

# **Modeling of the Wolf Bay and Perdido Bay Watersheds using HSPF**

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## **ABSTRACT**

This study is the first stage of the larger project for determining the transport mechanism of endocrine disruptors that flow through the Perdido Bay Basin. Given within are the methods and processes used to perform watershed delineation, determine watershed area and hydrologic and hydraulic connections of subwatersheds and rivers, properties of subwatersheds, and other hydrologic modeling parameters. These were determined by starting with LIDAR raster data to create digital elevation models, then using geographic information systems to create drainage basin networks for eight major watersheds. Hydrological Simulation Program-Fortran (HSPF) models were then developed for these watersheds, and model parameters were specified using HSPFParm and other available data.

HSPF models for the Perdido River, Styx River, and Elevenmile Creek watersheds were all calibrated sufficiently. The Hammock Creek, Milflin Creek, and Blackwater River watersheds had no gage data to calibrate with, however models were created and adjusted from default values by using the values from the most similar calibrated model. The Wolf Creek model had partial calibration due to a lack of wastewater treatment plant discharge data availability. Finally, the Marcus Bayou model's calibration was not satisfactory (low model efficiencies) due to multiple data issues and unique watershed characteristics (e.g., low slope, coastal groundwater effects).

This study's conclusions are that the Perdido, Styx and Elevenmile HSPF models are sufficiently modeled and calibrated and a plan to integrate simulated discharges from HSPF models and unmodeled areas with a hydrodynamic model of Perdido Bay and Wolf Bay was developed. However, more data needs to be acquired to adequately model Wolf Creek and Marcus Bayou. In addition, more sources of water quality data need to be obtained to perform adequate water quality analysis.

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## LIST OF ABBREVIATIONS

AGWRC	Basic Groundwater Recession Rate
AWW	Alabama Water Watch
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BMP	Best Management Practice
CFS	Cubic feet per second
CLOU	Cloud Cover (%)
DEEPER	Fraction of Groundwater Inflow that enters Inactive Groundwater
DEM	Digital Elevation Modal
DO	Dissolved Oxygen
DSM	Digital Surface Model
EPA	Environmental Protection Agency
FFWCC	Florida Fish and Wildlife Conservation Commission
GIS	Geographic Information System
GIWW	Gulf Intercostal Waterway
GWVS	Groundwater Slope
HSPF	Hydrological Simulation Program-Fortran
HUC	Hydrologic Unit Code

INFILT	Infiltration Capacity
INTFW	Interflow Inflow
IRC	Interflow Recession Coefficient
LIDAR	Light Detection and Ranging
LSPC	Loading Simulation Module, in C++
LZETP	Lower Zone Evapotranspiration
LZSN	Lower Zone Nominal Storage
MRLC	Multi-Resolution Characteristics Consortium
NCDC	National Climatic Data Center
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NWS	National Weather Service
NPS	Non-Point Source
NRCS	National Resources Conservation Service
NOAA	National Oceanic and Atmospheric Administration
NSUR	Manning's n for Overland Flow Plane
PEVT	Potential Evapotranspiration
PREC	Precipitation (in)
PLOAD	Pollutant Loading Estimator
RETSC	Retention Storage Capacity
SAM	South Alabama Mesonet
SOLR	Solar Radiation (Langley)

SSURGO	Soil Survey Geographic database
SWMM	Storm Water Management Model
TEMP	Temperature (°F)
TMDL	Total Maximum Daily Load
WASP	Water Quality Analysis Simulation Program
WDM	Weather Data Management
WIND	Wind Speed at 2 m/6 ft. (MPH)
WSS	Web Soil Survey
WWTP	Wastewater Treatment Plant
USDA	United States Department of Agriculture
USCS	National Resource Conservation Service
USGS	United States Geological Survey
UZSN	Upper Zone Nominal Storage

## CHAPTER 1 INTRODUCTION

### 1.1 Background

The study area is the Perdido River basin in southeast Alabama and southwest Florida (Figure 1.1) that is a part of two US Geological Survey (USGS) 12 digit Hydrologic Units (HU), 03140106 and 0314107. The Perdido River basin is located through Baldwin and Escambia counties, Alabama and Escambia County, Florida. The Perdido River, which flows to Perdido Bay, is the division between Florida and Alabama (Figure 1.1). Perdido Bay itself is 33.2 miles long, with an average width of 2.6 miles. The surface geology of the Florida Panhandle and Coastal Alabama is sedimentary, with limestone, organics, and clastics (gravel, sand, silt, clay) forming the primary sediment types (Livingston, 2001). In addition, the groundwater and surface water bodies are often directly connected by porous limestone channels. The bay receives its freshwater from the Perdido River system and other smaller stream networks. Saltwater flows in through Perdido Pass from the Gulf of Mexico.

The Perdido Bay basin is considered important to both states, due to its watersheds being in both states and heavily used for recreation and irrigation. The boarder within the bay is more complicated, since the mouth of the bay changed locations multiple times within the last few hundred years (most recently in 1911), primarily due to hurricanes. The Perdido Bay basin is nearly 1250 mi<sup>2</sup>. Perdido Bay is connected westward to Wolf Bay, a smaller inland estuary in Alabama; and its south connects to the Gulf of Mexico through the Perdido Pass (Figure 1.2). Perdido Bay, which covers over 50 mi<sup>2</sup>, is ‘connected’ to Mobile Bay and Pensacola Bay by the Gulf Intercostal Waterway (GIWW), a man-made navigational channel. The only bridge crossing the bay (HWY 98) was built in the 1930’s that connected Pensacola and Apalachicola. In the 1950’s a bridge connecting Perdido Key to Orange Beach at Perdido Pass was built.



Figure 1.1 Perdido Bay and River along the Florida/Alabama Boarder

Before 1900, Perdido Bay was a freshwater bay, but then Perdido Pass was enlarged in the 1900's, for better ship access and for better wastewater drainage from Pensacola (Livingston, 2001). This caused Perdido bay to have a stratified salinity, with higher salinity near the mouth of the bay (i.e., Perdido Pass). During the 1970's the mouth of the bay was dredged during improvements to the bridge. This channel enlargement caused additional tidal flow into the bay, which increased the average salinity. This increased salinity caused harm to many freshwater species in the bay and the intrusion of saltwater species into the upper-bay by the 1980's (Vernberg, 1996). Since that improvement, the U.S. Army Corps of Engineers maintained Perdido Pass at a controlling depth of roughly 3 ft. as part of the GIWW. This depth was increased to 4 ft. in the 1990's and is currently maintained at roughly 5 ft. ([www.charts.noaa.gov/PDFs/11378.pdf](http://www.charts.noaa.gov/PDFs/11378.pdf)).

Perdido Bay can be divided into five distinct regions: the lower Perdido River area, upper Perdido Bay (north of HWY 98 Bridge), lower Perdido Bay (bounded to the south by a line between Ross and Inerarity Points and to the west by Wolf Bay), Wolf Bay, and the Perdido Pass complex (Figure 1.2). The transport of chemicals in the Perdido River has been blamed for algae blooms and fish kills in the past few years (Livingston, 2001), and are affecting the fishing and tourism operations of the area. One such kill in August 2015 is pictured in Figure 1.3.

It shows a portion of a rather large fish kill in Cotton Bayou in the lower section of Perdido Bay. The Florida Fish and Wildlife Conservation Commission (FFWCC) has a Fish Kill Hotline where citizens

can report incidences ([myfwc.com/FishKill](http://myfwc.com/FishKill)). From the FFWCC's database there are over 60 reported kills in the Perdido Bay watershed since 2000. Table 1.1 shows only the kills with specimen counts over 50. From this data, it can be seen that kills of a variety of species are an unfortunately common occurrence throughout the bay.

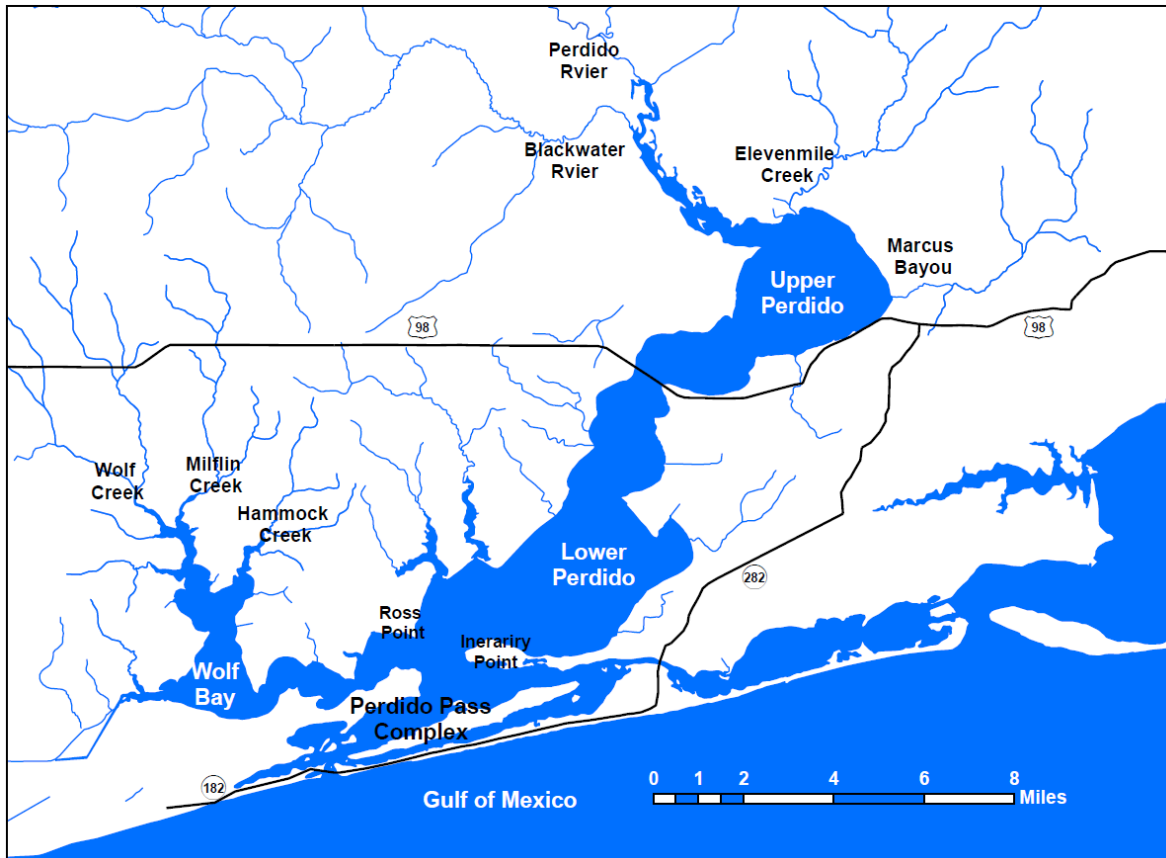


Figure 1.2 Division of Perdido Bay into Five Area with Streams





Figure 1.3 Fish Kill in Cotton Bayou, AL

[www.al.com/news/mobile/index.ssf/2015/08/fish\\_kills\\_reported\\_in\\_orange.html](http://www.al.com/news/mobile/index.ssf/2015/08/fish_kills_reported_in_orange.html)

In addition, the results of a twenty year bloom monitoring program done by Robert Livingston (2001) at the Center for Aquatic Research and Resource Management in Tallahassee, FL are shown in Table 1.2. As can be seen from the table, many of these events occurred when temperatures are high and when DO of the bay was lower. In addition, it can be seen that most of the blooms occurred in the upper bay (Figure 1.2) and only a few exclusive to the lower bay. From the study, there were considerably higher nutrient loads in the upper bay compared to the lower bay. This coupled with the change in salinity from the Perdido River through the bay to Perdido Pass, resulted in limited algal species being able to bloom within the entire bay at once (i.e., *C. choctawhatcheeana*).

Also discussed, was how drought impacts the water quality of the bay. This is important because due to the changing climate, drought years have become longer and dry, while flooding during regular years has also increased. Human activities that pollute the bay do not decrease during low flow periods, so the occurrence of algal blooms increases. Also, many fish that have been caught have tested high in chemicals that are thought to disrupt the endocrine system in humans, a potential health hazard.

While the main goal is to model the flow into Perdido Bay, this project looks at Wolf Bay, a subbasin of Perdido Bay, to calibrate the parameters before it is scaled to the entire watershed. Wolf Bay's three main inflows are Wolf Creek, Milflin Creek, and Hammock Creek. The watershed area draining into the Wolf Bay is about 48 mi<sup>2</sup>.

Table 1.1 Perdido Bay Fish Kills

<b>Report Date</b>	<b>City</b>	<b>Water Body Name</b>	<b>Specimen Count</b>	<b>Species</b>
1/29/2001	Pensacola	Bayou Marcus	100	Species Unknown
6/27/2005	Pensacola	Johnson Beach	250	Menhaden, Glass Minnow
6/29/2005	Pensacola	Upper Perdido Bay	100	Flounder
7/4/2006	Pensacola	11 Mile Creek	100	Mullet, Flounder, Eel, Pinfish, Largemouth Bass, Blue Crab, Bluegill, Catfish, Trout
7/4/2006	Pensacola	11 Mile Creek	100	Flounder, Mullet, Catfish, Crab
7/7/2006	Pensacola	Perdido Bay	100	Flounder, Species Unknown
9/9/2006	Pensacola	Perdido Bay	100	Alewives, Menhaden
9/9/2006	Pensacola	Perdido Bay	60	Pinfish
10/16/2007	Perdido Key	Perdido Key Beach	100	Species Unknown
10/20/2007	Gulf Breeze	Navarre Beach to Perdido Key	2101	Red Snapper, Mullet, Red Drum, Catfish
1/15/2010	Pensacola	Gongora Drive/Perdido Key	100	Mullet
6/16/2010	Perdido Key	Johnsons Beach	100	Alewives, Minnow
6/23/2010	Pensacola	Perdido Key State Park	150	Species Unidentified
6/23/2010	Perdido Key	Behind Perdido Towers	100	Species Unidentified
6/30/2010	Pensacola	Perdido Key Beach	100	Crab
6/30/2010	Pensacola	Perdido Key Beach	100	Crab
7/8/2010	Perdido Key	Exact Location Unknown	100	Sand Crab
8/16/2010	Pensacola	Johnsons Beach	2000	Herring, Anchovy
8/18/2010	Pensacola	Eden Condos/Perdido Key	2000	Minnow
8/18/2010	Pensacola	Johnsons Beach	100	Species Unidentified
12/7/2010	Perdido Key	Johnsons Beach	100	Skate Eggs
7/21/2011	Pensacola	Near Tarkylin & Dupont Point	500	Catfish
7/21/2011	Pensacola	Near Tarkylin & Dupont Point	50	Catfish
8/4/2011	Pensacola	Perdido Bay/Dupont Point	100	Species Unidentified
6/24/2012	Perdido Key	Perdido Bay/Ramsey Beach	100	Gray Snapper, Flounder, Blue Crab, Croaker, Pinfish, Catfish
1/21/2014	Pensacola	Perdido Bay/Riola Lane	100	Species Unidentified
11/13/2015	Pensacola	Perdido Key Beach	100	Banjofish
12/20/2015	Pensacola	Perdido Bay	50	Catfish
5/13/2017	Pensacola	GOM/Perdido Key	50	Bonito

The Wolf Bay watershed also has some tidal flow in the lower section that is connected to Perdido Bay as an estuary where freshwater and saltwater mix, Wolf Bay creates a diverse environment for plant and animal life. Wolf Bay and its surrounding waters are some of the most pristine estuarine waters in Alabama, granted ‘Outstanding Alabama Water’ status by the Alabama Department of Environmental Management in April, 2007.

Table 1.2 Perdido Bay Algal Blooms

<u>Year</u>	<u>Month</u>	<u>Area</u>	<u>Species</u>
1994	February	Upper	<i>L. danicus</i>
1994	Mar- Apr	Bay Wide	<i>C. choctawhatcheeana</i>
1994	March	Upper	<i>M. thronesnii</i>
1996	June	Upper	<i>Synedropsis</i> sp.
1996	July	Upper	<i>H. akashiwo</i>
1996	July	Upper	<i>Synedropsis</i> sp.
1996	August	Upper	<i>Synedropsis</i> sp.
1997	March	Upper	<i>M. thronesnii</i>
1997	March	Upper	<i>H. akashiwo</i>
1997	May	Upper	<i>H. akashiwo</i>
1997	May	Upper	<i>H. akashiwo</i>
1997	July	Upper	<i>Synedropsis</i> sp.
1997	September	Upper	<i>H. akashiwo</i>
1998	Mar- Apr	Bay Wide	<i>C. choctawhatcheeana</i>
1998	May	Bay Wide	<i>C. choctawhatcheeana</i>
1998	June	Upper	<i>H. akashiwo</i>
1998	June	Upper	<i>Synedropsis</i> sp.
1998	July	Upper	<i>Synedropsis</i> sp.
1998	August	Upper	<i>H. akashiwo</i>
1998	October	Upper	<i>U. eriensis</i>
1999	January	Upper	<i>P. minimum</i>
1999	Mar- Apr	Bay Wide	<i>C. choctawhatcheeana</i>
1999	April	Upper	<i>M. thronesnii</i>
1999	May	Bay Wide	<i>C. choctawhatcheeana</i>
1999	June	Upper	<i>H. akashiwo</i>
1999	September	Upper	<i>H. akashiwo</i>
2001	Mar- Apr	Bay Wide	<i>C. choctawhatcheeana</i>
2001	April	Upper	<i>M. thronesnii</i>
2001	April	Upper	<i>H. akashiwo</i>
2000	May	Upper	<i>H. akashiwo</i>
2000	August	Lower	<i>P. minimum</i>
2000-2001	Dec- Jan	Bay Wide	<i>C. choctawhatcheeana</i>

## 1.2 Scope and Objectives

The overall goal of the project is to determine how much water and chemicals from upstream and surrounding watersheds flow into Perdido Bay, how long the residence time of chemicals is, and the concentration distribution within the bay. This study will focus on the first goal only. Wolf Bay was chosen to start the process. Next, the entirety of the Perdido Bay watershed was modeled. This included watersheds of the Blackwater River, Styx River, Perdido River, Elevenmile Creek, and Marcus Bayou.

