basin characteristics in nine river segments numbered from the mouth of the St. Johns River (1) to the headwaters (9). Data from Kinser et al. (2012).

No.	Segment Name	Urban	Basin Area (km^2)*	Ag.	Forest	Other Upland	Wetland	Water Bodies
1	Mill Cove	38%	1,056	3%	18%	9%	22%	10%
2	Doctors Lake	40%	779	2%	17%	6%	18%	17%
3	Deep Creek	11%	5,370	9%	41%	6%	26%	7%
4	Lake George	4%	1,061	4%	49%	3%	19%	22%
5	Lake Woodruff	17%	1,568	11%	35%	5%	27%	5%
6	Central Lakes	29%	1,627	11%	17%	7%	27%	10%
7	State Road 50	16%	2,004	23%	9%	9%	39%	4%
8	Chain of Lakes	4%	1,705	51%	3%	4%	34%	4%
9	Blue Cypress Lake	2%	1,411	48%	3%	4%	36%	7%
	OVERALL	**15%**	**16,581**	**18%**	**25%**	**6%**	**28%**	**8%**

*km^2 x 0.38 = square miles.

Table 1-4. Floodplain characteristics in nine river segments numbered from the mouth of the St. Johns River (Segment 1) to the headwaters (9). Data from Kinser et al. (2012). Floodplain width calculated as area over segment length. Floodplain is defined as that part of the basin adjacent to the River that was inundated by the highest river stage on record.

No.	Segment Name	Segment Length (km)*	Floodplain (km^2)**	Floodplain Width (km)	Floodplain Wetland	Floodplain Water Bodies	Imbedded Uplands
1	Mill Cove	39.6	187	4.7	45%	46%	9%
2	Doctors Lake	25.4	151	5.9	14%	80%	6%
3	Deep Creek	100.1	581	5.8	41%	50%	8%
4	Lake George	41.2	295	7.2	28%	68%	5%
5	Lake Woodruff	49.2	217	4.4	82%	15%	3%
6	Central Lakes	56.3	198	3.5	41%	55%	4%
7	State Road 50	68	186	2.7	87%	12%	1%
8	Chain of Lakes	64.8	311	4.8	75%	14%	11%
9	Blue Cypress Lake	33.4	246	7.4	77%	11%	12%
	OVERALL	**478**	**2,372**	**5.0**	**54%**	**39%**	**7%**

*km x 0.62 = miles; km^2 x0.38 = square miles

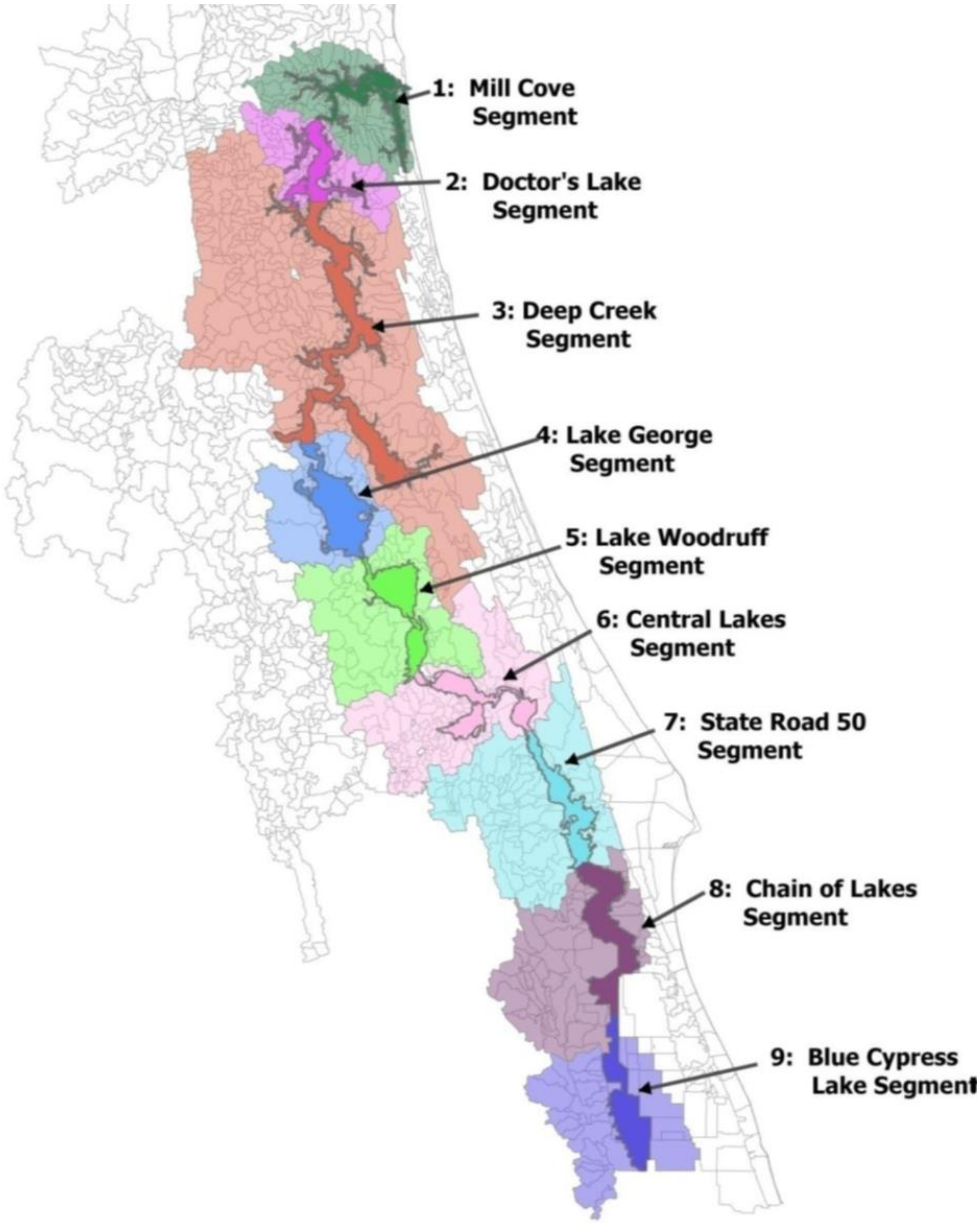


Figure 1-7. River segments. Regionalization of the River: segment floodplain (dark color) and local drainage (light color). Source: St. Johns River Water Management District, St. Johns River Water Supply Impact Study (Kinser et al. 2012).

Earlier studies and management programs generally divided the River into three basins. The Lower Basin includes Segments 1 through 4; the Middle Basin, Segments 5 and 6; and the Upper Basin, Segments 7 through 9 (Fig. 1-6). In addition, the Ocklawaha Basin is often included separately. Nevertheless, the rich collection of studies and management documents provide valuable support information for any ecological services evaluation of the St. Johns River.

Conclusions and Recommendations for Future Work

The St. Johns River watershed is a complex mosaic of urban, agricultural, and wild lands. Highly managed ecological services of photosynthesis in the watershed help produce food, clothing, and shelter within farm fields and planted pine forests. In addition, unmanaged free services of wetlands and dense beds of submersed aquatic vegetation continuously restore water quality and quantity in the River. Much is already known about the St. Johns River watershed that can provide meaningful estimates of the value of ecosystem services to the local economy using tools and evaluation methods available today. Research reports and publications of the St. Johns River Water Management District, and many scientists and engineers in agencies, universities, and environmental consulting firms in Jacksonville, Gainesville, and elsewhere form a sound basis for ecological services evaluations.

The method of developing conceptual influence diagrams to identify important feedback loops provides one mechanism for organizing relevant scientific and policy information toward an ecological services evaluation. The importance of feedback as a control or amplifier of tendencies is easily recognized through the construction and review of such diagrams. Feedback controls and amplifiers can be intentionally created to preserve ecosystem services, or can be unwittingly formed in a manner that rapidly eliminates such services before their value is appreciated.

The two general phases of any ecological services evaluation are the inventory of systems and the unit valuation of each item in the inventory. Modern Geographic Information Systems (GIS) can set the parameters for a thorough inventory of the watershed and a variety of methods can be used to identify monetary and non-monetary values of ecosystems in the landscape. Models and the tools for evaluation are under development and should be continually tested and applied with caution, review, and critique. Through that process, models will converge on an acceptable valuation tailored to the needs and values of the people freely served by ecosystems in the St. Johns River watershed.

Our simplified conceptual economic models can be deconstructed into parts, and economic values estimated for the various linkages, using such methods such as described earlier in this chapter. Such evaluations have even been done at the scale of the world (Costanza et al. 1997, 2014; Westman 1997) and at very small scales (see Bagstad et al. 2013). After evaluation by specialists, conceptual economic models can be revisited and revised as needed along the way to an acceptable evaluation. In addition, models could also include a spatial aspect; our generalized model does not. For example, the extensive wetlands of the Upper Basin protect the Middle and Lower Basins from flooding.

In the following chapters, values of some specific ecosystem services are explored. Topics include the value of wetlands and other ecosystems on flood control, water quality and human health, the effect of ecosystem services on property values and tax revenues, the supply of water for human consumption and industrial needs, and the values of recreation, ecotourism, and fisheries. Data are available for appropriate conceptual models for each of these topics.

Although feedbacks arise naturally, they can also be created. Exposing the likely positive and negative feedback loops involved can light the path forward for establishing effective policies for managing growth and development in the watershed. Policies that create feedback loops can be powerful for halting the disappearance of free ecosystem services, or working with the unavoidable tradeoffs and costs involved in achieving local goals of population and industrial growth. Conceiving the ideas is the first step.

ACKNOWLEDGMENTS

Background information on the St. Johns River and its basin was graciously provided by staff of the SJRWMD, especially by Palmer Kinser and Christine Mundy.

References

Bagstad, K. J., D. J. Semmens, S. Waage, and R. Winthrop. 2013. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosystem Services 5: 27-39.

Bell, F. W. and G. D. Lynne. 1997. Marginal Value of Coastal Wetlands to Florida's Commercial Fisheries. In: C. L. Coultas and Yuch-Ping Hsieh (eds.). Ecology and Management of Tidal Marshes: A Model from the Gulf of Mexico. Delray Beach, FL. St. Lucie Press, pp. 231-257.

Costanza R. R. D'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Costanza R., R. de Groot, P. Sutton, S. van der Ploeg, S. J. Anderson, I Kubiszewski, S. Farber, and R. K. Turner. . 2014. Changes in the global value of ecosystem services. Global Environmental Change 26: 152-158.

de Groot, R., L. Brander, S. van der Ploeg, R. Costanza, F. Bernard, L. Braat, M. Christie, N. Crossman, A. Ghermandi, L. Hein, S. Hussain, P. Kumar, A. McVittie, R. Portela, L. C. Rodriguez, P. ten Brink, P. van Beukering. 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services 1: 50-61.

Holzman, D. C. 2012. Accounting for nature's benefits: The dollar value of ecosystem services. Environmental Health Perspectives 120(4): A152-A157.

Jackson, B., T. Pagella, F. Sinclair, B. Orellana, A. Henshaw, B. Reynolds, N. Mcintyre, H. Wheater, and A. Eycott. 2013. Polyscape: A GIS mapping framework providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services. Landscape and Urban Planning 112: 74-88.

Kinser P., S. Fox, and A. Ceric. 2012. Appendix 2-B. Description of River Segments used in the WSIS Study. In: E. Lowe et al. (eds.). St. Johns River Water Supply Impact Study. Technical Publication SJ2012-1. St. Johns River Water Management District, Palatka, FL. 35 pp. http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ2012-1_Appendix02-B.pdf

National Oceanic and Atmospheric Administration. 1985. National Estuarine Inventory Data Atlas, Volume 1: Physical and Hydrologic Characteristics. NOAA, Rockville, MD. 40 pp.

Odum, H.T. 1996. Environmental Accounting. John Wiley & Sons, Inc., New York. 370 pp.

Rosenthal, A., G. Verutes, E. McKenzie, K. K. Arkema, N. Bhagabati, L. L. Bremer, N. Olwero, and A. L. Vogl. 2014. Process matters: a framework for conducting decision-relevant assessments of ecosystem services. International Journal of Biodiversity Science, Ecosystem Services & Management. 14 pp. http://dx.doi.org/10.1080/21513732.2014.966149

Sucsy, P. et al. 2012. Chapter 5. River hydrodynamics calibration. In: E. Lowe et al. (eds.). St. Johns River Water Supply Impact Study. Technical Publication SJ2012-1. St. Johns River Water Management District, Palatka, FL. 314 pp. http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ2012-1_Chapter05.pdf

Villa, F., K.J. Bagstad, B. Voigt, G.W. Johnson, R. Portela, M. Honzak, and D. Batker. 2014. A methodology for adaptable and robust ecosystem services assessment. 18 pp. PLoS ONE 9(3): e91001.

Westman, W. E. 1977. How much are nature's services worth? Science 197: 960-964.

Wycoff, R. L. 2010. Lower Ocklawaha River basin hydrologic data review and discharge analysis. Special Publication SJ2010-SP10, St. Johns River Water Management District, Palatka, FL. 76 pp. http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ2010-SP10.pdf

Chapter 2

Economic Valuation of Wetlands as Related to Flood Abatement and Flood Insurance Rates

by

Peter Bacopoulos[1], Dingbao Wang[2], Stephen C. Medeiros[2], Christopher J. Brown[1] and Chung-Ping (Albert) Loh[1]

[1]Assistant/Associate Professor, UNF

1 UNF Drive, Bldg 50, Room 2500

Jacksonville, FL 32224

[2]Assistant/Research Assistant Professor, UCF

4000 Central Florida Blvd, P.O. Box 162450

Orlando, FL 32765

peter.bacopoulos@unf.edu

dingbao.wang@ucf.edu

stephen.medeiros@ucf.edu

christopher.j.brown@unf.edu

cloh@unf.edu

Abstract

The integration of hydrologic and hydrodynamics models to inform was used to develop an economic valuation of the wetlands as related to flood abatement and flood insurance rates. The hydrologic modeling included the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) and SWAT (Soil and Water Assessment Tool) to describe infiltration and runoff for the entire drainage basin of the St. Johns River. The model computed watershed runoff which was fed into an ADCIRC (ADvanced CIRCulation) simulation of tides, surge and flooding for the lower St. Johns River Basin. Products from the modeling included aerial extent of flooding and water heights generated from scenario-based model runs, including existing conditions (Tropical Storm Fay), an approximate 100-year rainfall event and the same 100-year event, but with the wetlands hypothetically converted to developed-type land cover/land use. The modeled water extents and water heights were geospatially analyzed and fed into an economic valuation model to yield measures of the wetland economic value based on flood-abatement alone. There was no positive economic value of wetlands for flood prevention in the study area.

Introduction

The strategy was to integrate multiple models for economic valuation of wetlands as related to flood abatement and flood insurance rates. Multiple models included HEC-HMS and SWAT for hydrology simulation and ADCIRC for hydrodynamic simulation. The two processes, hydrology and hydrodynamics, are interconnected in reality via freshwater river inflows to the estuary, and the multiple models were interconnected, so that the hydrology and hydrodynamics of the lower St. Johns River Basin could be integrated in the simulations. The simulations were applied for different scenarios involving land use/land cover changes reflecting existing and future conditions of wetlands. The simulation output included water extents and water heights for the lower St. Johns River Basin, which were fed into an economic analysis. The economic analysis used property values and distances to flooding extent, for the different applied scenarios, to generate economic valuation of the wetlands.

Numerical Model Development

HEC-HMS Model Domain - The U.S. Army Corps of Engineers Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) simulates natural and controlled hydrologic conditions in watershed systems and simulates precipitation-runoff processes (Scharffenberg et al., 2010). HEC-HMS utilizes infiltration losses, hydrograph transformations, and hydrologic routing with the option of using various calculation methods. Additionally, mathematical models for simulating the response of the watershed to precipitation and evapotranspiration are available. Also, the code permits the user to input baseflow into the simulated watershed to model real-world hydrologic functions. The HEC-HMS modeling platform allows the Upper and Middle St. Johns River Basins hydrologic processes to be simulated using one large-scale model with adequate detail to determine the changes in runoff processes due to land cover and land use conditions. This model will provide input flow and stage data to a SWAT model under development by the University of Central Florida (UCF). That model will, in turn, provide flow inputs to an existing hydrodynamic model of the Lower St. Johns River Basin. Collectively, the three models encompass the entire St. Johns River watershed and permit evaluation of such interesting research topics as the valuation of wetlands in the watershed or capacity for flood storage in the same. The HEC-HMS model developed for this study is a derivative of the U.S. Army Corps of Engineers (USACE) and St. Johns River Water Management District (SJRWMD) hydrologic boundaries that have been identified in both previously constructed models (SJRWMD) and models that are currently under development (USACE).

The model domain for the HEC-HMS model includes the entire Upper St. Johns River (USJR) watershed and a majority of the Middle St. Johns River (MSJR) watershed, as seen in Figure 2-1.The modeled area of the Upper St. Johns River Watershed includes sub-basin delineation from the U.S. Army Corps of Engineers and includes the SJRWMD defined Planning Units of Fort Drum Creek, Blue Cypress Creek, Fellsmere, Jane Green Creek, St. Johns Marsh, Lake Poinsett, Toschatchee, and Puzzle Lake. The modeled area of the Middle Basin includes the following Planning Units, also defined by the SJRWMD: Econlockhatchee River Planning Unit, Deep Creek Planning Unit, Lake Jesup Planning Unit, and the Lake Monroe Planning Unit. The only portion of the Middle St. Johns River watershed that will be modeled separately is the Wekiva River Planning Unit. The pertinent SJRWMD detailed planning units used in this modeling effort are shown on Figure 2-2.

Each planning unit consists of multiple sub watersheds or sub-basins which subdivide each planning unit into more detailed areas for hydrologic modeling purposes. These sub-basins are normally defined by a geographic area of natural orientation or by manmade structures such as levees or canals that contribute flow to a similar outlet location. The sub-basin delineations for the Upper and Middle St. Johns River were delineated using contours and flow paths as well as the sub-basin shapefiles received from the SJRWMD (T. Jobes, personal communication, 2014). Smaller sub-basins were often combined to form larger sub-basins for ease in modeling calculations and development. This approach was deemed satisfactory since the focus of the research study was on large-scale processes. The sub-basins for the Middle and Upper St. Johns River can be seen in Figure 2-3.

The Upper St. Johns River Basin sub-basin delineations were developed based on projects completed with the Upper Basin in the project baseline year of 1995. Consequently, the model inputs including land use sub-basin delineation has not changed significantly since 1995, but flow patterns have been altered by continued increases in urban development. This has caused disruptions in the historical runoff conveyance due to drainage ditching, retention ponds, and increased impervious areas.

Basin Model Manager – As stated above, HEC-HMS can be used to estimate runoff volumes and flow hydrographs from multiple computation parameters and models or methods for approximating these processes. To begin the HEC-HMS model design, a new "Basin Model" was created. It was decided that one basin model will be used for both the Upper and Middle St. Johns areas to ensure flow is properly conveyed throughout the system without the interruptions of linking multiple basin models.

Sub-basin Elements - Within the basin model, the first hydrologic element to be added was the sub-basin element which has no inflow and only one outflow. A sub-basin element was added for each sub-basin identified in the model domain. The sub-basin area must be entered and a Canopy Method or Surface Method should be specified. The Canopy Method is meant to represent the interception of precipitation due to the presence of foliage. This tool leads to decreased precipitation that is available for runoff. In addition, the intercepted precipitation is subject to evaporation between rain events. The Canopy Method was not used in the base HEC-HMS model. The Surface Method represents the interception and accumulation of runoff due to the depressions in the ground and increased infiltration. The Surface Method was also set as none in the HEC-HMS model. Both methods were not included because this form of precipitation interception is accounted for when using the U.S. Department of Agriculture Soil Conservation Survey (SCS) method (1972) and through the assignment of initial abstraction, which will be discussed in further detail later in the report.

HEC-HMS computes outflow by subtracting the losses, transforming excess precipitation, and adding baseflow to the precipitation data that is applied to each sub-basin. The following sections will explain how the various input parameters for the sub-basin element were computed.

Figure 2-1 – Overall Study Area.

Figure 2-2 - Planning units.

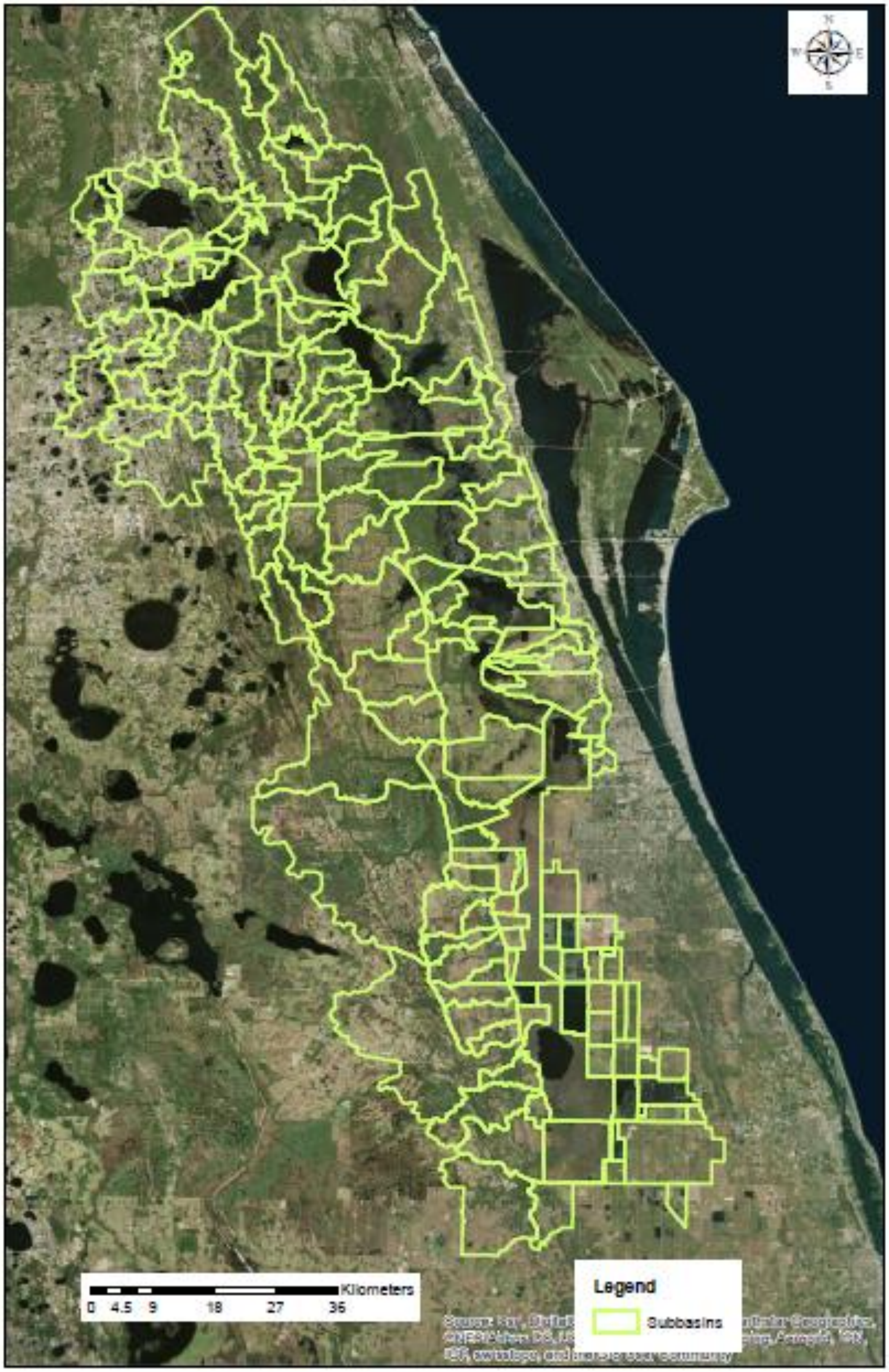


Figure 2-3 – Modeled Sub-basins

Model Inputs

Loss Method - The SCS Curve Number Loss was selected as the Loss Method for each sub-basin in the Upper and Middle St. Johns River modeling effort. The calculation of the curve number, initial abstraction and percent impervious are all parameters that must be entered as part of the SCS Loss Method in HEC-HMS. The following paragraphs explain the methodology and computational methods for determining these parameters for each sub-basin.

The land use and land cover data was downloaded from the St. Johns River Water Management District (SJRWMD) for the project baseline year 1995 (SJRWMD, 2014). Data was available for each Florida County, and therefore only counties associated with the project area were downloaded. Each data set was imported into ArcGis as a shape file until the entire project area contained Land Use data. Within each shapefile the land use data was expressed using the Florida Land Use and Cover Classification System (FLUCCS), with over 100 different land cover types included (SJRWMD, 2014). This would suggest a relatively adequate land use representation due to the detailed nature of each land use shapefile. The STATSGO soil group classification data was also imported into ArcGIS as a shapefile. The soil group data expresses the soil group behavior as an A, B, C, D, or as a dual hydrologic soil group type (T. Jobes, personal communication, 2014).

The "A” soil type has a high infiltration rate and low runoff potential. Class "B" soil has moderate infiltration rates and a moderate rate of runoff. Class "C" soils have low infiltration rates and may contain a layer of soil that impedes the downward movement of water. Class “D” soils have very low infiltration rates and include poorly drained, very silty/clayey/organic soils with a very high rate of runoff. The dual hydrologic classification includes soils that can have an unsaturated and saturated condition. The first letter of a dual classification applies to the undrained condition whereas the second letter is for the drained condition. The drained condition is normally dependent on the soils depth to permanent water table.

The sub-basin delineation was also imported into ArcGis to allow for a spatial comparison between land use, soil group, and sub-basin area. This was completed within ArcGis using the “Join” feature based on spatial properties of the datasets. The resulting data set contains each sub-basin with the respective land use codes and soil groups for all coverage area within the sub-basin perimeter.

The Soil Conservation Services (SCS) curve number method was used to estimate the amount of runoff potential from the rainfall event based on the relationship between soil type, land use and hydrologic soil conditions. The hydrologic soil condition is known as the Antecedent Moisture Condition (AMC) which describes the preceding soil moisture before the modeled rainfall event. AMC I is used for basins that have had a low amount of rainfall before the modeled event, whereas AMC III is used for a high amount of rain before the modeled event. AMC II may be considered the average condition and is normally used in modeling applications. Curve numbers representing AMC conditions I and III are calculated by applying adjustment factors to the CN reflecting the AMC II condition, as seen in Equation 1 and Equation 2.

$$AMCI = \frac{4.2 * AMCII}{10 - (0.058 * AMCII)}$$ *Equation 1*

$$AMCIII = \frac{23 * AMCII}{10 + (0.13 * AMCII)}$$ *Equation 2*

The SCS curve number may be related to the potential maximum retention by Equation 3.

$$S = \left(\frac{1000}{CN}\right) - 10$$ *Equation 3*

S = Potential maximum retention after runoff begins (in)

CN = Curve number

For many modeling applications a certain amount of the precipitation is abstracted immediately due to potential losses. These losses can occur in the form of infiltration into the soil, interception due to foliage, and depression storage due to ponding or surface undulations. In the SCS method these loses were combined and termed Initial Abstraction. The empirical equation used to determine the Initial Abstraction can be seen in Equation 4.

$$I_a = 0.2 * S$$ *Equation 4*

I_a = Initial Abstraction (in)

Using these parameters the runoff depth can be predicted using Equation 5 below.

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$ *Equation 5*

P = Precipitation (in)

Q = Runoff (in)

The runoff curve numbers for the Upper and Middle St. Johns River were determined using previously derived SCS curve numbers for the each Florida Land Use Cover code in AMC II condition (Ayres Associates, 2001; Inwood Consulting Engineers, 2009). Each sub basin is comprised of multiple land uses and soil types so a composite weighted curve number for each sub basin was calculated. Calculations were based on the relative percentages of the land use and soil group classifications within the sub basin. Curve numbers were calculated for the AMC I and AMC III condition as well as the respective initial abstraction for each.

In addition to using the land cover type to determine the curve number, it was also used to calculate the percent impervious. The SJRWMD has correlated FLUCCS to the Hydrological Simulation Program-Fortran (HSPF) land use groups to assign the percent impervious for each land use code (SJRWMD, 2012). A composite percent impervious was determined for each sub-basin.

Transform Method- To accurately represent the response of each sub basin to the rain event, a hydrograph for each sub basin based on the time of concentration and lag time must be calculated. The time of concentration is defined as the time it takes water to travel from the hydraulically furthermost point in the watershed to the outlet. The lag time is the time it takes for the center of mass of the rainfall to the peak of the hydrograph. Within the hydrologic modeling platform, the lag time is used to create the resulting hydrographs. A common relationship between lag time and time of concentration is that the lag time is 0.6 of the time of concentration (Mays, 2011).

There are many different formulas available to estimate both the time of concentration and lag time. A common formula is the SCS Watershed Lag Time Equation. It uses parameters such as the flow length, average sub basin slope, and retention based on the curve number to determine the adequate lag. The Natural Resources Conservation Service (NRCS) developed two additional methods similar to the SCS method in the years of 1972 and 1997, which utilized similar parameters (Li et al., 2008; Sharifi et al, 2011). The NRCS also uses a method known as the velocity method where the time of concentration may be calculated using the Manning's kinematic solution for sheet flow, shallow concentrated flow, and open channel flow (U.S. Department of Agriculture Natural Resources Conservation Service, 2010). Since the sub-basins involved in this study mainly have sheet flow and shallow concentrated flow, only these lag time calculation methods were used. A modified version of the Snyder lag time equation was also utilized. This form of the lag equation was originally developed by Snyder but was later revised by the U.S. Corps of Engineers and U.S. Bureau of Reclamation (City and County of Sacramento, 1996).

The initial lag time designated for each sub-basin within the HEC-HMS model was determined using the average of the lag times calculated from the various equations. The lag time was adjusted during calibration after each sub-basin was analyzed further to ensure that the lag time was sufficient to describe the hydrologic conditions present.

Baseflow Method - The Baseflow Method represents the subsurface calculations for each sub-basin. The main source of baseflow within the model would be the presence of groundwater and spring discharge which will be explained later in this report. Due to the large number of basins and scale of the model, a constant monthly baseflow was specified. The initial baseflow was approximated between 0 and 0.5 m^3/s for many of the sub-basins and the baseflow separation method was used for those sub-basins that contained discharge gauges (Mays, 2011). Further modifications to the baseflow estimations were completed during calibration.

Reach Elements - A reach element has one or more sources of inflow from another element and computes one combined outflow. It represents a segment of the river or flow way and simulates the movement of water by using a user-selected routing method.

Routing Method - The hydrologic routing method chosen for the model was the Muskingum-Cunge Routing Method because it can be used in reaches with a small slope and is based on the conservation of mass and the diffusion representation of the conservation of momentum (Scharffenberg et al., 2010).

Also, the Muskingum-Cunge Method is based on physical parameters such as the reach length, Manning coefficient, channel geometry, and slope that were available in the study area.

The reach parameters were used to represent the flow way of the Upper and Middle St. Johns River. A reach element was added in the model between each point of inflow from contributing sub-basins. Adding multiple reaches permits the definition of the channel properties between each sub-basin inflow point separately. This is important due to the significant variations in channel width and roughness as the St. Johns channel becomes more defined as it flows north. Reach elements were also included to represent any canals, minor flowways, or if the flow length from the sub-basin outlet to the defined flow path of the St. Johns River was long enough to be significantly influenced by routing.

The routing parameters were measured using GIS software to determine the correct reach length and channel bed slope. Aerial photography and engineering judgment were used to determine the appropriate manning coefficient. The cross section configuration was set to a standard trapezoid shape with an average flow width measured from GIS and a side slope of 1V to 3H.

The Muskingum-Cunge method was chosen based on the following model criteria: minimal observed hydrograph data available in the flow way for calibration, flood wave will enter floodplain and channel slopes are less than 0.004. In relation to the St. Johns River, one of the largest issues with routing is properly modeling the flood plain storage. This is especially true in the upper St. Johns River where most of the flow way is a flood plain with heavy vegetation. According to the HEC-HMS manual "Flood flows through extremely flat and wide flood plains may not be modeled adequately as one-dimensional flow (USACE, 1988; 2000). To overcome the potential overestimation in flow due to inadequate modeling of storage availability, a loss method may be needed to account for reduction in flow."

Loss/Gain Method - A reach element can also represent interaction of the flow with the subsurface, flow reductions due to withdrawals, or the bi-directional movement of water. To account for these losses the constant loss/gain method was used because it applies a reduction to the flow by a fixed flow rate and/or a fraction of the flow. The fraction amount reduces the inflow by multiplying the flow rate by the vale one minus the fraction. The initial fraction of loss used in the model was between 0 and 0.05 and was used as a tool to help calibrate the model by accounting for the large amount of storage potential in the flow way. In addition specific losses were used for water withdrawals and recharge rates. The calculated monthly average recharge rates to the Upper Floridian Aquifer from drainage wells during 1995 to 2006 were about 74,000 m^3/day (19.6 Mgal/d) (Sepulveda et al. 2012). The City of Melbourne also had a water supply withdrawal of about 51,000 m^3/day (14Mgal/d) at Lake Washington.

Reservoir Element - A reservoir element has one or more inflow and one computed outflow. It was used in this model for any sub-basin that either had an outlet structure, specified pumping rate, or any obstruction to the flow such as a levee or roadway. If the reservoir had a specified pumping rate the outflow method was set as an Outflow Curve and the Storage Method was set to Elevation-Storage-Discharge. The Elevation-Storage Function was calculated using ArcGis for each sub-basin. The Storage-Discharge function was estimated for each sub-basin that discharges using a pump (e.g. agricultural pumping or water transfers). Since many of these pumps are operated at the discretion of the land owner, the discharge values ranged from zero near minimal storage and increased to the maximum pumping rate as storage increased. The Storage-Discharge functions can be refined during calibration to ensure the discharge rate is realistic to what may occur in the field after large precipitation events occur. In many cases, the actual discharge versus time function is unknown since these are not reported to the SJRWMD or no instrumentation exists to measure the discharge. Therefore, the simulated functions used in the model are reasonable estimates using the best available information.

The outlet structures routing method was used for any reservoir that had an outlet structure such as a weir, spillway, or culverts. It was also used if flow was restricted to flow through a certain opening, such as a bridge, due to levees or roadways. Information regarding structure geometry was obtained from the U.S. Army Corps of Engineers and the SJRWMD and was input into the model when necessary. The initial condition was set to inflow=outflow for the beginning of the simulation, but during calibration changes in either initial elevation or storage may be incorporated.

Meteorologic Model Manager - The Meterologic Model is used to specify the meteorological conditions for the sub-basins. It includes the precipitation method and evapotranspiration for the modeled area.

Precipitation Method - The Precipitation Method selected for this modeling effort was Gauge Weights which is based on precipitation gauge data. This method uses separate parameter data for each gauge and for each sub-basin in the model. The precipitation gauge data was obtained from point rain gauges from the SJRWMD and South Florida Water Management District (SFWMD). Only gauges that contained, at a minimum, the daily precipitation data for the calibration and validation period were used. Since there is limited precipitation gauges located in or near the project area, the Thiessen polygon method was used for the calibration and validation models. The Thiessen polygon defines an individual area of influence surrounding each gauge and represents an effective uniform depth of precipitation over the model area. Any sub-basin or portion of sub-basin falling within this area is closer to the rain gauge at its center than to any other rain gauge. Therefore, it is assumed that the gauge data, which was collected at a single point, is representative of the entire Thiessen polygon. Thiessen polygons were computed for the entire model domain using GIS and can be seen in Figure 2-4. ArcGIS was used to determine the relative area of each sub-basin within each Thiessen Polygons. For sub-basins that fell within multiple Thiessen Polygons, a percentage of area per Thiessen Polygon was computed. This was applied in the form of the Depth Weight which assigns a weight to each gauge in proportion to the area of sub-basin. A Time Weight can also be specified but is set at one for all sub-basins because the precipitation gauge data is to be applied throughout the entire simulation run.

Evapotranspiration Method - Evapotranspiration combines the evaporation of water from the ground surface and vegetation. The Evapotranspiration Method is set as monthly average which is designed to work with pan evaporation measurements. The rates selected were based on literature research including the Preliminary Water Control Manual – Upper St. Johns River Basin (USACE, 1991) and journal articles (Mao et al., 2002). The input evaporation was set the same for each sub-basin and can be seen in Table 2-1 below.

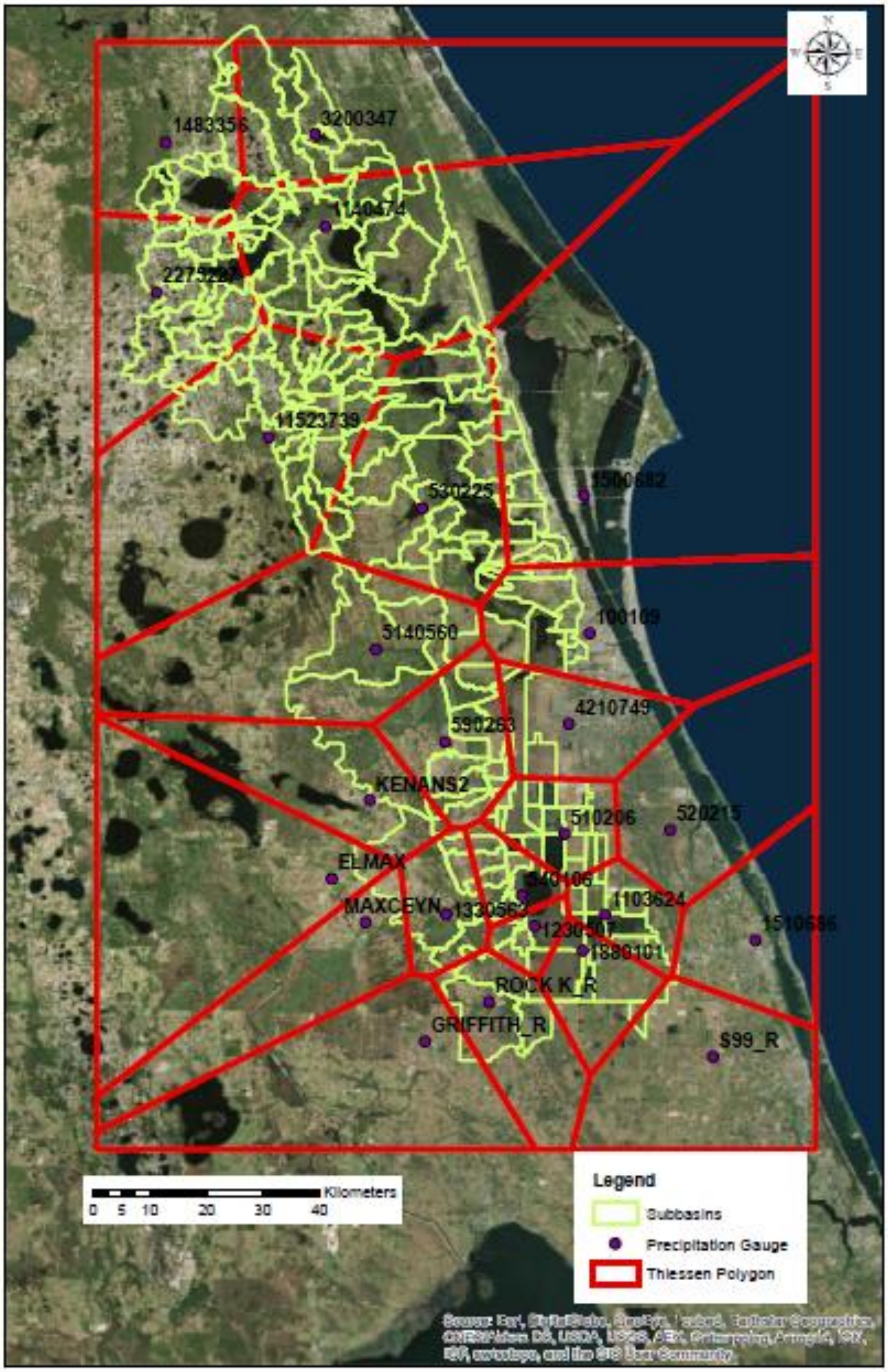


Figure 2-4. Thiessen Polygons

Month	Rate (mm/Month)
January	53.086
February	66.04
March	90.932
April	114.046
May	134.874
June	112.014
July	123.952
August	121.92
September	102.108
October	91.186
November	69.088
December	53.086

Table 2-1. Evapotranspiration Rates.

Control Specifications - The purpose of the control specification is to designate when the model is to start and stop simulations and what time interval is to be used. The specific start and end date and time was entered to match the set calibration and validation time periods. The time interval was based on the necessary simulation output hydrograph data for downstream modeling applications.

Time-Series Data - The Time-Series Data Manager allows measured gauge data to be incorporated into the model either as an initial condition, boundary condition, or parameter. Two types of Time-Series Data were used for the model, Precipitation Gauges and Discharge Gauges. As stated previously, precipitation gauge data was obtained from SJRWMD and SFWMD rain gauges. Discharge Gauge data was obtained from the United States Geological Survey (USGS) National Water Information System (USGS Water Resources, 2014). The data was entered manually for each precipitation and discharge gauge with the time interval for each matching that of the calibration and validation period in one day time increments. The discharge gauge data was applied as observed flow to the specific location in the model that correlated to the real-time location. The discharge gauge data was compared to the hydrograph at these locations to help with the calibration and validation of the model. A complete list of the precipitation gauges and discharge gauges can be seen in Table 2-2 and 2-3, respectively. The locations of the precipitation gauges can be seen in Figure 2-5 whereas the locations of the discharge gauges can be seen in Figure 2-6. Precipitation data was collected from SJRWMD and the South Florida Water Management District (SFWMD).

SJRWMD Gauges	SFWMD Gauges
1230507	Kenans2
1880101	Elmax
1330563	Maxceyn
1103624	Griffith_R
1510686	Rock K_R
520215	S99_R
510206	
590263	
4210749	
5140560	
1500682	
530225	
1140474	
2275227	
1483356	
3200347	
11523739	

Table 2-2. Precipitation Gauges

USGS/SJRWMD Gauges
02231342
02231396
02231458
02231600
02232000
02232155
02232200
02232400
02232500
02234000
02233460
02233473
02233484
02233500
02234010
02830228
02234440
02234500

Table 2-3. **Discharge Gauges**

Paired Data - The Paired Data Manager is used to describe an input function that relates physical processes. The Paired Data used in this model were Storage-Discharge and Elevation-Storage Functions as described earlier in the report. Elevation-Storage functions were measured using Lidar data in ArcGIS whereas the Storage-Discharge functions were estimated based on the best data available (Jobes, personal communication, 2014).

Model Boundary Conditions - The modeled area covers roughly 6,700 square kilometers (2587 square miles), from the beginning near Florida's Turnpike in the Upper St. Johns River Basin (USJRB) and flowing north until the outlet of Lake Monroe in the Middle St. Johns River Basin (MSJRB). Figure 2-7 shows the modeled area, including natural features and the St. Johns River Flowway boundary. The boundary conditions to the east and west are the hydrologic boundaries defined by the SJRWMD which contribute to the total flow of the St. Johns River, which includes both man-made and natural boundaries. The number of sub-basins containing urban development is higher within the northern portion of the USJRB and MSJRB due to the various cities within these regions. In addition to precipitation and associated runoff from the defined sub-basins, flow also enters the system through groundwater discharges and point source discharges such as wastewater treatment facilities. Flow exits the system from multiple locations due to the surface water withdrawals, discharges to tide, and power generation. More specifically, the St. Johns River Water Management Area discharges water through the C-54 canal to tide, municipal water is withdrawn at Lake Washington, and surface water is used for recreation irrigation, agricultural supply, commercial and industry self-supply. A majority of the USJRB area between Florida's Turnpike and U.S. 192 has been divided into a number of storage areas for flood control and storage, as well as for environmental purposes.

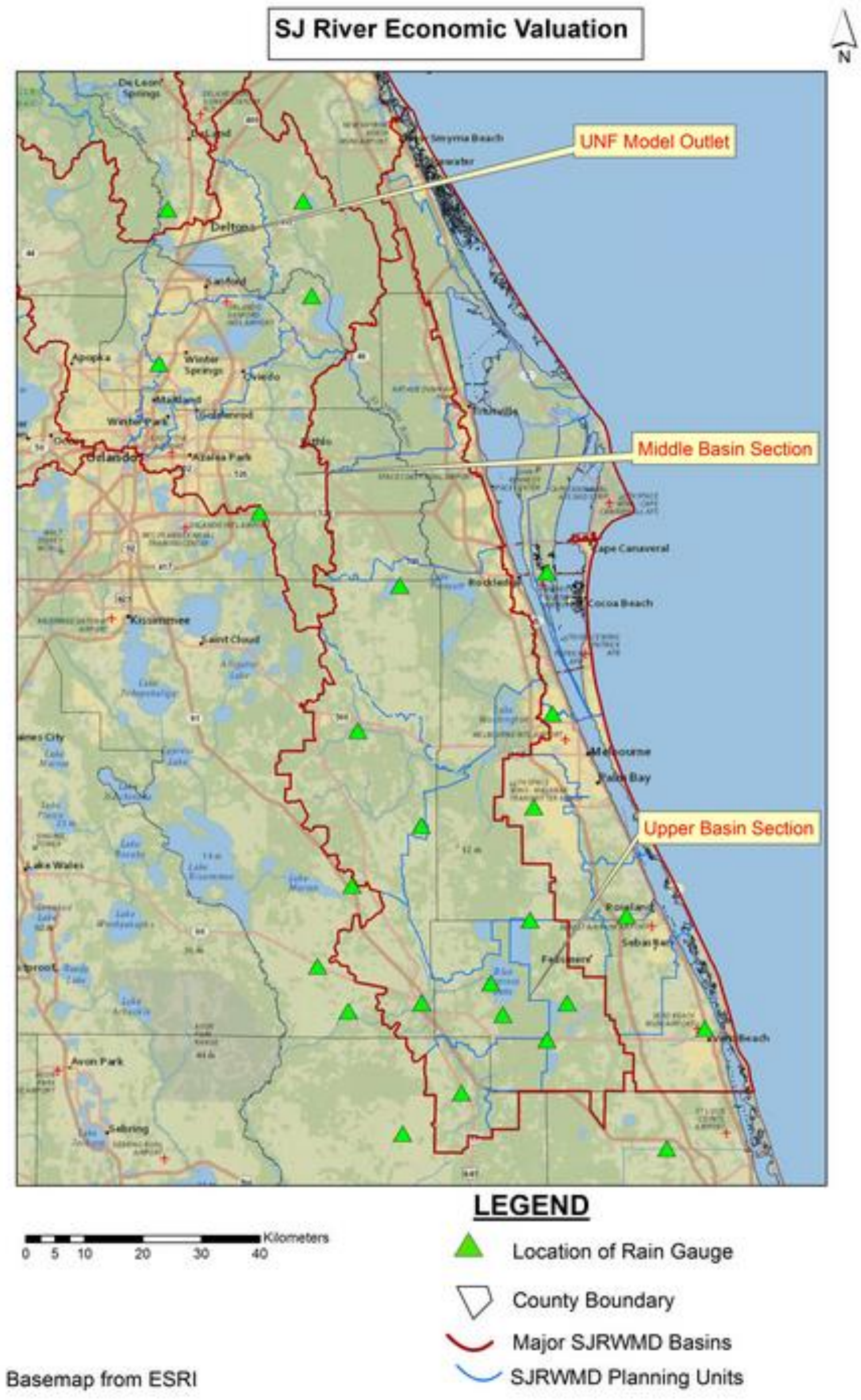


Figure 2-5. Rain Gauge Locations.

These sub-basins, which are often surrounded completely by levees, are heavily regulated using pumping stations and water control structures. The flow-way within this area is bounded by SJRWMD levees, private levees, and natural upland areas to the west and USACE levee to the east. Between U.S. 192 and S.R. 520, the western sub basins have relatively natural drainage patterns, with the exception of the Taylor Creek Reservoir which contains a control structure. There are areas of significant urbanization in the coastal sub basins which discharge to the St. Johns River by pumping or through canals. The main flow-way within this section passes through Lake Washington, Lake Winder, and Lake Poinsett and contains private levee systems on both the eastern and western side of the river to protect adjacent land from flooding. From S.R. 520 to the inlet of Lake Monroe, are the final sub-basins which make up the USJRB. The western sub-basins within this area drain naturally into the basin with minor interference from features such as roads. The eastern sub-basins are similar to those between U.S. 192 and S.R. 520, with a majority of the basins containing a percentage of urbanization, retention ponding features, and flow interruption due to multiple highway systems.

The most southern portion of the MSJRB is the Econlockhatchee River watershed which is comprised of natural draining wetlands at the headwater, to more urbanized areas in the western and northern sub-basins. In addition multiple detention ponds exist within this area and act as storage facilities for the stormwater runoff that occurs. The flow path is dominated by the natural topography with elevations being the highest at the headwaters and gradually decreasing until the Econlockhatchee River joins the St. Johns River before Lake Monroe. The MSJRB from Lake Monroe to the outlet of Lake Jesup receives natural drainage from the large sub-basins to the north and east. The Lake Jesup watershed consists of the highly urbanized area surrounding Lake Jesup. The surround sub-basin watersheds drain to Lake Jesup through multiple canals and tributaries and many sub-basins contain multiple detention lakes. The final portion of the MSJRB includes Lake Monroe and its tributaries. The area surrounding Lake Monroe is similar to that of Lake Jesup in that it is highly urbanized, with many intermittent detention ponds, and water drains through tributaries and canals.

Model Assumptions - The model input parameters were estimated using best available data and common engineering practices and logic. Model assumptions were only made when the validity of data was in question or if data measurements had not been taken or were missing. The St. Johns River's natural flow pattern has been greatly altered by human activities over the years; therefore certain sub-basins may not produce runoff similar to that of a natural physical watershed. Examples of this would be runoff being collected or diverted in small canals or ditches, interruption of runoff due to levees, roadways, or other manmade structures, storm drains, sewer systems, groundwater recharge locations, retention ponds and drainage wells. The required input parameter data must take into account these disruptions in the natural flow process and subsequent increases in retention time in order to properly model the hydrologic processes present. In addition, many sub-basins in the USJRB provide temporary storage of floodwaters or long-term storage for environmental purposes. Many of the sub-basins which form water management areas or water conservation areas are heavily regulated and discharges occur only when water levels reach a certain level within the sub-basin. This is also true for many of the sub-basins which are currently used for agricultural purposes where water withdrawals and releases are at the discretion of the land owner. Each sub-basin element and its associated loss, transform, and baseflow methods were reviewed and modified to produce a runoff hydrograph that was realistic to the particular physical conditions.

The USJRB and portions of the MSJRB have extremely small channel slopes, are heavily vegetated, contain pervious soils, and have a wide floodplain with flood control storage. These factors can greatly reduce the runoff potential and downstream flow rates. In order to produce outflow hydrographs similar to that of the discharge gauge data, assumptions regarding the model parameters were made to account for the site conditions mentioned above.

Runoff Assumptions - Research has indicated that runoff values in the Upper and Middle St. Johns River are relatively low compared to amount of precipitation received. The "Runoff to Streams in Florida Map Series", FGS Map Series 122 showed that the average rainfall was approximately 48 inches in the St. Johns River over the period of 1951-1980 with an average runoff of only 10 to 20 inches (Rumenik, 1988) or about 21% to 42% of the total annual precipitation. In addition, the State of Florida Department of Transportation specifies the normal runoff coefficients used for a Design Storm Return Period of 10 years of less (State of Florida Department of Transportation, 2012). This runoff coefficient is the empirical parameter used to calculate the excess rainfall as a fixed percentage of precipitation. The runoff coefficient for a flat slope (0-2%) ranges from 0.10 to 0.20 for woodlands, from 0.15 to 0.25 for pasture, grass, and farmland, and from 0.30 to 0.60 for bare earth. These values depend on the soil type with sandy soils having a lower runoff coefficients than clay soils but since many areas of the watershed are sandy in nature, may be representative.

Storage in the headwater swamps and river floodplains reduces and delays the flood peaks in downstream areas of the river (KBN Engineering and Applied Sciences, 1993). The longer the water is delayed due to storage attenuation, the more exposure it may have to evapotranspiration and further runoff reduction will occur. To adequately predict downstream hydrographs, the model must account for the historically low runoff rates and the large amount of storage due to the relatively flat topography and presence of intermittent hardwood swamps and marsh areas within the St. Johns River watershed.

Since the precipitation runoff calculated in the HEC-HMS model is directly related to the curve number and initial abstraction, these values were modified slightly to produce more accurate runoff values. As stated previously, the curve number values for the Florida Land Use and Cover Classification System were obtained from different literature sources. The curve number values for the land use cover for wetlands are normally very high due the saturated condition and impervious nature of many wetland systems which causes significant runoff to occur. These values were modified from what is normally found to be more representative of the site conditions of the St. Johns River. Since the wetlands within the project area may experience periods of drying and wetting, a lower composite curve number was used to account for increases in potential surface storage capacity. According to the SJRWMD (2012), wetlands act as a storage attenuation feature, which may correlate to less runoff and a lower overall curve number. The overland flow may occur rapidly within the upland landscape but once it enters the lowlands or wetlands, runoff is stored and discharged over a delayed period (SJRWMD, 2012). Lower curve number values were obtained from additional research, mainly from technical notes written by the SJRWMD, which confirmed lower curve number values may be appropriate (Suphunvorranop, 1985; Di et al., 2010) for wetlands in these instances.

Another important factor that influences the overall curve number value for the entire drainage basin is the AMC as discussed previously. According to SCS 1972, the condition can be based on the 5-day antecedent rainfall (Charbonnier et al., 2000). The antecedent rainfall is the total rainfall preceding the runoff event that is under consideration. The SCS also determined the corresponding rainfall limits for each of the AMC classes during the dormant, growing and average season. The calibration storm of Tropical Storm Fay selected for this modeling effort occurred after a relative dry period and many of the sub-basins in the Upper and Middle St. Johns River had a 5 –day antecedent rainfall of less than 36mm. This is the limit for the AMC I condition in the growing season and therefore many of the sub-basins may be classified as AMC I with respect the curve number assignment in the model. All sub-basin curve numbers in the model are between the AMC I and AMC II condition, depending on what is most appropriate for the basin under consideration. The sub-bains representing the flow way of the St. Johns River and any reservoir that was saturated within the model was assigned an AMC II or higher due to these areas being partially saturated. Many of the sub-basins were modeled between an AMC I and AMC II due to most sub-basins containing areas of dryer upland and partially saturated lowlands.

Using a reduced curve number value for wetlands and a lower AMC class allowed for a lower composite curve number to be used for each sub-basin. A lower curve number means there is a greater storage potential and higher initial abstraction, which may more accurately represent actual conditions. Since the initial abstraction describes the main loss of precipitation due to infiltration, interception, and depression storage, it is directly related to the runoff generated. To further decrease the amount of runoff, the ratio applied to the potential maximum retention should be increased from 0.2 to a higher value. It is believed this increase in initial abstraction is reasonable due to the dense vegetation, high depression storage potential, and low runoff values measured. Additionally, the equation of initial abstraction suggested by SCS was justified on the basis of measurements in watersheds less than 10 acres in size and since considerable scatter was present in the data, other studies have used higher initial abstraction ratios than 0.2 (Ponce et al., 1996).

This methodology was also applied to the reach parameters within the model. Due to way the model was set up, the reach parameters represented the flow way of the St. Johns River and therefore storage potential must be incorporated. The Muskingum-Cunge routing method was used to geographically to represent each reach, or portion of the St. Johns River flowway. This method calculates the respective lag time as the flow travels up the St. Johns River, but did not reduce the flow rate, as would occur naturally due to storage potential. Therefore, a Loss Method was incorporated into each reach depending on the site characteristics present. Loss rates were highest near the beginning of the USJRB and gradually decreased as the SJR stream became more defined and overall saturation increased, resulting in less storage potential. The loss percentages applied were also a function of the length of reach present, with longer reaches having more loss because of increased area for storage. The total loss percentage applied to the USJRB and MSJRB was set with the intention of replicating the runoff percentages presented in the "Runoff to Streams in Florida Map Series".

Assumptions regarding the Middle basin, especially in the Orlando area, were made due to the presence of drainage wells that aid in the disposal of excess surface water (Kimrey et al, 1984). Most of the drainage wells provide artificial recharge of the Upper Floridan Aquifer and provide either direct street and urban drainage or lake-level control. A study completed by CH2M Hill evaluated the runoff coefficient for ten street and urban drainage well areas. It was determined that the average runoff coefficient was 0.578 but ranged from 0.376 to 0.837. The recharge from lake-level control wells was also estimated to be approximately 18.06 inches per year but the observed ranges varied greatly (CH2M Hill, 1997). Based on the findings from these studies and the large runoff coefficients determined, the loss rate for the developed areas surrounding the Orlando area was increased.

Lag Time Assumptions - Once the composite curve number for the proper AMC class was determined it was input into the lag time equations for SCS and NRCS lag time. Using multiple equations for lag time as noted previously in the report led to determination of an upper and lower bound of acceptable lag times for the sub-basins. Lag times were modified at higher or lower values than the average if the sub-basin had extensive drainage structures, retention ponds, or other property that would increase or decrease lag times. All lag times defined within the model were within the upper and lower bound determined by the calculated lag times using the various equations.

Reservoir Parameter Assumptions - The main reservoir parameter assumptions made are for the outlet method used. For sub-basins that contained structures such as culverts or spillways, known geometry was used. The geometric properties came from multiple sources such as USACE, SJRWMD, and Central and Southern Florida project design memorandums (USACE, 1991; Armstrong, 2001; Jobes, Personal Communication, 2014). As was stated previously, all stage-discharge curves were computed to discharge the maximum amount that was feasible due to the pump stations present.

Baseflow Assumptions - The hydrogeology condition within the Upper and Middle St. Johns River is comprised of two primary aquifer systems, the Surficial Aquifer System (SAS) and the Floridan Aquifer System (FAS). The aquifer systems are separated by the Hawthorn Formation confining unit. The Hawthorn Formation varies in thickness across the St. Johns River basin (SJRWMD, 2012). Within the Upper St. Johns River the formation is relatively thick upstream of SR 520 but becomes very thin from SR 520 to SR 40 and within a majority of the middle St. Johns River. In areas where the formation is thick, groundwater discharge is minimal but in areas where the formation is thin or non-existent, groundwater discharge into or out of the FAS can be significant. According to the SJRWMD's St. Johns River Water Supply Impact Study; Groundwater Hydrology (2012), the potentiometric surface of the Upper FAS is above the water table of the SAS in many areas which creates a positive head difference and since the Upper FAS is in direct interaction with the river, groundwater can discharge into the river. This discharge occurs mainly through springs and by diffuse seepage.

Groundwater inflow from the FAS was modeled mainly as subbasin baseflow. Within the study area, much of middle St. Johns River Basin and lower portion of the Upper St. Johns River Basin experience discharge from the FAS in areas surrounding the actual "flowway" of the St. Johns River. In addition, two springs in the Middle basin, Starbuck Spring and Clifton Spring which produce 1 to 10 million gallons per day (mgd) and are incorporated into the baseflow calculations in this area (Florida Geological Survey, 2004).

Model Calibration - The full HEC-HMS model was calibrated and validated using existing observed precipitation events in the study area. The calibration and validation periods were chosen based upon the total St. Johns River watershed so that all three integrated models discussed earlier could be tied together. Due to the large area under consideration, precipitation was quite different spatially for the three model domains. This is especially true for the chosen validation period. Spatial differences in precipitation totals and intensity were also noted for the calibration period chosen, however, the precipitation return frequency for all watershed areas was generally greater than 25 to 50 years so the differences turned out to be less important. This was not the case for the chosen validation period which is discussed in subsequent sections of this report.

To ensure that the model simulates the proper results and environmental processes, the model is calibrated to the observed conditions during the period of August 1, 2008 to October 8, 2008 which coincided with landfall of Tropical Storm Fay. The process for calibration includes: 1) establishing the model parameters and determining those that will be changed for calibration, 2) defining the observed values and locations to which the model results should reproduce, 3) determining statistical goals for the model to be considered "calibrated", 4) performing iterative solutions and adjustment of parameters until the calibration goals have been met.

Calibration Parameters - The model input parameters were previously discussed in Section 3.0. Particular emphasis was placed upon variables that may need modification to produce a best fit between the model and gauge observations. For the sub-basin parameters, these variables include the lag time, curve number, initial abstraction, and baseflow. Initial values for these parameters include: using the average lag time, average curve number between the AMC I and AMC II condition, initial abstraction at 0.2 of the potential maximum retention, and baseflow value assigned at a value of 0 to 0.5 m^3/s for each sub-basin, depending on the basin size. As stated previously, multiple lag time equations were used to provide an assumed reasonable range for calibration. The results of the lag time values show the SCS lag time equation having the average lowest calculated lag time whereas the NRCS 1972 or Manning's Kinematic Shallow Concentrated equation had the larger calculated lag times. The curve number was only adjusted based on an assumed AMC because the land use/land type data is expected to be correct, but the moisture content may vary depending on the simulation starting condition. The initial abstraction value was changed depending on the curve number chosen, due to their interrelation based on the percent of potential maximum retention. The baseflow values were estimated for those basins that are ungauged based on the approximate baseflow from gauged basins, known existing water levels, and any calculated spring flows.

It became apparent that the timing of the peak flow compared well to that of the discharge gauges, but the flow rate was greater than recorded at the gauge. In addition, the flow rates at the beginning of the simulation were too low within the flow way (USGS gauges 02232000 and 02232400), which meant the initial baseflow for the St. Johns was too low. The outflow results for the sub-basins which had discharge gauge data matched relatively well, with only minor modifications to the curve number and lag time to reproduce the gauge results.

The calibration parameter for each reach element was the selected manning's N value within the Muskingum-Cunge routing method because all other parameters are physically measured. In addition, the loss/gain method will act as a calibration parameter due to the storage potential within the St. Johns flowway.

The reservoir element parameters for calibration include the initial reservoir elevation and outflow curves. Starting water surface elevations for the calibration model reservoirs were based on observed gauge data at locations where observed data was available. Typical water surface elevations, where observed gauge data was not available, were estimated on basin knowledge and elevations relative to the gauged basins. The outflow curve data is meant to replicate realistic pumping rates for those basins and therefore the storage-discharge rates were modified to improve calibration statistics downstream while maintaining relatively close inflow and outflow rates.

Calibration Locations - The calibration locations are determined by the available discharge data locations as provided by USGS, SJRWMD, and SFWMD during the calibration timeframe. Unfortunately, there is not available discharge data for most of the subbasins within the Upper and Middle St. Johns River. There are multiple calibration points within the St. Johns River flowway channel. Calibration of these locations will afford the assumption that sub-basins upstream are also relatively calibrated. The locations of the pertinent gauges can be seen in Figure 2-6, as was mentioned earlier.

Calibration Goals - The primary goal of the calibration process is to match the simulation results to the observed USGS gauge data as closely as possible. The modeled error, as measured by statistical analysis, should be minimized by calibration process. The statistical results will be included later in this report.

Calibration Simulations - Calibration of the model is achieved by running the HEC-HMS simulations, comparing the results to the observed data, adjusting parameter values within their reasonable ranges, and re-simulating until the best possible match is achieved. During this process the optimal or near-optimal values of the specified calibration parameters are identified. The calibration parameters are varied during the initial calibration process in order to develop an indication of parameter sensitivity. Those parameters that seem to produce a relatively close approximation to the observed data remain the same, while other parameters are modified to reproduce the results as closely as possible. This process was repeated multiple times, beginning at the headwater of the St. Johns and moving further downstream (North) until the simulation data matched relatively well to that of the discharge gauge data. It is an iterative process where parameters for are changed both on a large scale (multi sub-basin) and small scale (singular sub-basin) basis for the closest calibration match possible.

Calibration Results - Preliminary results, at the specified parameters mentioned above, showed a reasonable fit between the model and gauge observations data. The observed hydrograph peaks and shaping matched relatively well but it became apparent the model was overestimating runoff. Continuous runoff was reduced by incorporating a higher rate of initial abstraction (approximately 0.4 for most basins). In addition, curve numbers were decreased for sub-basins believed to have dry starting conditions. Lag time values were also recalculated for any sub-basin if the soil type or infiltration topography was believed to warrant a shorter or longer lag time. The lag times were increased if the time to peak was believed to be disrupted due to structures or man-made storm drainage but were all kept within the originally calculated bounds. The specified baseflow was modified for gauged basins to provide a best-fit match to the days leading up to the storm event to replicate proper starting conditions. The final calibration parameter that was used to match the model and gauge observations was the hydrologic routing Manning's N and loss amounts. Manning's N numbers were modified slightly to ensure the proper lag time between gauge observations within the flow-way. The loss percentage within each reach was also increased or decreased slightly to ensure the proper amount of runoff was being conveyed downstream. The final Manning's N values, Lag time, and initial abstraction values for the calibration run can be seen in Figure 2-8a and Figure 2-8b. The model calibration results can be seen in Figures 5-9 thru 5-26 below. These figures show the discharge flow rate in cubic meters per second (CMS) versus time/date for the observed data (black circles) as compared against the simulated flow rate (blue continuous line). For some figures, which are representative of reach parameters, the inflow rate(s) is/are shown as a dashed blue line with the outflow being a blue continuous line. Finally, the results for the outlet of Lake Monroe shows the discharge gauge data surface water elevation in terms of meters NGVD.

Figure 2-6. Discharge Gauge Locations

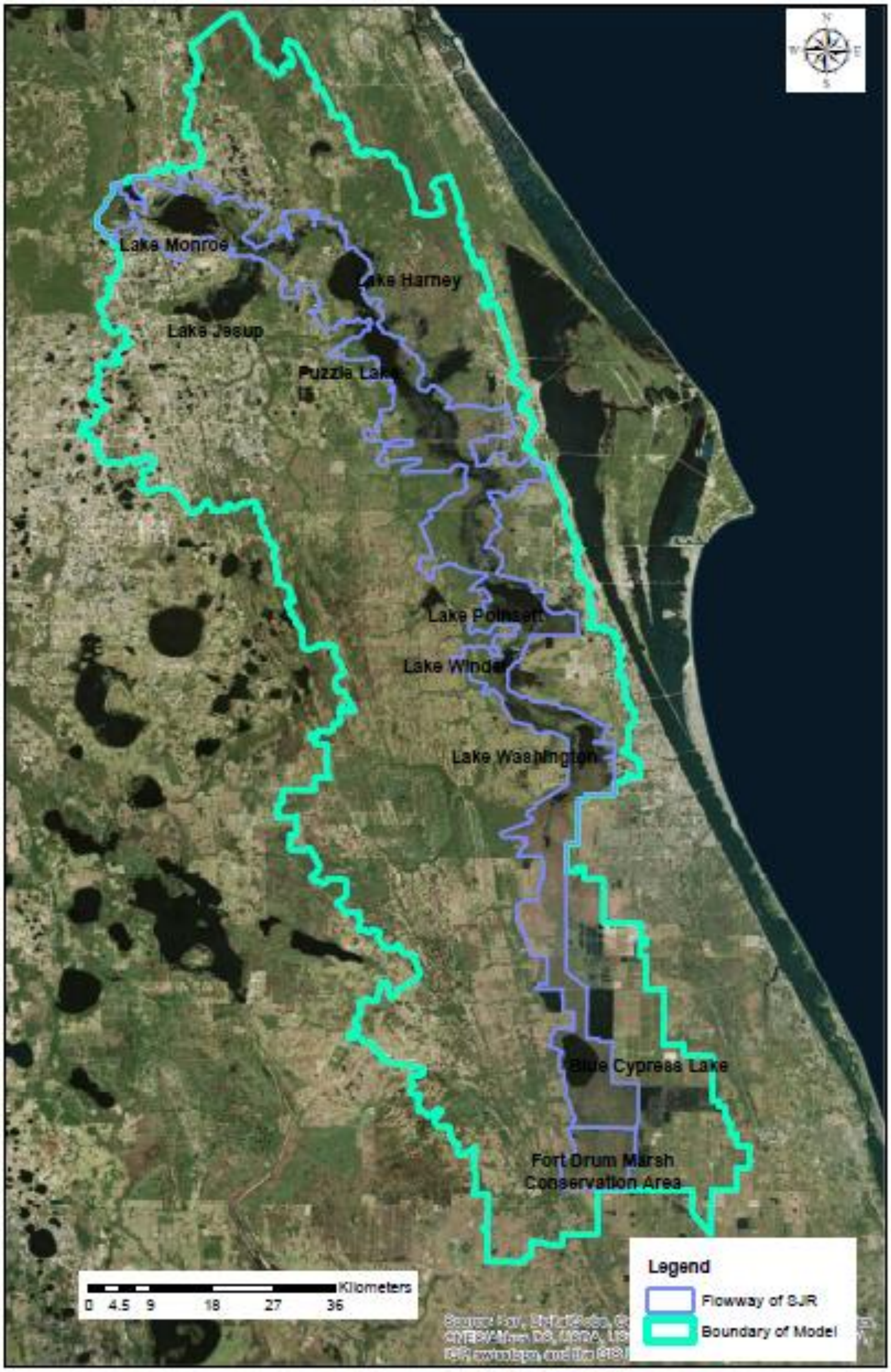


Figure 2-7. Model Boundary and St. Johns River Flowway.

Subbasin	I. A. (mm)	C. N.	Lag Time (min.)	Subbasin	I. A. (mm)	C. N.	Lag Time (min.)
Akins Blay Slough	38	73	1335	Lake Jesup Trib	38	74	750
Ashby Canal	27	80	1550	Lake Poinsett Rainfall North	37	74	3200
Barney Green	42	72	1560	Lake Poinsett Rainfall South	34	74	2850
Barry Groves	24	81	2646	Lake Price Outlet	47	68	1000
BC East Rainfall	14	88	3351	Lake Proctor	81	51	550
BCMCA Rainfall	27	79	7400	Lake Theresa	80	55	2600
BC West Rainfall	23	82	1700	Lake Wash 1 Rainfall	13	89	5700
Bear Gully	51	68	1712	Lake Wash 2 Rainfall	13	89	3600
Beck Hammock	17	86	700	Lake Wash 3 Rainfall	13	89	2900
Bel-Air Ditch	24	81	483	Lake Wilson Outlet	27	79	2361
Bird Lake Combined	30	78	1800	Lake Winder Rainfall	22	83	4200
Bird Lake Ditches	31	78	1000	Lake Winnemissett	110	43	242
Bithlo Branch	26	80	650	Lake Winnemissett Oulet	46	70	400
Blue Cypress Creek	55	65	3500	Lemmon Bluff Ditch	55	65	700
Broadmoor Marsh	32	76	1370	Little Creek	38	72	2000
Bull Creek	36	75	1300	Little Econlock River	51	66	2000
Buscombe Creek	15	87	1000	Little Econlock Tributary	43	70	2100
C25 Ext	43	71	2130	Little Lake Howell	72	60	800
C54 Retention Area	10	92	1163	Little Lake Outlet	42	72	560
Cabbage Slough	31	76	2300	Long Branch	23	75	650
Caine Farms	18	85	1250	Mary A Groves	15	87	715
Cannon Ditch	10	91	350	Mary A Groves Res Rain	29	79	500
Christmas Creek	14	89	1500	Mary A Groves Restoration	6	95	574
Chub Creek	21	83	400	Mary A Rainfall	37	74	1400
Clark Lake Outlet	30	78	3100	Mills Creek	27	80	1550
Cocoa Canals	21	84	2000	Mitchell Creek	15	88	1285
Cow Creek	31	78	1884	Moccasin Isl 1	40	73	7600
Cowpen Branch	28	79	750	Moccasin Isl 2	17	86	3000
Cox Creek Lower	41	71	1400	Moccasin Isl 3	21	83	2500
Cox Creek Res Rainfall	41	73	990	Moccasin Isl 4	26	80	2000
Cox Creek upper	30	78	1300	Moccasin Isl 5	35	75	1800
Crane Strand Drain	55	68	1500	Moccasin Isl 6	47	69	3300
Cross Triangle	32	77	1900	Muti Lakes of Orlando	45	71	2400
Deep Creek	56	64	4800	Padgett Branch	28	79	2405
Deep Creek Lower	40	73	800	Pennywash Creek	38	65	1350
Deforest Lake Outlet	106	51	1333	Pressley Ranch	40	73	1282
Delespine Grant	34	76	1400	Pressley Ranch South	33	76	869
Delta Farms	64	63	1240	Ravenna Park Ditches	56	66	872
Delta Farms Res Rain	20	84	735	Rdd Primary Canal	33	76	1650
Deseret 1	10	91	720	Red Bug Lake	96	53	400
Deseret 2	21	84	662	Roberts Branch	30	77	1600
Deseret East	24	81	1525	Rockledge	50	68	2129
Deseret Farms	40	73	2240	Rollins Ranch	40	73	955
Deseret Farms South	41	72	1400	Rollins South A	41	72	1143

Figure 2-8A. Calibration Parameter Values.

Subbasin	I. A. (mm)	C. N.	Lag Time (min.)	Subbasin	I. A. (mm)	C. N.	Lag Time (min.)
Econlock 1	35	73	1300	Rollins South B	40	73	1143
Econlock 2	72	58	1200	Rollins South C	40	73	1143
Econlock 3	53	65	2500	Salt Creek Combined	28	79	1050
Econlock 4	44	70	2150	Samsula Canal	29	79	1500
Econlock 5	50	67	1700	Sartori East	40	73	1459
Econlock River Swamp	56	64	3000	Sartori Farms	16	87	1797
Econlock River Trib 1	36	74	1000	Savage Creek	16	87	1000
Econlock River Trib 2	36	74	1000	Second Creek	27	80	1700
Evans Grove	31	77	1190	Sixmile Creek	26	80	2000
FDMCA Rainfall	27	79	2570	Sixmile Restoration Area	35	75	1131
FF PS1	36	75	1970	Sixmile Tributary	26	80	745
FF PS2	36	75	1720	SJR Cone	20	84	2100
FF PS3	18	85	1265	SJR Harney	12	89	1650
FF PS4	34	76	1525	SJR Monroe	23	77	3500
FF PS5	15	87	875	SJR Mullet	22	83	3200
FF PS6	38	74	1751	SJR Puzzle	12	92	2500
FF PS7	33	76	1593	SJR State Road 46	29	79	1300
Fort Drum Creek	54	66	2400	SJR State Road 50	20	84	3500
Fourmile Creek	45	74	3000	SJR Tornhill	7	94	1250
Gee Creek	54	67	1088	SJWMA Rainfall	40	73	1681
Golden Lake Outlet	7	92	420	SN Knight (Kenansville)	16	86	130
Goupher Slough	19	85	2074	Soldier Creek	56	66	1087
Green Branch	32	76	650	South Lake Outlet	35	75	1200
Howell Creek	68	61	2083	St Johns Imp Dis	37	74	7054
JG Bull Creek	50	67	3400	St Johns Imp Dis Res Rain	37	74	1516
JG Crabgrass Creek	57	64	3500	St Johns Trib 1&2	21	83	2500
JG Creek	39	73	2984	St Johns Trib 3	17	86	850
JG Tributary	37	74	2363	St Johns Trib 7	24	82	1200
Jim Creek	32	77	2700	St Johns Trib 9	38	74	3500
Jim Creek North	41	72	2200	Taylor Creek	23	82	1102
Jim Green Creek	33	76	2125	Taylor Creek Res Rainfall	41	72	2511
Joshua Creek	19	84	2200	Tenmile Creek	41	72	2272
King Street	36	75	2500	The Savannah	72	60	500
Knight Creek	13	89	1483	Tootoosahatchee Creek	38	74	1600
Lake Ashby	18	85	400	Tropic Lagoon Combined	47	70	445
Lake Ashby Tributary	36	75	2500	Tucker Rainfall	34	76	669
Lake Berge Outlet	44	70	1000	Turkey Creek	38	73	1150
Lake Gleason	102	45	320	Underhill Slough	17	86	836
Lake Hell n Blazes	41	72	1200	Union Park Canal	55	69	1600
Lake Irma Outlet	60	68	1200	Wolf Creek	65	64	1400
Lake Jesup Rainfall	9	89	1800	Wolf Creek North	24	76	1500

Figure 2-8B. Calibration Parameter Values.