There are challenging issues to model coastal watersheds associated with an estuary. The concept of a watershed is basic to all hydrologic modeling since a large watershed is made up of many smaller watersheds or sub-watersheds. It is conventional to define or delineate a watershed in terms of a point called as the watershed or drainage outlet. With respect to the outlet, the watershed or drainage area consists of all land area that sheds runoff to the outlet during and after a rainfall event. For any hydrologic design and modeling, any point or cross section in a stream could be selected as a watershed outlet, and then a unique watershed associated with the outlet can be delineated using digital elevation model (DEM) and the geographic information system (GIS). For a large waterbody such as Perdido Bay and Wolf Bay, most likely there are several rivers that flow into. When each river mouth is considered as a watershed outlet, there are possibly several watersheds associated with a waterbody. Therefore, to model water flowing into Perdido Bay and Wolf Bay (Figure 1.2) we have to develop several watershed models for those independent and separate watersheds that flow into the same waterbody because almost all existing watershed models are designed for a single outlet watershed. Coastal watersheds or drainage basins typically have relatively small elevation difference from the highest point inside the watershed and the outlet (typically assumed as the lowest elevation point). Therefore, for many wetlands surrounding an estuary, existing DEM may not have a high enough elevation resolution to allow GIS to delineate watersheds, and then hydrological models for them may not be established. Both challenging issues are encountered in the study of modeling Perdido Bay and Wolf Bay watersheds and will be discussed further in other chapters.

The programs needed to complete the objectives of this study are as follows: ArcMap - used for its GIS capabilities for sub-basin/stream/outflow delineation; BASINS - used for extracting data and the connection to the Hydrological Simulation Program-Fortran (HSPF),

organizing/storing EPA data sources, and performing watershed delineation; Excel - for data management; HSPF - for watershed hydrologic and water quality simulation; HSPFEXP - for model calibration; HSPFParm - for selecting model parameters for calibration; WinHSPF - as the current HSPF interface; WDMUtil - for weather data storage for access with HSPF.

An aerial map of the Wolf Bay watershed with the stream network outlined can be found in Figure 1.4. The modeling software that is being used is BASINS and HSPF. A detailed description of HSPF and accompanying software are presented in Chapter 2.

BASINS takes land-use, weather, stream flow, and soil type into account when determining water transport and quality. HSPF can model chemicals and sediment directly, however a tracer is being used as a placeholder. Three of the four main inputs for HSPF deal with the geography of the watershed, which means that a GIS needs to be used to create the backbone of the model. ArcMap, a GIS software designed of ESRI was used in all GIS based processes. An overview of how the GIS aspects were done can be found in Appendix B.

### **1.3 Literature Review**

“Water resource managers consistently ask similar questions when examining problems at the watershed level. These questions include: Where is the extent of the water quality problem? Where are the problems occurring in the watershed? Where sampling or monitoring locations should be established to assess the problem more accurately? The abundance of “where” questions points out the spatial nature of water watershed management.” (Strager, 2010)

This quote shows the need to integrate GIS applications with water resource modeling. This is not a new idea. Since even before the 1990’s enough water modeling programs utilized some form of mapping software. Therefore, the US Army Corp of Engineers felt the need to review the many programs to determine each program’s strengths and weaknesses to improve the quality of the market (Devantier, 1993). The ArcMap manual (Booth, 2001) was consulted heavily in the processing of the raw data, the production of watershed basins and sub-basins, and for the creation of maps. Also other studies were consulted to find how other watersheds were modeled using GIS (Finn, 2000). It was decided that BASINS would be used to store the spatial hydrologic data since it is a frequently used EPA watershed model that deals with the total maximum daily load (TMDL) method which uses the sum of the individual waste load allocations for point sources, load

allocations for nonpoint sources and natural background concentrations of chemicals (Daniel, 2010).



Figure 1.4 Aerial photo of Wolf Bay watershed with streams

Table 1.3 is a comparison from multiple watershed models (Shoemaker, 2005). At first, the Loading Simulation Program in C++ (LSPC) was desired due to the project team having used

the model before. LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. Unfortunately, the existing downloadable version of LSPC has not been updated for a while, and there are various issues on compatibility with updated GIS software and other support software. EPA's contractor is upgrading LSPC, but that has not been publicly released yet; therefore, LSPC was not used for the project. In addition, compatibility to the EPA's TMDL toolbox was desired. The BASINS 4.1 manual was consulted to determine which watershed model within the BASINS TMDL toolbox would be the most efficient for the project's needs (Parmer, 2015). There are several modeling systems within BASINS such as Storm Water Management Model (SWMM), Water Quality Analysis Simulation Program (WASP), AQUATOX, Pollutant Loading Estimator (PLOAD) and HSPF.

After referring to studies that compare each model with its best use (Ogden, 2001) HSPF was selected as this project's model. This is because as Table 1.4 (Shoemaker, 2005) shows HSPF has a few advantages over LSPC, in addition to being the model that LSPC is based on. Also, the WinHSPF interface greatly improves the usability of HSPF over LSPC. HSPF is a tool that simulates the movement of water, sediment, and other water quality constituents through natural and man-made watersheds. HSPF can simulate continuous, dynamic event, or steady-state behavior of both hydrologic/hydraulic and water quality processes, which makes it versatile to model any type of rainfall event. It is also designed to facilitate the delineation of watershed boundaries, which can serve as a check against the delineations that were made by manual methods (Deliman, 2002).

Table 1.3 Comparison of Available Watershed Models

<u>Model</u> <u>Acronym</u>	<u>Model Name</u>	<u>Source</u>	Receiving Water- Hydrodynamics	Receiving Water- Water Quality	Watershed	BMP	System	Statistical	Process-based
AQUATOX		EPA	-	Y	-	-	-	-	Y
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources	EPA	Y	Y	Y	Y	Y	-	Y
CE-QUAL-W2	-	USACE	Y	Y	-	-	-	-	Y
EFDC	Environmental Fluid Dynamics Code	EPA TetraTech	Y	Y	-	-	-	-	Y
HEC-HMS	Hydraulic Engineering Center Hydrologic Modeling System	USACE	-	-	Y	-	-	-	Y
HEC-RAS	Hydraulic Engineering Center River Analysis System	USACE	Y	-	-	-	-	-	Y
HSPF	Hydrologic Simulation Program—FORTRAN	EPA	-	Y	Y	Y	-	-	Y
LSPC	Loading Simulation Program in C++	EPA TetraTech	-	Y	Y	Y	-	-	Y
PCSWMM	Stormwater Management Model	Computational Hydraulics	-	Y	Y	Y	-	-	Y
QUAL2E	Enhanced Stream Water Quality Model	EPA	-	Y	-	-	-	-	Y
SWAT	Soil and Water Assessment Tool	USDA-ARS	-	Y	Y	Y	-	-	Y
SWMM	Storm Water Management Model	EPA	-	Y	Y	Y	-	-	Y
WARMF	Watershed Analysis Risk Management Framework	Systech Engineering	-	Y	Y	Y	-	-	Y
WASP	Water Quality Analysis Simulation Program	EPA	Y	Y	-	-	-	-	Y
WinHSPF	Interactive Windows Interface to HSPF	EPA	-	Y	Y	Y	-	-	Y



Table 1.4 Type, Complexity, and Modeling outputs of Available Models

Acronym	Model Name	Source	Steady State	Quasi-dynamic	Dynamic	Grid Based	Stream Routing	1-D	2-D	3-D	Physically Based	User-Defined	Sediment	Nutrients	Toxics	Metals	BOD	DO	Bacteria
			Type	Complexity			Water Quality												
AQUATOX		EPA	-	-	Y	-	-	Y	-	-	-	-	Y	Y	Y	-	Y	Y	-
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources	EPA	-	Y	Y	-	Y	Y	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
CE-QUAL-W2	-	USACE	-	-	Y	-	-	-	Y	-	-	-	-	Y	-	-	Y	Y	Y
EFDC	Environmental Fluid Dynamics Code	EPA TetraTech	-	-	Y	-	-	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y
HEC-HMS	Hydraulic Engineering Center Hydrologic Modeling System	USACE	-	-	-	-	Y	-	-	-	Y	-	-	-	-	-	-	-	-
HEC-RAS	Hydraulic Engineering Center River Analysis System	USACE	-	-	Y	-	-	Y	-	-	-	-	-	-	-	-	-	-	-
HSPF	Hydrologic Simulation Program— FORTRAN	EPA	-	-	Y	-	Y	Y	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
LSPC	Loading Simulation Program in C++	EPA TetraTech	-	-	Y	-	Y	Y	-	-	Y	Y	Y	Y	Y	Y	-	-	Y
PCSWMM	Stormwater Management Model	Computational Hydraulics	-	-	Y	-	Y	Y	-	-	Y	Y	Y	Y	Y	Y	-	-	Y
QUAL2E	Enhanced Stream Water Quality Model	EPA	-	Y	-	-	-	Y	-	-	-	Y	-	Y	-	-	Y	Y	Y
SWAT	Soil and Water Assessment Tool	USDA-ARS	-	Y	-	-	Y	Y	-	-	Y	-	Y	Y	Y	Y	Y	Y	-
SWMM	Storm Water Management Model	EPA	-	-	Y	-	Y	Y	-	-	Y	Y	Y	Y	Y	Y	-	-	Y
WARMF	Watershed Analysis Risk Management Framework	Systech Engineering	-	-	Y	-	Y	Y	Y	-	Y	-	Y	Y	Y	Y	Y	Y	Y
WASP	Water Quality Analysis Simulation Program	EPA	-	-	Y	-	-	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	-
WinHSPF	Interactive Windows Interface to HSPF	EPA	-	-	Y	-	Y	Y	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y

Once HSPF was selected, trainings produced by AQUA TERRA, the company that assisted the EPA with the development of HSPF, were used to determine what type of data would need to be used. One of the main parameters that HSPF deals with is land-use. Since the land use is tied to many model parameters it is essential that it is as accurate as possible (Hetherington, 1995). A study of how land use has changed in the Perdido Bay area was considered when looking for land use patterns (Sherestha, 2011). In addition, HSPFParm is a database of previous HSPF models with model parameters as a reference for similar models. Users can utilize them to assist in specifying the land-use parameters (Donigan, 1997).

Land use is tied to many model parameters, so an excellent understanding of how the watershed’s land area affected modeling was needed. Multiple landuse studies were consulted (Lafontaine, 2015; Boll, 2015; Estes 2015) to assist in determining how other HSPF models had

used land-use data and what affects there were on the results of those models. In addition, the watershed has many nonpoint sources (NPS), since there are several crop lands and public areas, so how to include both point source and NPS had to be determined. Many of the existing NPS models are mixed with varying degrees of empiricism, functional representation, and deterministic description of hydrologic processes; this requires large amounts of input data which are not always available. WDMUtil is a weather data storage program that can also use existing data to derive missing data. For Example, WDMUtil can use cloud cover, latitude, and longitude of a weather station to calculate solar radiation (Hummel, 2001). This improves the ability to gather all necessary data for the model. There is a lack of simple models capable of simulating spatial processes and suitable for the identification of critical areas of NPS pollution (Tim, 1992). This is the main reason why HSPF was selected since it deals reliably with NPS (Deliman, 2002; Im, 2003). To determine HSPF's capabilities, limitations, and data requirements, SMART's study on traditional and innovative HSPF model calibrations was consulted to determine the best method of parameter selection (Skahill, 2004).

Also, in considering larger scale studies it was determined that the Perdido Bay watershed would be too large to model and calibrate all at once (Daggupati, 2016). This caused the Wolf Bay watershed to be selected for first optimization of parameters, then the model could be scaled up to all of Perdido Bay. This decision was also made based on Robert Livingston's work in the book *Eutrophication Process in Coastal Systems* (Livingston, 2001) which discusses in depth the workings of Perdido Bay, where the bay is broken up into the Upper bay, Lower bay and Wolf bay.

There are numerous studies that describe how to determine model parameters when limited data is available. The entire Perdido Bay watershed is nearly 1000 mi<sup>2</sup>. Yet there are only four flow gages that monitor four of the five largest rivers that flow into the bay and one for the over 25 other named streams that flow into the bay. Crossette (2015) gives examples on how to utilize BASINS data to its fullest. Some researchers conducted sensitivity analysis studies that determined what model parameters are most important to the outcome of the model (Fonseca, 2014; Magette, 1976) and others try to determine if manual or automatic calibration gives better results (Kim, 2007).

## **1.4 Thesis Organization**

Chapter 1 is organized to first give the needed background on the project's objectives and to provide a short literature review. Secondly, a description of the software used is provided.

Chapter 2 deals with how the Wolf Bay watershed was delineated. It will discuss both the data that are needed to run the model and where the data were acquired. Chapter 3 will explain how to create and edit an HSPF watershed model. In this section there is also an in-depth discussion of the functions within HSPF and how HSPF deals with stream flow throughout the model. Finally the process, method and results of calibration are discussed.

Chapter 4 details the method for the Wolf Bay model to be increased to include all major inputs to Perdido Bay itself, such as Styx River, Perdido River, Blackwater River, Elevenmile Creek and Marcus Bayou. Methods on how this was accomplished are given.

Chapter 5 deals with how the calibrated model will be applied to the entire watershed. It also gives recommendations on the second phase of the research which is to do more in depth water quality modeling within Wolf Bay watershed.

## CHAPTER 2 MODEL DESCRIPTION AND DEVELOPMENT

### 2.1 Study Area

Wolf Bay has an area of 81 mi<sup>2</sup> that consists of three watersheds, each with several catchments. The primary land uses of Wolf Bay watershed are given in Table 2.1. More than 20% are either crops or wetlands. The outline of the watershed was done using a DEM that was created through LIDAR data using the method ‘LIDAR to DEM’ (see section A.1 in the appendix). The DEM was used determine where the flow would accumulate within the watershed so that sub-watershed could be determined (see section A.2 in the appendix).

Table 2.1 Primary Land uses in Wolf Bay Land Use (NLCD 2011)

<b>% of area</b>	<b>Wolf Bay Land use</b>
21.4%	Cultivated Crops
20.8%	Wetlands
17.3%	Forest
14.7%	Grassland
9.9%	Developed, Open Space

A map of the sub-watersheds can be seen in Figure 2.1. Furthermore, the watershed was broken down into East, Middle, and West. These divisions are based on the main stream that flows through each. East follows Hammock Creek, Middle follows Milflin, and West follows Sandy and Wolf Creek. A map of the Wolf Bay and Perdido Bay DEM can be seen in Figure 2.2. From the DEM, it can be seen that this is a fairly low slope coastal area with a large number of possible streams and flow areas.

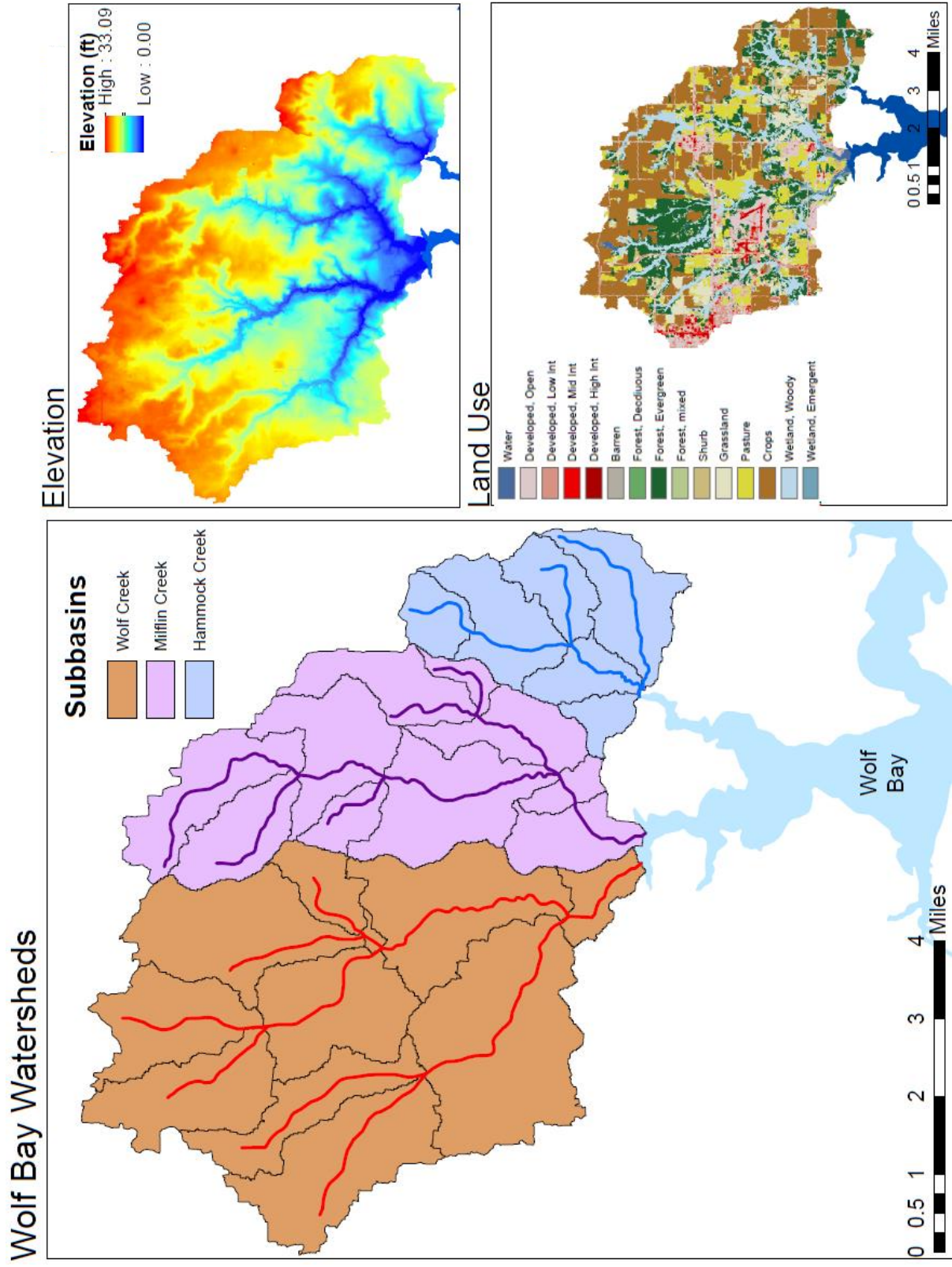


Figure 2.1 Wolf Bay Catchments including Elevation and Land Use Maps

# Perdido Bay DEM

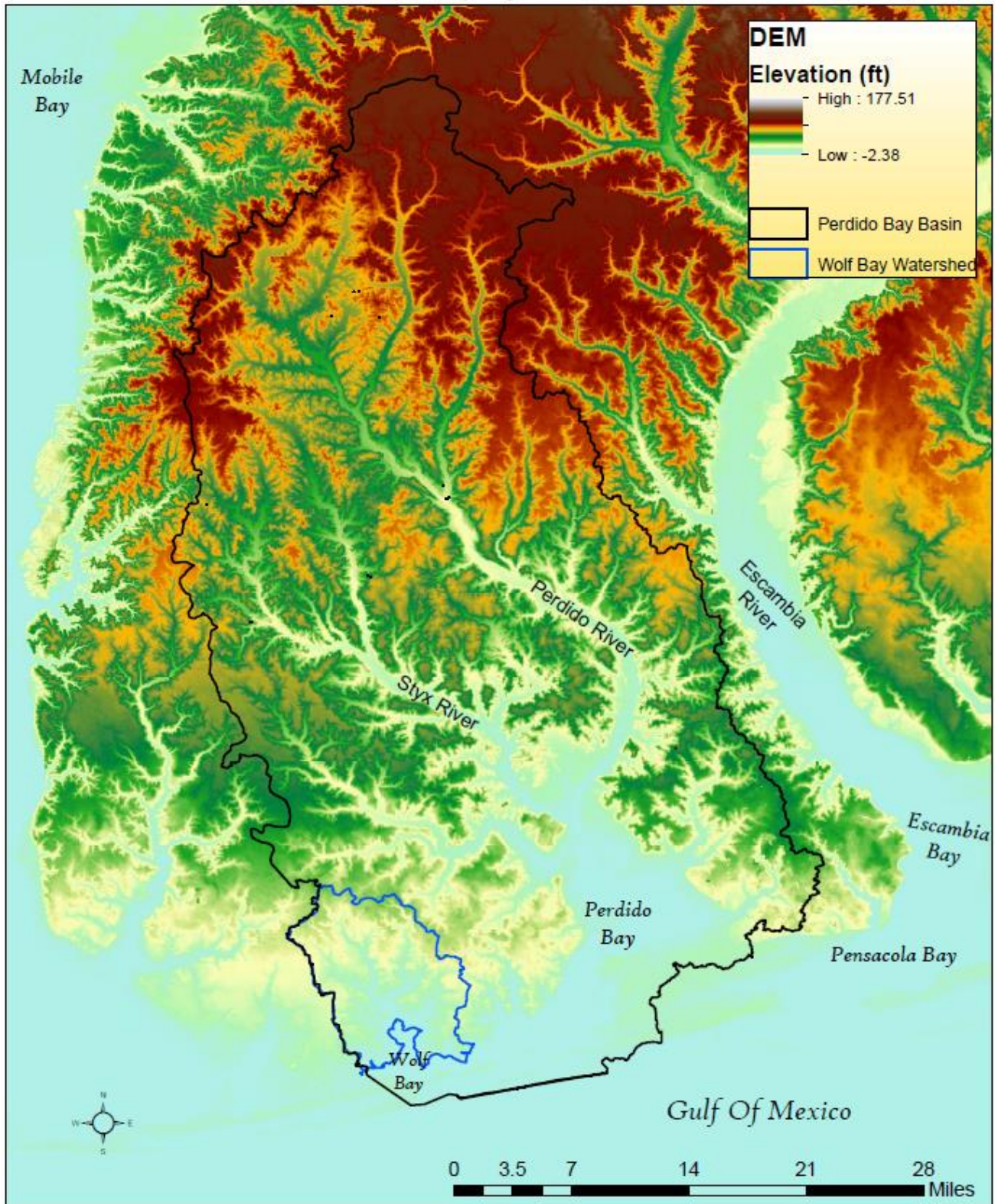


Figure 2.2 DEM for Perdido Bay Watershed

## **2.2 Method**

Model development combines art with science. The science comes in the theoretical derivation and empirical verification of equations describing such specific hydrologic processes as infiltration or flood wave movement. The art comes in reviewing the large body of available equations and supporting data, then combining appropriate expressions in the manner which will give the best results (James, 1972).

### **2.2.1 HSPF Description**

Hydrologist Ray K. Linsley approached modeling with paper and pencil using daily time steps while working at Stanford in 1942 (Crawford, 1996). Linsley began using an IBM 650 in 1959 to speed up the calculations while still using a daily time step. In 1960 - 61 Norman Crawford wrote more advanced software that could deal with more physical processes (infiltration, soil moisture, actual evapotranspiration, and channel flow hydraulics), and a smaller time step. The Stanford Watershed Model was finally developed by Crawford and Linsley in 1962. Then the model was updated to the Stanford Watershed Model II and then again to the Stanford Watershed Model IV in 1966 (Crawford, 2004).

In the 1970's the EPA funded comprehensive watershed model development efforts that resulted in the development of several watershed modeling software, one of them being a descendant of the Stanford Watershed Model IV, Hydrocomp Simulation Program (HSP). HSP was now capable of simulating simultaneous flows at a large number of points within the watershed. Then the Hydrological Simulation Program—Fortran (HSPF), a FORTRAN version of HSP was first released publicly in 1980. It included preprocessing and post processing software, algorithm enhancements, and use of the U.S. Geological Survey (USGS) Watershed Data Management (WDM) system. An interactive version (HSPEXP) was developed by the USGS in the 1990's. By 1999 an interface to the HSPF model in the EPA Watershed Modeling System (WMS) was established. HSPFEXP was upgraded by Aqua Terra into a new Window interface called WinHSPF. As part of the integration into the WDM, the model has been fully integrated into EPA's BASINS system and is the primary watershed model for that system. This means that there is now a direct link between BASINS and HSPF for ease of processing data and viewing the models' output.

Currently, version 12 of HSPF is available to be downloaded free from EPA and USGS web sites ([www.aquaterra.com/resources/hspfsupport/index.php](http://www.aquaterra.com/resources/hspfsupport/index.php)). With its latest version HSPF can simulate interception soil moisture, surface runoff, interflow, base flow, snowpack depth and water content, snowmelt, evapotranspiration, groundwater recharge, dissolved oxygen, biochemical oxygen demand (BOD), temperature, pesticides, conservatives, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. This is a vast increase from the original Stanford Watershed Model. In addition, any time step that can be evenly divided into 1 day (24 hour or 1440 minutes) can be used. However, the most common time steps are quarter, half, and full hours.

To simulate the surface runoff response to precipitation in a river basin, the basin is typically represented as an interconnected system of hydrologic and hydraulic components. For example, in HEC-HMS (Scharffenberg, 2010) the hydrologic component is subbasin that generates a hydrograph by considering rainfall losses, rainfall excess transformation through kinematic routing or unit hydrograph method, and base flow. The hydraulic component includes stream channels and ponds/reservoirs for hydrograph routing. HSPF's interface shows the watershed's catchments by numbers and the hydrological/hydraulic connectivity among catchments (Figure 2.3). A "reach" in HSPF does not just represent a segment of a river, but includes the surrounding land that it sheds runoff into. This means HSPF combines hydrologic and hydraulic components into the reach component. Each catchment has one named (or numbered) stream associated with it. Each catchment then has different land uses given to it after watershed delineation using DEM and land use data. These are seen as the tiny bar graph above the catchment's name, i.e., RCHRES 2. These can also be a quick visual guide to the relative sizes of the catchments, since the bar graphs for all catchments in the same watershed are in the same scale. Figure 2.3 visually indicates that RCHRES 10 is much larger than RCHRES 6. Once a particular reach is selected details about it can be seen. Both the individual land uses and the individual catchments have parameter values associated with them. More details about these values are given and discussed in the section 3.1.3. The lines connecting the reaches are just visual guides that show what reach upstream reaches flow into and contain no data themselves. Upstream catchments are always the top of the schematic and the final outflow of the watershed is always alone on the lowest part of the schematic.



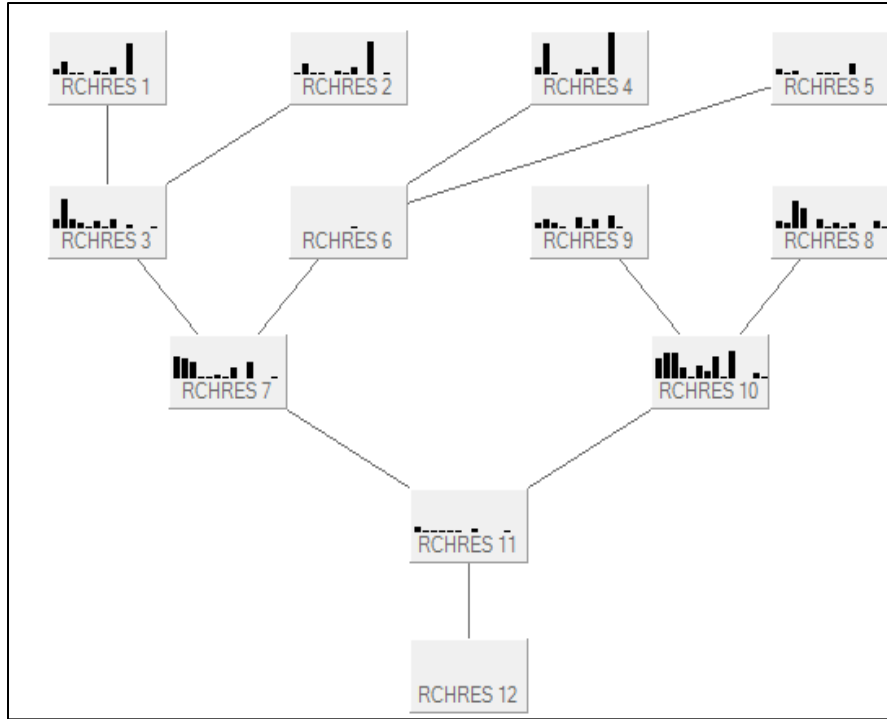


Figure 2.3 Sample HSPF Model Setup

There are now several support software for HSPF. Each assists with a different aspect of the model's functionality. WDMUtil assists with meteorological station maintenance. HSPFParm deals with model parameters for calibration. Finally, HSPEXP and WinHSPF assist with the model creation. GenScn allows users to display, save and print the output results better than HSPF does alone. However, WDMUtil, the program used to store weather data, can also show HSPF output.

### 2.2.2 BASINS Description

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is a multipurpose environmental analysis system designed to help regional, state, and local agencies perform watershed- and water quality-based studies. The U.S. Environmental Protection Agency's (EPA's) Office of Water ([www.epa.gov/waterscience/basins/](http://www.epa.gov/waterscience/basins/)) developed BASINS to assist in watershed management and TMDL development by integrating environmental data, analysis tools, and watershed and water quality models. From 1998 through 2009, AQUA TERRA Consultants has served as the prime contractor for development and support of BASINS.

Through the use of GIS, BASINS has the flexibility to display and integrate a wide range of information (e.g., land use, point source discharges, and water supply withdrawals) at a scale chosen by the user. Because GIS combines mapping tools with a database management system, it provides the integrated framework necessary to bring modeling tools together with environmental, spatial, and tabular data. Beginning in 2004, BASINS development efforts focused on a new version of BASINS, known as BASINS 4.0, which is the first to be primarily based on a non-proprietary, open-source GIS foundation known as MapWindow GIS. MapWindow was originally developed by the Utah Water Research Laboratory at Utah State University and is currently updated by multiple developers. The underlying software architecture provides a clear separation between interface components, general GIS functions, and GIS platform-specific functions. Separating these components and functions provides a future migration path for using core GIS functions from other GIS packages, or for accommodating future updates to the already-supported GIS packages. For this project BASINS 4.1 was used.

The BASINS system includes a tool, known as the BASINS Data Download tool, for downloading and extracting a set of databases that facilitate watershed analysis and modeling. Some of the data downloaded using this tool have been preprocessed for use in BASINS. These datasets provide a starting point for watershed analysis. However, additional datasets where locally derived data may be at a higher resolution or compiled more recently may be available elsewhere. In addition to downloading the BASINS data from the EPA web server, the Data Download tool provides links to the federal agencies where certain data types are hosted, as well as tools to download the data and convert them into forms usable by BASINS. Since data available on the web are not static, this tool allows a user to check for more recent data and update the BASINS project data as appropriate.

### **2.2.3 Manual Watershed Delineation**

Both HSPF and BASINS requires accurate elevation data to function properly (Figure 2.2). ArcMap, and BASINS can use this elevation data to delineate the Wolf bay watershed. However, knowing how this process was done before computers is important. This is so that a manual check can be done to the computer's output. The delineation should appear as a solid line around a watercourse. Surface water runoff from rain falling anywhere in this area should flow out of the watershed at the indicated outlet. Once the outlet is located with a DEM or topographic map, the

watershed is delineated in a trial and error fashion. Initially the delineation is made using the following steps. First, mark what is considered the outlet or downstream point of the watershed (Figure 2.4). Secondly, mark the high points along both sides of the watercourse, working upstream towards the headwaters of the watershed. Starting at the outlet, draw a line connecting the high points along one side of the watercourse. This line should cross the elevation contours at right angles (i.e., it should be perpendicular to each contour line it crosses). Next, continue the line until it passes around the head of the watershed and down the opposite side of the watercourse. Completing the polygon around the watershed, it should connect with the outlet from which you started.

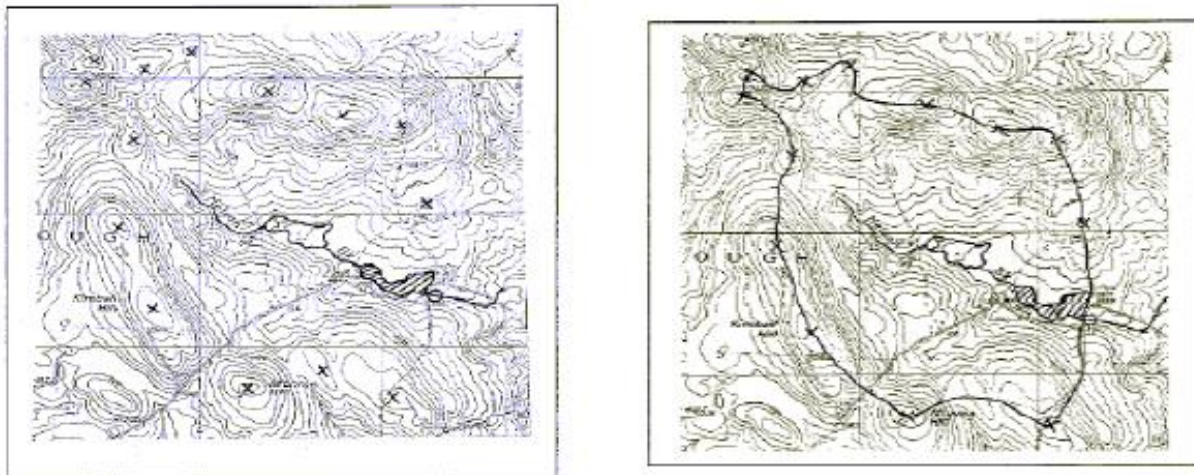


Figure 2.4 Partial and Complete Watershed Delineation using Topographic Map

### 2.2.4 Watershed Delineation using ArcMap

ArcMap has several tools that assist with watershed delineation. These include 'Fill', 'Flow Direction', 'Flow Accommodation', and 'Flow'. Most are found within the Hydrology Toolbox. A step-by-step guide on how to take a DEM and compute a watershed area is located in Appendix B. In essence, this process takes the elevation of each cell in the watershed area and determines which adjacent cells water will flow into, the cell with the lowest elevation, or steepest slope. Then it computes which cells are linked together and which are not to create a flow map that shows the path water will take from the highest points of the watershed to the outlets. This is an accurate method, but only gives the outline of the watershed and its flow paths. The methods used by BASINS were found to be more useful to this study.