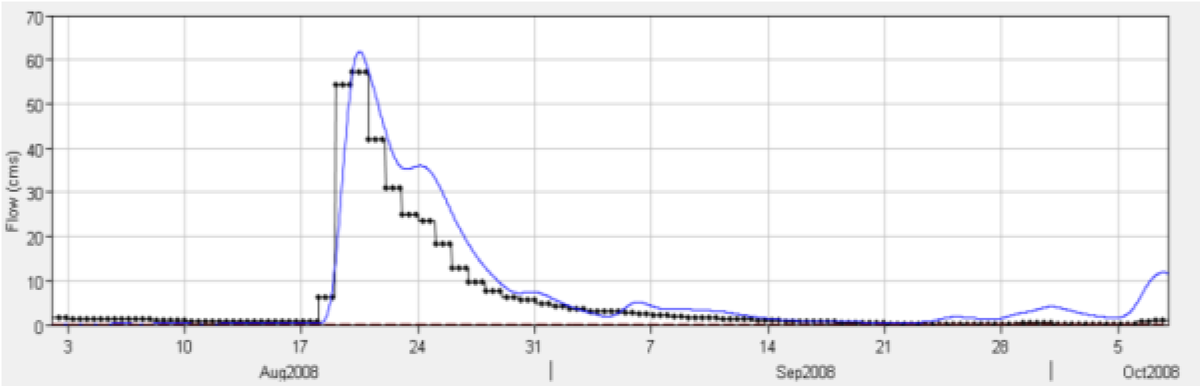


Figure 2-9. Ft. Drum Creek Calibration Results, USGS Gauge 02231342

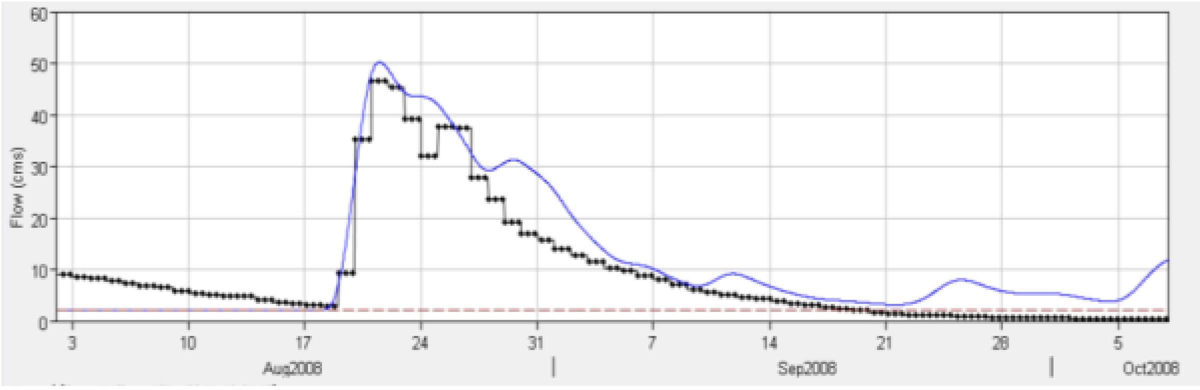


Figure 2-10. Blue Cypress Creek Calibration Results USGS Gauge 02231396

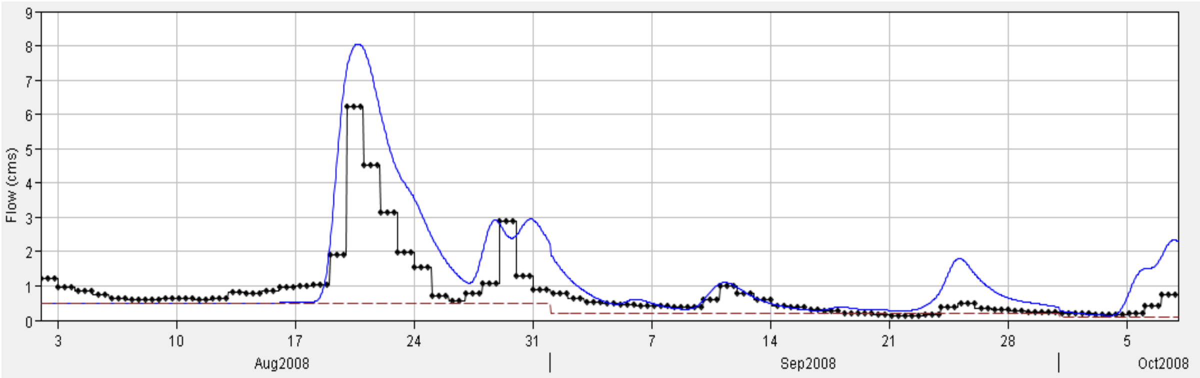


Figure 2-11. Wolf Creek Calibration Results USGS Gauge 02231458

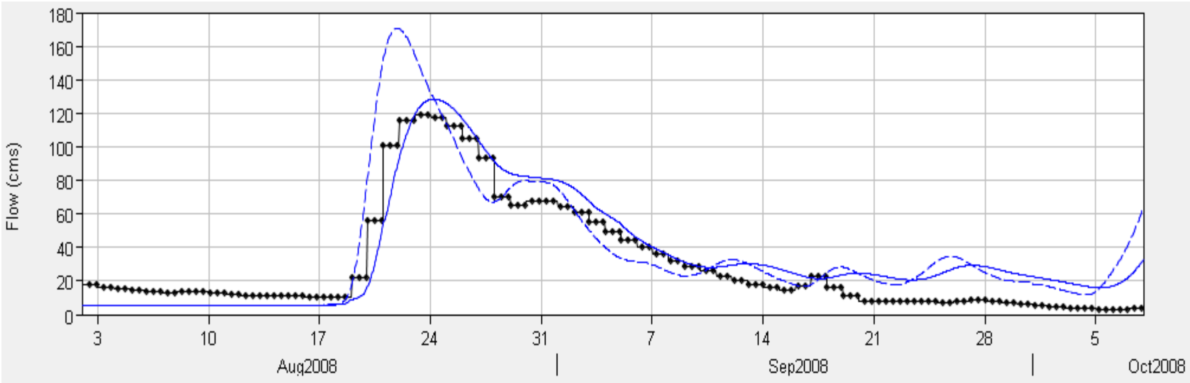


Figure 2-12. Jane Green Reservoir Calibration Results USGS Gauge 02231600

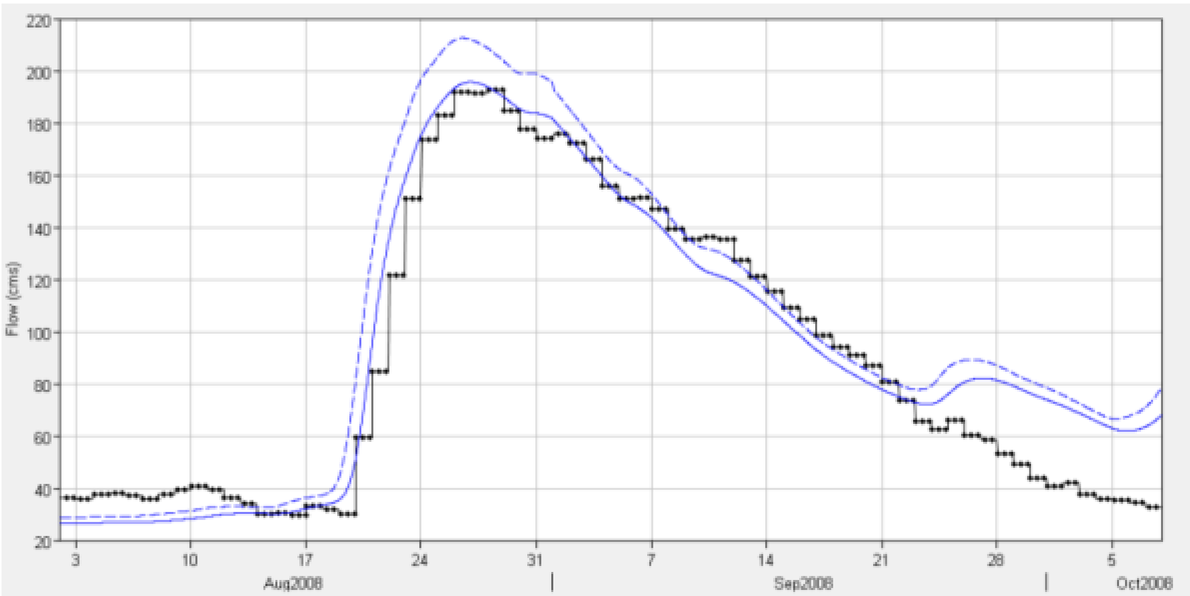


Figure 2-13. St. Johns River at U.S. Highway 192 Calibration Results USGS Gauge 02232000

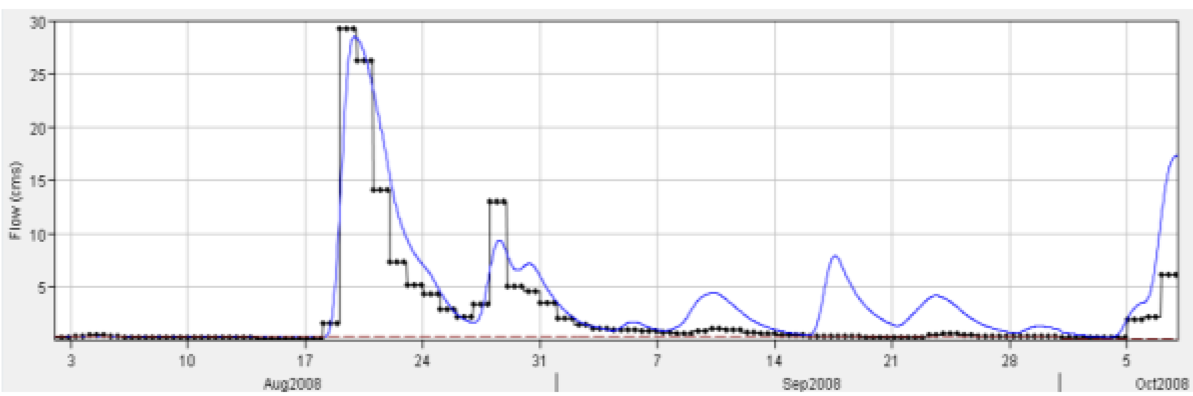


Figure 2-14. Pennywash Creek Calibration Results USGS Gauge 02232155

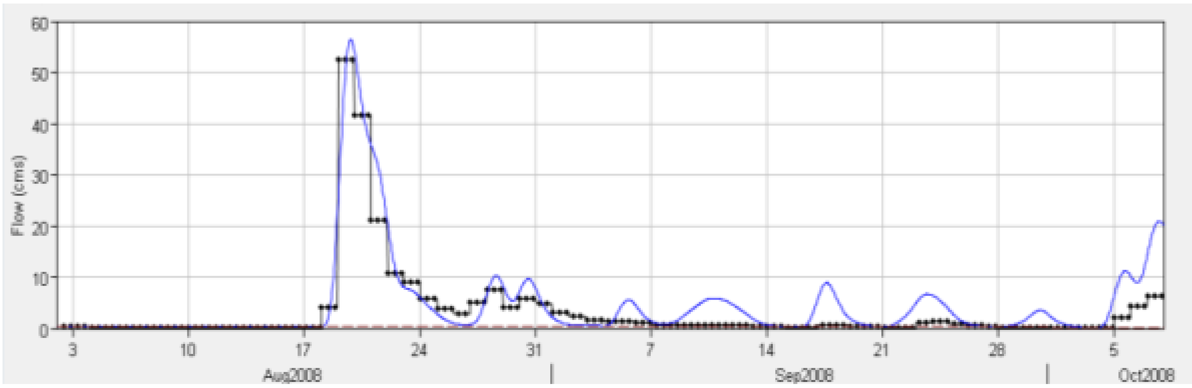


Figure 2-15. Wolf Creek North Calibration Results USGS Gauge 02232200

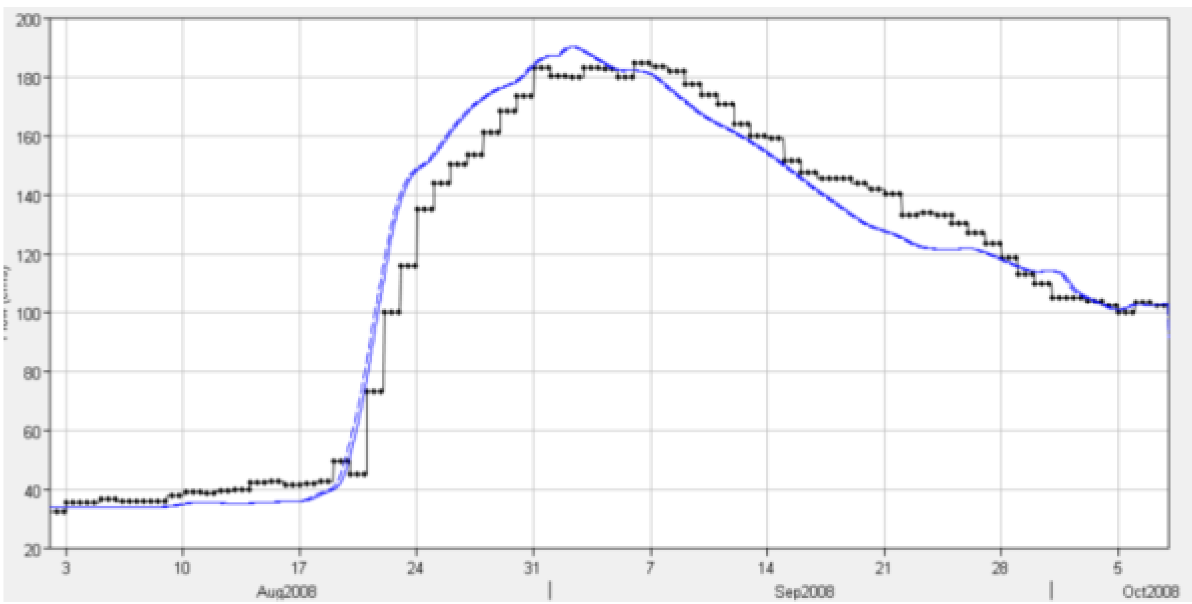


Figure 2-16. St. Johns River at State Highway 520 Calibration Results USGS Gauge 02232400

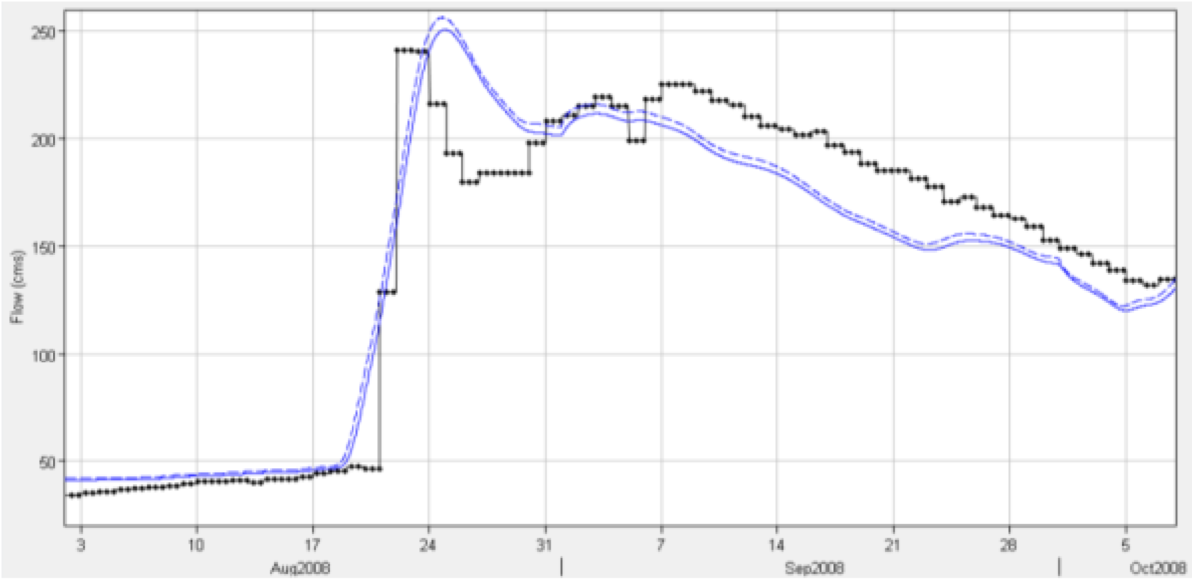


Figure 2-17. St. Johns River at State Highway 50 Calibration Results USGS Gauge 02232500

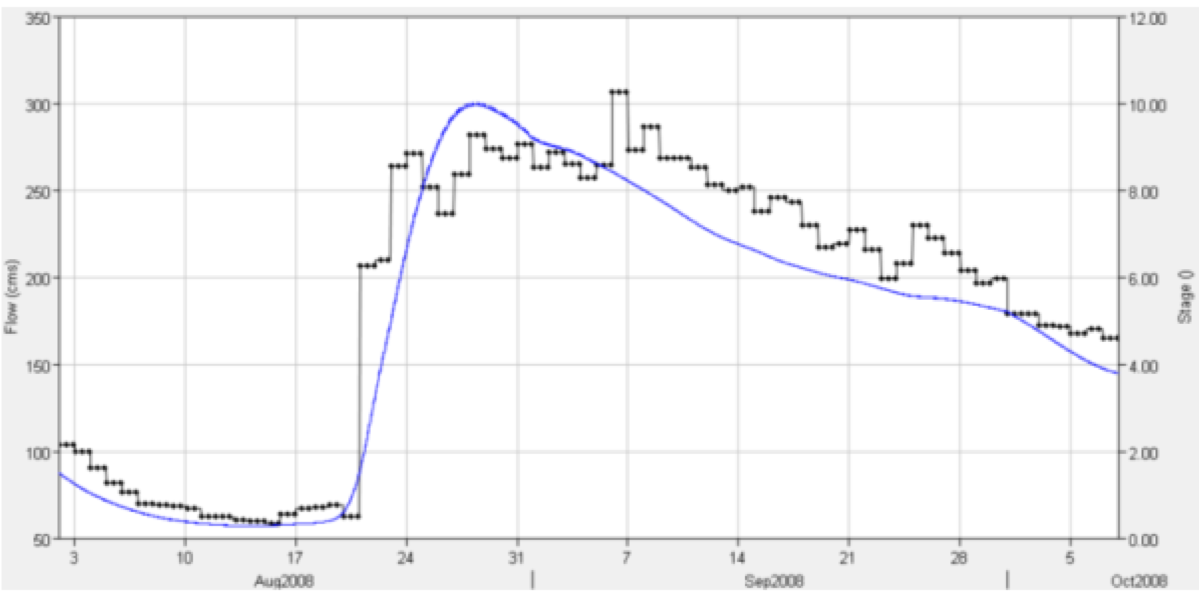


Figure 2-18. St. Johns River at Inlet of Lake Harney Calibration Results USGS Gauge 02234000

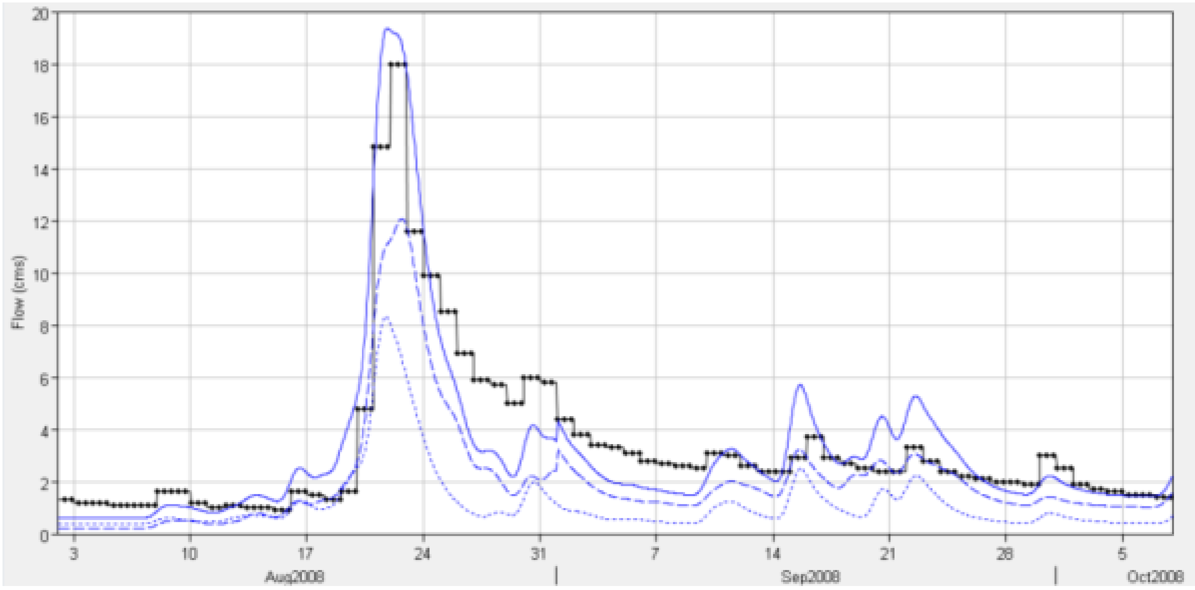


Figure 2-19. Little Econlockhatchee River near Union Park Calibration Results USGS Gauge 02233460

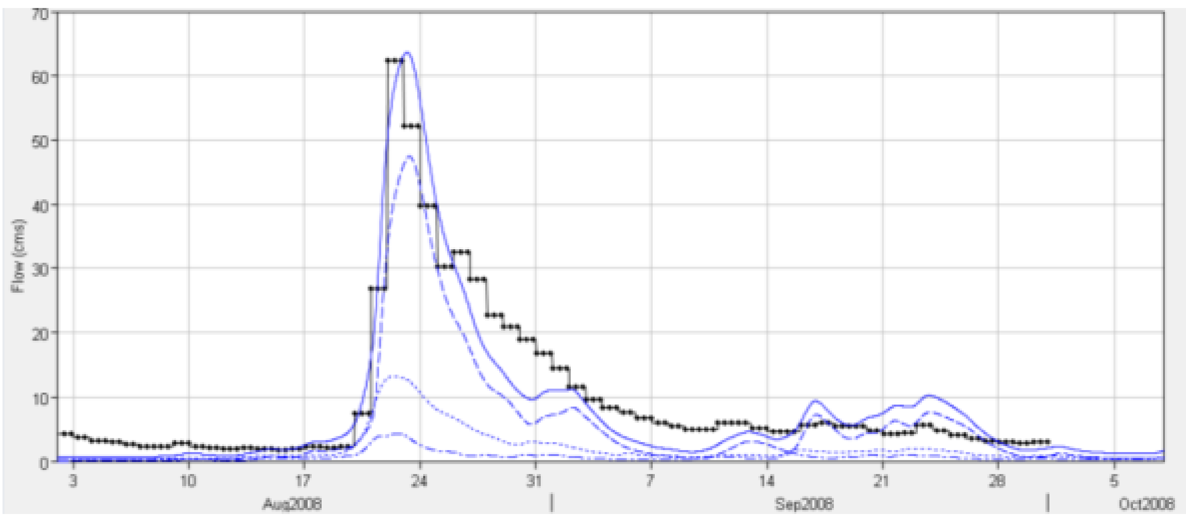


Figure 2-20. Little Econlockhatchee River at University Blvd. Calibration Results USGS Gauge 02233473.

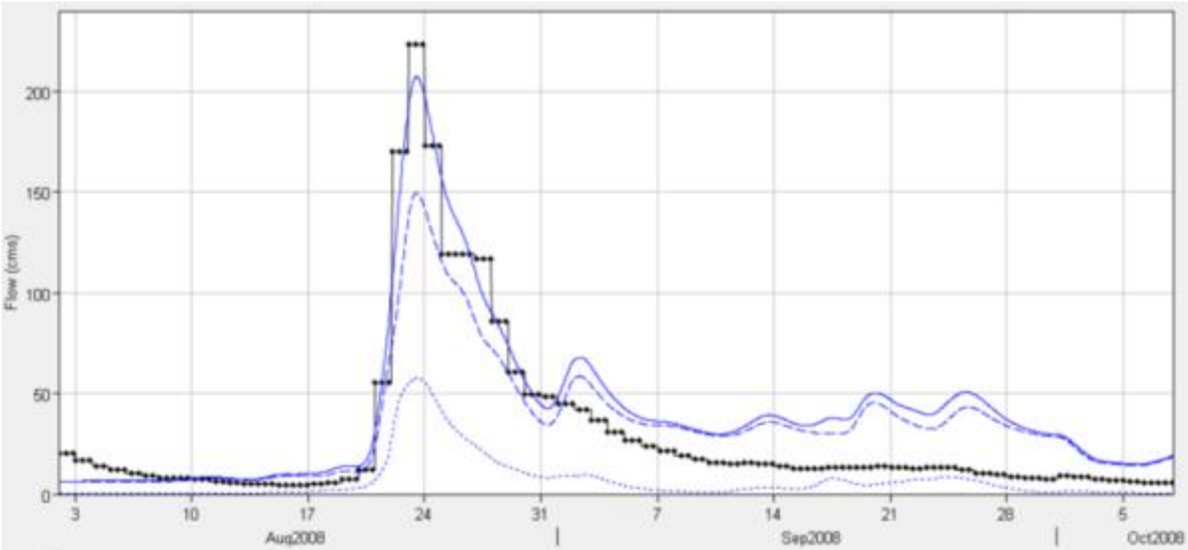


Figure 2-21. Econlockhatchee River near Oviedo Calibration Results USGS Gauge 02233484

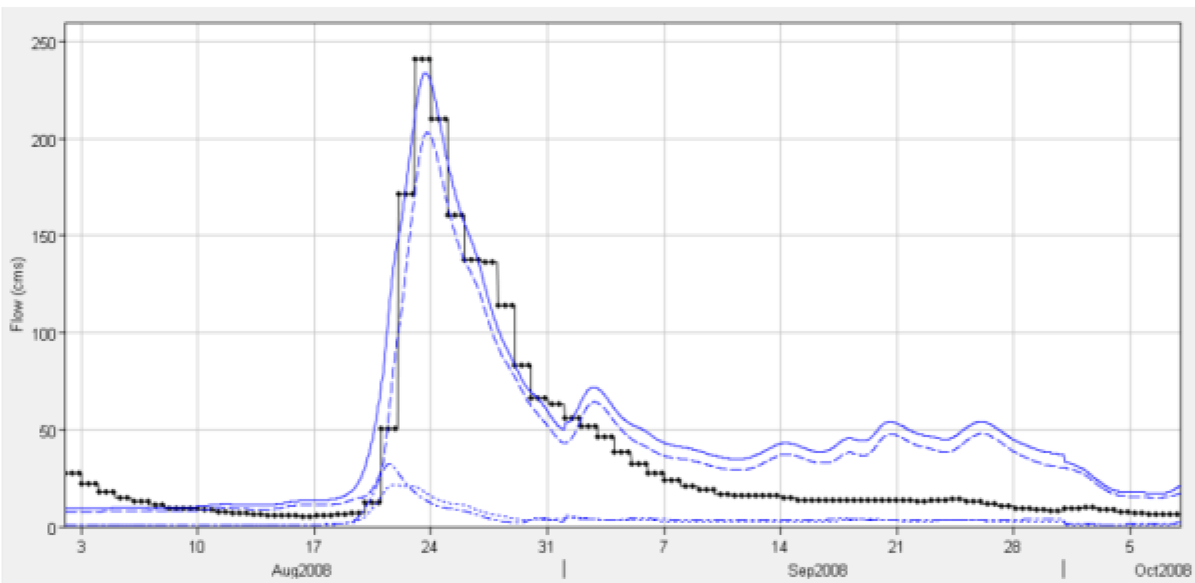


Figure 2-22. Econlockhatchee River near State Highway 13 Calibration Results USGS Gauge 02233500

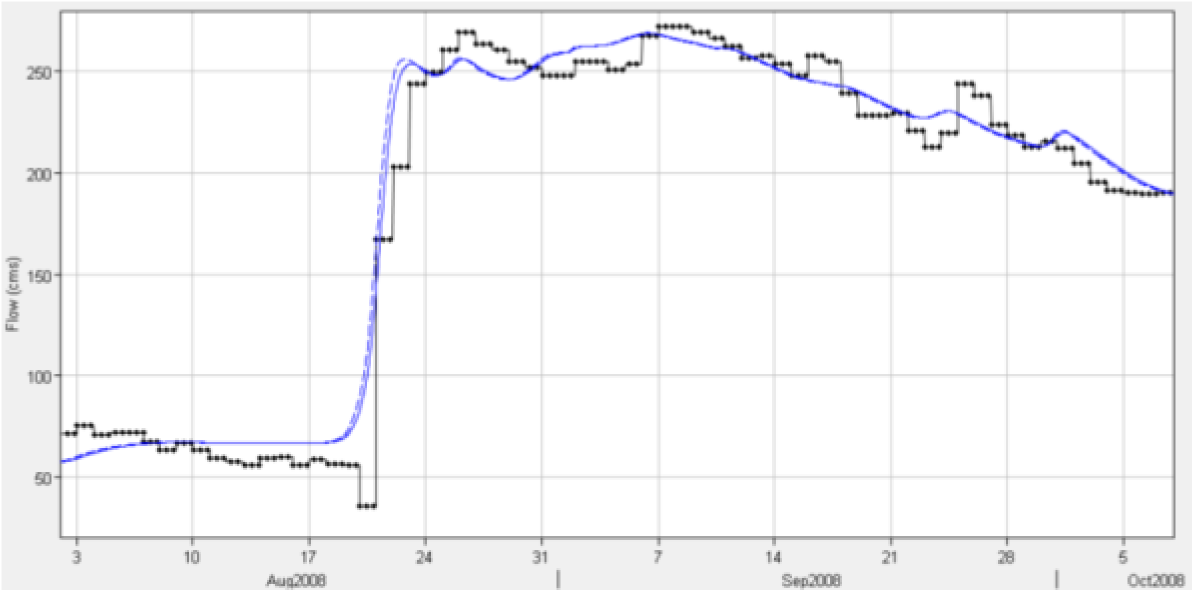


Figure 2-23. St. Johns River at Outlet of Lake Harney Calibration Results USGS Gauge 02234010

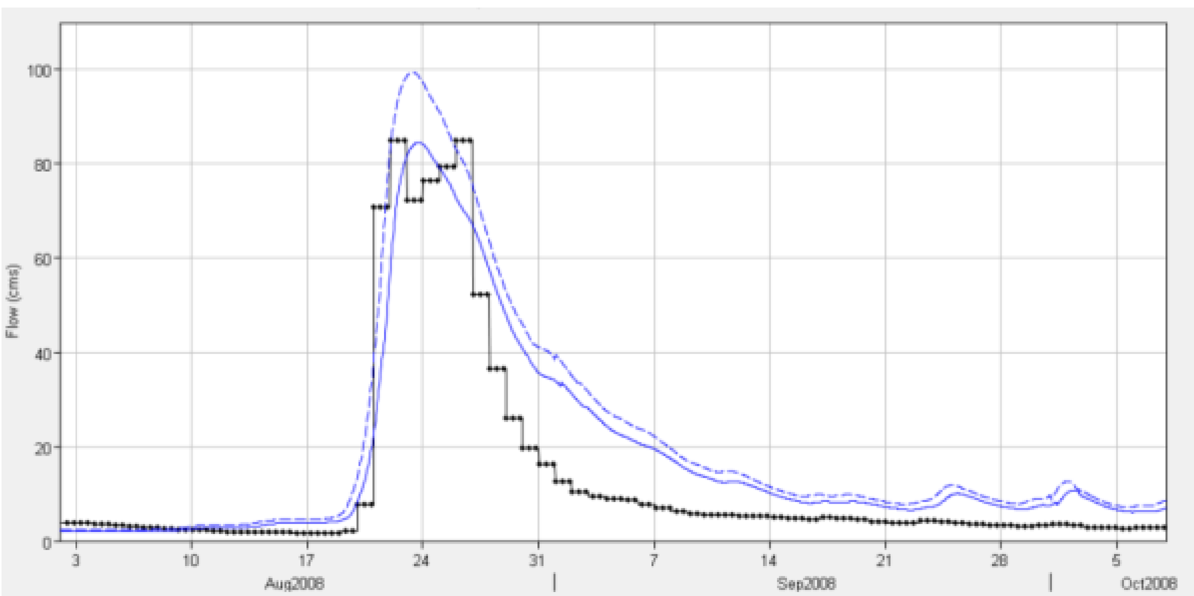


Figure 2-24. Deep Creek Outlet SJRWMD Calibration Results Gauge 02830228

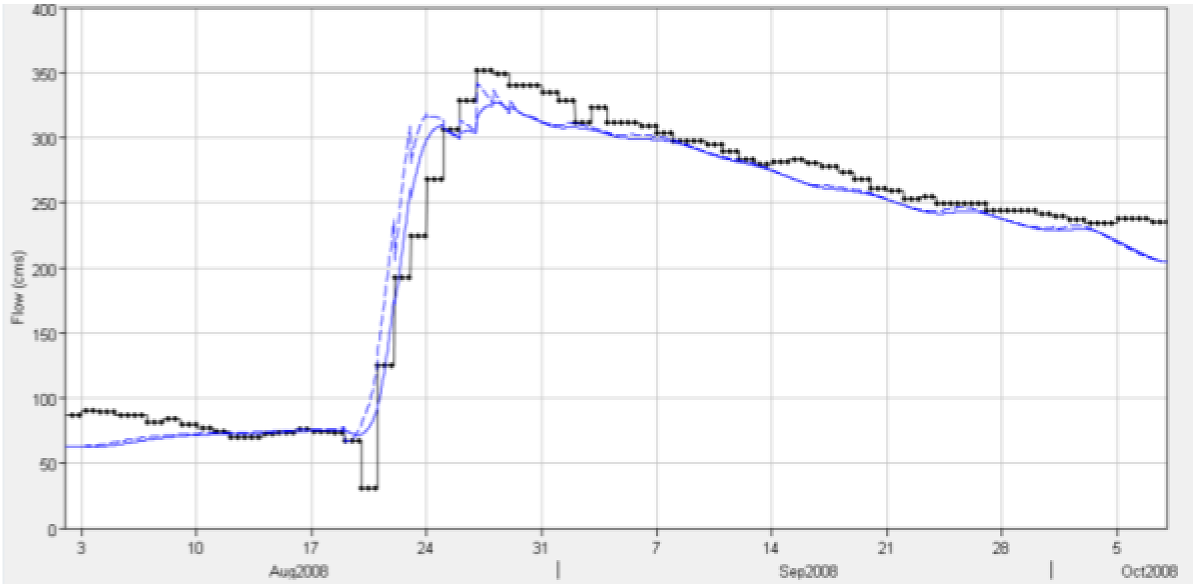


Figure 2-25. St. Johns River at Inlet of Lake Monroe Calibration Results USGS Gauge 02234440

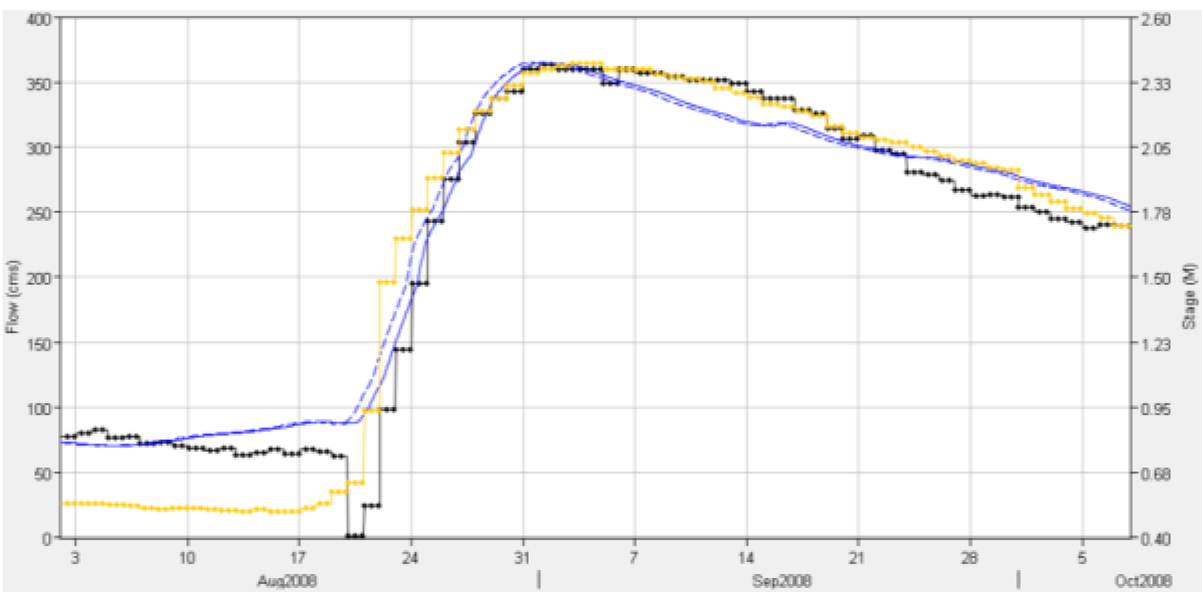


Figure 2-26. St. Johns River at Outlet of Lake Monroe Calibration Results USGS Gauge 02234500

Model Calibration Performance Evaluation - Having known discharge gauge and simulation data allows a direct comparison to be made to evaluate the performance of the model. This comparison will be completed using two different statistical measures: the coefficient of correlation and the Nash-Sutcliffe efficiency coefficient. The coefficient of correlation (r) measures the strength and direction of the linear relationship between variables of the measured gauge data and simulation data. The calculated r value will be between -1 and 1, with 0 representing no correlation. The linear correlation becomes stronger as the r value approaches -1 or 1. The coefficient of determination (r^2) gives the variance of the data and assesses a goodness of fit at each calibration point for the model. It can help explain the variability of the model and how well the model may produce results for future predictions. The coefficient of determination is between 0 and 1, with 1 indicating a perfect fit with all variation explained.

The Nash-Sutcliffe efficiency coefficient (E) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance and indicates how well the plot of the observed data versus the simulated data fits the 1:1 line (Wang et al., 2009). The ranges for E can vary between $-\infty$ to 1, where: E=1 corresponds to a perfect match between discharge data and observed data; E=0 shows that the model predictions are as accurate as the mean of the observed data; and $-\infty<E<0$ occurs when the observed mean is a better predictor than the model, which indicates unacceptable performance (Wang et al., 2009). The St. Johns River Water Supply Impact Study (2012) completed by the SJRWMD used the Nash-Sutcliffe statistic to explain the calibration performance for their hydraulic model. Following similar methodology, the Nash-Sutcliffe coefficient values will be divided into intervals which explain performance rating. The intervals are as follows: $0.75 < E < 1$ is a "very good" performance rating, $0.65 < E < 0.75$ is a "good" performance rating, $0.50 < E < 0.65$ is a "satisfactory" performance rating, and $E < 0.50$ is an "unsatisfactory" performance rating.

The calibration performance results for the calibrated model are shown in Table 2-4. As can be seen, all 18 calibration locations except USGS gauge 02231458 at Wolf Creek show a "very good" performance rating. In addition, the coefficient of correlation is above .90 and coefficient of determination is above .80 for all gauges, except Wolf Creek. The Wolf Creek gauge data versus the simulation data shows that the hydrograph peaks at the appropriate time but the simulated run-off is higher than that of the observed data. Further study of this sub-basin may be warranted in the future to improve model calibration in this area.

Location	Gauge	r	r^2	E
Fort Drum Creek	USGS 02231342	0.94	0.88	0.84
Blue Cypress Creek	USGS 02231396	0.94	0.88	0.80
Wolf Creek	USGS 02231458	0.89	0.78	0.17
Jane Green Reservoir	USGS 02231600	0.94	0.88	0.85
U.S. Highway 192	USGS 02232000	0.96	0.93	0.93
Pennywash Creek	USGS 02232155	0.90	0.81	0.75
Wolf Creek North	USGS 02232200	0.92	0.85	0.81
State Highway 520	USGS 02232400	0.99	0.97	0.97
State Highway 50	USGS 02232500	0.95	0.91	0.90
Inlet of Lake Harney	USGS 02234000	0.96	0.92	0.89
Little Econlockhatchee River at Union Park	USGS 02233460	0.91	0.84	0.79
Little Econlockhatchee River at University Blvd.	USGS 02233473	0.95	0.90	0.88
Econlockhatchee River near Oviedo	USGS 02233484	0.94	0.89	0.82
Econlockhatchee River near State Highway 13	USGS 02233500	0.94	0.88	0.79
Outlet of Lake Harney	USGS 02234010	0.99	0.97	0.97
Deep Creek	SJRWMD 02830228	0.93	0.86	0.82
Inlet of Lake Monroe	USGS 02234440	0.99	0.97	0.97
Outlet of Lake Monroe	USGS 02234500	0.99	0.97	0.97

Table 2-4. Calibration Statistical Performance Results.

Model Validation - The model is validated to the observed conditions during the period of October 1, 2007 to October 13, 2007. Issues arose during model validation because the basin received rain in the period before the validation period; therefore runoff was still occurring at the start of the validation period. The model start up for the validation period was commenced on 29 Sept to allow for so-called model "spin-up time".

Similar processes to those explained in section 3.5 Model Calibration were used during the model validation effort. The starting parameters of the validation model were the same as those determined in the model calibration. The goal of the validation model was to keep as many parameters the same as the calibration model, with minor changes due to initial starting conditions and basin behaviors due to the differences in initial conditions and rainfall events. It was determined that the different starting conditions would be accounted for by changing the initial abstraction values and baseflow values. Certain sub-basins during the validation run may be considered AMC II condition due to the precipitation received before the simulation began. For these sub-basins, the initial abstraction ratio was modified to a value lower than used in the calibration. In addition, the loss percentage within the flow way of the St. Johns River was altered for this smaller rain event. This is due to the larger loss percentages in the smaller rain event due to a higher storage volume available. In the large calibration event storage was reduced due to the large rain event occupying most of the overbank storage. The elevated water levels assumed during calibration caused lower storage availability because once the flow dominates the overbank section it begins to flow faster and the floodplain conveyance will increase. It has been seen in previous studies that the under low flow conditions the floodplain can act as a storage reservoir with low out of bank flow rates, but the retention potential rapidly increases as the return period of the storm event increases due to the floodplain approaching the conditions of a conveyance channel due to the elevated water conditions (Wyzga, 1999).

The final validation parameters can be seen in Figure 2-27a and Figure 2-27b, and the validation results can be seen in Figures 5-28 thru 5-46. The validation results do not match the discharge gauge data as well as the calibration model. Reasons for this may be the large difference in order of magnitude of precipitation during the simulation runs for the calibration period (e.g. high return frequency precipitation event) and validation period (very low return frequency precipitation event). Due to the minimal amount of precipitation received during the validation period, runoff values are very sensitive to the initial abstraction rate, curve number, and lag time parameters. As can be seen from the figures below, many of the gauges had changes in discharge rates of under 5 cms. Explanations for possible error in the Validation run results and possible improvements to the model and subsequent validation results will be explained later in this report.

Subbasin	I. A. (mm)	C. N.	Lag Time (min.)	Subbasin	I. A. (mm)	C. N.	Lag Time (min.)
Akins Blay Slough	38	73	1335	Lake Jesup Trib	38	74	750
Ashby Canal	27	80	1550	Lake Poinsett Rainfall North	37	74	3200
Barney Green	42	72	1560	Lake Poinsett Rainfall South	34	74	2850
Barry Groves	24	81	2646	Lake Price Outlet	47	68	1000
BC East Rainfall	14	88	3351	Lake Proctor	81	51	550
BCMCA Rainfall	27	79	7400	Lake Theresa	80	55	2600
BC West Rainfall	23	82	1700	Lake Wash 1 Rainfall	13	89	5700
Bear Gully	51	68	1712	Lake Wash 2 Rainfall	10	89	3600
Beck Hammock	17	86	700	Lake Wash 3 Rainfall	13	89	2900
Bel-Air Ditch	24	81	483	Lake Wilson Outlet	27	79	2361
Bird Lake Combined	30	78	1800	Lake Winder Rainfall	19	83	4200
Bird Lake Ditches	31	78	1000	Lake Winnemissett	110	43	242
Bithlo Branch	26	80	650	Lake Winnemissett Oulet	46	70	400
Blue Cypress Creek	31	65	3500	Lemmon Bluff Ditch	55	65	700
Broadmoor Marsh	32	76	1370	Little Creek	38	72	2000
Bull Creek	36	75	1300	Little Econlock River	51	66	2000
Buscombe Creek	15	87	1000	Little Econlock Tributary	43	70	2100
C25 Ext	43	71	2130	Little Lake Howell	72	60	800
C54 Retention Area	10	92	1163	Little Lake Outlet	42	72	560
Cabbage Slough	31	76	2300	Long Branch	23	75	650
Caine Farms	18	85	1250	Mary A Groves	15	87	715
Cannon Ditch	10	91	350	Mary A Groves Res Rain	296	79	500
Christmas Creek	14	89	1500	Mary A Groves Restoration	6	95	574
Chub Creek	21	83	400	Mary A Rainfall	37	74	1400
Clark Lake Outlet	30	78	3100	Mills Creek	27	80	1550
Cocoa Canals	21	84	2000	Mitchell Creek	15	88	1285
Cow Creek	31	78	1884	Moccasin Isl 1	40	73	7600
Cowpen Branch	28	79	750	Moccasin Isl 2	17	86	3000
Cox Creek Lower	41	71	1400	Moccasin Isl 3	21	83	2500
Cox Creek Res Rainfall	41	73	990	Moccasin Isl 4	26	80	2000
Cox Creek upper	30	78	1300	Moccasin Isl 5	35	75	1800
Crane Strand Drain	55	68	1500	Moccasin Isl 6	47	69	3300
Cross Triangle	32	77	1900	Muti Lakes of Orlando	45	71	2400
Deep Creek	62	64	4800	Padgett Branch	28	79	2405
Deep Creek Lower	40	73	800	Pennywash Creek	48	65	1350
Deforest Lake Outlet	106	51	1333	Pressley Ranch	40	73	1282
Delespine Grant	34	76	1400	Pressley Ranch South	33	76	869
Delta Farms	64	63	1240	Ravenna Park Ditches	56	66	872
Delta Farms Res Rain	20	84	735	Rdd Primary Canal	33	76	1650
Deseret 1	10	91	720	Red Bug Lake	96	53	400
Deseret 2	21	84	662	Roberts Branch	30	77	1600
Deseret East	24	81	1525	Rockledge	50	68	2129
Deseret Farms	40	73	2240	Rollins Ranch	40	73	955
Deseret Farms South	41	72	1400	Rollins South A	41	72	1143

Figure 2-27A. Validation Parameter Values.

Subbasin	I. A. (mm)	C. N.	Lag Time (min.)	Subbasin	I. A. (mm)	C. N.	Lag Time (min.)
Econlock 1	35	73	1300	Rollins South B	40	73	1143
Econlock 2	72	58	1200	Rollins South C	40	73	1143
Econlock 3	53	65	2500	Salt Creek Combined	28	79	1050
Econlock 4	44	70	2150	Samsula Canal	29	79	1500
Econlock 5	50	67	1700	Sartori East	40	73	1459
Econlock River Swamp	56	64	3000	Sartori Farms	16	87	1797
Econlock River Trib 1	36	74	1000	Savage Creek	16	87	1000
Econlock River Trib 2	36	74	1000	Second Creek	27	80	1700
Evans Grove	31	77	1190	Sixmile Creek	26	80	2000
FDMCA Rainfall	27	79	2570	Sixmile Restoration Area	35	75	1131
FF PS1	36	75	1970	Sixmile Tributary	26	80	745
FF PS2	36	75	1720	SJR Cone	20	84	2100
FF PS3	18	85	1265	SJR Harney	12	89	1650
FF PS4	34	76	1525	SJR Monroe	31	77	3500
FF PS5	15	87	875	SJR Mullet	22	83	3200
FF PS6	38	74	1751	SJR Puzzle	12	92	2500
FF PS7	33	76	1593	SJR State Road 46	29	79	1300
Fort Drum Creek	20	66	2400	SJR State Road 50	20	84	3500
Fourmile Creek	45	74	3000	SJR Tornhill	7	94	1250
Gee Creek	54	67	1088	SJWMA Rainfall	40	73	1681
Golden Lake Outlet	7	92	420	SN Knight (Kenansville)	16	86	130
Goupher Slough	19	85	2074	Soldier Creek	56	66	1087
Green Branch	32	76	650	South Lake Outlet	35	75	1200
Howell Creek	68	61	2083	St Johns Imp Dis	37	74	7054
JG Bull Creek	45	67	3400	St Johns Imp Dis Res Rain	37	74	1516
JG Crabgrass Creek	45	64	3500	St Johns Trib 1&2	21	83	2500
JG Creek	39	73	2984	St Johns Trib 3	17	86	850
JG Tributary	37	74	2363	St Johns Trib 7	23.5	82	1200
Jim Creek	32	77	2700	St Johns Trib 9	38	74	3500
Jim Creek North	41	72	2200	Taylor Creek	23	82	1102
Jim Green Creek	33	76	2125	Taylor Creek Res Rainfall	41	72	2511
Joshua Creek	19	84	2200	Tenmile Creek	41	72	2272
King Street	36	75	2500	The Savannah	72	60	500
Knight Creek	13	89	1483	Tootoosahatchee Creek	38	74	1600
Lake Ashby	18	85	400	Tropic Lagoon Combined	47	70	445
Lake Ashby Tributary	36	75	2500	Tucker Rainfall	34	76	669
Lake Berge Outlet	44	70	1000	Turkey Creek	38	73	1150
Lake Gleason	102	45	320	Underhill Slough	17	86	836
Lake Hell n Blazes	41	72	1200	Union Park Canal	55	69	1600
Lake Irma Outlet	60	68	1200	Wolf Creek	68	64	1400
Lake Jesup Rainfall	9	89	1800	Wolf Creek North	15	76	1500

Figure 2-27B. Validation Parameter Values.

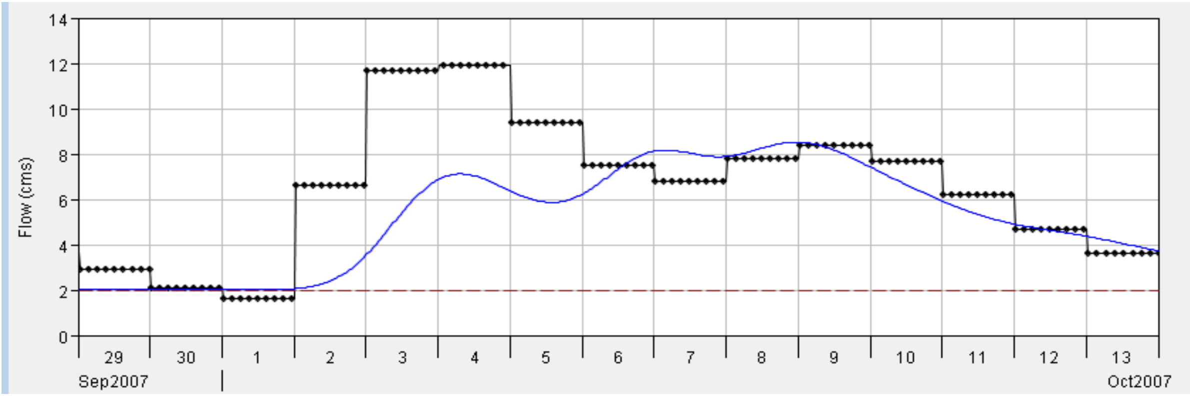


Figure 2-28. Ft. Drum Creek Validation Results, USGS Gauge 02231342

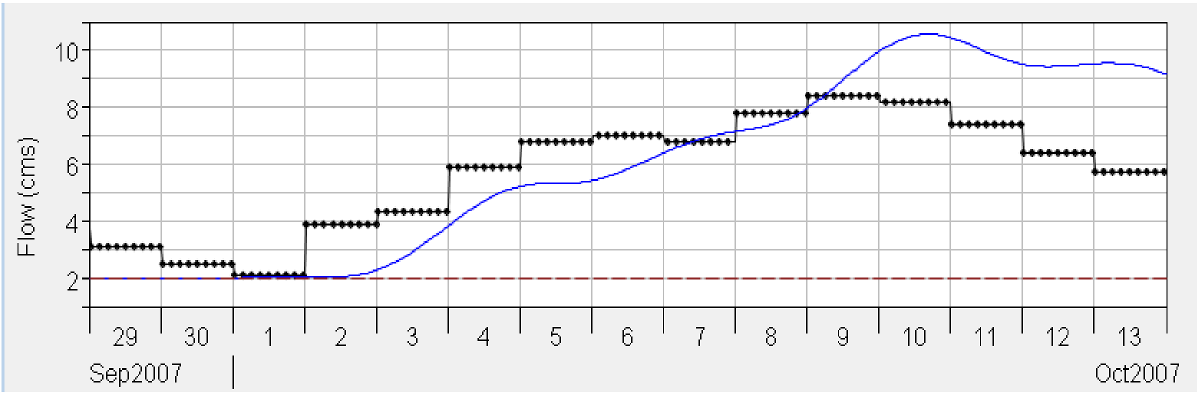


Figure 2-29. Blue Cypress Creek Validation Results USGS Gauge 02231396

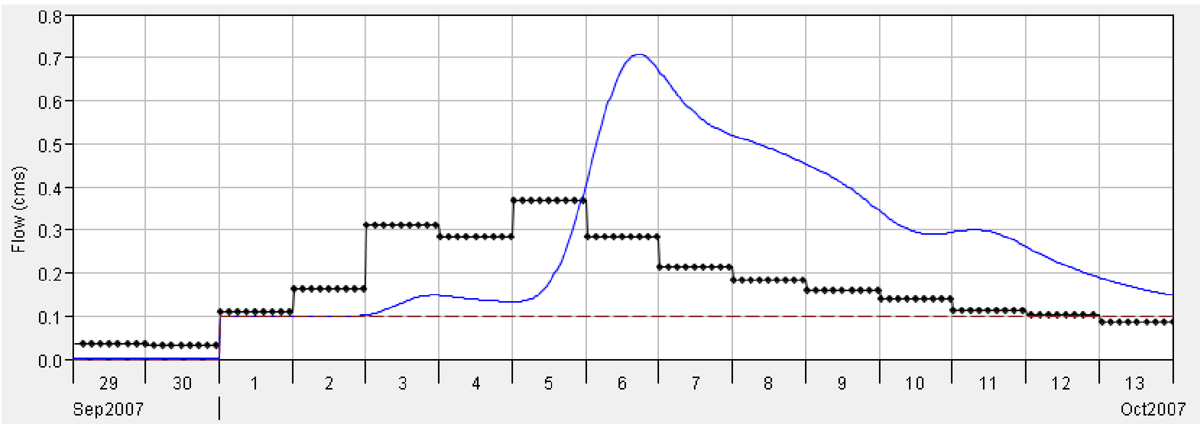


Figure 2-30. Wolf Creek Validation Results USGS Gauge 02231458

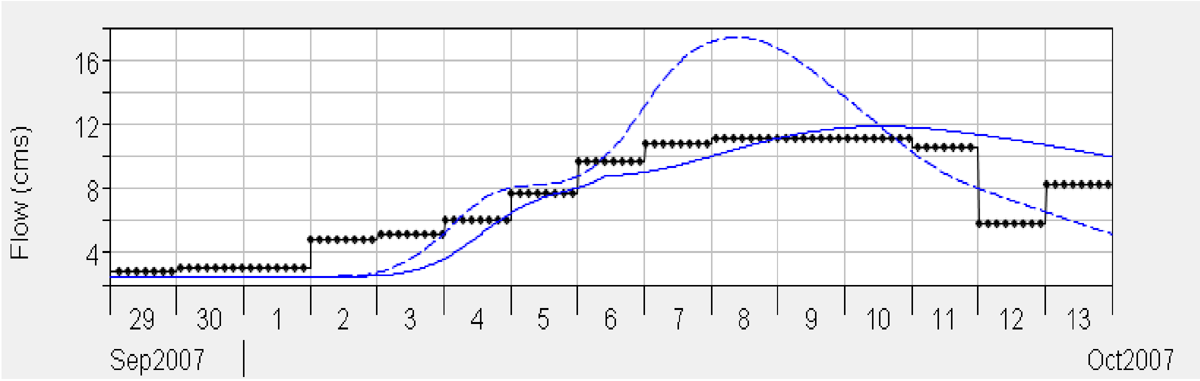


Figure 2-31. Jane Green Reservoir Validation Results USGS Gauge 02231600

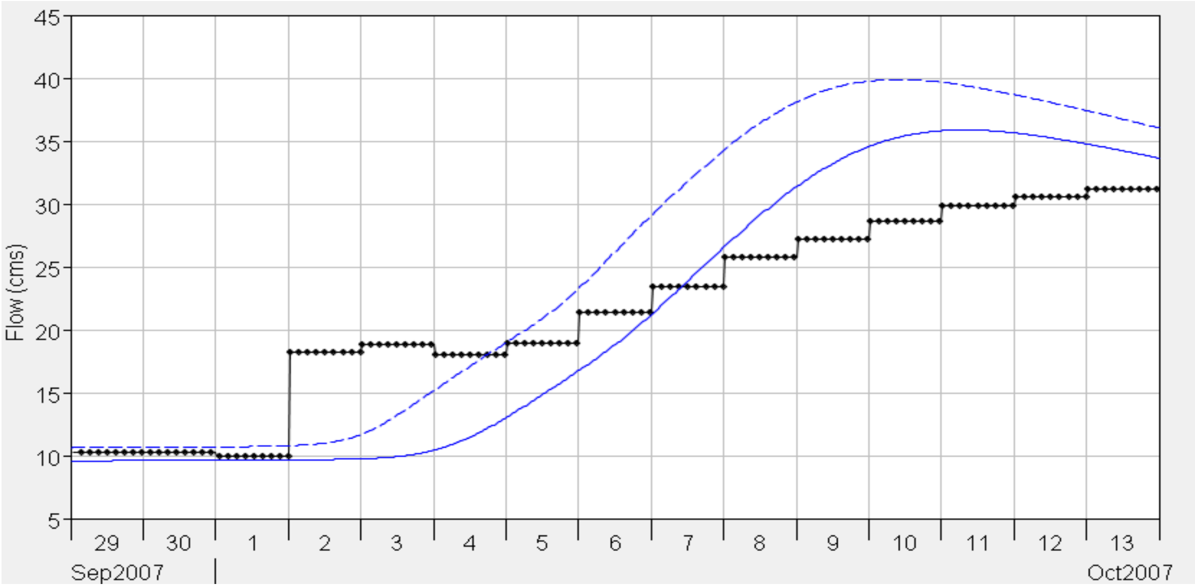


Figure 2-32. St. Johns River at U.S. Highway 192 Validation Results USGS Gauge 02232000

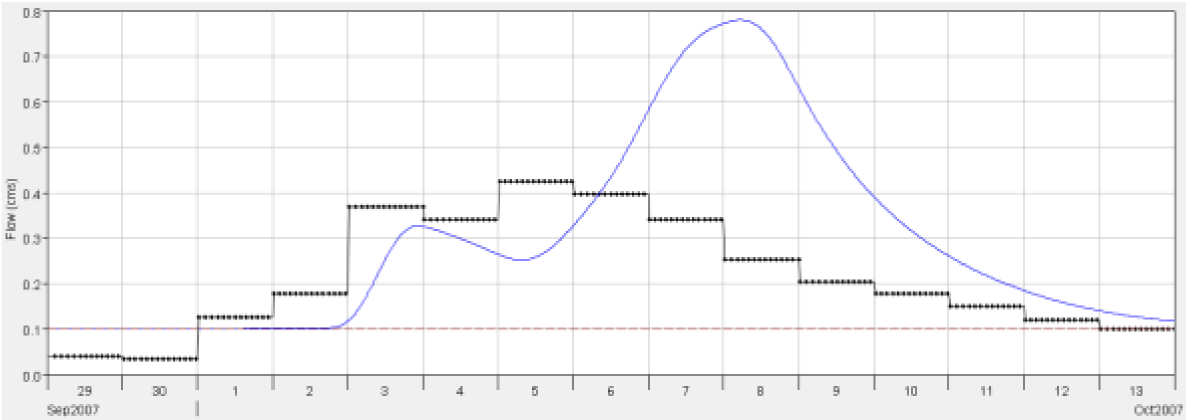


Figure 2-33. Pennywash Creek Validation Results USGS Gauge 02232155.

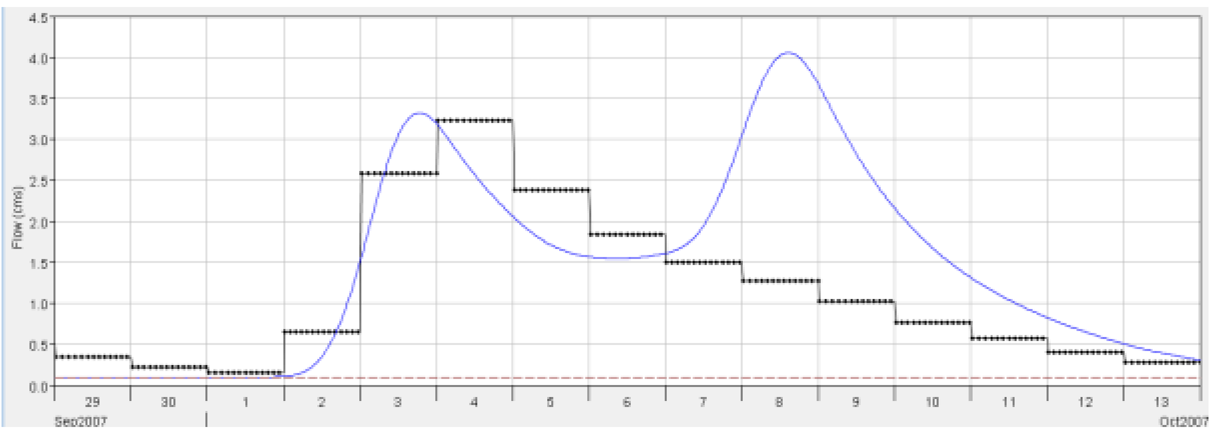


Figure 2-34. Wolf Creek North Validation Results USGS Gauge 02232200

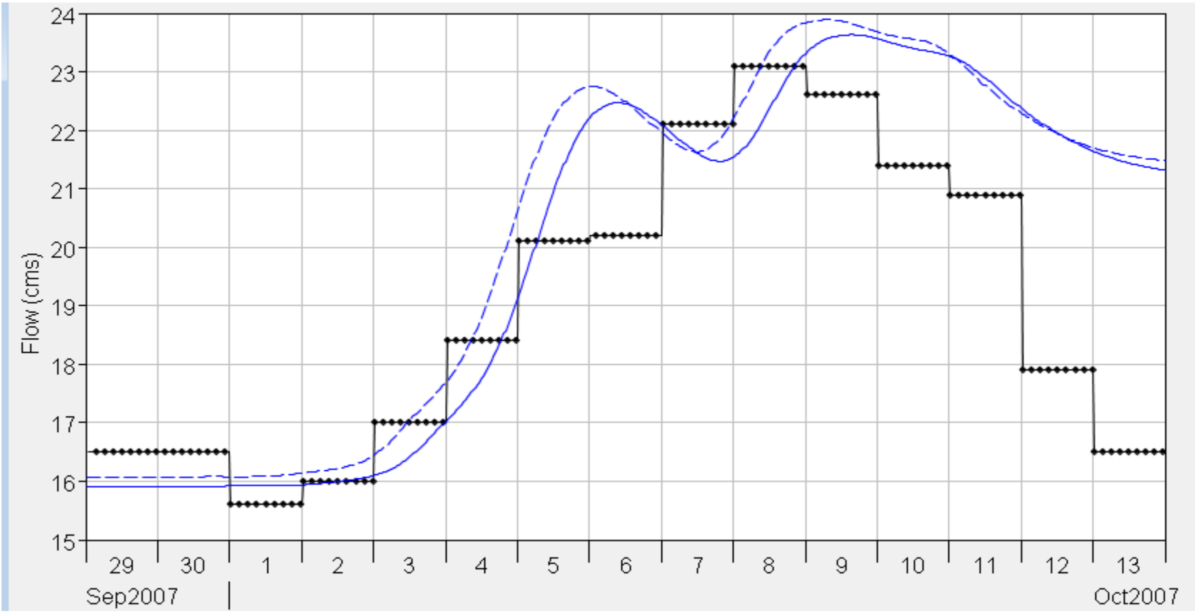


Figure 2-35. St. Johns River at State Highway 520 Validation Results USGS Gauge 02232400

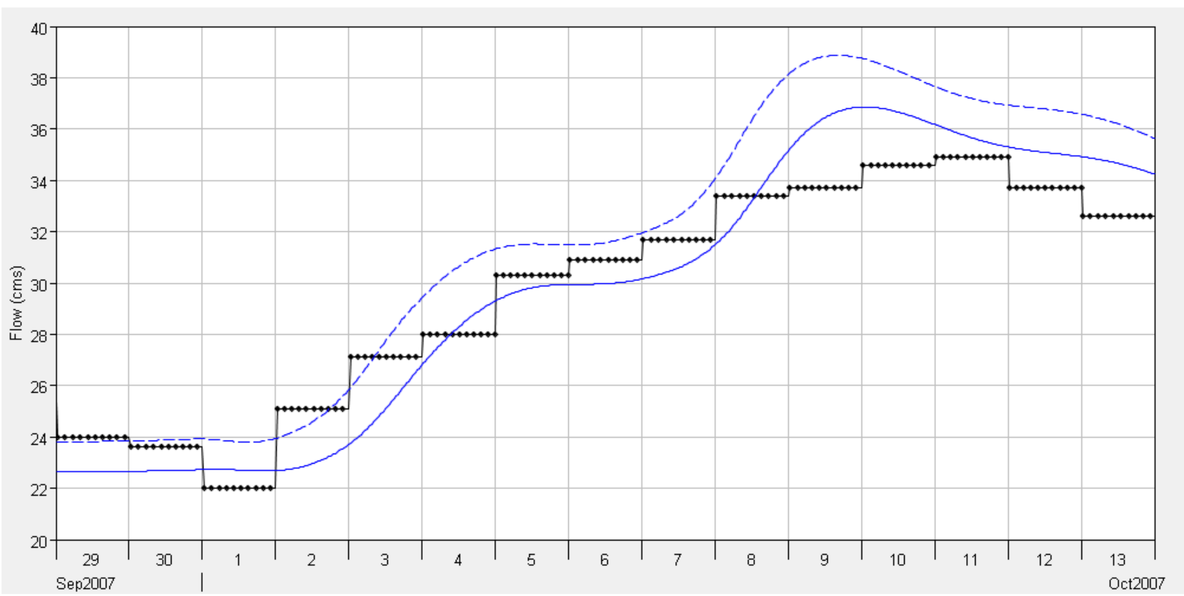


Figure 2-36. St. Johns River at State Highway 50 Validation Results USGS Gauge 02232500

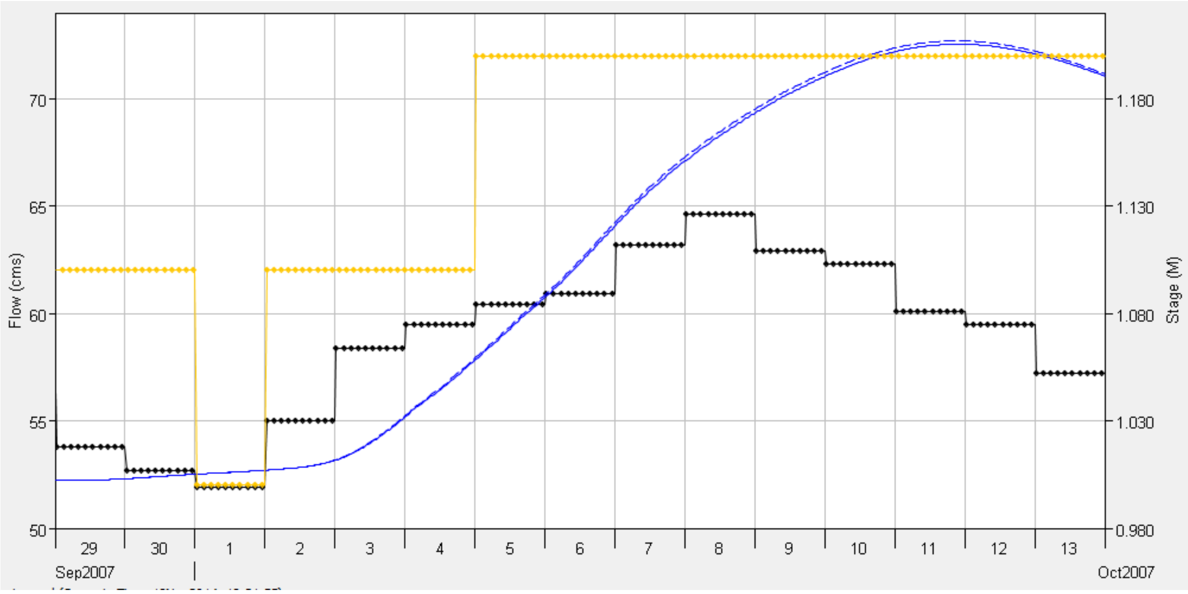


Figure 2-37. St. Johns River at Inlet of Lake Harney Validation Results USGS Gauge 02234000

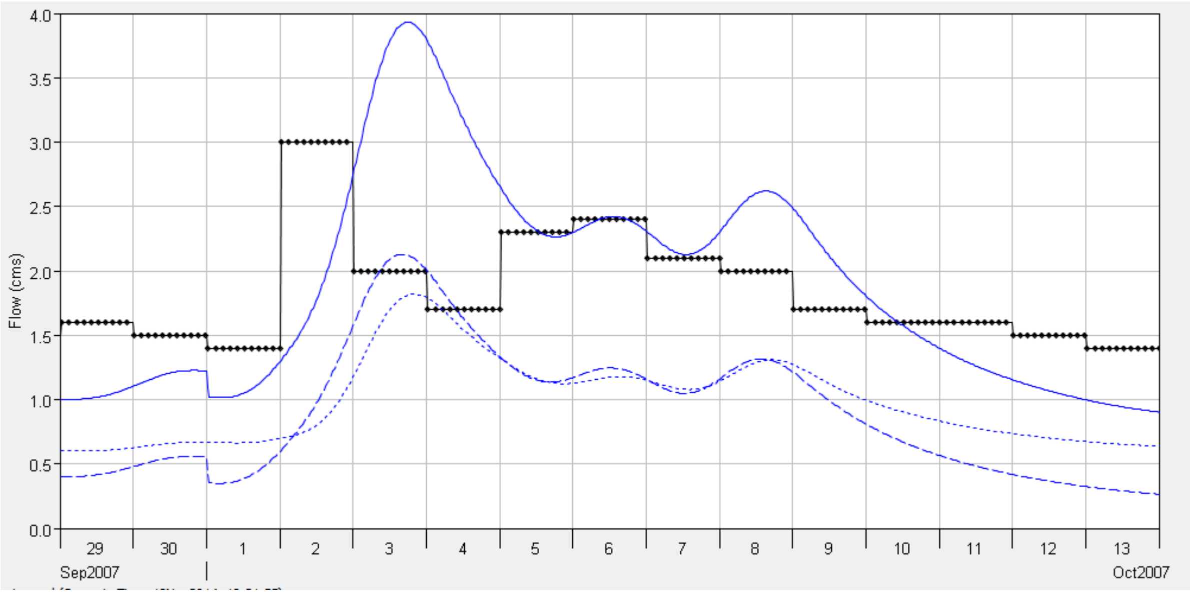


Figure 2-38. Little Econlockhatchee River near Union Park Validation Results USGS Gauge 02233460

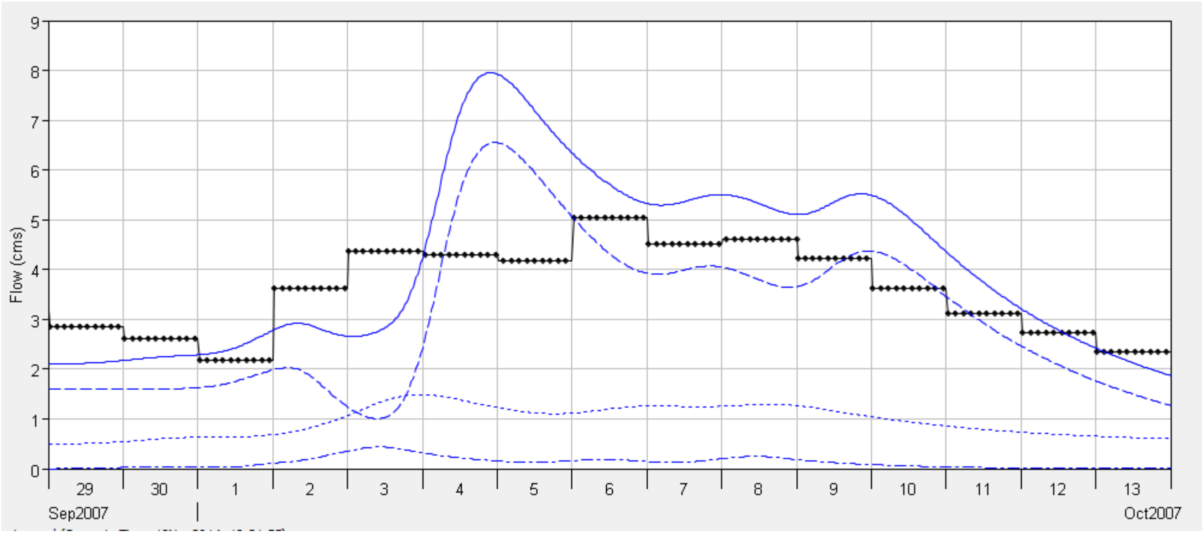


Figure 2-39. Little Econlockhatchee River at University Blvd. Validation Results USGS Gauge 02233473

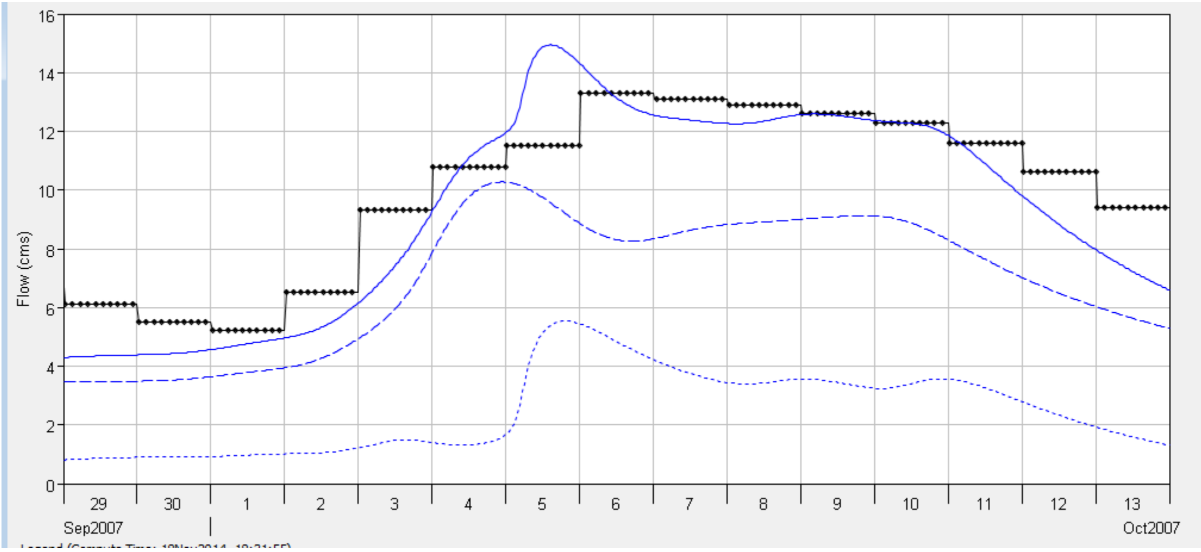


Figure 2-40. Econlockhatchee River near Oviedo Validation Results USGS Gauge 02233484

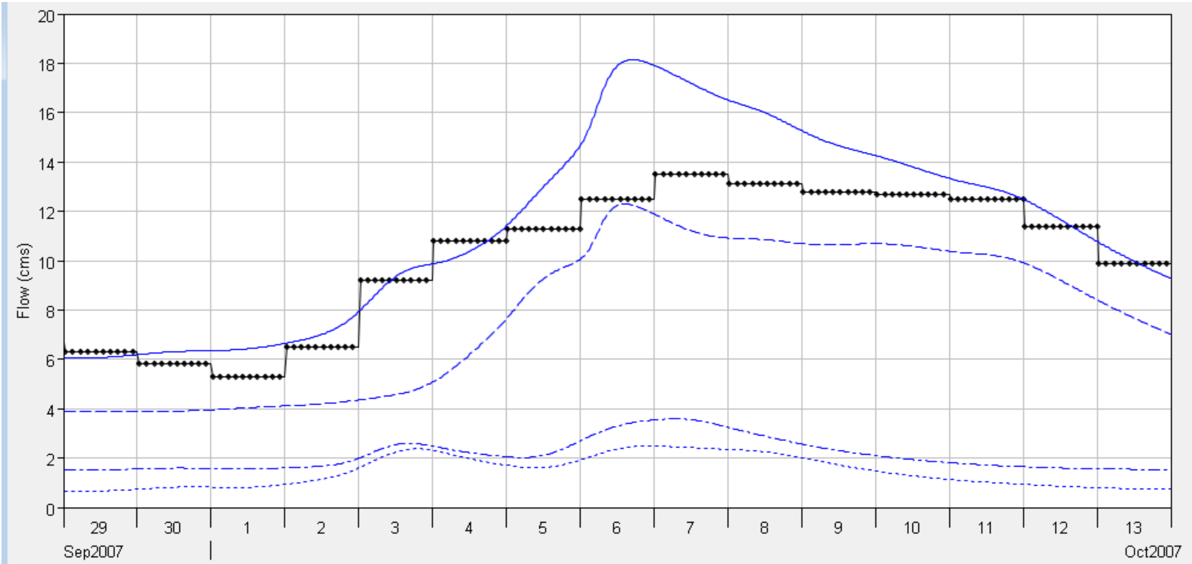


Figure 2-41. Econlockhatchee River near State Highway 13 Validation Results USGS Gauge 02233500

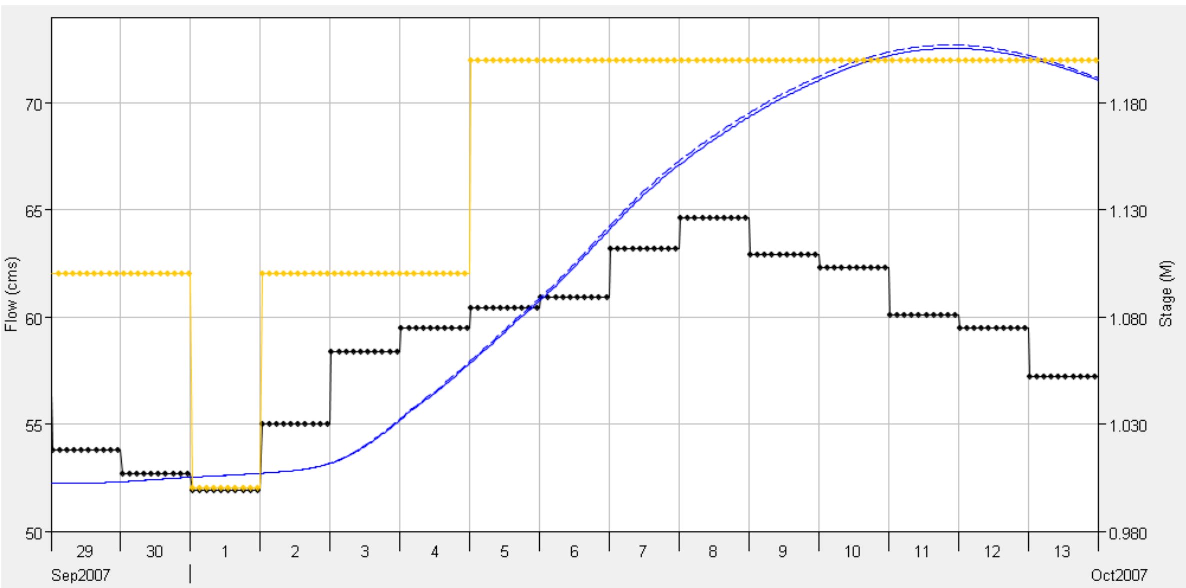


Figure 2-42. St. Johns River at Inlet of Lake Harney Validation Results USGS Gauge 02234000

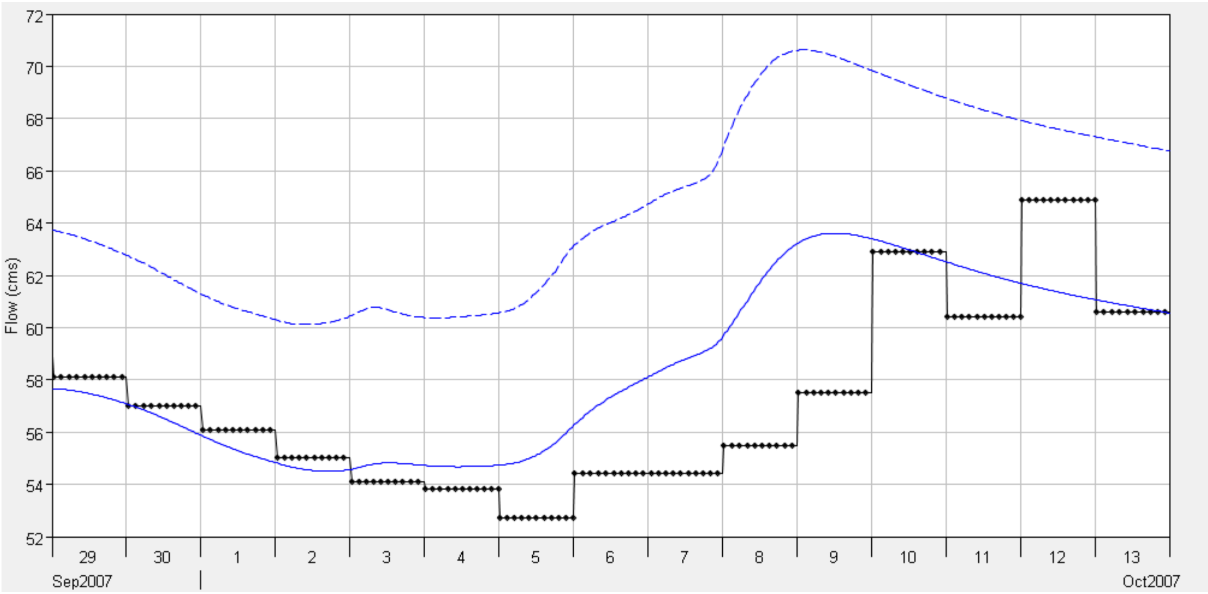


Figure 2-43. St. Johns River at Outlet of Lake Harney Validation Results USGS Gauge 02234010

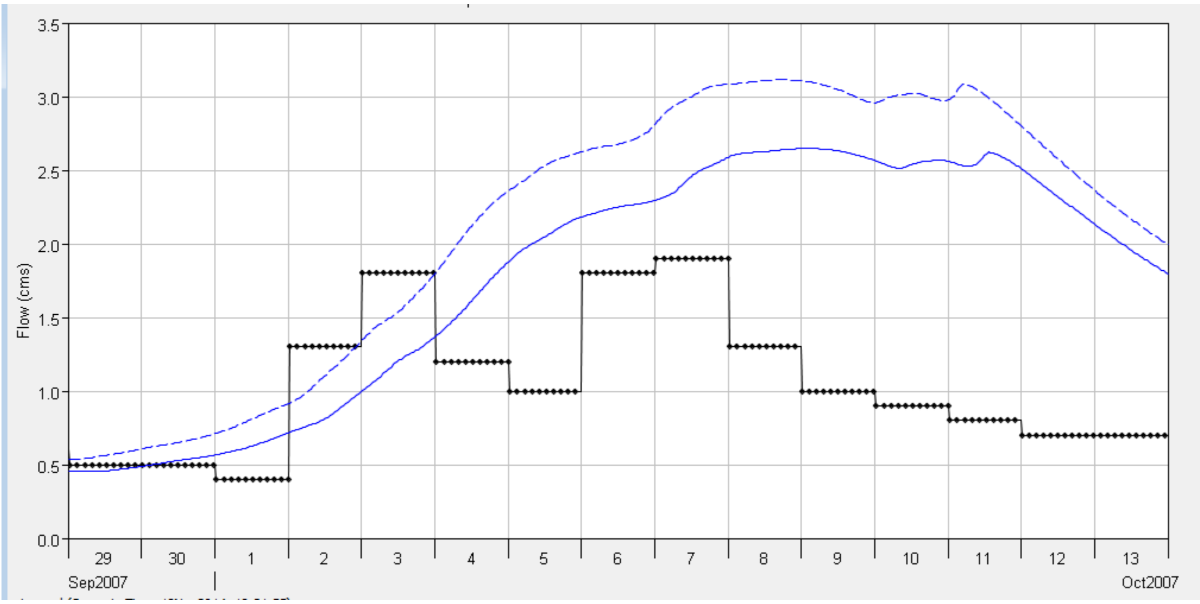


Figure 2-44. Deep Creek Outlet SJRWMD Validation Results Gauge 02830228

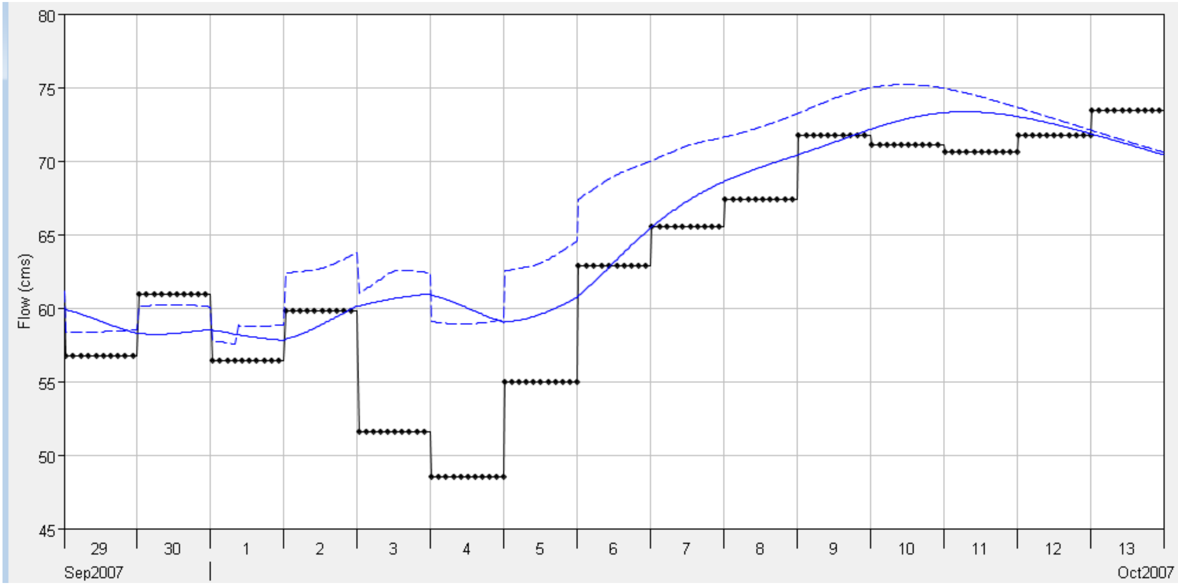


Figure 2-45. St. Johns River at Inlet of Lake Monroe Validation Results USGS Gauge 02234440

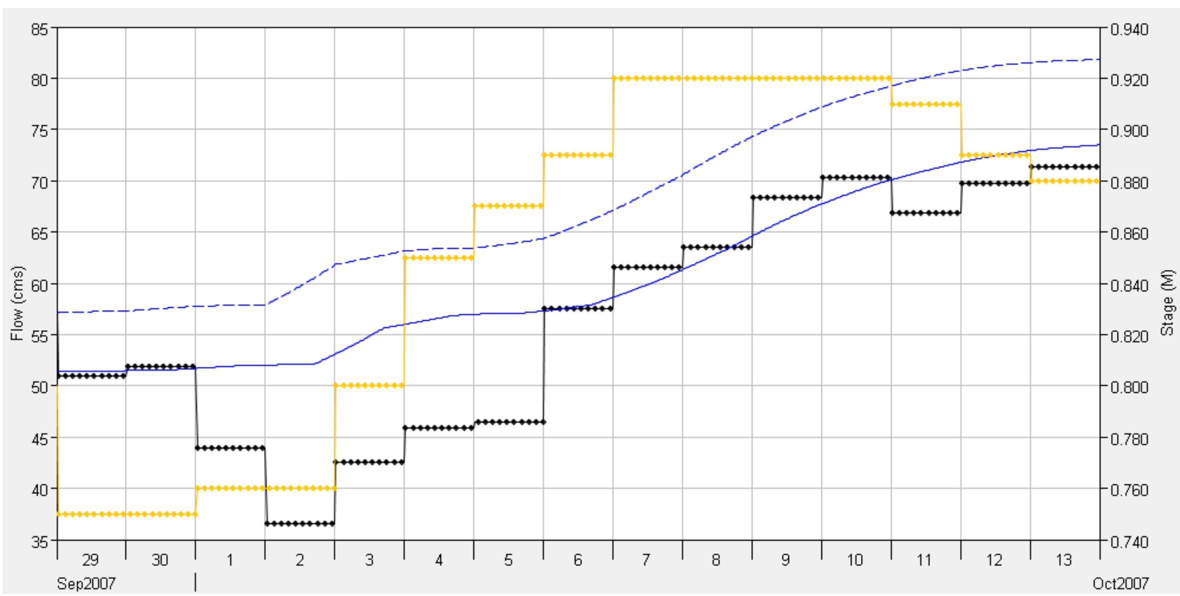


Figure 2-46. St. Johns River at Outlet of Lake Monroe Validation Results USGS Gauge 02234500

The validation statistics can be seen in Table 2-5. From the validation statistics it can be inferred that many of the low flow regions, as is the case for the individual sub-basin measurements, are considered "unsatisfactory" per the SJRWMD model calibration definition whereas only 6 of 18 gauges are considered "unsatisfactory" per Wang et al. (2009) criteria. For areas of higher flow, such as within the flow way, the Nash-Sutcliffe efficiency coefficient and coefficient of correlation show a much stronger statistical agreement. This would support a conclusion that the model may be more accurate and more appropriate to use for higher flow events with concomitant higher return frequency precipitation. It should be noted that the E value at the outlet of Lake Monroe is considered satisfactory for the validation period. This is important as this is where the HEC-HMS model connects to the UCF SWAT model.

Location	Gage	r	r^2	E
Fort Drum Creek	USGS 02231342	0.69	0.48	0.29
Blue Cypress Creek	USGS 02231396	0.83	0.69	0.24
Wolf Creek	USGS 02231458	0.15	0.02	0.35
Jane Green Reservoir	USGS 02231600	0.87	0.76	0.65
U.S. Highway 192	USGS 02232000	0.93	0.86	0.52
Pennywash Creek	USGS 02232155	0.56	0.31	-1.24
Wolf Creek North	USGS 02232200	0.67	0.45	-0.02
State Highway 520	USGS 02232400	0.80	0.64	0.24
State Highway 50	USGS 02232500	0.99	0.99	0.96
Inlet of Lake Harney	USGS 02234000	0.70	0.50	-2.14
Little Econlockhatchee River at Union Park	USGS 02233460	0.46	0.21	-1.88
Little Econlockhatchee River at University Blvd.	USGS 02233473	0.76	0.58	-1.25
Econlockhatchee River near Oviedo	USGS 02233484	0.94	0.89	0.82
Econlockhatchee River near State Highway 13	USGS 02233500	0.94	0.89	0.76
Outlet of Lake Harney	USGS 02234010	0.69	0.48	0.29
Deep Creek	SJRWMD 02830228	0.35	0.12	-3.97
Inlet of Lake Monroe	USGS 02234440	0.89	0.78	0.69
Outlet of Lake Monroe	USGS 02234500	0.89	0.79	0.62

Table 2-5. Validation Statistical Performance Results

Calibration and Validation Discrepancies - As can be seen from the runoff vs. observed data hydrographs, different points within the model show different degrees of agreement. There are multiple explanations as to why the calibration and validation results have some level of error as compared to the observed data.

The difference of scale for the calibration and validation storm events is very significant. The calibration storm event of Tropical Storm Fay produced historic rainfall totals within the St. Johns River basin whereas the validation storm event was less than the 1 year – 24 hour rainfall event as defined by Technical Paper No. 40, Rainfall Frequency Atlas of the United States (Hershfield, U.S. Department of Commerce, 1961). In more northern areas of the three-model study area, the precipitation return frequency for the validation period was higher. Creating a model that is sensitive enough to capture small rain events posed challenges due to the large domain size of the model. The spatial variability of rainfall represents the dominant effect in the production of runoff; as the spatial variability increases, so does the significance of appropriate rainfall characterization (Ly et al., 2012). It may also be true that further model detail needs to be added to the smaller sub-basins within the HEC-HMS in order to better simulate small precipitation events.

The Thiessen polygon methodology applies uniform precipitation gauge data over a substantial area, which may cause significant over or underestimation of rainfall within the modeled area. When reviewing the precipitation gauge data, different gauges in adjacent geographical areas can have highly inconsistent rainfall amounts. For example, gauge 510206 recorded a precipitation of 3.2 inches on October 3, 2007 whereas the nearby gauge 540106, recorded only 2.2 inches on this data. Also, when reviewing the rain gauge data it can be concluded that the rainfall is concentrated in certain areas with an uneven distribution. The temporal variability has a great impact on peak flows at a small scale because the Thiessen polygon method will either underestimate or overestimate rainfall. When basin averages are used to distribute rainfalls from storms with varying concentration, the flow forecasts can be incorrect. For smaller storm events this varying concentration and inner variability present can cause significant changes in the local precipitation and subsequent runoff amounts within the modeled area. Since the precipitation amounts are so minimal for the validation event, small scale changes in the precipitation applied to the model can have large scale effects in the Validation statistics. As the scale increases, the importance of spatial rainfall decreases and distribution of catchment response time, rather than spatial variability of rainfall, becomes the dominant factor governing runoff generation (Ly et al., 2012). The Calibration event had a much higher precipitation amount and gauge recordings were comparable throughout most of the model domain as well as in the other two models discussed in this research report. Also since the storm system was so large, wide spread coverage of similar rainfall intensities and distributions were likely present during the Calibration event. Due to the large amount of precipitation, discrepancies of one to two inches during the Calibration period may not be noticeable in the runoff calculations, whereas significant changes would occur in the runoff of the Validation period.

Different hydrologic runoff processes become important at different spatial scales and processes that are imperative to properly model small scale events may not be important at large scales. Uncertainty arises when simplifications and approximations are introduced into the model through regional parameter estimation. Although the model was created using the best data available, sub-basin properties were often averaged over large areas thereby creating spatial homogeneity that may not be representative of actual conditions. Due to the large scale of the model, spatial averaging became necessary and many properties were averaged based on the sub-basin delineation, which is relatively large for many smaller size sub-basins. Finer resolutions may be needed to capture the smaller peaks and fluctuations in discharge rates for the validation period. In addition it may be necessary to perform catchment subdivision and additional channel routing for the larger sub-basins for adequate runoff values for smaller storm events.

This includes the land use and land type data, which depending on its location within the sub-basin, can significantly impact runoff intensities and times. Each land use and land type data has a direct relation to different SCS curve number values, thereby directly impacting the hydrologic response of the watershed. It should also be noted that the methodology incorporating the SCS method can lead to errors due to its lack of physical reality in the development of the equation but instead is based off an empirical rainfall-runoff relationship and soil-vegetation-land complex. Previous studies have shown that the effects of the CN variation decrease as the rainfall depth increases, such as for the large storm event of Tropical Storm Fay (Bondelid et al., 1982). The SCS curve number procedure was developed for estimating streamflow volume generated by larger rain storms. Therefore, the intensity and duration of the validation storm may not be adequate enough for proper SCS runoff estimation practices. A main weakness of the SCS curve number method is that the relationship parameters are discrete rather than continuous. This can readily be seen in the initial abstraction values which are not readjusted over time as natural processes such as evaporation and infiltration change catchment storage values. This can be seen in the validation results due to the storm event containing two peaks with little to no rainfall in between. The initial abstraction amount reduces the runoff significantly for the first precipitation event whereas the second event produces greater than measured runoff values. In an area such as the St. Johns River, evaporation is high and run off is low, especially during low flow events, and therefore different methodology consisting of a nonlinear continuous variation of storage may be needed.

The AMC specified for each sub-basin may also cause model run-off value discrepancies due to its direct impact on the SCS curve number value chosen. Many of the sub-basins were computed using a curve number value in between the AMC I and AMC II condition but could vary from these approximations. The AMC condition is watershed dependent and therefore each sub-basins initial condition may need to be further analyzed for proper AMC estimation.

Other sources of error may include parameters initially estimated based on best available data. This would include the storage-discharge functions for sub-basins that have pump stations, flow patterns of developed areas that include storm drainage structures and retention ponds, and the constant monthly baseflow estimates. To improve these areas of the model, more information must be gathered regarding the pumping schedule, normal discharge amounts, and frequency for which pumping occurs. During the Calibration period, pumping rate volumes were minimal compared to the magnitude of the precipitation and subsequent rainfall the project area received. This is the opposite for the validation period where pumping rates of 1 to 2 cms could cause noticeable changes in the flow rates downstream. In addition, more detailed modeling is necessary to capture the inconsistency present in highly developed areas where non-natural discharges may occur due to complex drainage systems. Urbanization in areas can cause significant changes in the timing and frequency of peak flows that are difficult to estimate using the SCS methodology. The baseflow method may need to be changed within the model from constantly monthly, to a more complex baseflow method to capture the detailed interaction between surface water and groundwater hydrology. Also, the model is currently unable to properly model the flow-ways ability to store and slowly release flow over time. This may be able to be remediated through incorporation of a more complex baseflow method or additional storage-discharge functions through the model.

A final source of error is the uncertainty associated with measured streamflow discharge gauge data. Many of the USGS gauge measurements are made from a water-stage recorder and/or an acoustic velocity meter. Water depth measurement devices are normally converted to a streamflow rate with a predetermined stage-discharge relationship based on channel geometry near the gauge. According to Harmel et al. (2006), a main source of uncertainty of measured streamflow for natural channels is the possible change in channel dimensions which would change the stage-discharge relationship. Also, measurement of flow velocity can introduce uncertainty due to turbulence. Research compilations completed by Harmel et al.(2006) shows that under average conditions, the direct discharge method can have a $\pm$6% uncertainty, the stage-discharge relationship for a stable channel can have $\pm$ 10% uncertainty, and a continuous stage measurement float recorder can have $\pm$ 2% uncertainty. USGS also states that the gauges “may differ from individual measurements because of changes in tidal influence, wind, or other factors.” Individual gauges, such as the Wolf Creek gauge include specific remarks for the surface-water records which state that the records are poor and the discharge is affected at times by variable backwater from the St. Johns River headwaters (USGS, 2009). Although it is difficult to determine the specific error associated with each gauge, recognizing that there is are uncertainty limits associated with the gauge data is important. “Models should be expected to produce output within the uncertainty limits inherent in measured data, not to produce outputs with low deviation from measured data” (Harmel et al., 2006).

Sensitivity Analysis - The final model simulation results are not equally sensitive to all input parameters for the model. To determine which input parameters are the most sensitive during the calibration and validation effort a sensitivity analysis was completed. The parameter sensitivity analysis was conducted for the sub-basin parameters which are responsible for most of the variability during the computation of run off values; curve number, initial abstraction, and lag time. The technique that was adopted for the sensitivity analysis was to vary each input parameter the same relative percentage for all sub-basins while keeping the other sub-basin parameters constant, with the same values used during the calibration and validation periods. It was decided to increase and decrease the sub-basin parameters by 10 percent during the sensitivity analysis. This percentage was applied consistently for all sub-basins within the model. Therefore, six different model runs were completed and compared to the original calibration and validation run results. The sensitivity analysis was performed and measured at five different gauge locations within the model. These locations were chosen based on varying watershed sizes and relative areas upstream of the measurements to ensure different magnitudes of flow were captured for sensitivity analysis comparisons. Other parameters such as the base flow and relative loss percentages were not included in the sensitivity analysis due to their linear relationship with runoff production.

As can be seen in Figures 5-47 thru 5-76 the model is the least sensitive to the initial abstraction amounts and the most sensitive to curve number values. Increase or decreases in lag time had effects on the timing and magnitude of peaks but not to the extent of the curve number changes. For the calibration period the trend of the curve number and lag time being the most sensitive and initial abstraction being the least sensitive seems to be true for all gauge locations. For the validation period, the changes in the initial abstraction (I.A. in the figures) and lag time for the smaller sub-basins produced more noticeable changes in the outflow hydrograph. The larger sub-basins seemed to follow a similar trend to that of the calibration run sensitivity analysis. Therefore, from the sensitivity analysis it can be inferred that at smaller flow rates, the initial abstraction parameter can be sensitive but for larger flow events it is less sensitive. This also seems true of lag time values but with a higher level of sensitivity. The curve number (C.N. in the figures) and Lag Time parameter are similar in sensitivity between both models, each having the ability to change peak flow values substantially.

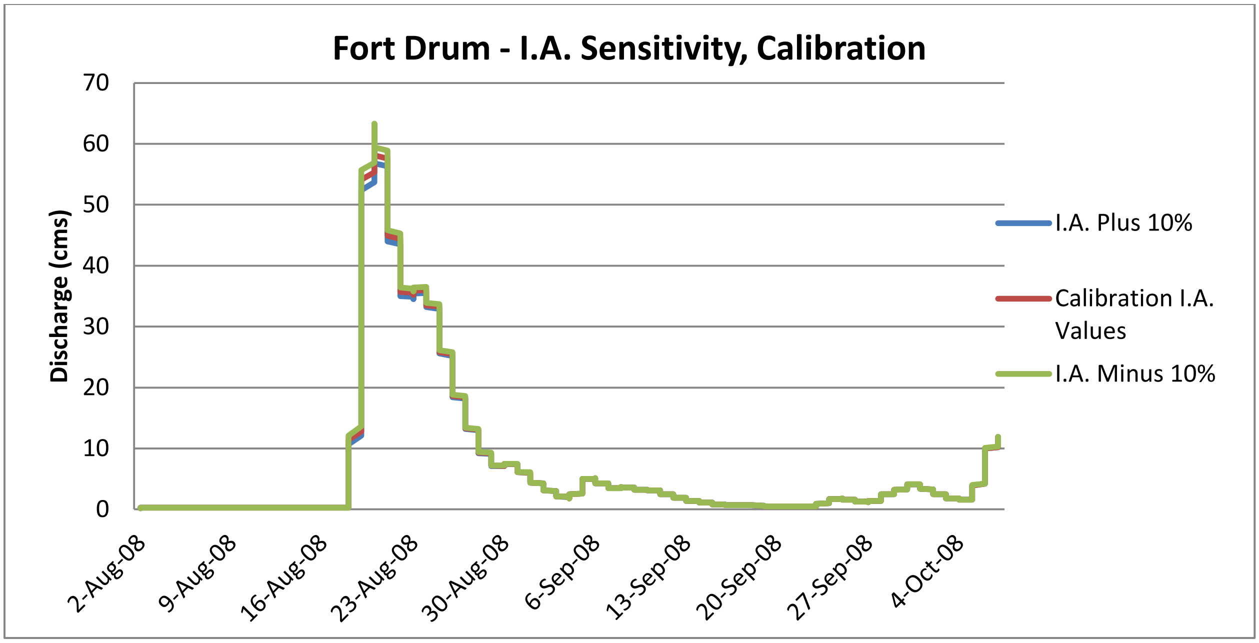


Figure 2-47. Fort Drum, Initial Abstraction Sensitivity Analysis for Calibration

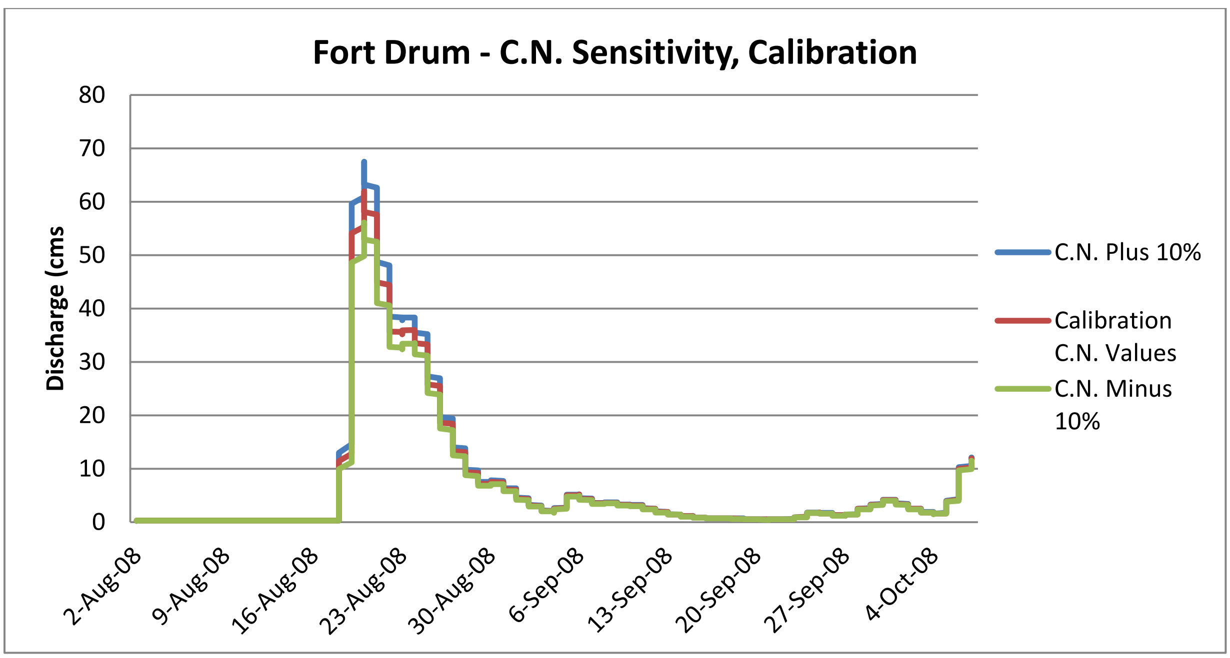


Figure 2-48. Fort Drum, Curve Number Sensitivity Analysis for Calibration

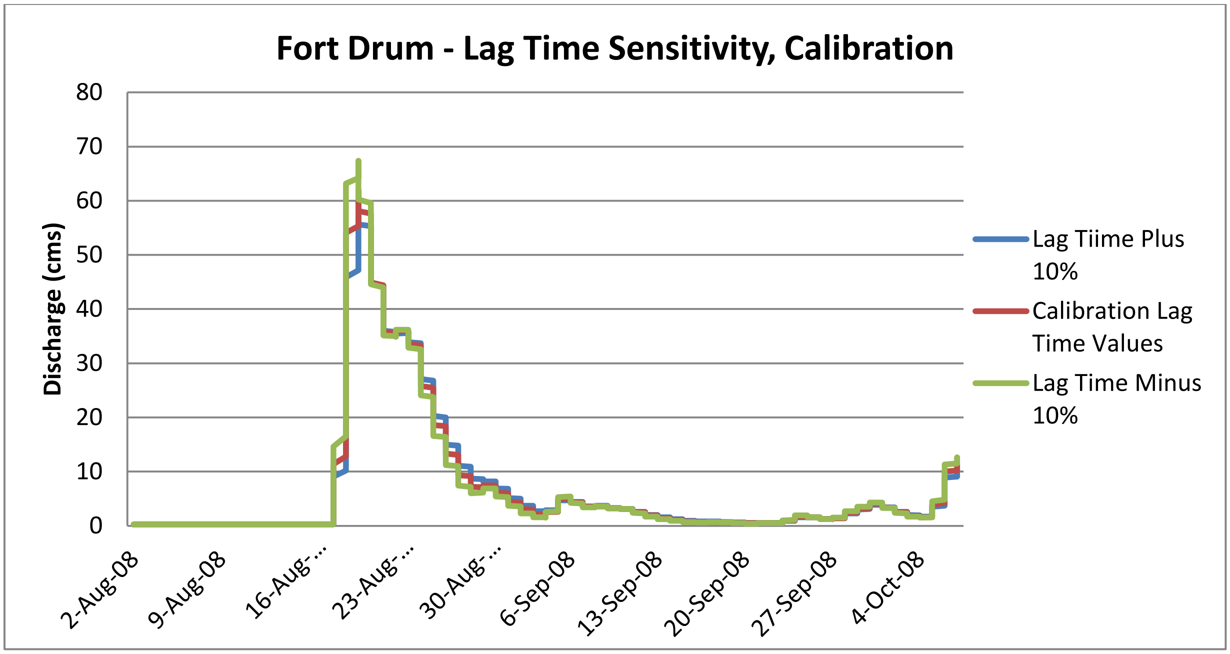


Figure 2-49. Fort Drum, Lag Time Sensitivity Analysis for Calibration

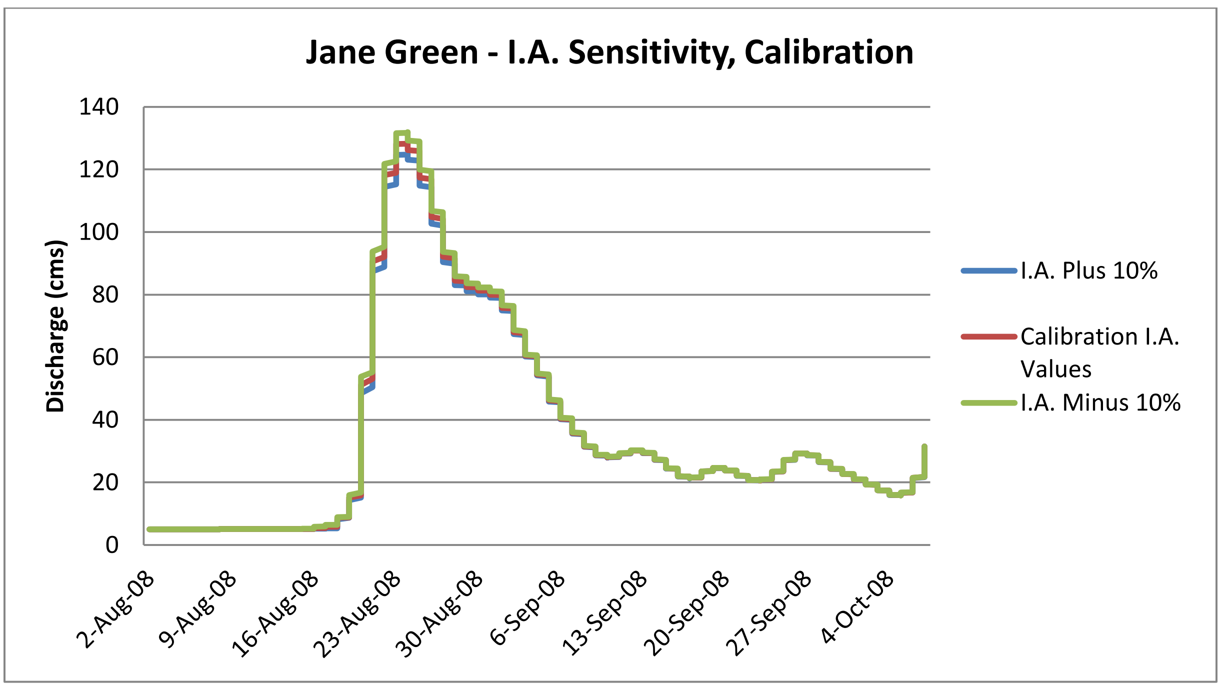


Figure 2-50. Jane Green, Initial Abstraction Sensitivity Analysis for Calibration

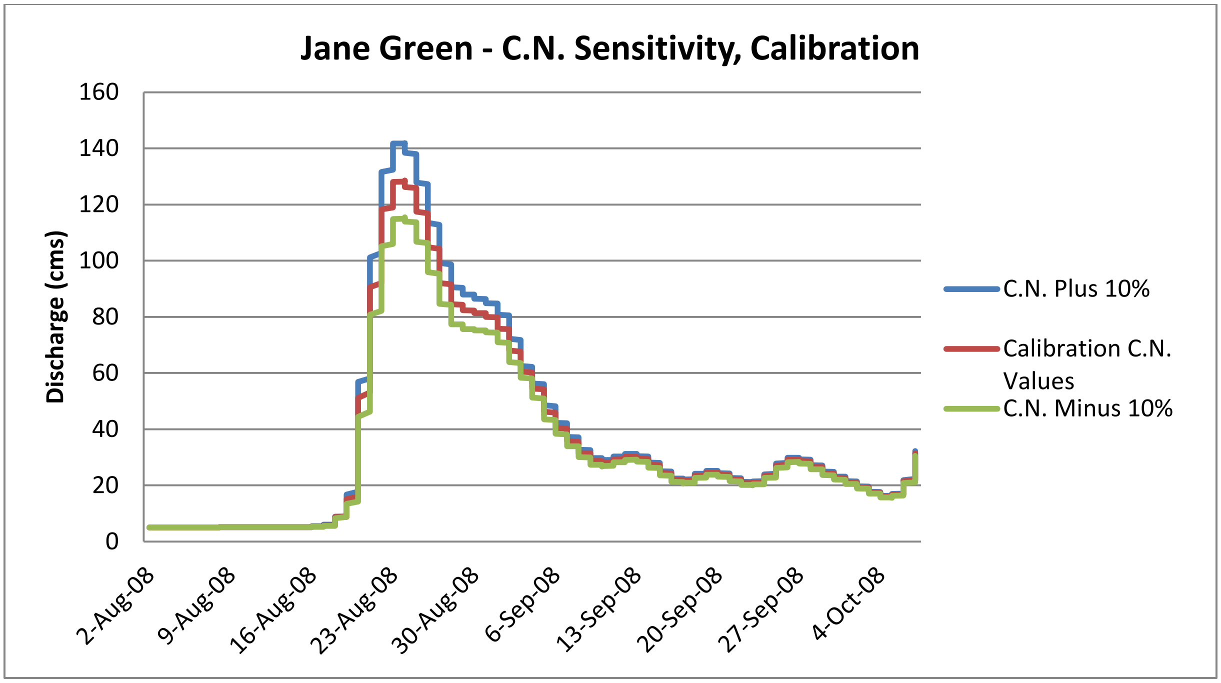


Figure 2-51. Jane Green, Curve Number Sensitivity Analysis for Calibration

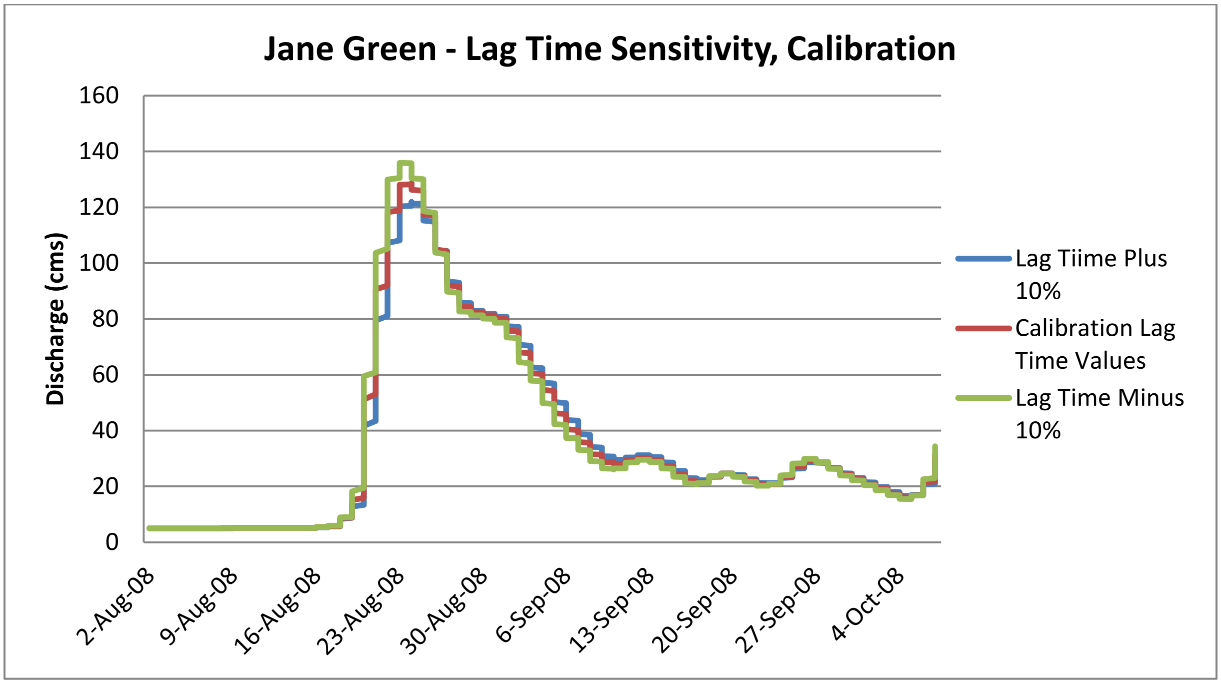


Figure 2-52. Jane Green, Lag Time Sensitivity Analysis for Calibration

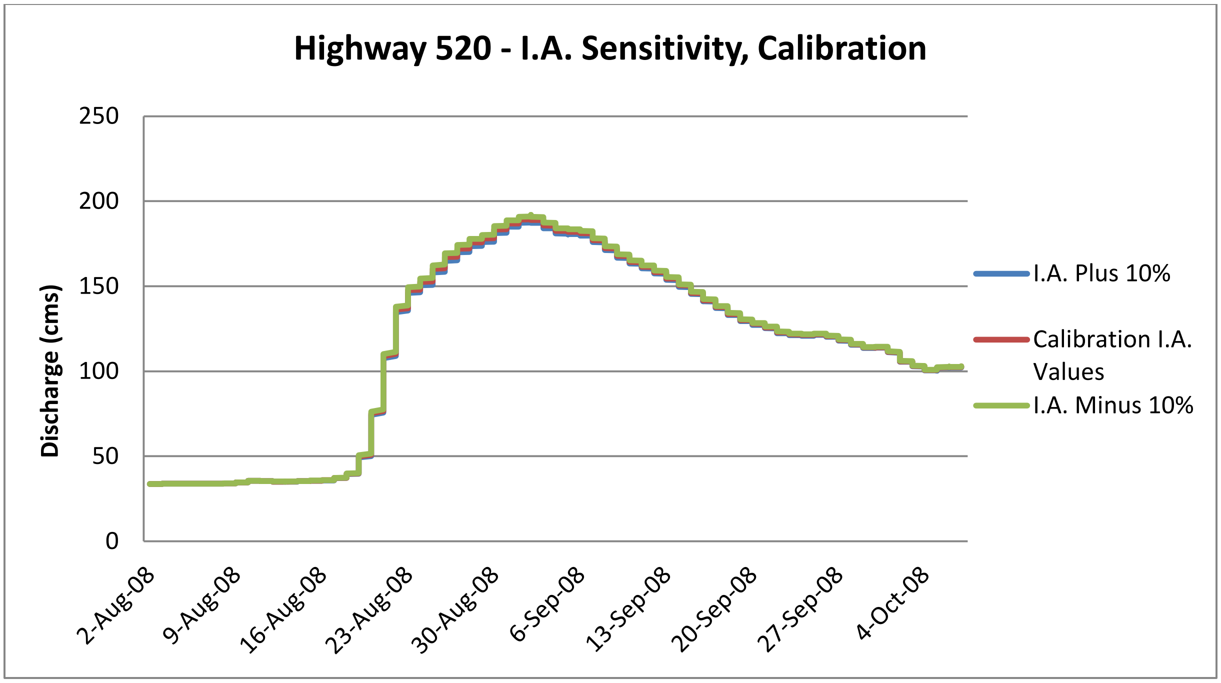


Figure 2-53. Highway 520, Initial Abstraction Sensitivity Analysis for Calibration

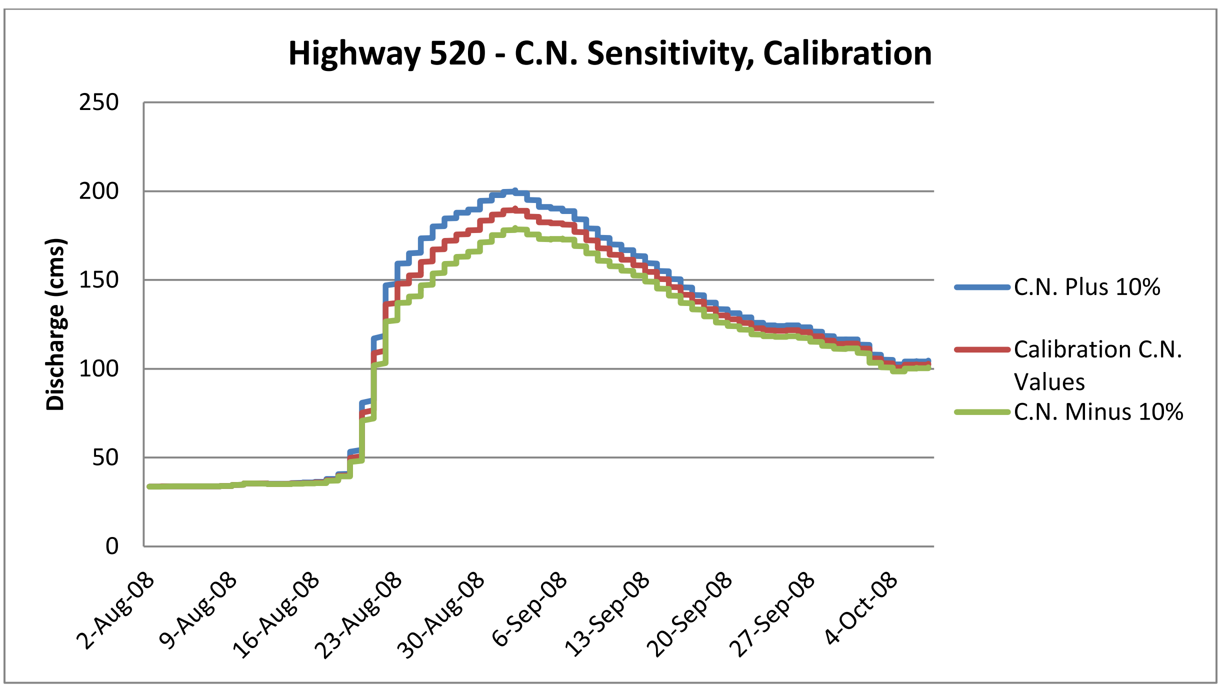


Figure 2-54. Highway 520, Curve Number Sensitivity Analysis for Calibration

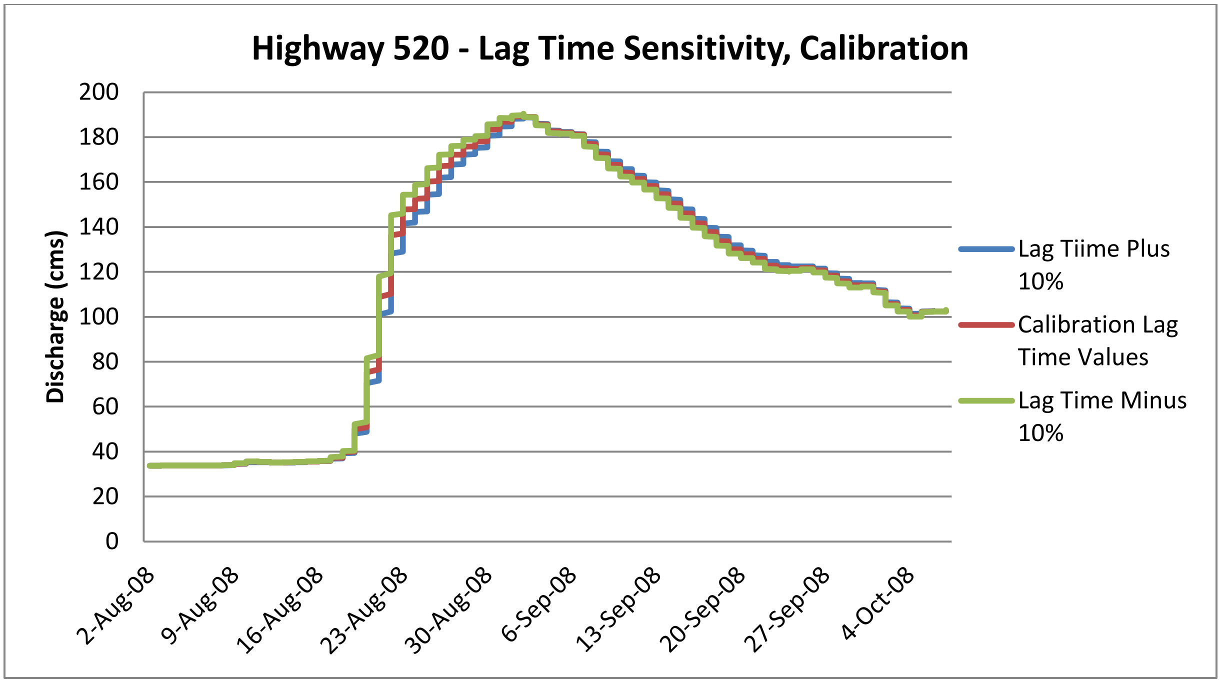


Figure 2-55. Highway 520, Lag Time Sensitivity Analysis for Calibration

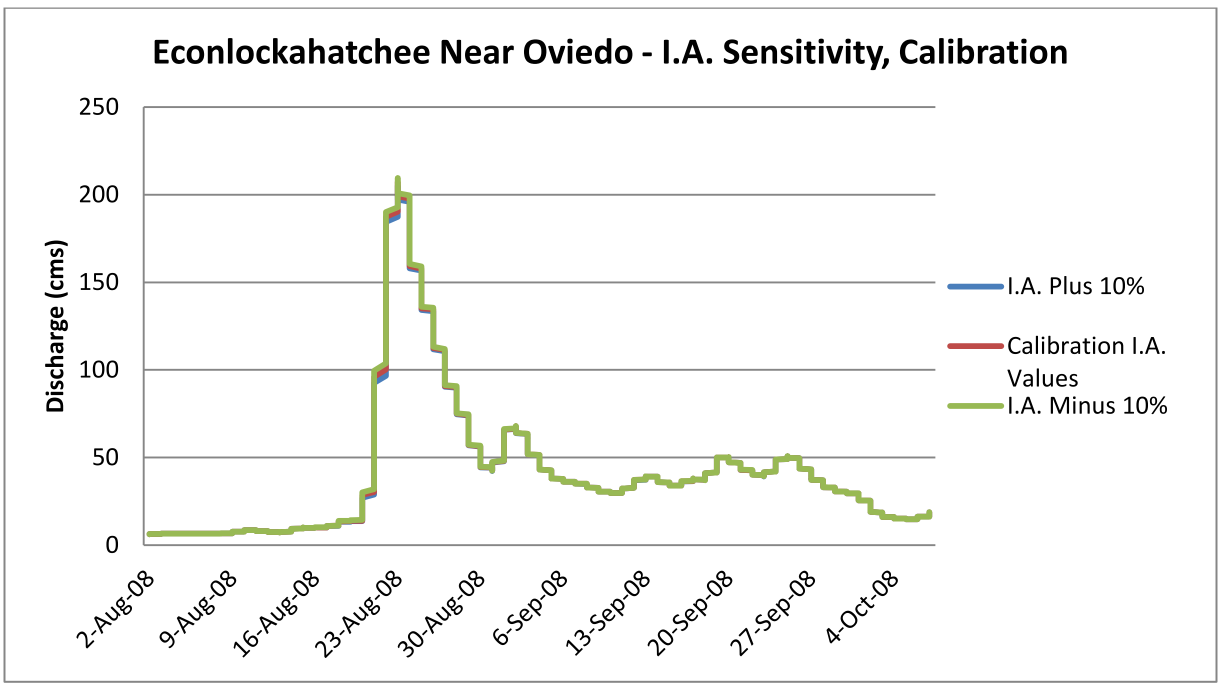


Figure 2-56. Econlockahatchee Near Oviedo, Initial Abstraction Sensitivity Analysis for Calibration

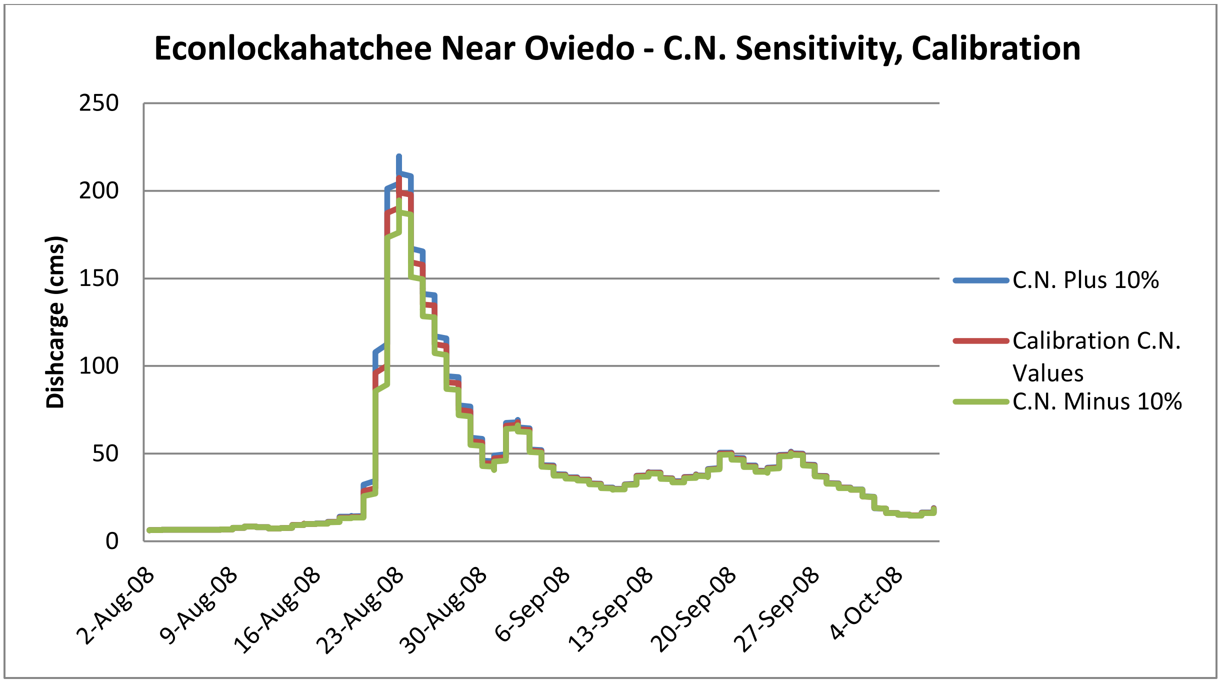


Figure 2-57. Econlockahatchee Near Oviedo, Curve Number Sensitivity Analysis for Calibration

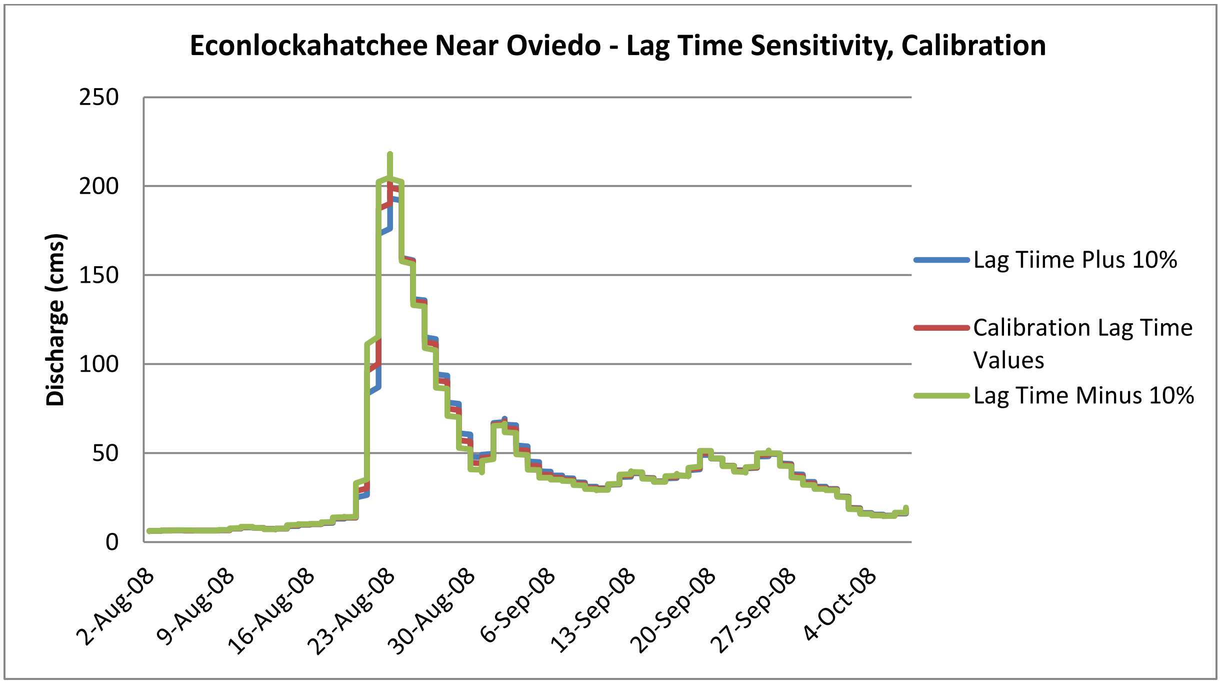


Figure 2-58. Econlockahatchee Near Oviedo, Lag Time Sensitivity Analysis for Calibration

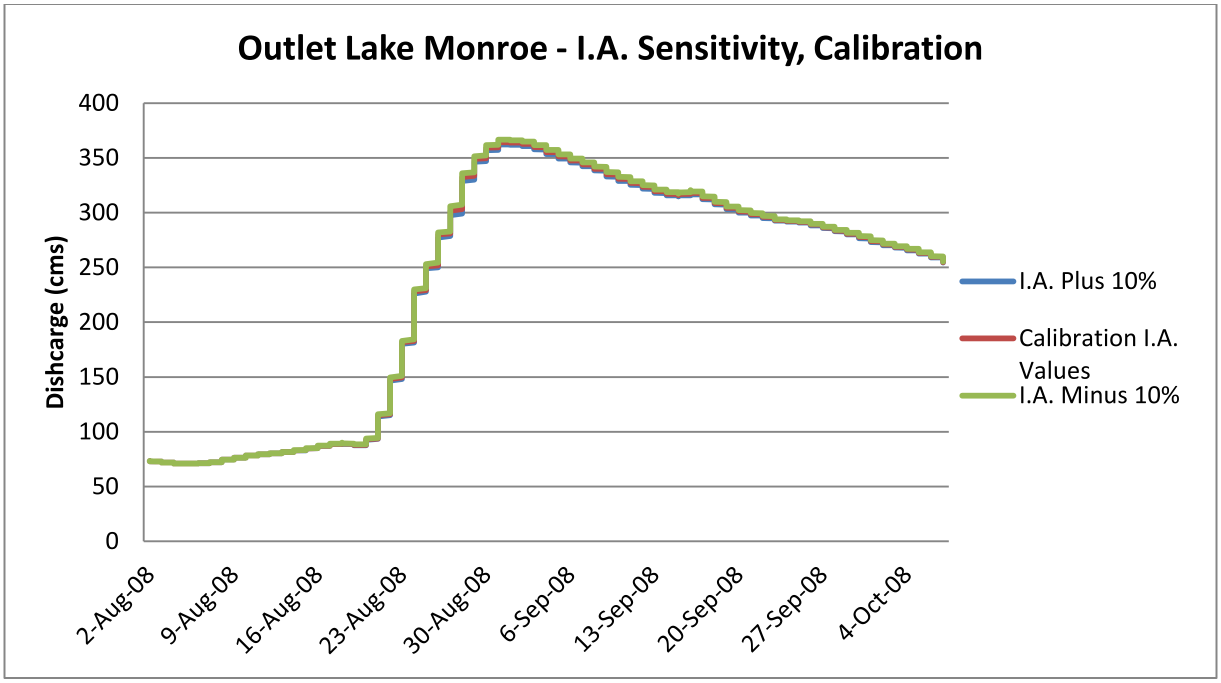


Figure 2-59. Outlet Lake Monroe, Initial Abstraction Sensitivity Analysis for Calibration

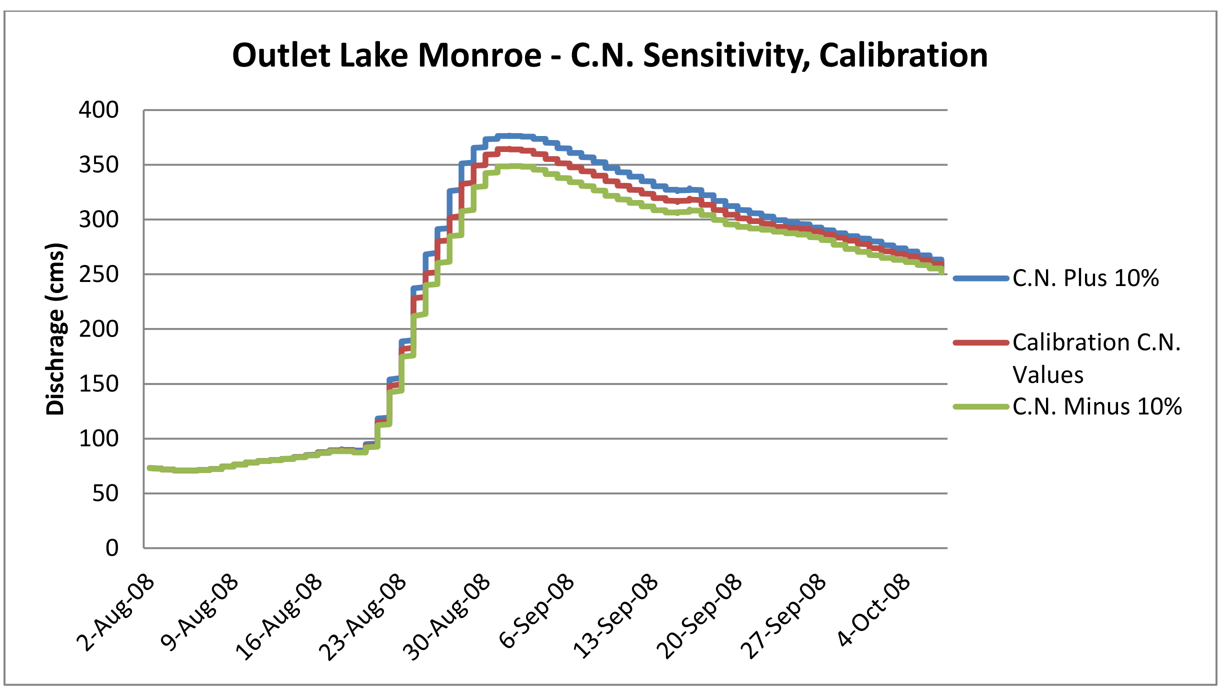


Figure 2-60. Outlet Lake Monroe, Curve Number Sensitivity Analysis for Calibration

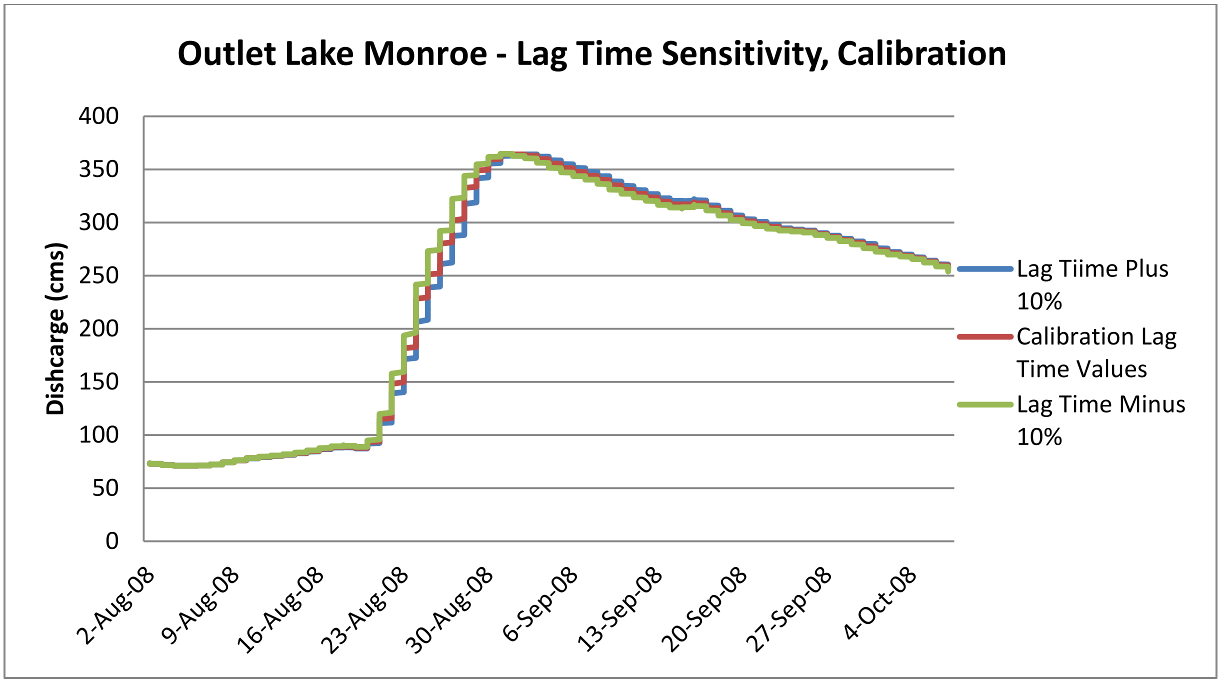


Figure 2-61. Outlet Lake Monroe, Lag Time Sensitivity Analysis for Calibration

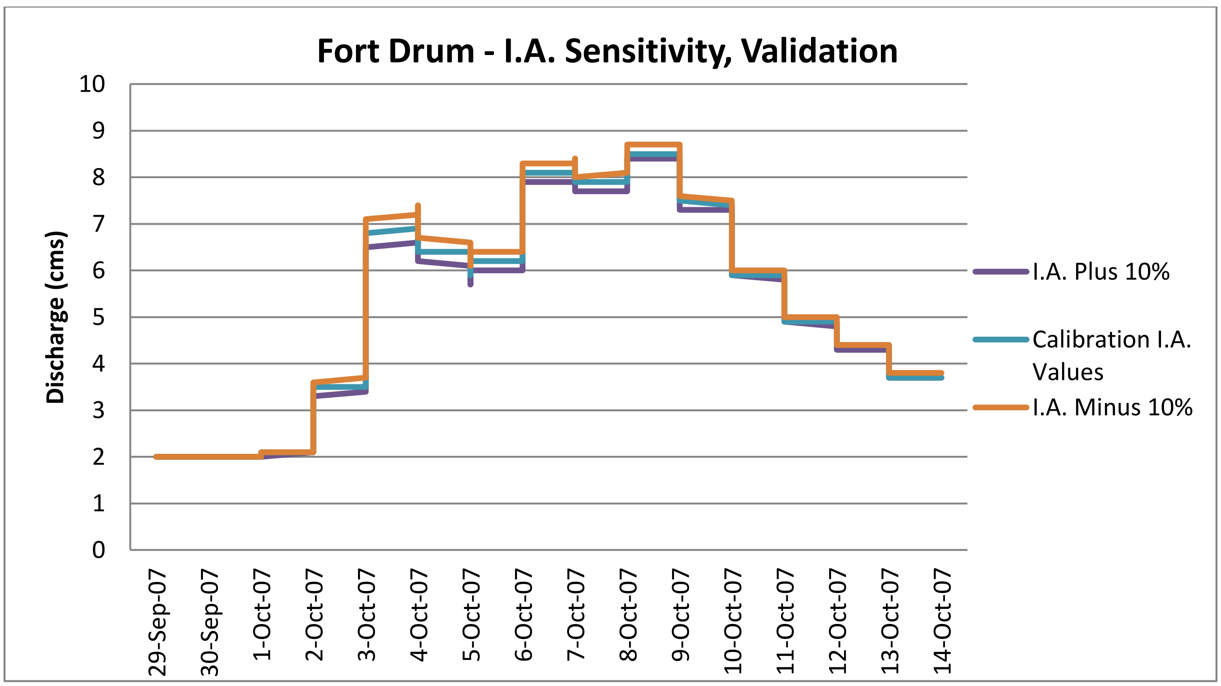


Figure 2-62. Fort Drum, Initial Abstraction Sensitivity Analysis for Validation

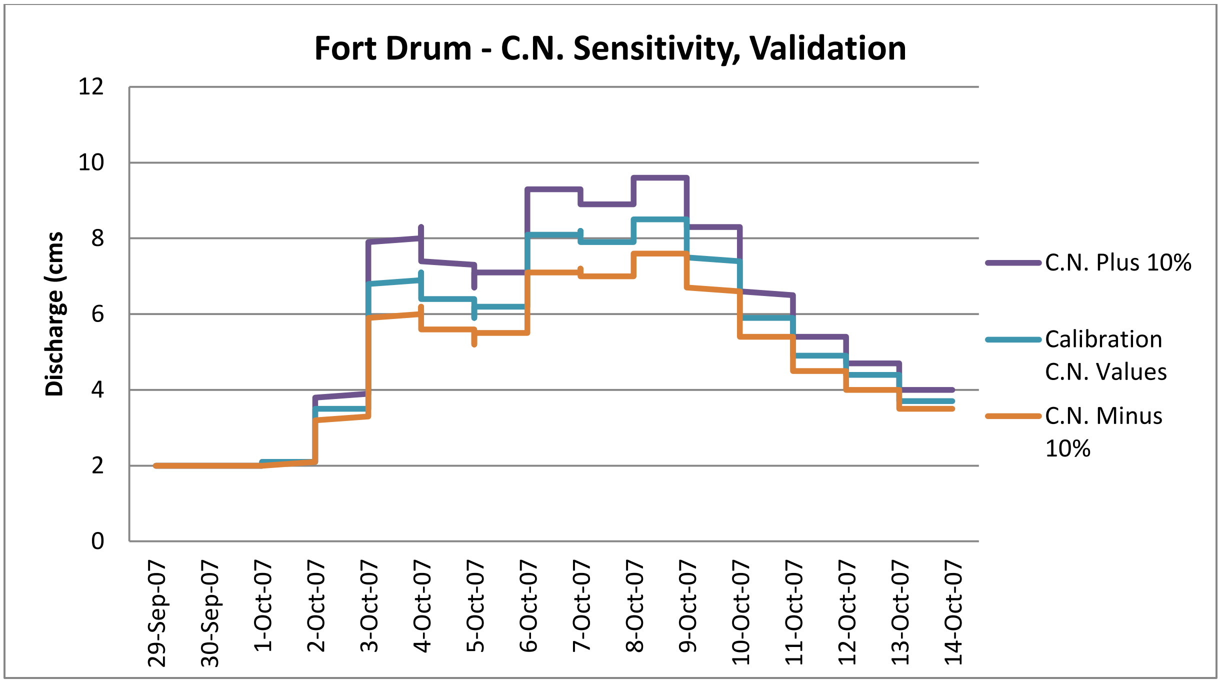


Figure 2-63. Fort Drum, Curve Number Sensitivity Analysis for Validation

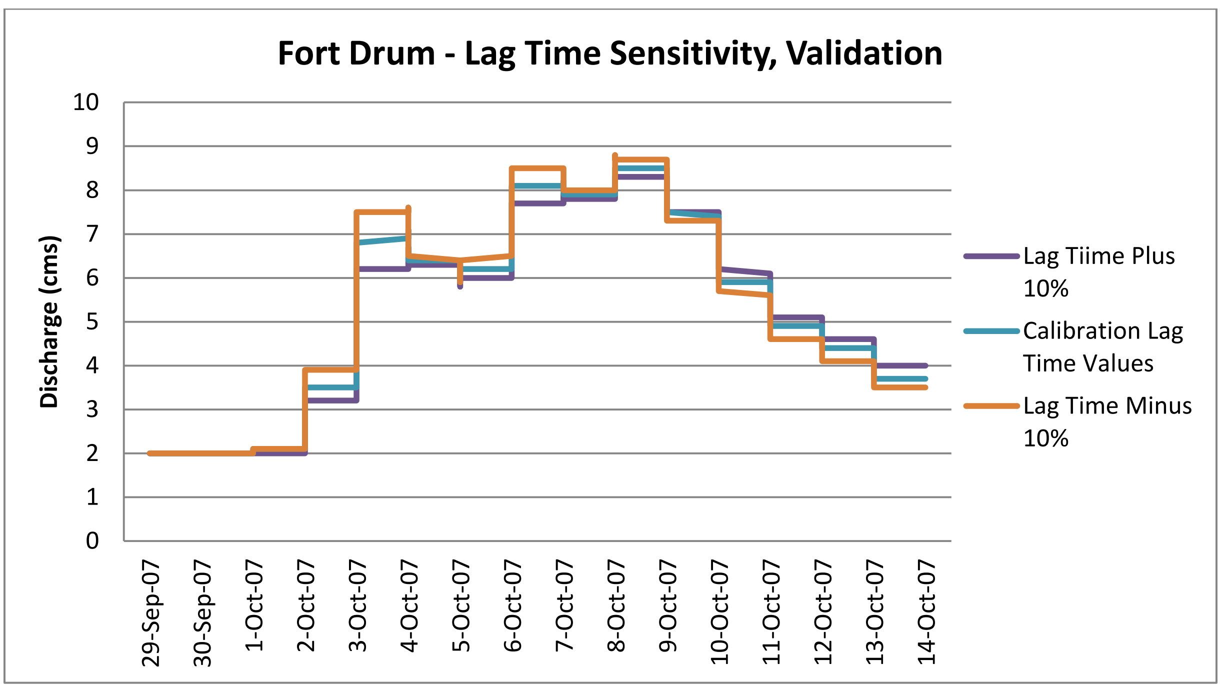


Figure 2-64. Fort Drum, Lag Time Sensitivity Analysis for Validation

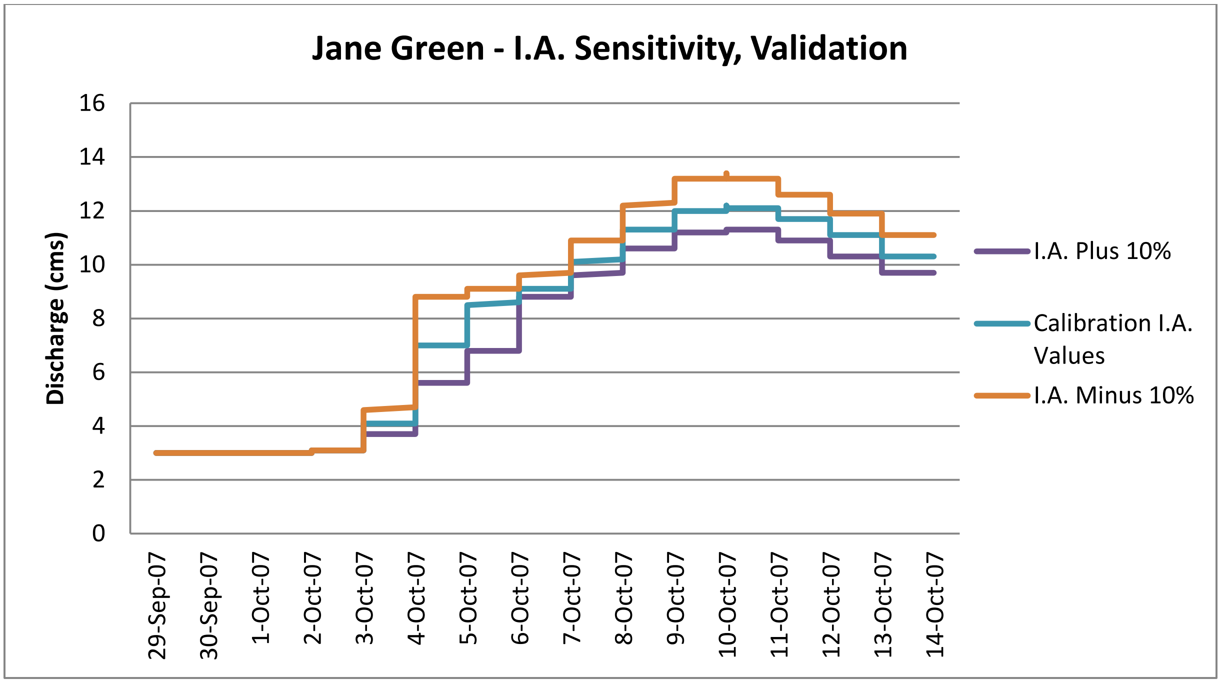


Figure 2-65. Jane Green, Initial Abstraction Sensitivity Analysis for Validation

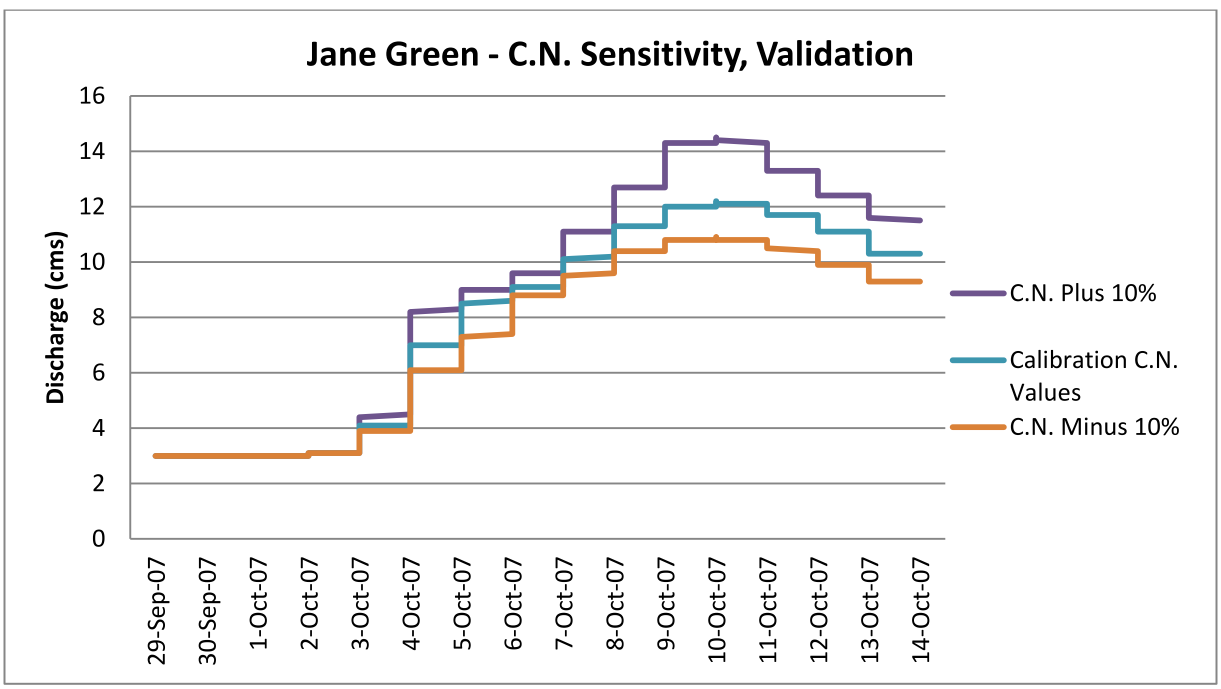


Figure 2-66. Jane Green, Curve Number Sensitivity Analysis for Validation

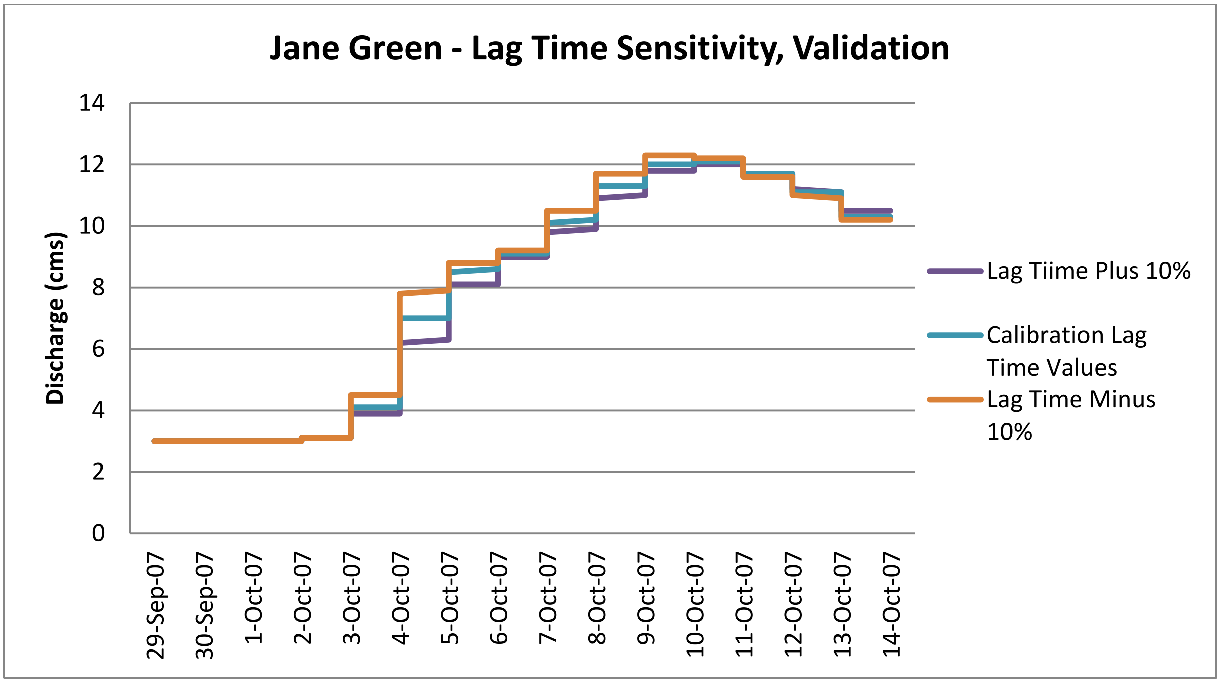


Figure 2-67. Jane Green, Lag Time Sensitivity Analysis for Validation

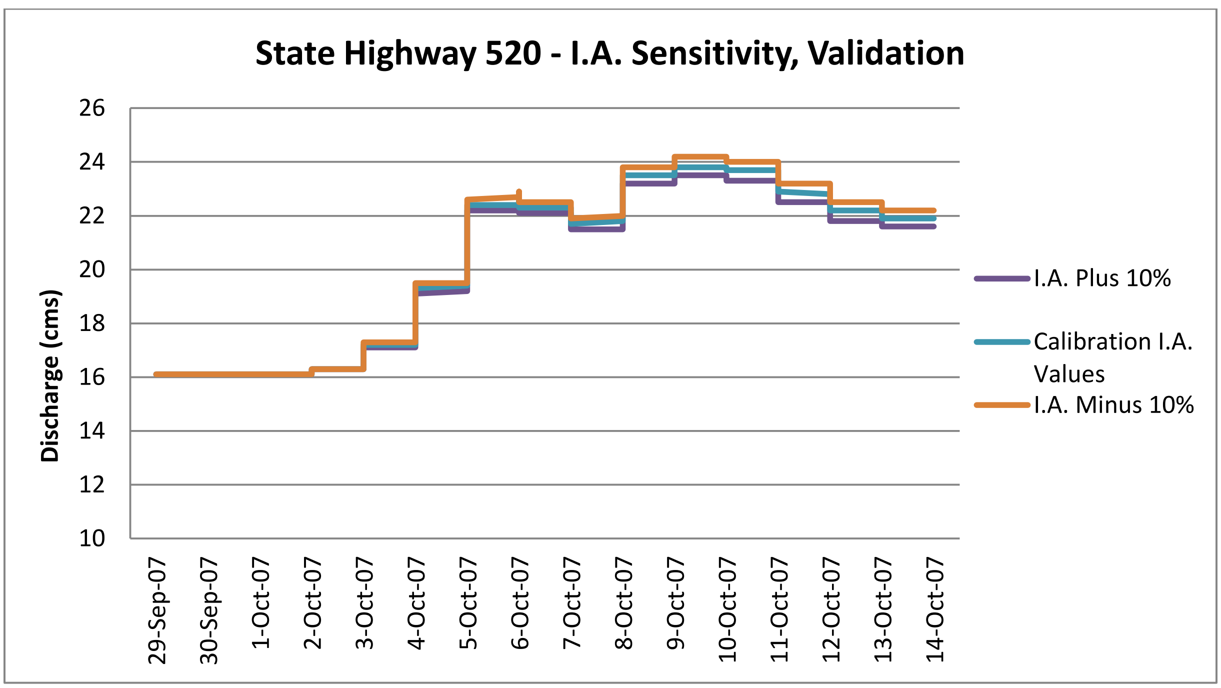


Figure 2-68. State Highway 520, Initial Abstraction Sensitivity Analysis for Validation

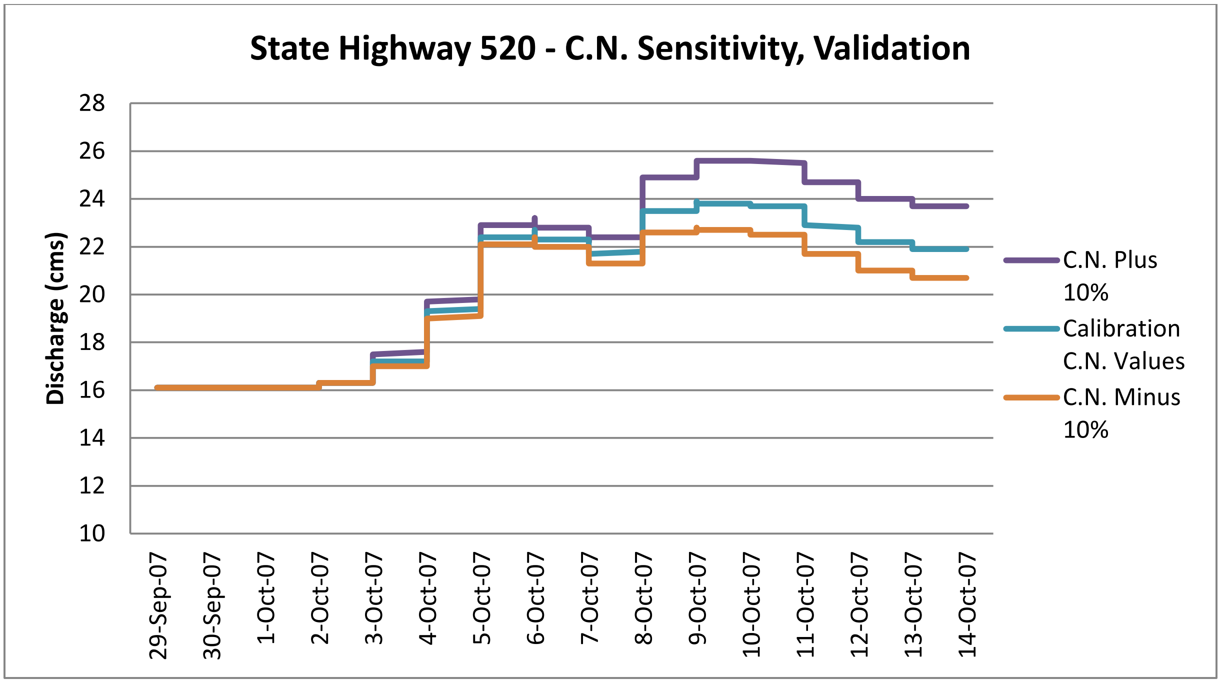


Figure 2-69. State Highway 520, Curve Number Sensitivity Analysis for Validation

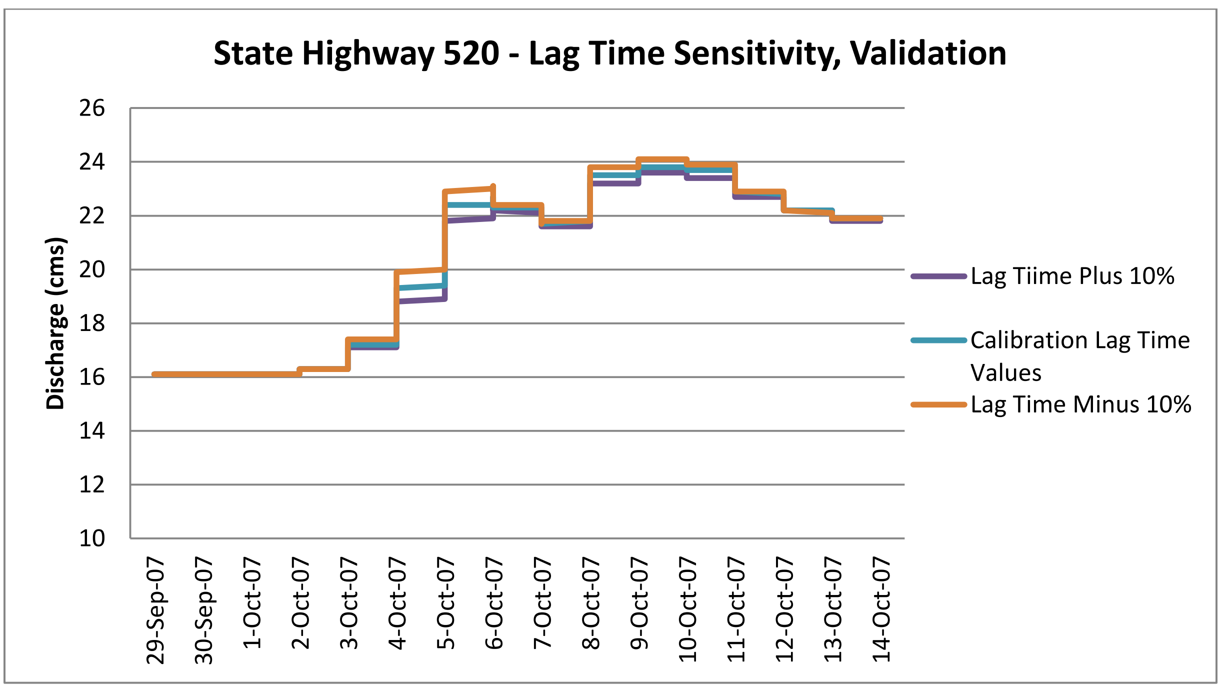


Figure 2-70. State Highway 520, Lag Time Sensitivity Analysis for Validation

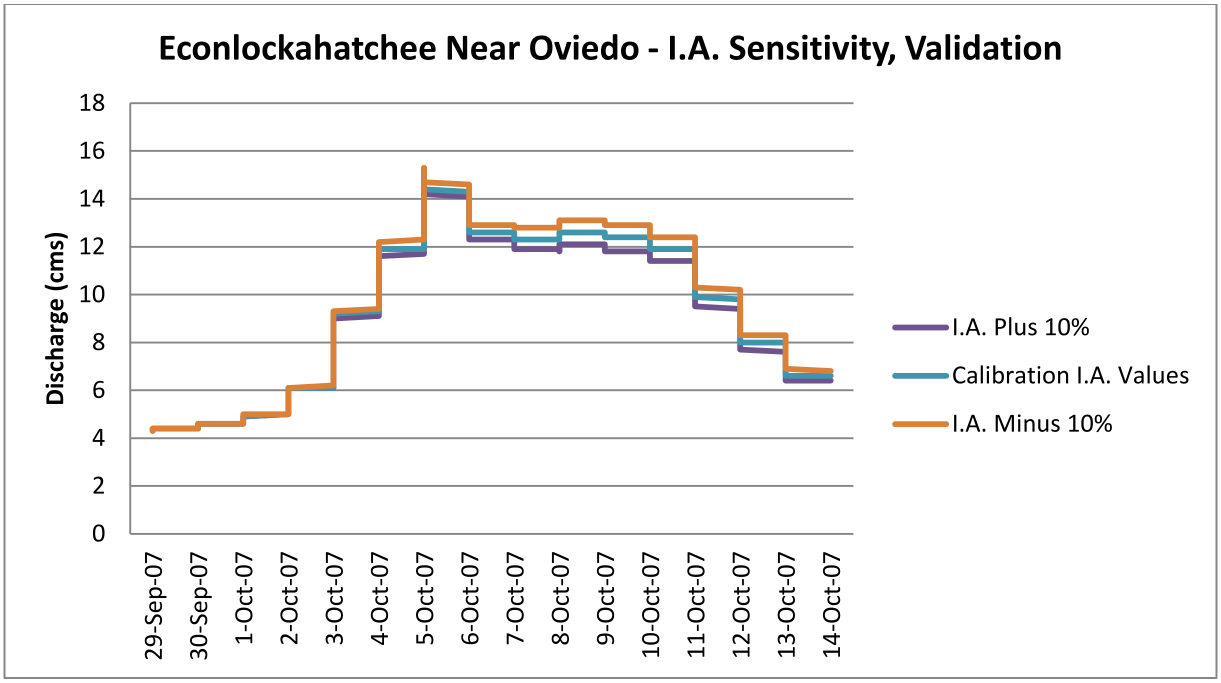


Figure 2-71. Econlockahatchee Near Oviedo, Initial Abstraction Sensitivity Analysis for Validation

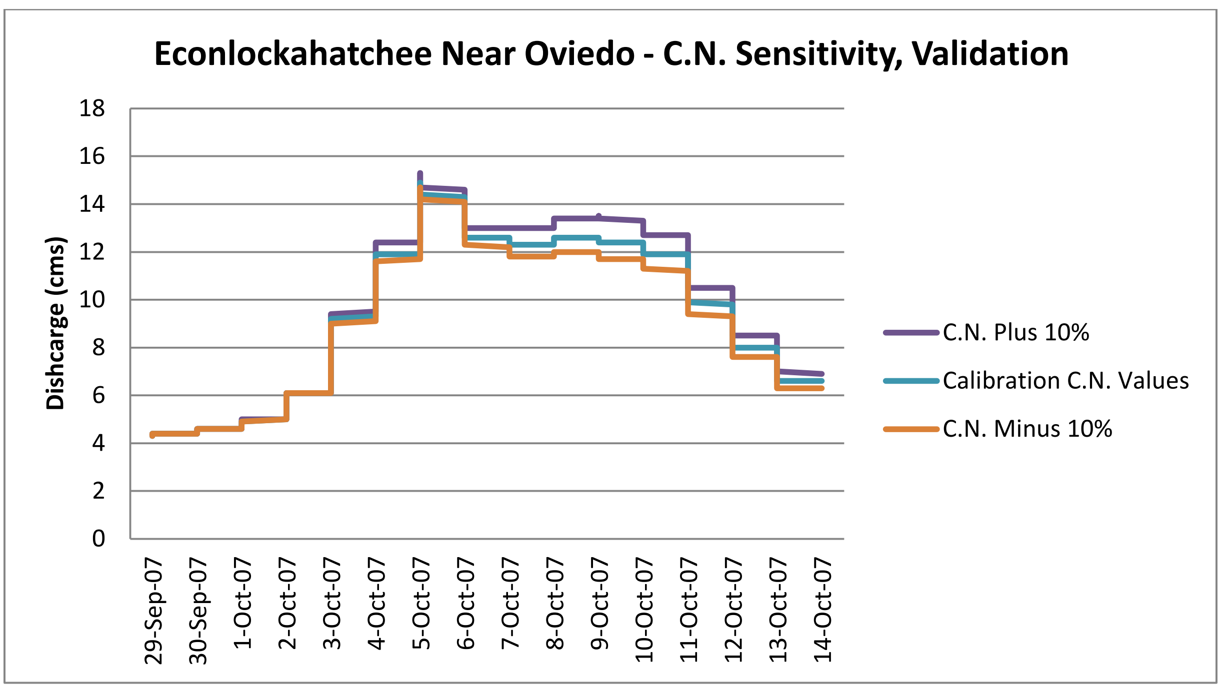


Figure 2-72. Econlockahatchee Near Oviedo, Curve Number Sensitivity Analysis for Validation

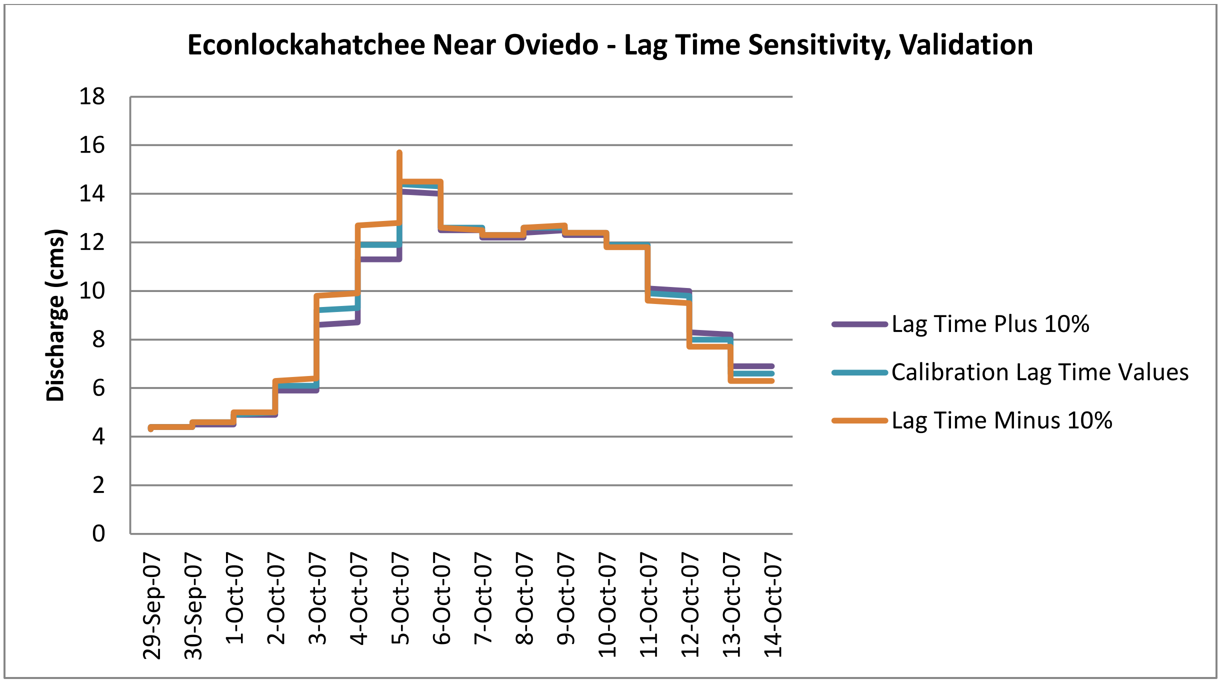


Figure 2-73. Econlockahatchee Near Oviedo, Lag Time Sensitivity Analysis for Validation

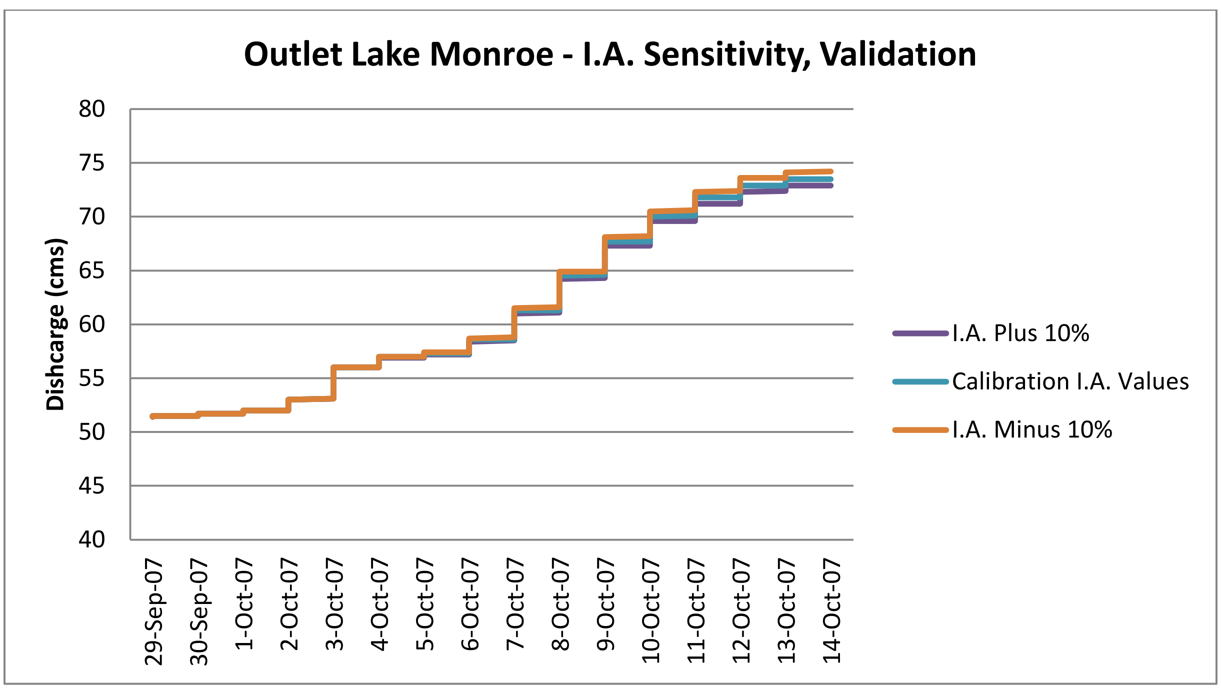


Figure 2-74. Outlet Lake Monroe, Initial Abstraction Sensitivity Analysis for Validation

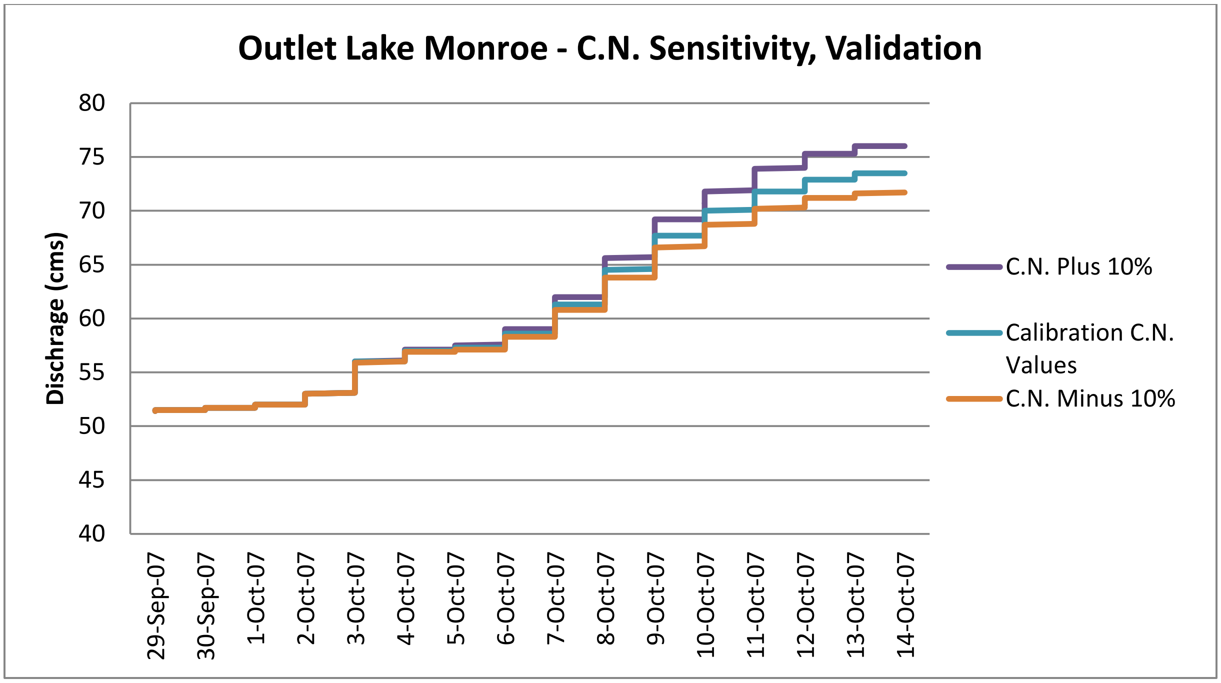


Figure 2-75. Outlet Lake Monroe, Curve Number Sensitivity Analysis for Validation

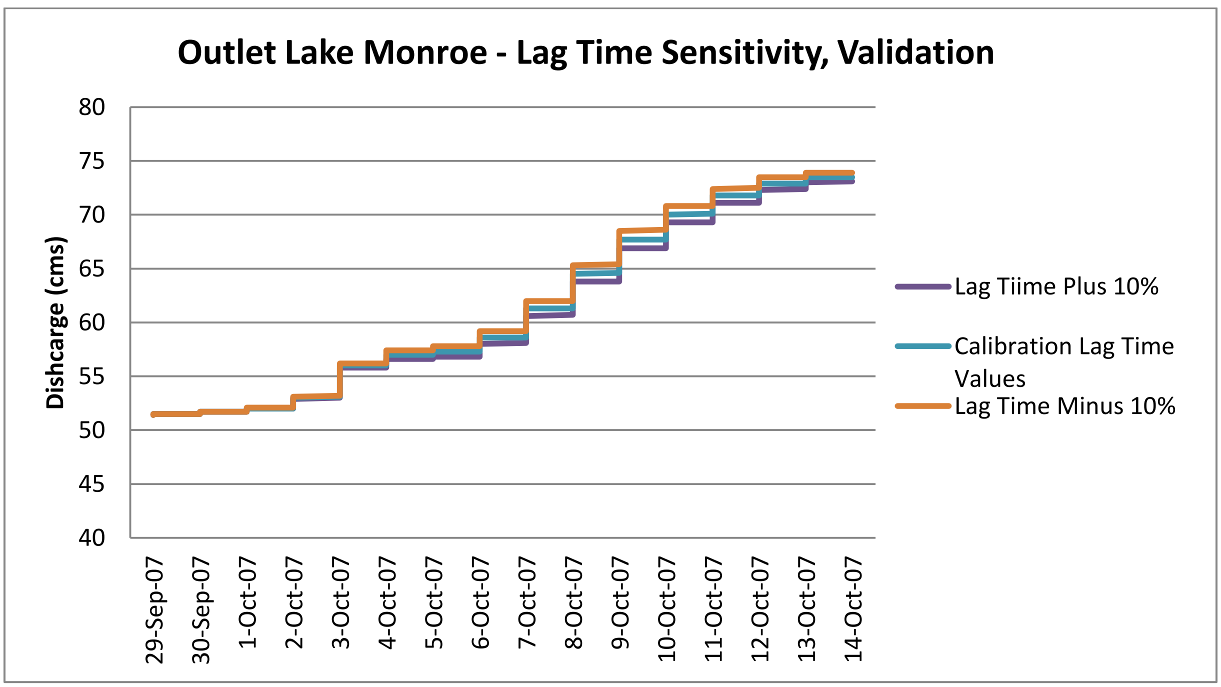


Figure 2-76. Outlet Lake Monroe, Lag Time Sensitivity Analysis for Validation

Goodness-of-fit Statistics for Sensitivity Analysis - In order to provide further insight regarding the sensitivity of the tested parameters, the coefficient of determination statistical analysis was performed for the sensitivity runs for calibration and validation. This was completed to determine if a “global change” to the parameters values may improve overall calibration or validation model results. Tables 2-6 and 2-7 show the original simulation results vs. gauge data coefficient of determination to the left, with the various changes in parameter values coefficient of determination values in the following columns. The r^2 values are reported in red, black, or green to aid in representing the changes from the original r^2 value. Red values represent a weaker statistical correlation, black values represent a similar statistical correlation, and green values show an improved or greater statistical correlation.