### 2.2.5 Watershed Delineation using BASINS

One drawback of HSPF is since it was developed by the EPA, it prefers BASINS geographic output files. It cannot read shapefiles, the output of GIS programs, directly. Through editing within the BASINS program, the shapefiles that were already created can be processed into a file type that HSPF can read. BASINS allows for the direct download of stream, watershed, catchment, and elevation data for any (or multiple) 8-digit Hydrologic Unit Code (HUC) directly from the EPA HUC database. The stream, watershed and catchment data are downloaded from the National Hydrography Dataset (NHD).

BASINS downloads elevation rasters from the 2006 National Elevation Dataset (NED) with a 1-arc-second resolution. These arc-second maps rely on longitude and latitude to register cell values and use degrees as the measure of distance. At the equator, an arc-second of longitude approximately equals an arc-second of latitude, which is  $1/60^{\text{th}}$  of a nautical mile (101.27 ft. or 30.87 m). Arc-seconds of latitude remain nearly constant, while arc-seconds of longitude decrease in a trigonometric cosine-based fashion as one moves toward the earth's poles (Equation 2.1). Pensacola has a longitude of  $30.42^{\circ}\text{N}$  and therefore the DEM created using this data would have a resolution of 11.0 m (~36 ft.).

$$30.87m * 0.6561\cos(N^{\circ}) \quad (2.1)$$

Once these files are downloaded, they should be checked against a more detailed DEM to adjust (if necessary) the edges of the catchments, ensuring that the most updated information is available. While this does entail acquiring elevation data, it is important due to the fact that the BASINS download datasets tend to be further out of date than other available datasets.

BASINS have both manual and automatic delineation tools (Figure 2.5). These have a similar physical basis to the delineation in ArcMap. They both use elevation and slope to determine the path a water drop will take from the upper catchment to the outlet. For both methods, a subbasin layer, elevation raster and stream file are chosen. The subbasin layer contains data about the catchments, the elevation raster should be a DEM in .tiff format, and the stream file contains data about the streams that correspond to each catchment.

For Manual Delineation, a new stream file and outlet file are created using the supplied subbasin layer. While Automatic Delineation uses the specified catchment details to create a new

stream file, outlet file, and subbasin layer. The new subbasin layer is changed based on either the area of each catchment or number of catchments specified. In addition, an outlet file can be input to create the subbasin layer which conforms to the specified outlet locations.

For streams, BASINS has a similar editing feature to ArcMap, so the stream paths can be edited if necessary. Some streams had to be adjusted due to the bay borders propagating further upstream after the data had been last updated. Therefore, the current stream locations were ending within the bay. HSPF models basins to streams, then streams to outlets. This necessitated the creation of four HSPF models since the bay itself borders many subbasins.

There are three models for the upper streams that directly discharge to Wolf Bay, (Wolf Creek including Sandy Creek, Milflin Creek, and Hammock Creek) and one for the lower basins that discharge through primarily overland flow or urban drainage channels, not stream flow. This similarly necessitated the creation of three stream files. A detailed map of the streams and outlets can be found in Figure 2.6.

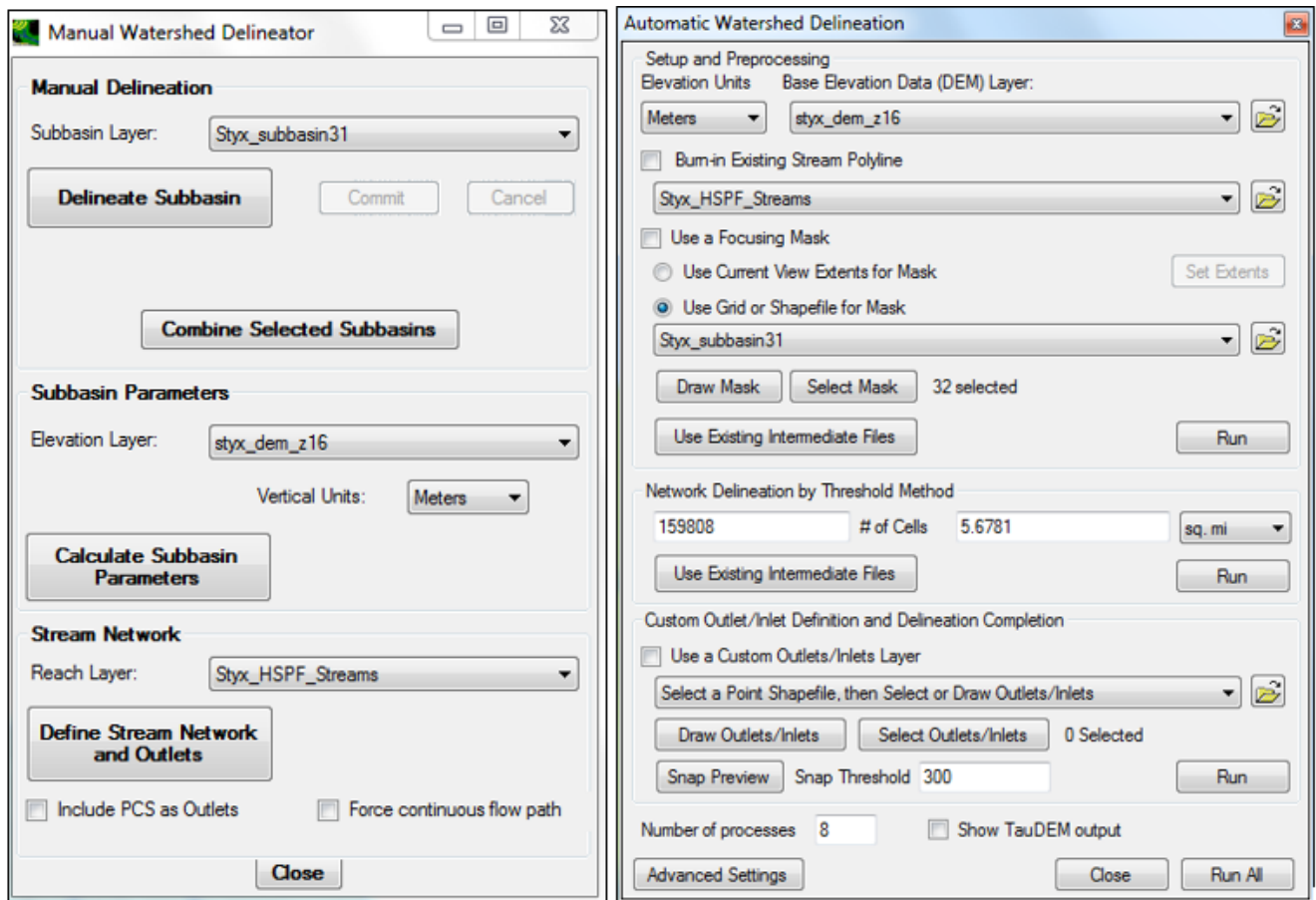


Figure 2.5 Manual and Automatic Delineation Interface

# Wolf, Milflin, and Hammock Creeks

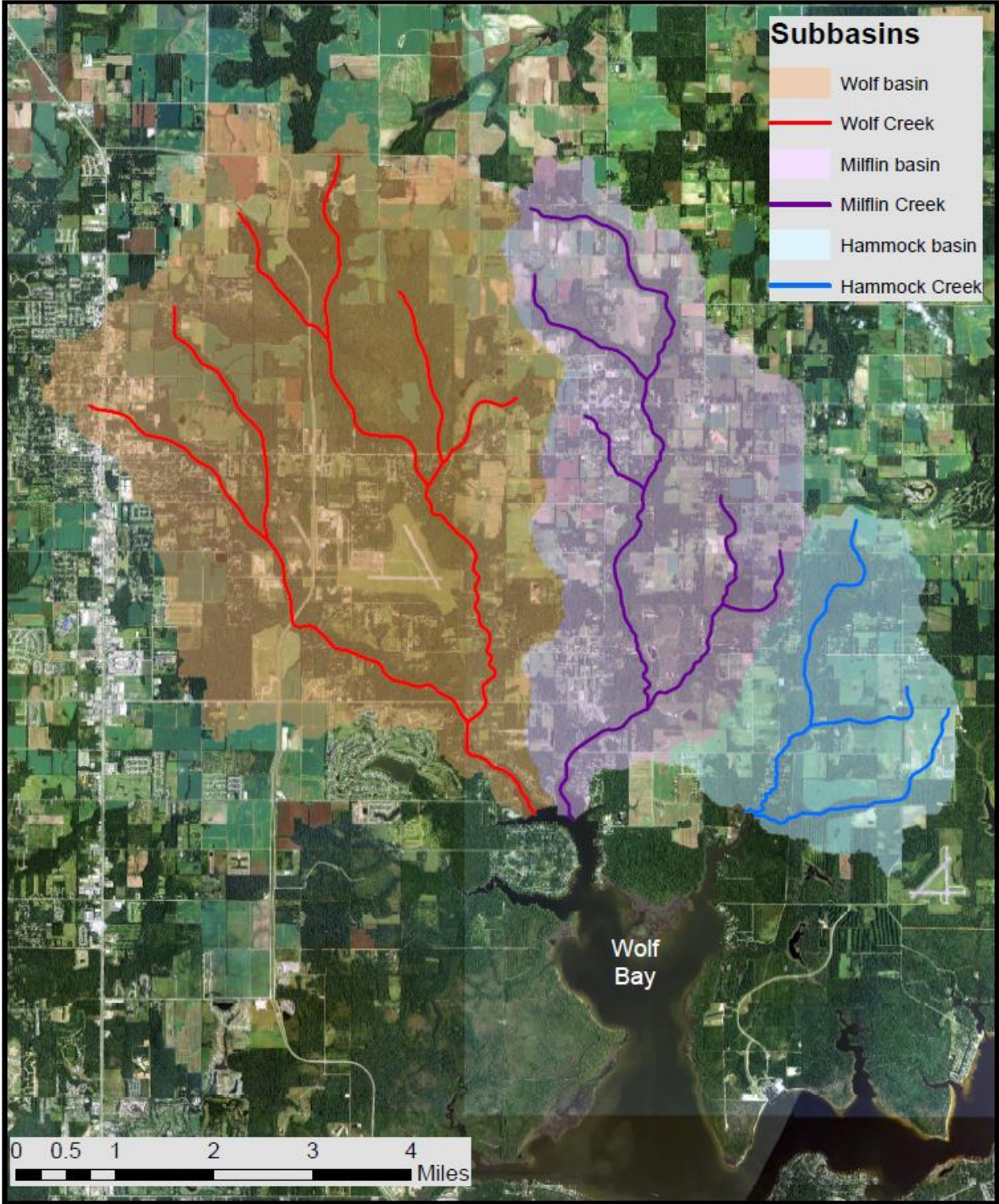


Figure 2.6 Three Sub-Watersheds and Streams in Wolf Bay Watersheds

### 2.2.6 Watershed Delineation Editing

Catchments for Wolf Creek and the other seven watersheds were created (Table 2.2) through the following process. First, LIDAR point cloud data were downloaded from the National Map through the USGS ([viewer.nationalmap.gov/basic/](http://viewer.nationalmap.gov/basic/)). Then the process described in Appendix A.1 was done to create a DEM. This DEM was used to compare against the EPA HUC map as discussed in section 2.2.5. This was only done to the edges of a watershed, and not the catchments within it. However, when using the USGS HUC 03140106 and 0314107 catchment map for HSPF creation, there were far too many catchments within the watershed to create user friendly HSPF models (Table 2.2). This is because HSPF has separate parameters for each catchment and for each land use. This means that the complexity of the model increases as the number of catchments increases. While the number of delineated catchments for each of the three Wolf Bay watersheds was reasonable, the Perdido, Styx, and Blackwater River watersheds were not. Therefore, some smaller catchments (of level 1 tributaries, or at stream intersection points) were combined. The BASINS delineation tool (Figure 2.5) has a built-in tool (Combine Selected Subbasins) for merging catchments.

Table 2.2 Number of HUC Catchments vs. Model catchments

	Wolf Creek	Milfin Creek	Hammock Creek	Perdido River	Styx River	Blackwater River	Elevenmile Creek	Marcus Bayou
HUC catchments	14	10	7	480	115	111	39	19
HSPF catchments	12	10	6	41	30	36	20	10

Catchments were merged in regard for flow path, similar elevation, similar land use, and desired stream detail. The HUC catchment map has many very small catchments (< 0.05 mi<sup>2</sup>) where multiple tributaries intersect, to help show the detail of the stream's bends and curves. These were often merged into the catchment just upstream to cut down on the number of catchments. In addition, catchments with smaller tributaries were merged with the larger streams into which they fed. These were often merged into the catchment just upstream to cut down on the number of catchments. These tiny catchments were more prevalent in the larger watersheds, due to the more complex stream networks, and in Marcus Bayou, due to a winding stream path.

## 2.3 HSPF Model Input

BASINS/HSPF trainings produced by AQUA TERRA were utilized to insure the files created would be compatible with the HSPF model. Soil data, stream networks, land-use data, streamflow gage data, and weather data would be needed from the watershed area in order to develop the model. Data should ideally be in the same time units at which the HSPF simulation is run. Our model uses an hourly time-step, so all data was collected in hourly increments. The specifics about each type of data and how they were obtained is described below in detail.

### 2.3.1 Meteorological Data

HSPF uses a Weather Data Management system (WDM) to manipulate and store solar radiation, cloud cover, wind speed, precipitation, potential evapotranspiration, and air temperature. The interface used in this study was WDMUtil 2.27, produced by AQUA TERRA. Perdido Bay itself has no active long term weather gages, however Pensacola, FL, Robertsdale, AL, and Fairhope, AL along the watershed boundaries do. Unfortunately no one station has a full set of data available. In addition, all these parameters vary over space. HSPF stores them at specific locations, and cannot average them over the watershed area itself based on distance. The meteorological data was downloaded from the BASISN download process (through EPA WDMs), the National Climatic Data Center (NCDC) website ([www.ncdc.noaa.gov/cdo-web/datatools/findstation](http://www.ncdc.noaa.gov/cdo-web/datatools/findstation)) and the South Alabama Mesonet (SAM) station list ([http://chiliweb.usouthal.edu/archived\\_data.php](http://chiliweb.usouthal.edu/archived_data.php)).

While the EPA had all datasets before 2009, the site has not updated since, so more current data had to be obtained from the other sites. The NCDC Robertsdale station has precipitation (PREC), air temperature (ATEM), and potential evaporation (PEVT). The NCDC Fairhope station has PREC, ATEM, and PEVT. The SAM Fairhope station has PREC, solar radiation (SOLAR), ATEM, and wind speed (WIND). Finally, the NCDC Pensacola Station has SOLAR, ATEM, PEVT, dew point temperature (Dewpoint), and WIND. Each of the required datasets were converted to a WDMUtil compactable data format (Appendix B). In addition, no one station covers the entire simulation period of 1990-2015, so the station data was integrated with each other as shown:

ATEM:            1990 - 2009 BASINS Robertsdale, 2010 - 2015 NCDC Robertsdale



CLOU: 1994 - 2009 BASINS Pensacola, 2010 -2015 SAM Fairhope\*  
 PERC: 1990 - 2009 BASINS Robertsdale, 2010 - 2015 NCDC Robertsdale  
 PEVT: 1995 - 2009 BASINS Fairhope, 2010 - 2015 SAM Fairhope\*  
 SOLR: 1995 - 2009 BASINS Pensacola, 2010 - 2015 SAM Fairhope  
 WIND: 1994 - 2009 BASINS Pensacola, 2010 - 2015 SAM Fairhope

\* calculated using SAM solar data

In Figure 2.7 the blue line is the hourly BASINS rainfall data from Robertsdale (2009–2015), while the green line is the hourly NCDC Robertsdale data (1930–2009). Both stations measure rainfall in inches. The datasets match well. The average rainfall is the same for both, however the maximum is considerably different. The large spike in 2014 is a hurricane that made landfall just southwest of the weather station. That means the northeast of the hurricane (the area of highest rainfall) hit the station.