	Calibration	I.A. + 10%	I.A. - 10%	C.N. + 10%	C.N. - 10%	LAG + 10%	LAG - 10%
Fort Drum							
r =	**0.94**	0.93	0.94	0.94	0.93	0.92	0.95
r^2 =	**0.88**	0.87	0.88	0.89	0.87	0.84	0.91
Jane Green							
r =	**0.94**	0.94	0.94	0.95	0.93	0.92	0.95
r^2 =	**0.88**	0.87	0.89	0.89	0.87	0.85	0.90
State Highway 520							
r =	**0.99**	0.98	0.98	0.98	0.99	0.99	0.97
r^2 =	**0.97**	0.97	0.96	0.95	0.98	0.98	0.95
Econlockahatchee Near Oviedo							
r =	**0.94**	0.94	0.94	0.95	0.94	0.94	0.94
r^2 =	**0.89**	0.89	0.89	0.90	0.88	0.88	0.89
Outlet Lake Monroe							
r =	**0.99**	0.99	0.99	0.99	0.98	0.99	0.98
r^2 =	**0.97**	0.97	0.97	0.97	0.97	0.97	0.97

Table 2-6. Calibration Coefficient of Determination Results vs. Parameter Change Coefficient of Determination.

	Validation	I.A. + 10%	I.A. - 10%	C.N. + 10%	C.N. - 10%	LAG + 10%	LAG - 10%
Fort Drum							
r =	**0.69**	0.67	0.71	0.71	0.68	0.65	0.73
r^2 =	**0.48**	0.45	0.50	0.50	0.46	0.42	0.53
Jane Green							
r =	**0.87**	0.86	0.87	0.86	0.88	0.86	0.88
r^2 =	**0.76**	0.75	0.76	0.75	0.78	0.74	0.78
State Highway 520							
r =	**0.80**	0.80	0.80	0.76	0.83	0.79	0.81
r^2 =	**0.64**	0.65	0.63	0.57	0.69	0.62	0.66
Econlockahatchee Near Oviedo							
r =	**0.94**	0.94	0.95	0.95	0.93	0.96	0.92
r^2 =	**0.89**	0.88	0.90	0.90	0.87	0.92	0.85
Outlet Lake Monroe							
r =	**0.89**	0.89	0.89	0.89	0.89	0.89	0.89
r^2 =	**0.79**	0.79	0.79	0.79	0.79	0.78	0.80

Table 2-7. Validation Coefficient of Determination Results vs. Parameter Change Coefficient of Determination

The overall change in coefficient of determination values was determined by calculating the difference between the original calibration and validation coefficients of determination to the sensitivity analysis coefficient of determination. If the total change per parameter over all locations was positive it was deemed as a parameter that could improve the model.

The results of the coefficient of determination statistics for the calibration sensitivity runs show that improvements may be possible by increasing the curve number 10% and decreasing the lag time by 10%. For the validation sensitivity runs, the coefficient of determination statistics show improvements may be made by decreasing the I.A. by 10% and decreasing the lag time by 10%. Improvements to the calibration and validation model may be made by decreasing the lag time by 10%.

The results also provide further confirmation regarding the sensitivity of the different parameters for the calibration and validation results. The coefficient of determination values for the calibration results have an average change from the original calibration results of $\pm$ .01 whereas the coefficient of determination values for the validation results have an average change of $\pm$ 0.17. The average change in coefficient of determination is also the greatest for the lag times for the calibration model, with an average change of $\pm$ 0.02 (0.01 greater than C.N.). The average change in coefficient of determination is the greatest for the lag time and curve number values for the validation model. The magnitude of change for the I.A. for the validation model was much greater than for the calibration model, confirming that at lower flow rates the initial abstraction is more sensitive.

Recommendations – For this modeling effort the calibration and validation dates were set based on collaborative inputs from the University of Central Florida and the University of North Florida for the entire St. Johns River Basin. The calibration event chosen was for Tropical Storm Fay, which covered a majority of the St. Johns River Basin with high precipitation and subsequent runoff values. The validation event was more of a frontal system, with a larger precipitation event occurring in the more northern areas of the St. Johns River. The validation event within the Upper and Middle St. Johns River showed minimal precipitation values. Due to the scale of the model and the areas of discrepancy as explained previously, it is recommended that additional validation of the model be completed tied to a larger storm event with a higher return frequency of 24-hour to 48-hour precipitation. Further validation events should probably select precipitation events that are at least of 10 year return frequency. From the calibration results it can be concluded that the model produces very accurate results for larger flow events similar to that seen in Tropical Storm Fay in 2008. Caution should be used if trying to apply this model to small rain events, such as the one that occurred during validation which was a bit less than a 1 year return frequency precipitation event.

Unfortunately, due to project time constraints and set dates for calibration and validation outputs for delivery to downstream models for this project, additional validation has not yet been completed. Future areas of research pertaining to this model would be measuring the improvement or decline in goodness-of-fit statistics for the model when using NEXRAD radar precipitation data versus the Thiessen polygon method to capture the variability of the rainfall distribution. Additionally, a comparison of precipitation inputs using NEXRAD data versus rain gauge data at different return frequency would add to the understanding of the value of using more accurate, yet more cumbersome input data (e.g. NEXRAD data) for different level of storm events. Also, the benefits of using different input precipitation datasets at different spatial and temporal scales could provide further interesting research studies.

Numerical Model Development – SWAT Model

Model Domain - Soil and Water Assessment Tool (SWAT) is a continuous simulation model that has proven to be an effective tool for assessing the impact of management on water sources and nonpoint source pollution in rural watersheds and large river basins at annual, monthly and daily time steps (Wang et al., 2011; Maharjan et al., 2013; Tang et al., 2013; Chen et al., 2014). The SWAT model is developed by USDA Agricultural Research Service (Arnold et al., 1998). The SWAT model domain for the lower St. Johns River basin is shown in Figure 2-77. There are two inlets to the model: 1) the discharge from Lake Monroe with latitude 29°00'29" and longitude 81°22'58"; and 2) the inflow from the Oklawaha Basin through the Cross Florida Barge Canal with latitude 29°10'00" and longitude 81°31'20". The discharge from the outlet of the HEC-HMS model (i.e., discharge from Lake Monroe) is used an inflow to SWAT.

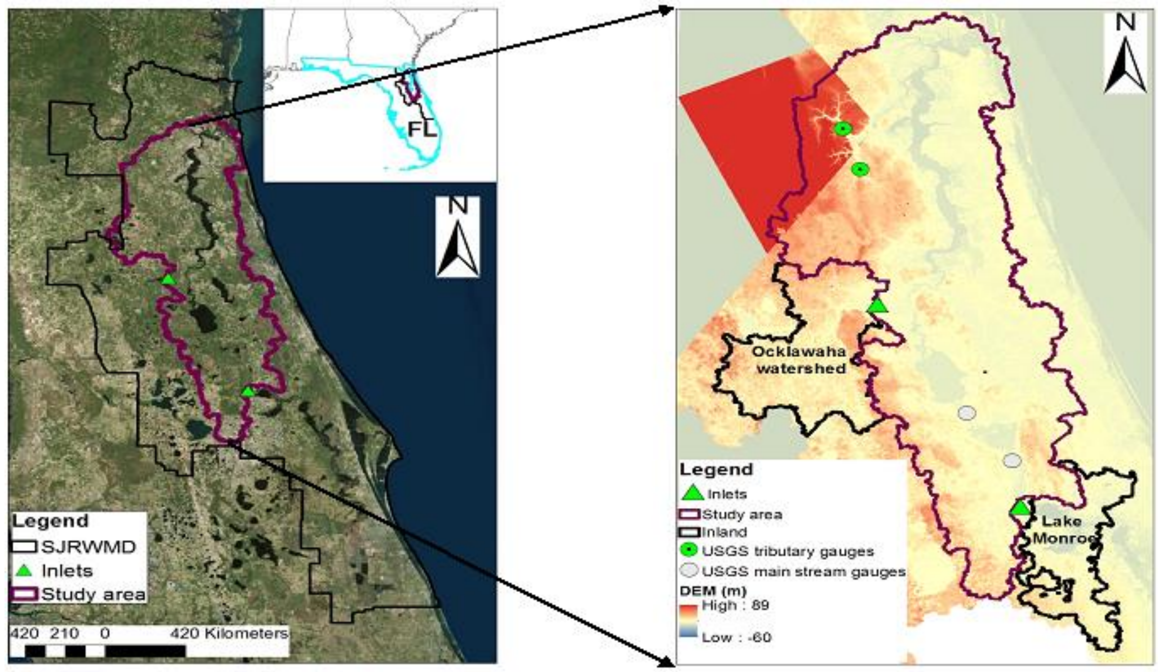


Figure 2-77. The model domain of the SWAT model for the lower St. Johns River basin.

SWAT Model Inputs - The inputs for the SWAT model include digital elevation model (DEM), soil property, land cover and land use, and rainfall. The data sources for the input data are listed in Table 2-8. The details for these data are described in the following sections.

URL	Organization	Data
http://ned.usgs.gov/	United States Geological Survey	DEM
http://www.sjrwmd.com/	St. Johns River Water Management District Center for Environmental	NEXRAD
http://www.mrlc.gov/nlcd2006.php	National Land Cover Database 2006	LULC
http://www.nrcs.usda.gov/	United States Department of Agriculture	Soil
http://waterdata.usgs.gov/nwis	United States Geological Survey	Streamflow

Table 2-8. The data sources for SWAT inputs.

NEXRAD Rainfall Data - Since rainfall data with high spatial and temporal resolutions are required in this project, the NEXRAD data is obtained from SJRWMD. The spatial resolution of the NEXRAD data is approximately 2 km by 2 km, and the temporal resolution is hourly.

In SWAT, rainfall input is uniform within each sub-basin as shown in Figure 2-78a. NEXRAD pixels are overlaid with sub-basins (Figure 2-78b), and the area-weighted average rainfall is computed for each sub-basin and the weights are the area of NEXRAD pixels within the corresponding sub-basin. The average rainfall is assigned to the centroid of each sub-basin generated based on the boundary of the sub-basins (Figure 2-79).

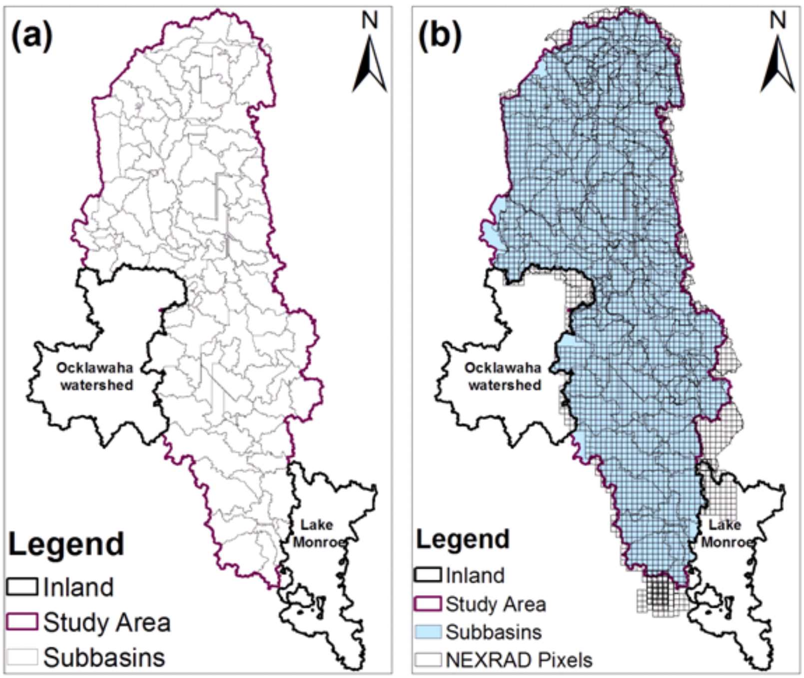


Figure 2-78. a) The delineated sub-basins for SWAT; b) Overlay of NEXRAD pixels and sub-basins.

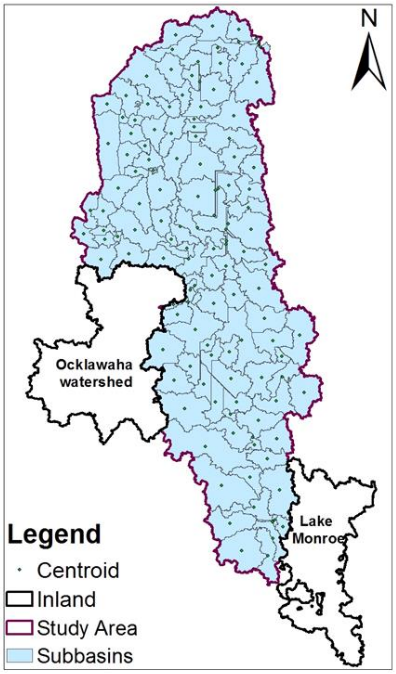


Figure 2-79. The centroids for delineated sub-basins

Digital Elevation Model (DEM) - DEM with a resolution of 30 m by 30 m is obtained from USGS (Figure 2-80a). The data in the northwest part of the lower St. Johns River basin is missing and DEM with 5 m resolution is obtained from LiDAR. The merged DEM (Figure 2-80b) was used to generate the model domain based on the outlet and two inlets. Slope was computed from the merged DEM.

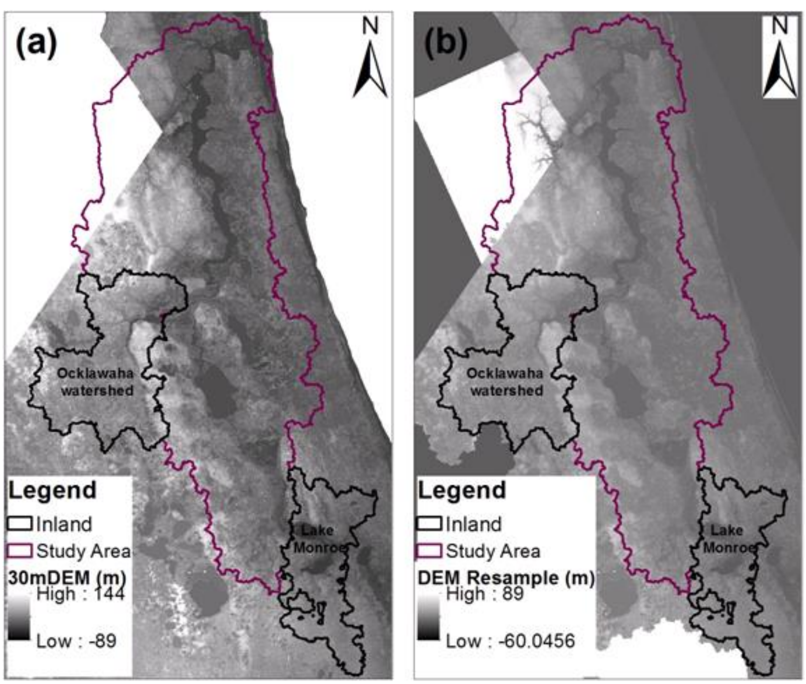


Figure 2-80. a) DEM with resolution of 30 m by 30 m; b) Merged DEM.

Land use and land cover data-In this project the land use and land cover (LULC) data with a 30 m resolution was obtained from National Land Cover Database 2006 (NLCD 2006), which is a 16-class land cover classification scheme. SWAT provides a land use database to compute parameter values related to land use such as CN number. SWAT has its own code for each land use type, and the NLCD code is transferred to SWAT code (Figure 2-81). The description and area ratio of each land use type is listed in Table 2-9. The dominating LULC types are forest (30.5%), wet land (23.1%) and urban area (17.3%) in the region (Table 2-9).

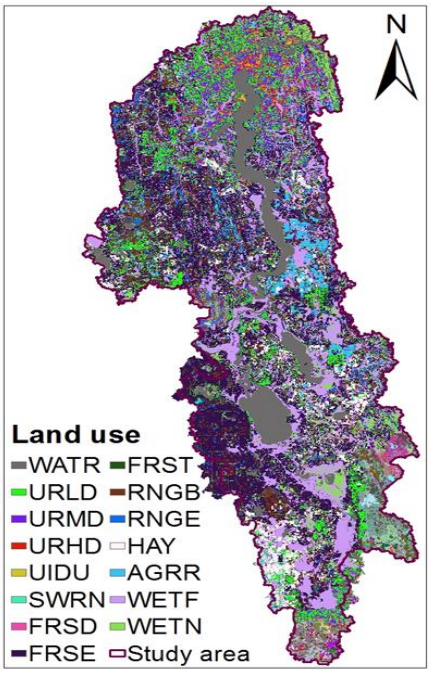


Figure 2-81. Land use and land cover map based on the SWAT code.

NLCD ID	Description of NLCD	SWAT ID	Description of SWAT	Area ratio (%)
11	Open water	WATR	Water	9.07
21	Developed, open space	URLD	Residential-Low Density	10.10
22	Developed, low intensity	URMD	Residential-Medium Density	5.10
23	Developed, midium intensity	URHD	Residential-High Density	1.69
24	Developed, high intensity	UIDU	Industrial	0.65
31	Barren land	SWRN	Southwestern US (Arid) Range	0.46
41	Deciduous forest	FRSD	Forest-Deciduous	0.12
42	Evergreen forest	FRSE	Forest-Evergreen	29.74
43	Mixed forest	FRST	Forest-Mixed	0.66
52	Scrub/Shrub	RNGB	Range-Brush	9.42
71	Grassland/Herbaceous	RNGE	Range-Grasses	3.45
81	Pasture/Hay	HAY	Hay	4.62
82	Cultivated crops	AGRR	Agricultural Land-Row Crops	1.83
90	Woody wetlands	WETF	Wetlands-Forested	19.10
95	Emergent Herbaceous wetlands	WETN	Wetlands-Non-Forested	4.00

Table 2-9. Description and area ratio for each land use type.

Soil Data - In this project soil data is obtained from SSURGO database collected by the National Cooperative Soil Survey. The SSURGO database is integrated into the version of ArcSWAT 2009. In lower St. Johns River basin, there are 542 MUKEY (Map of Unit key), and the soil hydrologic group map is shown in Figure 2-82.

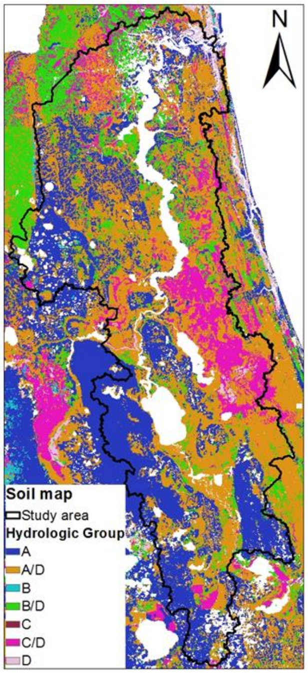


Figure 2-82. Soil hydrologic group in the lower St. Johns River basin.Slope - Computed from DEM, are shown in Figure 2-83. As we can see, most area is less than 5%, which indicates a flat land surface.

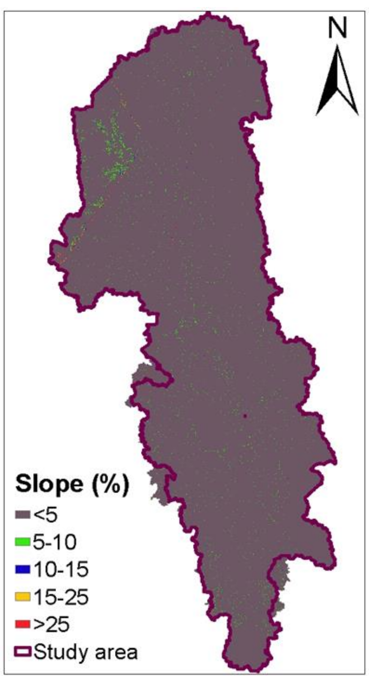


Figure 2-83. Slope in lower St. Johns River basin

SWAT Model Setup

Watershed delineation - The lower St. Johns River basin is divided into a number of sub-basins as shown in Figure 2-78a. There are 128 sub-basins in the model domain. Each sub-basin is further divided into HRUs based on land use and land cover, soil type and slope. Totally, 17,375 HRUs are delineated for the lower St. Johns River basin in this study.

Running period - The SWAT model was calibrated for Tropical Storm Fay (July 1 – August 27, 2008) at an hourly time step. The model was then validated using an event during September 1 – October 13, 2007. The first month for each simulation duration served as a warm-up period to generate initial conditions for the model runs.

Surface runoff volume - SWAT provides two methods for estimating surface runoff: the SCS curve number (CN) method and the Green-Ampt method. The Green-Ampt equation is a physically based model that allows continuous simulation of infiltration assuming that the soil profile is homogeneous and antecedent moisture is uniformly distributed in the profile. The Green-Ampt equation uses a direct relationship between infiltration and rainfall intensity based on physical parameters allowing continuous surface runoff simulation. While the CN method is widely used, its usage in continuous simulation is controversial because it estimates direct runoff using empirical relationships between the total rainfall and watershed antecedent properties. In this study, the Green-Ampt method is used for simulating hourly surface runoff in the lower St. Johns River basin.

Evapotranspiration - SWAT computes evaporation from soils and plants separately (Ritchie, 1972). Potential soil water evaporation is estimated as a function of potential evaporation and leaf area index. Actual soil water evaporation is estimated by using exponential functions of soil depth and water content. Transpiration is simulated as a linear function of potential evapotranspiration and leaf area index. There are four ways to calculate the potential evapotranspiration including Hargreaves (Hargreaves et al., 1985), Priestley- Taylor (Priestley and Taylor, 1972), and Penman-Monteith (Monteith, 1965), and the observed data by user. The Penman-Monteith method is used in this project.

Pond and Wetland - Ponds and wetlands are water storage structures located within a sub-basin. As above mentioned, one of dominating land use types in the lower St. Johns River basin is wetland. SWAT provides a bunch of parameters to simulate this process. In SWAT, the pond and wetlands water storage is a function of storage capacity, inflows and outflows, seepage and evaporation. In order to estimate the impact of wetland change on floods, the related parameters to ponds and wetlands are calibrated.

Routing in the main channel - Runoff in the SWAT model is routed through the channel network using the variable storage routing method or the Muskingum routing method. Both methods are variations of the kinematic wave model which simulates short duration storms better than the nonlinear reservoir model. In this project, the Muskingum routing method is used.

Matlab code for reading the hourly simulations - A Matlab code was developed to extract hourly hydrograph for each sub-basin outlet.

Model Calibration - The SWAT model was calibrated for Tropical Storm Fay at an hourly time step. Observations from four USGS stream gauges are used for calibration: gauge #02236000 and gauge #02236125 located in the main channel, gauge #02245500 and gauge # 02246000 in tributaries (Figure 2-84).

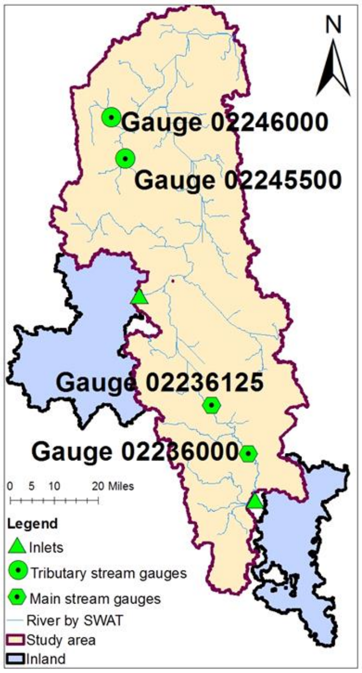


Figure 2-84. Stream gauges used for calibrating SWAT model.

Calibrated parameters - Since CN2 and AWC (available water capacity) vary with LULC and soil type, they are calibrated by a percentage of change. The calibrated values for other parameters are uniform in space. The estimated values for the main parameters are listed in Table 2-10. The first nine parameters are related to surface runoff and base flow; and the five other parameters are for runoff routing.

Parameters	Definition	Initial Value	Range	Calibrated Value at Gauge			
				#02236000	#02236125	#02245500	#02246000
ALPHA_BF	Base flow recession constant	0.048	0.001~1	0	0	0	0
GWQMN	Threshold water level in shallow aquifer	0	0~2000	0	0	30	0
GWDELAY	Delay time for aquifer recharge	31	0~100	0.018	0.012	0.98	0.98
CN2	SCS runoff curve number for moisture condition II	35~92	30~98	-15%	-10%	+20%	+5%
ESCO	Soil evaporation compensation factor	0.95	0~1	0.55	0.55	0.95	0.5
AWC	Avaliable water capacity of soil layer (mm/mm)	0~0.4	0~1	+20%	+20%	-5%	+15%
Ksat	Saturated hydraulic conductivity (mm/hr)	331.2	0~2000	600	331.2	730.264	180.264
PND_FR	Fraction of the subbasin area draining into the pond	0	0~1	0.05	0.3	0.001	0.05

WET_FR	Fraction of the subbasin area draining into the wetland	0	0~1	0.4	0.5	0.1	0.3
CH_N1	Manning's n value for the tributary channels	0.014	0.014~30	0.014	0.014	30	30
CH_N2	Manning's n value for the main channels	0.014	-0.01~0.3	0.032	0.032	0.074	0.034
OVR_N	Manning's n value for the overland flow	0.1	0~10	0.14	0.14	30	30
MSK_CO2	Weighting factor for influence of normal flow on storage time constant	0.25	0~10	4.5	4.5	4.5	4.5
MSK_CO1	Weighting factor for influence of low flow on storage time constant	0.75	0~10	1.75	1.75	1.75	1.75

Table 2-10. Calibrated parameter values for SWAT

Calibration results - Figure 2-85 shows the calibration results at gauge #02236000, indicating good performance. The calibrated results at gauge #02236125 is worse than those at gauge #02236000 (Figure 2-86). The calibrated results in tributaries are shown in Figure 2-87 and Figure 2-88. The simulated low flow matches the observed one while there are more peaks in the simulated hydrograph, especially at gauge #02246000.

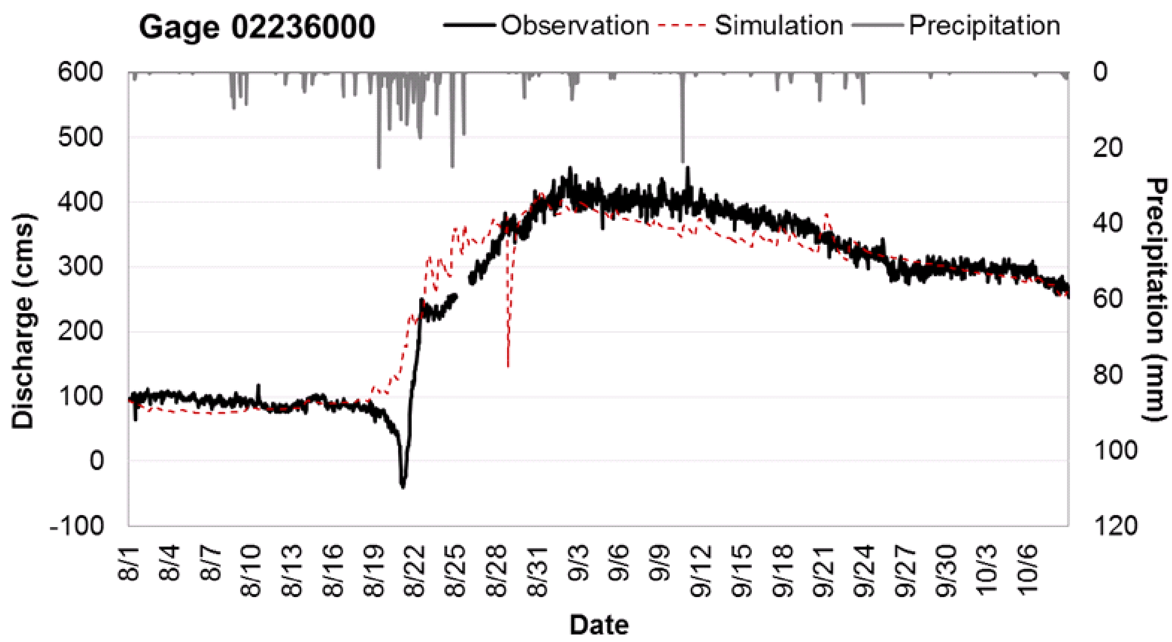


Figure 2-85. The calibration results at gauge #2236000.

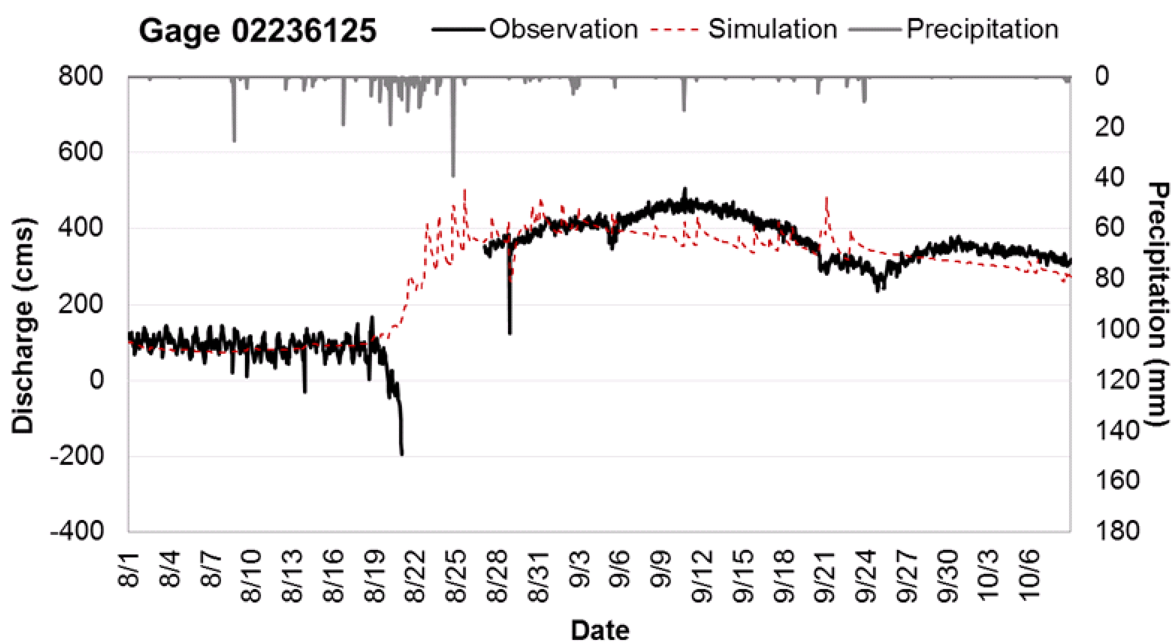


Figure 2-86. The calibration results at gauge #2236125.

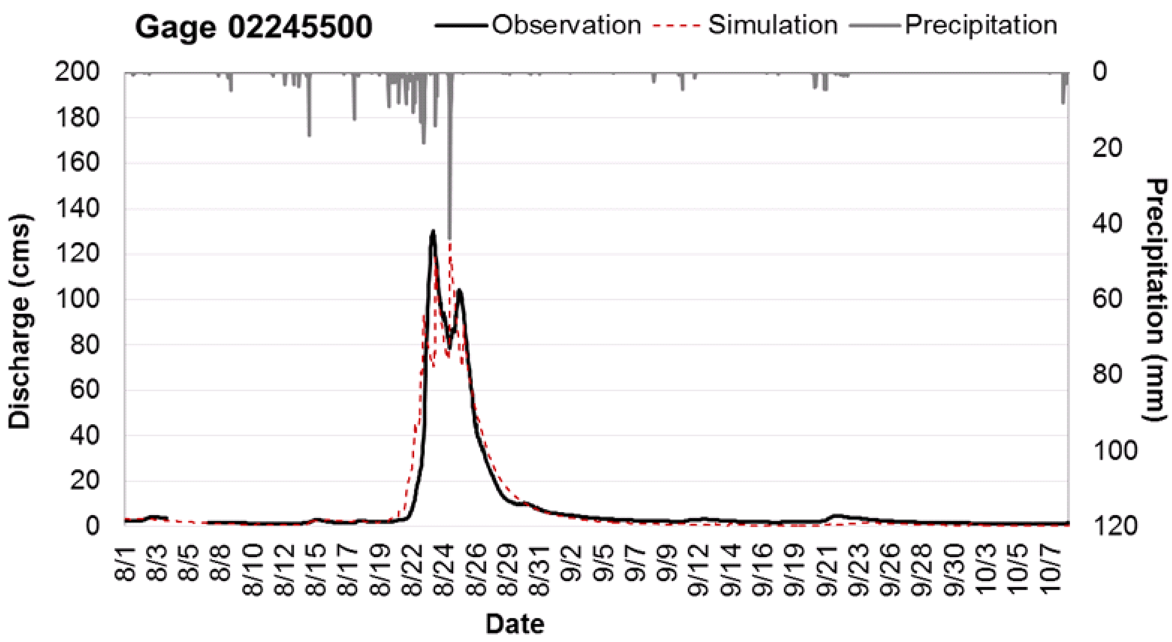


Figure 2-87. The calibration results at gauge #2245500.

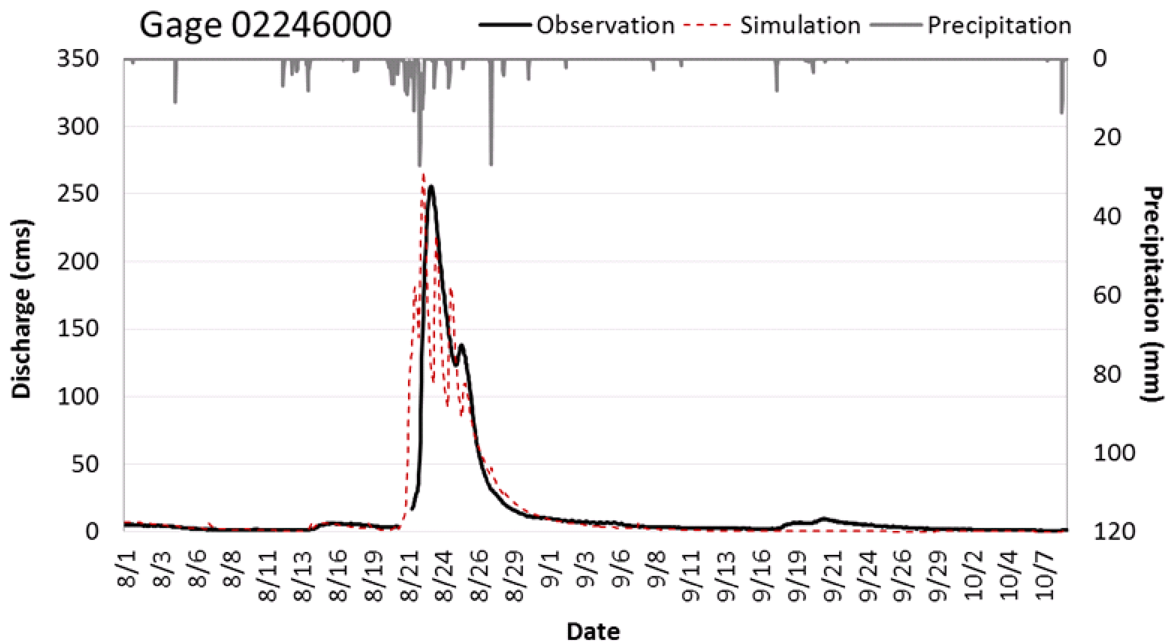


Figure 2-88. The calibration results at gauge #2246000.

Model Calibration Performance Evaluation - The warm-up period during calibration is July 1, 2008 to July 31, 2008. The calibration period covers the Tropical storm Fay which is the period of Aug 1, 2008 to October 8, 2008. To evaluate the performance of the SWAT, two indicators are computed: the coefficient of determination (R2) and the Nash-Sutcliffe efficiency (ENS). The coefficient of determination (R2) indicates the degree of collinearity between simulated and measured data. It describes the proportion of the variance in measured data explained by the model. R2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable. The ENS is Nash-Sutcliffe efficiency which is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information"). ENS ranges between $-\infty$ and 1.0 (1 inclusive), with ENS = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values < 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

The performance of the SWAT model at the hourly time step during the calibration is shown in Table 2-11. R2 is 0.92 and ENS is 0.81 for gage #02236000; and R2 is 0.88 and ENS is 0.82 for gage #02236125; Both R2 and ENS are 0.89 for gage #02245500; and R2 is 0.75 and ENS is 0.71 for gage #02246000.

USGS Gauge	Calibration period	
	R^2	E_{NS}
# 2236000	0.92	0.81
# 2236125	0.88	0.82
# 2245500	0.89	0.89
# 2246000	0.75	0.71

Table 2-11. The performances during calibration period

Model Validation - The model is validated against the observations during the period of Oct. 1, 2007 -- Oct. 13, 2007. During the validation period, all the parameter values are obtained from the calibration period.

Validation results - Figure 2-89 shows the validation results at gauge #02236000 and the simulations are out of phase with observation, especial in Oct. 4. The same situation can be found at gauge $02236125 (Figure 2-90). During validation period, the best performance is at gauge #02245500 although the magnitude of peak flow does not agree very well with the observation (Figure 2-91). The patterns of hydrograph are similar between the observation and simulation at gauge #02246000 but the magnitude of simulation is quite larger than that of observation (Figure 2-92).

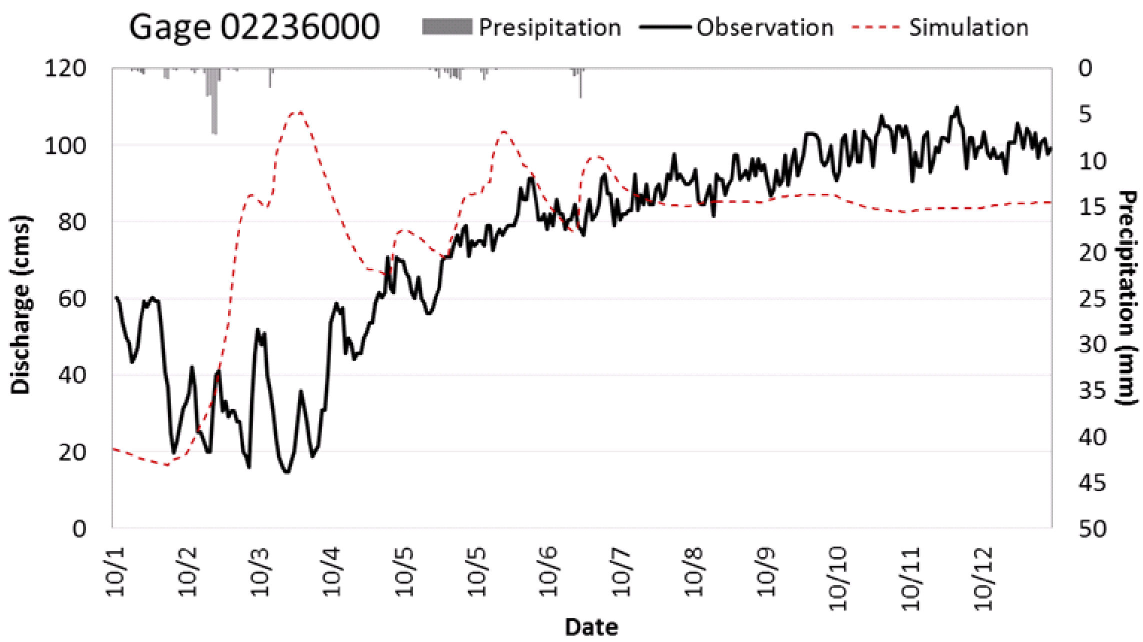


Figure 2-89. The validation results at gauge #2236000.

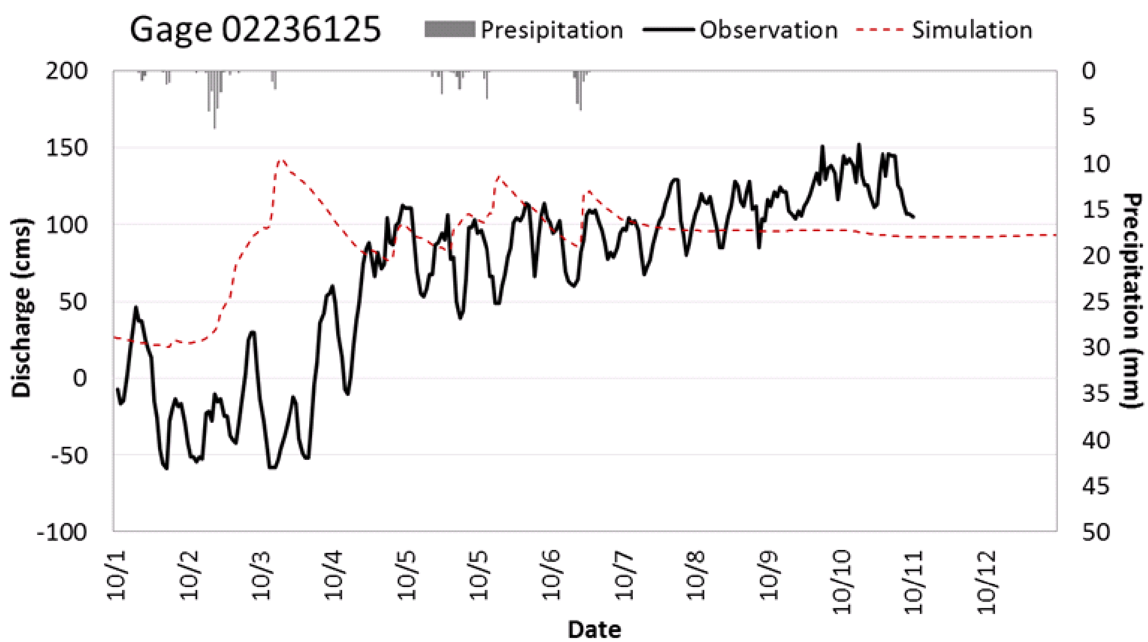


Figure 2-90. The validation results at gauge #2236125.

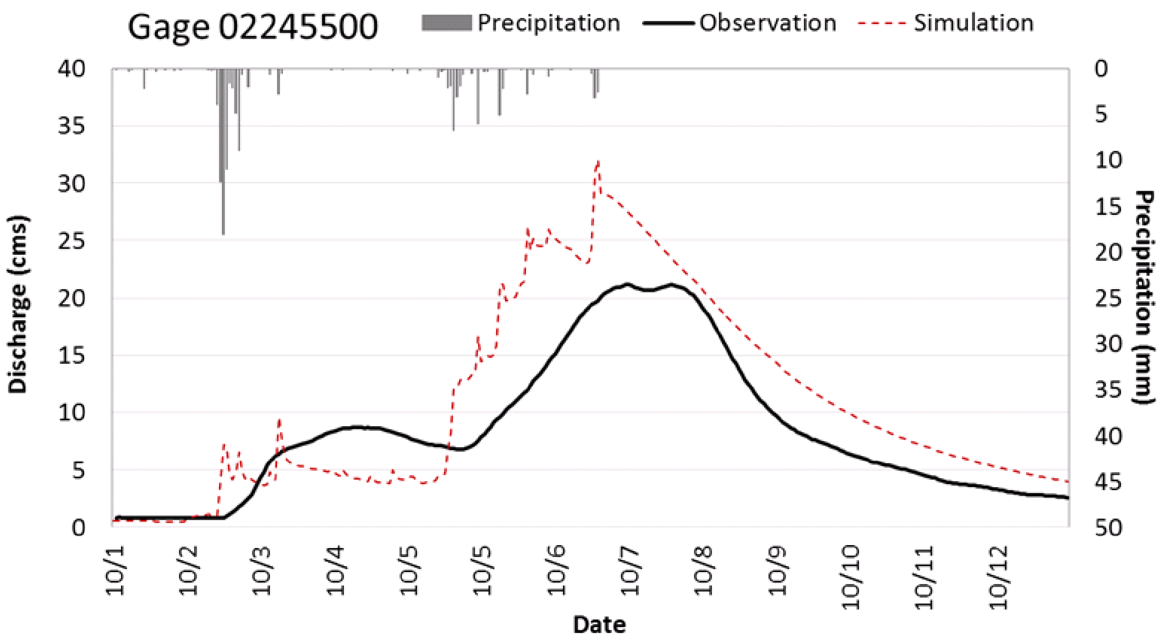


Figure 2-91. The validation results at gauge #2245500.

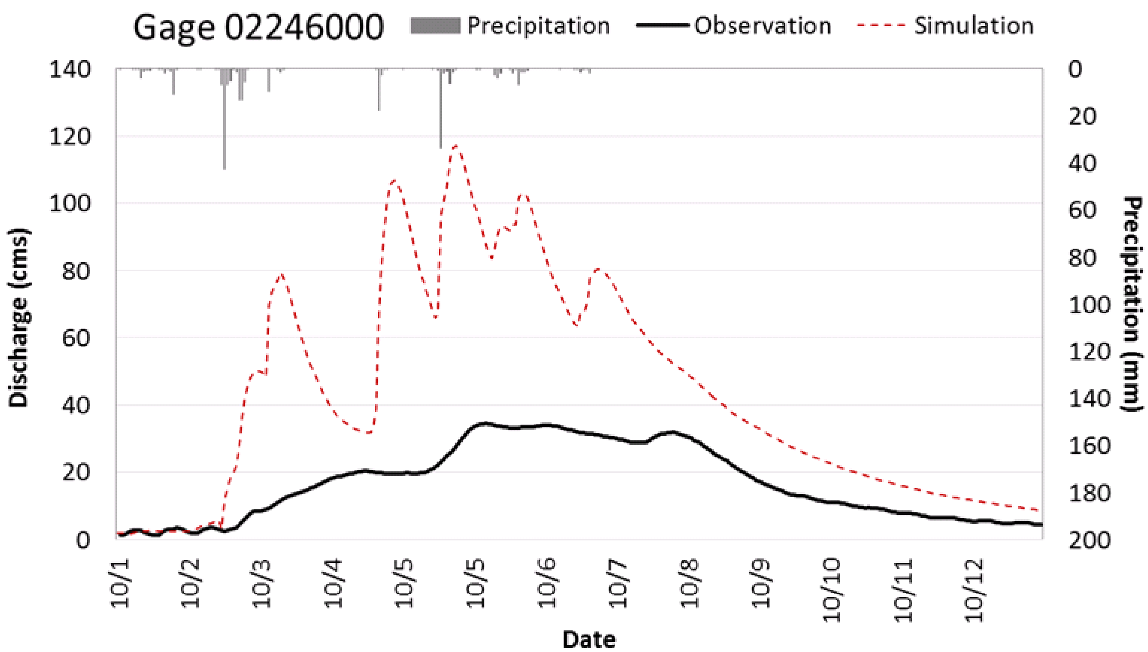


Figure 2-92. The validation results at gauge #2246000.

Model Validation Performance Evaluation - The performance of the SWAT model at the hourly time step during the validation period is shown in Table 2-12. During the validation period, R^2 is 0.16and E_{NS} is –0.04 for gage #02236000; and R^2 is 0.17 and E_{NS} is -0.16 for gage #02236125; R^2 is 0.82 and E_{NS} is 0.5 for gage #02245500; and R^2 is 0.66 and E_{NS} is -10.2 for gage #02246000.

USGS Gauge	Validation period	
	R^2	E_{NS}
# 2236000	0.16	-0.04
# 2236125	0.17	-0.16
# 2245500	0.82	0.5
# 2246000	0.66	-10.2

Table 2-12. SWAT performance during the validation period.

Validation Discrepancies - There are many explanations to the reason that the SWAT model performance during the validation period is quite worse than that during the calibration period. Firstly, the reason might be the difference of storm scales for the calibration and validation periods. Secondly, for the main stream gauges they are affected significantly by the upper stream inlet and the simulated errors will be enlarged here. For gauge #2246000, the big difference between the calibration and validation periods may be caused by significant rainfall error. As Figure 2-92 and Figure 2-89 show, rainfall during the validation period at this gauge is much larger than that during Tropical Storm Fay.

Numerical Model Development

ADCIRC Model, Model Domain - An existing hydrodynamic model (finite element mesh) for the lower St. Johns River was used as the basis for the hydrologic-hydrodynamic modeling in this study (Bacopoulos et al., 2012). Firstly, the existing mesh was extended beyond the river banks and into the watershed basin. For this mesh development, the watershed basin was meshed in a modular fashion using 128 contiguous sub-watersheds (Lowe et al., 2012). Figure 2-93 shows the 128 sub-basins (SWAT) and the developed mesh (ADCIRC) for the lower St. Johns River Basin. The mesh for the lower St. Johns River Basin contains 111,458 nodes and 215,573 elements. Mesh resolution is 50–150 m for the first 5 km outward from the river bank, 150–300 m for the next 5 km outward and 300–500 m beyond to the 5-meter topographic contour. The developed mesh for the lower St. Johns River Basin was appended to the existing mesh to generate a comprehensive mesh to be used for numerical simulation in this paper. This comprehensive mesh for the lower St. Johns River Basin contains 210,340 nodes and 414,762 elements.

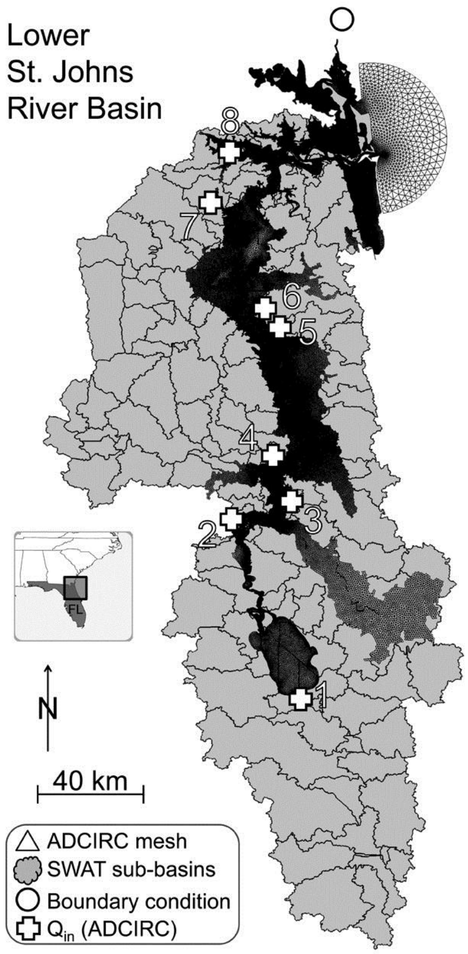


Figure 2-93. The ADCIRC mesh and the 128 sub-basins (SWAT) for the lower St. Johns River Basin. The eight locations where freshwater river inflow boundary conditions are applied to ADCIRC are numbered (Q_{in}).

Topography refers to elevations above NAVD88 and bathymetry refers to depths below NAVD88. Topography was generated from a 30-m DEM based on elevation data supplied by the National Elevation Dataset (website http://ned.usgs.gov/ accessed on October 15, 2014). Bathymetry was based on the existing mesh (Bacopoulos et al., 2012). The topography and bathymetry were merged and linearly interpolated to the comprehensive mesh for the lower St. Johns River Basin (Figure 2-94). Topographic elevations are as high as 77 m above NAVD88 on the far western edge of the watershed basin. The western part of the watershed basin has high topographic relief with elevations greater than 10 m and most of the area's elevations above 30 m. Near the river and for most of the watershed basin east of the river, topographic elevations are less than 10 m with most of the area's elevations below 5 m. Drainage patterns are well-represented with topographic channels (invert elevations of 2–0 m) clearly visible in the mesh. Bathymetric depths are as deep as 20 m below NAVD88 in the inlet of the St. Johns River and offshore. Channel depths in the lower 40 km of the river are 10–15 m. Upstream of river km 40, the channel opens to 2–4 km wide and shoals to 2–4 m deep. Depths are 3 m on average in Lake George.

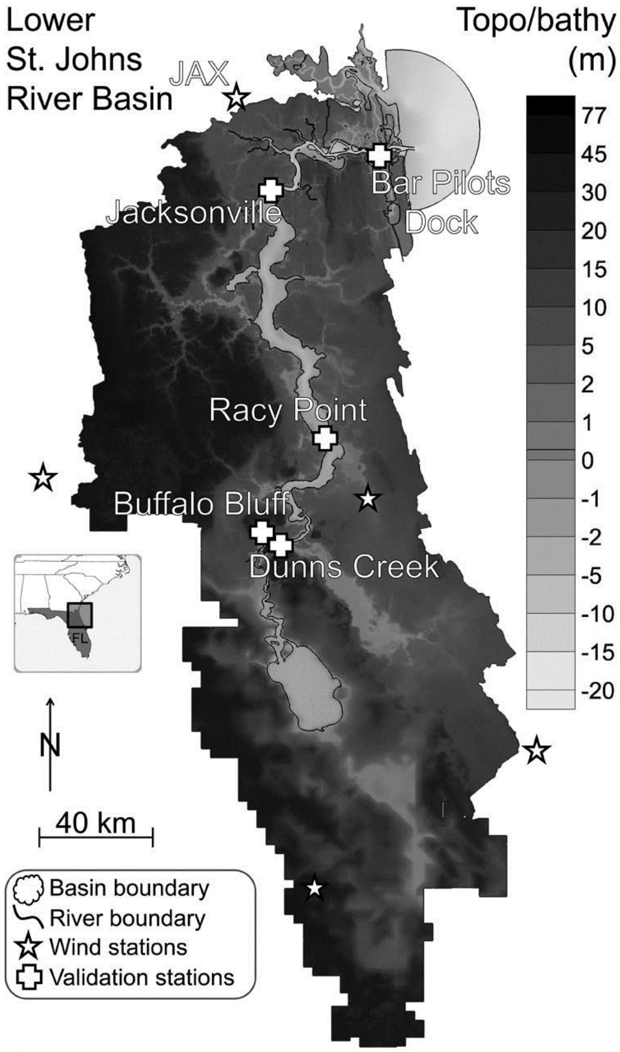


Figure 2-94. The DEM and locations of the wind and water level stations used in the model simulations for the lower St. Johns River Basin.

Model Inputs - Wind data were collected from the Florida Automated Weather Network (website http://fawn.ifas.ufl.edu/ accessed on October 15, 2014) for five stations, including Jacksonville International Airport, to construct the wind forcing in the model (Figure 2-94 and Table 2-13). Figure 2-95a shows wind speeds and directions measured at Jacksonville International Airport for the duration August 15–27, 2008. Directions are reported as degrees measured from true north and are the directions from which the winds are blowing. Wind speed spiked at 17.5 m/s on August 22, 2008. Before the peak of the storm (August 19–22, 2008), winds were out of the 45° direction (northeast) and after the peak of the storm (August 22–24, 2008), winds were out of the 135° direction (southeast).

The wind data were converted from wind speeds and directions to *x*- and *y*-wind vector components and linearly interpolated from the five stations (Figure 2-94 and Table 2-13) to the nodes of the comprehensive mesh for the lower St. Johns River Basin. At all mesh nodes, the *x*- and *y*-wind vector components were converted to *x*- and *y*-wind stress vector components using the formulation of Garratt

(1977). Both surface stresses (τ_s) and wind speeds (V_{10}) are as *x*- and *y*-vector components. The *x*- and *y*-surface stress vector components were constructed into a single file meteorological forcing input for the ADCIRC (ADvanced CIRCulation) simulation (Luettich et al., 1992) for all mesh nodes over the durations of August 1 – October 8, 2008 (calibration period) and October 1 – 9, 2007 (validation period).

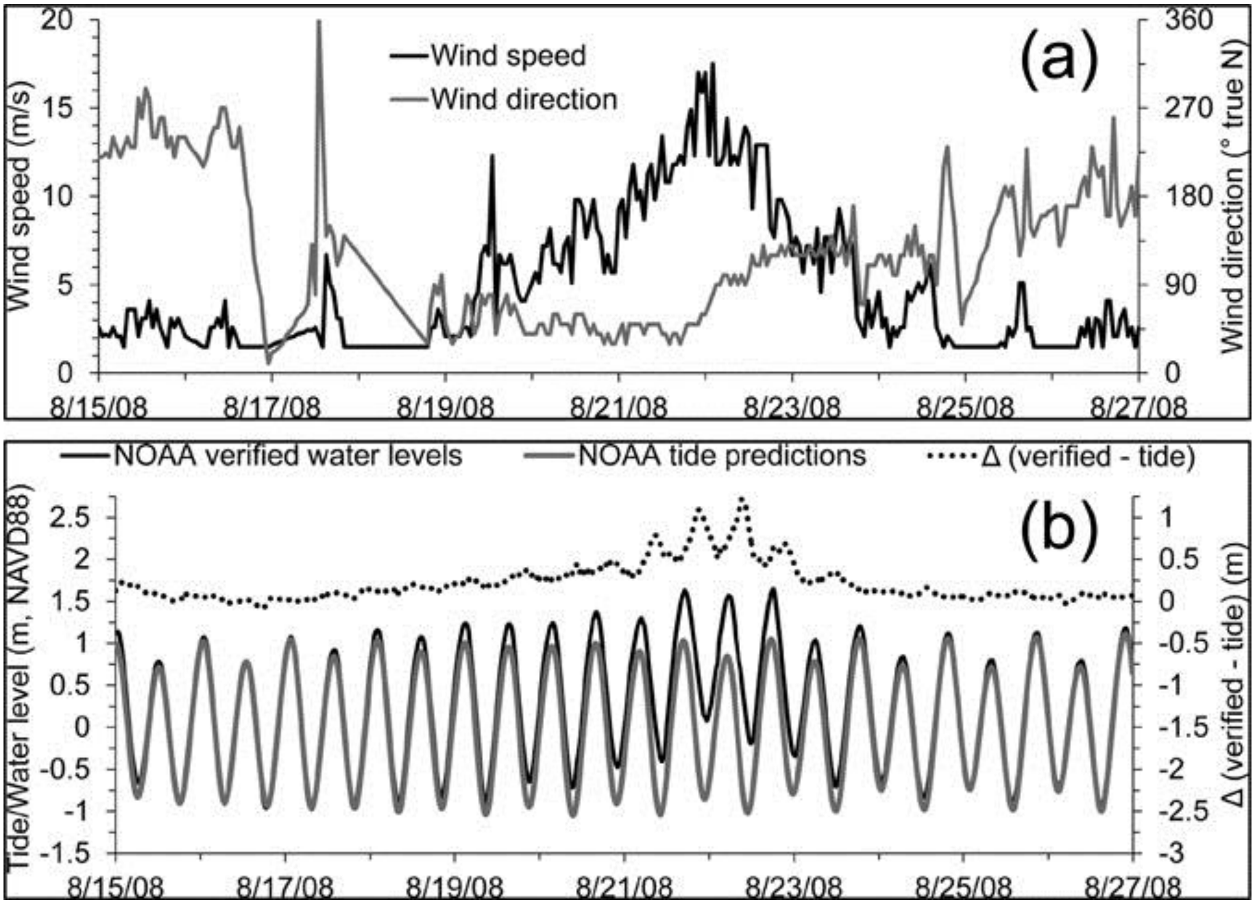


Figure 2-95. (a) The wind speeds and directions measured at Jacksonville International Airport and (b) NOAA tide predictions, NOAA verified water levels and Δ (verified – tide) at Fernandina Beach for the duration August 15–27, 2008.

Type	Description	Longitude (°W)	Latitude (°N)	River km
W-F	Jacksonville International Airport	81.687900	30.494100	–
W-F	Hastings FAWN	81.444850	29.693320	–
W-F	Gainesville Regional Airport	82.271800	29.690100	–
W-F	Daytona Beach International Airport	81.063300	29.180300	–
W-F	Umatilla FAWN	81.630750	28.919130	–
WL-BC	NOS 8720030 Fernandina Beach	81.465000	30.671670	–
WL-V	NOS 8720625 Bar Pilots Dock	81.430000	30.396667	6
WL-V	USGS 02246500 Jacksonville	81.549889	29.800167	40
WL-V	NOS 8720625 Racy Point	81.665556	30.322222	107
WL-V	USGS 02244040 Buffalo Bluff	81.683333	29.596111	141
WL-V	USGS 02244440 Dunns Creek	81.626389	29.577500	147

Table 2-13. Details on the stations used in the study. For type, W-F = wind forcing, WL-BC = water level used for boundary condition and WL-V = water level used for validation.

Model Boundary Conditions - Water levels were collected from the Center for Operational Oceanographic Products and Services (website http://tidesandcurrents.noaa.gov/ accessed on October 15, 2014) for one station (NOAA 8720030 Fernandina Beach, FL) to use for tide (or hydrograph) boundary condition (Figure 2-93 and Table 2-13). The tide gauging station for Fernandina Beach is located in Fernandina Beach Marina just inside St. Mary's Inlet and is the station (containing NOAA tide predictions and NOAA verified water levels) located nearest the open-ocean boundary making it the optimum station from which to derive tide (or hydrograph) boundary conditions. Figure 2-95b shows NOAA tide predictions and NOAA verified water levels for Fernandina Beach over the duration August 15–27, 2008. The NOAA tide predictions were used to construct the tide boundary condition and the NOAA verified water levels were used to construct the hydrograph boundary condition. The tide and hydrograph boundary conditions were applied uniformly for all nodes on the open-ocean boundary.

The SWAT model provided hydrographs routed to each of the sub-basin outlets. The challenge was to feed the discharge from each outlet to the ADCIRC model, in the form of freshwater river inflow boundary conditions, on a spatial and temporal basis. Considering the numerical stability of the ADCIRC model with regards to inflow boundary conditions and the spatial distribution of freshwater discharge from overland runoff, the discharge outlets were aggregated to eight freshwater river inflow points as boundary conditions of ADCIRC (Q_{in}; see Figure 2-93 for locations). Table 2-14 shows the channel width and drainage area of the eight inflow boundaries of ADCIRC. $Q_{in}1$ (Astor/Lake George) contains the largest drainage are (9892 km^2), $Q_{in}2$ (Oklawaha) contains the second-largest drainage area (2023 km^2), where $Q_{in}3$, $Q_{in}7$ and $Q_{in}8$ each contain drainage area in the 1000's km^2 range and $Q_{in}4$, $Q_{in}5$ and $Q_{in}6$ each contain drainage area on the order of hundreds of km^2.

Figure 2-96 shows the eight aggregated hydrographs (Q_{in}) from the SWAT simulation, which were fed into ADCIRC. The $Q_{in}8$ hydrograph (Trout/Northside) has the largest magnitude of all hydrographs, and the $Q_{in}7$ hydrograph (Orange Park/Ortega) has the second-largest magnitude, where the $Q_{in}1$, $Q_{in}3$, $Q_{in}4$ and $Q_{in}6$ hydrographs (Astor/Lake George, Hastings, Palatka and Julington/Mandarin, respectively) have relatively moderate magnitudes and the $Q_{in}2$ and $Q_{in}5$ hydrographs (Oklawaha and Green Cove Springs, respectively) have relatively mild magnitudes.

Q_{in}	Description	Channel width (m)	Drainage area (km^2)
1	Astor/Lake George	322	9892
2	Oklawaha	99	2023
3	Hastings	540	1131
4	Palatka	431	825
5	Green Cove Springs	417	202
6	Julington/Mandarin	466	383
7	Orange Park/Ortega	245	1074
8	Trout/Northside	549	1392

Table 2-14. The eight freshwater river inflow boundary conditions of ADCIRC (Q_{in}).

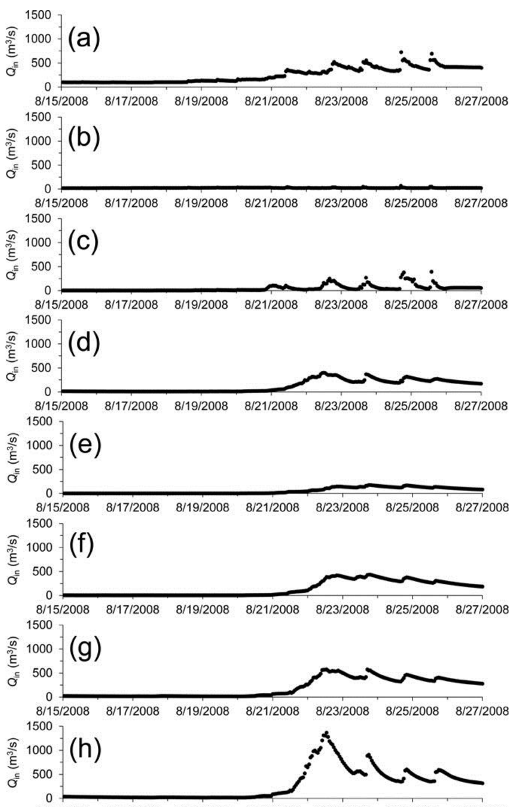


Figure 2-96. Hydrographs for the duration August 15–27, 2008 at the eight locations where freshwater river inflow boundary conditions are applied to ADCIRC (Q_{in}): (a) $Q_{in}1$ Astor/Lake George; (b) $Q_{in}2$ Oklawaha; (c) $Q_{in}3$ Hastings; (d) $Q_{in}4$ Palatka; (e) $Q_{in}5$ Green Cove Springs; (f) $Q_{in}6$ Julington/Mandarin; (g) $Q_{in}7$ Orange Park/Ortega; and (h) $Q_{in}8$ Trout/Northside.

Model Assumptions - ADCIRC stands for ADvanced CIRCulation and is a numerical code for simulation of two-dimensional, depth-integrated hydrodynamics (Luettich et al., 1992). For this project, the model was run in barotropic mode, meaning that pressure-driven flows were considered but that density-driven flows were ignored. The code solves the mass and momentum balances for three variables (water surface deviation from still level, east-west velocity and north-south velocity) using Galerkin finite element method for space (x and y) with time-marching scheme for time (t). The model capably simulates longwave physics driven by tides, winds (storm surge) and lateral flux (freshwater river inflows). The model runs for this project enable a wetting and drying algorithm within the ADCIRC model for the simulation of flooding.

Model Calibration - Parameters estimated and model forcings varied during the calibration period (August 1, 2008 – October 8, 2008) are shown in Table 2-15. Figure 2-97 shows the water levels for the five validation stations during the calibration period. Root mean square (RMS) errors were calculated for the four forcing-varied simulations (0.34, 0.34, 0.19 and 0.16 m, or 27, 27, 14 and 11%) and show progressively decreasing RMS errors with the addition of subsequent model forcings, most especially for inclusion of hydrograph (i.e., offshore surge) but also importantly for inclusion of freshwater river inflows.

Parameter	Definition	Value	Unit
n	Manning's roughness	0.020	–
Eh2	Horizontal eddy viscosity	0	m/s^2
H0	Minimum wetting height threshold	0.10	m
Code name	Forcing(s)	RMS (m)	RMS (%)
T	Tides	0.34	27
TW	Tides + local winds	0.34	27
HW	Hydrograph (= tides and offshore surge) + local	0.19	14
HWX	Hydrograph + local winds + freshwater river	0.16	11

Table 2-15. The estimated parameter values and varied model forcings during the calibration period.

Model Validation - Figure 2-98 shows the water levels for the validation period of October 1 – 9, 2007. RMS errors for the data-model fits are 0.13, 0.14, 0.11 and 0.07 m for the four stations, Bar Pilots Dock, Racy Point, Buffalo Bluff and Dunns Creek, respectively.

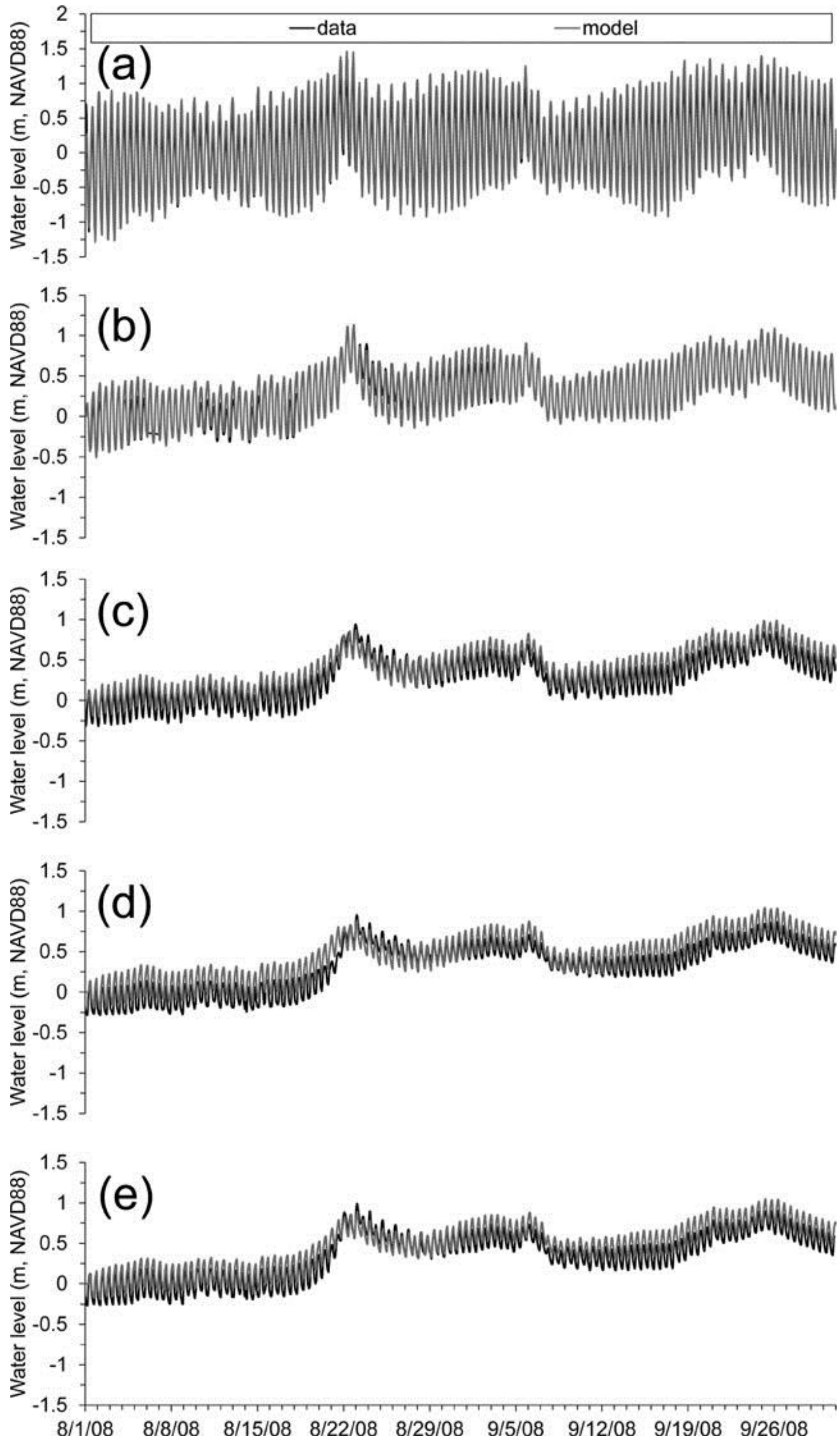


Figure 2-97. Predicted tide and water levels for the four simulations that were run versus measured water levels for the five validation stations over the duration August 1 – October 1, 2008 (calibration period): (a) Bar Pilots Dock; (b) Jacksonville; (c) Racy Point; (d) Buffalo Bluff; and (e) Dunns Creek.

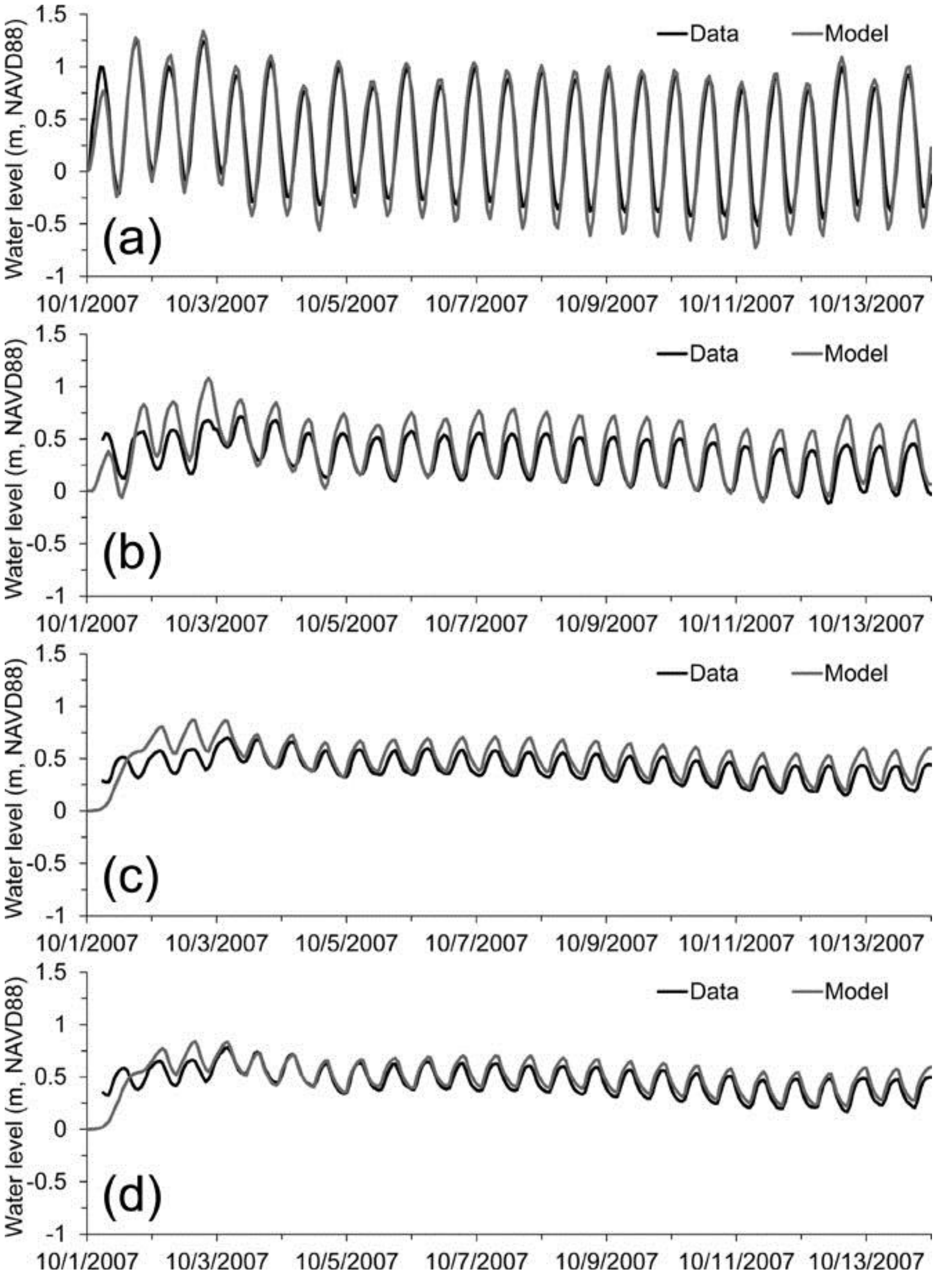


Figure 2-98. Predicted tide and water levels for the four simulations that were run versus measured water levels for four of the five validation stations over the duration October 1 – 14, 2007 (validation period): (a) Bar Pilots Dock; (b) Racy Point; (c) Buffalo Bluff; and (d) Dunns Creek.

Model Integration

Model Coverage - The model integration covers the entire St. Johns River Basin (Figure 2-99). For this, the SWAT model was extended south and the HEC-HMS model was extended north to cover the middle basin (Figure 2-100). With the ADCIRC model integrated with SWAT and HEC-HMS, the model encompasses the western North Atlantic Ocean out to the 60°W meridian, telescopes into the St. Johns River and extends out-of-bank to include to entire watershed.

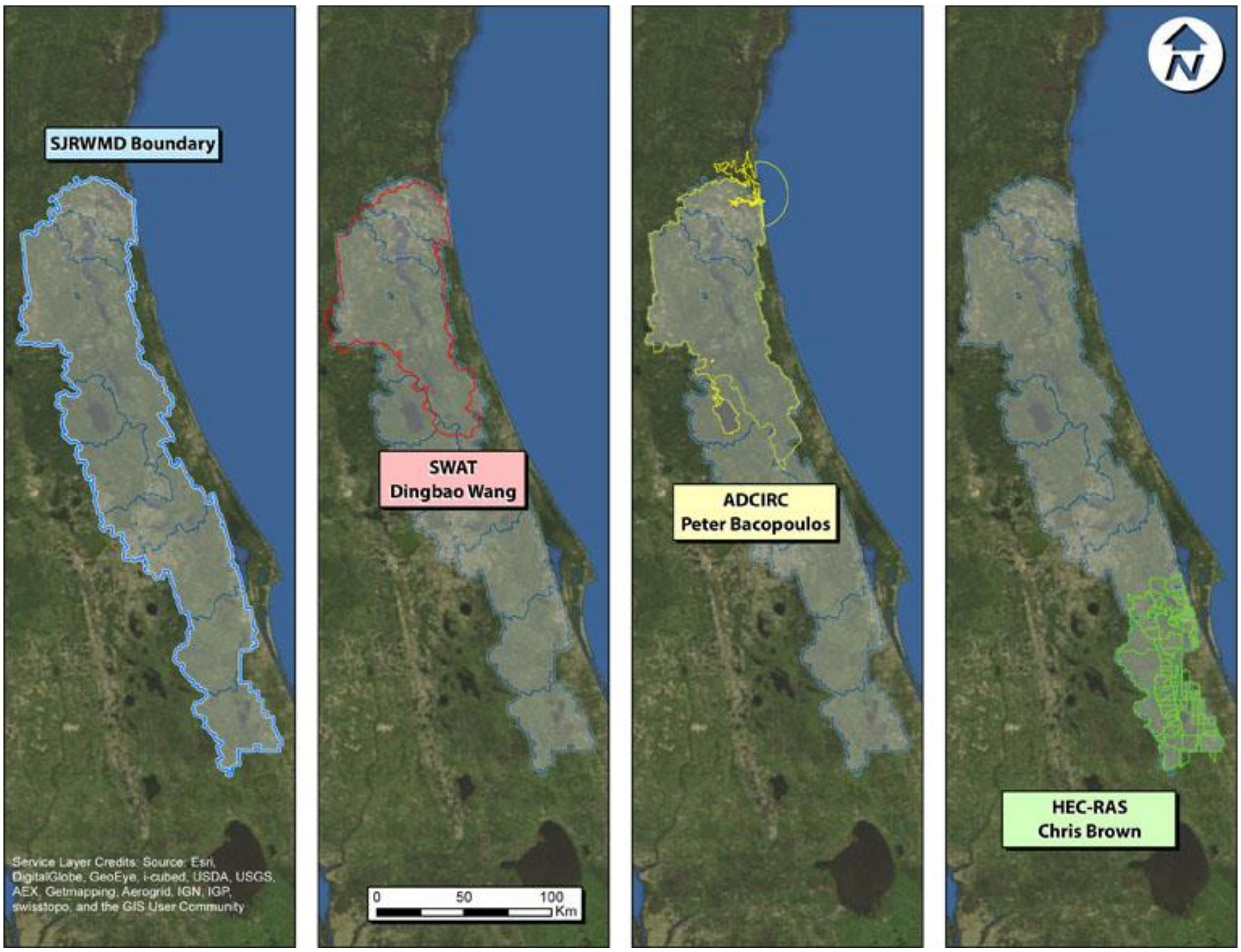


Figure 2-99. The model extents of SWAT, ADCIRC and HEC-RAS, which together cover the entirety of the St. Johns River Water Management District domain

Exchange of Boundary Conditions - Going from upstream to downstream, HEC-HMS sends output to SWAT for input, which then SWAT delivers output to ADCIRC for input. With the exchange of boundary conditions, the basin (upper, middle and lower) and river dynamics and interactions are captured for the system as a whole.

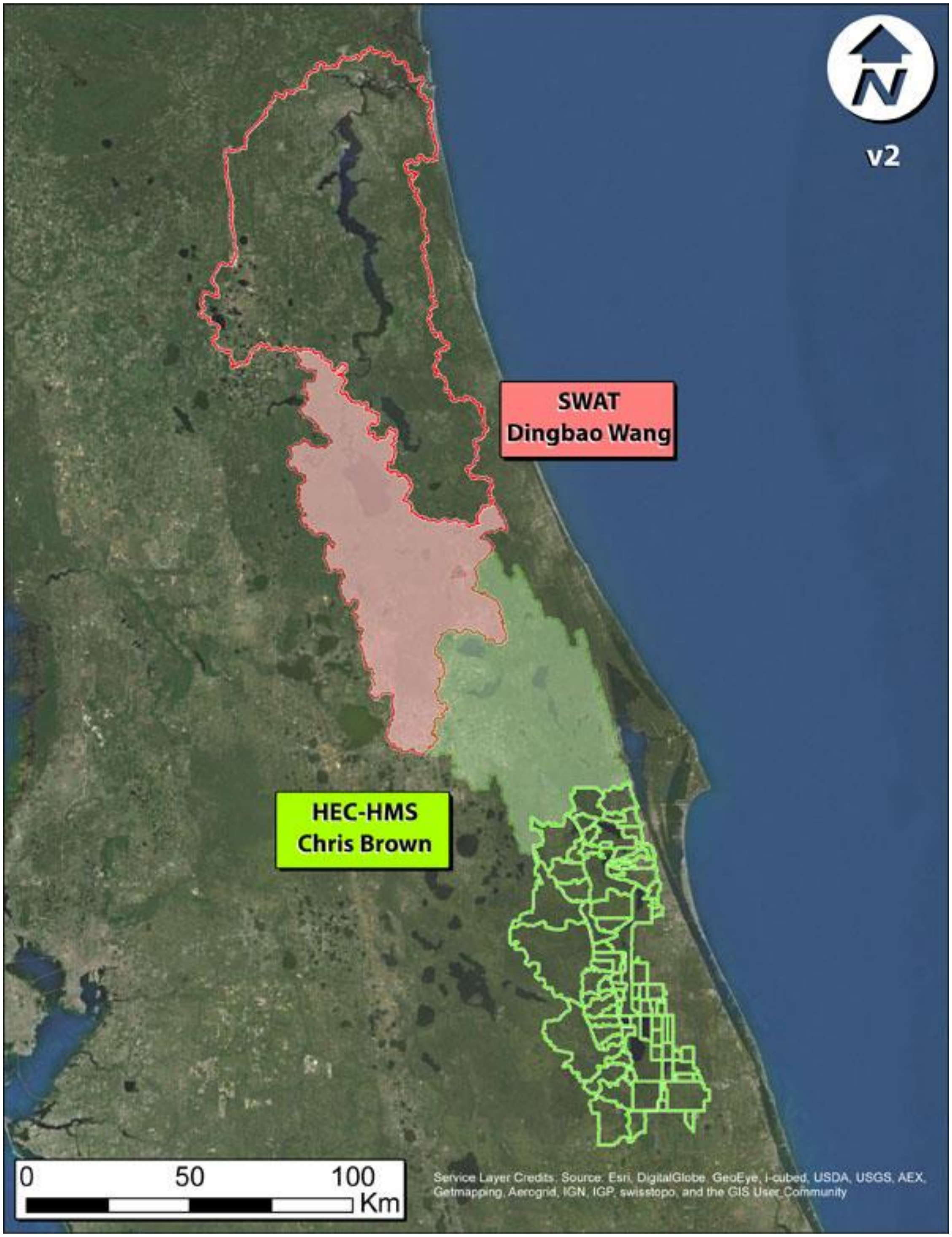


Figure 2-100. Extensions of the SWAT and HEC-HMS models to cover the middle basin: SWAT model extended south; and the HEC-HMS model extended north.

Model Simulations

100-Year Flood Scenario using Fay Base Run - The 100-year flood scenario utilized the tides and winds for Tropical Storm Fay while using a 100-year, 24-hour precipitation for hydrologic input. The 100-year, 24-hour precipitation was obtained from Hershfield (1961) and Rao (1988), and it was implemented in the hydrologic models with a Soil Conservation Service (SCS) synthetic hyetograph for a 24-hour Type III precipitation event. The 24-hour precipitation was applied starting at 12:01 am on day 16 of the calibration run. No other precipitation was applied during the calibration run for this simulation.

Wetland-Value Scenario using Changed Land Use - This simulation is the same as described above, except all wetlands were converted within the hydrologic models to “developing urban area” landuse which (when also assuming wet conditions) correlates to a curve number of about 98 for the hydrologic models. This simulation, when compared against the simulation above, will assess the possible benefits from wetlands in the system.

Flooding Analysis - The model-produced flooding was analyzed for water extent and water height. Figure 2-101 shows modeled water surface elevations (WSE) at August 31, 2008 03:54 UTC for the three different scenarios (existing, 100-year and 100-year w/LULC). Table 2-16 lists the out-of-bank flooded extent in surface area for the three different scenarios and the water heights at the three reference locations shown on the flooding maps (Racy Point, Palatka and Buffalo Bluff). On the basis of water extent and water height, the existing condition of Tropical Storm Fay (2008) was of greater magnitude than the hypothetical 100-year scenario. On a similar basis, the LULC scenario was of greater magnitude than the 100-year scenario.

Scenario	Extent	WSE (m)		
		Racy Point	Palatka	Buffalo Bluff
Existing	163.8	0.419	0.329	0.715
100-year	159.6	0.398	0.293	0.626
100-year w/LULC	160.9	0.416	0.321	0.679

Table 2-16. The out-of-bank flooded extent in surface area for the three different scenarios and the water heights at the three reference locations shown on the flooding maps (Racy Point, Palatka and Buffalo Bluff). The data are for August 31, 2008 03:54 UTC.

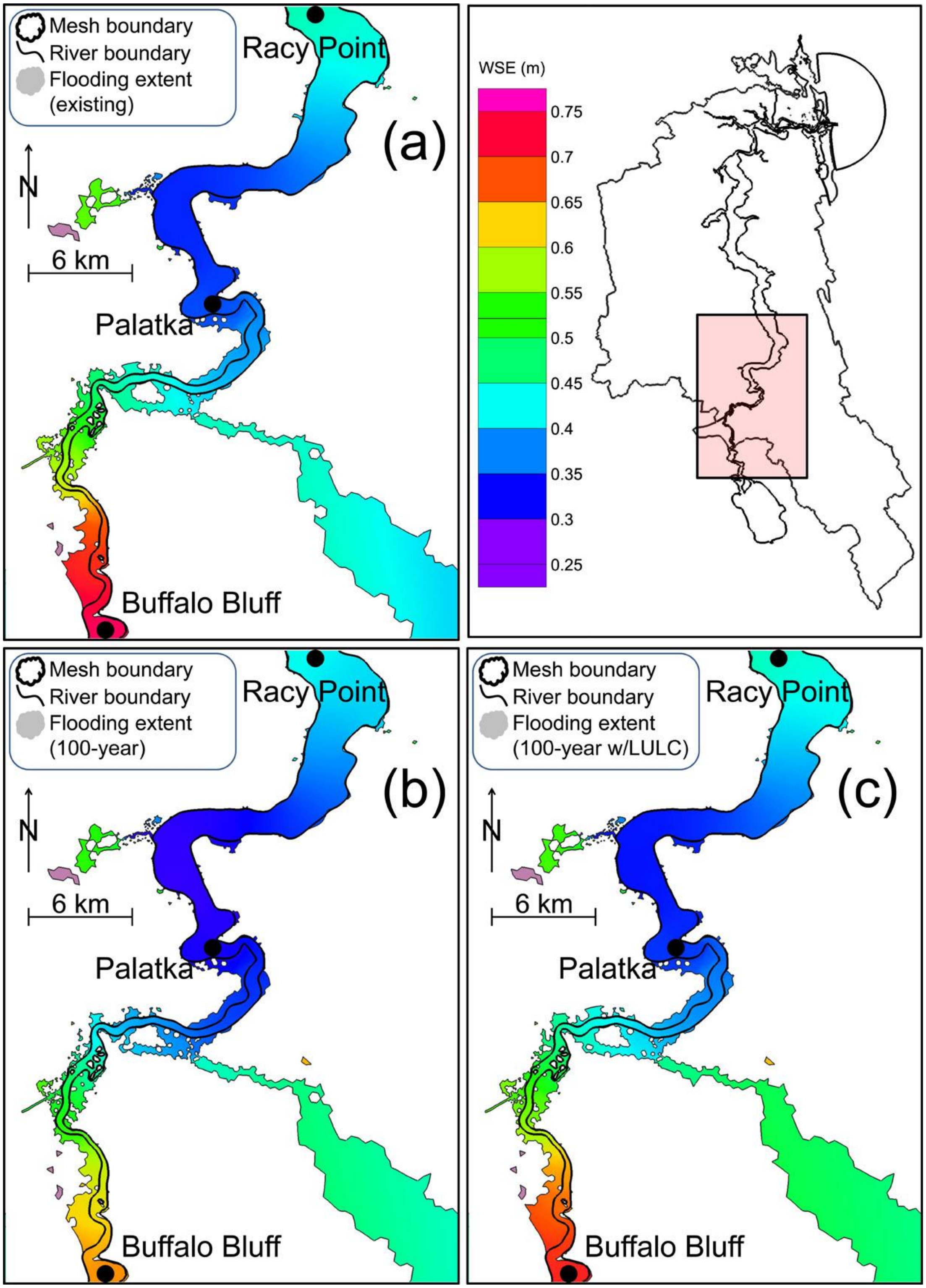


Figure 2-101. Modeled water surface elevations (WSE) at August 31, 2008 03:54 UTC for the three different scenarios: (a) existing; (b) 100-year; and (c) 100-year w/LULC.

Figure 2-102 shows modeled water surface elevations (WSE), as time series over the duration August 29 12:00 – 31 12:00, 2008, for the three different scenarios (existing, 100-year and 100-year w/LULC). Table 2-17 lists the average water levels calculated for the five validation stations over the duration August 29 12:00 – 31 12:00, 2008. On the basis of average water level, the existing condition of Tropical Storm Fay (2008) was of greater magnitude than the hypothetical 100-year scenario. On a similar basis, the LULC scenario was of greater magnitude than the 100-year scenario.

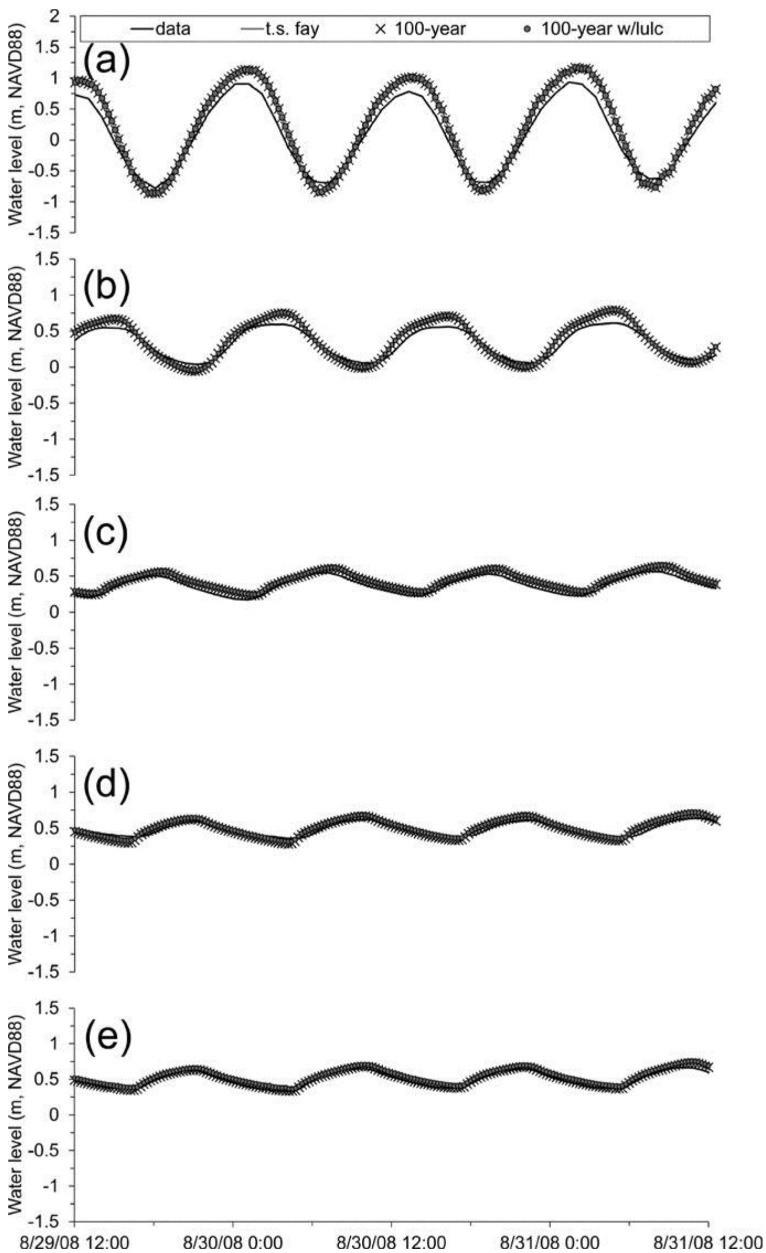


Figure 2-102. Modeled water surface elevations (WSE) at August 31, 2008 03:54 UTC for the three different scenarios: (a) existing; (b) 100-year; and (c) 100-year w/LULC.

Station	Average* water level (m)		
	Existing	100-year[1]	100-year w/LULC[2]
Bar Pilots Dock (river km 6)	0.450	0.432 (–0.018)	0.450 (0.018)
Jacksonville (river km 40)	0.196	0.195 (–0.001)	0.196 (0.001)
Racy Point (river km 107)	0.375	0.366 (–0.009)	0.376 (0.010)
Buffalo Bluff (river km 141)	0.520	0.490 (–0.030)	0.517 (0.027)
Dunns Creek (river km 147)	0.551	0.517 (–0.034)	0.547 (0.030)

* Average water level is calculated for August 29 12:00 – 31 12:00, 2008.

[1] Differences are shown in parentheses and are calculated as "100-year" minus "existing."

[2] Differences are shown in parentheses and are calculated as "100-year w/LULC" minus "100-year."

Table 2-17. Average water levels calculated for the five validation stations over the duration August 29 12:00 – 31 12:00, 2008.

Economic Valuation

Data and Method - For the economic evaluation of flood prevention, our examination focuses on the property value. The rationale is that the potential damage from flooding or the benefit of avoidance of flooding may be reflected in the consumers' valuation of the property. The valuation of a property can be measured by its selling price, thus the difference in the selling price between properties in and outside the flood zone may reveal the value of flood damage or flood avoidance.

Considering that the selling price can be influenced by many factors, such as age of the property, size of land and living area, constructional materials, market area, and location of the property, our analysis attempts to account for as many of these factors as possible given data availability. However, even with a rich set of covariates, there are still major factors not accounted for. For example, properties deep in the flood zones may have more convenient access to the boat ramp or may be waterfront property and thus are valued higher. If these features are not controlled in the analysis, the estimates may suffer from omitted variable bias. To reduce such concern, the strategy was to compare properties within a narrow band across the flood line (±0.3 mile), assuming that properties close to each other are more comparable in these locational features.

We use Florida Department of Revenue's property tax data (NAL file) in 2008 for this analysis. The NAL data contain information on all properties (residential, commercial, industrial, agricultural, and others combining 2,959,679 properties in total) in the 20 counties covered by the Lower St. Johns River basin. We geocode each property and determine its location and distance to the FEMA's 100-year flood line using ArcGIS. Properties located within a ±0.3 mile band from the FEMA flood line with a transaction record in 2008 are used to estimate the property value attributable to the avoidance of flood.

A hedonic price model is employed for the analysis. The hedonic pricing approach assumes that the value of the property is a composite of multitude of factors, including the property's size, condition, age, specific features, community characteristics, and others factors which the property owner consider relevant, such as the potential of flood damage. To separate the contribution of individual factors, we specify a linear regression model where the dependent variable is the sell price (SP). The explanatory variables considered include:

- Land Square Footage
- Construction Class indicators (fireproof steel, reinforced concrete, masonry, wood, steel frame)
- Age of primary structure on the parcel (2008 minus the actual year built)
- Total Living or Usable Area
- Special Features indicators / values (Residential: out-buildings, pools, site improvements, docks, interior features; Commercial: site improvement, out-buildings, recreational facilities, miscellaneous structures and features)
- Market Area indicators (168 distinct market areas)
- Neighborhood identifier (6229 neighborhoods)
- Indicators of distance to the river under (0.1 / 0.5) mile or less.
- FEMA Flood Zone indicator (1 if inside the flood zone; 0 otherwise)

In the list above, the last two location indicators, including the key variables which identify the location of the properties in relativity to the flood zone, are constructed by the team using ArcGIS. The physical address of a property is linked to the US Census Bureau's TIGER geodatabase, and intersected with the 100-year flood map from FEMA to identify whether the property is located within or outside the flood zone.

The model is specified as:

$$SP_i = \alpha + \beta F_i + \boldsymbol{X}_i' \boldsymbol{\gamma} + \boldsymbol{Z}_c' \boldsymbol{\delta} + \varepsilon_{\boldsymbol{i}} \quad (1)$$

where F_i is the flood zone indicator for property i, $\boldsymbol{X_i}$ a vector containing characteristics specific to individual property i, $\boldsymbol{Z_c}$ a vector containing characteristics of community c in which the property i is located. The coefficient β represents the impact of being in the flood zone on the property value, which is expected to be negative. The correlation in sell price for properties in the same neighborhood is accounted for by cluster-robust standard error at the neighborhood level.

The model is separately estimated for three major types of properties:

- Residential – Single Family Home
- Residential – Others (Vacant residential, multi-family, condominiums, cooperatives, and retirement homes)
- Commercial

In each property category, the model is estimated for the entire study area to yield an estimate for the evaluation of the simulated scenarios. The model is also estimated for individual counties for us to get a better understanding of the unequal influence across counties.

Average Impact of Flood Zone Designation on Property Value - As shown in Table 2-18, for the category of residential – single family homes, being located in the FEMA flood zone is associated with an average of $15,156 decrease in property value (significant at 10% level) in the study area. At the county level, it seems that the impact of being in FEMA flood zone is insignificant for many states, which could be partly due to the small county sample sizes relative to the number of controlled covariates. For Volusia County, however, we found a significant decrease in property value of $30,983 associated with being located in the FEMA flood zone. Please note that the results for some counties are missing due to insufficient amount of data given our study design.

	(1)	(2)	(3)	(4)
	ALL COUNTY	BAKER	BRADFORD	DUVAL
femaFZ (*F*)	-15156.2*	-1022.9	6021.2	4743.2
	(6903.310)	(39057.739)	(21886.161)	(15323.786)
N	13146	25	69	3065

(Continued)

	(5)	(6)	(7)	(8)
	LAKE	MARION	NASSAU	OSCEOLA
femaFZ (*F*)	18138.3	-8118.7	28167.2	1226.2
	(18446.613)	(7783.352)	(33523.110)	(22467.172)
N	350	1677	321	1734

(Continued)

	(9)	(10)	(11)	(12)
	PUTNAM	SEMINOLE	ST. JOHNS	ST LUCIE
femaFZ (*F*)	-27747.2	-17750.0	25979.3	44485.9
	.	.	(21267.889)	(66696.290)
N	347	1001	559	610

(Continued)

	(13)	(14)
	UNION	VOLUSIA
femaFZ (*F*)	74950.1	-30983.0**
	(41339.504)	(11989.506)
N	20	3368

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2-18. Regression Estimation of Sell Price: Residential Property (Single Family Home).

	(1) ALL COUNTY	(2) BAKER	(3) BRADFORD	(4) DUVAL
femaFZ	-9192.3	5819.9	-167.0	64797.6
	(35986.555)	(12437.816)	(4177.803)	(182052.932)
N	10627	71	118	1976

(Continued)

	(5) LAKE	(6) MARION	(7) NASSAU	(8) OSCEOLA
femaFZ	-16094.6	-4665.9	10853.9	-219925.5
	(51998.839)	(2657.851)	(32172.829)	(166096.996)
N	299	2086	266	712

(Continued)

	(9) PUTNAM	(10) SEMINOLE	(11) ST. JOHNS	(12) ST LUCIE
femaFZ	11758.1	143876.4	25176.1	10088.61
	.	.	(55343.210)	(36947.33)
N	1188	379	209	1212

(Continued)

	(13) UNION	(14) VOLUSIA
femaFZ	-21153.2**	-29603.2
	(1366.716)	(30371.171)
N	52	2059

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2-19. Regression Estimation of Sell Price: Residential Property (all but single family homes)

Table 2-19, above, shows the estimates for the category of residential – others. In this category, the property value does not have a statistically significant variation between property in or out of the flood zone. The only exception is Union county, where being located in the FEMA flood zone is associated with a statistically significant $21,153 decrease in property value.

In the category of commercial properties, properties meeting the sample selection criteria are only available in 7 counties. Among these counties, the impact of locating in the FEMA flood zone is only found in the Lake County, where property value is found $21,568 less for those locate in the FEMA flood zone than those that are outside. When all counties are considered, the impact on commercial property is statistically insignificant, although the estimate is negative as one would expect.

	(1) ALL COUNTY	(2) DUVAL	(3) LAKE	(4) MARION
femaFZ	-30581.9	30357.7	-21568.3*	182431.5
	(177941.979)	(198682.219)	(7862.660)	(237221.269)
N	806	165	19	135
(Continued)				
	(5) OSCEOLA	(6) ST. JOHNS	(7) ST LUCIE	(8) VOLUSIA
femaFZ	-254967.2	402239.6	-87178.1	-407967.1
	(475115.772)	(478867.720)	(171033.828)	(409412.095)
N	41	35	38	289

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2-20. Regression Estimation of Sell Price: Commercial Property

Economic Valuation - To obtain the economic valuation for the entire study area, estimates from the regression analysis in the previous section was used to predict the property values for the full sample. The prediction is then repeated based on each of the simulated scenarios previously described.

Specifically, the estimates from equation (1) were used to predict the mean value of a property conditional on the FEMA flood zone indicator of the property and all the controlled characteristics. That is

$$\widehat{SP}_i = \hat{\alpha} + \hat{\beta}F_i + \boldsymbol{X}_i'\hat{\boldsymbol{\gamma}} + \boldsymbol{Z}_c'\hat{\boldsymbol{\delta}}$$

An interesting counterfactual is the total prevention of flood, where the selling price of a property can be predicted as

$$\widetilde{\widehat{SP}}_i = \hat{\alpha} + \boldsymbol{X}_i'\hat{\boldsymbol{\gamma}} + \boldsymbol{Z}_c'\hat{\boldsymbol{\delta}}$$

The economic valuation of the total prevention of flood can be calculated as $\sum\left(\widehat{SP}_i - \widetilde{\widehat{SP}}_i\right) = \hat{\beta}F_i$. As shown in Table 2-21, the economic value of total prevention of flood (measured as the gain in total property value) amounts to approximately $3 billion.

Table 2-21. Economic Value of Total Prevention of Flood

	Number of Properties within FEMA Flood Zone	Economic Value of Total Prevention of Flood
Residential - Single Family Home	110,668	$1,677,306,342
Residential - Others	113,499	$1,043,316,858
Commercial	7,577	$231,719,056
Total		$2,952,342,256

Removal of wetlands altered the extent and depth of flooding within the SJR Basin, which would presumably impact flood insurance rates and costs of development in flood zones. Property values closer to the river are higher than non-river ones and generate higher property taxes (See Chapter 4).

References

Armstrong, D. R. (2001, April). Project Works, the Physical Mechanisms of Water Management. St. Johns River Water Management District.

Ayres Associates. (2001, August). Hillsborough River Watershed Management Plan.

Bacopoulos, P., Hagen, S.C., Cox, A.T., Dally, W.R., Bratos, S.M., 2012. Observation and simulation of winds and hydrodynamics in St. Johns and Nassau Rivers. Journal of Hydrology 420–421, 391–402.

Barbier, Edward B. (2007). *Valuing Ecosystem Services as Productive Inputs.* Retrieved from: http://onlinelibrary.wiley.com/doi/10.1111/j.1468-0327.2007.00174.x/abstract

Baumbach, Emily, Cruz-Orrtiz, Catherine, Miller, Kate (2013). Economic Value of the Christina River Watershed. Retrieved from: http://www.wra.udel.edu/wp-content/uploads/2013/01/Economic-Value-of-the-Christina-River_DRAFT.pdf

CH2M Hill. (1997). *Water supply needs and sources assessment alternative water supply strategies investigation artificial recharge of the floridan aquifer through drainage or injection wells in Orange and Seminole Counties* (Publication No. SJ97-SP14). Palatka, FL: St. Johns River Water Management District.

Charbonnier, S. F., & Genta, J. L. (2000). The antecedent soil moisture condition of the curve number procedure. *Hydrological Sciences- Journal*, *45*(1).

City and County of Sacramento. (1996, December). *Drainage Manual Volume 2: Hydrology Standards, Chapter 7 Lag Time*. Retrieved October 18, 2014, from http://www.waterresources.saccounty.net/DrainageManual_Volume2/V2_Chap07.PDF

Di, J. J., Smith, D., Lippincott, C., & Marzolf, E. (2010). *Pollutant Load Reduction Goals for Newnans Lake* (Publication No. SJ2010-1). Palatka, FL: St. Johns River Water Management District.

Everard, Mark, Moggridge, Helen H. (2011). Rediscovering the Value of Urban Rivers. Retrieved from http://link.springer.com/article/10.1007%2Fs11252-011-0174-7#page-1

Feug, X.Y, Luo, G.P, Li, C.F, Dal, L, Lu, L (2011).Dynamics of Ecosystem Service Value Caused by Land use Changes in Manas River of Xinjiang, China. Retrieved from:www.ijer.ir/pdf_519_0abeea62211402a091681636f9b2e978.html

Florida Geological Survey. (2004). *Bulletin No. 66: Springs of Florida*. Tallahassee, Fl.

Frederick, Kenneth D, VandenBerg, Tim, Hanson, Jean. (1996). Economic Values of Freshwater in the United States. Retrieved from: http://www.ecy.wa.gov/programs/wr/hq/pdf/evfus_frederick.pdf

Harmel, R., Cooper, R., Slade, R., Haney, R., & Arnold, J. (2006). Cumulative uncertainty in measured streamflow and water quality data for small watersheds. Transactions of the ASABE, 49(3), 689–701.

Hawkins, R. H., Hjelmfelt, A. T., and Zevenbergen, A. W. (1985). "Runoff probability, storm depth, and curve numbers." J. Irrig. Drain. Eng., 10.1061/(ASCE)0733-9437(1985)111:4(330), 330–340.

Hershfield, D.M., 1961. Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. Technical Paper No. 40, Department of Commerce, 65p.

Inwood Consulting Engineers. (2009, November). Stormwater master plan, Hydrological & Hydraulic Model Summary Report. Retrieved October 10, 2014, from http://www.alachuacounty.us/Depts/PW/engineering/stormwaterManagementProgram/SWMasterPlan/Pages/FinalHydrologicalandHydraulicModel.aspx

Jacksonville Electric Authority (2012). *Rates.* Retrieved from: https://www.jea.com/rates/

Jain MK, Mishra SK, Babu PS, Venugopal K, Singh VP (2006) Enhanced runoff curve number model incorporating storm duration and a nonlinear Ia-S relation. J Hydrol Eng 11(6):631–635.doi:10.1061/(ASCE)1084-0699(2006)11:6(631)

KBN Engineering and Applied Sciences. (1993, June). SJ93-SP7: A Wetland Management Strategy for the St. Marys River Basin.

Kimrey, J. O., & Fayard, L. D. (1984). *Geohydrologic reconnaissance of drainage wells in Florida*. U.S. Geological Survey.

King, Dennis M & Mazzotta, Marisa J. (2000). U.S Department of Agricultural Natural Resources

Conservation Service. National Oceanographic and Atmospheric Administration. *Ecosystem Valuation*. Retrieved from: http://www.ecosystemvaluation.org/

Li, M.-H., & Chibber, P. (2008). Overland Flow Time of Concentration on Very Flat Terrains. Journal of the Transportation Research Board No. 2060, 133-140. http://dx.doi.org/10.3141/ 2060-15

Lowe, E.F., Battoe, L.E., Wilkening, H., Cullum, M., Bartol, T., 2012. St. Johns River Water Supply Impact Study. Technical Publication SJ2012-1, St. Johns River Water Management District, 27p.

Luettich, R.A., Westerink, J.J., Scheffner, N.W., 1992. ADCIRC: An advanced three-dimensional circulation model for shelves, coasts and estuaries, I: Theory and methodology of ADCIRC-2DDI and ADCIRC-3DL. Technical Report DRP-92-6, United States Army Corps of Engineers, 144p.

Mao, L.M, M.J. Bergman and C. Tai (2002). "Evapotranspiration Measurement and Estimation of Three Wetland Environments in the Upper St. Johns River Basin, Florida*". Journal of the American Water Resources Association,* 5(38), 1271- 1285.

Marella, Richard (2014). U.S. Geological Survey. *Water Withdrawals, Use, and Trends in Florida, 2010.* Retrieved from: http://pubs.usgs.gov/sir/2014/5088/pdf/sir2014-5088.pdf

Mays, L. W. (2011). *Water resources engineering* (2nd ed.). John Wiley & Sons, Inc.

Mohamoud, Y. (2004, September). *Comparison of Hydrologic Responses at Different Watershed Scales*. Research Triangle Park, NC: U.S. Environmental Protection Agency.

Orlando Utility Commission (2009). *Water Rates.* Retrieved from: http://www.ouc.com/residential/service-rates-and-costs/water-rates

Ponce, V. M., & Hawkins, R. H. (1996). Runoff Curve Number: Has It Reached Maturity? *Journal of* H*ydrologic Engineering*, *1*, 11-19.

Rao, D.V., 1988. Rainfall analysis for northeast Florida, IV: 24-hour to 96-hour maximum rainfall for return periods 10 years, 25 years and 100 years. Technical Publication SJ-88-3, St. Johns River Water Management District, 47p.

Rumenik, R. P. (1988). *Runoff to Streams in Florida* [Map]. Tallahassee, FL.

Scharffenberg, W. A., & Fleming, M. J. (2010, August). *Hydrologic Modeling System HEC-HMS User's Manual*. Davis, Ca: U.S. Army Corps of Engineers, HEC.

Sepúlveda, Nicasio, Tiedeman, C.R., O'Reilly, A.M., Davis, J.B., and Burger, Patrick, 2012, Groundwater flow and water budget in the surficial and Floridan aquifer systems in east-central Florida: U.S. Geological Survey Open-File Report 2012–1132, 195 p., plus appendixes.

Sharifi, S., & Hosseini, S. M. (2011). Methodology for Identifying the Best Equations for Estimating the Time of Concentration of Watersheds in a Particular Region. *Journal of Irrigation and Drainage Engineering*, *137*(11), 712-719.

State of Florida Department of Transportation, Drainage Handbook (Office of Design, Drainage Section, Comp.). (2012, February). Tallahassee, FL.

St. Johns River Water Management District. (2012, July). St. Johns River Water Supply Impact Study (Publication No. SJ2012-1).

St. Johns River Water Management District. (2014). *Land Cover / Land Use 1994-95 - SJRWMD* [Map]. Retrieved from GIS data download table database.

St. John's River Water Managemen District. (2010). 2010 Survey of Estimated Annual Water Use for St. Johns River Water Management District. Retrieved from:http://www.sjrwmd.com/technicalreports/pdfs/FS/SJ2011-FS1.pdf

St. John's River Water Managemen District. (2011). 2011 Survey of Estimated Annual Water Use for St. Johns River Water Management District. Retrieved from: http://www.sjrwmd.com/technicalreports/pdfs/FS/SJ2012-FS1.pdf

St. John's River Water Managemen District. (2012). 2020 Survey of Estimated Annual Water Use for St. Johns River Water Management District. Retrieved from:http://www.sjrwmd.com/technicalreports/pdfs/FS/SJ2013-FS1.pdf

St. John's River Water Managemen District. (2014). Upper St. Johns River Basin. Retrieved from: http://www.sjrwmd.com/upperstjohnsriver/

Suphunvorranop, T. (1985, July). *A Guide to SCS Runoff Procedures* (Publication No. 85-5). Palatka, FL: St. Johns River Water Management District.

Tellinghuisen, Stacy (2010). Water for Power Generation: What's the Value?. Retrieved from: http://lawschool.unm.edu/nrj/volumes/50/3/06-tellinghuisen-water.pdf

U.S. Army Corps of Engineers, Hydrologic Modeling System HEC-HMS, Rep. No. CPD-74B, at 145 (2000).

U.S. Army Corps of Engineers, Preliminary Water Control Manual Upper St. Johns River Basin, Doc. (1991).

U.S. Department of Agriculture Natural Resources Conservation Service, National Engineering Handbook, Chapter 15, *Time of Concentration,* 2010.

U.S. Department of Agriculture Soil Conservation Service, National Engineering Handbook, Section 4, *Hydrology,* available from U.S. Government Printing Office, Washington, DC, 1972.

U.S. Department of Commerce, Rainfall Frequency Atlas of the United States, Doc., at 61 (1961). U.S Department of Labor Bureau of Labor Statistics (2014). *Databases, Tables & Calculators by Subject.* Retrieved from http://www.bls.gov/data/inflation_calculator.htm

USGS Water Resources. (2014). USGS Current Water Data for the Nation. Retrieved November 3, 2014, from USGS Current Water Data for the Nation website: http://waterdata.usgs.gov/nwis/rt

U.S. Geological Survey (2005). *Estimated Use of Water in the United States in 2005.* Retrieved from:http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf

Wyzga, B. (1999). Estimating mean flow velocity in channel and floodplain areas and its use for explaining the pattern of overbank deposition and floodplain retention. *Geomorphology*, *28*(3-4), 281-297. http://dx.doi.org/10.1016/S0169-555X(98)00110-X

Young, Robert, & Loomis, John (2005). *Determining Economic Value of Water Concept and Methods.* New York, NY: RFF Press.

Chapter 3

Removal of Phosphorus and Nitrogen by Wetlands Along the St. Johns River: An Economic Perspective

By

Christopher Craft, Jeff Ehman and Scott Perry

School of Public and Environmental Affairs

Indiana University

ccraft@indiana.edu

Abstract

Using geographic information systems (GIS) data, and data on wetland nitrogen (N) and phosphorus (P) accumulation in the SJR watershed and nearby areas (northern Everglades, southeastern Georgia), watershed-wide rates of wetland N and P removal were calculated. Wetlands in the SJR remove approximately 188,000 Metric Tons of N each year, half from burial and half from denitrification. The amount of P removed each year is nearly 2400 MT. The economic value of this watershed-wide nutrient removal was determined using the cost (per pound) of N and P removal by wastewater treatment plants and the cost (per pound) of N and P bought and sold in nutrient trading programs in the SJR watershed, Florida and nearby states. Based on wastewater treatment costs to remove N, including denitrification, wetlands of the SJR watershed provide 95 to 122 billion dollars in service each year to the state of Florida. Nitrogen removal using nutrient trading program costs values the SJR wetlands at 3.3 to 21.7 billion dollars each year. For P removal, the value of the SJR wetlands is 20 to 490 million dollars/year based on wastewater treatment costs and 360 million dollars/year based on nutrient trading programs. Uncertainty in these estimates results from limited data on these wetlands and the wide variety of wetlands (and their ability to remove N and P) in the watershed. Assuming a very conservative N/P removal cost of $1 per pound, the economic value for nutrient removal by SJR wetlands still exceeds 400 million dollars/year for N and 5.3 million dollars/year for P. The large economic value of the SJR wetlands underscores their importance in the maintenance and protection of water quality in eastern and northeastern Florida.

Introduction

Freshwater and estuarine wetlands maintain and enhance water quality by removing pollutants, sediment, nutrients such as nitrogen (N) and phosphorus (P), and other contaminants (Craft 1997, Craft and Schubauer-berigan 2006). Nitrogen and P are particularly problematic pollutants. They are applied in large amounts, especially N, to enhance agricultural crop yields but much of it runs off into receiving waters, rivers, lakes, and estuaries, where it leads to nutrient over-enrichment, eutrophication, hypoxia and fish kills (NRC 2000, Howarth et al. 2002).

Wetlands, located at the boundary between land and water, are uniquely positioned to intercept nutrients as they are washed off the terrestrial landscape and preventing them from reaching aquatic ecosystems where they cause eutrophication. Nitrogen is removed mostly by biological means. One mechanism is uptake by wetland vegetation, followed by deposition of decaying biomass and burial in soil (Craft 1997). A second mechanism is denitrification where microorganisms in wetland soils convert nitrate (NO_3^-) to nitrogen gas (N_2), returning it to the atmosphere. The two mechanisms remove comparable amounts of N, about 6 g/m^2/yr (53.53 lb/ac/yr) (1 g/m^2 = 8.9218 lb/ac) under low nutrient conditions (Craft 1997). Under high nutrient loadings, burial of N in soil doubles whereas denitrification increases as much as five fold.

Removal of P occurs primarily by physical and geochemical processes. Much of the P that is retained in wetlands is bound to sediment that is deposited (Craft 1997). Sorption and precipitation of P with iron (Fe), aluminum (Al) and calcium (Ca) bearing minerals also occurs, but it depends on the relative abundance of these minerals in the soil. Sorption represents temporary storage pools as these reactions are reversible. Also, there are a limited number of sorption sites that become saturated over time, limiting the ultimate amount of P that can be removed by this mechanism. Precipitation represents a larger and more permanent sink for P than sorption. Overall, P removal by wetlands is much less than for N. Most wetlands accumulate P in soil at rates usually much less than 1 g/m^2/yr (8.92 lb/ac/yr). Under high nutrient loadings, the rate of P accumulation in wetland soils may approach 1 g/m^2/yr (8.92 lb/ac/yr) (Richardson and Craft 1993, Richardson and Qian 1997).

Using a combination of geographic information systems (GIS) data, published data on wetland N and P accumulation in the Saint Johns River (SJR) watershed and nearby areas (northern Everglades, southeastern Georgia), and newly collected soils data as part of this project, we calculated the total quantity of P and N wetlands in the Saint Johns River watershed could remove. We then calculated the economic value of this watershed-wide nutrient removal using the cost (per pound) of N and P removal by wastewater treatment plants and the cost (per pound) of N and P bought and sold in water quality trading programs and trades in the SJR watershed, Florida and nearby states.

Methods

Wetland N and P Accumulation: Literature Review - We reviewed published papers describing N and P accumulation in freshwater wetland soils of the upper SJR watershed, i.e. Blue Cypress Lake area (Brenner et al. 2001) and the northern Everglades (Craft and Richardson 1998) (Table 3-1). The sampling area of the upper SJR watershed is characterized by sawgrass (*Cladium jamaicense Crantz*) and mixed herbaceous marsh vegetation. The data included both nutrient enriched areas – those receiving nutrient enriched agricultural drainage, and un-enriched areas. The northern Everglades, characterized by sawgrass vegetation, are very similar to the upper SJR watershed around Blue Cypress Lake. In the northern Everglades, nutrient loading originates from the Everglades Agricultural Area, south of Lake Okeechobee, whereas the high N and P loads entering the upper SJR watershed originate from extensive citrus farms in the area. In both wetlands, nutrient enriched areas exhibit much higher rates of P and to some extent, N accumulation. This is evident in cores 3B and 2XII931 in the upper SJR watershed and enriched areas of Water Conservation Area 2A (Table 3-1). We also reviewed published literature describing N and P accumulation in soils of tidal wetlands in southeastern Georgia, including the Satilla, Altamaha and Ogeechee Rivers (Craft et al. 2012, Loomis and Craft 2010). Nitrogen and P accumulation in these tidal wetlands have been extensively studied by Craft and co-workers as part of the Georgia Coastal Ecosystems Long Term Ecological Research Program, funded by the National Science Foundation.

From the upper SJR watershed dataset of Brenner et al. (2001), we classified areas of nutrient enrichment into zones of high, medium and low rates of P (and N) accumulation (Table 3-2), similar to what was done by Craft and Richardson (1993) in WCA 2A of the northern Everglades. Compared to the upper SJR watershed, the rate of P accumulation in nutrient enriched areas of the northern Everglades is comparable to wetlands with high (0.65-0.90) and medium (0.40-0.65) distances from intensive agriculture (i.e. citrus) (Figure 3-1). The regressions show an exponential decrease accumulation of P with distance from agriculture, from a maximum of 1.13 $g/m^2/yr$ (10.08 lb/ac/yr) and leveling off at 0.13 g $P/m^2/yr$ (1.16 lb P/ac/yr) at about 3500 m (2.17 mi) (1 m = 0.00062 mi) distant.

Table 3-1. Published rates of N and P accumulation ($g/m^2/yr$) in freshwater wetlands of the upper SJR watershed (1 $g/m^2/yr$ = 8.9218 lb/ac/yr).

Upper Saint John's Watershed[1]

Type	Sampling Location	N		P	
		Cs-137	Pb-210	Cs-137	Pb-210
Freshwater	1B	---	11.1	---	0.13
	2B	---	16.1	---	0.22
	3B	---	25.8	---	1.13
	2XII931	---	22.1	---	0.85
	2XII932	---	15.8	---	0.42
	2XII933	---	10.6	---	0.14
	2XII934	---	10.6	---	0.12
	2XII935	---	8.8	---	0.14
	2XII936	---	12.5	---	0.24
	2XII938	---	17.6	---	0.38
	8II9410	---	17.7	---	0.66

Northern Florida Everglades[2]

Type	Sampling Location	N		P	
		Cs-137	Pb-210	Cs-137	Pb-210
Freshwater	Loxahatchee NWR	1.5	2.9	0.01	0.02
	WCA 2A (enriched no. 1)	21.3	16	0.47	0.39
	WCA 2A (enriched no. 2)	11.9	11.1	0.46	0.40
	WCA 2A (unenriched)	9.4	7.3	0.14	0.07
	WCA 3A	4.8	5.2	0.07	0.06
	Everglades Natl. Park	3.1	10.2	0.03	0.09

Southeastern Georgia[3]

Type	Vegetation Type	N		P	
		Cs-137	Pb-210	Cs-137	Pb-210
Tidal	Salt Marsh	2.4	4.4	0.29	0.41
	Brackish Marsh	6.8	6.3	0.99	0.95
	Tidal Fresh Marsh	8.1	7.2	0.69	0.48
	Tidal Forest	3.0	6.2	0.27	0.70

[1]Brenner et. al (2001), [2]Craft and Richardson (1998), [3]Craft (2012)

Table 3-2. N and P accumulation rates (g/m^2/yr) in freshwater wetlands of the upper SJR watershed (1 g/m^2/yr = 8.9218 lb/ac/yr).

Upper Saint John's Watershed[1]

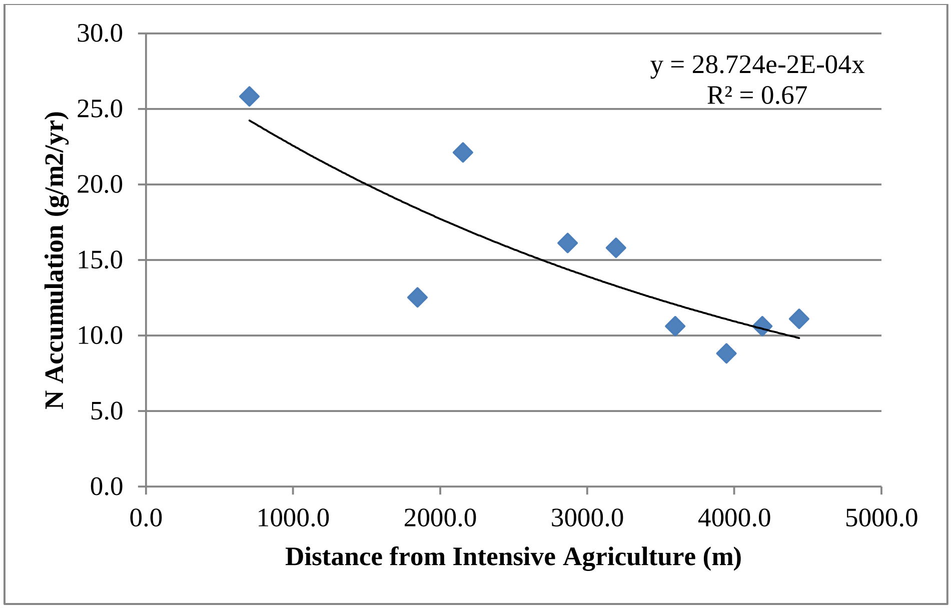
Storage	Sampling Location		P		N
High	3B		1.13		25.8
	2XII931		0.85		22.1
		Mean	0.99 ± 0.14	Mean	24.0 ± 1.85
Moderate	2XII932		0.42		15.8
	2XII936		0.24		12.5
	2B		0.22		16.1
		Mean	0.29 ± 0.06	Mean	14.8 ± 1.15
Low	2XII933		0.14		10.6
	2XII935		0.14		8.8
	1B		0.13		11.1
	2XII934		0.12		10.6
		Mean	0.13 ± 0.005	Mean	10.3 ± 0.51

[1]Brenner et. al (2001)

A similar relationship is seen for N (Figure 3-1). We also evaluated linear regressions of P and N accumulation with distance from intensive agriculture as well as linear and exponential regressions of accumulation versus distance from the nearest ditch. There are many ditches in the SJR watershed and many do not drain intensive agriculture. These regressions offered no significant improvement in their "goodness of fit" over those in Figure 3-1.

Based on the regressions in Figure 3-1 and the moderate rate of N/P accumulation in Table 3-2, we constructed regressions from N/P removal from wetlands near medium intensity agriculture. We used the mean rate of N (14.8 g/m^2/yr) (132.04 lb/ac/yr) and P (0.29 g P/m^2/yr) (2.59 lb P/ac/yr) accumulation to represent wetland N/P removal directly adjacent to medium intensity agriculture, then used the points from moderate and low N/P accumulation in Table 3-2 to construct regressions (Figure 3-2). The goodness of fit (R^2) for the regressions was not as strong as for the high intensity agriculture (Figure 3-1) mainly because the change in N/P accumulation with distance is not very great.

Wetland N and P Accumulation: Direct Measurement - We directly measured N and P accumulation in soil collected from tidal and non-tidal wetlands in the SJR watershed. Five soil cores were collected from two estuarine wetlands and three freshwater wetlands in the watershed. On July 21 2014, we visited tidal marshes near the mouth of the SJR, on Pasco Creek, with Mark Middlebrook of the Saint Johns River Alliance. We collected one core each from a *Spartina alterniflora*-dominated salt marsh and a *Juncus roemerianus*-dominated brackish marsh. The following day, we traveled to the Upper SJR where we met Kim Ponzio of the SJR Water Management District who took us out to collect soils from three freshwater wetlands in the Lake Winder area. Here, we sampled *Spartina bakeri*-dominated freshwater marsh, *Taxodium distichum* cypress forest, and *Salix carolininiana*-dominated shrub land.



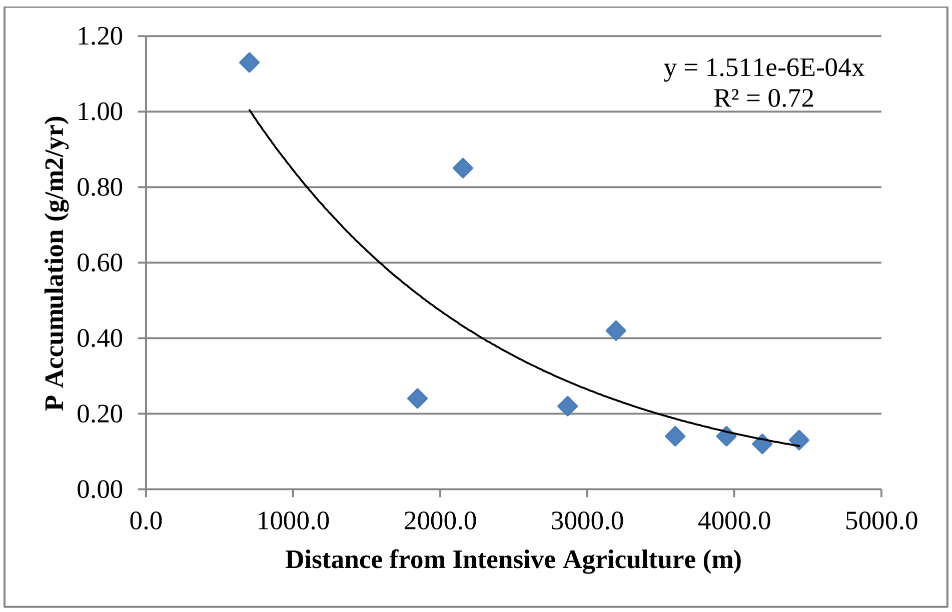
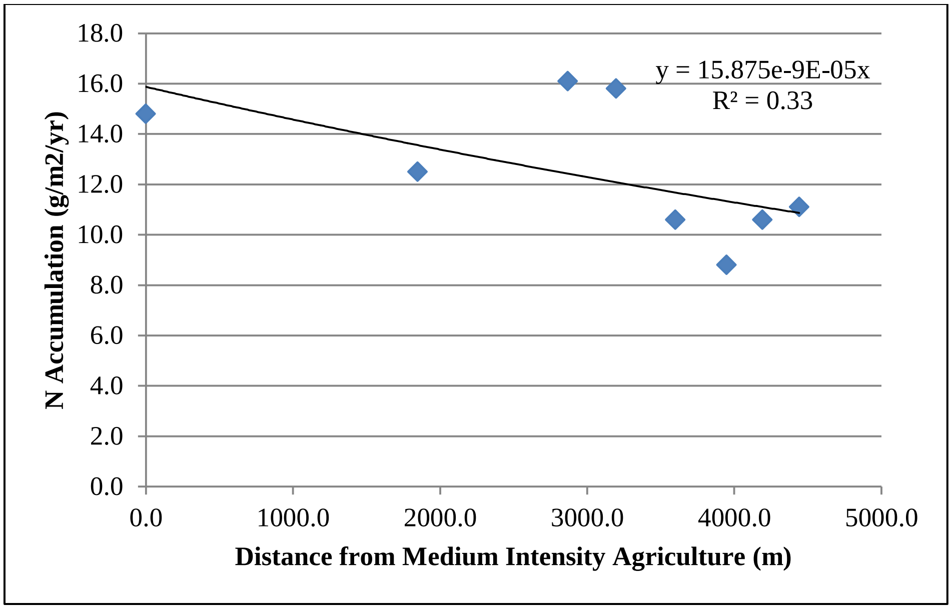


Figure 3-1. Regressions of wetland N and P accumulation with distance from intensive agriculture (i.e. citrus) based on the work of Brenner et al. (2001) in the upper SJR watershed, near Blue Cypress Lake (1 $g/m^2/yr$ = 8.9218 lb/ac/yr). See text for explanation for how regressions were constructed.



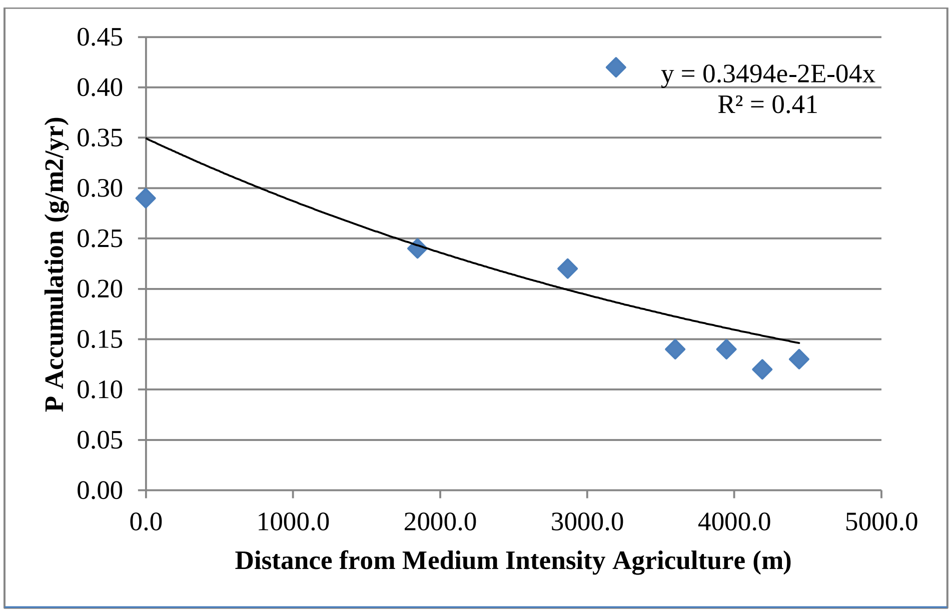


Figure 3-2. Regressions of wetland N and P accumulation with distance from medium intensity agriculture (1 $g/m^2/yr$ = 8.9218 lb/ac/yr). See text for explanation for how regressions were constructed.

Cores were sectioned into 2 cm (0.79 in) (1 in = 2.54 cm) depth increments in the field and transported to the lab where they were prepared for measurement of bulk density, percent organic C, total N and total P (see appendix 1). Depth increments were also analyzed by gamma spectrometry of the 46.5 keV and 66.1.62 photopeaks, respectively, for ^{210}Pb and ^{137}Cs. Cs-137 is an impulse marker from aboveground nuclear weapons tests in the 1950's and 1960's and can be used to calculate the rate of soil accretion (and hence N and P accumulation) during the past 50 years. Pb-210 is a naturally occurring radionuclide whose half-life (22 yr) enables calculation of soil accretion for the past 100 years. Procedures described in Craft (2012) were used for measuring ^{137}Cs and ^{210}Pb accretion and N and P accumulation.

Agricultural Land Use: Identifying Areas of High-, Medium-, and Low-intensity - We evaluated fertilizer use for various agricultural crops grown in Florida in order to estimate relative N and P loads leaving fields (Table 3-3). In particular, we evaluated citrus and sod, two crops with extensive acreage in the SJR watershed. Both citrus and sod require very large amounts of N and P, up to 320 lb/acre for sod. Citrus requires less N but it is much greater than N added to row crops (e.g. corn) and field crops (wheat).

We used the fertilizer and Florida Natural Areas Inventory land cover (FNAI 2012) data to identify agricultural land use of high-, medium- and low-intensity (Table 3-4). This was done, in part, by reviewing the descriptions of the various types of agriculture in the FNAI. High intensity agriculture consists of citrus and sod, as well as floriculture and feeding operations that do not account for much acreage. Medium intensity agriculture consists of row (corn, tomatoes) and field crops (wheat), vineyards, nurseries and ornamentals. All other agricultural land uses were considered low intensity, including areas of large acreage such as improved and unimproved pasture, coniferous plantations and specialty farms. The specialty farms are clustered in the Ocala area and most likely consist of horse farms.

Crop Type	N	P
Corn (row crop)	60-90[1]	0-45[1]
Citrus	10-240[2]	--
Wheat (field crop)	90-120[3]	--
Sod	120-320[4]	0-80[4]

[1]Wright et al. (2004)
[2]Obreza et al. (2006)
[3]Wright et al. (2007)
[4]Sartain (1988)

Table 3-3. The amount of N and P fertilizers (lbs./acre/yr) applied to major agriculture crops in Florida.

Land use	Acreage	Agricultural intensity		
		High	Medium	Low
Agriculture	3337			X
Cropland/pasture	56490			X
Row crops	42011		X	
Field crops	63392		X	
Improved pasture	488706			X
Orchards/groves	2781		X	
Citrus	86350	X		
Vineyards & nurseries	1359		X	
Tree nurseries	5836			X
Sod farms	23719	X		
Ornamentals	21710		X	
Floriculture	15	X		
Feeding operations	933	X		
Specialty farms	80709			X
Unimproved/woodland pasture	57810			X
Fallow cropland	686			X
Fallow orchards	1068			X
Coniferous plantations	638450			X

Table 3-4. Classification of agricultural land into high-, medium- and low-intensity agriculture based on fertilizer use of crops shown in Table 3-3.

Using the regressions in Figures 3-1 and 3-2, and the low-, medium- and high-intensity agriculture classes in Table 3-4, we estimated P and N removal rates for wetlands proximal to high-, medium- and low-intensity agriculture (Table 3-5). For high intensity agriculture, P removal rates range from a high of 0.99 g/m^2/yr (8.83 lb/ac/yr) to a background of 0.13 g/m^2/yr (1.16 lb/ac/yr) at a distance of 3500 m (2.17 mi). For medium intensity agriculture, the maximum rate of P removal is 0.29 g/m^2/yr (2.59 lb/ac/yr), decreasing to 0.13 g/m^2/yr (1.16 lb/ac/yr), the rate assigned to low intensity agriculture. Rates of N removal under high-, medium-, and low-intensity agriculture also are shown in Table 3-5. Exponential regressions based on Table 3-5 were applied to wetlands of varying distance, up to 3500 m (2.17 mi), from low-, medium- and high-intensity agriculture to calculate watershed-wide P and N removal by wetlands of the SJR watershed. Beyond 3500 m (2.17 mi), we assumed that freshwater wetlands in the SJR watershed remove 0.13 g P/m^2/yr (1.16 lb P/ac/yr) and 10 g N/m^2/yr (89.22 lb N/ac/yr).

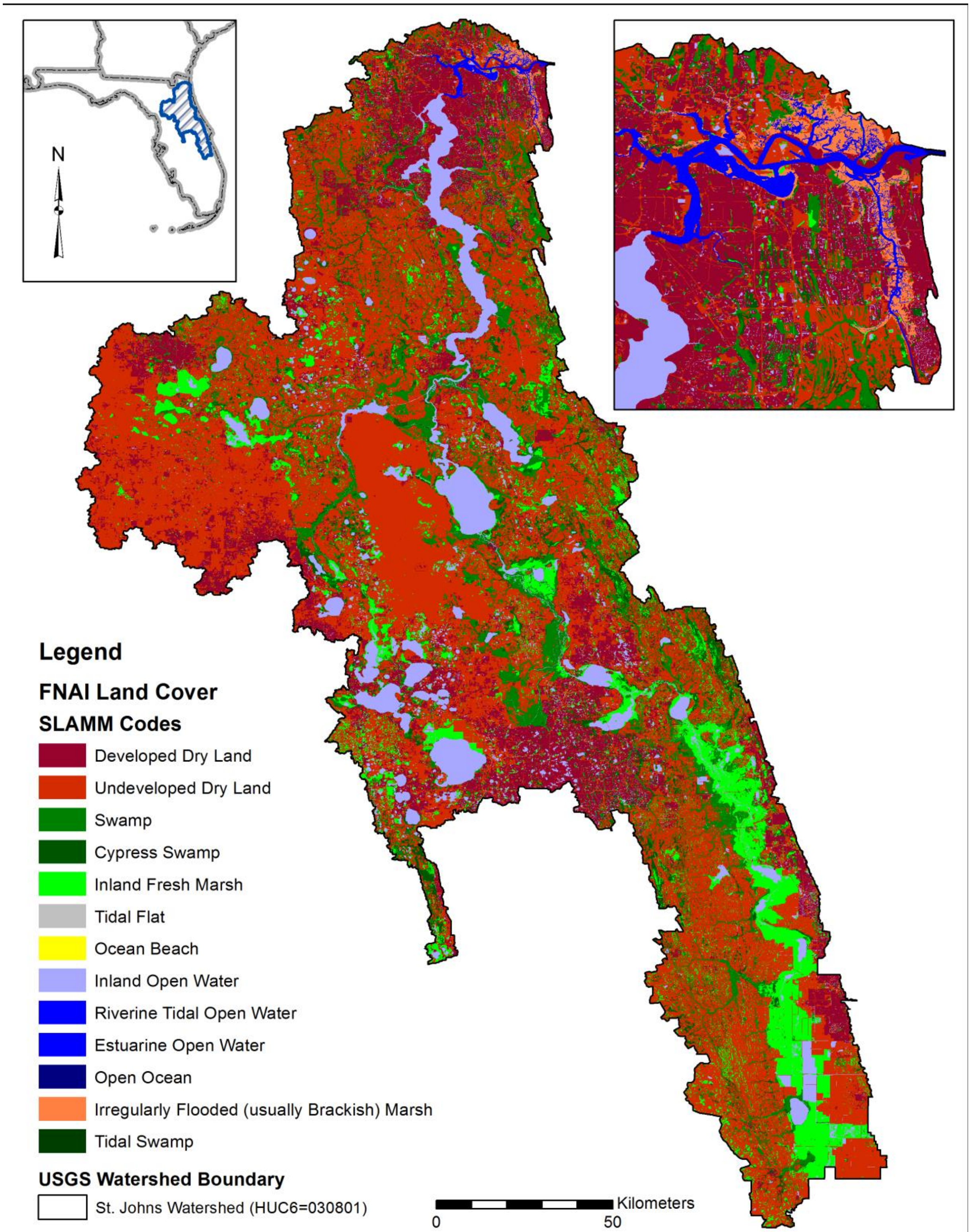


Figure 3-3. Land cover of the SJR watershed based on the Florida Natural Inventories Area converted to the classification system of the Sea Level Affects Marsh (SLAMM) model.

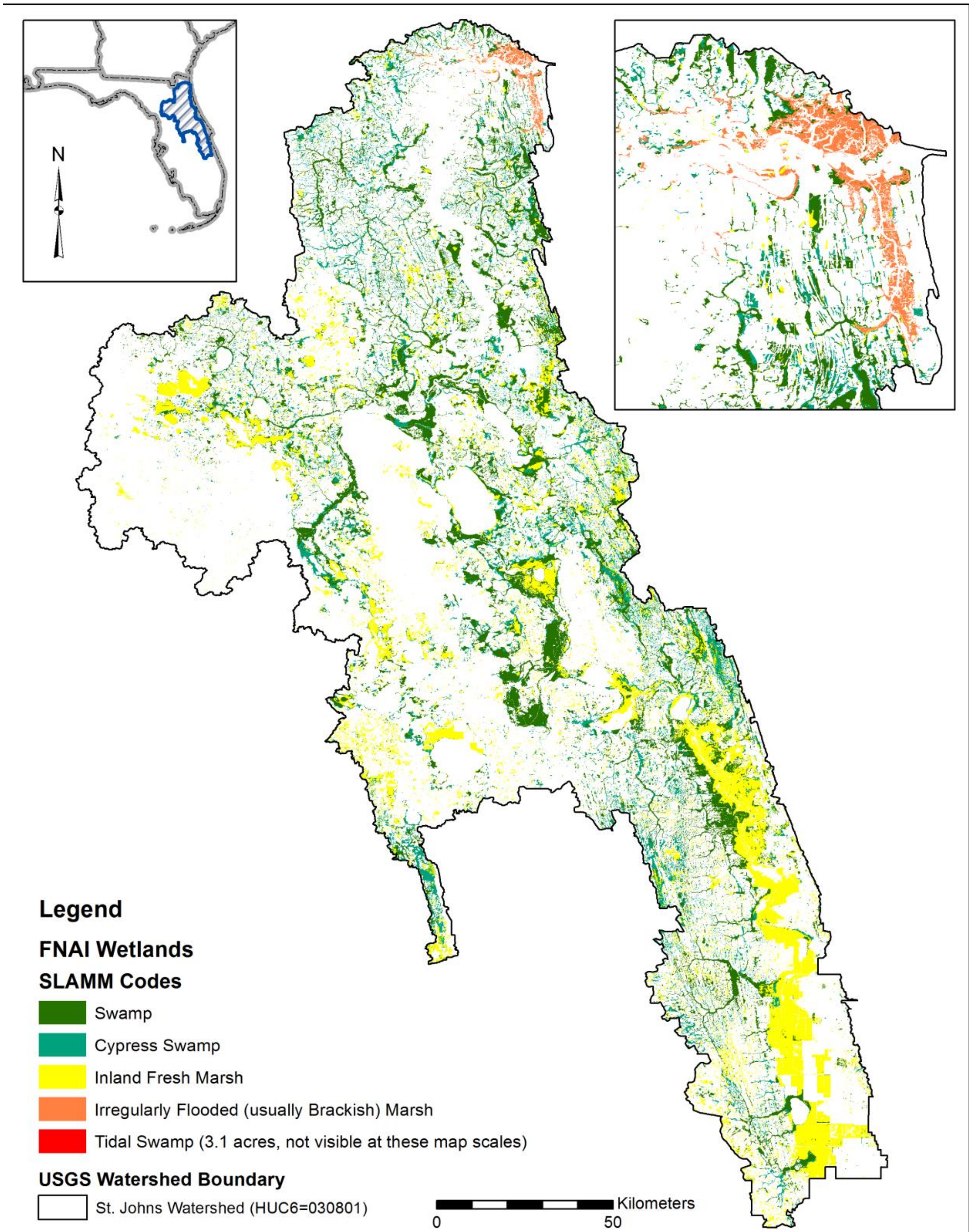


Figure 3-4. Freshwater and estuarine wetland cover of the SJR watershed based on the Florida Natural Inventories Area and converted to the classification system of the Sea Level Affects Marsh (SLAMM) model.

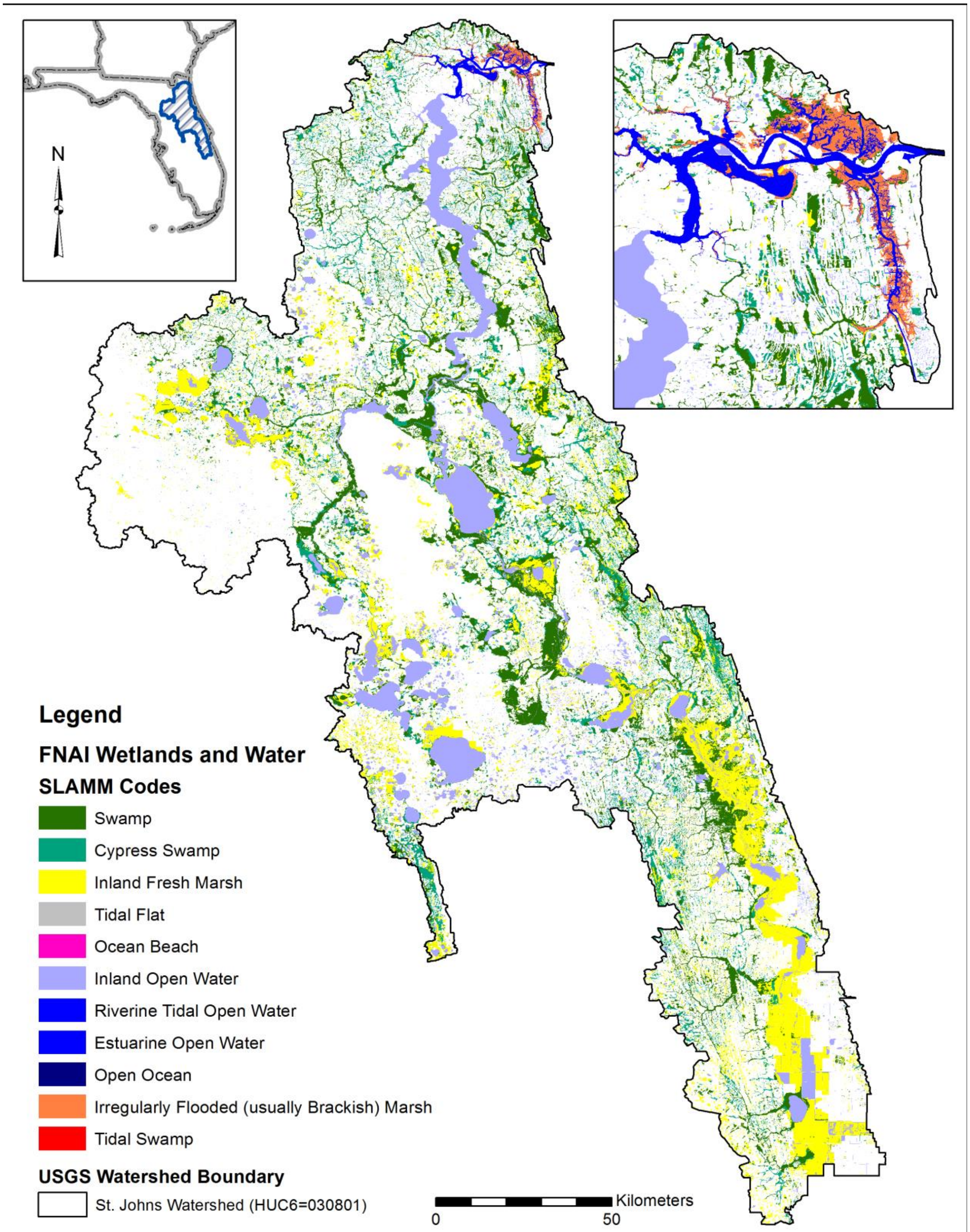


Figure 3-5. Wetland and water cover of the SJR watershed based on the Florida Natural Inventories Area and converted to the classification system of the Sea Level Affects Marsh (SLAMM) model.

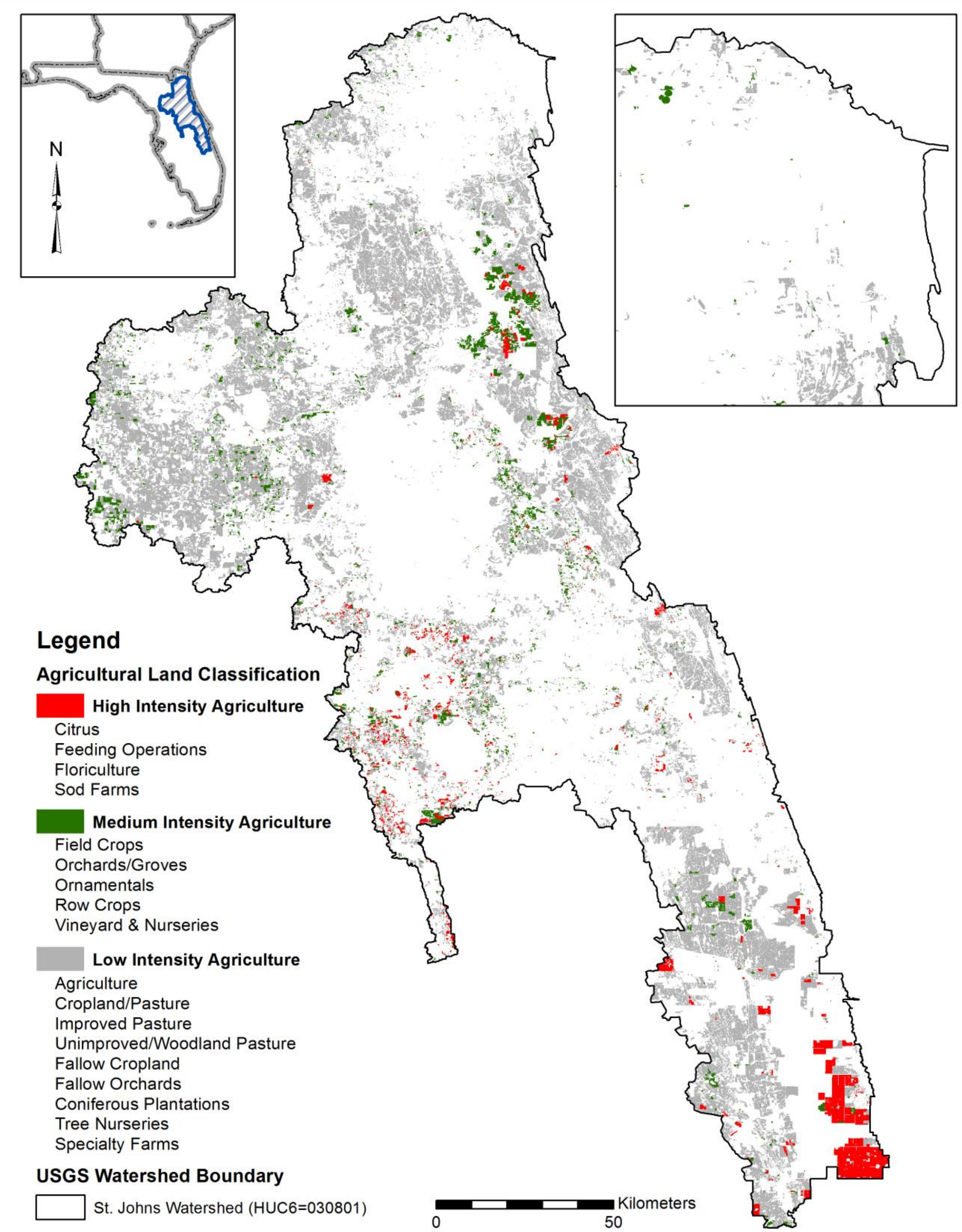


Figure 3-6. High-, medium-, and low-intensity agriculture cover in the SJR watershed. See Table 3-2 for an explanation of the cover classes.

Agricultural intensity	P accumulation ($g/m^2/yr$)	N accumulation ($g/m^2/yr$)
High	0.99-0.13	24-10
Medium	0.29-0.13	14.8-10
Low	0.13	10

Table 3-5. Maximum and minimum (background) rates of wetland P and N accumulation with distance (0-3500 m) based on the regressions (Figure 2-1) developed from the data of Brenner et al (2001) in the upper SJR watershed(1 $g/m^2/yr$ = 8.9218 lb/ac/yr).

Tidal wetlands account for only a small percentage (1%) of the total wetland acreage in the SJR watershed. We used N and P accumulation rates measured by Loomis and Craft (2010) and Craft (2012) for salt-, brackish-, and tidal fresh-marsh, and tidal forests. In tidal wetlands, N and P accumulation is driven more by sea level rise that drive soil accretion and nutrient accumulation than by proximity to agricultural land use (which drives N and P accumulation in non-tidal wetlands in the watershed). For tidal wetlands, the rate of P accumulation ranges from 0.27 $g/m^2/yr$ (2.41 lb/ac/yr) in tidal forests to 0.99 $g/m^2/yr$ (8.83 lb/ac/yr) in brackish marshes (Table 3-1). For N, rates range from 2.4 $g/m^2/yr$ (21.41 lb/ac/yr) (salt marsh) to 8.1 $g/m^2/yr$ (72.27 lb/ac/yr) (tidal fresh marsh).

Economic Analysis: Cost Estimates for N and P Removal - We reviewed literature to determine the cost of P and N removal by (1) wastewater treatment and (2) water quality trading programs (Table 3-6). The cost of N removal from wastewater treatment ranged from \$230 to \$295/lb. For P, the cost was much more variable, \$3 to \$93/lb. Studies of water quality trading programs in the Chesapeake Bay and the Mississippi River basin indicate that potential trades of N may range from \$8/lb to \$50/lb. For P, a water quality trading program in the lower SJR watershed estimated that removing 1 pound of P would cost more than \$68 (Table 3-6, Florida DEP 2010).

GIS Analysis of Wetland and Land Cover in the SJR Watershed - Geographic information system (GIS) technologies and data were used to scale the wetland nutrient removal relationship with distance to intense agriculture, as expressed in the regression equations. The geospatial (polygonal) FNAI land cover data was utilized for developing the wetlands "layer" and the agricultural lands "layer" as used in the project. For the walking the FNAI wetland site classes into the classification system of the Sea Level Affecting Marshes Model (SLAMM; Clough 2010) as presented in Figures 3-3, 3-4, and 3-5. To produce the agricultural layer (presented in Figure 3-6), the cross-walk of FNAI relevant site classes to fertilizer use intensity classes, as presented in Table 3-4, was applied.

Type	Nitrogen ($/lb.)	Phosphorus ($/lb.)
Wastewater Treatment Plant[1]	285 (230-295)[2]	3.18-34.02[3] 4-18[4] 68.04-92.78[5]
Nutrient Trading Program	10.50[6] 8-50[7]	68.87[8]
Mean	100.67 (8-295)	44.72 (3.18-92.78)

[1] Base and range (in parentheses)
[2] CCC (2013)
[3] Jiang et al. (2004)
[4] Ribauldo et al. (2008)
[5] Jiang et al. (2005)
[6] Ribaldo et al. (2005)
[7] Jones et al. (2010)
[8] Florida DEP (2010)

Table 3-6. Cost estimates for N and P removal by (1) wastewater treatment plants and (2) nutrient trading programs for point sources (i.e. wastewater treatment and industrial operations) of N and P.

The GIS data was further used to subdivide the SJR wetland landscape into proximity to agricultural nutrient source (PTANS) categories based on distance from high intensity and medium intensity agriculture. Distance increments of 500 m (0.31 mi) were used, from wetlands directly bordering intensely used agriculture lands to wetlands located a maximum of 3500 m (2.17 mi) away. The seven PTANS "buffer" categories thus ranged from 0-500 m (0-0.31 mi), 500-1000 m (0.31-0.62 mi), and so on, up to a 3000-3500 m (1.86-2.17 mi) increment. Again, this wetland landscape categorization was performed two times and produced for each wetland PTANS category with totals equaling the total acreage presented in Table 2-7.

The curvilinear relationships of nutrient accumulation in wetlands with distance from high and medium agricultural land were used to find values for the distinct wetland PTANS categories.

Wetland Type	Acres	km^2	N (Mt/yr)	Total N[1] (Mt/yr)	P (Mt/yr)
Swamp	578220	2340	34315	68631	806
Cypress Swamp	323845	1311	20141	40282	508
Inland Fresh Marsh	635627	2572	39156	78312	1009
Tidal Swamp	3	0.01	0.19	0.38	0.004
Irregularly Flooded Marsh	17031	69	770	449	67
Total	1554726	6292	94383	187,765	2390

[1]accounts for denitrification

Table 3-7: Cumulative N and P Removal (Mt/yr) of wetlands freshwater and estuarine wetlands in the SJR watershed (1 Mt = 1.1023 US ton).

For example, to find the predicted N removal rate for the wetlands in the 500-1000 m (0.31-0.62 mi) distance from high intensity agriculture PTANS category, the value of 750 m (0.46 mi) was entered as the x-value into the appropriate exponential equation, where 750 m (0.46 mi) is the midpoint of the 500-1000 m (0.31-0.62 mi) buffer class. The set of predicted values for the 14 wetland PTANS categories, as well as nutrient removal values assigned to the background PTANS category, were then scaled to the SJR watershed. The scaling was accomplished for each PTANS category by simply multiplying the predicted accumulation flux rate (mass/area/time) by the summary PTANS wetland area to obtain the yearly mass of nutrients removed for that PTANS category. Then, the yearly removal values for all PTANS categories were summed to produce a total nutrient removal value that to which a dollar value for both N and P could be calculated. Because the SLAMM-based wetland type identity was maintained through this process, these total yearly values can be presented by wetland type in Table 3-7.

The land cover data was used to calculate acreage of dryland, wetland and wetland & water features in the SJR watershed (Figures 3-3 to 3-5) and to identify locations of high-, medium- and low-intensity agriculture based on Table 4. Freshwater and estuarine wetlands make up 20% of the watershed. Non-tidal freshwater marsh and forest (swamp) account for most of the wetland area, 99% (Table 3-7). They are found throughout the watershed though much marsh is located in the upper watershed (Figure 3-4). Fresh marsh accounts for 41% of the wetland area, forested swamp 38% and cypress forest 21%. Estuarine wetlands consist of brackish marsh (1%), located in the lower SJR watershed. There is very little salt marsh in the watershed except at the mouth of the SJR.

Agricultural land occupies 26% of the watershed. High and medium intensity agriculture occupy 1.8% and 2.2% of the watershed, respectively. Low intensity agricultural land accounts for the remainder. Most high intensity agriculture, especially citrus farms, is located in the Upper SJR watershed (Figure 3-6). Medium-intensity agriculture is found throughout, with some concentration in the lower watershed.

Results and Discussion

Inland freshwater wetlands of the SJR removed considerable N and P annually, through burial/accumulation in soil and denitrification. Wetlands remove nearly 188,000 Mt of N each year (207,230 US ton/yr), half from burial and half from denitrification (Table 3-7). The amount of P removed each year is nearly 2400 Mt (2650 US ton/yr). Nearly all removal occurs in freshwater wetlands given that they account for 99% of total wetland area in the watershed.