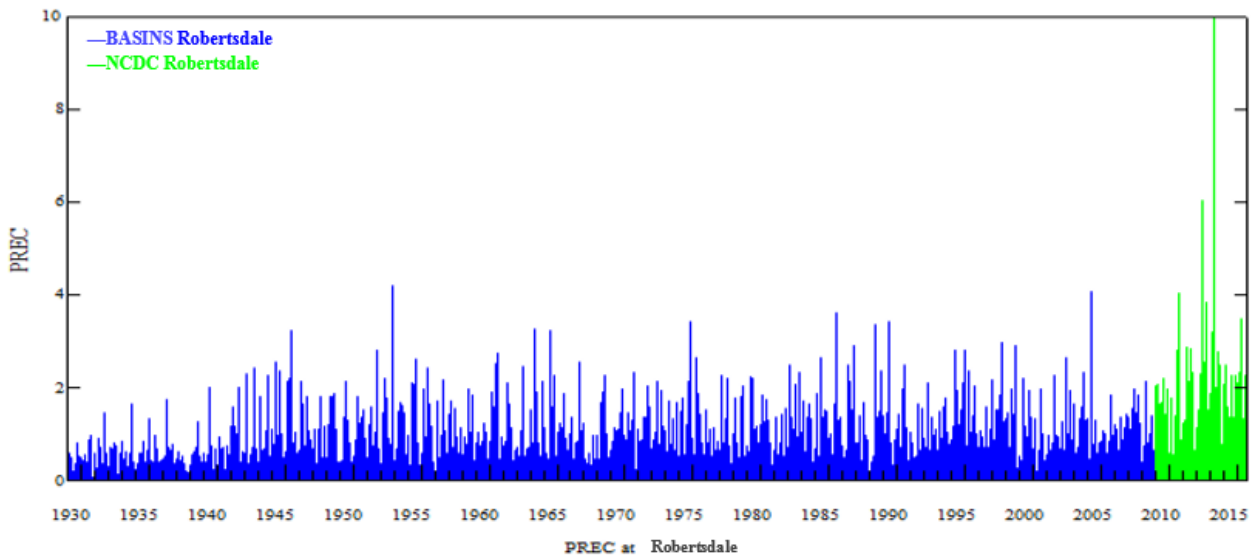


Figure 2.7 Hourly Precipitation Data (in.) at Robertsdale, AL

In Figure 2.8 the green line is the BASINS data from Pensacola, while the blue line is the NCDC Fairhope data. The BASINS Pensacola station measures wind speed in mph, while the NCDC Fairhope station measures in m/s. So a conversation was done to bring both to mph. In addition, the height that the measurement is taken at matters a great deal, since wind speed near the ground is much different than wind speed at higher altitudes. The BASINS Pensacola station only records at a height of 5 ft. (1.52m). The NCDC Fairhope station records at both 2 m and 10

m, so the 2m (6.5ft) measurement was used. The two datasets are easily distinguished due to their locations. Pensacola’s wind speed is consistently higher than Fairhope due to it being located along the coast, while Fairhope is more inland.

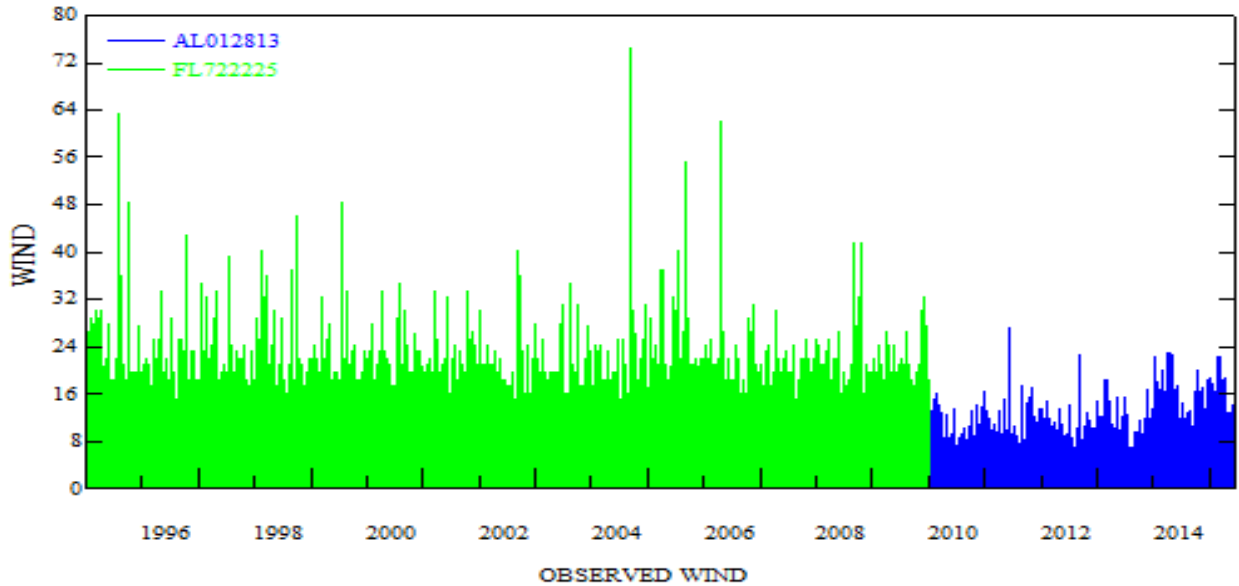


Figure 2.8 Hourly Wind Speed (mph) from Pensacola (FL72225) and Fairhope (AL012813)

In Figure 2.9 the blue line is the BASINS data from Robertsdale (1935–2009), while the green line is the NCDC Robertsdale data (2009–2015). The BASINS Pensacola station measures air temperature in Fahrenheit, while the NCDC Fairhope station measures in Celsius. A conversation was done to bring both to °F. These datasets match very well, since they are from the same location. The maximum, minimum, and average daily temperatures of both datasets are nearly the same.

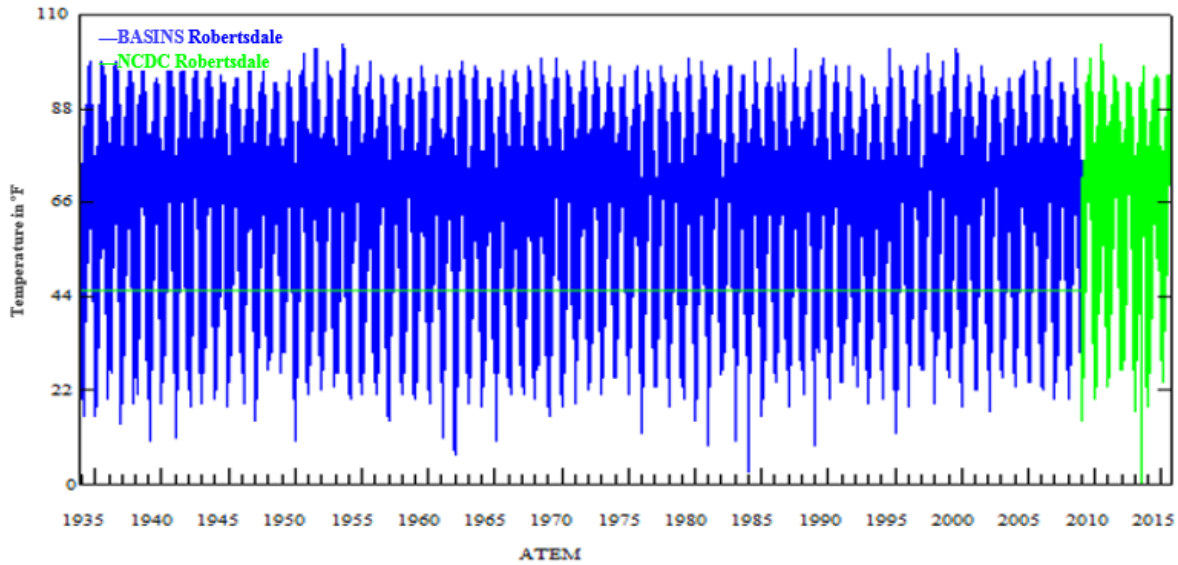


Figure 2.9 Air Temperature Data (°F) at Robertsdale, AL

In Figure 2.10 the green line is the BASINS data from Pensacola (1990–2009), while the blue line is the SAM Fairhope data (2009–2015,  $W/m^2$ ). Both were collected using a Li-Cor LI-200S Pyranometer for measuring global solar radiation—the combination of direct and diffuse solar radiation at outdoors under unobstructed natural daylight conditions. It measures solar radiation from 400-1000 nanometers range. The BASINS dataset is in Langleys. A conversion was done to bring both to Langleys. Just as the wind speed data showed a mismatch, so does the solar data. While the change in latitude between the two stations may account for small variations in the data, the increase is too large to be attributed to location alone. In the USA, there are very limited weather stations that have directly measured solar radiation data. Most of the solar radiation in other cities or weather stations are modeled using numerical models (either SUNY or NSRDB model). These computed datasets can be found at the National Solar Radiation Database ([rredc.nrel.gov/solar/old\\_data/nsrdb/](http://rredc.nrel.gov/solar/old_data/nsrdb/)). Therefore, solar radiation data at Pensacola from BASINS are most likely modeled.

In addition, the solar radiation data were the most problematic dataset. There was an error in 2005 that had to be adjusted. The gap began at 12/30/2005 0:00 and ended at 12/31/2005 23:00 (Figure 2.11), where two days erred out -999. Negative values are used to denote a sensor error, however HSPF cannot accept negative values. This may have been due to a power outage, or a

problem transmitting the data. The data was edited to match 12/29/2005 and 1/1/2006 (the week after the error).

The next data error to be fixed was the unexpected spikes at the beginning of 2010 and throughout 2014 (Figure 2.12). In the 2010 spike, the outliers are nearly double what the surrounding days make it seem they should be (upper right), since solar radiation shouldn't increase by so much from one day to the next. Radiation values above 75 Langley were halved, since 62 was the average when the outliers were not taken into account (lower left). Some values over 75 were unaltered if they fit into the pattern of that day (e.g., 54, 63, 82, 78, 47, where 82 and 78 would be left as was). These errors may have occurred when data was converted from one format to another at the data center, or because of an error at the gage location. A similar process was done to the 2014 spike to create the radiation data seen in Figure 2.10.

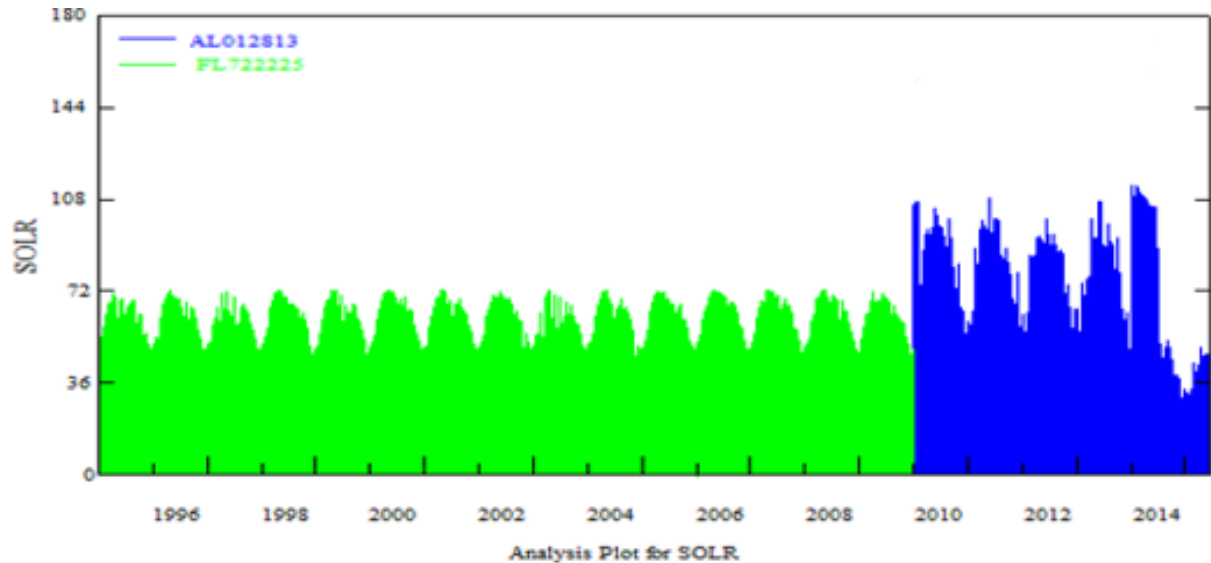


Figure 2.10 Solar Data (Langley) from Pensacola (FL72225) and Fairhope (AL012813)

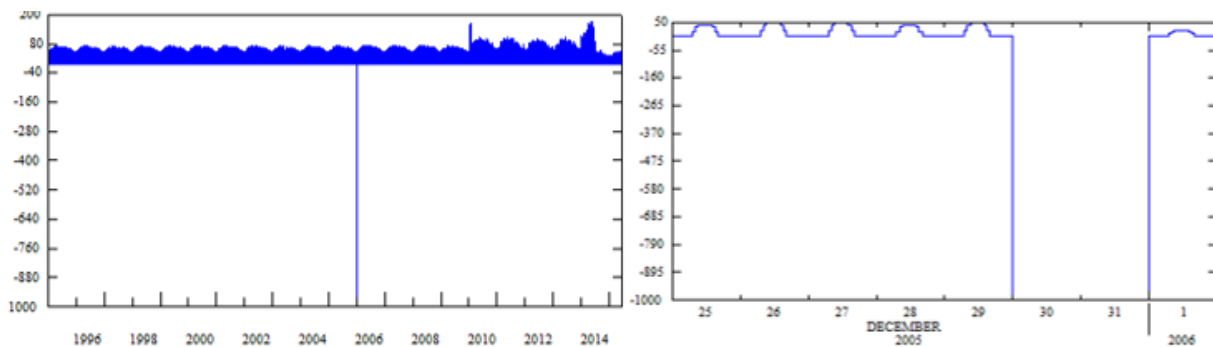


Figure 2.11 Negative Solar Data during December 2005

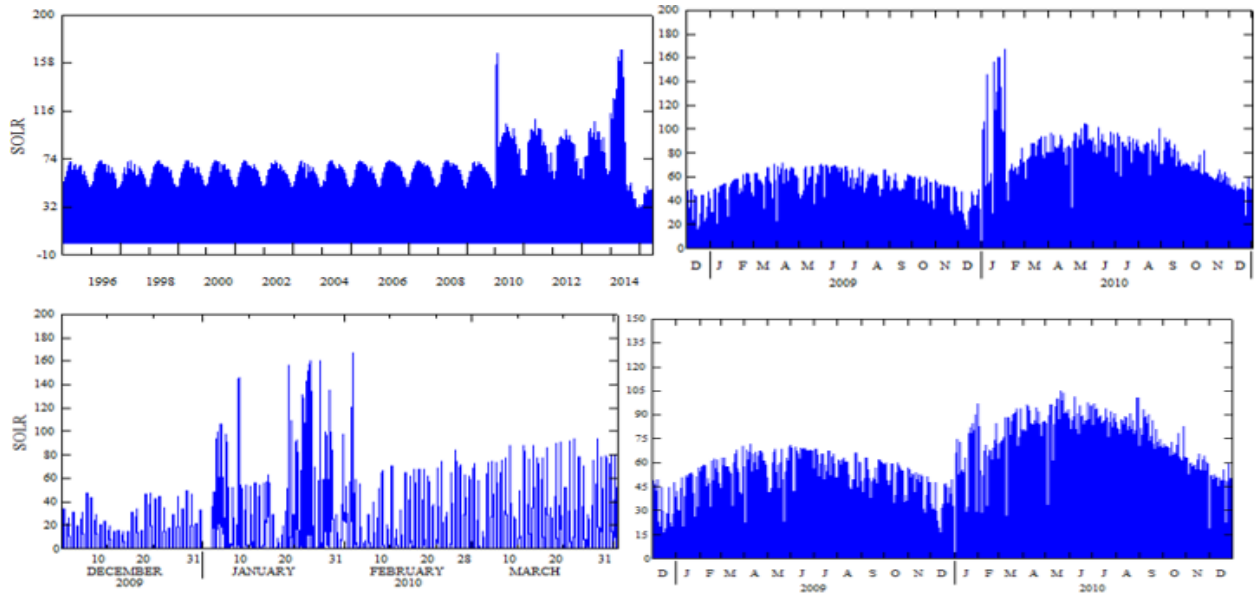


Figure 2.12 Description of Manually Editing Solar Radiation Outliers

Although this mismatch is not a major concern for the hydrologic part of the study, for the water quality part, this data is vital. In addition, the solar radiation data was used to calculate the cloud cover and evapotranspiration data. Therefore, the source of solar data for the water quality study may need to be changed or improved.

Since no station had cloud cover (CLOU) data for the entire simulation period, we used the CE-QUAL-W2 (Cole, 2003) method to convert SOLR data to CLOU. In this method, if the user chooses the internally computed short wave solar, the model computes the clear sky solar radiation  $\emptyset_s$  (Hs, short wave solar radiation in Btu/ft<sup>2</sup>/day) using the EPA (Annear, 2007) relationship:

$$\emptyset_s = 24(2.044A_0 + 0.1296A_0^2 - 1,941E - 3A_0^3 + 7.591E - 6A_0^4) * 0.1314 \quad (2.2)$$

$$A_0 = ASin\{Sin(Lat)Sin(\lambda) + Cos(Lat)Cos(\lambda)Cos(H)\} \quad (2.3)$$

$$H = \frac{2\pi}{24} \{ HOUR - (Long - \theta) \frac{24}{360} + EQT - 12 \} \quad (2.4)$$

$$EQT = 0.170Sin\left\{\frac{4\pi(INT(Jday)-80)}{373}\right\} - 0.129Sin\left\{\frac{2\pi(INT(Jday)-8)}{355}\right\} \quad (2.5)$$

Here 'Lat' is the latitude, ' $\lambda$ ' is the solar declination, and 'H' is the local hour angle of the weather station. The local hour angle H (radians) is the angular position of the sun for a given location at a specific time during the day, and was calculated from Ryan and Stolzenbach (Annear,

2007). ‘*HOUR*’ is the local hour; ‘*θ*’ is standard meridian in degrees; ‘*Long*’ is the longitude of the weather station; ‘*EQT*’ is the equation of time; ‘*Jday*’ is the Julian day represented by a floating-point value on a scale of 1 to 365 or 366 days for a year with ‘*INT*’ as the integer function of the day. More details of the process can be found in the Heat Exchange section of the CE-QUAL-W2 Manuel. The code that was used to convert SOLR to CLOU can be found in the Appendix C.

The PEVT was calculated using the WDMUtil Compute tool. (Figure 2.13). The Jenson Pet function was used, which utilizes the Jenson and Haise formula (Jenson, 1963). This requires the minimum and maximum temperature and the SOLR with monthly coefficients. The computations are based on Equation 2.5 and 2.7.

$$PET = CTS * (TAVF - CTX) * RIN \quad (2.6)$$

$$RIN = SWRD / (597.3 - (.57 * TAVC)) * 2.54 \quad (2.7)$$

Where ‘*PET*’ daily potential evapotranspiration (in), and ‘*RIN*’ is daily solar radiation expressed in inches of evaporation, ‘*SWRD*’ is daily solar radiation (langleys), ‘*TAVF*’ is the mean daily air temperature (°F), and ‘*TAVC*’ is mean daily air temperature (C). In addition, there are default values and calculations that can be used to find ‘*CTS*’ which is the monthly variable coefficient, and ‘*CTX*’ which is a seasonal coefficient (ASCE, 2005). Examples of these coefficients for different crops and seasons can be found in the ASCE Standardized Reference Evapotranspiration Equation.

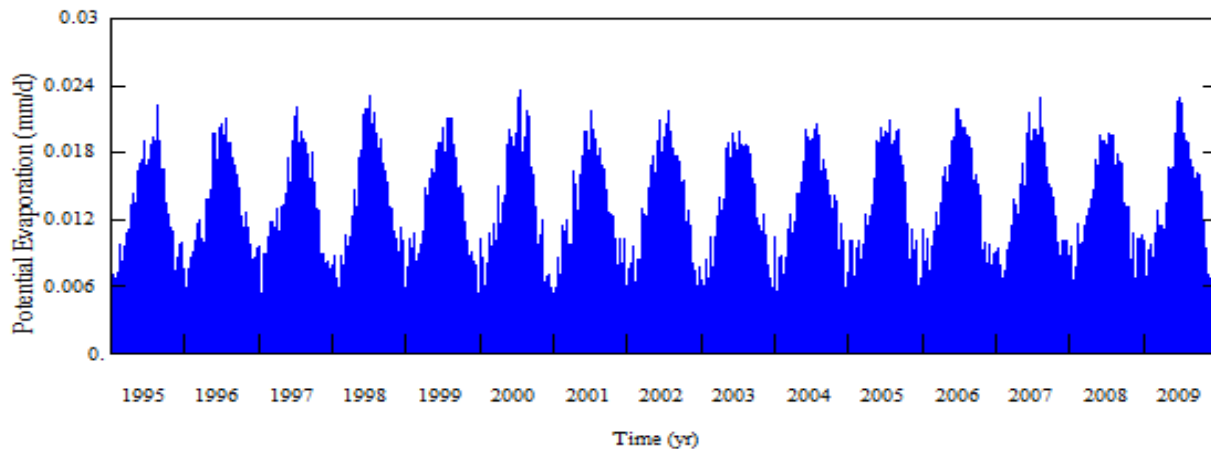


Figure 2.13 PEVT Data (mm/d) Computed from Solar Data

### 2.3.2 Land Use

Land use describes surface characteristics of the watershed. The Multi-Resolution Characteristics Consortium’s (MRLC) NLCD 2011 land use data was available for Baldwin County from their website, [www.mrlc.gov/nlcd2011.php](http://www.mrlc.gov/nlcd2011.php).

















The watershed is primarily forest, crop, and wetland with a strip of development along a highway leading to the Gulf of Mexico. The exact land use map can be seen in Figure 2.14. As with two previous NLCD land cover products (2006 and 2001), NLCD 2011 keeps the same 16-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters. Some categories we combined to ease the calibration process, since much of the soil and land use parameters were to be assumed or estimated. These combinations and the associated original NDCD code (inside brackets) are shown in Table 2.3. The full descriptions for each land use are given in Appendix A.

Table 2.3 Wolf Bay Land use Types

<u>Land Use Types</u>		<u>Revised Land Use Types</u>	
<i>Code</i>	<i>Name</i>	<i>Code</i>	<i>Name</i>
11	Water	11	Water
21	Urban, Open	21	Urban, Open
22	Urban, Low intensity	22	Urban, Low intensity
23	Urban, Middle intensity	23	Urban, Middle intensity
24	Urban, High intensity	24	Urban, High intensity
31	Barren	30	Barren (31)
41	Forest, Deciduous	40	Forest (41,42,43)
42	Forest, Evergreen	50	Scrub (51,52)
43	Forest, Mixed	70	Grassland (71,72,81)
51	Dwarf Scrub	80	Crops (81)
52	Scrub	90	Wetland (90,95)
71	Grassland		
72	Sedge		
81	Pasture		
82	Crops		
90	Wetland, Woody		
95	Wetland, Emergent		

# Wolf Bay Land-use Types

## Legend

-  Catchment
-  Woody Wetlands
-  Shrub
-  Pasture/Hay
-  Open Water
-  Mixed Forest
-  Herbaceous Wetlands
-  Grassland/Herbaceous
-  Evergreen Forest
-  Developed, Open Space
-  Developed, Mid Int
-  Developed, Low Int
-  Developed, High Int
-  Deciduous Forest
-  Cultivated Crops
-  Barren Land

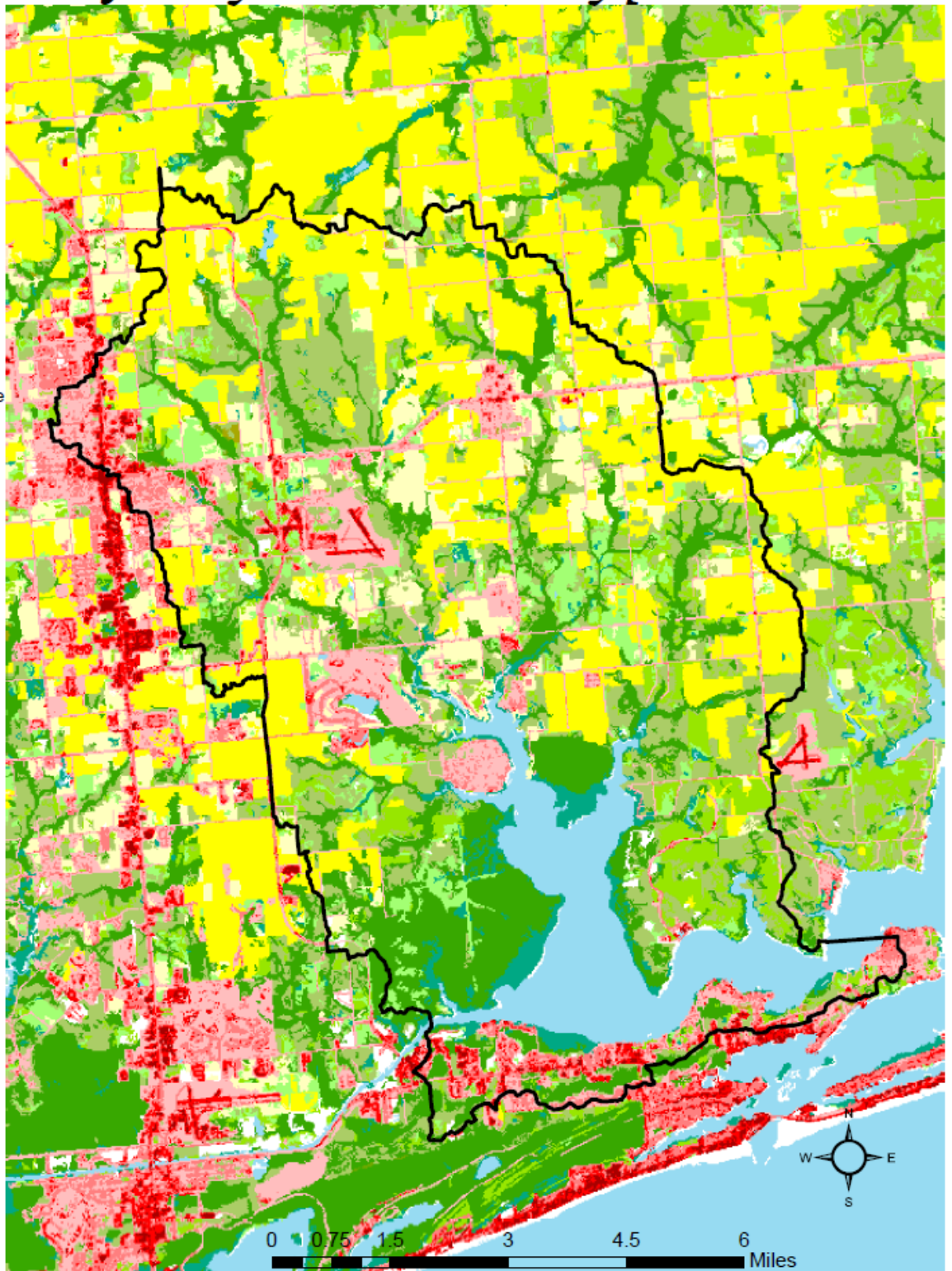


Figure 2.14 Wolf Bay Landuse Map



### 2.3.3 Soils Data

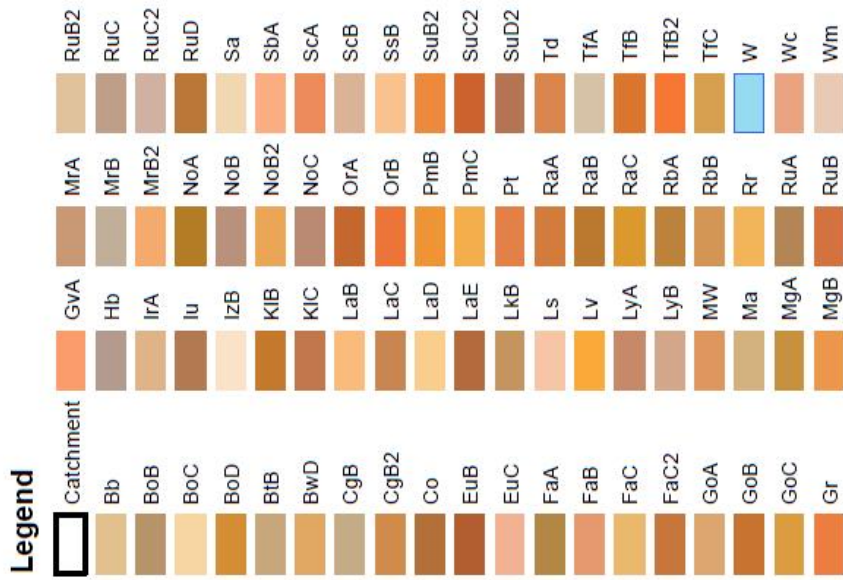
The USGS's Soil Survey was used as the soil data. This database can be found at [websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx](http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx). This dataset is easier to work with than the land-use, as it is vector data with each polygon having the same soil type. This ease results from ArcMap being better at processing vector vs raster data, and for vector data having a smaller data storage requirement. The USGS website allows for the download of specific areas. The process to create and download this dataset is further discussed in Appendix A. The map created through this process is shown in Figure 2.15. Here there are over 75 individual soil types represented by soil code, i.e., SbA. Each color represents a separate soil, these can be continuous, or separated by other soils types.

The top six prominent soil coverage based on percentage coverage were all combinations of sands and loams as shown in Table 2.4. They were Klej loamy fine sand, Lakeland loamy fine sand, Goldsboro fine sandy loam, Norfolk fine sandy loam, Hyde, Bayboro, and Muck soils, and Scranton loamy fine sand. Water was added to the table to show how much of the watershed area is dominated by the bay and the wetlands around it. Based on these soil types, soil parameters such as soil thickness, field capacity, saturation moisture, horizontal conductivity, vertical conductivity, etc. were estimated by averaging the soil properties downloaded from the Soil Survey. The soil parameters were adjusted during model calibration to generate good matches between modeled and observed data.

Table 2.4 Primary Wolf Bay Soil type (2016 Soil Survey)

Map unit	Map unit name	Rating	Watershed % (by acre)
KIB	Klej loamy fine sand	A-2-4	13.40%
LaB	Lakeland loamy fine sand	A-2-4	11.10%
GoA	Goldsboro fine sandy loam	A-4	7.00%
NoA	Norfolk fine sandy loam	A-4	6.80%
Hb	Hyde, Bayboro, and Muck soils	A-4	5.50%
ScA	Scranton loamy fine sand	A-2-4	5.50%
W	Water	-	9.70%
Total			59.00%

# Wolf Bay Soil Types



Description:  
 Coordinate System: USA Contiguous Albers Equal Area Conic USGS version  
 Projection: Albers  
 Datum: North American 1983  
 False Easting: 0.0000  
 False Northing: 0.0000  
 Central Meridian: -96.0000  
 Standard Parallel 1: 29.5000  
 Standard Parallel 2: 45.5000  
 Latitude Of Origin: 33.0000  
 Units: Meter

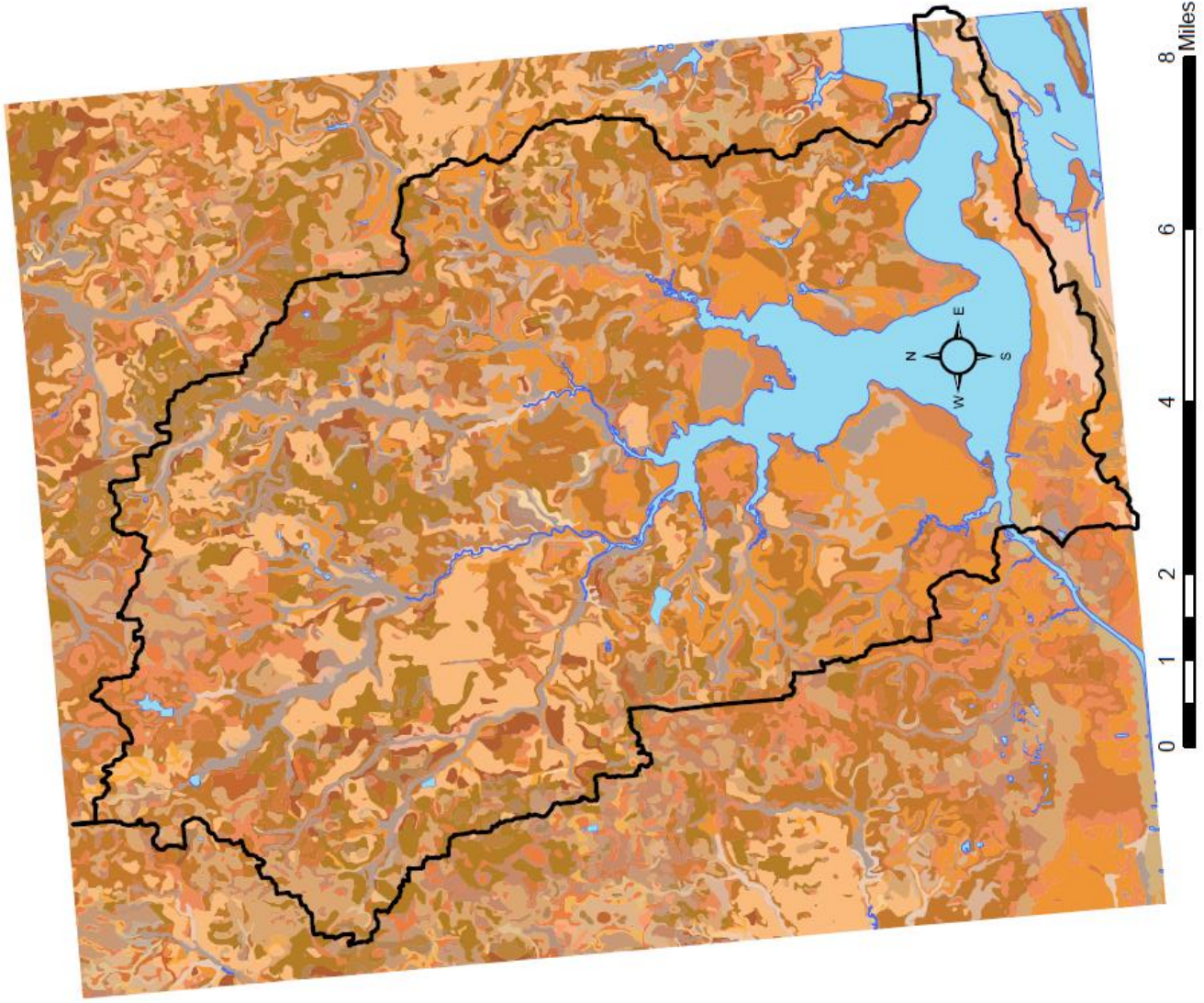


Figure 2.15 Wolf Bay Soil Type Map

### 2.3.4 Point Sources Data

The major point source dischargers in are the Riviera Utilities Wastewater Treatment Plant. (Figure 2.16) The Riviera Utilities WWTP treats inflow from over 20,000 people. Actual discharge data was unobtainable, therefore assumed WWTP discharge was used. Therefore an estimated outflow to the creek of around 3.5 cfs was assumed; when average US water usage, city size, and population of Foley, AL is considered. In addition, Wolf Creek, one of the three main inflows to Wolf Bay goes through the nearby center of the City of Foley. Within the town there is a Community center, Veterinarian Office, a large horse boarding facility, and dozens of homes. Furthermore, Wolf Creek has seven crossing points with city roads and highways. With all this activity there are plenty of possible sources for small point sources of contaminants.