Based on the cost of removing N in wastewater that ranges from \$230 to \$295/lb (Table 3-6, Figure 3-7), we calculate that the removal of 187,765 Mt N/yr (206,980 US ton/yr) through accumulation/burial has a value of nearly 48 to 61 billion dollars each year (Table 3-8). Nutrient trading programs value the cost of N removal at \$8 to \$50/lb (Table 3-6, Figure 3-7). The value of the wetlands for N removal through accumulation/burial still is substantial using these lower trading program costs: 1.66 billion dollars each year at the low end of \$8/lb and 10.4 billion dollars at the high end of \$50/lb. If denitrification removes comparable amounts of N, the value of the SJR wetlands for N removal doubles to 95 to 122 billion dollars/yr based on wastewater treatment costs and 3.3 to 21.7 billion dollars/yr based on nutrient trading programs. For P, the cost of P removal at wastewater treatment plants is \$3 to \$93/lb (Table 3-6, Figure 3-7). The ability of SJR wetlands to remove 2390 Mt P/yr (2630 US ton/yr) amounts to 20 to 490 million dollars each year. Based on a pilot water quality trading credit program in the lower SJR watershed (Florida DEP 2010), we estimate that the value of P removal is 360 million dollars per year.

Uncertainties in the N/P accumulation dataset may lead to some over-estimation of N and P removal by wetlands in the watershed. We relied on the dataset of Brenner et al. (2001) who made detailed measurements of N and P accumulation in the upper SJR watershed, near Blue Cypress WMA. These areas are characterized by high N and P loading from citrus farms. But, with increasing distance from agricultural land, N and P accumulation decline and level off to 10 g N/m^2/yr (89.22 lb N/ac/yr) and 0.13 g P/m^2/yr (1.16 lb P/ac/yr) about 3.5 km (2.17 mi) (1 km = 0.6214 mi) away (see Figure 3-1). Since the 1970's, rates of N and P accumulation in background areas of the Blue Cypress WMA ranged from 10-15 g N/m^2/yr (89.22-133.83 lb N/ac/yr) and 0.08-0.12 g P/m^2/yr (0.71-1.07 lb P/ac/yr) (Brenner et al. 2001). These *background* rates of N and P accumulation are comparable to ^{210}Pb-based measurements of 5-10 g N /m^2/yr (44.61-89.22 lb N/ac/yr) and 0.06-0.09 g P/m^2/yr (0.54-0.80 lb P/ac/yr) in low nutrient areas (WCA 3A, Everglades National Park) of the Florida Everglades to the south (Craft and Richardson 1998) and that are far removed from agricultural nutrient sources. (See Table 3.8 for explanation of the calculations.)

Cost	N (Burial)	Total N (Burial + Denitrification)	P (Burial)
$/lb	230-295[1] 8.0-50.0[2]	230-295[1] 8.0-50.0[2]	3.0-93.0[1] 69[2]
1000 $/Mt	507-650[1] 17.6-110[2]	507-650[1] 17.6-110[2]	6.61-205[1] 152[2]
Wetland Removal (1000 Mt/yr)	94.38	187.76	2.39
Total (Billion $/yr)	47.9-61.3[1] 1.66-10.40[2]	95.2-122.0[1] 3.3-20.7[2]	0.02-0.49[1] 0.36[2]

[1]Wastewater Treatment
[2]Nutrient Trading Programs

Table 3-8: Economic value of SJR wetlands for cumulative N and P removal in the watershed (1 Mt = 1.1023 US ton).

Two assumptions in the land cover data should be noted. First, we assume that land use in the upper SJR watershed, near Blue Cypress WMA, has not changed appreciably between 2009 and the time of data collection for the Brenner study (1992). Distance from the more recent FNAI agricultural land locations (polygons) were used to establish the regression relationships (Figure 3-1) with the Brenner sampled data. To be clear, (1) the FNAI land cover data is derived from a large number of sources and is nominally representative of 2009 conditions given the primary orthoimagery upon which it was verified, and therefore (2) our watershed-scale estimates should be considered to be applicable to the 2009 landscape matrix and its specific configuration. We do not believe that the sharply defined boundaries separating the citrus groves and wetlands sampled by Brenner et al. have changed appreciably since the time of sampling. Second, we assume that the intensity of fertilizer use, and levels of runoff to the wetlands, have not decreased since the time of the Brenner study. To the contrary, our literature review indicates that fertilizer use levels have stayed constant or increased during that period.

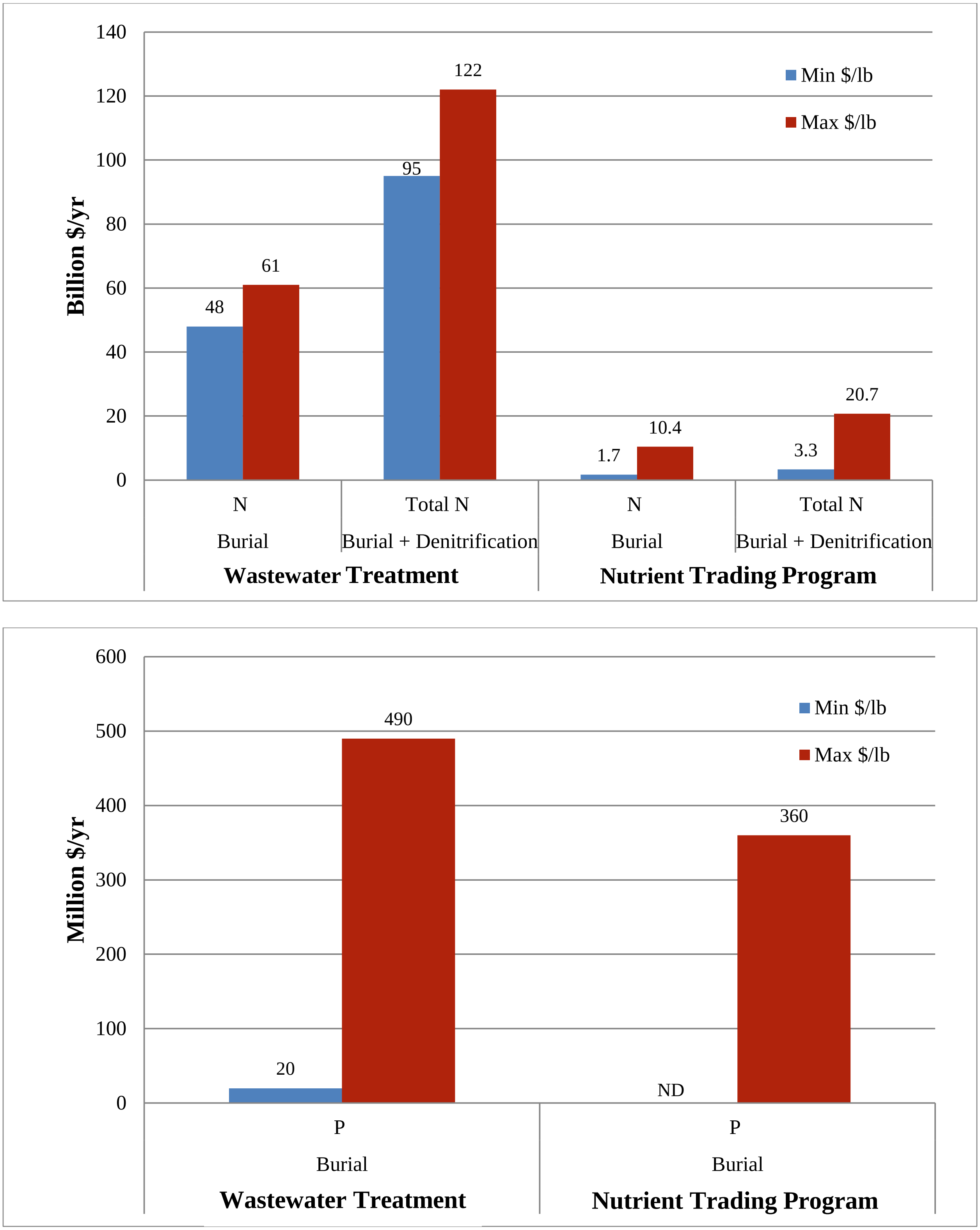


Figure 3-7. Economic value of SJR wetlands for cumulative N and P removal in the watershed.

Even greater uncertainty is associated with estimates for N and P removal by wastewater treatment plants and nutrient trading programs and the wide range in values associated with each. However, even if we assume that the cost of N/P is only $1 per pound, our economic valuation of nutrient removal by SJR wetlands by burial alone is considerable, 208 million dollars/yr for N and 5.3 million dollars/yr for P. Assuming denitrification removes comparable amounts of N as burial, the value of N removal based on $1/lb doubles to more than 400 million USD/yr.

Our assumption that denitrification removes an equal amount of N as burial, effectively doubling the N removal rate, also produces uncertainty in our economic valuation. However, in wetlands receiving high N loadings from agricultural runoff, denitrification removes considerable N, even more than burial (Craft 1997). Some N enters wetlands via biological fixation as well. This input may range from 0.01 to 17 g N/m^2/yr (0.09-151.67 lb N/ac/yr) with negligible N fixation in environments with high nutrient (N) loadings (Howarth et al. 1988). If we assume that inputs from N fixation are balanced by losses from denitrification that range 10 g/m^2/yr (89.22 lb/ac/yr) (background areas) to 24 g $/m^2$/yr (214.12 lb/ac/yr) (high nutrient areas) of Blue Cypress Marsh (see Table 3-5), our N removal rates are halved. Even so, the economic value of wetlands for N removal is considerable, in the billions of dollars per year.

Conclusions

The large economic value of the SJR wetlands reveals their importance in the maintenance and protection of water quality in eastern and northeastern Florida. Their value, estimated in the millions of dollars for P removal and billions of dollars for N removal cannot be overstated.

References

Brenner, M., C.L. Schelske, and L.W. Keenan. 2001. Historical rates of sediment and nutrient accumulation in marshes of the Upper St. Johns River Basin, Florida, USA. Journal of Paleolimnology 26:241-257.

CCC (Cape Cod Commission). 2013.Regional Wastewater Management Plan: Understanding the Cost factors of Wastewater Treatment and Disposal. http://www.capecodcommission.org/resources/RWMP/RWMP_costs_comparative.pdf

Clough, J.S, R.A. Park, and R.Fuller. 2010. SLAMM 6 beta Technical Documentation. Waitsfield. Vermont. http://warrenpinnacle.com/prof/SLAMM6/SLAMM6_Technical_Documentation.pdf , accessed 1 September 2014.

Craft, C.B. 1997. Dynamics of nitrogen and phosphorus retention during wetland ecosystem succession. Wetlands Ecology and Management 4:177-187.

Craft, C.B. 2012. Tidal freshwater forest accretion does not keep pace with sea level rise. Global Change Biology 18:3615-3623.

Craft, C.B. and C.J. Richardson. 1993. Peat accretion, nutrient accumulation and phosphorus storage efficiency along a eutrophication gradient in the northern Everglades. Biogeochemistry 22:133-156.

Craft, C.B. and C.J. Richardson. 1998. Recent and long-term organic soil accretion and nutrient accumulation in the Everglades. Soil Science Society of America Journal 62:834-843.

Craft, C., and J. Schubauer-Berigan. 2006. The role of freshwater wetlands in a water quality trading program. P. 143-158. In, D. Wichelns (ed.) Proceedings: Innovations in Reducing Nonpoint Source Pollution: Methods, Policies, Programs, and Measurements. November 28-30, 2006. Indianapolis, IN.

Florida DEP (Dept. of Environmental Protection). 2010. The Pilot Water Quality Trading Credit Program for the Lower St. Johns River: A Report to the Governor and Legislature. Division of Environmental Assessment and Restoration. Florida Department of Environmental Protection. Tallahassee, Florida.http://www.dep.state.fl.us/water/wqssp/docs/WaterQualityCreditReport-101410.pdf

Florida Natural Areas Inventory (FNAI). 2012. Florida Cooperative Land Cover Map, Version 2.3. Tallahassee, Florida. http://www.fnai.org/LandCover.cfm, accessed 1 September 2014.

Howarth, RW., R. Marino, and J.J. Cole. 1988. Nitrogen fixation in freshwater, estuarine, marine ecosystems. 2. Biogeochemical controls. Limnology and Oceanography 33:688-701.

Howarth, R.W., A. Sharpley, and D. Walker. 2002. Sources of nutrient pollution to coastal waters in the United States: Implications for achieving coastal water quality goals. Estuaries 25:656-676.

Jiang, F., M.B. Beck, K. Rowles, and R.G. Cummings. 2004. Pollutant Trading; Estimating the cost of phosphorus removal in wastewater treatment facilities. In, K.J. Hatcher (ed.), Proceedings of the 2004 Georgia Water Resources Conference. April 23-24 2004. Athens, Georgia.

Jiang, F., Beck, M. B., Cummings, R. G., Rowles, K., and Russell, D. (2005). Estimation of costs of phosphorus removal in wastewater treatment facilities: adaptation of existing facilities. Water Policy Working Paper, 11.

Jones, C., Branosky, E., Selman, M., and Perez, M. (2010). How nutrient trading could help restore the Chesapeake Bay. World Resources Institute Working Paper.

Loomis, M.J. and C.B. Craft. 2010. Carbon sequestration and nutrient (N, P) accumulation in river-dominated tidal marshes, Georgia, USA. Soil Science Society of America Journal 74:1028-1037.

National Research Council. 2000. Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. National Academy Press. Washington, D.C.

Obreza, T. A., R. Rouse, and E.A. Hanlon. 2006. Advancements with Controlled-Release Fertilizers for Florida Citrus Production: 1996-2006. University of Florida Department of Soil and Water Science, EDIS.

Ribaudo, M.O., R. Hemlich, and M. Peters. 2005. Nitrogen sources and Gulf hypoxia: Potential for environmental credit trading. Environmental Economics 52:159-168.

Ribauldo, M., L. Hansen, D. Hellerstein, and C. Greene. 2008. The use of markets to increase private investment in environmental stewardship. Economic Research Report No. 64. Economic Research Service. U.S. Department of Agriculture. Washington D.C.

Richardson, C.J. and C.B. Craft. 1993. Effective phosphorus retention in wetlands: Fact or fiction? In G.A. Moshiri (ed.) Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, Florida.

Richardson, C.J. and S. Qian. 1997. Long-term phosphorus assimilative capacity in freshwater wetlands: A new paradigm. Environmental Science and Technology 33:1545-1551.

Sartain, J. B. 1988. Fertility considerations for sod production. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS.

Wright, D., J. Marois,, J. Rich,, and R. Sprenkel. 2004. Field corn production guide. University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, EDIS.

Wright, D.L., A.R. Blunt, R.D. Barnett, C.L. Mackowiak, N. Dufault, and J. Marois. 2007. Management Considerations for Wheat Production in Florida. University of Florida department of Agronomy, EDIS.

Chapter 4

Economic Impact of the St. Johns Water Quality on Property Values

By
Valerie Seidel
The Balmoral Group
165 Lincoln Ave
Winter Park 32789
VSeidel@balmoralgroup.us

J. Walter Milon,
Department of Economics
University of Central Florida
Orlando, FL 32816
Alicia Barker and Craig Diamond
The Balmoral Group
165 Lincoln Ave
Winter Park 32789

Abstract

An econometric model was used to estimate the economic value of properties in the lower SJR basin (Duval, Clay, Putnam and St. Johns Counties) fronting or near the SJR. The model incorporated data on properties, demographics, water quality, and public awareness of harmful algal blooms for the past ten years to make estimates and used more than 20,000 property sales over the period 2003-2013. Riverfront properties in the four counties studied increased in value $944 million due solely to river frontage. Tributary frontage properties increased $117 million over properties that lack frontage, but were otherwise similar in property characteristics. The increased value attributable to the river carried to surrounding neighborhoods as well, with an $837 million value for proximity to the river.

Health of the SJR measured as water clarity added significant value to waterfront properties. Waterfront properties with the highest water clarity enjoyed an increased value premium of close to 24% for river frontage, while properties with the lowest clarity saw this premium reduced to only 6% of sales price. If all riverfront properties were adjacent to the highest water quality, i.e. six feet clarity, the hypothetical improvement in economic value attributable to the water quality improvement alone would total $346.1 million. The property tax revenue associated with this increase in water quality would total $45.3 million over 20 years.

Introduction

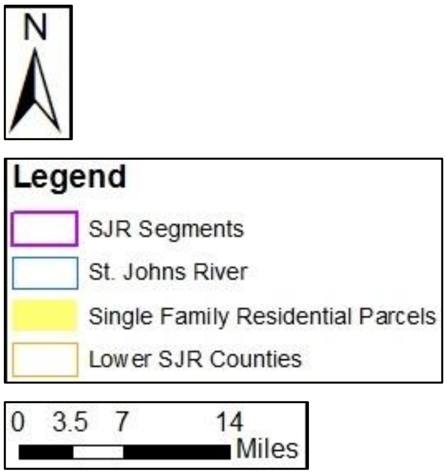
The impacts of proximity premiums for properties near the SJR were analyzed. The public perception of value related to aesthetics, access and open space enjoyment of the River are reflected in property values which impact ad valorem taxes. This economic value can be estimated through hedonic pricing models (Palmquist 2005). The economic impact related to lower water quality, e.g. toxic algal blooms, and other effects on the ecological health of the River, can be quantified through reduced property values, and reduced tax revenue. Forty years of literature has found that lower water quality and related algal blooms reduce nearby property values (Palmquist 2005). Recent work has measured the effects of regulation of nutrient loadings on economic values in Florida (Walsh 2011). A study published in Land Economics using hedonic pricing models (Walsh 2011) found that the value of improved water quality from reduced nutrient loads depends upon property location and proximity to waterfront. Benefits to non-waterfront homes near a water body may even exceed those realized by waterfront homes.

Here we apply a variation of the same hedonic pricing model used by Walsh (2011) to estimate the significance of the St. Johns River as reflected through property values, and the economic effects of changes in water quality, for the Lower St. Johns Basin.

Technical Approach

The work documents the relationship between the mainstem Lower St. Johns River (north of Welaka) and its annual floodplain to the value of residential real estate adjoining and near the River. **Figure 4-1** shows the general subject area, a buffer (described below) and residential parcels within the buffer.

Figure 4-1. St. Johns River Parcels



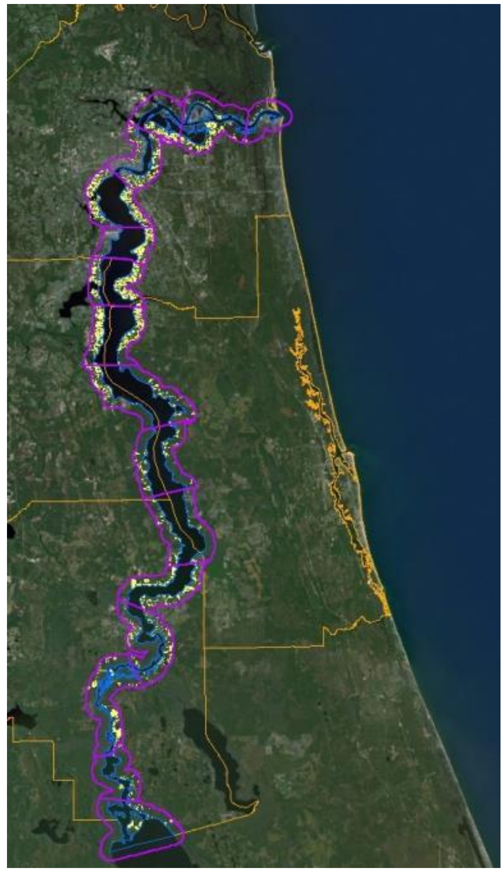


Figure 4-2. St. Johns River Tributaries

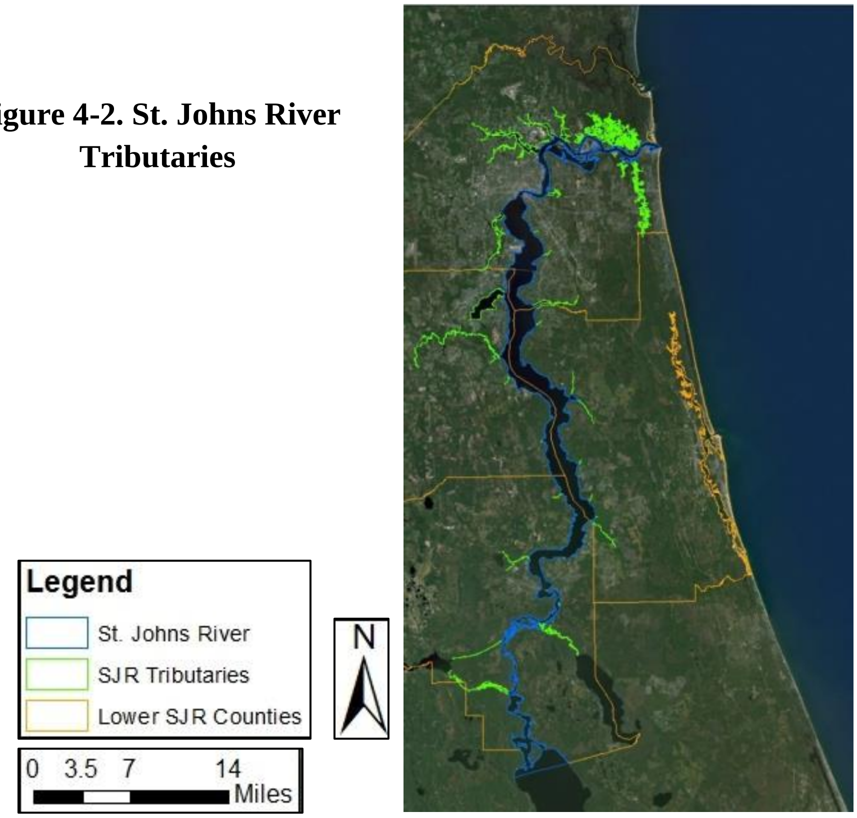


Figure 4-2 shows the tributaries of the St. Johns River as reflected in data from the St. Johns River Water Management District. The effects of location on tributaries will be explored and an estimate of the economic value of the St. Johns River made as revealed through property values. Published research affirms that water resources, and changes in water quality, contribute to property values in Florida at varying distances based on attributes of "edge," representing waterfront premiums and "proximity," to the waterfront or access point. Using GIS (geographic information system), a dataset was developed and regression analysis applied, quantifying values for proximity effects of the River on property values in four counties (Putnam, Clay, St. Johns, and Duval). Regression models of property value (i.e., hedonic methods) used GIS data to account for lot size, building size, existing land use, access (e.g., distance to boat ramps), and neighborhood effects, which account for nearby amenities (such as parks) as well as potential "dis-amenities" (such as landfills, etc.). Value increases attributable to rivers or other natural amenities dissipates at 1,500 meters. Hence, the study includes only properties within 1,500 meters of the River.

Descriptive Statistics – Housing - Table 4-1 reflects the composition of housing within the dataset. Sales of housing which occurred between January 1, 2003 and December 31, 2013 for all four counties were included if the property was located within 1500 meters of the River's edge. Analysis of data found that certain delimiters were appropriate and properties excluded if (a) sale price was less than $15,000, (b) land area was more than twice the standard deviation from the mean for the county (generally representing lands that appeared to be improperly coded as single family residential), (c) land area for the lot was less than 500 m2, (d) sales price of more than $2,500,000, of which there were 12, and (e) living area was less than 500 ft2. The resulting dataset includes 23,901 records, skewed heavily toward Duval

County, which has the greatest population. Sales prices in current dollars ranged from an average of $160,000 to just under $440,000 by County. Table 4-2 provides similar information by County.

Table 4-1. Housing Characteristics within study area.

Variable Description	Unit	Study Area (N = 23,494)			
		Mean	Std Deviation	Min	Max
Property Characteristics					
Sales Price	2013 Dollars	243,615	216,064	15,500	2,408,000
Total Living Area	$Feet^2$	2,097	885	515	8,995
Area of Parcel	$Feet^2$	14,012	11,862	4,301	167,419
Home Age	Years	40	25	1	153
Water Quality Interaction (DRSD)	--	535	350	0	2,600
% River Front (within 50 meters)	--	4.01	--	--	--
% Tributary Front (within 15 meters)	--	1.32	--	--	--
Spatial Characteristics					
Distance to Central Business District	Meters	17,208	19,194	1,127	7,568
Distance to St. Johns River	Meters	736	418	0	1,501
Distance to Access Points	Meters	2,699	1,840	0	7,568
Latitudinal Coordinate	Kilometers	691.96	21.92	598.46	714.71
Longitudinal Coordinate	Kilometers	627.44	5.52	618.91	647.07
Neighborhood Characteristics					
% of Population Caucasian	--	75.20	--	--	--
% of Population Black	--	18.59	--	--	--
% of Population Senior	--	14.56	--	--	--
Persons per Household	Persons	2.55	0.37	0.00	6.13
Median Household Income	2013 Dollars	59,429	24,399	0	125,461
Distribution of Sales by Year					
% of Sales in 2003	--	16.21	--	--	--
% of Sales in 2004	--	17.35	--	--	--
% of Sales in 2005	--	17.89	--	--	--
% of Sales in 2006	--	14.37	--	--	--
% of Sales in 2007	--	9.89	--	--	--
% of Sales in 2008	--	3.79	--	--	--
% of Sales in 2009	--	3.43	--	--	--
% of Sales in 2010	--	4.06	--	--	--
% of Sales in 2011	--	3.23	--	--	--
% of Sales in 2012	--	3.82	--	--	--
% of Sales in 2013	--	5.96	--	--	--

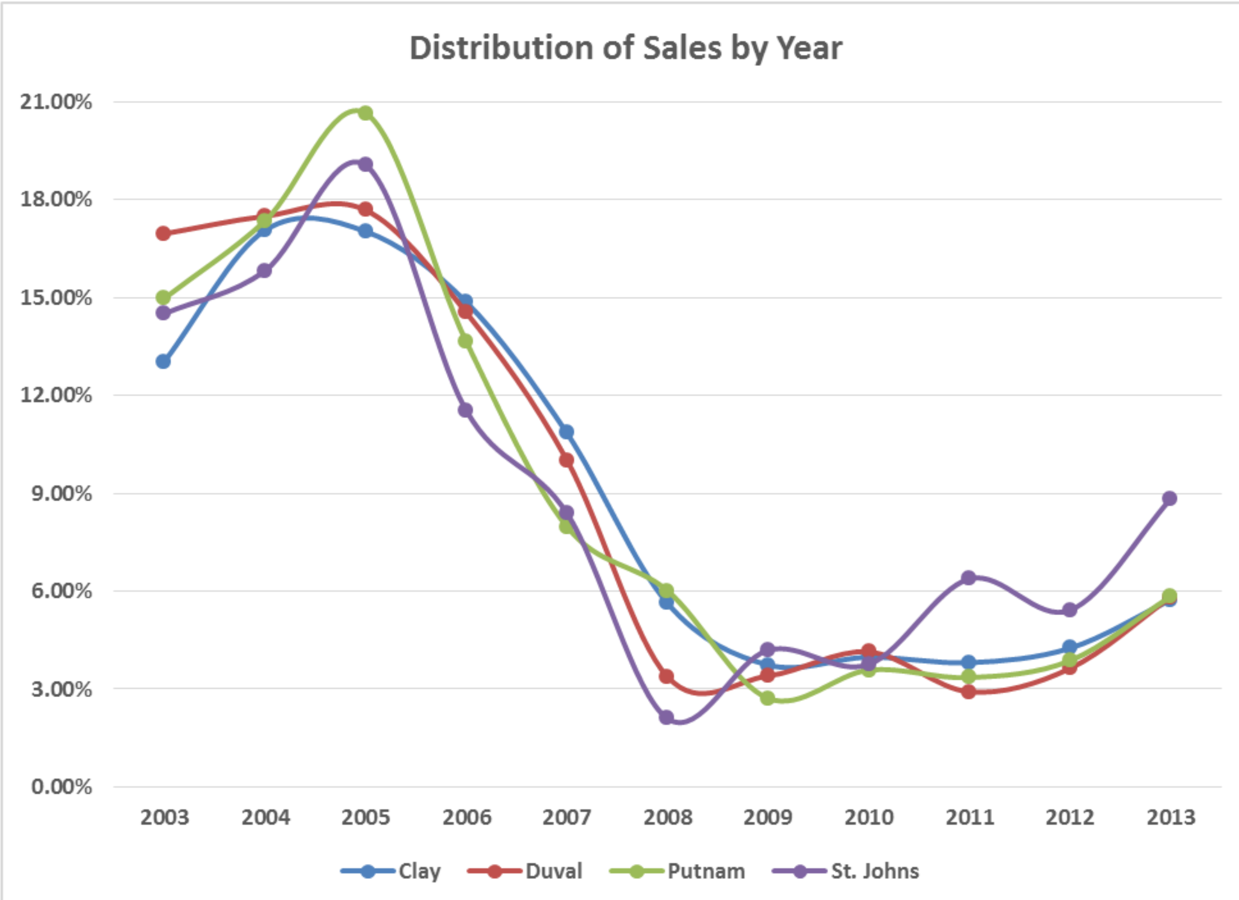
Table 4-2. Housing Characteristics by County

Variable Description	Unit	Clay County (N = 2,913)		Duval County (N = 17,708)		Putnam County (N = 1,729)		St. Johns County (N = 1,144)	
		Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation
Property Characteristics									
Sales Price	2013 Dollars	241,319	161,755	242,464	220,650	160,673	151,180	392,632	267,231
Total Living Area	$Feet^2$	2,287	766	2,014	861	2,172	1,009	2,785	950
Area of Parcel	$Feet^2$	16,751	12,904	11,907	8,630	21,468	19,925	28,367	18,320
Home Age	Years	18	16	44	24	43	27	17	12
Water Quality Interaction (DRSD)	--	513.41	289.06	563.11	355.99	353.26	340.72	432.45	305.41
% River Front (within 50 meters)	--	3.81	--	1.94	--	19.90	--	12.41	--
% Tributary Front (within 15 meters)	--	1.37	--	1.14	--	2.72	--	1.84	--
Spatial Characteristics									
Distance to Central Business District	Meters	27,807	6,400	8,840	4,891	76,966	8,580	29,436	7,931
Distance to St. Johns River	Meters	747	399	760	405	534	494	633	436
Distance to Access Points	Meters	3,857	2,303	2,604	1,652	1,114	1,033	3,609	2,006
Latitudinal Coordinate	Kilo-meters	676.51	6.51	701.91	7.37	627.30	8.69	674.91	7.66
Longitudinal Coordinate	Kilo-meters	621.36	1.03	628.17	5.64	629.49	2.82	628.42	2.77
Neighborhood Characteristics									
% of Population Caucasian	--	86.96	--	72.81	--	66.91	--	94.71	--
% of Population Black	--	7.18	--	20.72	--	27.34	--	1.43	--
% of Population Senior	--	15.08	--	14.26	--	18.44	--	12.05	--

Table 4-2. Housing Characteristics by County (continued)

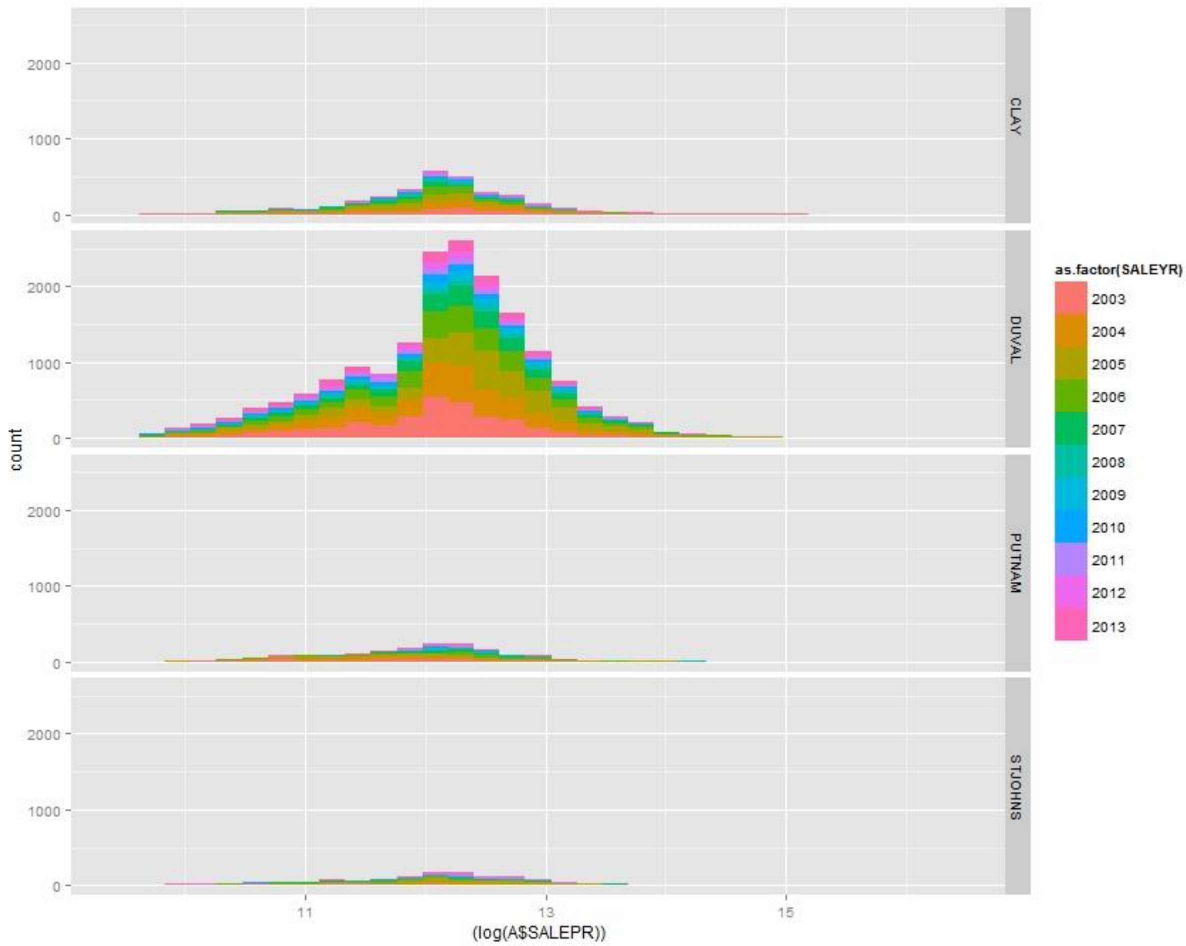
Variable Description	Unit	Clay County (N = 2,913)		Duval County (N = 17,708)		Putnam County (N = 1,729)		St. Johns County (N = 1,144)	
		Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation	Mean	Std Deviation
Persons per Household	Persons	2.76	0.24	2.49	0.38	2.59	0.19	2.86	0.19
Median Household Income	2013 Dollars	88,458	21,310	57,969	23,592	35,619	7,933	88,458	16,862
Distribution of Sales by Year									
% of Sales in 2003	--	13.04	--	16.96	--	14.98	--	14.51	--
% of Sales in 2004	--	17.06	--	17.49	--	17.35	--	15.82	--
% of Sales in 2005	--	17.03	--	17.68	--	20.65	--	19.06	--
% of Sales in 2006	--	14.86	--	14.54	--	13.65	--	11.54	--
% of Sales in 2007	--	10.85	--	10.02	--	7.98	--	8.39	--
% of Sales in 2008	--	5.63	--	3.38	--	6.02	--	2.10	--
% of Sales in 2009	--	3.74	--	3.41	--	2.72	--	4.20	--
% of Sales in 2010	--	3.98	--	4.15	--	3.59	--	3.76	--
% of Sales in 2011	--	3.81	--	2.92	--	3.35	--	6.38	--
% of Sales in 2012	--	4.26	--	3.64	--	3.88	--	5.42	--
% of Sales in 2013	--	5.73	--	5.82	--	5.84	--	8.83	--

Figure 4-1. Distribution of Sales by Year



The effects of the housing boom and bust cycle are evident in the sales activity. Sales counts by year, as shown in **Figure 4-3**, show the decline in activity during the bottom of the recession, gradually recovering in recent years. **Figure 4-4** provides a graphic distribution of sales price in log form by County, by year.

Figure 4-2. Log Sales Price by Year by County



The River segments, as shown in **Figure 4-5**, represent 16 separate Water Body ID's as assigned by the Florida Department of Environmental Protection. **Table 4-3** shows the breakout of housing sales by WBID. Housing sales are distributed throughout the length of the River, as shown in **Figure 4-6**. The southernmost WBIDs represent the most rural portions of the Area of Interest. This is reflected in the mean sales price, as well as in the median household income, which are half or less of the median incomes found in the northern segments of the River.

Figure 4-3. St. Johns River Segments by Water Body ID ("WBID")

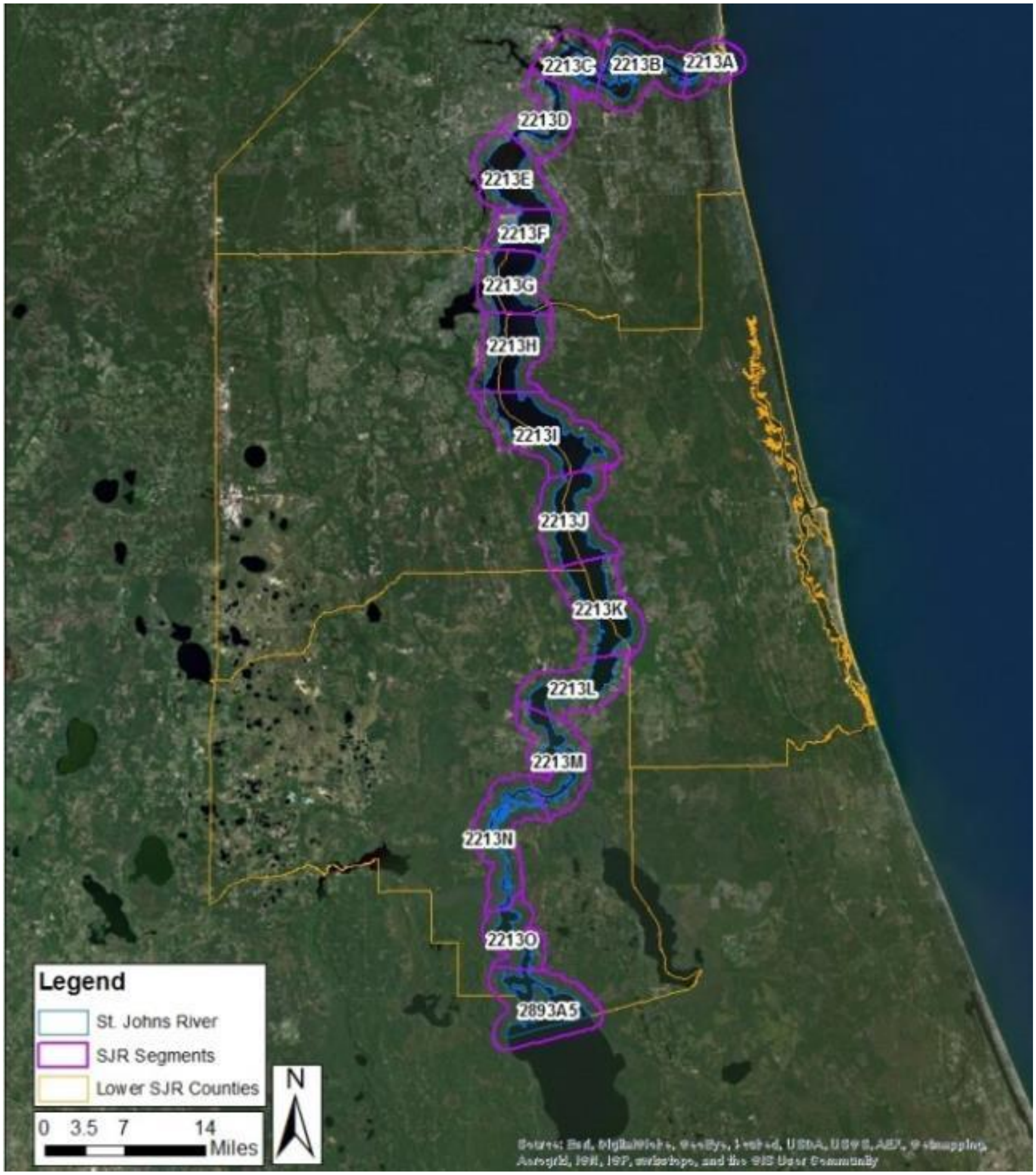
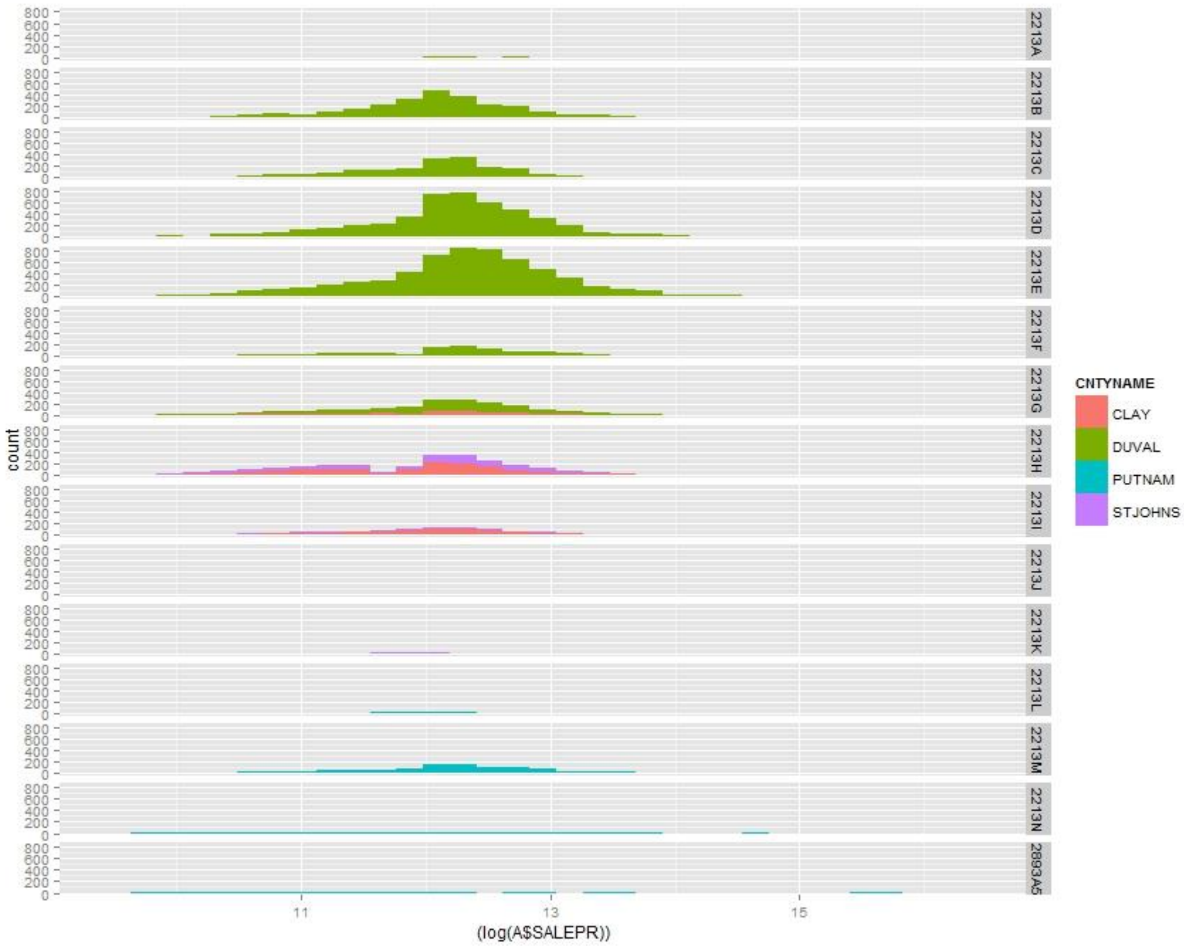


Table 4-3. Housing Sales by WBID

WBID Name	Share of Total Sales	Average Sale Price
2213A	0.5%	$583,290
2213B	11.1%	$247,275
2213C	7.7%	$190,739
2213D	20.2%	$147,967
2213E	25.5%	$294,898
2213F	4.6%	$290,044
2213G	8.8%	$301,745
2213H	10.1%	$317,725
2213I	3.8%	$209,502
2213J	0.3%	$377,614
2213K	0.7%	$299,248
2213L	1.1%	$234,837
2213M	4.8%	$121,297
2213N	0.7%	$215,927
2893A5	0.3%	$211,603

Figure 4-3. Sales Price by WBID



Virtually all of the parcels in the dataset were located in the flood plain, due to their proximity to the river. FEMA flood maps changed during the period of analysis. Since the designation of flood zone determines requirements for flood insurance (which can affect housing costs by thousands of dollars annually) there may be effects on housing prices for properties that were newly identified as being located in a floodplain. For some portions of the study area, new floodplain designations went into effect in 2004, and for some areas new floodplain designations went into effect in 2013. **Table 4-4** shows the net effect of the floodmap changes.

Table 4-3. Parcels in Flood Plain

Year	Total Parcels	Number of Parcels in Zone X			Change in number of parcels			Percent in Zone X		
		1996 FIRM	**1996 & 2004 FIRM**	**2013 FIRM**	**1996-2004**	**2004-2013**	**1996-2013**	**1996**	**1996 & 2004**	**2013**
2003	3,713	3,524	3,522	3,598	2	-76	-74	94.9%	94.9%	96.9%
2004	4,049	3,848	3,839	3,905	9	-66	-57	95.0%	94.8%	96.4%
2005	4,500	4,284	4,284	4,368	0	-84	-84	95.2%	95.2%	97.1%
2006	3,619	3,465	3,465	3,520	0	-55	-55	95.7%	95.7%	97.3%
2007	2,693	2,583	2,578	2,612	5	-34	-29	95.9%	95.7%	97.0%
2008	913	874	874	885	0	-11	-11	95.7%	95.7%	96.9%
2009	853	809	810	830	-1	-20	-21	94.8%	95.0%	97.3%
2010	1,012	974	974	981	0	-7	-7	96.2%	96.2%	96.9%
2011	882	817	813	843	4	-30	-26	92.6%	92.2%	95.6%
2012	1,033	975	971	1,002	4	-31	-27	94.4%	94.0%	97.0%
2013	1,617	1,526	1,520	1,555	6	-35	-29	94.4%	94.0%	96.2%

Descriptive Statistics – Water Quality - Water quality is defined by a variety of parameters, determined in part by field measurements (such as dissolved oxygen, specific conductance, pH or turbidity), and by laboratory assessments (such as bacteria, nutrients, or toxics). For the purposes of this study, a general indicator of the river's water quality was desired. The "Trophic State Index" (TSI), an indicator of biomass within the water column, provides one such measure. Historically applied to lakes, the TSI can be applied to flowing systems such as the St. Johns River. While the TSI is a continuum, its range has been partitioned into general classes of ecological health from oligotrophic to hypertrophic (or dystrophic).

The TSI (based on Carlson, 1997) is constructed from the values one or more of the following variables: Secchi Disk ("SD") Depth (water clarity); Chlorophyll α; and Total Phosphorus (TP). In Florida, Kratzer and Brezonik (1982) developed a TSI using the concentration of Total Nitrogen (TN). There is no specific advantage to using a TSI derived from an average of these variables, although it is common practice.

A TSI derived from Chlorophyll α (CHLa) will inherently be the strongest predictor as it is a direct measure of one component of aquatic biomass, rather than a proxy. However, CHLa is a laboratory measurement, which requires specific sample handling protocols and laboratory costs. Secchi Disk readings, on the other hand, are routinely taken as part of most sampling events, providing field context for lab results. Nutrients, CHLa, and other lab-oriented measurements are generally taken as part of a defined sampling program to address a particular scientific, ecological or public health objective, and such observations are often limited to particular locations during particular windows of time.

Ideally, a consistent data stream would be used for the entire period of analysis (2003-2013). Data has been collected for all available water quality monitoring stations and ad hoc monitoring, with the assistance of staff from SJRWMD, Florida Fish & Wildlife Commission, USGS, Florida Department of Environmental Protection, and NOAA. **Table 4-5** summarizes the sources of data for the St. Johns River.

Secchi Disk readings are available at 15 of the 16 WBIDs for all ten years of this study. Observations for other components of the TSI (TN, TP and CHLa) are generally less frequent, and are unavailable in several WBIDs and for select years. Consequently, while it is a less robust predictor of water quality, the broad availability of Secchi Disk depth data lends itself to longitudinal study. As the TSI is intended to be a relative indicator of river system health, the following TSI based on Secchi Disk data meets this need:

$$TSI(SD) = 60 - 14.41 * \ln(SD)$$

Where SD is the Secchi depth in meters, and ln is the natural logarithm.

Table 4-4. Water Quality Monitoring Data

Attribute	Sources
Algae	FWC
Algae, Severity	EPA/USGS
Algal Growth Potential	EPA/USGS, STORET
Chlorophyll a	EPA/USGS, SJRWMD, STORET
Dead Fish, Severity	EPA/USGS
Secchi Disk Depth	EPA/USGS, SJRWMD, STORET
TN	EPA/USGS, STORET
TP	EPA/USGS, SJRWMD, STORET
Discharge	SJRWMD, USGS
Chlorophyll a to Pheophytin Ratio	SJRWMD
Flow	STORET

Analysis of the available data reveals a number of interesting trends.

As shown in **Figure 4-7**, the Secchi disk values reflect some unexpected patterns. SD measures have been averaged over the entire year, by WBID, for purposes of this analysis. By year, the data shows deterioration in Secchi disk measure and then recovery in the middle stretches of the river, while the southernmost and northernmost segments – the most rural and urban, respectively – showed reasonably steady improvement over the time period in question.

Figure 4-4. Secchi Disk, annual average by WBID

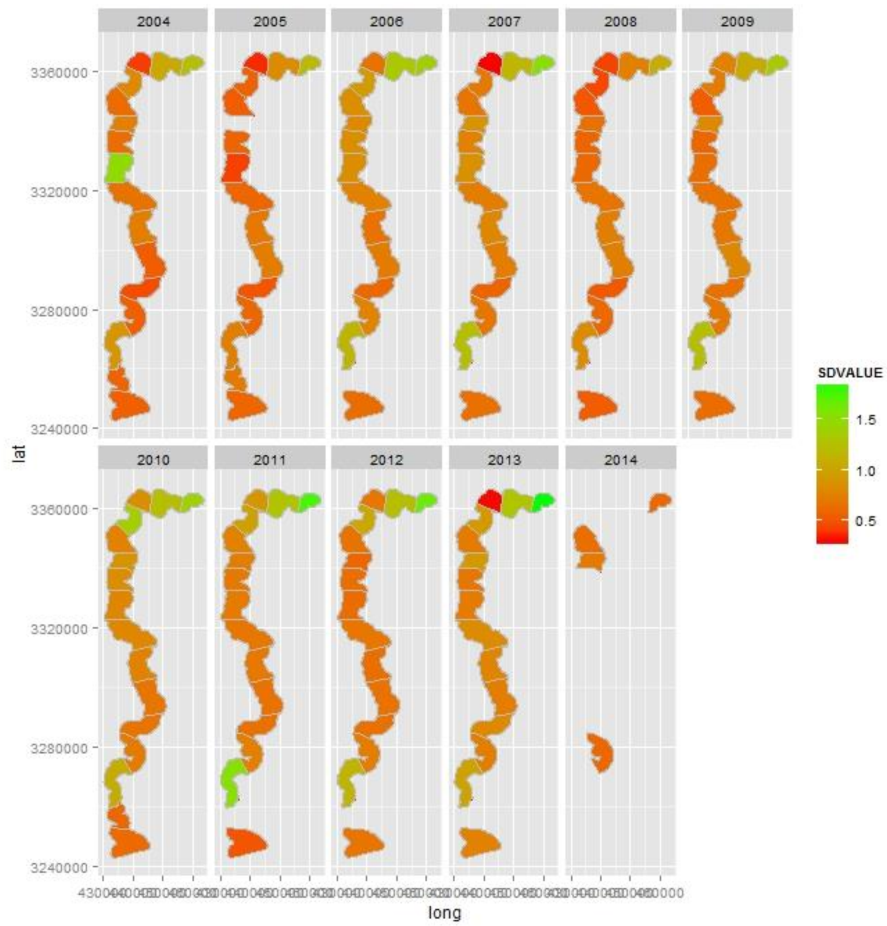


Figure 4-8 shows the readings when restricted to those measures clustered around the mean; i.e. measures within one standard deviation from the mean for that segment. With this filter applied, patterns emerge that reflect more intuitive trends: rural areas reflect higher measures of clarity, while segments closer to urbanized centers show changes in both directions. Grey areas represent areas with no data under this restriction.

Figure 4-5. Secchi Disk Measures, Annual Average by WBID, Restricted To Mean-Clustered Readings

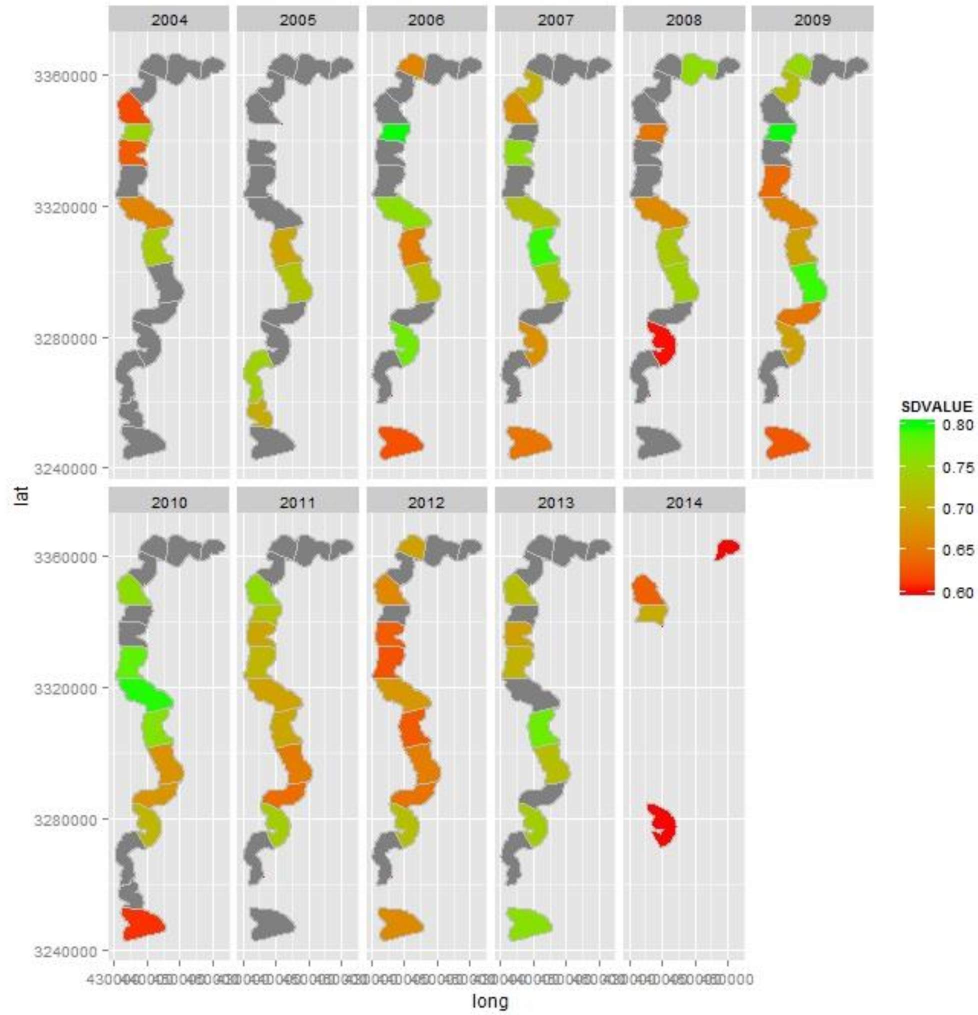
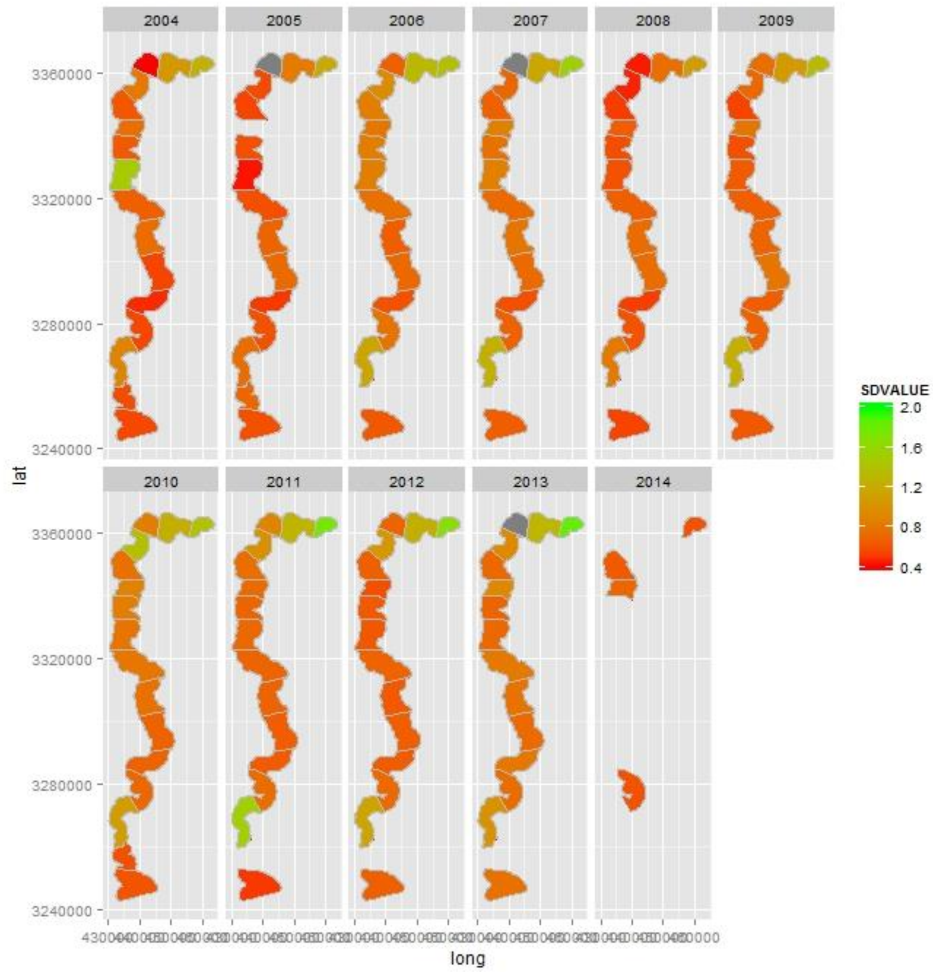


Figure 4-9 shows the readings when only outliers have been removed. This may represent the conditions most representative of the public perception, when major flushing events have been removed. Unfortunately, this also reflects the lowest set of clarity measures, with all segments showing measures at the lower end of the clarity spectrum.

Figure 4-6. Secchi Disk Measure, Annual Average by WBID, With Outliers Removed



Finally, **Figure 4-10** shows the overall Secchi disk measures by year, for the length of the river. The mean is represented by the bar in each box, with the distribution within each box and dashed line representing interquartile ranges, and circles representing outliers. **Figure 4-11** shows the averaged SD measures by WBID, over all years.

Figure 4-7. St. Johns River system Secchi disk mean values by year, in meters

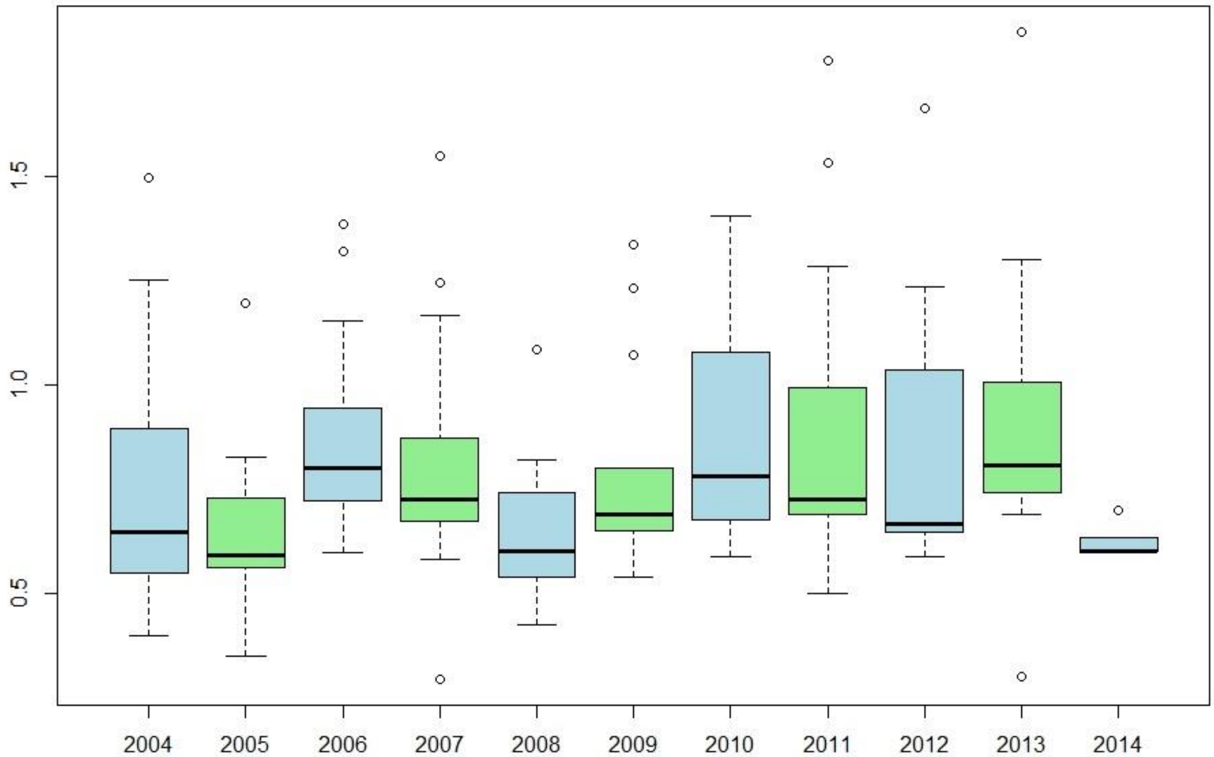
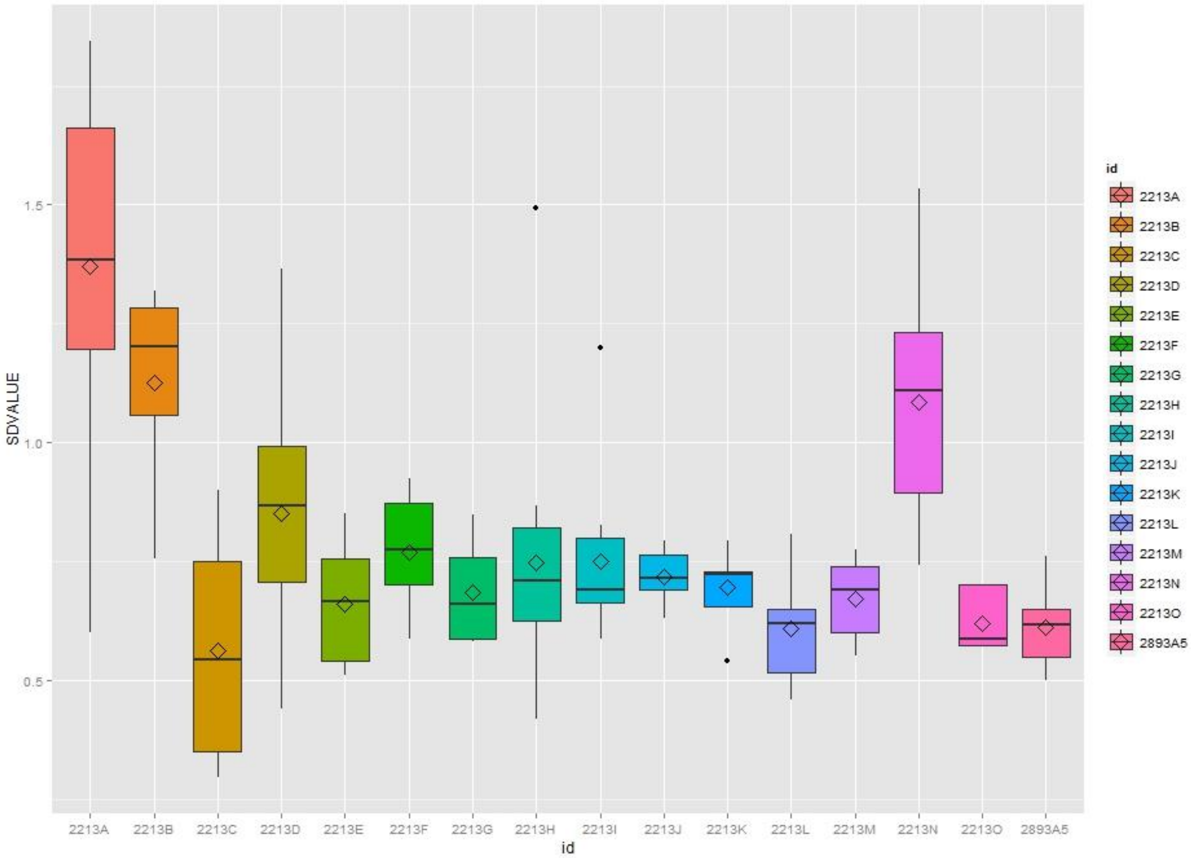


Figure 4-8. Secchi Disk measure, in meters, by WBID



For purposes of the analysis, Secchi Disk data was used to generate Trophic State Index values by WBID. Using Brezonik's (1984) classification:

- <50 "oligotrophic" –clear water, low nutrient levels
- 50 – 61 "mesotrophic" – relatively clear water, moderate nutrient levels
- 61 – 70 "eutrophic" – high nutrient levels, impaired clarity
- >70 "hypertrophic" or "dystrophic"

The TSI values for the river system range from 51.2 to 77.5, with the frequency distribution as shown in **Table 4-6**. Dummy coefficients were assigned for three categorical groups: TSI < 60, TSI < 70, and TSI > 70.

Table 4-5. Frequency Distribution of TSI by Parcel sales

TSI Value	**Parcel Sales Count**
<50	0
50 – 61	3,447
61 – 70	19,253
>70	1,201

Because the TSI calculations include a built-in log transformation, raw Sechhi Disk measures will be tested as a variable as well as TSI.

In an effort to eliminate any conflating effects (upon water quality) caused by river stage or flow/discharge, data was collected to reflect overall river level/depth conditions during the time period of interest. Stream flow data was available for only three of the 16 WBIDs for the period in question, as was depth data. Rainfall data was available for the entire time period from NLDAS and AHPS. AHPS Rainfall data is gage-corrected daily radar rainfall gridded data published by the NOAA Advanced Hydrologic Prediction Service. This set of data is provided in the form of daily point shapefiles for the entire continental USA and Puerto Rico. Within Florida, there are 12,656 points spaced approximately 3.5 to 4 km apart (point spacing decreases from north to south). Each of these points was converted into an AFSIRS daily time series. Geoprocessing occurred to compute the annual average of point data within each WBID. The available period of record for this data set is 2005 to 2013. For 2003 and 2004, satellite-based rainfall from the NASA North America Land Data Assimilation Systems program is available. Within Florida, there are 980 points spaced approximately 12 km apart; the period of record for this set of data is 1992-2012. For the NLDAS, the average annual rainfall for the nearest station was used.

For each WBID, statistical analysis was completed to discern housing sales that took place during periods of intense wet or dry weather. Years in which rainfall exceeded 1.5 standard deviations of mean annual rainfall for each WBID were identified as "wet" years and assigned a dummy, as were years in which rainfall fell below 2 standard deviations. **Table 4-7** shows the outcomes. Testing of a lag variable for delayed effects of intense rain or drought was incorporated into econometric modeling.

Table 4-6. Wet and Dry Years by WBID

WBID	Dry Year			Wet Year		
	Year	Min	StDev = 2	Year	Max	StDev = 1.5
2213A	2010	20.17	0	**2003**	**75.79**	**1**
2213B	2010	25.84	0	2004	58.26	0
2213C	2010	30.11	0	2004	58.26	0
2213D	2006	32.55	0	2005	69.14	0
2213E	2006	30.71	0	**2004**	**65.01**	**1**
2213F	2010	32.74	0	2004	61.25	0
2213G	2006	30.13	0	2004	61.25	0
2213H	2006	23.40	0	2004	60.67	0
2213I	2006	24.35	0	2004	59.74	0
2213J	**2006**	**24.15**	**1**	2004	59.74	0
2213K	**2006**	**22.87**	**1**	**2004**	**60.93**	**1**
2213L	**2006**	**25.33**	**1**	**2004**	**62.02**	**1**
2213M	2006	27.83	0	**2004**	**63.23**	**1**
2213N	**2006**	**26.87**	**1**	**2004**	**59.59**	**1**
2213O	**2006**	**24.38**	**1**	2004	58.74	0
2893A5	**2006**	**29.70**	**1**	2004	57.59	0

Harmful algal blooms (HABs), another indicator of declining water quality, have been observed on the Lower St. Johns River and reported publicly ("Algae bloom in St. Johns River causes health concerns," Inclan, Action News Jax, October 6, 2013; "Algal blooms reach toxic levels on the St. Johns," Patterson, St. Augustine News Record, October 11, 2013; "On the River: Swimming the St. Johns," Blankinship, Metro Jacksonville, October 20, 2013). Literature suggests that such publicity impacts homebuyers' decisions as well as realtor's decisions to steer potential buyers to or away from certain segments of the river. The FDEP included determinations of detrimental effects of algal concentrations in its TMDL report for the Lower St. Johns, and specific segments are recognized for purposes of tracking various water quality features. Identification of specific segments closest to a property may reflect some of the effects of local water quality.

Harmful Algal Blooms may be identified through routine water quality monitoring, or by ad hoc reports from the public or environmental professionals. A review of data provided by FFWC reveals the following pattern of HAB reports by WBID, over the 1-year period. We would expect the high frequency HAB segments to reflect lower property values, ceteris paribus. As HABs would be expected to interact with overall water quality, interaction effects will be tested in the econometric model.

Table 4-7. Reports of Harmful Algal Blooms

Count of WBID	2005	2010	2011	2012	2013	Total by WBID
2213B	3					3
2213C					1	1
2213D		1	1			2
2213E		26	101	143	74	344
2213F		5				5
2213G		17	239	277	111	644
2213H		51	4			55
2213I		57				57
2213K		4			12	16
2213M			10			10
2213N			34			34
2893A5		11				11
Annual Total	**3**	**172**	**389**	**420**	**198**	**1182**

Source: FWC

Hedonic Model - The model specifies the sales price as a function of the structural and spatial attributes of the property. The basic composite hedonic specification is as follows:

$$\lambda\nu(\pi) = \beta_0 + \beta_1 \Omega\Phi + \beta_2 (P\Sigma) + \beta_3\ \Omega\Phi * \lambda\nu(\Omega\Theta) + \beta_4\ \lambda\nu(\delta\iota\sigma\tau) + \beta_5\ \lambda\nu(\delta\iota\sigma\tau) * \lambda\nu(\Omega\Theta) + \beta_6\ \lambda\nu(\alpha\rho\varepsilon\alpha) * \lambda\nu(\Omega\Theta) + \beta_7 \Lambda o\omega + \beta_8 \Lambda o\omega * \lambda\nu\ (\Omega\Theta) + \beta_\sigma \Sigma + \beta_\Lambda \Lambda + \beta_T T + \varepsilon$$

where *WF* is a waterfront indicator, *RS* is a dummy representing the respective river segment closest to the subject property, *WQ* is a water quality indicators, *dist* is the distance to the River, *S* is a vector of structural attributes, *L* is a vector of location attributes, and *T* is a vector of time dummies; *p* represents price, for housing sales prices and □ represents a vector of parameters to be estimated.

A number of functional forms were tested including log transformation, following the literature. In the end, the model with dependent variable in natural log form, and other variables in normal and quadratic forms proved superior.

Summary statistics of the attributes are provided in **Tables 4-1** and **4-2** by County, prior to transforming selected variables to natural logarithms

Outcome - A full set of variables was estimated. Selected Hedonic Estimation Results are shown in **Table 4-9**. A full table of variables is included in the Appendix. The final dataset included 23,494 observations, with an R^2 is 0.63.

Table 4-8. Selected Hedonic Estimation Results

Variable Name	Variable Description	Coefficient	Standard Error	Mean
Dependent Variable				
LNSALEP	Natural log of sale price	--	--	12.11
Independent Variables				
RVFRNT	Indicator if home is riverfront	0.461 **	0.055	0.04
TRFRNT	Indicator if home is tributary-front	0.304 **	0.107	0.01
RVRFSD	Interaction of riverfront indicator and secchi disk	0.137 **	0.068	0.03
TRFSD	Interaction of tributary-front indicator and secchi disk	0.214	0.148	0.01
DRSD	Interaction of distance to St. Johns River and secchi disk	(0.000)	0.000	535.15
DISTRVTW	Distance to river in meters	(0.000) **	0.000	735.71
CLAY	Dummy variable for Clay County (Base is St. Johns County)	(0.160) **	0.020	0.12
DUVAL	Dummy variable for Duval County (Base is St. Johns County)	0.126 **	0.021	0.75
PUTNAM	Dummy variable for Putnam County (Base is St. Johns County)	0.086**	0.041	0.07
LVGAREA	Living area in square feet	0.001 **	0.000	2,097

LIVARSQ	Living area squared	(0.000) **	0.000	5,180,380
LNDAREA	Land area in square feet	0.000 **	0.000	14,012
LANARSQ	Land area squared	(0.000)*	0.000	337,034,060
AGE	Age of home	(0.008) **	0.001	39.72
AGESQ	Age of home squared	0.000 **	0.000	2,218
LNMHHI	Natural log of median household income	0.128 **	0.013	10.90
PERBLA	Percent of black population	(1.027) **	0.029	0.19
PERSEN	Percent of senior population	(1.580) **	0.086	0.15
DISTCBD	Distance to central business district in meters	(0.000) **	0.000	17,208
*** denotes significance at the 0.05 level; * at the 0.10 level*				

Housing Characteristics - Results produced housing patterns that fit expectations. Additional area in lot size and structure size adds about $14,000 per quarter acre and $150 per square foot, and is statistically significant. Age of housing stock was significant, with a loss of $1,475 for each additional year between the home's construction and sale date. Values between the counties reflect the greater demand for homes in the most urbanized county of the dataset, Duval, which garners a 12% premium over the mean, while Putnam generates a, 8% premium and Clay a 15% discount, relative to the base St. Johns County.

Demographic variables reflect a premium gradient for higher income census tracts, with 12% increase in sales value for every $1.00 in increased median household income; signs for increased percentages of minorities and senior citizens were as expected and statistically significant, but larger in magnitude than anticipated. This appears to be largely driven by three segments of the river, which average 38% minority and sale prices of close to $150,000, compared to the overall dataset's average 19% minority and sales price of $180,000.

Distance to the central business district (downtown Jacksonville) is negative and significant with a value of about $3,300 lost for each additional mile from downtown.

The effects of changes in the FEMA maps were carefully assessed, and produced no meaningful result; the vast majority of properties in the dataset require flood insurance, and the small amount of variation around this variable produced no explanatory value.

The tests of wet and dry years produced no explanatory value. The time dummies and Secchi Disk values presumably captured the variation that this attribute was attempting to quantify, namely, whether particularly high or low flows affected property values. Lagging the variables had no effect either.

Waterfront Amenity Values - The coefficients on Riverfront location, at 46.2% of sales price, and Tributary frontage, at 45.3% of sales price, are significant, which is consistent with literature. Premiums associated with river and tributary frontage generate substantial economic value to their respective counties. Of the total $5.2 billion in property sales evaluated, approximately $650 million in sales value related to waterfront homes, of which $300 million in value is attributable solely to river and tributary frontage, all else being equal. The effects of this premium on the entire community can be calculated by extrapolating the riverfront dummy coefficient to the entire set of riverfront properties in the four-county area. The coefficient is applied to the Just Value records provided by the Property Appraiser's office. In

Florida, Just Values are intended to reflect approximate market value. **Table 4-10** provides a breakdown of the premium associated with current waterfront properties that is attributable solely to the river or tributary frontage of these private properties.

There is a public benefit associated with this premium, in the form of the tax revenues derived directly from this premium. This benefit can be estimated by applying the county general tax revenue millage rates to the assessed values for the relevant properties. **Table 4-11** provides an estimate of the tax revenue benefit.

Table 4-9. Waterfront Premium Values by County, 2013

County	Total No. of Riverfront Properties	Riverfront Premium ($mil.)	Total No. of Tributary Frontage Properties	Tributary Frontage Premium ($mil.)
Clay	603	$102	112	$11
Duval	1,808	$573	715	$88
Putnam	1,130	$111	124	$5
St. Johns	903	$159	111	$14
Total	4,444	$944	1,062	$117

Table 4-10. Property Tax Revenue associated with riverfront and tributary frontage premiums

		20-year Tax Revenue*	
County	Millage	Riverfront Premium ($mil.)	Tributary Frontage Premium ($mil.)
Clay	11.4419	23.10	2.42
Duval	5.2349	59.35	9.07
Putnam	5.39	11.79	0.49
St. Johns	8.9	27.91	2.41
Total		122.15	14.39

*Assumes 3% annual inflation and 4% discounting over 20 years.

Proximity Amenity Values - Proximity effects measure the decline in property values associated with increased distance to the amenity, i.e. the further from the river, the less valuable the same property would be. In the case of this model, proximity effects were estimated for properties that were not riverfront, but were within 1500 meters of the river's edge. The coefficient of proximity effects, measuring distance to the river, is negative and significant. For each additional meter from the river, a loss in value of approximately $30 is shown. The premium drops quickly beyond the immediate riverfront, as reflected in Table 4-12, which shows the proximity effects at a variety of gradients. The value declines $29.72 for each meter further away (on an average of 735 meters distance, keeping in mind all parcels are within 1,500 meters by definition of the dataset).

Table 4-11. Proximity Values by County for Non-Riverfront Properties

100m from River's Edge

County	Count	Property Just Value	Approximate Decline in Property Value due to increased distance
Clay	151	24,662,079	-325,042
Duval	819	216,810,573	-2,759,892
Putnam	161	15,333,683	-193,970
St. Johns	209	53,260,020	-660,456
Total	**1,340**	**310,066,355**	**-3,950,236**

Table 4-12. Proximity Values by County for Non-Riverfront Properties (continued)

250m from River's Edge

County	Count	Property Just Value	Approximate Decline in Property Value due to increased distance
Clay	639	107,164,203	-3,126,379
Duval	3,793	934,481,516	-27,531,597
Putnam	575	57,228,885	-1,645,455
St. Johns	478	129,239,091	-3,656,072
Total	**5,485**	**1,228,113,695**	**-35,516,130**

500m from River's Edge

County	Count	Property Just Value	Approximate Decline in Property Value due to increased distance
Clay	1,183	181,575,556	-11,273,271
Duval	7,334	1,346,800,324	-83,233,754
Putnam	668	55,778,055	-3,324,163
St. Johns	642	151,169,498	-9,397,429
Total	**9,827**	**1,735,323,433**	**-106,569,707**

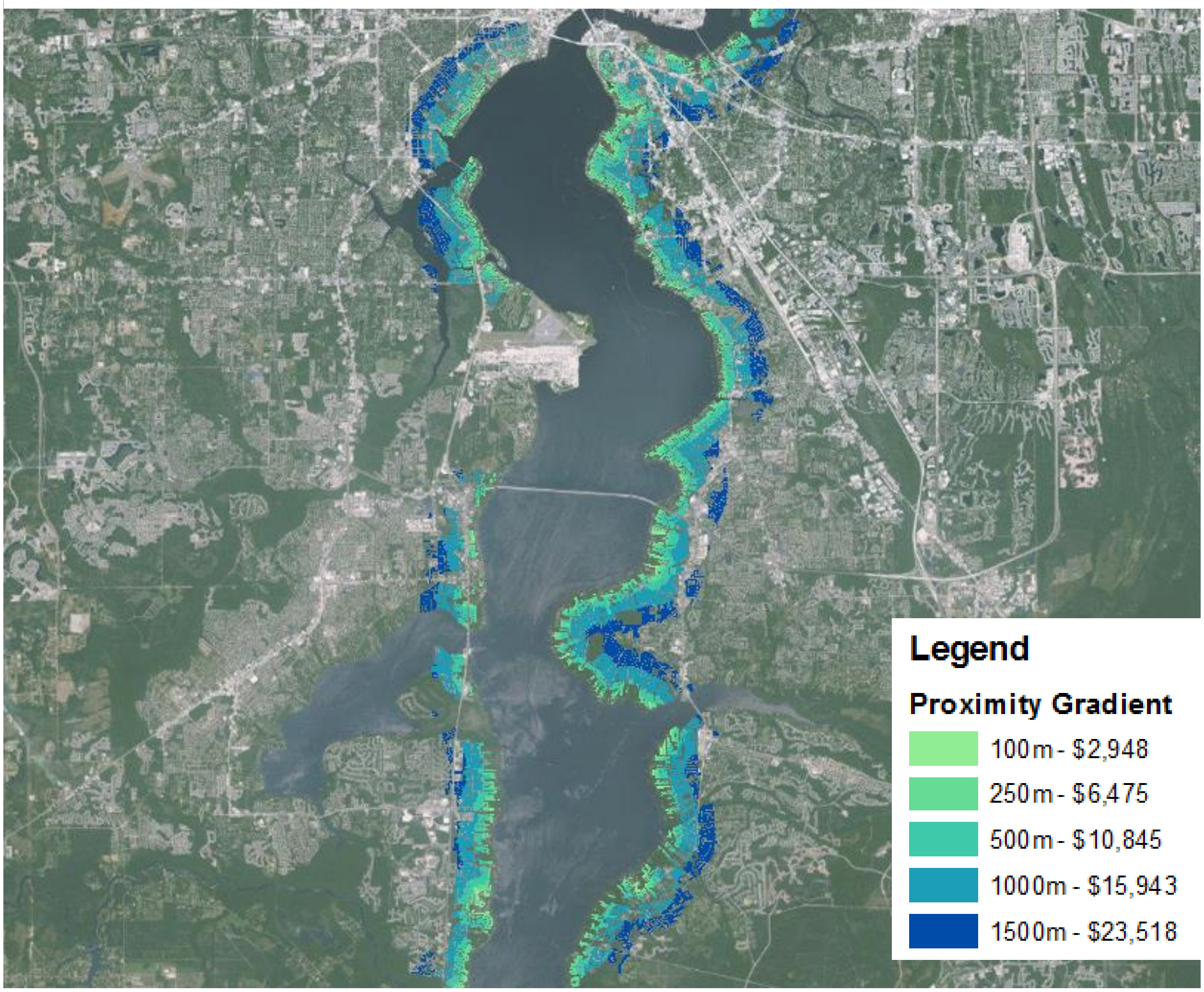
Table 4-13. Proximity Values by County for Non-Riverfront Properties (continued)

1000m from River's Edge

County	Count	Property Just Value	Approximate Decline in Property Value due to increased distance
Clay	2,445	334,093,239	-40,577,257
Duval	14,825	1,883,878,904	-230,783,577
Putnam	886	55,355,276	-6,797,334
St. Johns	1,119	247,095,050	-29,882,746
Total	**19,275**	**2,520,422,469**	**-307,296,389**

The map in **Figure 4-10** illustrates the proximity effect on property values for a selected stretch of the river. The legend shows the decline in property values that is reflected in each successive distance gradient from the river. The proximity effect ranges from a $2,948 decline in value for non-waterfront properties closest to the river, up to $23,500 decline in value for properties between 1,000 and 1,500 meters from the river.