Currently, we have been unable to obtain the actual discharge from the WWTP. While a WWTP discharge can be inferred by the amount of drinking water a community uses, it is not completely accurate. This is due to losses in the system, agricultural uses, outdoor use, and travel losses (Bulter, 1995). A variable method was used around the average assumed flow, however the actual discharge would be preferred and the attempt is still being made to acquire it from the city of Foley.

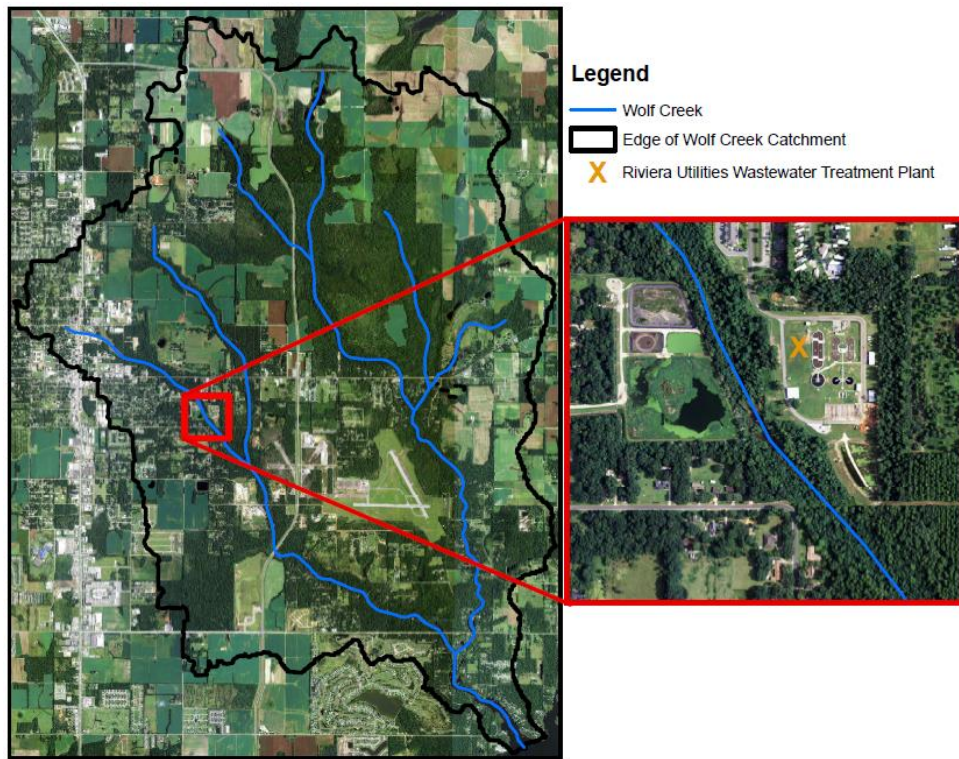


Figure 2.16 Location of Point Source from Riviera WWTP

### 2.3.5 Observed flow

There is one USGS discharge gage located on Wolf Creek. There are two privately used stage gages on Milflin Creek. The daily flow data can be obtained from USGS water data web site, [waterdata.usgs.gov/nwis/sw](http://waterdata.usgs.gov/nwis/sw). The only available USGS station with continuous daily data is USGS 02378170 in the Wolf Creek at Foley Beach Express crossing south of Foley. (Figure 2.17). The USGS daily data available from December 2007 through 2015 was used for model calibration and validation. The USGS daily flow data was downloaded from the USGS site and is shown in Figure 2.16. There is a large data gap in 2014, however only small data gaps exist in the rest of the time period.

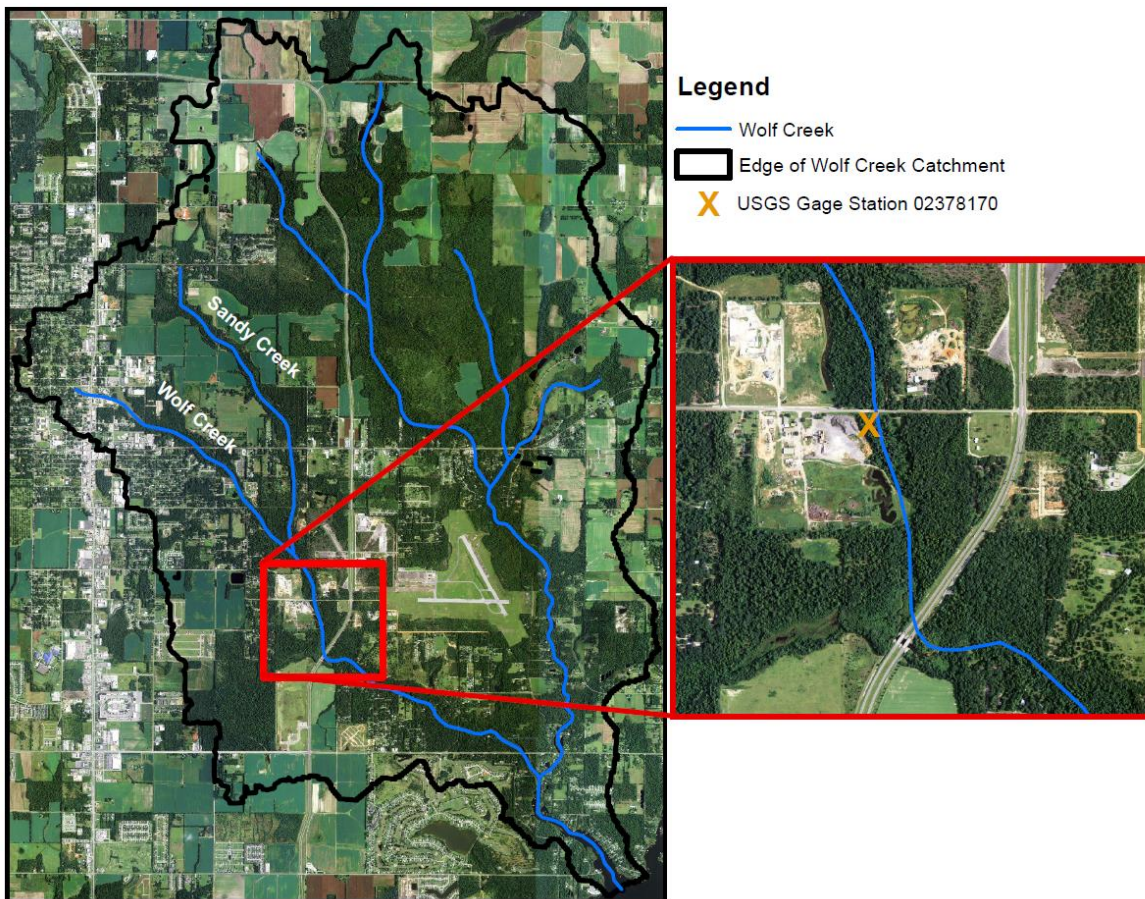


Figure 2.17 USGS Discharge Gage Location on Wolf Creek

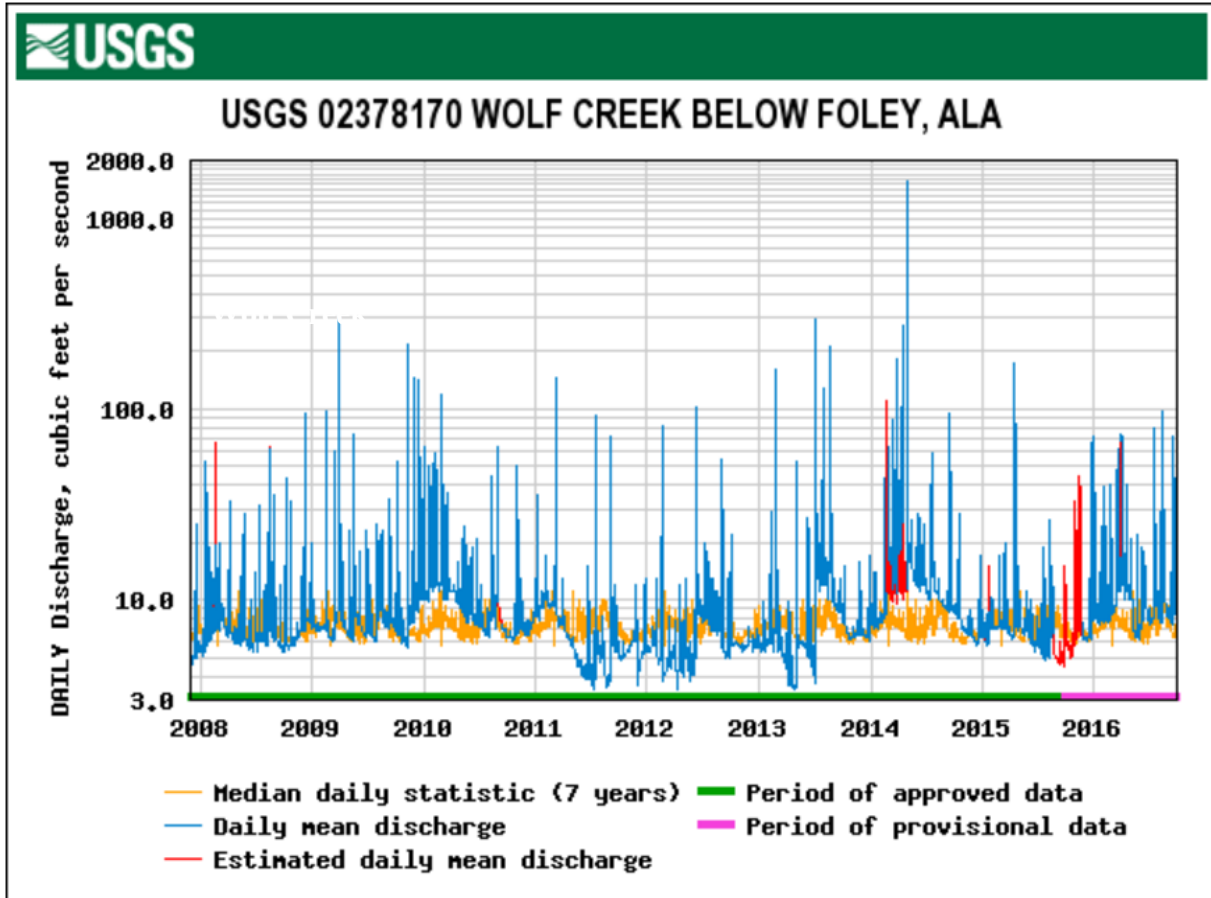


Figure 2.18 Discharge (cfs) from 2007-2016 at USGS 02378170

### 2.3.6 Observed Water Quality

The last set of data that will be needed is actual water quality. There are several private sampling sites within the watershed, however none that can be used. The Alabama Water Watch (AWW) is an organization of trained citizens that test water throughout the state. They have over 40 monitoring sites in the Wolf Bay watershed alone and nearly 60 throughout the Perdido Bay watershed. Their sites measure water temperature, pH, DO, hardness, alkalinity, and turbidity, general E. Coli, and total coliforms. In Figure 2.19 the red dots are former sites and the green dots are active sites. All the data from AWW sites can be found on the AWW website, [www.alabamawaterwatch.org/water-data/AWWmap/](http://www.alabamawaterwatch.org/water-data/AWWmap/). While AWW's data can be used as a good baseline and some of the sites have a decade of data, more data will be required to match against the output of HSPF.

However, AWW is not currently considered a reliable water quality data source. These observations have no standard time step. At these sites citizens may take measurements each week, monthly or even randomly. Also, sites begin and stop sampling at the whim of the volunteer taking data. The Auburn University Fisheries department began regular water quality testing at the Elevenmile Creek and Marcus Bayou entrances to Perdido Bay in February 2017, soon the new data can be used for model calibration.

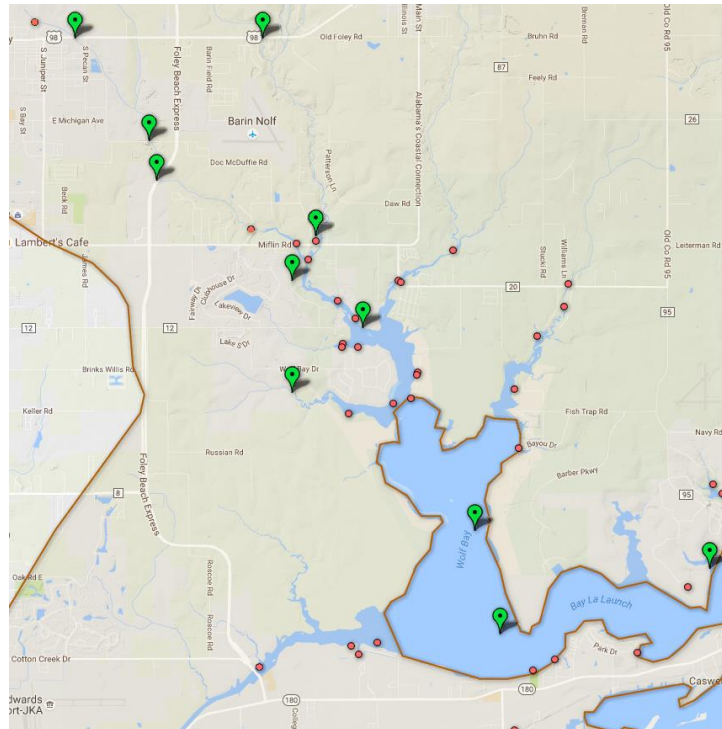


Figure 2.19 AWW Water Quality Stations in Wolf Bay Watershed

## 2.4 Summary

All the data needed for HSPF modeling of Wolf Bay are available. However, due to gage limitations, only Wolf Creek can be adequately calibrated. Therefore Wolf Creek will be the first model created towards the goal of modeling all of Perdido Bay. In addition, when Figure 1.4 is viewed it is obvious that HSPF will not be able to properly model the lower Wolf Bay watershed, due to a lack of streams. The creation of the Wolf Creek HSPF model is detailed in Chapter 3. What will happen with the lower bay is discussed in Chapters 4 and 5.

## CHAPTER 3 WOLF CREEK MODLING

### 3.1 HSPF Simulation

To create a HSPF project four files are needed: the Watershed (.wsd), the Reach (.rch), the Channel Geometry (.ptf), and the Point Source (.psr) files. A visual of what data the .wsd and .rch files contain can be seen in Figure 3.1 for three Wolf-Bay watersheds. The .wsd file shows catchments in a watershed and how they connect each other, the .rch file shows one major stream associated with each catchment and associated outlet (one for each catchment). The .ptf contains the channel length, slope, and geometry of catchments.

#### 3.1.1 HSPF Creation and Editing

The model creation process begins with the collection of all needed data (elevation, precipitation, land use, etc.), then data processing must be done to create the necessary files to start HSPF. The EPA's BASINS can be used to help with this data processing (Figure 3.2). Weather and hydrology data can be downloaded in a supported file format (A table of formats can be found in Appendix B) directly from the EPA site. Land-use and elevation can be uploaded as raster files. Watershed delineation can be done either manually or automatically using the Delineation Tools, more information is given in the EPA Training Exercise 2 as discussed in Appendix A.