Figure 4-9. Proximity Gradient Map



Water Quality Amenity Values - Variables for Harmful Algal Blooms and TSI measures did not produce meaningful results. As noted in the description of the variables, the researchers speculate that the inherent log transformation within TSI imputed distributions that were not compatible with the data. The Harmful Algal Bloom data appears to be collected in a manner that may not allow statistical treatment across all years and river segments consistently. As a result, "raw" Secchi disk measures were used, as they were available for all segments for all years and could be tied to home sales consistently.

The variation in Secchi disk measure at the time of sale is reflected in the selling price of riverfront homes. The contribution of value increases as the Secchi disk measure increases, following a gradient that reflects the improved value represented by the highest readings – 1.8 meters. **Table 4-13** shows that for riverfront properties with Secchi Disk measures greater than 1.5 (1.86 was the maximum in the dataset), up to 24% of the premium associated with river frontage could be attributable to the clearer water conditions. For riverfront properties that sold at times when the water was not as clear by Secchi disk measures, as in the 32 sales at 0.5m or 748 sales at less than 1.0 meter, the premium drops to 6-9%.

Table 4-14. Implicit Price for Secchi Disk Measure Improvement reflected in dataset (Riverfront)

Secchi Disk Measure	< .5	.5 - 1	1-1.5	1.5+
Number of observations	32	748	152	9
Premium associated with SD measure	23,626	56,210	90,857	107,572
Average Sales Price ($)	420,933	605,225	555,673	452,895
Percentage of Premium	6%	9%	16%	24%

For properties with tributary frontage, the result is more pronounced. Properties at the low end of Secchi disk measures experienced a greater share of their frontage premium attributable to water quality, as did properties at the highest end of water quality measure. The overall sales price for properties with river frontage versus tributary frontage in the dataset was similar, at $589,000 versus $577,000. **Table 4-14** provides estimates.

Table 4-15. Implicit Price for Secchi Disk Measure Improvement reflected in dataset (Tributary-front)

Secchi Disk Measure	< .5	.5 - 1	1-1.5	1.5+
Number of observations	13	277	18	2
Premium associated with SD measure	25,843	87,575	93,492	34,838
Average Sales Price ($)	307,070	608,191	361,884	95,750
Percentage of Premium	8%	14%	26%	36%

For properties without frontage, the interaction term for proximity to the river and effect of water quality was neither statistically significant, nor nominally significant.

An implication of the value for improved water clarity can be found in the difference between the high and low Secchi disk measures. The implicit price for improved water clarity across all riverfront properties can be estimated by extrapolating the effects of improved water clarity to all riverfront properties in the four counties. If all segments improved water clarity to 1.5, ceteris paribus, the hypothetical increase in property value is reflected in **Table 4-15**. The associated property tax revenues were also calculated.

Table 4-16. Implicit Price for Improved Water Clarity across all Riverfront properties, by county

County	**Count of Riverfront Properties**	**Riverfront Premium with Current Water Quality ($mil.)**	**Hypothetical Riverfront Premium with Improved Water Quality ($mil.)**	**Difference ($mil.)**	**Hypothetical 20-year Tax Revenue After Improvements to Water Quality ($mil.)**
Clay	603	24.3	64.8	40.5	9.2
Duval	1,808	145.5	351.5	206.0	21.3
Putnam	1,130	29.1	68.2	39.2	4.2
St. Johns	903	36.2	96.6	60.4	10.6
Total	4,444	235.1	581.1	346.1	45.3

Literature Cited

Carlson, Robert E., 1977. "A Trophic State Index for Lakes." *Limnology and Oceanography* 22(2), 361-69. *JSTOR*.

FDEP, 1996. 1996 Water Quality Assessment for the State of Florida, Section 305(b) Main Report, Chapter 2, pp. 75-105. Florida Department of Environmental Protection. Tallahassee, FL.

FDOR, 2014. *Parcel Data for Clay, Duval, Putnam and St. Johns Counties.* Property Tax Oversight Program. Office of Tax Research. Florida Department of Revenue. Tallahassee, FL.

FEMA, 2014. *National Flood Hazard Layer Data*. Flood Map Service Center. Federal Emergency Management Agency. Washington, DC.

FGDL. 2014. *Parcel Data for Clay, Duval, Putnam and St. Johns Counties from 2002 to 2010*. GeoPlan Center. University of Florida. Gainesville, FL.

FGDL, 2014. *Flood Insurance Rate Map Data for St. Johns County 2004 Revisions*. GeoPlan Center. University of Florida. Gainesville, FL.

FGDL, 1999. FEMA Flood Insurance Rate Maps 1996. FDGL Metadata Explorer. Florida Geographic Data Library. GeoPlan Center. University of Florida. Gainesville, FL.

Florida Dept. of Environmental Protection, "FINAL TMDL Report: Lower St. Johns Basin, Lower St. Johns River, Nutrients." (August 2003)

FWC, 2014. *Harmful Algal Bloom Data*. Fish and Wildlife Research Institute. Florida Fish and Wildlife Conservation Commission. St. Petersburg, FL.

Huber W.C., P.L. Brezonick, J.P. Heaney, R.E. Dickinson, S.D. Preston, D.S. Dwornik, and M.A. DeMaio, 1982. A Classification of Florida Lakes. University of Florida Water Resources Research Center, Publication No. 72, Chapter 3, pp. 1-74.

Huber W.C., P.L. Brezonik, J.P. Heaney, R.E. Dickinson, S.D. Preston, D.S. Dwornik, and M.A. DeMaio, 1982. A Classification of Florida Lakes. University of Florida Water Resources Research Center.

Kratzer, Charles R., and Patrick L. Brezonik, 1981. "A Carlson-Type Trophic State Index for Nitrogen in Florida Lakes." *Journal of the American Water Resources Association* 17(4), 713-15.

Lower St. Johns River TMDL Executive Committee, "BASIN MANAGEMENT ACTION PLAN for the Implementation of Total Maximum Daily Loads for Nutrients Adopted by the Florida Department of Environmental Protection for the Lower St. Johns River Basin Main Stem. (October 2008)

NASA, 2014. *Rainfall Data 2003 to 2004*. NLDAS. Retrieved from Hydrology Data and Information Services Center. Goddard Earth Sciences Data and Information Services Center. http://ldas.gsfc.nasa.gov/nldas/.

NOAA, 2014. *Rainfall Data 2005 to 2013*. AHPS. Retrieved from Advanced Hydrologic Prediction Service. Office of Hydrologic Development. National Oceanic and Atmospheric Administration. Silver Spring, MD.

Palmquist, Raymond B. 2005 “Property Value Models”. In *Handbook of Environmental Economics*, Vol.2, ed. Karl-Goran Mailer and Jeffrey Vincent, 763-819. Amsterdam: Elsevier: North Holland.

R.E. Carlson. A Trophic State Index for Lakes. Limnology and Oceanography, Vol. 22, No. 2 (Mar., 1977), pp. 361-369

Seidel, Valerie. 2013. “Development of Parcel-level Urban Water Use Estimates for the USGS Peninsular Florida Model for Groundwater Recharge and Water Conservation Potential”. *Special Publication 2013-SP5*. St. Johns River Water Management District.

SJRWMD, 2014. Water Quality Data 01/01/2003 to 01/01/2014. Retrieved from St. Johns River Water Management District, Environmental Data Retrieval Tool.

USEPA, 2014. *Water Quality Data 01/01/2002 to 01/01/2014*. Retrieved from STORET Data Warehouse. http://www.epa.gov/storet/about.html. United States of America Environmental Protection Agency. Washington, D.C.

USGS, 2014. *Water Quality Data 01/01/2002 to 01/01/2014*. Retrieved from National Water Quality Monitoring Council. Water Quality Portal. http://www.waterqualitydata.us/. United States Geological Survey. Washington, D.C.

Walsh, Patrick, Milon, J. Walter, Scrogin, David. 2011. “The Spatial Extent of Water Quality Benefits in Urban Housing Markets*.” Land Economics 87(4) 628-644.*

Winkler, Steve, and Asia Ceric. "Status and Trends in Water Quality in Northeast Florida." St. Johns River Water Management District. Palatka, FL.

Appendix 4-A. Estimates of Hedonic Model

Variable Name	Variable Description	Coefficient	Standard Error	Mean
Dependent Variable				
LNSALEP	Natural log of sale price	--	--	12.1069
Independent Variables				
Constant	Statistically computed constant value	19.965 **	0.595	--
CLAY	Dummy variable for Clay County (Base is St. Johns)	(0.1597) **	0.020	0.12
DUVAL	Dummy variable for Duval County (Base is St. Johns)	0.1258 **	0.021	0.75
PUTNAM	Dummy variable for Putnam County (Base is St. Johns)	0.0848 **	0.041	0.07
LAT	Y-corrdinate (latitude) in kilometers	(0.0041) **	0.001	691.96
LONG	X-corrdinate (longitude) in kilometers	(0.0119) **	0.001	627.44
LVGAREA	Living area in square feet	0.0008 **	0.000	2,097
LIVARSQ	Living area squared	(0.0000) **	0.000	5,180,380
LNDAREA	Land area in square feet	0.0000 **	0.000	14,012
LANARSQ	Land area squared	(0.0000) *	0.000	337,034,060
AGE	Age of home	(0.0081) **	0.001	39.72
AGESQ	Age of home squared	0.0001 **	0.000	2,218
YEARTHR	Indicator if home was sold in 2003 (Base is 2013)	0.2826 **	0.016	0.16
YEARFOU	Indicator if home was sold in 2004 (Base is 2013)	0.3743 **	0.015	0.17
YEARFIV	Indicator if home was sold in 2005 (Base is 2013)	0.5037 **	0.016	0.18
YEARSIX	Indicator if home was sold in 2006 (Base is 2013)	0.6085 **	0.016	0.14
YEARSEV	Indicator if home was sold in 2007 (Base is 2013)	0.5093 **	0.017	0.10
YEAREIG	Indicator if home was sold in 2008 (Base is 2013)	0.3644 **	0.021	0.04
YEARNIN	Indicator if home was sold in 2009 (Base is 2013)	0.1498 **	0.022	0.03
YEARTEN	Indicator if home was sold in 2010 (Base is 2013)	0.0961 **	0.021	0.04
YEARELE	Indicator if home was sold in 2011 (Base is 2013)	0.0166	0.022	0.03

Variable Name	Variable Description	Coefficient	Standard Error	Mean
YEARTWE	Indicator if home was sold in 2012 (Base is 2013)	(0.0146)	0.021	0.04
RVFRNT	Indicator if home is riverfront	0.4612 **	0.068	0.04
TRFRNT	Indicator if home is tributary-front	0.3044 **	0.107	0.01
RVRFSD	Interaction of riverfront indicator and secchi disk	0.1371 **	0.068	0.03
TRFSD	Interaction of tributary-front indicator and secchi disk	0.2140	0.148	0.01
DRSD	Interaction of distance to St. Johns River and secchi disk	(0.0000)	0.000	535.15
LNMHHI	Natural log of median household income	0.1279 **	0.013	10.90
PERBLA	Percent of black population	(1.0273) **	0.029	0.19
PERSEN	Percent of senior population	(1.5798) **	0.086	0.15
DISTRVTW	Distance to river in meters	(0.0002) **	0.000	735.71
DISTCBD	Distance to central business district in meters	(0.0000) **	0.000	17,208
*** denotes significance at the 0.05 level; * at the 0.10 level*				

Chapter 5

Value of St. Johns River Surface Water and Groundwater

by
Christopher J. Brown

Associate Professor,
University of North Florida
Jacksonville, FL 32224
christopher.j.brown@unf.edu

Abstract

A water-use valuation was completed for the major surface water and groundwater sources and uses of the SJR watershed. The evaluation used the "benefit-transfer" approach to value the annual surface and groundwater use in the watershed. Water use data was compiled from the United States Geological Survey (USGS) and the SJR Water Management District (SJRWMD) for 2009 and 2010. The valuation data was collected from various literature sources as well as the Jacksonville Electric Authority and the Orlando Utility Commission. Valuation estimates were normalized to the year 2010 using consumer price index data multipliers available from the Bureau of Labor Statistics and other similar entities. The water use data was sub-divided into discrete categories including public supply, commercial and industrial supply, agricultural irrigation supply, recreational water supply, and power generation. Overall the annual value of surface water used in the SJR Basin (in 2010 dollars) was about $70,000,000, while the value of groundwater used was greater than $420,000,000.

Introduction

An important and direct economic value of the St. Johns River is the actual water supply function the system provides for potable purposes, agricultural irrigation, recreational irrigation (e.g. golf courses), and thermoelectric power cooling. Some of these uses are considered "consumptive" uses where water is permanently removed from the system and which is subject to permitting requirements of the SJRWMD. Thermoelectric power cooling may include some consumptive uses and "once-through" uses where a large majority of the water is returned to the river system albeit with higher temperatures in most cases. The economic value of these water use categories can be estimated using a number of different methodologies in order to determine a more representative value of the resource.

Ecosystems are commonly described as the interaction between living organisms and the non-living physical environment. Ecosystems provide many goods and service that are often overlooked (See Chapter 1 in the report). For example, ecosystems provide flood reduction, drinking water, water filtration, and storm protection. Ecosystem services are defined as the conditions and processes through which natural ecosystems support humanity as well as foods and services that contribute both directly and indirectly to human welfare (Feug et al, 2011). However, describing the value of an ecosystem are difficult to determine. Products physically obtained from an ecosystem, e.g. ecosystem goods, are much easier to quantify economically as opposed to an ecosystem service, such as recreational benefits (Barbier, 2007). Many uncertainties exist due to the heterogeneity and non-linearity of ecosystems. However, it is necessary to quantify the benefits from an ecosystem because they are limited (Feug et al, 2011). If the value of an ecosystem remains undervalued, the benefits and services will decline and degrade in value. Therefore, it is vital to quantify and protect the most important benefit from any ecosystem, which in the case of a river is water.

Water is critical to human life, recreational activities, wildlife, and ecological systems. Humans use water both consumptively and non-consumptively. It is less difficult to quantify the value of consumptive water, i.e. water used for drinking, agriculture, recreational irrigation. It is more difficult to quantify non-consumptive water use, such as water used for cooling in thermoelectric power plants. With human populations increasing, demands for water for both consumptive and non-consumptive water will increase. Freshwater is becoming scarce as population and demand increase and will ultimately exceed supply (Frederick et al., 1996).

This issue of population increase can be directly applied to the St. Johns River Basin. Based on the best available data, the St. Johns River Water Management District (SJRWMD) has reported an increase of over 50,000 people from 2010 to 2012 (SJRWMD 2010-2012). This may not seem noteworthy, but the increasing population leads to an increase in direct water use for humans. In the St. Johns River Basin, demand for surface water continues to rise, making it critical to place an economic value on water.

Determining the economic value for groundwater can be difficult. Many different methods exist to aid with the process. Each approach has certain limitations, but all assist in understanding the economic value of a good or service. For the evaluation of surface water and groundwater, the benefit transfer method was utilized. The benefit transfer method values ecosystem benefits by utilizing data from studies completed in one location and transferring that information to a different location (King & Mazzotta, 2000). In order to complete a benefit transfer approach, existing studies must be obtained and utilized to transfer the values to different locations. The benefit transfer method contains a degree of uncertainty in changing information from one location to another and the end valuation is only as accurate as the initial studies. However, the benefit transfer method is the least costly of the five approaches, and can be done more quickly than the rest; making it the best choice for this study.

General Study Area

Florida's principle commercial and recreational waterway is the 310 mile long St. Johns River (SJRWMD, 2014). The St. Johns River Basin consists of three sub-basins (upper, middle, and lower) and two other smaller watersheds that are managed by the SJRWMD (SJRWMD, 2014). The borders defined by the SJRWMD for the St. Johns River Basin along with the sub-basins are shown in Figure 2-1.

The 12,300 square mile SJRWMD includes 18 counties: Alachua, Baker, Bradford, Brevard, Clay, Duval, Flagler, Indian River, Lake, Marion, Nassau, Okeechobee, Orange, Osceola, Putnam, St. Johns, Seminole, and Volusia (SJRWMD, 2010). Even though Baker and Nassau counties are included in the SJRWMD, they do not encompass any significant portion of the St. Johns River Basin. Levy, Polk, and St. Lucie counties are not in the SJRWMD, however, a small portion of the St. Johns River Basin flows through these counties. Using GIS analysis, the percentage of the county covered by the basin is shown in Table 5-1. Table 5-1 denotes those basins included in the study predominately and those that are less important in nature including those covering only a small percentage of the St. Johns River watershed boundary. Those counties denoted in "red font" are completely contained within the basin boundary while those in "green font" and "blue font" include portions of the county in other watersheds.

County	% of Basin Covering County (From GIS Analysis)
Alachua	44%
Bradford	3%
Brevard	55%
Clay	98%
Duval	82%
Flagler	100%
Indian River	58%
Lake	82%
Levy	16%
Marion	58%
Okeechobee	10%
Orange	67%
Osceola	37%
Polk	2%
Putnam	100%
St. Johns	100%
St. Lucie	1%
Seminole	100%
Volusia	92%
LEGEND:	
xxxxxx	Contained completely in SJR Basin Boundary
xxxxxx	Contained predominately in SJR Basin Boundary
xxxxxx	Contained predominately outside SJR Basin Boundary

Table 5-1. Percentage of County Encompassed in St. Johns River Basin

Urbanization plays a major role in monetary water value. More urbanization leads to an increase in water use, and can also degrade the value of water (Everard and Moggridge, 2011). The most urbanized of these counties are Orange, Duval, Polk, Brevard, and Volusia, respectively. Most of these counties are completely in the St. Johns River Basin. However, only 2% of Polk County lies in the basin. Therefore, Polk will not contribute as much water use in this study as the other urbanized counties completely encompassed in the St. Johns River Basin. For determining monetary value, the total amount of water withdrawn in each county needs to be adjusted based on the following percentages. For example, only 44% of Alachua County lies in the St. Johns River Basin, therefore only 44% of the total water withdrawn in that county will be applied in calculations for this study.

From a water supply perspective, a few counties contributed a tiny fraction of the total water used in a given year, so they were excluded including Baker County. The United States Geological Survey (USGS) updates water use for each state every five years. The 2010 data collated by the USGS was used for this study (Marella, R., USGS, 2014). The values noted and estimated by the USGS were also checked against similar data published by the SJRWMD itself. The USGS report organizes water use in several categories and by Florida county. This report adopted the same organizational structure to sub-divide water use categories. The USGS also distinguishes between groundwater and surface water sources. This report also evaluates surface water sources although it is recognized that groundwater is the most important source of water supply in the State of Florida. A number of surface water use categories are included in this study including:

- Public water supply withdrawals;
- Industrial and commercial self-supply;
- Agricultural irrigation self-supply;
- Recreational irrigation self-supply; and,
- Thermoelectric power generation.

Public self-supply is another typical category for water supply studies, but no surface water withdrawals were noted for the St. Johns River basin for this category in 2010.

Water Budget, Use Category, and Estimated Value

Water Uses - The main five categories for water use evaluated in this study include the following: (1) public supply, (2) commercial and industrial use, (3) agricultural irrigation, (4) recreational use (e.g. golf course irrigation mostly), and (5) power generation. The water use data presented comes directly from USGS and SJRWMD best available data for 2010.

Public Supply - Public supply water refers to water that has been withdrawn, treated, and delivered to both publically and privately owned water supply utilities (SJRWMD, 2010). This water is initially withdrawn from river, lakes, or reservoirs, aquifers, and serves both residential and nonresidential customers. Approximately 86% of the United States relies on public supply for their household water (USGS, 2005). Florida has one of the largest populations of all the states; Therefore, Florida withdraws vast quantities of water each year (USGS, 2005).

Data by County: In 2010, public supply served more than 5 million people an estimated 736 million gallons per day (mgd). Table 5-2 below shows the USGS data for public supply water.

County	Groundwater Withdraw (MGD)	Surface Water Withdraw (MGD)	Total Water Use (MGD)	Adjusted GW % in basin	Adjusted SW % in basin	Adjusted Total % in basin
Alachua	26.31	0.00	26.31	11.58	0.00	11.58
Bradford	1.62	0.00	1.62	0.05	0.00	0.05
Brevard	16.32	14.34	54.12	8.98	7.89	16.86
Clay	11.13	0.00	11.13	10.91	0.00	10.91
Duval	122.14	0.00	122.14	100.15	0.00	100.15
Flagler	8.70	0.00	8.70	8.70	0.00	8.70
Indian River	14.78	0.00	14.78	8.57	0.00	8.57
Lake	40.55	0.00	40.55	33.25	0.00	33.25
Levy	1.48	0.00	1.48	0.24	0.00	0.24
Marion	29.88	0.00	29.88	17.33	0.00	17.33
Okeechobee	0.65	1.51	2.16	0.07	0.15	0.22
Orange	192.86	0.00	169.40	129.22	0.00	129.22
Osceola	34.92	0.00	34.92	12.92	0.00	12.92
Polk	67.35	0.04	67.37	1.35	0.00	1.35
Putnam	2.56	0.00	2.56	2.56	0.00	2.56
St. Lucie	27.50	0.00	27.50	0.28	0.00	0.28
St. Johns	13.49	0.00	13.49	13.49	0.00	13.49
Seminole	54.97	0.00	54.97	54.97	0.00	54.97
Volusia	52.47	0.00	52.47	48.27	0.00	48.27
Summations =	***719.68***	***15.89***	***735.55***	***462.87***	***8.04***	***470.91***

Table 5-2. Public Supply Water Use Data

Table 5-2 presents the total amount of freshwater withdrawn from each county as 736 mgd. However, not all of these counties lie completely in the St. Johns River Basin. Therefore, the amount of water withdrawn from each county must be adjusted based on how much of that county lies within the basin. These percentages presented earlier in Table 5-1 were applied to the data. The counties with the largest population, Duval and Orange, report the largest amount of public supply consumption. Public supply has the largest groundwater usage of all the five water categories. Groundwater withdrawn accounted for 463 mgd while surface water was 8 mgd, only 1% of the freshwater withdrawn. This translates to 171,915 million gallons of freshwater annually, 2920 million being surface water. The only counties that withdrew surface water were Brevard, Okeechobee, and Polk. Surface water withdrawn in Brevard, Okeechobee, and Polk constitutes 46.8%, 69.9%, and 0.05%, respectively of the total amount of water withdrawn.

Economic Evaluation - The Jacksonville Electric Authority (JEA) provides water supply to approximately 313,000 customers (JEA, 2012). JEA is a community owned utility that charges customers \$0.93 per thousand gallons for less than 6000 gallons and \$2.60/1,000 gallons for water supply greater than 6000 gallons (JEA, 2012). According to the Bureau of Labor Statistics, \$0.93 and \$2.60 in 2012 dollars coverts to \$0.88 and \$2.47 in 2010 dollars using changes in the Consumer Price Index. Orlando Utility Commission (OUC), similar to JEA, provides electric and water services to Orlando, St. Cloud, Orange County, and Osceola County. For their water services, the 2010 unit cost is \$0.64/1,000 gallons for the first 3,000 gallons, \$1.09/1,000 gallons for the next 4,000 gallons, \$1.62/1,000 gallons for the next 12,000 gallons, \$2.88/1,000 gallons for the next 11,000 gallons, and \$5.39/1,000 gallons for over 30,000 gallons (OUC, 2009). Averaging the 2010 JEA and OUC cost and applying it to the groundwater and surface water used in each county yields the results exhibited in Table 5-3.

County	Adjusted GW	Adjusted SW	Adjusted Total	Annual Cost	Annual Cost	Annual Cost
	% in basin	% in basin	% in basin	GW($)	SW ($)	Total ($)
Alachua	11.58	0.00	11.58	9042326.04	0.00	9042326.04
Bradford	0.05	0.00	0.05	37961.46	0.00	37961.46
Brevard	8.98	7.89	16.86	7011153.60	6160535.70	13171689.30
Clay	10.91	0.00	10.91	8519770.14	0.00	8519770.14
Duval	100.15	0.00	100.15	78230914.28	0.00	78230914.28
Flagler	8.70	0.00	8.70	6795570.00	0.00	6795570.00
Indian River	8.57	0.00	8.57	6695901.64	0.00	6695901.64
Lake	33.25	0.00	33.25	25972356.10	0.00	25972356.10
Levy	0.24	0.00	0.24	184964.48	0.00	184964.48
Marion	17.33	0.00	17.33	13536775.44	0.00	13536775.44
Okeechobee	0.07	0.15	0.22	50771.50	117946.10	168717.60
Orange	129.22	0.00	129.22	100930773.82	0.00	100930773.82
Osceola	12.92	0.00	12.92	10092124.44	0.00	10092124.44
Polk	1.35	0.00	1.35	1052141.70	624.88	1052766.58
Putnam	2.56	0.00	2.56	1999616.00	0.00	1999616.00
St. Lucie	0.28	0.00	0.28	214802.50	0.00	214802.50
St. Johns	13.49	0.00	13.49	10537039.00	0.00	10537039.00
Seminole	54.97	0.00	54.97	42937067.00	0.00	42937067.00
Volusia	48.27	0.00	48.27	37705571.64	0.00	37705571.64
Summations	***462.87***	***8.04***	***470.91***	361547600.78	6279106.68	367826707.46

Table 5-3. Annual Cost of Public Supply Water

If JEA and OUC costs are representative of all water users in the watershed, then customers within the St. Johns River Basin spent approximately $367 million annually on public supply water. Most of this comes from groundwater withdrawals. An estimated $6.28 million is spent annually on surface water from the St. Johns River Basin for public supply. It is apparent that Duval and Orange County use the most groundwater sources while Brevard County uses the most surface water sources. These two counties are highly urbanized. Each day, 463 mgd of groundwater are withdrawn for public supply use. As a consequence, the St. Johns River Basin spends $361 million on groundwater for public supply use. Conversely, 8 mgd of surface water is withdrawn, resulting in only a $6.28 million cost annually. For the purposes of this study, the mean cost of these annual withdrawals are equated with their value.

Commercial and Industrial Use - Commercial and industrial water use refers to water used for commercial, industrial, or institutional purposes that are not provided by public supply (SJRWMD, 2011). Government facilities, businesses, schools, hospitals, and other industrial uses fall into this category. Mining, for example, uses water to extract minerals that are in forms of solids (USGS, 2005). This does not include water used in thermoelectric power plants.

Data by County: The majority of the freshwater used for commercial and industrial purposes comes from groundwater. Although, there are few county exceptions where surface water is used more often than groundwater. The data for freshwater use for commercial and industrial purposes is shown below in Table 5-4.

County	Groundwater	Surface Water	Total Water	Adjusted GW	Adjusted SW	Adjusted Total
	Fresh (mgd)	Fresh (mgd)	Fresh (mgd)	% Basin	% Basin	% Basin
Alachua	0.43	0.00	0.43	0.19	0.00	0.19
Bradford	1.30	0.00	1.30	0.04	0.00	0.04
Brevard	5.09	0.91	6.00	2.80	0.50	3.30
Clay	0.25	0.10	0.35	0.25	0.10	0.34
Duval	16.03	0.55	16.58	13.14	0.45	13.60
Flagler	0.00	0.00	0.00	0.00	0.00	0.00
Indian River	0.00	0.00	0.00	0.00	0.00	0.00
Lake	4.16	1.23	5.39	3.41	1.01	4.42
Levy	0.15	0.00	0.15	0.02	0.00	0.02
Marion	6.52	0.10	6.62	3.78	0.06	3.84
Okeechobee	0.33	0.00	0.33	0.03	0.00	0.03
Orange	19.70	0.01	19.71	13.20	0.01	13.21
Osceola	0.37	0.00	0.37	0.14	0.00	0.14
Polk	42.83	0.20	43.03	0.86	0.00	0.86
Putnam	2.71	22.22	24.93	2.71	22.22	24.93
St. Johns	0.30	0.74	1.04	0.30	0.74	1.04
St. Lucie	0.08	0.00	0.08	0.00	0.00	0.00
Seminole	0.00	0.00	0.00	0.00	0.00	0.00
Volusia	1.27	0.28	1.55	1.17	0.26	1.43
Summations =	**101.52**	**26.34**	**127.86**	**42.04**	**25.34**	**67.38**

Table 5-4. Freshwater Use for Commercial and Industrial Supply

The total amount of freshwater withdrawn was 67.38 mgd. Only 25.34 mgd of the water withdrawn came from surface water sources. Therefore, surface water accounted for approximately 37% of the water used in this category. The counties with the largest amount of commercial and industrial supply were Duval, Putnam, and Orange. Putnam, and Duval were high because of the pulp and paper industries located in these counties (SJRWMD, 2010).

Economic Evaluation - Valuing water for commercial and industrial supply is more difficult than valuing water for public supply. A great deal of uncertainty exists depending on location, climate, and willingness to pay. In a report by Frederick et al. (1996) the minimum, median, average, and maximum cost per ac-ft was given as $28, $132, $282, and $802 respectively. Converting to gallons in 2010 dollars generates new costs per 1000 gallons: minimum of $0.12, maximum of $3.46, median of $0.57, and an average of $1.21. Applying these monetary values to the groundwater use and surface water use data yields the results shown in Table 5-5 and Table 5-6 respectively.

County	AdjustedGW	Cost Min	Cost Max	Cost Median	Cost Average
	% Basin (mgd)	($/ gal/ yr)	($/ gal/ yr)	($/ gal/ yr)	($/ gal/ yr)
Alachua	0.19	8286.96	238940.68	39363.06	83560.18
Bradford	0.04	1708.20	49253.10	8113.95	17224.35
Brevard	2.80	122618.10	3535488.55	582435.98	1236399.18
Clay	0.25	10731.00	309410.50	50972.25	108204.25
Duval	13.14	575733.48	16600315.34	2734734.03	5805312.59
Flagler	0.00	0.00	0.00	0.00	0.00
Indian River	0.00	0.00	0.00	0.00	0.00
Lake	3.41	149410.56	4308004.48	709700.16	1506556.48
Levy	0.02	1051.20	30309.60	4993.20	10599.60
Marion	3.78	165634.08	4775782.64	786761.88	1670143.64
Okeechobee	0.03	1445.40	41675.70	6865.65	14574.45
Orange	13.20	578116.20	16669017.10	2746051.95	5829338.35
Osceola	0.14	5996.22	172891.01	28482.05	60461.89
Polk	0.86	37519.08	1081800.14	178215.63	378317.39
Putnam	2.71	118698.00	3422459.00	563815.50	1196871.50
St. Johns	0.30	13140.00	378870.00	62415.00	132495.00
St. Lucie	0.00	35.04	1010.32	166.44	353.32
Seminole	0.00	0.00	0.00	0.00	0.00
Volusia	1.17	51175.92	1475572.36	243085.62	516023.86
Summations =	**42.04**	**1841299.44**	**53090800.52**	**8746172.34**	**18566436.02**

Table 5-5. Annual Cost of Commercial and Industrial Water-Groundwater Sources

County	Adjusted SW	Cost Min	Cost Max	Cost Median	Cost Average
	% Basin (mgd)	($/ gal/ yr)	($/ gal/yr)	($/ gal/yr)	($/ gal/yr)
Alachua	0.00	0.00	0.00	0.00	0.00
Bradford	0.00	0.00	0.00	0.00	0.00
Brevard	0.50	21921.90	632081.45	104129.03	221045.83
Clay	0.10	4292.40	123764.20	20388.90	43281.70
Duval	0.45	19753.80	569567.90	93830.55	199184.15
Flagler	0.00	0.00	0.00	0.00	0.00
Indian River	0.00	0.00	0.00	0.00	0.00
Lake	1.01	44176.68	1273760.94	209839.23	445448.19
Levy	0.00	0.00	0.00	0.00	0.00
Marion	0.06	2540.40	73248.20	12066.90	25615.70
Okeechobee	0.00	0.00	0.00	0.00	0.00
Orange	0.01	293.46	8461.43	1393.94	2959.06
Osceola	0.00	0.00	0.00	0.00	0.00
Polk	0.00	175.20	5051.60	832.20	1766.60
Putnam	22.22	973236.00	28061638.00	4622871.00	9813463.00
St. Johns	0.74	32412.00	934546.00	153957.00	326821.00
St. Lucie	0.00	0.00	0.00	0.00	0.00
Seminole	0.00	0.00	0.00	0.00	0.00
Volusia	0.26	11282.88	325323.04	53593.68	113769.04
Summations =	**25.34**	**1110084.72**	**32007442.76**	**5272902.42**	**11193354.26**

Table 5-6. Annual Cost Commercial and Industrial Water-Surface Water Sources

In Frederick et al. (1996), seven data points were used to determine the minimum, maximum, median, and average value. Based on the best available data, the value for surface water for commercial and industrial supply can range from $1 million to $53 million dollars a year. The original value for the minimum and maximum are over $2 per 1000 gallons apart; therefore, neither the minimum nor the maximum are the best choice for a further analysis. The median of $0.57/1000 gallons appears quite low compared to the maximum $3.46. Therefore, the results from the average value present the best analysis as compared to the minimum, maximum, and median. Industrial and commercial customers within the St. Johns River Basin spend a total of $29,759,790 annually for water supply. Of this, $18.5 million can be attributed to groundwater, while $11.1 million is surface water sources. These results also come with some uncertainty. The minimum and maximum values differ quite drastically which can account for some uncertainty. Perhaps having more than seven data points would allow for a better estimation in terms of cost for water per 1000 gallons. Even with the slight uncertainty, it is important that these uncertainties are not overlooked because the annual cost is quite sizeable.

Agricultural Uses/Irrigation - Agricultural self-supply refers to freshwater withdrawn (groundwater or surface water) and used for crop irrigation (SJRWMD, 2012). Other than public supply, agricultural irrigation withdraws the largest amount of freshwater from both groundwater and surface water sources, using approximately 30% of total water withdrawn.

Data by County - Agricultural irrigation is responsible for a substantial amount of freshwater withdrawals. Table 5-7 shows agricultural irrigation use in the St. Johns River Basin. Table 5-7 also shows the adjusted freshwater values based on the percentage of the county that lie in the St. Johns River Basin.

County	Groundwater	Surface water	Total	Adjusted GW	Adjusted SW
	Fresh (mgd)	Fresh (mgd)	(mgd)	% Basin	% Basin
Alachua	19.70	0.34	20.04	8.67	0.15
Bradford	0.68	0.02	0.70	0.02	0.00
Brevard	46.92	21.57	68.49	25.81	11.86
Clay	4.58	0.20	4.78	4.49	0.20
Duval	0.95	2.57	3.52	0.78	2.11
Flagler	10.18	1.12	11.30	10.18	1.12
Indian River	38.00	74.22	112.22	22.04	43.05
Lake	35.28	5.19	40.47	28.93	4.26
Levy	27.99	0.58	28.57	4.48	0.09
Marion	13.86	0.44	14.30	8.04	0.26
Okeechobee	45.66	12.03	57.69	4.57	1.20
Orange	20.25	2.42	22.67	13.57	1.62
Osceola	47.33	3.19	50.52	17.51	1.18
Polk	109.14	3.35	112.49	2.18	0.07
Putnam	17.49	4.34	21.83	17.49	4.34
St. Johns	21.28	0.06	21.34	21.28	0.06
St. Lucie	5.91	53.19	59.10	0.06	0.53
Seminole	10.45	0.23	10.68	10.45	0.23
Volusia	33.73	14.99	48.72	31.03	13.79
Summations =	**509.38**	**200.05**	**709.43**	**231.57**	**86.11**

Table 5-7. Agricultural Irrigation Water Use Data by Category

The total amount of water withdrawn for agricultural irrigation is 317 mgd, which equates to 115,705 million gallons annually. Groundwater makes up the majority of water withdraws, however, agricultural irrigation uses an estimated 30% of the total surface water withdrawn for all the categories. The amount of groundwater withdrawn in 2010 for agricultural irrigation was 231 mgd, 73% of the total water used in this category. The amount of surface water withdrawn was 86.1 mgd, approximately 27% of the total water withdrawn. Indian River County not only uses the most agricultural irrigation water, but also the highest use of surface water as a percentage of total water used. In Indian River County, 65.08 mgd of freshwater is withdrawn, and only 34% comes from groundwater sources. Therefore, Indian River County obtains 66% of its agricultural irrigation from surface water sources, the most of any other county in the St. Johns River Basin.

Economic Evaluation - Agricultural irrigation uses a large quantity of water. However, since agricultural irrigation water is not processed or treated, it should be cheaper than water used for public supply. Young and Loomis (2005) reported a unit value cost of $0.17 per 1000 gallons of water used for agricultural purposes, which is equivalent to $0.19 per 1000 gallons in 2010 values. However, Frederick et al. (1996) reported an average value of $0.06 per 1000 gallons for irrigation in the South Atlantic-Gulf Region. In 2010 dollars, the Frederick et al. (1996) cost increases to $0.08 per 1000 gallons. Both of these costs will be taken into account and averaged to help eliminate uncertainty and determine the most reasonable cost. Applying these costs to the USGS and SJRWMD data yields the monetary values shown in Table 5-8.

			Frederick, VandenBerg, Hanson			Young and Loomis		
County	Adjusted GW % Basin	Adjusted SW % Basin	Cost Avg GW ($/ ac-ft/yr)	Cost Avg SW ($/mgd/yr)	Cost Avg Total ($/mgd/yr)	Cost Avg GW ($/mgd/yr)	Cost Avg SW ($/mgd/yr)	Cost Avg Total ($/mgd/yr)
Alachua	8.67	0.15	253105.60	4368.32	257473.92	601125.80	10374.76	547132.08
Bradford	0.02	0.00	595.68	17.52	613.20	1414.74	41.61	1303.05
Brevard	25.81	11.86	753535.20	346414.20	1099949.40	1789646.10	822733.73	2337392.48
Clay	4.49	0.20	131061.28	5723.20	136784.48	311270.54	13592.60	290667.02
Duval	0.78	2.11	22746.80	61536.08	84282.88	54023.65	146148.19	179101.12
Flagler	10.18	1.12	297256.00	32704.00	329960.00	705983.00	77672.00	701165.00
Indian River	22.04	43.05	643568.00	1256989.92	1900557.92	1528474.00	2985351.06	4038685.58
Lake	28.93	4.26	844744.32	124269.36	969013.68	2006267.76	295139.73	2059154.07
Levy	4.48	0.09	130769.28	2709.76	133479.04	310577.04	6435.68	283642.96
Marion	8.04	0.26	234732.96	7451.84	242184.80	557490.78	17698.12	514642.70
Okeechobee	4.57	1.20	133327.20	35127.60	168454.80	316652.10	83428.05	357966.45
Orange	13.57	1.62	396171.00	47344.88	443515.88	940906.13	112444.09	942471.25
Osceola	17.51	1.18	511353.32	34464.76	545818.08	1214464.14	81853.81	1159863.42
Polk	2.18	0.07	63737.76	1956.40	65694.16	151377.18	4646.45	139600.09
Putnam	17.49	4.34	510708.00	126728.00	637436.00	1212931.50	300979.00	1354551.50
St. Johns	21.28	0.06	621376.00	1752.00	623128.00	1475768.00	4161.00	1324147.00
St. Lucie	0.06	0.53	1725.72	15531.48	17257.20	4098.59	36887.27	36671.55
Seminole	10.45	0.23	305140.00	6716.00	311856.00	724707.50	15950.50	662694.00
Volusia	31.03	13.79	906122.72	402691.36	1308814.08	2152041.46	956391.98	2781229.92
Summations =	**231.57**	86.11	**6761776.84**	**2514496.68**	**9276273.52**	**16059220.00**	**5971929.62**	**19712081.23**

Table 5-8. Annual Cost of Agricultural Irrigation Water

Frederick, VandenBerg, and Hanson estimates the value (equated with the actual estimated cost) of groundwater as $6.7 million and surface water as $2.5 million, while Young and Loomis estimate the value of groundwater as $16 million and surface water as $5.9 million. These high and low costs are the domain within which the actual value must fall. The mean value using these two valuation sources include a new groundwater value as $11,410,498 and new surface water value as $4,243,212. Therefore, annually, the value that farmers of the St. Johns River Basin receive from groundwater and surface water is approximately $15,653,710. It is important to note that even though agricultural irrigation uses the second most quantity of freshwater and surface water, it does not contribute the second most to total annual cost of water. The basis for this inequality is because agricultural water is the least expensive. Because companies pay an initial cost for permits to withdraw water, this drastically reduces the cost of agricultural water, making it inexpensive in comparison to other water use categories. The permit cost was not taken into account for the calculations in Table 5-8, which allows for a fair amount of uncertainty to exist. If more sources for the economic value of agricultural irrigation existed, uncertainty could be reduced.

Recreational - Recreational water includes water used for recreational purposes such as golf course irrigation, urban landscapes, athletic fields, and other water-based recreational areas (SJRWMD, 2010). This water is mostly used for aesthetics and not for recreational activities such as kayaking and fishing.

Data by County - Recreational water comes from both groundwater and surface water sources. The distribution of how much groundwater and surface water is withdrawn is shown in Table 5-9.

County	Groundwater Fresh (mgd)	Surface water Fresh (mgd)	Total Fresh mgd	Adujsted GW % Basin (mgd)	Adujsted SW % Basin (mgd)	Adujsted Total % Basin (mgd)
Alachua	1.22	0.21	1.43	0.54	0.09	0.63
Bradford	0.06	0.02	0.08	0.00	0.00	0.00
Brevard	1.76	5.91	7.67	0.97	3.25	4.22
Clay	0.65	2.64	3.29	0.64	2.59	3.22
Duval	2.43	3.49	5.92	1.99	2.86	4.85
Flagler	0.29	1.04	1.33	0.29	1.04	1.33
Indian River	3.66	11.04	14.70	2.12	6.40	8.53
Lake	4.73	6.01	10.74	3.88	4.93	8.81
Levy	0.38	0.04	0.42	0.06	0.01	0.07
Marion	5.54	1.55	7.09	3.21	0.90	4.11
Okeechobee	0.35	0.35	0.70	0.04	0.04	0.07
Orange	3.84	5.75	9.59	2.57	3.85	6.43
Osceola	3.76	3.75	7.51	1.39	1.39	2.78
Polk	8.66	0.60	9.26	0.17	0.01	0.19
Putnam	0.26	0.15	0.41	0.26	0.15	0.41
St. Johns	1.47	4.04	5.51	1.47	4.04	5.51
St. Lucie	3.67	6.76	10.43	0.04	0.07	0.10
Seminole	0.62	1.16	1.78	0.62	1.16	1.78
Volusia	0.74	2.56	3.30	0.68	2.36	3.04
Summations =	**44.09**	**57.07**	**101.16**	**20.94**	**35.13**	**56.07**

Table 5-9. Recreational Water Use in the St. Johns River Basin

Considering adjustments for the percent of the county that lies within the basin, the St. Johns River Basin uses 20.94 mgd of recreational irrigation water from groundwater sources, and 35.12 mgd from surface water sources for a total of 56.07 mgd of freshwater used for recreational purposes. Typically, water withdrawn for recreational purposes is considered insignificant. Counties with the most withdrawals are Indian River and Orange because of the main attractions in these counties is tourism. Indian River is home to Vero Beach, a major tourist attraction where recreational activities are plentiful. Orange County is famous for being home to the one of the biggest recreational water use facilities, Disney World. These main attractions may explain the high recreational use of water.

Economic Evaluation - JEA also provides water to many landscaping and irrigation companies that use this water for recreational purposes. JEA charged $2.47 per 1000 gallons for water used for recreational irrigation (JEA, 2012). JEA's reasoning for the high cost of recreational water is mainly due to the different types of systems. JEA charges a public supply fee and a sewage fee. However, when it comes to recreational water, a sewage fee cannot be charged because there is no sewage port. Therefore, making recreational water more expensive will offset this cost. OUC 2010 unit cost is $1.62 for the first 19,000 gallons, $2.88 for the next 11,000 gallons, and $5.39 for over 30,000 gallons. Table 5-10 presents the total estimated value of the recreational water by applying the averaged JEA and OUC cost, $3.09/1,000 gallons, to the groundwater and surface water.

County	Adujsted GW % Basin (mgd)	Adujsted SW % Basin (mgd)	Adujsted Total % Basin (mgd)	Annual Cost Groundwater ($)	Annual Cost Surface Water ($)	Annual Cost Total ($)
Alachua	0.54	0.09	0.63	605429.88	104213.34	709643.22
Bradford	0.00	0.00	0.00	2030.13	676.71	2706.84
Brevard	0.97	3.25	4.22	1091758.80	3666076.43	4757835.23
Clay	0.64	2.59	3.22	718440.45	2917973.52	3636413.97
Duval	1.99	2.86	4.85	2247353.91	3227681.13	5475035.04
Flagler	0.29	1.04	1.33	327076.50	1172964.00	1500040.50
Indian River	2.12	6.40	8.53	2394199.98	7221849.12	9616049.10
Lake	3.88	4.93	8.81	4374479.01	5558270.37	9932749.38
Levy	0.06	0.01	0.07	68573.28	7218.24	75791.52
Marion	3.21	0.90	4.11	3624007.62	1013937.15	4637944.77
Okeechobee	0.04	0.04	0.07	39474.75	39474.75	78949.50
Orange	2.57	3.85	6.43	2901732.48	4345042.13	7246774.61
Osceola	1.39	1.39	2.78	1569064.92	1564891.88	3133956.80
Polk	0.17	0.01	0.19	195343.62	13534.20	208877.82
Putnam	0.26	0.15	0.41	293241.00	169177.50	462418.50
St. Johns	1.47	4.04	5.51	1657939.50	4556514.00	6214453.50
St. Lucie	0.04	0.07	0.10	41392.10	76242.66	117634.76
Seminole	0.62	1.16	1.78	699267.00	1308306.00	2007573.00
Volusia	0.68	2.36	3.04	767840.28	2656312.32	3424152.60
Summations =	**20.94**	**35.13**	**56.07**	**23618645.21**	**39620355.44**	**63239000.64**

Table 5-10. Recreational Water Use Annual Cost

Recreational water use the smallest amounts of water, however, that does not make it the least expensive. The various recreational water customers within the St. Johns River Basin spend an estimated $63 million dollars on recreational water supply. A groundwater cost of $23,618,645 and a surface water cost of $39,620,355 encompass the total $63 million amount. The cost for recreational water is higher than commercial/industrial and agricultural, making it the most expensive of the five water use categories. Utilities often consider recreational irrigation as a "luxury," not vital for human life; therefore, they charge more in order to provide this service.

Power Generation - Water in this category refers to water used in the generation of power. Typically, water is used to cool steam after it is used to drive turbines (Frederick et al., 1996). After water is withdrawn from either a groundwater or surface water source, it is circulated through heat exchangers, then returned to surface water bodies, thus making this water non-consumptive (Frederick et al., 1996).

Data by County: Power generation is the only water use category that uses saline water. However, since this report values only freshwater, the saline water withdrawn for power generation was ignored. The USGS data for the amount of freshwater withdrawn from each county is adjusted to the percentage of the county lying in the basin and presented in Table 5-11.

County	Groundwater Fresh (mgd)	Surface water Fresh (mgd)	Total water Fresh (mgd)	Adjusted GW % Basin (mgd)	Adjusted SW % Basin (mgd)	Adjusted Total % Basin (mgd)
Alachua	2.50	0.00	2.50	1.10	0.00	1.10
Bradford	0.00	0.00	0.00	0.00	0.00	0.00
Brevard	0.05	0.00	0.05	0.03	0.00	0.03
Clay	0.00	0.00	0.00	0.00	0.00	0.00
Duval	6.97	0.00	6.97	5.72	0.00	5.72
Flagler	0.00	0.00	0.00	0.00	0.00	0.00
Indian River	0.00	0.00	0.00	0.00	0.00	0.00
Lake	0.74	0.00	0.74	0.61	0.00	0.61
Levy	0.00	0.00	0.00	0.00	0.00	0.00
Marion	0.00	0.00	0.00	0.00	0.00	0.00
Okeechobee	0.00	0.00	0.00	0.00	0.00	0.00
Orange	0.44	0.00	0.44	0.29	0.00	0.29
Osceola	0.09	0.00	0.09	0.03	0.00	0.03
Polk	10.58			0.21	0.00	0.21
Putnam	0.62	17.49	18.11	0.62	17.49	18.11
St. Johns	0.00	0.00	0.00	0.00	0.00	0.00
St. Lucie	0.00	0.00	0.00	0.00	0.00	0.00
Seminole	0.00	0.00	0.00	0.00	0.00	0.00
Volusia	0.33	119.11	119.44	0.30	109.58	109.88
Summations =	22.32	136.60	148.34	**8.91**	**127.07**	**135.98**

Table 5-11. Water Withdrawn for Power Generation

The total amount of water used for power generation in the St. Johns River Basin was 135.98 mgd. Only 8.9 mgd was from groundwater sources, while 127.07 mgd came from surface water sources. Power generation uses almost twice as much surface water as any other category. Volusia County used 81% of the total amount of water used, and the majority was from surface water. Volusia County is home to Sanford Power plant and G.E. Turner Power plant. Both of these plants contribute to the vast amount of surface water for Volusia County.

Economic Evaluation - Most utilities do not integrate water into their electric resource planning because it is difficult to place a value on this kind of water (Tellinghuisen, 2010). Values for water vary by location, scarcity, urbanization, and climate, making it difficult to place a monetary value on water used for power generation. Frederick et al. (1996) reported a minimum, maximum, median, and average value as $9, $63, $29, $34 per acre-feet, respectively. Converting these values using inflation data to 2010 dollars per 1000 gallon results in a minimum, maximum, median, and average of $0.04, $0.28, $0.13, $0.15, respectively, per 1000 gallons. Applying these values to the quantity of water used by each county produces the values shown in Table 5-12 and 5-13. Table 5-12 shows the value of groundwater while Table 5-13 shows the value of surface water.

County	Adjusted GW % Basin (mgd)	Cost Min ($/ gal/ yr)	Cost Max ($/ gal/ yr)	Cost Median ($/ gal/ yr)	Cost Average ($/ gal/ yr)
Alachua	1.10	16060.00	112420.00	52195.00	60225.00
Bradford	0.00	0.00	0.00	0.00	0.00
Brevard	0.03	401.50	2810.50	1304.88	1505.63
Clay	0.00	0.00	0.00	0.00	0.00
Duval	5.72	83444.84	584113.88	271195.73	312918.15
Flagler	0.00	0.00	0.00	0.00	0.00
Indian River	0.00	0.00	0.00	0.00	0.00
Lake	0.61	8859.28	62014.96	28792.66	33222.30
Levy	0.00	0.00	0.00	0.00	0.00
Marion	0.00	0.00	0.00	0.00	0.00
Okeechobee	0.00	0.00	0.00	0.00	0.00
Orange	0.29	4304.08	30128.56	13988.26	16140.30
Osceola	0.03	486.18	3403.26	1580.09	1823.18
Polk	0.21	3089.36	21625.52	10040.42	11585.10
Putnam	0.62	9052.00	63364.00	29419.00	33945.00
St. Johns	0.00	0.00	0.00	0.00	0.00
St. Lucie	0.00	0.00	0.00	0.00	0.00
Seminole	0.00	0.00	0.00	0.00	0.00
Volusia	0.30	4432.56	31027.92	14405.82	16622.10
Summations =	**8.91**	130129.80	910908.60	422921.85	**487986.75**

Table 5-12. Value for Groundwater used for Power Generation

County	Adjusted SW	Cost Min	Cost Max	Cost Median	Cost Average
	% Basin (mgd)	($/ gal/ yr)	($/ gal/ yr)	($/ gal/ yr)	($/ gal/ yr)
Alachua	0.00	0.00	0.00	0.00	0.00
Bradford	0.00	0.00	0.00	0.00	0.00
Brevard	0.00	0.00	0.00	0.00	0.00
Clay	0.00	0.00	0.00	0.00	0.00
Duval	0.00	0.00	0.00	0.00	0.00
Flagler	0.00	0.00	0.00	0.00	0.00
Indian River	0.00	0.00	0.00	0.00	0.00
Lake	0.00	0.00	0.00	0.00	0.00
Levy	0.00	0.00	0.00	0.00	0.00
Marion	0.00	0.00	0.00	0.00	0.00
Okeechobee	0.00	0.00	0.00	0.00	0.00
Orange	0.00	0.00	0.00	0.00	0.00
Osceola	0.00	0.00	0.00	0.00	0.00
Polk	0.00	0.00	0.00	0.00	0.00
Putnam	17.49	255354.00	1787478.00	829900.50	957577.50
St. Johns	0.00	0.00	0.00	0.00	0.00
St. Lucie	0.00	0.00	0.00	0.00	0.00
Seminole	0.00	0.00	0.00	0.00	0.00
Volusia	109.58	1599885.52	11199198.64	5199627.94	5999570.70
Summations =	**127.07**	1855239.52	12986676.64	6029528.44	6957148.20

Table 5-13. Value of Surface Water used for Power Generation

Using the average cost value, the total amount of freshwater used was valued at $7,445,134 annually. A groundwater value of $487,986 and a surface water value of $6,957,148 comprise the total annual cost for water used in power generation. Most of the water used for generation of power originates from surface water sources, while only a mere 8.9 mgd originate from groundwater sources. This minimal use of groundwater reveals an explanation as to the lesser value for water used in power generation. In addition to the minimal groundwater use, power generation water was the least expensive of the five water use categories. However, urbanization and scarcity can make water more valuable. The reason most companies do not take this water into account in resource planning is because of the difficult nature in determining its monetary values as well as the fact that the true value of water used in power generation is constantly changing.

Discussion

The total amount of groundwater and surface water withdrawn from each county has been adjusted based on how much percent of the county lies within the basin. These values have been presented in the figures above, and the monetary value for each water use categories has been calculated. Summing each water use categories economic value equates to the total value spent on freshwater annually. Summing the data yields a final cost shown in Table 5-14.

	Water Withdrawn (mgd)	Cost ($/yr)
All Groundwater	766.33	$420,279,888.75
All Surface Water	281.70	$70,021,894.19
Total	1048.03	**$490,301,782.94**

Table 5-14. Annual Value of Freshwater in St. Johns River Basin

Public supply water use not only withdraws the most freshwater, but is one of the most valuable categories. At a value of $2.14 per 1000 gallons, public supply is responsible for $367 million annually. This is mainly because of the large amounts of groundwater that is withdrawn for public supply uses. Minimal amounts of water are withdrawn for commercial and industrial purposes; however, this category still amounts to $29 million annually. Agricultural water is the least expensive of the water use categories, and uses approximately 30% of total water withdrawn. Agricultural water use accounts for $15 million annually, so still contributes significantly to the total. The least amount of freshwater withdrawn comes from recreational irrigation; however, since this water is the most expensive, it contributes a significant $63 million annually. Power generation uses more surface water than the other categories and barely uses any groundwater. Consequently, water used for power generation has the cheapest annual cost at $7 million. Summing both the water withdrawn and the costs, displayed in Table 5-14, generates a total of $490 million spent on freshwater annually. Each year the St. Johns River Basin spends approximately $420 million on groundwater and $70 million on surface water.

Based on data from USGS, SJRWMD, and existing literature and studies, freshwater in the St. Johns Basin has an economic value of $490 million annually. GIS analysis provided a percentage of how much of each county was encompassed in the St. Johns River Basin. Multiplying the percent by the amount of water withdrawn from each county produced the adjusted amount of freshwater withdrawn. These adjustments allow potential error to enter into calculations. A more exact estimate of the percentage of the county encompassed in the St. Johns River Basin would allow for a better estimate of how much water actually is withdrawn from each county. If this project could be done without any adjustments, and the data of withdrawals came strictly from the St. Johns River Basin, it would create a more accurate estimate.

More uncertainty enters the calculation because of lack of data. This report used the best available data from USGS, SJRWMD, and existing literature. However, minimum and maximum prices for different water uses varied drastically. If more data existed in terms of water pricing, a much more accurate economic valuation of freshwater could be generated. However, pricing water is extremely difficult because the actual value of water is constantly changing based on scarcity, location, climate, urbanization, and other factors.

Summary

The goods and services provided by ecosystems are often undervalued. Benefits are often underestimated, but cannot be overlooked because they are crucial to human societies. Water is the most crucial of all the goods and services provided by an ecosystem. In order to adequately value ecosystems, an economic value must be assigned to the services they offer. The main challenge to placing an economic value on water is that water has various uses, and each use has its own distinctive price. Using the benefit transfer method, this reports focused on the economic valuation of five water use categories in the St. Johns River Basin: public supply, commercial and industrial, agricultural, recreational, and power generation. USGS and SJRWMD provided data on the total amount of freshwater withdrawn by each county in the basin in 2010. Existing literature assisted in determining a price point for each water use category and are reported in 2010 dollars based on the Consumer Price Index.

It was calculated that the amount of money spent annually on public supply, commercial and industrial, agricultural, recreational, and power generation water use was $367 million, $29 million, $15 million, $63 million, and $7 million, respectively. The amount spent on groundwater totaled $420 million annually, while surface water was $70 million. Overall, the St. John River Basin spent over $490 million annually on freshwater in 2010. Over a 25 year period and assuming no growth in water use within the St. Johns River Basin, the estimated value of groundwater can be conservatively estimated as about 10.5 billion dollars while the value of surface water is 1.75 billon dollars over that same period.

References

Barbier, Edward B. (2007). Valuing Ecosystem Services as Productive Inputs. Retrieved from: http://onlinelibrary.wiley.com/doi/10.1111/j.1468-0327.2007.00174.x/abstract.

Everard, Mark, Moggridge, Helen H. (2011). Rediscovering the Value of Urban Rivers. Retrieved from http://link.springer.com/article/10.1007%2Fs11252-011-0174-7#page-1.

Feug, X.Y, Luo, G.P, Li, C.F, Dal, L, Lu, L (2011).Dynamics of Ecosystem Service Value Caused by Land use Changes in Manas River of Xinjiang, China. Retrieved from: www.ijer.ir/pdf_519_0abeea62211402a091681636f9b2e978.html.

Frederick, Kenneth D, VandenBerg, Tim, Hanson, Jean. (1996). Economic Values of Freshwater in theUnited States. Retrieved from: http://www.ecy.wa.gov/programs/wr/hq/pdf/evfus_frederick.pdf

Jacksonville Electric Authority (2012). Rates. Retrieved from: https://www.jea.com/rates/

King, Dennis M & Mazzotta, Marisa J. (2000). U.S Department of Agricultural Natural Resources Conservation Service. National Oceanographic and Atmospheric Administration. Ecosystem Valuation. Retrieved from: http://www.ecosystemvaluation.org/

Marella, Richard (2014). U.S. Geological Survey. Water Withdrawals, Use, and Trends in Florida, 2010. Retrieved from: http://pubs.usgs.gov/sir/2014/5088/pdf/sir2014-5088.pdf

Orlando Utility Commission (2009). Water Rates. Retrieved from: http://www.ouc.com/residential/service-rates-and-costs/water-rates .

St. Johns River Water Management District. (2012, July). St. Johns River Water Supply Impact Study (Publication No. SJ2012-1).

St. Johns River Water Management District. (2014). Land Cover / Land Use 1994-95 - SJRWMD [Map]. Retrieved from GIS data download table database.

St. Johns Water Managemen District. (2010). 2010 Survey of Estimated Annual Water Use for St.Johns River Water Management District. Retrieved from:http://www.sjrwmd.com/technicalreports/pdfs/FS/SJ2011-FS1.pdf

St. Johns Water Managemen District. (2011). 2011 Survey of Estimated Annual Water Use for St. Johns River Water Management District. Retrieved from:http://www.sjrwmd.com/technicalreports/pdfs/FS/SJ2012-FS1.pdf

St. Johns Water Managemen District. (2012). 2020 Survey of Estimated Annual Water Use for St.Johns River Water Management District. Retrieved from:http://www.sjrwmd.com/technicalreports/pdfs/FS/SJ2013-FS1.pdf

St. Johns Water Managemen District. (2014). Upper St. Johns River Basin. Retrieved from:http://www.sjrwmd.com/upperstjohnsriver/

Tellinghuisen, Stacy (2010). Water for Power Generation: What's the Value?. Retrieved from: http://lawschool.unm.edu/nrj/volumes/50/3/06-tellinghuisen-water.pdf

USGS Water Resources. (2014). USGS Current Water Data for the Nation. Retrieved November 3, 2014, from USGS Current Water Data for the Nation website: http://waterdata.usgs.gov/nwis/rt

U.S. Geological Survey (2005). Estimated Use of Water in the United States in 2005. Retrieved from:http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf

Young, Robert, & Loomis, John (2005). Determining Economic Value of Water Concept and Methods.New York, NY: RFF Press.

Chapter 6

Economic Value of Recreation along the Freshwater Portion of the St. Johns River

Xiang Bi[1], Tatiana Borisova[1], Sherry Larkin[2]

and

James Longanecker[3]

[1]Assistant professor, [2]Professor, and [3]M.S. student, at the Food and Resource Economics Department, University of Florida.

Abstract

The economic value of recreation along the freshwater portion of the SJR, were evaluated through surveys, online surveys selected from Florida freshwater fishing license holders and those belonging to organizations that potentially use the river, e.g. Florida Professional Paddlesports Association. Sixteen percent of the general public surveyed had traveled to the SJRB to participate in inland outdoor recreation activities in the past 12 months, while 44% of the frequent users had traveled to the area. For frequent users, the SJRB provided year-round recreation opportunities while the general public visited the SJRB more often in the summer months. The top four most frequently reported activities for the general public were fishing (23%), swimming (17%), hiking (15%), and motorized boating (13%). Frequent users reported kayaking (non-motorized boating, 27%), fishing (23%), motorized boating (12%), and hiking (12%). Most respondents considered the visited site as having "good" or "excellent" water quality.

Forty-one percent of the general public considered their home counties to have "moderate" to "severe" problems with surface water quality, as opposed to 60% of the frequent users. Only 20% of the respondents believed their counties to have "minor" problems with surface water quality. In addition, respondents were less concerned about water shortage problems in their home counties than water quality problems. Of the respondents, 56% of the general public sample believed water shortage was "likely" or "extremely likely" to occur in their home counties in the next 10 years; while only 34% of the frequent recreational user sample believed this to be true. Of the respondents, 69% of the frequent users had made donations for environmental causes compared to 43% of the general public in the past five years.

Survey responses were used to estimate a travel cost model (TCM) to determine the economic value of recreation along the freshwater portion of the SJR. The value of the freshwater portion of the SJR to each household in Florida was calculated to be between $80.56 and $97.67. Based on the United States Census Bureau (2013), the annual recreational benefit provided by the SJRB to Florida residents ranges from $89.8 million to $108.9 million.

Introduction

The St. Johns River (SJR), the longest river in the state, is located in northeastern Florida. Starting from the marshes near Vero Beach, the SJR flows northward along the Atlantic coast, skirting 18 Florida counties, passes Orlando, runs through Palatka, and flows into the Atlantic Ocean at Jacksonville. Over its 310-mile journey to the Atlantic, it forms numerous lakes and receives inflow from many lakes and smaller streams, creating 8,840 square miles of drainage and forming major interior wetlands and primary commercial and recreational waterways. Given the complex hydrologic system, the size of the St. Johns River Basin (SJRB) and its importance for the state of Florida, a dedicated regional government entity—the St. Johns River Water Management District (SJRWMD)—was created to manage water resources in the SJRB (Figure 6-1).

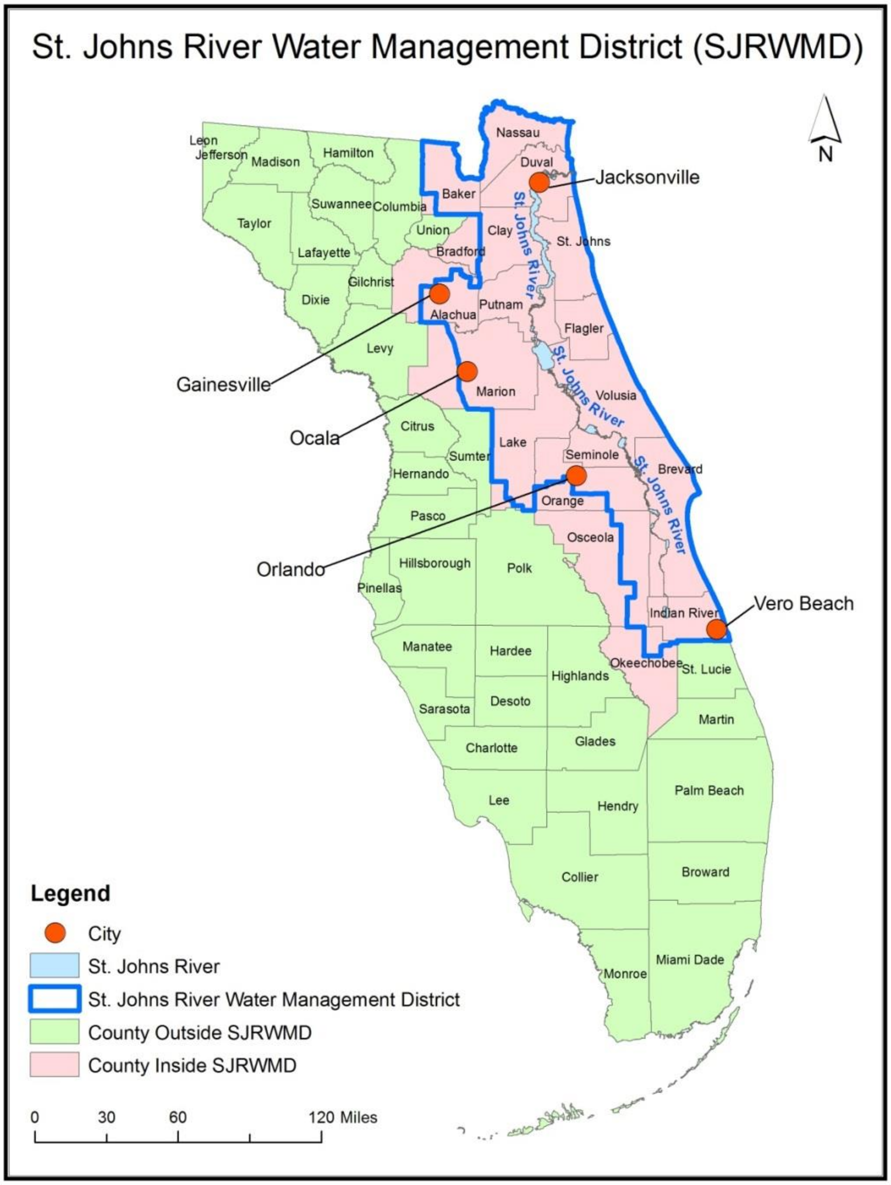


Figure 6-1. Location and coverage of the SJR water management district
Source: SJRWMD GIS data (accessed August 24, 2014).

The SJR and the lakes, streams, and springs in the SJRB provide a variety of ecosystem services, including cultural services (e.g., recreation and tourism and cultural heritage services), provisioning services (e.g., public water supply, fish and shrimp harvesting), regulating services (e.g., climate and water regulation, habitat support), and supporting services (e.g., nutrient cycling). Because of its historic, cultural, recreational, economic, and environmental value to the community along its banks, the SJR is designated an American Heritage River (American Rivers 2008). The resource valuation literature emphasizes the importance of identifying, analyzing, and valuing the flow of ecosystem services to guide a regional planning process (Elmqvist et al. 2011). As a result, the tradeoffs and synergies in the provision of various ecosystem services should be explicitly accounted for in watershed management.

In the SJRB, the tradeoffs in the provision of various ecosystem services are often evident. In 2008, the SJR was listed as one of America's most endangered rivers (US EPA 1997; American Rivers 2008) due to pressures from population growth, threats from climate change, and the diversity of land-use types and stakeholder interests complicating effective river basin management. Between 2000 and 2010, population growth in Osceola and St. Johns Counties exceeded 50% each, and the growth in Flagler County reached 92% (FOEDR 2012). The projected population growth in the counties that contain the SJRB is 38% from 2010 to 2035 (i.e., an increase from 4.7 million people in 2010 to 6.5 million people in 2035). Increasing water demand driven by population growth will likely increase the use of inter-connected groundwater and surface-water resources in the SJRB for freshwater withdrawals (SJRWMD 2014a). The SJRWMD and several counties and utilities are considering the potential of using the SJR as a water supply source to supplement their groundwater withdrawals and to meet growing water demand in the public water supply sector (Patterson, 2009).

In addition to urban areas, agriculture is a main land-use in the SJRB; In 2012 total sales of agricultural products in the 18 counties of the SJRWMD reached $1.6 billion (USDA 2014). A large proportion of the agricultural acreage is irrigated (USGS 2014), and access to freshwater is crucial for the future of agricultural industry in the region.

The use of water resources in the SJRB for provisioning services (freshwater withdrawals) can potentially impact the flow of cultural ecosystem services, such as in-stream recreation and tourism. For example, reductions and/or irregularities in the flow of several springs in the SJRB resulted in the need to develop "Minimum Flows and Levels" plans to quantify the maximum water withdrawals (provisioning service) that does not result in harm to specific water bodies (i.e., supporting, regulating, and cultural services) (SJRWMD 2014b).

Recreation and tourism in the SJRB can also be affected by water quality impairments. The main stem of the SJR, as well as lakes and smaller streams in the SJRB, are classified as "impaired" with nutrient- and pathogen-related causes, urban stormwater, and runoff from agricultural areas being among the major pollution sources (US EPA 2014; FDEP 2014; Gao 2006; Lakes Harney and Monroe and Middle St. Johns River Basin Technical Stakeholders 2012; Lower St. Johns River TMDL Executive Committee 2008). Nutrient impairment results in periodic algae blooms, many of which are associated with fish kills and the presence of blue-green algae that are toxic to both aquatic life and humans.

The SJR is one of the recreational designations for Florida residents and visitors from other states. Protecting water quality and water flow, and providing for additional nature-based recreational opportunities will ensure and increase the contribution of tourism activities to the local economy.

Regional water quality and allocation policies are being developed to meet the water demand of the agricultural industry and the growing state population while protecting in-stream water use. Such policies should be based on understanding the flow of ecosystem services provided by the SJR and the associated economic values of all the services society currently benefits from.

Unlike other goods and services for which the economic value can be assessed using market prices, the economic values associated with ecosystem services are often unpriced or undervalued by the market because of the nonexclusive (public and/or common) nature of these services (Costanza et al. 1997; Hanley et al. 2007; MEA 2005). To understand and estimate the values associated with ecosystem services provided by a natural resource (e.g., a river) to society, it is important to identify the distinct components of the Total Economic Value (TEV) generated by the resource (Figure 6-2).

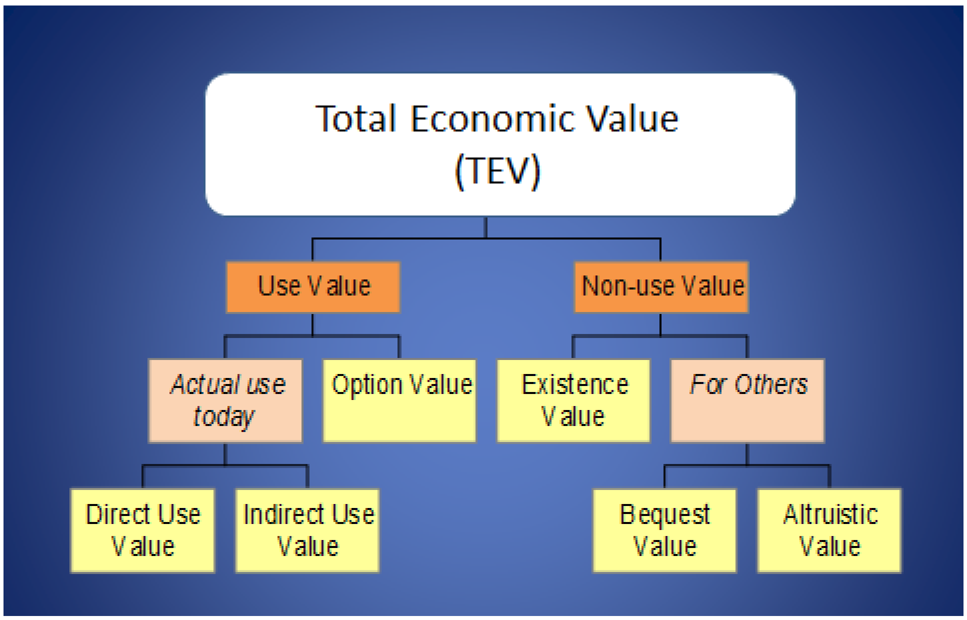


Figure 6-2. Example of classification of Total Economic Value (TEV) components for a given natural resource (based on Barbier et al. 2011).

The concept of total economic value (TEV) helps identify distinct components of the values generated by a natural resource (e.g., a river) to society, and Figure 6-1 shows one depiction of these mutually exclusive values. TEV is first classified into "use" and "non-use" components from the perspective of the individual; the former includes actual use today and any potential future uses by the individual, whereas the latter includes all values the individual has but from the perspective of other individuals in society (i.e., it is a "non-use" value to him/her since the individual is not using the resource today or in the future).

Given its significance as a major recreational waterway in the state of Florida, the objectives of this chapter are to determine the economic value of recreation along the freshwater portion of the SJR. In particular, the recreational benefit of the SJR is part of the use value provided by the SJR, which is a component of the Total Economic Value (TEV) generated by the SJR. In particular, recreation generates a direct use value since an individual is interacting directly with the river[1].

To achieve this objective, we designed and implemented two surveys to elicit information on household outdoor recreational experiences with respect to the freshwater portion of the SJR and its surrounding inland green space. One survey gathered information from the general population and the other focused on information from existing users of the SJRB. The data was used with the Travel Cost Method (TCM) to estimate the household demand for natural-based outdoor recreation in the SJRB. The rest of the chapter discusses the empirical approach, survey instrument development and implementation, estimation and conclusions.

Empirical Approach: Travel Cost Method (TCM) - The economic foundation of the TCM is that the recreational costs (transportation, lodging, fees, etc.) a consumer incurs are equal to or less than the value the consumer places on the recreational benefits provided by the site (e.g., the SJR). In particular, a consumer demand function for recreation can be estimated from data on the number of trips taken at different prices/travel costs. The total value consumers derive from the recreational trip can be higher than the total costs they incur. The difference between the value and the costs is referred to as consumer surplus. Consumer surplus, the measure of the total economic value, can be estimated by integrating the area under the demand function and above the travel cost level (Hanley et al. 2007).

For a single-site TCM, assuming just one substitute site, the model of demand for recreational trips becomes (1):

$$x_1 = f(p_1, p_2, q_1, y) \tag{6-1}$$

where x_1 is the number of trips to study site 1, p_1 is the travel cost to site 1, p_2 is the travel cost to an alternative site (i.e., cross-site price), q_1 is quality at site 1, and y represents a set of the visitor's characteristics that influence the frequency of visiting the site 1 (e.g., household income and demographic variables).

In order to employ the TCM, estimates of the travel costs to each site (p_1, p_2) are needed. In particular, we need the cost for each respondent to travel to the site visited and then we need an estimate of the costs that would have been incurred to travel to each alternative site (i.e., the implicit own-price and cross-price variables, respectively). In this study, we estimate the travel cost using the following two measures: the monetary cost of travel and the opportunity cost of travel time. Both measures are calculated using the distance traveled from the mid-point of household *i*'s home ZIP code to the site 1:

$$p_{i1} = cd_{i1} + g w_i \left(\frac{d_{i1}}{mph}\right) \tag{6-2}$$

[1] In this study, we focus on the economic value of recreation and nature-based tourism services. Note that for developing a water resource management program, decision-makers also need information about the economic contributions of agriculture, industry, construction and other economic activities that are also dependent on the water resources in the area that but are not examined in this study.

where c is the cost per mile, d_{i1} is the round trip distance (e.g., from Google Maps; if the site is spread over a geographic area, then the approximate midpoint is used for the estimations); *mph* is miles per hour traveling speed; $i = 1, \ldots, N$ respondent households; $0 < \gamma < 1$ is a faction of the hourly wage rate w_i. Implicit wage rate is calculated using the respondent's household income. Given the literature estimates of γ (Anderson 2010; Parsons 2003), we assumed that $\gamma = 1/3$. The cost c is \$0.56 per mile based on the standard mileage rate (IRS 2014).

Since households in Florida face a large number of substitute sites for freshwater-based recreation, we defined the alternative site that a household could visit as the least expensive alternative to site 1 (i.e., the nearest site along the SJR area based on the zip code in which the household resides except for site 1).

Given the nonnegative integer feature of the expected number of trips, x_1, a typical travel cost model is estimated assuming a Poisson distribution of trips x_1. The probability of observing a household i taking x_{i1} trips to site 1 in the last 12 months is given in (6-3):

$$pr(x_{i1}) = \frac{\exp(-\lambda)\cdot\lambda^{x_{i1}}}{x_{i1}!} \quad \text{and } x_{i1} = 0,1,2,3,\ldots \qquad (6\text{-}3)$$

The parameter λ is the expected number of trips that a household undertakes (or the latent demand). To ensure nonnegative probabilities, λ usually takes a long-linear form, and the number of trips household i undertakes to site 1 can be calculated as

$$\ln(\lambda_{i1}) = \beta_0 + \beta_1 p_1 + \beta_2 p_2 + \beta_3 q_1 + \beta_4 y_i \qquad (6\text{-}4)$$

Following (3), the expected number of trips per household to site 1 in a given year can be obtained by

$$\hat{\lambda}_{i1} = \exp(\hat{\beta}_0 + \hat{\beta}_1 p_1 + \hat{\beta}_2 p_2 + \hat{\beta}_3 q_1 + \hat{\beta}_4 y_i) \qquad (6\text{-}5)$$

Using the estimated coefficients of this model, the consumer surplus (CS) of one trip to the study site 1 can be calculated as follows (Bockstael et al. 1987, 1995; Creel & Loomis 1990):

$$CS/household/trip/year = -\frac{1}{\hat{\beta}_1} \qquad (6\text{-}6)$$

To calculate the value consumer surplus, we can multiply (6-4) and (6-5),

$$CS/household/year = -\frac{\hat{\lambda}_{i1}}{\hat{\beta}_1} \qquad (6\text{-}7)$$

We can then multiply (6-6) with the estimated number of households in the sample area that visited the SJR area in the last 12 months. The estimated percentage of households in the survey area can be obtained through a survey of the offsite random sample of the population. Specially, random digit dialing is used to call the target population in Florida, and the percentage of visitors can be estimated.

The typical Poisson model described in (6-2) has a number of drawbacks. First, the conditional mean of each count dependent variable is equal to its conditional variance. This property of equi-dispersion is often found violated in empirical data, with over-dispersion often the case (Freeman et al. 2014). Second, data on recreation activities often include a relatively higher frequency of zero observations in offsite surveys on the general population. In the presence of over-dispersion and excess zeros, the Zero-Inflated Poisson (or zero-inflated Negative Binomial) model (Haab & McConell 1996, 2002; Anderson 2010) or the hurdle model (Bilgic & Florkowski 2007) have been used to estimate the TCM using data from offsite surveys on the general population.

The extension from the Poisson model to Zero-Inflated Poisson (ZIP model) follows the idea that two different processes can generate zero trip observations. In particular, zero trip observations can come from a "corner solution" or nonparticipation decision due to other factors than travel cost and preferences. For example, ill health may prevent people from undertaking a recreation trip, which is unrelated to travel cost or site quality. In the other situation, zero trip observation is generated from the Poisson process, and reflects the "corner solution" which means the current "market" price is higher than the choke price below which the individual would demand a positive number of trips. In the case of the ZIP model, the participation decision and the frequency decision is given (Haab & McConnell 1996; Anderson 2010):

$$pr(x_{i1}) = F(\beta_1^{'} z_1) + (1 - F(\beta_1^{'} z_1)) \frac{\exp(-\lambda_i)\lambda_i^{xi1}}{x_{i1}!} \qquad (6\text{-}8)$$

where $x_{i1} = 0,1,2,3,\ldots$, $z_1 = (p_1, p_2, q_1, y_1)$, and $F(.)$ represents the probability that $x_{i1} = 0$, and $1 - F(.)$ represents that the probability that the Poisson process holds. The variables (factors) influencing the two processes may not be mutually exclusive.

Survey Design and Data Collection

Develop Survey Instruments for SJR - The SJRB includes a variety of ecosystems (wetlands, springs, lakes, tributaries, and the main stem of the river, which is influenced by tidal waters) that offer many recreational opportunities such as boating, fishing, and wildlife watching (SJRWMD 2014c; Florida Division of Recreation and Parks 2014). The SJR can be categorized into smaller sections, referred to as the Upper, Middle, and Lower SJR, with corresponding basins (SJRWMD 2014a). As the three sections of the SJR have distinct characteristics, the recreational opportunities offered by the three basins also differ. The Upper (southern) SJRB is characterized by marshes. While the Upper SJRB is not navigable by commercial boats, it provides plentiful opportunities for air boating, seasonal hunting, fishing, and kayaking (SJRWMD 2014c). Downstream (in the Middle SJRB), where clearly delineated bodies of water begin to take form, kayaking, swimming, hiking, and wildlife viewing are abundant recreation opportunities with suited sites such as Lake George and the Blue Springs State Park. The SJR widens significantly in the Lower (northern) SJRB and supports both commercial and recreation uses. For example, the Port of Jacksonville serves as the largest vehicle exporting port in the United States (JAXPORT 2013). In addition, the Lower SJRB is characterized by cultural heritage sites such as the Timucuan Ecological and Historic Preserve.

Eleven sites that offered freshwater based recreation opportunities were identified along the SJR that were representative of the variety of nature-based activities, in order to cue survey respondents as to the landmark recreation sites along the SJR. The sites were decided upon based on their geography (a semi-uniform spatial distribution representing the spectrum of geographical features) and their visitation rates (sites with a higher number of visitors were given more consideration). A series of regional guidebooks provided information about the characteristics of the recreation sites, FDEP statistics ranked the most visited state parks in the study region, and personal interviews with SJRWMD officials and local business owners informed site selection when unclear (SJRWMD 2014c; Bellville 2000; McCarthy 2008). The locations of the eleven sites are shown in Figure 6-3. On those sites, in addition to water-based recreation, visitors have water-based recreation and ecotourism options, such as hiking, horseback riding, bicycling, camping, canoeing, kayaking, and geo-caching on public and private park lands in the SJRB (Table 6-1). Additionally, recreation opportunities also differ by season. For example, bird watching and hunting usually take place from October to March, whereas freshwater-based activities such as swimming are more common during the summer months. To apply the TCM, we included questions about the annual rate of visitation, most recent site visited, home zip code, site-specific water quality perceptions, and income. In addition, questions that can inform water resource management in the SJRB were also included (e.g., respondents' opinions of water issues in their home county and in the state). Supplemental variables that could influence a household's recreation demand are also included at the end of the survey, such as a respondent's residency, demographics, and donations for environmental causes.

Table 6-1. Major recreation sites and opportunities identified by regional guidebooks

	Fishing	Picnic	Diving / Swimmi	Kayak /canoein	Motoriz ed	Hunting	Campin	Wildlife /nature	Hiking	Bicyclin	Horseba ck	Geo tagging	Exhibiti on / tour
Lower SJR													
Timucuan Ecologic and Historic Preserve (including Ft. Caroline & Kingsley Plantation)				1				1					1
Big Talbot Island State Park	1	1		1	1			1		1			
Bayard Conservation Area	1					1	1	1		1	1		
Middle SJR													
Ocala National Forest	1	1			1	1	1	1	1	1	1		
Lake George	1				1	1	1	1	1				
Lake Ocklawaha (Rodman Reservoir)	1						1						
Silver Springs & Silver River	1	1	1	1			1	1	1	1	1	1	1
Blue Springs	1	1	1	1			1	1	1				1
Upper SJR													
Lake Monroe	1			1	1	1	1	1	1	1	1		
Lake Harney	1	1						1		1	1		
Blue Cypress Conservation Area	1			1	1	1	1	1	1	1			

Sources: Florida Division of Recreation and Parks. (2014); SJRWMD (2014c).

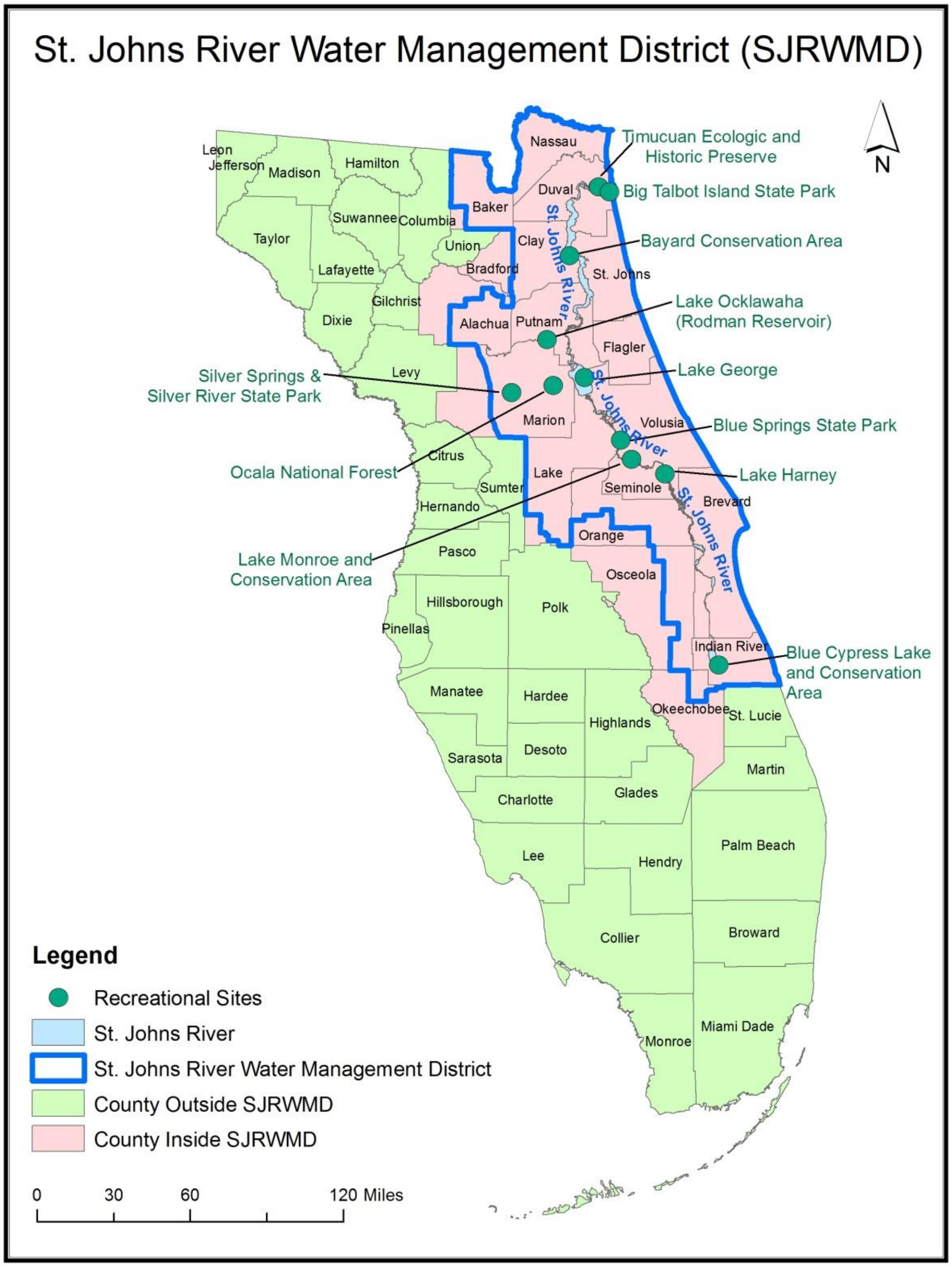


Figure 6-3. Locations of major recreation sites on the SJR. Source: St. Johns River Water Management District GIS data (Accessed August 2014); Florida Division of Recreation and Parks; St. Johns Rive Recreation Guide (McCarty, 2004).

Survey Formats - There is no single preferred survey mode for recreation demand analysis, and the choice of the survey modes depends on the research purpose. Past studies have successfully used both onsite and offsite surveys to estimate TCM. An advantage of intercept surveys at recreation sites is that they could provide researchers with a convenient sample of visitors, especially if the incident rate of visiting a site in the general population is low. However, a disadvantage of this method is that the visitors who use recreational sites often are more likely to be sampled using the onsite survey mode, implying that the sample of surveyed visitors may not be representative of all the visitors at the site (endogenous stratification). Additionally, seasonality of visiting patterns also needs to be taken into account while conducting onsite intercepts, as different groups of visitors use recreational sites in the SJR in different seasons.

Given the disadvantages of the onsite survey mode, we opted for the use of the offsite survey mode. However, we also recognized that given the potential low incident rate of Florida residents visiting SJR recreational sites during the study period, many respondents may have incurred zero trips during the study period using an offsite survey on the general population. Since no such studies have been conducted in the SJRB and there is no reliable statistics we can draw upon, estimating the percentage of the general population that visit SJR recreational sites is absolutely essential for extrapolating the total recreational value of the SJR. As an alternative to offsite random sampling of the general population in a region, previous literature has also suggested focusing on sampling known groups of users (Anderson 2010,) and using web surveys (Fleming and Bowden 2009).

In this study, we employed two types of surveys for two different populations of interests. First, a telephone survey was conducted using a random sample generated from random-digit dialing (RDD) to the landlines of households living in Florida. The telephone survey was administered through the Florida Survey Research Center from September 20, 2014 to October 31, 2014, with 500 completed responses collected. Tables 6-2a to 6-2c list the counties that were included in the random sampling and their population. Specifically, the survey was stratified by three sampling regions (north, central, and south), with 17 Florida counties excluded in the telephone survey due to their distance from the SJR and/or have other recreation substitutions.

Second, to better reach potential visitors to the SJR, we also created an online survey, following the same questionnaire used for the telephone survey. The online survey was created using Qualtrics®. Emails, with links to the online survey, were sent through list servers of the following organizations: Florida Professional Paddlesports Association (approximately 50 active members); Putnam County Blueways and Trails Citizen Support Organization (CSO) (approximately 350 active members); St. Johns River Alliance (approximately 250 members), and St. Johns Riverkeeper (approximately 250 active members). Additionally, we obtained email addresses of those who have freshwater fishing licenses (around 200,000 email addresses) from the Florida Fish and Wildlife Commission. From the list of email addresses, we randomly sent invitation emails to 20,277 license holders. Online survey data were collected from September10, 2014 to September 25, 2014. Emails were sent on September 10, 2014 and September 18, 2014, to solicit survey participation and completion of the survey. Since those respondents are more likely to use recreational sites in the SJRB and have greater knowledge about the SJR than the general public, we estimated a separate model and value for those people. Hereafter, we refer them as "frequent users" of the SJR.

Table 6-2a. Population distribution in north survey region in the telephone survey

	Population 2000	Population 2010
Alachua County	217,955	247,336
Baker County	22,259	27,115
Bradford County	26,088	28,520
Clay County	140,814	190,865
Columbia County	56,513	67,531
Dixie County	13,827	16,422
Duval County	778,879	864,263
Flagler County	49,832	95,696
Gilchrist County	14,437	16,939
Hamilton County	13,327	14,799
Jefferson County	12,902	14,761
Lafayette County	7,022	8,870
Leon County	239,452	275,487
Madison County	18,733	19,224
Nassau County	57,663	73,314
Putnam County	70,423	74,364
St. Johns County	123,135	190,039
Suwannee County	34,844	41,551
Taylor County	19,256	22,570
Union County	13,442	15,535
Total	1,930,803	2,305,201

Table 6-2a. Population distribution in north survey region in the telephone survey

Central survey region	Population 2000	Population 2010
Brevard County	476,230	543,376
Citrus County	118,085	141,236
Hernando County	130,802	172,778
Hillsborough County	998,948	1,229,226
Indian River County	112,947	138,028
Lake County	210,527	297,052
Levy County	34,450	40,801
Marion County	258,916	331,298
Orange County	896,344	1,145,956
Osceola County	172,493	268,685
Pasco County	344,768	464,697
Polk County	483,924	602,095
Seminole County	365,199	422,718
Sumter County	53,345	93,420
Volusia County	443,343	494,593
Total	5,100,321	6,385,959

Table 6-2c. Population distribution in south survey region in the telephone survey

South survey region	Population 2000	Population 2010
Manatee County	264,002	322,833
Okeechobee County	35,910	39,996
Martin County	126,731	146,318
St. Lucie County	192,695	277,789
Hendry County	36,210	39,140
Sarasota County	325,961	379,448
Broward County	1,623,018	1,748,066
Charlotte County	141,627	159,978
Collier County	251,377	321,520
Glades County	10,576	12,884
DeSoto County	32,209	34,862
Highlands County	87,366	98,786
Palm Beach County	1,131,191	1,320,134
Lee County	440,888	618,754
Total	4,699,761	5,520,508

Source: FOEDR (2012).

The questions and sequences of the online survey were almost identical to the telephone survey, with two exceptions: 1) we adjusted the format of certain questions containing visual cues (figures and graphs) to enhance the online survey experience. In particular, online respondents were asked to select the recreational site they most recently visited as shown on a given map (Figure 6-3), whereas telephone respondents were asked to recall the name of the recreational site they most recently visited; 2) the online survey included questions soliciting respondents' opinions about the expansion of ecotourism and recreation possibilities in the area, since the online survey was sent to "frequent users" who may have more insights about the recreation opportunities in the SJRB than the general public.

Survey Results - The online survey collected 787 responses, but some had to be deleted from the final analysis due to incomplete responses. The number of respondents for each group is summarized in Table 6-3a. Nearly half of the respondents were freshwater fishing license holders registered in Florida.

Table 6-3a. Response rate by groups of respondents from online survey

Group/Organization/	No. of respondents	Percentage
Audubon Florida	49	8%
Florida Fish and Wildlife Permit Holder	269	44%
Florida Professional Paddlesports Association	9	1%
Putnam County Blueways and Trails, CSO	50	8%
St. Johns River Alliance	48	8%
St. Johns Riverkeeper	58	9%
Other	106	17%
None of the above	198	32%
Total	787	100

Table 6-3b. Response rate by regions from telephone survey

Region	No. of respondents	Percentage	No. of visitors	Percentage
North	166	33%	31	18.7%
Central	168	33%	33	19.6%
South	166	33%	14	8.4%

The telephone survey collected 500 complete responses across three sampling regions in Florida. The 500 complete responses were evenly distributed across the three regions: 166 from the north, 168 from the central, and 166 from the south regions (Table 6-3b).

Participation in outdoor recreational activities in the SJRB - The telephone and online surveys from the general public and frequent users present different participation patterns. First, the participation rate for frequent users was much higher than for the general public. Out of the 500 respondents from the telephone survey (i.e., general public), 39.2% indicated that they had traveled more than 10 miles from home to participate in inland outdoor recreation activities in the past 12 months; and 78 out of 500 respondents (15.6%) traveled to the SJRB specifically. More importantly, residents of south Florida were less likely to travel to recreational sites in the SJRB: out of the 78 respondents who used recreational sites in the SJRB, only 18% were from south Florida, whereas 40% and 42% came from north and central Florida. This low participation rate from the south Florida can be explained by the longer distance these residents had to travel to reach the major recreational sites in the Upper and Middle SJR regions.

In contrast to the general public, out of the 787 respondents in the online survey (i.e., frequent users), 87% participated in inland outdoor recreation activities, and 44% traveled to the SJRB. Specifically, 24% of them visited the SJRB 1 to 5 times, 27% visited 6 to 9 times, and 34% visited 10 or more times, which confirms our expectation that the respondents contacted through emails were "frequent users" of the SJR (Table 6-4).

Table 6-4. Frequency of past trip and future trips

	Online survey		Telephone survey	
	Future trips	Past trips	Future trips	Past trips
Number of Trips	Percent of responses	Percent of responses	Percent of responses	Percent of responses
None	4%	8%	90%	84%
1 once	3%	7%	1%	4%
2-5 times	45%	25%	7%	6%
6-10 times	18%	26%	1%	3%
More than 10 times	30%	34%	0%	19%

Additionally, frequent users demand is expected to be consistent in the future (next 12 months), since the number of trips planned (Table 6-4) is correlated with the number of trips undertaken in the past 12 months.

Visitation pattern in the SJRB - Information about their most recent trip to the SJRB is summarized in Table 6-5. For frequent users, the SJR provided year-round recreation opportunities, with the frequency of visits being distributed evenly across the seasons. In contrast, the general public visited the SJR more often in the summer months (May to August).

Both online and telephone survey respondents provided details on their recreational activities in the freshwater portion of the SJR and its surrounding land (Figures 6-4a, 6-4b, and 6-4c). The top four most frequently reported activities by Florida residents included fishing (23%), swimming (17%), hiking (15%), and motorized boating (13%), as opposed to kayaking (non-motorized boating, 27%), fishing (23%), motorized boating (12%), and hiking (12%) for the frequent users. For both survey groups, the types of activities planned in the next 12 months were similar to past activities.

Table 6-5. Months in which the most recent visitation occurred

	Online survey	Telephone survey
	Percentage	Percentage
January-April	21%	17%
May- August	26%	46%
September to Dec	30%	33%
Total	100%	100%

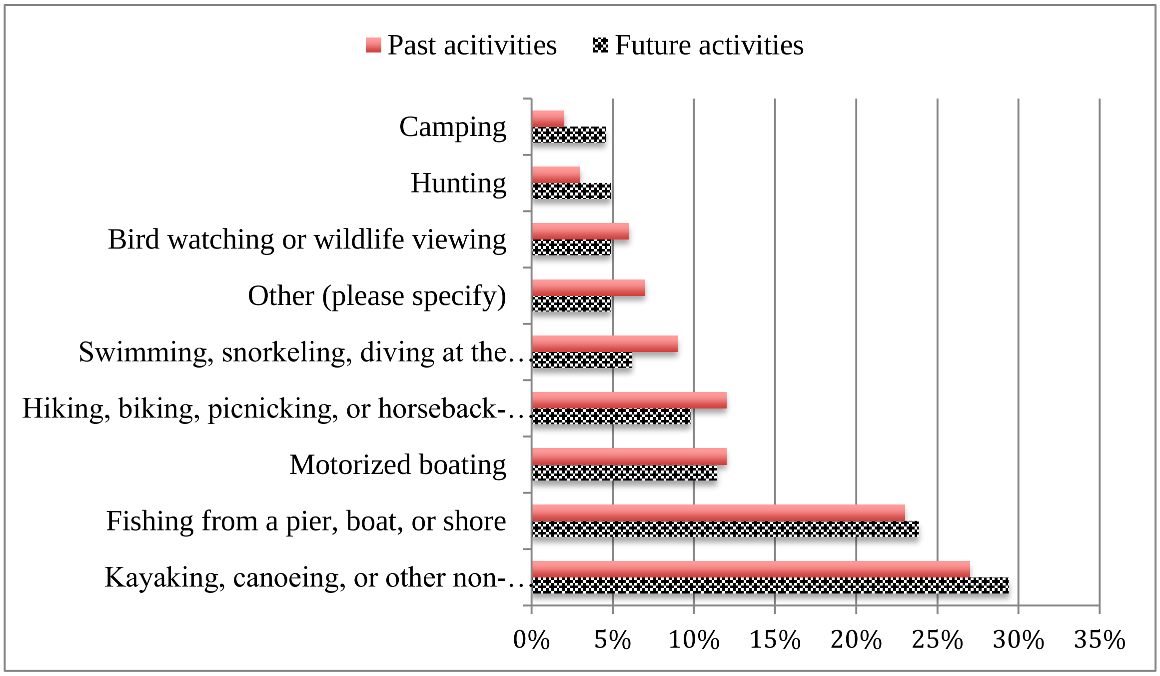


Figure 6-4a. Primary recreation activities of the most recent trip and future trip in SJR (online survey on frequent users, N=351).

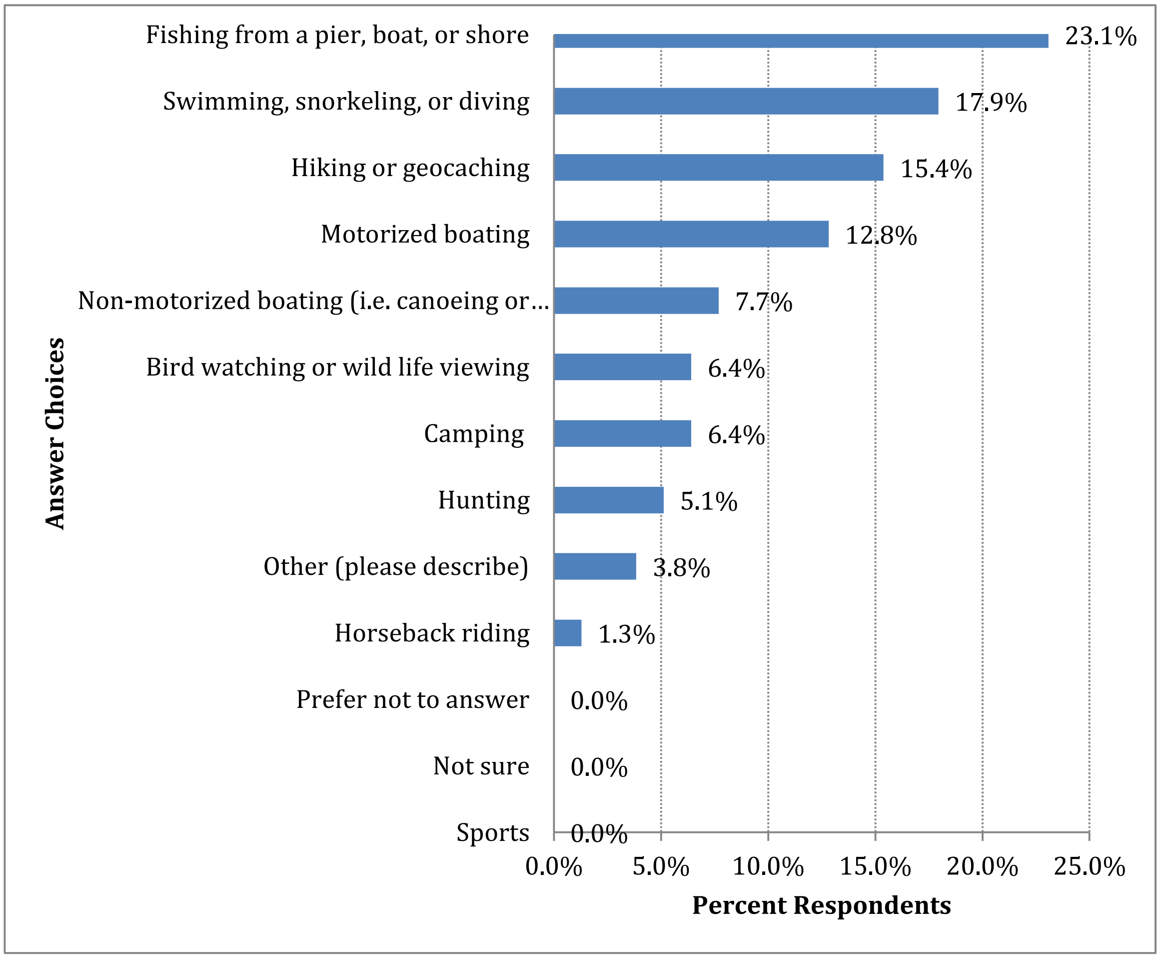


Figure 6-4b. Primary recreation activities of the most recent trip in SJR (telephone survey, N=78).

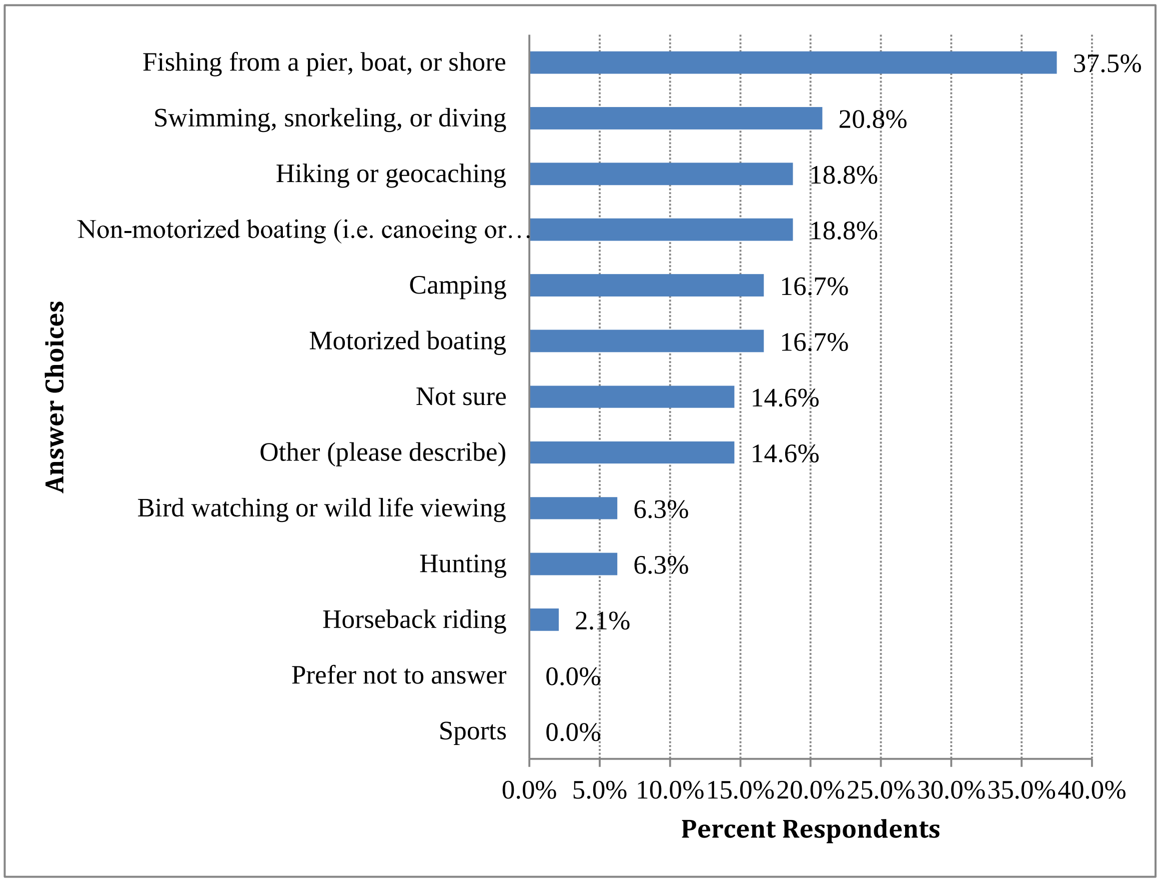


Figure 6-4c. Primary recreation activities of planned future trip in SJR (telephone survey, N=48).

Location of the most recent visit - In the telephone survey, we first asked the respondents whether their most recent trip to this part of Florida in the northern part of the region, from Jacksonville to Palatka; in the central part of the region, from Palatka to Sanford; or in the southern part of the region. The respondents indicated that the north and central regions of the SJR were the most visited. In particular, 42% of those who visited the SJR went to the central portion and 41% went to the northern portion, but only 20% went to the southern portion of the SJR.

In the online survey, we presented a map of the SJRB, along with eleven sites for respondents to choose (Figure 6-3). Table 6-6 shows the locations of their most recent visit in the SJRB. Middle (central) SJR offers abundant freshwater and land recreational opportunities. Survey results show that 57% of the respondents had visited the Middle SJRB in the last 12 months, compared to 15% to Upper SJRB and 21% to Lower SJRB.

Table 6-6. Sites in which the most recent visit occurred (online survey)

	No. of Response	Percentage
Lower/Northern SJR region	69	21%
1. Timucuan Preserve **2. (including Ft. Caroline & Kingsley Plantation)**	15	5%
3. Big Talbot Island Stake Park	11	3%
4. Bayard Conservation Area	8	2%
5. Other site in the northern SJRB	35	11%
Middle/Central SJR region	157	57%
6. Ocala National Forest	30	9%
7. Lake George	22	7%
8. Lake Ocklawaha (Rodman Reservoir)	14	4%
9. Silver Springs Stake Park	46	14%
10. Blue Springs State Park	17	5%
11. Other site in the central SJRB	58	18%
Upper/Southern SJR region	51	15%
12. Lake Monroe/Lake Monroe Park/Conservation Area	20	6%
13. Blue Cypress Conservation Area	13	4%
14. Lake Harney	4	1%
15. Other sites in the southern SJRB	14	4%
Other	18	6%
Total	325	100%

Perception of site quality - We summarize respondents' perception on the quality of the recreation site in Table 6-7. It is important to note that the respondents were specifically asked to rate the freshwater proportion of the recreational site for this question. Respondents in both the online and telephone surveys revealed similar perceptions on the freshwater proportion of the recreational site. Although the main stream of the SJR is classified as "impaired", most considered the site as having good and excellent quality, and only a few considered the site as having poor water quality.

Travel distances - Most of the respondents took day trips to visit the SJR, as 76% of the online respondents and 64% of the telephone respondents returned home on the same day as their visit. The average travel distance reported by online respondents was 78 miles, with a standard deviation of 136 miles, indicating large variation in the distances traveled by online respondents.

Table 6-7. Perception of the freshwater quality during the most recent visit (online survey)

Answer	Telephone survey Percentage	Online survey Percentage
Poor	3%	2%
Fair	9%	11%
Good	35%	37%
Excellent	54%	49%
Not sure	–	1%
Total observations	78	323

Table 6-8. Average travel distances to visit a site in SJR (Unit: miles, online survey)

	Mean	Stdev.
Timucuan Preserve (including Ft. Caroline & Kingsley Plantation)	44.6	51.3
Big Talbot Island Stake Park	116.2	277.8
Bayard Conservation Area	81.3	139.9
Other site in the northern SJRB	77.0	101.1
Ocala National Forest	72.1	59.2
Lake George	89.8	84.7
Lake Ocklawaha	76.8	142.7
Silver Springs Stake Park	47.0	36.6
Blue Springs Stake Park	80.9	66.6
Other site in the central SJRB	82.6	150.1
Lake Monroe	82.2	234.4
Blue Cypress conservation area	89.1	59.6
Other site in the southern SJRB	100.4	206.4
Lake Harney	25.6	5.0
Other	508.5	540.9

In the telephone survey, the average travel distance to the SJR was 55 miles, with a standard deviation of 24 miles, reflecting a smaller variation in the distances traveled by them.

The average travel distances to each site are summarized in Table 6-8. Most of the average distances to the 11 sites listed in the survey were less than 100 miles, indicating that most of the survey respondents lived nearby the recreational sites in the SJRB.

Reasons not to visit SJR - The respondents of the telephone survey who participated in outdoor recreation but who did not recreate in SJRB area were asked about the reasons why they did not consider SJRB, and 22.9% of them (or 27 out of 118 respondents) provided specific reasons. Most of them (17 respondents) stated that SJRB is too far to travel (with 53% of them, or 9 respondents, residing in south Florida region). In addition, 4 respondents stated that they are not familiar with the SJRB area, and 4 respondents preferred other areas for inland recreation. The responses aggregated in "other" category (5 respondents) included the lack of trails around St. Johns, and the availability of major recreational destinations located in the south of the SJRB area.

Demographics - The demographic characteristics of the two samples are summarized in Table 6-9. Most respondents in both samples are Caucasians (80% in the telephone survey and 91% in the online survey). The majority of respondents in the telephone survey are female (62%), while the majority of the respondents in the online survey are male (69%). The race and gender distributions in both surveys are not representative of the average demographics in the state of Florida, where 78.1% of the population is Caucasian and the female to male ratio is 51.1:48.9.

Table 6-9. Demographics characteristics of the samples

	Online survey	Telephone survey	Florida
Female	31%	61%	51%
Caucasians	91%	80%	78%
Median age	55	63	40.4
Education (College, professional and graduate level)	56%	50%	26.2%
Household income $50000 or more	72%	41%	50%[a]
Florida fulltime residents	91.73%	97.60%	–
Median/average household size	2	2	2.56
Home ownership	85%	85%	68%
Number of observations	511	475	19,552,860

Median household income in Florida was $47309 in 2012. Source: U.S. Census Bureau (2013).

The majority of the respondents in both samples are older than the median age (40.8) in Florida (US Census Bureau 2013). The median ages of the telephone and online respondents are 63 and 55 years old, respectively.

However, the gender, age, and racial compositions of the survey responses are comparable to national outdoor recreation statistics. According to the Outdoor Participation Report (OPR) (2013), females represented 45% of outdoor recreationists aged 25 to 44 years old, and 41% of recreationists were over 45 years old. Seventy percent of the respondents in the OPR identified themselves as Caucasian. For our survey, 91% of the online respondents were self-identified as Caucasian and 80% of the telephone respondents were Caucasians, which is closer to the census statistics on Florida. This higher percentage of Caucasian respondents in the online sample could be partially explained by the fact that our sample included both outdoor recreationists and members of advocacy organizations. Very few environmental organizations keep statistics regarding the diversity of their membership. However, of the 13 organizations out of a total of 103 that kept this information in the 2014 report, only 7 reported having any minority members (Taylor 2014). The participation of an older population is reinforced by the nature of these activities. Outdoor recreation is, after all, a leisure activity and requires a time commitment. It is possible that retired people are involved in organizations because they have more free time.

Respondents from both surveys tended to have higher levels of education and household income, compared to state categories. Over half of the respondents have a bachelor, graduate, or professional degree, compared with state statistics, which totaled 28.9% of citizens over the age of 25 years old. Higher levels of education were reflected in the income distribution, considering the median household income in Florida was $47,309. More than two-thirds of the respondents in the online survey had household income over $50,000, but only 41% of the telephone survey respondents had reported household income over $50.000. Respondents from both surveys tended to own their homes, with home ownership reported at more than 80%.

The future of freshwater resources and public policy opinions - To better understand outdoor recreation preferences, the questionnaire solicited information on respondents' level of concern for water issues and opinions about state environmental policies. It was hypothesized that environmental attitudes would be correlated with how individuals value outdoor recreation, which is shown by their trip demand function. Respondents were asked two questions about water expectations in their home county, as well as their opinion about state water laws and state budget expenditures, including spending on the environment. An additional question about their donation history to environmental causes was included.

It is clear that frequent users were more concerned about environmental quality than Florida residents in general, and they were more likely to donate for environmental causes. Of the respondents, 41% in the telephone survey considered their home counties to have severe to moderate problems with surface water quality (Figure 6-5a), as opposed to 60% in the online survey (Figure 6-6b). Only 20% of the respondents in both surveys considered their counties to have small problems with surface water quality. Of the respondents, 69% in the online survey had donated for environmental causes in the past five years, while 43% in telephone survey had done so.

In both surveys, respondents were less concerned about water shortage problems in their home counties than water quality problems. Of the respondents, 56% in online survey believed water shortage was likely or extremely likely to occur in their home counties in the next ten years (Figure 6-6b); while only34% in the telephone survey believed this to be true (Figure 6-6a).

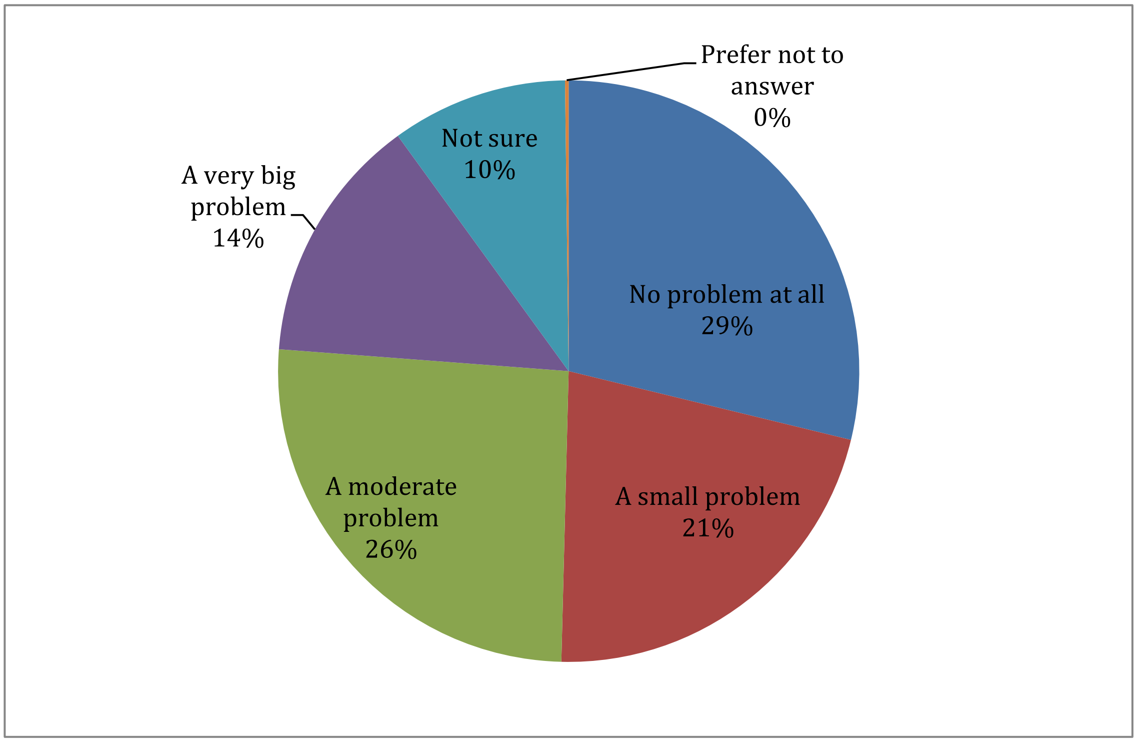


Figure 6-5a. Respondents' perception on the water quality in their home counties (telephone survey, N=500).

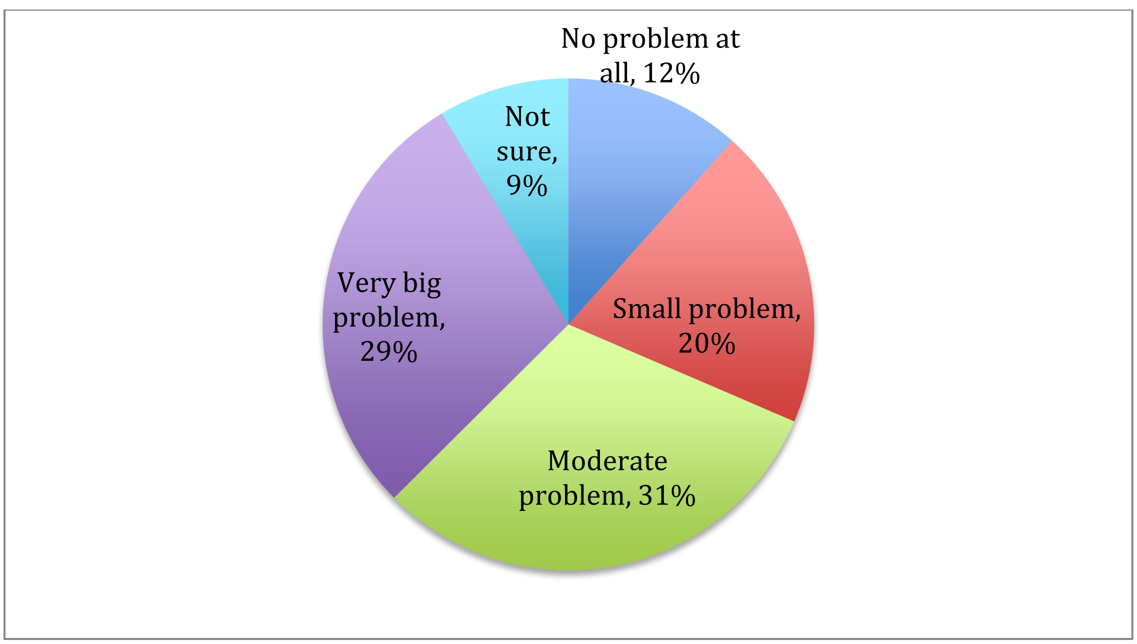


Figure 6-5b. Respondents' perception on the water quality in their home counties (online survey, N=534).

Note: the respondents were presented with the following question "In your home county, how much of a problem is the quality of water in the lakes, streams, rivers, and springs?"

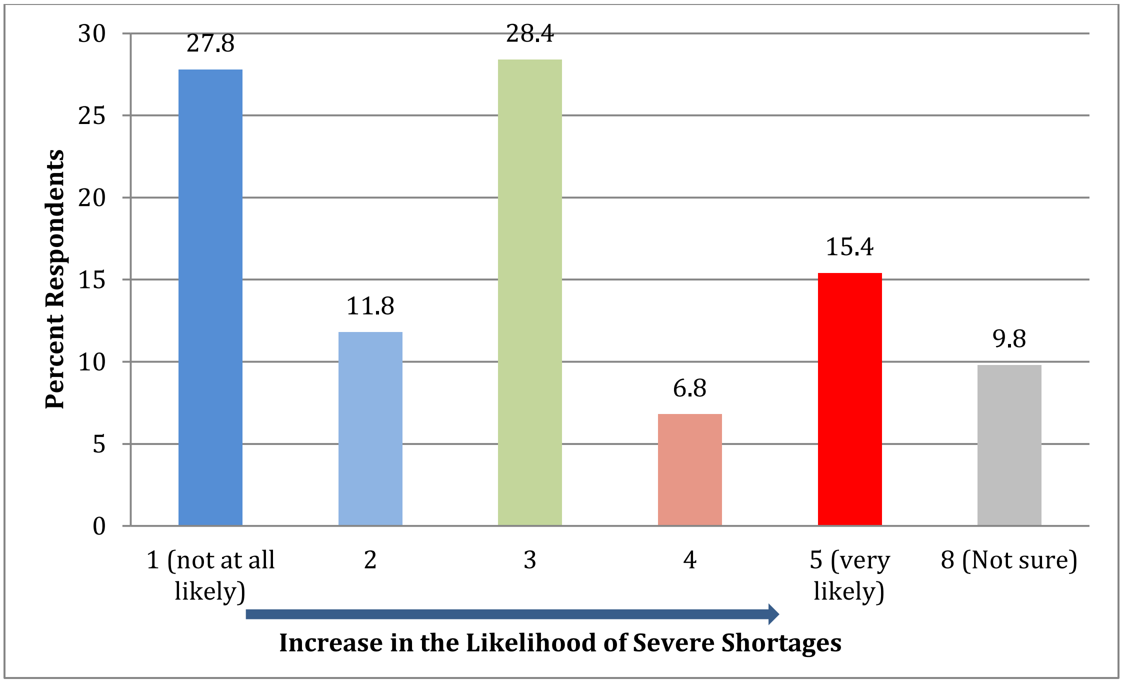


Figure 6-6a. Respondents' perception on the likelihood of water shortage in their home counties (online survey, N=500).

Note: the respondents were asked "using a scale from 1 to 5, where 1 is "not at all likely" and 5 is "very likely," how likely do you think it is that your home county will experience severe shortages of freshwater in the next 10 years? "

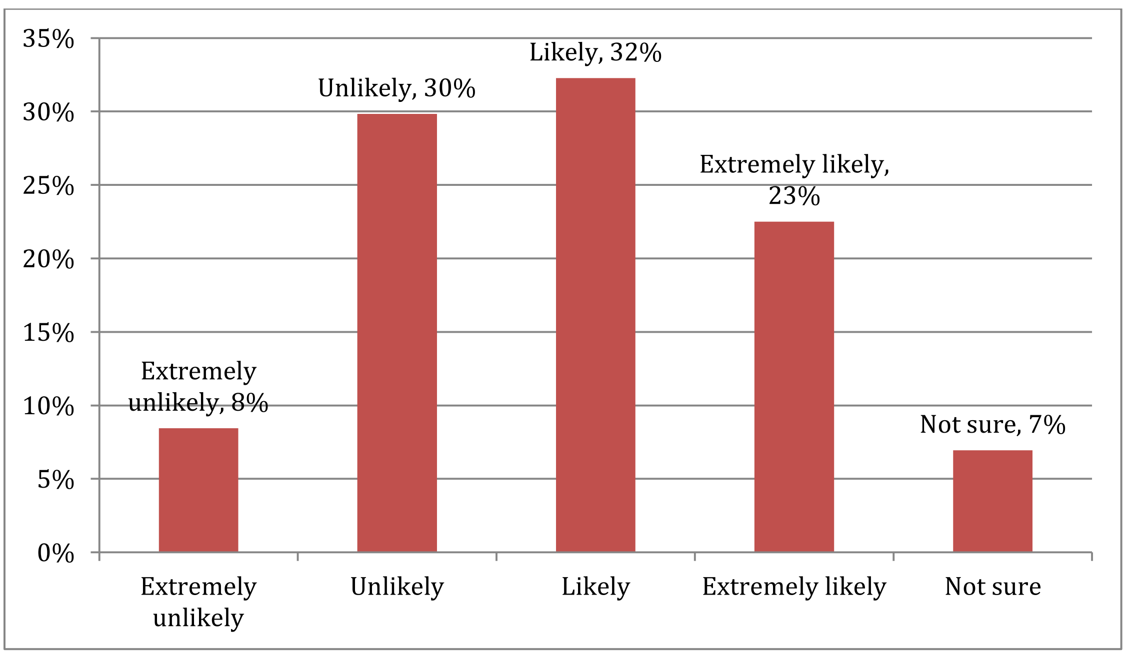


Figure 6-6b. Respondents' perception on the likelihood of water shortage in their home counties (online survey, N=533).

TCM estimation and Recreation Benefits - Following the stylized single-site TCM as shown in (1), we estimated an empirical model with the online survey responses from the "frequent users" of the SJR. In addition to the price/travel cost explanatory variables in (1), we added the following demographic variables that could shift the household recreation demand according to previous literature: household size, and respondents' education and income level, donations for environmental causes, and membership in environmental groups.

Calculating travel cost and substitute travel cost - As described in the Empirical approach section, the principal travel cost variable employs both travel and time expenses for each individual respondent. The first step in calculating the travel cost was estimating the distance traveled by each respondent. The mid-point of individuals' zip codes was used as a starting point to measure the distance to the latitude and longitude of the site respondents indicated as visiting during their last SJR trip. Distance calculated was the actual driving distance based on Google's Application Programming Interface (API)[2]. Each estimated distance was doubled in the TC calculation to represent round-trip distance, and then multiplied by $0.56 per mile cost (based on the 2014 IRS standard mileage rate). The travel cost to the substitute site (p_2) was calculated similarly. It is important to note that since the regions studied is small, the alternative TC values (p_2) were very close to the actual TC values (p_1), which could lead to underestimation of the effect of the substitute travel cost on trip frequency (x_1).

The opportunity cost of time was also included in total travel cost. Due to the hesitance of many people to provide exact income information, the survey questionnaire included income range categories for respondents to select. The ranges were consistent with the Internal Revenue Service income bracket definition. The lower bound of each category's dollar value was used[3] to estimate the opportunity costs of time (i.e., a conservative estimate). Furthermore, an average of 40 miles per hour (mpg) is assumed (Florida Department of Transportation 2014) to derive the driving time required to calculate the opportunity cost of driving to the site.

Perception of Site Quality – Visitors rated the quality of the most recently visited site, with the particular focus on the freshwater portion of the site, according to their own interpretation of "excellent" or "poor" quality. The rating may depend on education, experience in natural settings, visitation history to a particular area, and information available at the site. We hypothesized that the perception of the site quality would have a positive relationship to the number of trips to a site.

Many survey respondents were unable to rate the water quality because they had never been to particular sites. For such respondents, it was assumed that the site quality does not affect their visitation choice (i.e., zeros were entered for the water quality perception variable values for non-users). Although not optimal, it is common to impute zeros in studies that use offsite surveys (Bilgic and Florkowski 2007).

Model Estimation and Results - The summary statistics indicate potential for both an over-abundance of zeros in the dependent variable (i.e., large number of respondents who did not travel to the SJRB) and over-dispersion in the independent variables (i.e., larger than expected variability in the survey

[2] Euclidean distance was used in case driving distance was not readily available.
[3] Categories were under $20,000, $20,000–35,000, $35,000–49,000, $50,000–69,000, and $70,000 or more. The lower brackets of these categories were used to approximate household income level in the TCM.

responses). The suitability of a ZIP or ZINB model was tested against the standard Poisson or Negative Binomial using the Vuong test.[4] There was no statistical evidence suggesting that zero inflated models were preferred. To test for over-dispersion, a negative binomial model was regressed. In the output for this model, there is an α value that indicates over-dispersion, which was significant at the 1% level. In the end, Negative Binomial models were used to estimate TCM for both telephone and online samples (Table 6-10 and Table 6-13). Specifically, since we expect the online survey respondents to be frequent or avid recreationists of the SJR, a separate TCM was estimated for online sample in Table 6-13, as they may have different preferences than people who only recreate occasionally.

Table 6-10. Travel Cost Method Results (Telephone survey on Florida residents)

	Negative Binomial Model 1	Negative Binomial Model 2
VARIABLES	DV: No. of trips	DV: No. of trips
Travel cost	–0.017***	–0.018**
	(0.006)	(0.008)
Travel cost to alternative site	0.056***	0.042***
	(0.013)	(0.012)
Household income level	0.274	0.317
	(0.217)	(0.223)
Site quality	0.731***	0.806***
	(0.174)	(0.172)
Donation to environmental causes		
(1=had donation, 0 otherwise)		1.461***
		(0.341)
Age		-0.025**
		(0.011)

[4] The Vuong closeness test has a null hypothesis that the data are equally estimated in both models. A rejection of the null hypothesis signals that the data are more appropriately fit using a model with parallel processes (Bilgic and Florkowski 2007).

Household size		-0.148
		(0.142)
Alpha indicating over-dispersion	1.960***	1.796***
	(0.14)	(0.147)
Constant	–5.901***	–5.073**
	–2.194	–2.411
Log likelihood	362.24	334.68
AIC	736.48	687.45
Consumer surplus/ household /year/trip	$58.82	$55.56
Predicted number of trips per year	1.65	1.45
Annual consumer surplus per household	$97.67	$80.56
Observations	495	475
Total Households in Florida	7,147,013	7,147,013
Probability of visiting the SJR	15.6%	15.6%
Total annual benefits	$108.90 million	$89.82 million

Standard errors are in parentheses. ***, **, * significant at 1%, 5% and 10% level respectively.

Table 6-11. Marginal effects of site quality on number of visits

Perceived quality on the freshwater proportion of the site	Expected number of visits
Unknown (or indifferent)	0.11 (0.06)*
Poor	0.25 (0.11)***
Fair	0.54 (0.16)***
Good	1.22 (0.25)***
Excellent	2.75 (0.67)***

Standard errors are in parentheses. ***, **, * significant at 1%, 5% and 10% level respectively.

Table 6-12. Previous TCM literature and estimated recreation benefits in Florida

Publication	Geographical Scope	Recreation Activity	CS Estimates
Bell (1987)	Lake Okeechobee	Fishing	$8.3 million per year
Bell (1992)	Coastal beaches in Florida	Salt water fishing	$3.18 per day per person, $2 billion per year
Bell et al. (1995)	Lake Jackson	Water –based recreation	$3.68 per day per person
Bell et al. (1998)	Lake Tarpon	Water –based recreation	$3.3 per day per person
Siderelis and Moore (1995)	St. Marks Historic Railroad Trail in northern Florida (bike trail)	Biking, hiking	$49.78 per trip $8.55 million per year
Leeworthy and Bowker (1997)	Florida Keys	Open water recreation	$750 per person per day
Shrestha et al (2002)	Ocala national forest	Water-based recreation at the springs	$6.35 per person per trip; $1.3 million per year for current facility and $3.25 per year for greatly improved facility
Bhat (2003)	Florida Keys	Diving, snorkeling, glass-bottom boat riding	$122 per day per person
Shrestha et al (2007)	Apalachicola	Camping	$74.18 per trip per year
Morgan et al. (2009)	*USS Orskany* Pensacola	Diving	$480-750 per person per visit and $1.2-3.5 million per year

Table 6-13. Travel Cost Method Results (Online survey on frequent users)

	Negative Binomial Model
VARIABLES	DV: No. of trips
Travel cost	-0.00177**
	[0.000785]
Travel cost to alternative site	-0.00238**
	[0.00110]
Travel cost ^2	4.59e-06**
	[1.91e-06]
Travel cost to alternative site ^2	-0.00000087
	[3.02e-06]

Site Quality - Positive	-0.0195
	[0.0886]
Site Quality - Indifferent	-3.388***
	[0.201]
Household income - Middle	0.134
	[0.0956]
Household income - Upper	0.117
	[0.106]
Age	0.00461*
	[0.00262]
No Affiliation	-0.190**
	[0.0739]
Constant	1.813***
	[0.190]
AIC	1700.41
Log Likelihood	-838.21
Consumer surplus/ household /year/trip	$564.97
Predicted number of trips per year	4.67
Annual consumer surplus per household	$2638.41
Observations	477

Standard errors are in brackets. ***, **, * significant at 1%, 5% and 10% level respectively.

As expected, there was a negative inverse relationship between travel cost and recreation demand. However, in the telephone survey, alternative sites in the SJRB were substitutes (Table 6-10), but those became complements in the online survey (Table 6-13). It is likely that frequent users consider all those sites in the SJRB as complementary, whereas general population considered tradeoffs between distances and quality when selecting the location to visit.

Furthermore, as the water quality of the site improves, the number of trips was expected to increase, holding other variables constant. In particular, the expected number of trips would increase by 1.16 if the rating of the water quality increased by one unit. Table 6-11 summarized the marginal effects of the perceived water quality. For example, when the quality of the site was rated "poor", the expected number of visits would be 0.25; when the quality was rated "fair", the expected number of visits would be 0.54; when the quality was rated "excellent ", the expected number of visits would be 2.75.

Based on the estimated coefficients on travel cost variables in Table 6-10, we derived the per-household, per-trip benefit following equation (6-6). The median values of recreation benefits in the SJRB are between $55.56 and $58.82[5]. The predicted number of trips per year was $1.45 to 1.65. The annual consumer surplus for a household in Florida was between $80.56 and $97.67 provided by the SJR and the land-and-green space supported by the freshwater portion of the SJR. Given that the total number of households in Florida was about 7,147,013 (United States Census Bureau 2013), we found that 15.6% of those households visited the SJR for recreation in the past 12 months through the telephone survey. Conditional on the visitation rate of 15.6%, the annual recreational benefit provided by the SJR to the Florida residents was about $89.82 million to $108.90 million.

We compare the estimates with previous studies about water-based recreation in Florida, as summarized in Table 6-12. For example, Siderelis and Moore (1995) found the benefit of using the biking trail was $49.78 per person per trip (using 1993 US dollars), Shrestha et al. (2002) found that the benefit of recreating in the springs in Ocala National Forest was about $6.35 per person per trip in 2000; Bhat (2003) found that diving in the Florida keys provided $122 per person per day benefit; and Shrestha et al. (2007) found that the benefit of camping was $74.18 per trip per person. After converting those values to 2013 dollars and a trip of 2 persons, the per trip benefits reported ranged from $17.2 to $308. Excluding the highest benefit was from diving in the Florida Keys (i.e., salt-water recreation), the per trip benefits ranged from $17.2 to $160. Our estimates based on the sample from the general population in Florida fell within the above range.

We further estimated a separate TCM using online sample in Table 6-12. We found that the median per-household per-trip benefit was about $564.97, ten times of the benefit for the general public reported in Table 6-10. The predicted number of trips was 4.79, so the annual consumer surplus per household derived from visiting SJR was $2638.41 per household. Furthermore, 80% of the online respondents had visited the SJR in the past 12 months, and 67% of them planned to visit the SJR in the next 12 months. Thus, the estimated benefit conditional on their past visitation would be around 80%*4.79*$564.97 =$2176 per household per year.

Since the online survey used a convenient sample, we would not be able to estimate the exact proportion of the general population that would be frequent users of the SJR. However, we could make assumptions based the estimates from the telephone survey. Assuming our telephone survey represents the general population living in Florida, We found that 3% of the respondents in the telephone survey visited the SJR more than 6 times. Thus we could assume 3% of the Florida residents were avid recreationists, and their

[5] Assuming a normal distribution of the estimated coefficient on the travel cost variable, the derived consumer surplus from model 1 in table 6-10 is distributed with the median of 55.56, mean of 70.3, and standard deviation of 179.7 with 500 observations. Given the large variation in the derived consumer surplus, median values were reported.

benefits derived from recreating in the SJR would be much larger than the rest of the Florida residents. Additionally, 67% of them were planning to visit the SJR in the next 12 months, representing a consistent demand from the frequent users. The higher values derived from frequent users could be due to their pro-environmental altitudes, familiarity of the river, and higher social economic status (i.e., 72% of the online respondents had household income greater or equal to $50,000, Table 6-9).

Conclusions

In Summary, conducting surveys on the general public and the frequent users, we found that SJR provides direct recreation benefits to Florida residents. Specifically, the per-household, per-trip benefit derived from outdoor recreation in the SJRB is between $55.56 and $58.82 for the Florida residents, and was $564.97 for the frequent users of the SJR. Furthermore, 15.6% Florida residents (from the general population survey) had visited the SJR in the past 12 months, and their predicted number of trips to the SJR was 1.5. In contrast, 80% of the frequent users had visited the SJR in the past 12 months, and their predicted number of trips was 4.79.

The major recreational uses of the SJR include fishing, swimming, hiking, motorized boating, and non-motorized boating. The popular destination of the SJR was in the middle section, as 42% to 57% of the general population and frequent user respondents visited the Middle SJR. The SJR offers year-around recreation opportunities, and the visitations by frequent users from the online survey were distributed across spring, winter and summer months, but the general population respondents representing Florida residents concentrated their visits in the summer months (i.e., May to August).

We also found that those who live close to the SJR were more likely to recreate in the SJR, as the majority of online and telephone survey respondents undertook day trips to the SJR, and their average travel distances were 55 to 79 miles to a site in the SJR. Specifically, those who live in north and central Florida were more likely to visit the SJR than those from south Florida, since only 7% of the respondents sampled in the south Florida visited the SJR.

Respondents who participated in outdoor recreation but did not recreate in the SJR also explained their decisions. Far distance and unfamiliarity of the recreational opportunities in the SJR were specific reasons. In contrast, frequent users were familiar with the recreational opportunities in the SJR; 80% of them had visited the SJR in the past 12 months and 67% of them planned to visit again. Since lack of awareness seemed to have explained why Florida residents have not been enjoying the benefits offered by the SJR, market development strategies should be developed to market the SJR with the available recreational activities to the general public and emphasize the year-round opportunities.

We found that 86% to 89% of the online and telephone survey respondents perceived the quality of the freshwater during their last visited SJRB site to be “good” or “excellent”. Although we could not test the actual freshwater quality vs. the perceived freshwater quality, we found a strong and positive relationship between perceived water quality and the expected number of trips. For example, for a site rated as “fair” the predicted number of trips would be just 0.54; whereas for a site rated as “excellent” the predicted number of trips would be 2.75. Thus it is important to main freshwater quality at those recreation sites. Future research could also investigate the potential disparity of perceived freshwater quality vs. actual freshwater quality and examine how both indicators influence consumer’s willingness to pay for recreation. North and central Florida were more likely to visit the SJR than those from south Florida, since only 7% of the respondents sampled in the south Florida visited the SJR.

Respondents who participated in outdoor recreation but did not recreate in the SJR also explained their decisions. Far distance and unfamiliarity of the recreational opportunities in the SJR were specific reasons. In contrast, frequent users were familiar with the recreational opportunities in the SJR; 80% of them had visited the SJR in the past 12 months and 67% of them planned to visit again. Since lack of awareness seemed to have explained why Florida residents have not been enjoying the benefits offered by the SJR, market development strategies should be developed to market the SJR with the available recreational activities to the general public and emphasize the year-round opportunities.

Literature Cited

American Rivers (2008). *Most Endangered Rivers: 2008 Edition.* http://americanrivers.org.

Anderson, D. M. 2010. Estimating the economic value of ice climbing in Hyalite Canyon: An application of travel cost count data models that account for excess zeros. *Journal of Environmental Management, 91*(4), 1012-1020. doi:10.1016/j.jenvman.2009.12.010

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*(2), 169-193. doi:10.1890/10-1510.1

Bell, F.W. (1987). The Economic Impact and Valuation of the Recreational and Commercial Fishing Industries of Lake Okeechobee, Florida. Tallahassee, Florida, Final Report submitted to the Florida Game and Freshwater Fish Commission and Florida Department of Environmental Protection.

Bell, F.W., P.E. Sorensen and V.R. Leeworthy. (1982). Economic Impact and Valuation of Saltwater Recreational Fisheries in Florida. SGR 47. Tallahassee: Florida Sea Grant College Program

Bell, F. W., H. McGinnis, C. Story, and P. Rose (1995) The Economic Value of Lake Jackson. A.L. Burruss Institute of Public Service, Kennesaw State University, Kennesaw, Georgia.

Bell, F. W., H. McGinnis, C. Story, and P. Rose (1998). The Economic Value of Lake Tarpon, Florida, and the Impact of Aquatic Weeds A.L. Burruss Institute of Public Service, Kennesaw State University, Kennesaw, Georgia

Belleville, B. (2000). *River of Lakes: A Journey on Florida's Saint Johns River*. Athens.

Bhat, M. G. "Application of Non-Market Valuation to the Florida Keys Marine Reserve Management." Journal Environmental Management, 67(4): 315-325, 2003.

Bilgic, A., & Florkowski, W. J. (2007). Application of a hurdle negative binomial count data model to demand for bass fishing in the southeastern United States. *Journal of Environmental Management*, *83*(4), 478-490. doi:10.1016/j.jenvman.2006.10.009

Bockstael, N. E., Hanemann, W. M., & Kling, C. L. (1987). Estimating the value of water quality improvements in a recreational demand framework. *Water Resources Research*, *23*(5), 951-960. Retrieved from http://onlinelibrary.wiley.com/doi/10.1029/WR023i005p00951/full

Bockstael, N. E., Boynton, R. Costanza, R. Strand, & Bell, K. (1995). Ecological economic modelling and valuation of ecosystems. *Ecological Economics*, 14, 143-159.

Costanza, R., D'Arge, R., Groot, R., & Farber, S. (1998). The value of the world's ecosystem services and natural capital. *Nature*, *387*, 253-260. Retrieved from http://inis.iaea.org/search/search.aspx?orig_q=RN:29045320

Creel, M. D., & Loomis, J. B. (1990). Theoretical and empirical advantages of truncated count estimators for analysis of deer hunting in California. *American Journal of Agricultural Economics*, *72*(2), 434-441.

Elmqvist, T., Tuvendal, M. Krishnaswamy, J., and Hylander, K. (2011). Managing tradeoffs in ecosystem services. Ecosystem Services Economics (ESE) Working Paper Series #4. Ecosystem Services Economics Unit, Division of Environmental Policy Implementation, UNEP, Nairobi, Kenya.

Fleming, C. M., & Bowden, M. (2009). Web-based surveys as an alternative to traditional mail methods. *Journal of Environmental Management*, 90(1), 284-292.

Florida Department of Environmental Protection (FDEP). 2014. *Final TMDL Documents*. http://www.dep.state.fl.us/water/tmdl/final_tmdl.htm

Florida Division of Recreation and Parks. (2014). *Welcome to Florida State Parks: Activities*. Retrieved from http://www.floridastateparks.org/thingstodo/activities.cfm.

Florida Office of Economic and Demographic Research (FOEDR). 2012. *Florida 2010 Census Detailed County Profiles*. http://edr.state.fl.us/Content/population-demographics/2010-census/data/index.cfm

Florida Department of Transportation. (2014). *Frequently Asked Questions–Speed Limits*. Retrieved July 15, 2014, from http://www.dot.state.fl.us/trafficoperations/FAQs/SpeedLimitFAQ.shtm

Freeman,A. M., Herriges, J. A., & Kling, C. L. (2014).*The Measurement of Environmental and Resource Values: Theory and Methods*. Routledge.

Gao X. 2006. *TMDL Report: Nutrient and DO TMDLs for the St. Johns River above Lake Poinsett (WBID 2893L), Lake Hell n' Blazes (WBID 2893Q), and St. Johns River above Sawgrass Lake* (WBID 2893X). FDEP, http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp3/usjr_tmdl-060425_01.pdf

Haab, T. C., & McConnell, K. E. (1996). Count data models and the problem of zeros in recreation demand analysis. *American Journal of Agricultural Economics*, *78*(1), 89–102.

Haab, T. C., & McConnell, K. E. (2002). *Valuing Environmental and Natural Resources: The Econometrics of Non-market Valuation*.

Hanley, N., Shogren, J. F., & White, B. (2007). *Environmental Economics in Theory and Practice*. New York: Oxford University Press.

Internal Revenue Service (IRS). (2013). Notice 2013/80. http://www.irs.gov/pub/irs-drop/n-13-80.pdf

Internal Revenue Service (IRS). (2014). *Standard Mileage Rate* (2014).

JAXPORT. (2013). *Port Statistics 2013*. Retrieved from http://www.jaxport.com/sites/default/files/docs/statistics_september2013.pdf.

Lakes Harney and Monroe and Middle St. Johns River Basin Technical Stakeholders. (2012). *Basin Management Action Plan for the Implementation of Total Maximum Daily Loads for Nutrients and Dissolved Oxygen Adopted by the Florida Department of Environmental Protection in the Middle St. Johns River Basin for Lake Harney, Lake Monroe, Middle St. Johns River, and Smith Canal*. FDEP, Tallahassee, FL. Retrieved from http://www.dep.state.fl.us/water/watersheds/docs/bmap/harney-monroe-bmap-final.pdf.

Leeworthy, Vernon R.; Bowker, J. Michael 1997. Nonmarket economic user values of the Florida Keys/Key West. Silver Spring, MD: National Oceanic and Atmospheric Administration, Strategic Environmental Assessments Division. 41 p.

Lower St. Johns River TMDL Executive Committee. 2008. *Exhibit 1: Basin Management Action Plan For the Implementation of Total Maximum Daily Loads for Nutrients, Adopted by the Florida Department of Environmental Protection for the Lower St. Johns River Basin Main Stem*. FDEP, Tallahassee, FL. Retrieved from http://www.dep.state.fl.us/water/watersheds/docs/bmap/adopted-lsjr-bmap.pdf.

McCarthy, K. M. (2008). *St. Johns River Guidebook*. Sarasota, FL: Pineapple Press.

Millennium Ecosystem Assessment (MEA). (2003). *Ecosystems and Human Well-being: A Framework for Assessment*. Washington, D.C.: Island Press.

Morgan, O. A., Masey, D. M., & Huth, W. L. (2009). Diving demand for large ship artificial reefs. *Marine Resource Economics*, 24(1), 43-59.

Outdoor Foundation. (2013). *Outdoor Recreation Participation Report*. Retrieved from http://www.outdoorfoundation.org/pdf/ResearchParticipation2013.pdf.

Parsons, G. R. (2003). The Travel Cost Model. In P. A. Champ, K. J. Boyle, & T. C. Brown (Eds.), *A Primer on Nonmarket Valuation* (pp. 269–330). Norwell, MA: Kluwer Academic Publishers.

Patterson, S. (2009, April 13). SJR Water Withdrawal Permit Approved. Florida Times-Union (Jacksonville.com), Retrieved from http://jacksonville.com/news/2009-04-13/story/st_johns_water_withdrawal_permit_approved.

Shrestha, R.L., J.R.R. Alavalapati, T.V. Stein., D.R. Carter, and C.B. Denny. 2002. Visitor preferences and values for water-based recreation: A case study of the Ocala National Forest. ***Journal of Agricultural and Applied Economics*** 34(3):547–559.

Shrestha, R. K., Stein, T. V., & Clark, J. (2007). Valuing nature-based recreation in public natural areas of the Apalachicola River region, Florida. *Journal of Environmental Management*, 85(4), 977-985.

SJRWMD. (2013). *St. Johns River Water Management District Water Supply Plan* (pp. 1–115). SJRWMD, Palatka, FL:

SJRWMD. (2014a). Upper St. Johns River. Retrieved from http://www.sjrwmd.com/upperstjohnsriver.

SJRWMD. (2014b). Water Supply: Priority list and schedule and draft reports. Retrieved from http://floridaswater.com/minimumflowsandlevels/prioritylist.html.

SJRWMD. (2014c). *SJRWMD Recreation Guide to District Lands*. SJRWMD, Palatka, FL. Retrieved from http://www.sjrwmd.com/recreation/.

Siderelis, C and Moore, R.L. 1995. Outdoor recreation net benefits of rail-trails. *Journal of Leisure Research*, 27(4): 344–359.

Taylor, D (2014). *The State of Diversity in Environmental Organizations*. Prepared for Green 2.0.

United States Census Bureau. (1930). Census of Population and Housing. census.gov.

United States Census Bureau. (2013). *State and County QuickFacts*. Retrieved from http://quickfacts.census.gov/qfd/states/12000.html.

USDA. (2014). *2012 Census of Agriculture*. *Table 2*. Market Value of Agricultural Products Sold Including Direct Sales: 2012 and 2007. http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_County_Level/Florida/

US EPA. (1997). *American Heritage Rivers*. Washington, DC.

US EPA. (2014). *Watershed Assessment, Tracking & Environmental Results: Florida Impaired Waters and TMDL Information*, US EPA, Washington, D.C. Retrieved from http://iaspub.epa.gov/tmdl/attains_state.control?p_state=FL&p_cycle=&p_report_type=T

USGS. (2014). *Estimated Use of Water in the United States in 2005*. Download 2005 data for counties. http://water.usgs.gov/watuse/

Chapter 7

An Estimate of the Current and Potential Value of Ecotourism in the St. Johns River

By

Xiang Bi and Tatiana Borisova
Assistant Professors

Sherry Larkin, Professor
and
James Longanecker
M.S. Student

Food and Resource Economics Department
University of Florida
Gainesville, FL

Abstract

The economic value and the potential for future ecotourism activities in St. Johns River Basin (SJRB) area were evaluated through surveys including online surveys selected from Florida freshwater fishing license holders and those belonging to organizations that potentially use the river, e.g. Florida Professional Paddlesports Association. Assuming that ecotourism attracted both out-of-state and Florida residents a minimum estimated value from ecotourism activities could be around half of the recreational benefit provided by the SJRB or about 50 million dollars per year.

Introduction

Ecotourism is defined as “responsible travel to natural areas that conserves the environment and improves the well-being of local people.” Its principles include: “minimize environmental impact, build environmental and culture awareness and respect, provide direct financial benefits for conservation, provide financial benefits and empowerment for local people, and raise sensitivity to host countries’ political, environmental and social climate.” (TIES 2014). Following these principles, many existing recreation activities in the SJR could be considered as ecotourism activities. For the purpose of this chapter, we focus on non-motorized boating, wildlife viewing, hiking, biking, picnic or horseback riding, camping and swimming, snorkeling or diving.

According to the Outdoor Participation Report (Outdoor Foundation, 2014), 10% of Americans aged 6 and above participated in recreational kayaking, 6% participated in backpacking, 3% participated in wildlife viewing or bird watching, and 2% participated in hiking (Table 7-1). The potential of outdoor recreation participants could be from 10% to 21% of the U.S. population aged 6 and above. To tap into the potential market of developing ecotourism from those outdoor recreation activities, it is important to assess the current level and potentials of those activities in the SJR.

We identify the current level of ecotourism activities, examine the potential for future ecotourism activities, and provide valuation of current ecotourism in the SJR using standard approaches.

Technical Approach

To achieve the study objectives, we designed and administered two surveys targeting different populations of interests: (a) a telephone survey of a random sample of households living in Florida, and (b) an online survey distributed to a sample of Florida freshwater fishing license holders and subscribers and/or members of environmental and recreational organizations’ listserv in SJRB area (referred to as “frequent users” below). The surveys included questions about the trips to SJRB area for recreation activities in the past 12 months, the types of ecotourism activities during the most recent trip, socio-demographics, and other questions.

Respondents were asked to identify primary recreation activities of the most recent trip in SJR, and we classified the following activities as ecotourism: non-motorized boating, wildlife viewing, hiking, biking, picnic or horseback riding, camping and swimming, and snorkeling or diving. Such activities as fishing from a pier, boat, or shore, motorized boating, hunting were not considered to be ecotourism activities.

Environmental and recreational groups and people with Florida freshwater fishing licenses (referred to as “frequent users” below) are more likely to visit the SJR, and they have more information about the opportunities and current state of the SJR. Hence, the on-line survey targeting these groups included additional questions about the current level of ecotourism activities, as well as suggested additional ecotourism activities. These questions were omitted from the household phone survey. (For more details about the online survey design and administration, see Chapter 6 of this report.)

Current and Potential Level of Ecotourism Activities

Based on the online survey of frequent users, out of 323 online respondents that had recreated in the SJR Basin area in the past 12 months, 180 (55.72%) had participated in the ecotourism activities as we defined above (Table 7-1). The most popular eco-tourism activity was non-motorized boating. Out of the 351 online respondents that visited the SJR, 27% reported non-motorized boating (e.g., kayaking and canoeing), 12% reported land-based activities including hiking, picnic, biking and horseback riding, 9% reported swimming, and 6% reported wildlife viewing as the primary activity during their most recent visit to the SJR (Table 7-1). It is important to note that the online survey respondents include major paddler groups, which could explain the popularity of non-motorized boating in the sample. This order of popularity remains consistent across the upper, middle and lower segments of the SJR.

Table 7-1. Ecotourism's Activities Reported by Online and Telephone Survey Respondents.

	Online survey (random sample of households)	Telephone survey (frequent users)	Nationwide Outdoor participation report[a]
Swimming, snorkeling, or diving	9%	18%	3.4%(snorkeling)
Hiking, horseback riding, picnic and other land-based activities	12%	17%	10.8% (hiking)
Non-motorized boating	27%	8%	0.5% (recreational) kayaking)
Bird watching or wildlife viewing	6%	6%	13.2%
Camping	2%	6%	15.1%
Total ecotourism activities	56%	55%	43%
Observations	**351**	**78**	**19,240**

[a]Note: Those statistics were based on a national representative sample of all Americans aged 6 and above on participation of outdoor recreation activities and ecotourism activity was not directly included in the estimates. Source: Outdoor foundation, 2014. Outdoor Participation Report. http://www.outdoorfoundation.org/pdf/ResearchParticipation2014.pdf

Accessed on October 20, 2014

Out of the 180 (i.e., 56%) online respondents that participated in potential ecotourism activities, 67% of them visited the middle/central section of the SJR, and 21% visited the lower/northern section of the SJR and only 13% visited the upper/southern section of the SJR.

We further tabulated the frequency of visits to SJRB area by the quarters of the year (Table 7-2). The survey was conducted in September, and respondents were asked to recall their most recent trip, and that could partially explain the high reported frequency of visits in July to September. This visitation pattern was similar for ecotourism and other activities.

Table 7-2. Recreation Activities by Months (online survey)

	January-March	**April to June**	**July to September**	**October to December**
Ecotourism Activities				
Hiking/biking/picnic	21%	13%	58%	8%
Wild life viewing/Bird watching	5%	15%	80%	0%
Swimming	3%	20%	77%	0%
Camping	33%	17%	50%	0%
Non-motorized boating	6%	19%	74%	1%
Other recreation activities				
Hunting	33%	11%	33%	22%
Fishing	23%	24%	47%	5%
Motorized boating	8%	11%	82%	0%
Other	9%	50%	41%	0%
Total recreation activities	13%	20%	64%	3%

Perception of ecotourism opportunities (online survey only) – For the question about the number of available ecotourism opportunities in the SJR (based on the experience from the most recent visit), 50% of respondents that visited the SJR replied that the number was "just about right", and 43% indicated that there are "not enough" or "not nearly enough" (Figure 7-1). We further asked the respondents to identify /recommend additional ecotourism activities based on their recent visit to the SJR. The recommended activities, in order of frequency, include: non-motorized boating, bird watching or wildlife viewing, hiking, biking, picnic or horseback riding, camping, and geocaching. Comparing the recommended activities with the current activities respondents reported (see figure 6-4a in chapter 6), while 6% of respondents enjoyed bird watching and wildlife viewing type of activities in the past 12 months, 29% of them recommended such activities for the SJR (Figure 7-2). Additionally, less than 5% respondents reported to have camped or played geocache in the SJR, but a much higher percentage of respondents (i.e., 16% recommended geocaching and 25% recommended camping) recommended both activities to be suitable ecotourism activities in the SJR in the future. It is important to note, although the most frequently reported activity was swimming, snorkeling or diving in the telephone survey, such activities were not highly recommended by online respondents for additional ecotourism, potentially implying that the opportunities for such activities are already plentiful.

We also asked respondents to provide specific comments on expanding ecotourism activities. Some of the comments were listed here. Some commented, "additional interpretative activities and tours should be provided at the site." Other comments included: "additional boat ramps and boat rentals", "expanding areas for fishing"; "allowing swimming/snorkeling in the head springs", "adding mountain biking and zip lines", and "removing restrictions for motorized boating." Although those recommendations may not always fall into the categories of ecotourism, future research could focus on specific recreational sites and identify their potentials.

Value of Ecotourism Activities – The proportions of respondents that conducted ecotourism activities in the SJR ranged from 55% to 56% in both online and telephone survey. Based on the estimates reported in Table 6-10 and Table 6-13, we thus could assume that around 55% to 56% of those benefits supported by the SJR was derived from those ecotourism activities.

Conclusions

SJR offers great potentials for ecotourism activities and more than half of the visitors reported participating in ecotourism activities. Specifically, only 5-6% of the respondents participated in camping and bird watching/wild life viewing in the SJR Basin area, but 16% to 29% of them recommended those as additional activities.

However, lack awareness of those potentials could prevent Florida residents from visiting the SJR. Although we did not systematically interview local businesses that offer boat tours and other ecotourism services, anecdotally, respondents of our survey had mentioned lack of tours and facilities as potential hurdles.

This study focuses on the value of ecotourism activities for the visitors, and it does not consider the contribution of ecotourism to local economy. In future, an economic impact analysis study can be conducted to examine the total spending by the visitors, and related revenue generated by recreational businesses, number of jobs created, and tax revenues that can be attributed to the effects of the ecotourism activities in the SJRB area.

Literature Cited

The International Ecotourism Society (TIES).2014. http://www.ecotourism.org/ Accessed on August 20, 2014.

Outdoor Foundation. 2014. Outdoor Participation Report.

http://www.outdoorfoundation.org/pdf/ResearchParticipation2014.pdf Accessed on October 20, 2014

Chapter 8

What is a River Worth?
Summary

By

Courtney T. Hackney
Department of Biology
University of North Florida
Jacksonville, FL 32224
c.hackney@unf.edu

Introduction

The fact that the term Ecology and Economy are derived from the same Greek root should not be surprising, as both fields of study follow interactions and linkages within systems. Ecology examines linkages within the natural system, while Economy follows many of these same connections, albeit within the human system. Understanding the value of the St. Johns River (SJR) to people along its 310 mile length through use of an “Ecosystems Services” approach (See Chapter 1) brings both disciplines together. It also allows direct measurement in dollars of natural processes that are inherent in the SJR system. Conceptually, it is relatively easy to find potential linkages between economy and ecology. This was explored in Chapter 1. Determining actual value of the natural functions of the SJR to the people of Florida is far more complex (See Chapter 2), but possible, thanks to data on hydrology, water quality and Biology that resides with the St. Johns River Water Management District (SJRWMD). This data base and work by the SJRWMD staff over many years allows the application of an Ecosystems Services approach to this large and complex river system. Note that several of the priorities identified by the initial workshop (See Introductory Chapter) were not amenable to an Ecosystems Approach, e.g. property values along the SJR (Chapter 4). However, water quality produced by natural processes of the river directly influenced values associated with living and using the river (Chapters 4, 6 & 7).

Theoretical linkages between the economy of the SJR and river processes were explored in Chapter 1 and shown again in Figure 8-1. This table does not include every potential link or include economic benefits not directly connected to an ecological function of the SJR.

SERVICE → **ECO-SYSTEM ↓**	Storm protection	Water level buffer & flood regulation.	Water purification. & nutrient retention	Fish and wildlife production	Carbon sequestration	Sediment & erosion control	Agriculture & timber production	Arts, scenery, & recreation	Education & research	Job creation
Tidal marsh & mudflats										
Submersed vegetation beds										
Freshwater wetlands & floodplains										
Estuary*										
River, stream, & lake*										

Springs†										
Forests & timberland										
Cropland										
Grassland & rangeland										
Aquaculture										
Urban & roadway										

Figure 8-1 Showing aspects of the natural function of the SJR for which there are now economic estimates. Note the number of important ecosystem functions for which there are no direct economic estimates.

All estimates of economic value have margins of error associated with them and/or caveats that may require additional study, economic and ecological. Chapter 2 of this report includes extensive modeling constructed around a wealth of data supplied by the SJRWMD. Without these data, modeling of the degree to which wetlands and the SJR Basin absorb extreme rainfall events could not be done with the same level of precision. Output generated by the suite of models used in chapter 2 undoubtedly provides an extremely accurate picture of water level response of the SJR from extreme flood events, but does not necessarily relate to measurable increases in property value even though these wetlands retain large quantities of water that could flood downstream properties in flood zones. Clearly, wetlands retain floodwater during extreme events. The value of these wetlands for flood retention is difficult to evaluate, but based on the increased extent and depth of flooding without wetlands it is significant. Prevention of all flooding from 100-year events would result in almost $3 billion dollars is savings or $15,000 for each residence within the flood zone. There are limits to interpretation noted in Chapter 2, largely around use of these data for future projections in tributaries. The degree of future development along tributaries, which brings increasing impervious surfaces to the landscape is unknown, as are impacts from other land modifications within the basin.

It should also be noted that there are other issues that are not considered in these studies, but that may have large impacts depending on their resolution. Springs are a significant issue and an important source of water volume and nutrients to the SJR. Reduced flows from springs and reduced water quality in these water sources may be significant issues in the future.

Table 8-1. Summary estimates of economic values associated with the St. Johns River per annum.

Ecological Function	**Estimated Value in millions of dollars**
Flood Abatement (Chapter 2)	Total flood abatement would save approximately $3 billion dollars.
Nutrient Removal – Nitrogen (Chapter 3)	$400 (Conservative estimate See Chapter 3 for details)
Nutrient Removal – Phosphorus (Chapter 3)	$5.3 (Conservative estimate See Chapter 3 for details)
Increased Proximity to River [Property Values] - (Just for Nassau, Duval, St. Johns and Clay counties (Chapter 4)	
Riverfront	$944
Tributary Frontage	$117
Proximity to River	$837
Increased taxes if water quality highest	$2.2
Direct water Withdrawals (surface water) (Chapter 5)	
Public Use	$6.28
Agriculture	$4.23
Recreational (Irrigation)	$39.62
Power Generation	$6.96
Recreation	$89-108
Ecotourism	$45

Wetlands within the SJR basin have a dramatic impact on water quality by removing nutrients. Ideally, there would be data from similar rivers that describe uptake and sequestration of nutrients that could be used to provide additional data on uptake, but the subtropical nature and low slope of the SJR make it unique. Some data on nutrient uptake by other wetlands is included, but the unique status of the SJR necessitated at least some sampling and analyses for the report (Chapter 3). Additional sampling could improve the precision of estimates of nutrient removal by wetlands along the SJR. Estimates of costs associated with removal of nutrients vary dramatically because costs associated with different methodologies to remove nutrients from water vary depending on source of nutrients, concentration, etc. If people had to remove nitrogen and phosphorus via some other methods to maintain current water quality, billions of dollars would be required per year to accomplish what the river does naturally given current loading levels. Estimates in Table 8-1 assume the least costly alternative. Assumptions that the river system could continue to absorb the current or increased level of nutrient additions may not be warranted, especially given current estimates of potential sea level rise. The fact that a significant level of both phosphorus and nitrogen reach the mouth of the river and impact water quality, suggests that SJR wetlands have already reached their maximum ability to absorb nutrients.

The aesthetic value of the river to people is reflected in the price they are willing to pay to be adjacent to the SJR and associated tributaries. Table 8-1 shows the increased value of real property from its association with the SJR as compared to similar properties not associated with the river for just the four most downstream (northern) counties (See Chapter 4). These are the four most urbanized counties along the river. The increase in tax base from an association with the river is significant (Table 8-1). Perhaps most interesting is the potential increase ($2.2 million) in tax revenues per year if the water quality of the river was at its highest quality in portions of the SJR adjacent to these four counties where surface water is not of highest quality. While small in comparison to the total value of real property, this demonstrates the connection between river health and tax base of local governments. Conversely, a decline in water quality has the potential of significantly reducing the current tax base associated with proximity to the river. As urban and suburban areas associated with the SJR expand, this increased tax base will also expand in all counties along the SJR providing water quality can be maintained in high state.

Perhaps most surprising was the use of the SJR by Florida residents (Chapter 6). Sixteen percent had traveled to the SJR for some form of recreation during the past year. Florida residents in general seem to be aware of water quality issues with the river, but comfortable enough with the current quality to use the river and associated parks. The approach used to estimate economic value was based upon surveys. Final dollar values generated incorporated standard economic multipliers. There seems to be significant potential to increase out-of-state ecotourism in the river, which may currently be about $45 million dollars per year (Chapters 6 and 7).

It is tempting to summarize economic values estimated in this report (Table 1), but extreme caution should be used. Note that chapters 6 and 7 utilized multipliers that are standard in economic studies, while other chapters reported actual cost estimates, drastically underestimating the value of these functions to the public. Also, note aspects of the SJR that were not included because of the lack of both funding and time required to generate the required analyses. Commercial fish harvest within the river is relatively small and only reflected here in the recreational and ecotourism components (Chapters 6 and 7). The large commercial and recreational fishery associated with the coast of NE Florida is almost certainly important to the economy of the region. Extensive scientific literature on the relationship of river and estuaries to coastal fisheries exists (Boesch & Turner 1977, Lindall & Soloman 1977, Turner 1977,Weinstein 1979). The SJR is no exception and clearly serves as a nursery for many coastal fish and shellfish species harvested outside the SJR basin. An accurate estimate of this Ecosystem Service component would be significant from an economic standpoint.

Much of the value that most residents associate with the SJR revolves around the river as a transportation corridor that drives Jacksonville's commercial and military Ports, as well as upstream marinas that drive significant economic activity as far upstream as Green Cove Springs. Given the current funding being provided or promised by local, state and federal governments, it is clear that this component of the SJR's value to the economy of Florida is recognized.

It is hard today to imagine the SJR that the famous naturalist William Bartram followed south during his travels in 1773-1778 (Bartram republished in 1928). Bartram's adventures as he traveled along the SJR make interesting reading, especially his description of the SJR below.

> *"The shores of this great river St Juan are very level and shoal, extending in some places, a mile or two into the river, betwixt the high land and the clear waters of the river, which is so level, as to be covered not above a foot or two deep with water, and at a little distance appears as a green meadow, having water grass and other amphibious vegetation growing in oozy bottom, and floating upon the water."*

Some have interpreted this passage to mean that algae covered the river's surface, but Bartram makes it clear during his journey up the St. Johns River that water in the river was extremely clear; so much so that plants rooted on the bottom grew their leaves to the surface. For the people living along the SJR in the last part of the 18^{th} Century, this shallow river provided clean water, transportation and abundant food in the form of fish, birds and various other animals associated with the river. Since Bartram's travel in the SJR, sea level has risen, dams have been built, channels dredged, exotic plants and animals introduced and the entire landscape altered by an ever increasing human population. While some of the Ecosystem Services of the SJR have clearly changed since Bartram's time (some increased and some decreased), ecological functions associated with the river continue to benefit people and the economy of the entire region and state.

References

Bartram, W. 1928 (unabridged Edition). *Travels of William Bartram*. Dover Publications, NY.

Boesch, D.F. and R.E. Turner. 1984. Dependence of fishery species on salt marshes: The role of food and refuge. Estuaries 7:460-468.

Lindall, W.N., Jr. and C.H. Soloman. 1977. Alteration and destruction of estuaries affecting fishery resources of the Gulf of Mexico. Marine Fisheries Review 39:1-7.

Turner, R.E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Transactions of the American Fisheries Society 106:411-416.

Weinstein, M.P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, NC. Fishery Bull. 77:339-357.

UNF

UNIVERSITY *of*
NORTH FLORIDA™