# Basins, Streams, and Outlets

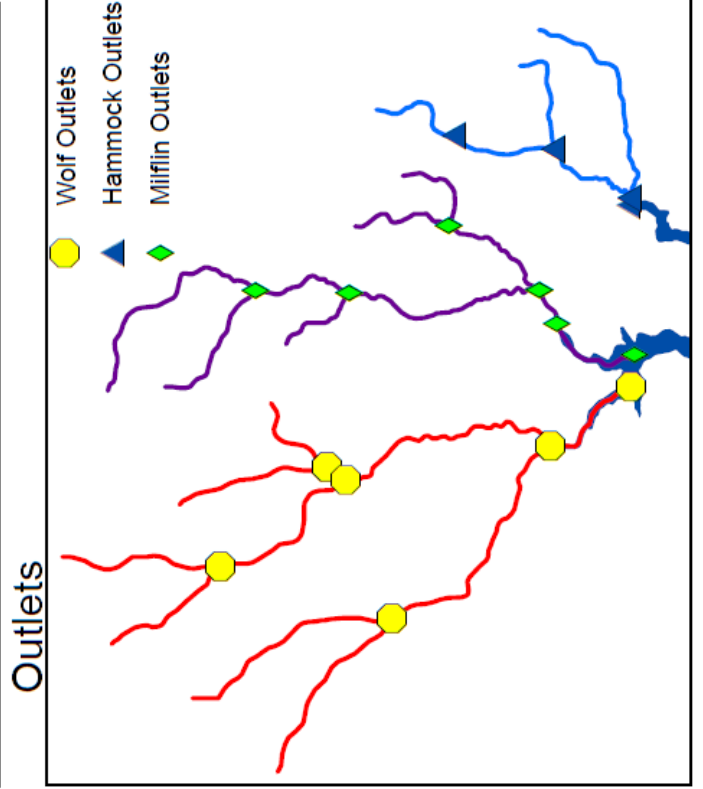
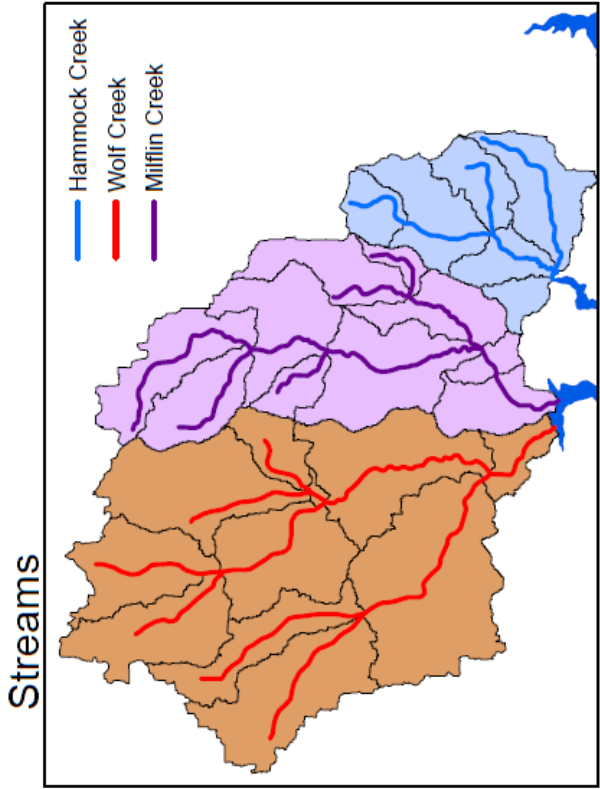
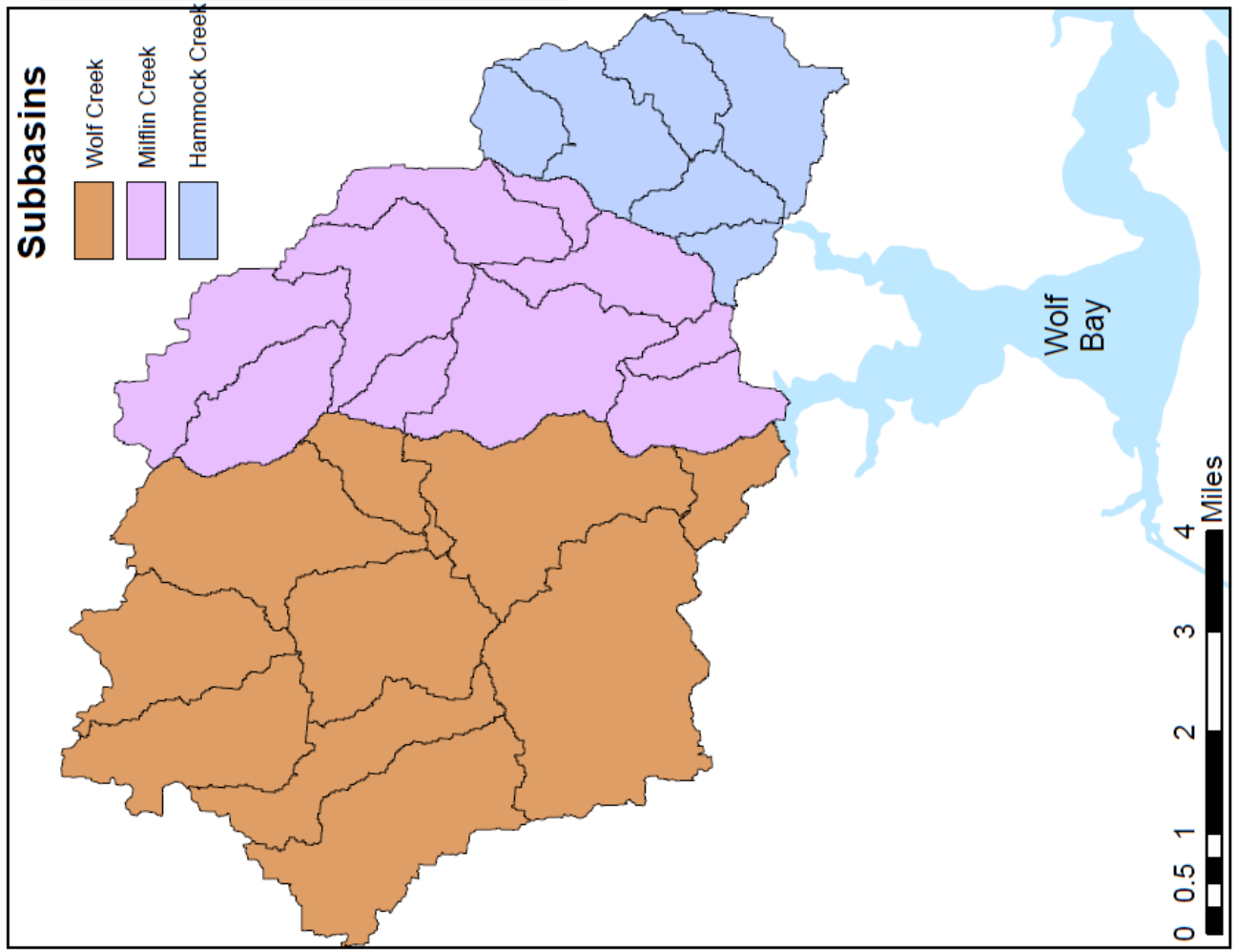


Figure 3.1 Streams, Sub-basins and Outlets for Wolf Bay Watersheds



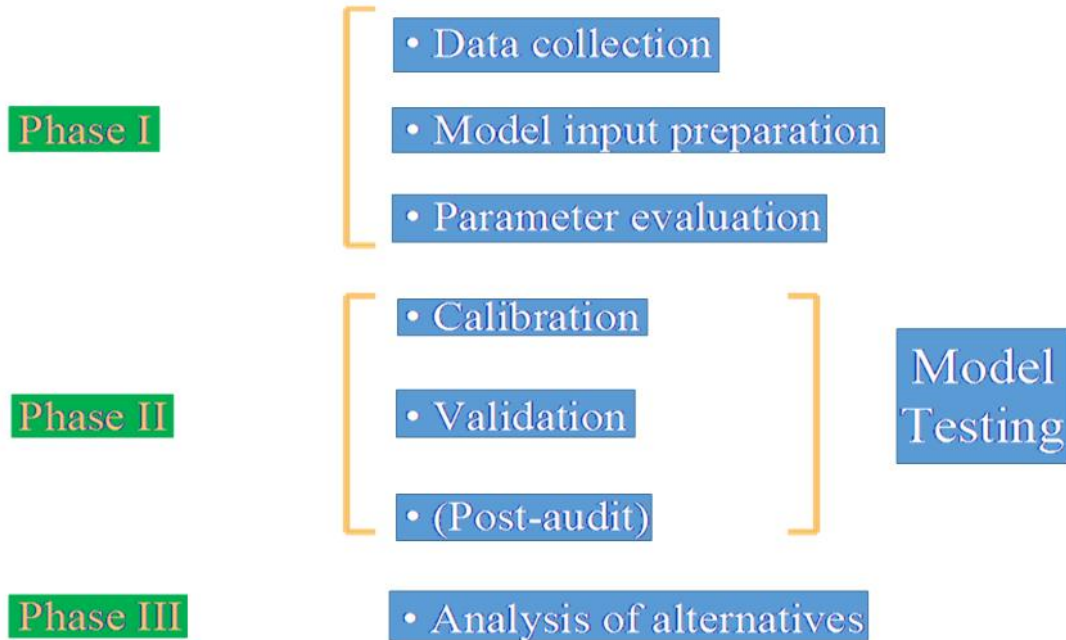



Figure 3.2 Model Creation Process

Once all geographic processes in BASINS are completed, the HSPF tool should be used. This requires the watershed shapefile, the stream shapefile, the outlet pointfile, the DEM, and the landuse raster. Once each of these files are loaded and the appropriate data pulled from each, BASINS will create the four files needed for the HSPF User Control Input (.uci) file. In addition to these four, the WDM is also needed. A downside of HSPF is that only one WDM file can be associated with each UCI (Johanson, 1996).

Once the UCI has been created it can be edited manually if needed. While it is possible to make changes directly to the .uci file, using WinHSPF reduces the possibility of errors and allows for a consistent method to be adopted. The GUI provided by WinHSPF also allows for some visual inspection as you configure the model. Data about the Reaches such as reach length, change in land elevation, and how catchments flow into each other are kept from the BASINS created .rch file. Reach lengths and areas can be edited in the Reach Editor tab (  , Figure 3.3).

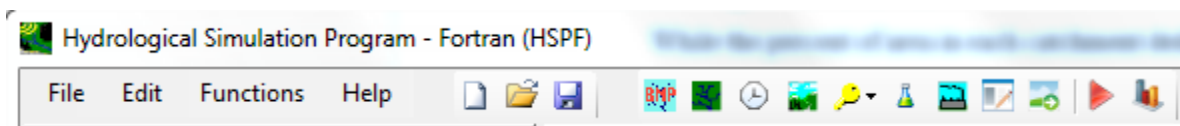








Figure 3.3 HSPF Toolbar

While the percent of area in each catchment dedicated to each land use type is automatically taken from the BASINS created .wsd file, land use areas can be edited in the Land use Editor tab (, Figure 3.3). However, if any new land uses need to be created, they must first be created in the Open Sequence tab and given a land use number and description. Then in the Schematic tab they can be assigned to a reach using the Target Operation and given the correct Mass Link number (1= impervious and 2= pervious). The Control Card Editor tab (, Figure 3.3) allows you to choose which parameters you would like to model. Each tab (PERLND, IMPLND, and RCHRES) contains a list of corresponding modules and parameters. Which parameters and modules wanted can be specify by checking the boxes beside the parameters. When you turn “on” (check the box beside) a module through this editor, other sections might turn on automatically because there are rules in the model’s coding that require certain modules as prerequisites to others. Then the parameters that affect the chosen module can be adjusted in the Input Data Editor tab (, Figure 3.X)

To choose which pollutants or water attributes that HSPF will provide simulation data for, the Pollutant Selection tab (, Figure 3.3) is used.  $\text{NH}^{3+}$ ,  $\text{NH}^4$ ,  $\text{NO}_3$ , F. Coliform, orthophosphorus, BOD, DO, metals, sediment, and water temperature are all options for modeled pollutants in HSPF. However, each selection adds additional model parameters and initial conditions into the HSPF model.

The Point Sources tab (, Figure 3.3) is where the choose source files can be turned “on” depending on if there are any additional flow sources. Most point source data will be in the WDM file, since the BASIN/HSPF integration allows for the ease of downloading or adding point source data into the WDM file. However, new point source files can also be created from the Point Sources tab. This entails creating a point source location (by catchment), picking what contaminants are within the source, then creating a discharge file in one of the supported import scripts. A list of these scripts can be found in Appendix B.

To adjust the time period that the model will run, the Time and Meteorological Data tab (, Figure 3.3) can be used. This tab can be used to adjust how long the model runs for, from minutes to years. However, the timeframe given must be included within the timeframe of the WDM file. This means the WDM file must contain at least the same or longer period of

meteorological data for the HSPF modeling. This tab also is used to change which WDM files are associated with the model. Only one WDM file can be attached, however it does not have to be associated with each model segment. Each WDM file may contain weather data from more than one weather station.

The FTables, the relationship between water depth, flow area, flow volume and discharge of each river, are taken from the BASINS created .ptf file, however, they can be edited manually if desired. All other parameters can be changed using the Input Data Editor tab, which contains nearly 100 possible tables. The number of tables, and therefore parameters used, is one way to adjust the complexity of the model. The parameters will be explained in more depth in the following section and in Chapter 4.

### **3.1.2 Running HSPF**

First insure that the model will run the desired scenario. HSPF run scenario has three options: Hydrology Calibration, Flow, and AQUAOX linkage. This can be done in the Output Manager tab. Flow provides the streamflow at the selection outlet. Hydrology Calibration shows the simulated flow, surface runoff, interflow, base flow, potential evapotranspiration, actual evapotranspiration, upper zone storage, lower zone storage, and total moisture supply at the selected outlet. AQUAOX linkage gives output ready to be used in that system. Run the model by clicking the Run Simulation tab. This creates output files that can be viewed in either BASINS, GenScn, or WDMUtil. A window will appear that requires a save before the model is run.

Press 'OK' and another window will appear to show the progress of the model run. Either the meter will go to 100% and finish, or the model can return an error message window. The error must be identified and addressed to achieve a successful model run. Once a complete run has occurred, press the View Output tab to open the BASINS interface. Full results can be viewed in BASINS and GenScn, however this report focuses on the BASINS process. Once BASINS has opened, click 'Launch' from the BASINS toolbar and select WDMUtil.

When the WDMUtil Window appears, navigate to the WDM file generated by the HSPF model and open the file. Output can be viewed by clicking the graph icon in the tools section of the interface. The time range of output data can be adjusted in the Dates section in the bottom left corner of the interface.

### 3.1.3 HSPFParm

The EPA has funded both the collection of HSPF parameter values from previous applications across North America, and the development of an interface that enables modelers to access and utilize the database. This meets the need for readily available sources of model parameter values that can provide the best possible starting point for developing new watershed applications (Donigan, 1997). Since the study was conducted in 1997, information of many recent studies using HSPF and LSPC, especially those unpublished projects and reports done by private consulting companies, is not available for new users yet.

The HSPFParm database contains parameter values for model applications in over 40 watersheds in 14 states and 9 HUC's. Figure 3.4 shows the locations of these 40 watersheds. The parameter values that are contained in the database characterize a broad variety of physical settings, land use practices, and water quality constituents. The database created by AQUA TERRA Consultants has been provided with a simplified interactive interface that enables modelers to access and utilize HSPF parameter values that have been developed and calibrated in various watersheds across the United States. Its purpose was to develop the model parameter database to provide guidance for future BASINS and HSPF users.

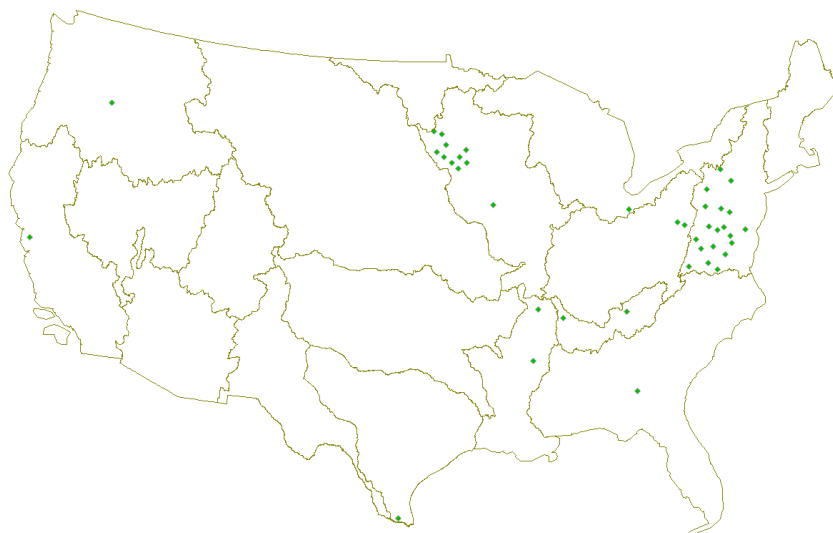


Figure 3.4 HSPFParm Sample Model Locations

HSPFParm is designed to increase modelers' ability to 'fine tune' the model to represent site-specific physical, chemical, and biological conditions that determine the fate and transport of pollutants. Its ultimate goal is to tie environment-dependent water quality parameter values directly to modeling units (e.g., USGS hydrologic units) across large areas of North America. This would greatly speed up development of new watershed models.

The first step to using HSPFParm is to look through the 40 watersheds to determine which have similar conditions to the current watershed. Here four different models were selected for use as guides. These were from Georgia, Mississippi, Oregon and Minnesota. Each has a significant area with wetland classification, a low slope throughout, and low urban land use. Each of the parameters were downloaded from the database and compared. Next, the default parameter values given by HSPF were compared to the chosen models and adjusted accordingly. Each parameter was then adjusted to increase the efficiency of the model. How the model's efficiency was assessed and details of parameter adjustments are discussed in the next section.

To ensure efficient representation of parameters, how other models approached parameter selection was also considered (Haan, 1972; Knisel, 2012; Moyer, 2003; Tang, 1993). Most had similar features to Wolf Creek; smaller watersheds and high precipitation, or at least using HSPF with details about their parameter selection. However, very few discussed the actual calibration process. None gave details about actual parameters as HSPFParm provides. HSPFParm combined with the guidance of HSPFEXP is still the best way to calibrate the HSPF model for new users.

### **3.1.4 Simulation parameters**

Models are only an approximation of reality and as such cannot precisely represent natural systems. However, with more accurate measurement of the physical attributes and calibration of unknown parameters, models can be useful.

Also, there is no single accepted statistic or test that determines whether or not a model is valid. Both graphical comparisons and statistical tests are required in model calibration and validation to insure that models are as accurate as possible. Models cannot be expected to be more accurate than the errors (confidence intervals) in the input and observed data.

The fourteen parameters in Figure 3.5, which shows the schematic of how each of the mentioned parameters links together and what part of the physical process to which they correspond, are part of the calibration process within HSPF. Six deal with groundwater volume

and recession (AGWRC, KVARY, DEEPER, INFILT, AGWETP, and BASETP). Six deal with surface runoff and interflow which can influence the shape of the hydrograph (UZSN, INTFW, IRC, LSUR, SLSUR, and NSUR). Four deal with the annual water balance (INFILT, DEEPER, LZSN, and LZETP). How all of these parameters relate to one another and to natural process can be seen in the graphical representation of HSPF modeled hydrological processes in Figure 3.5. A short description and range of these values can be found in Tables 3.1-3.4.

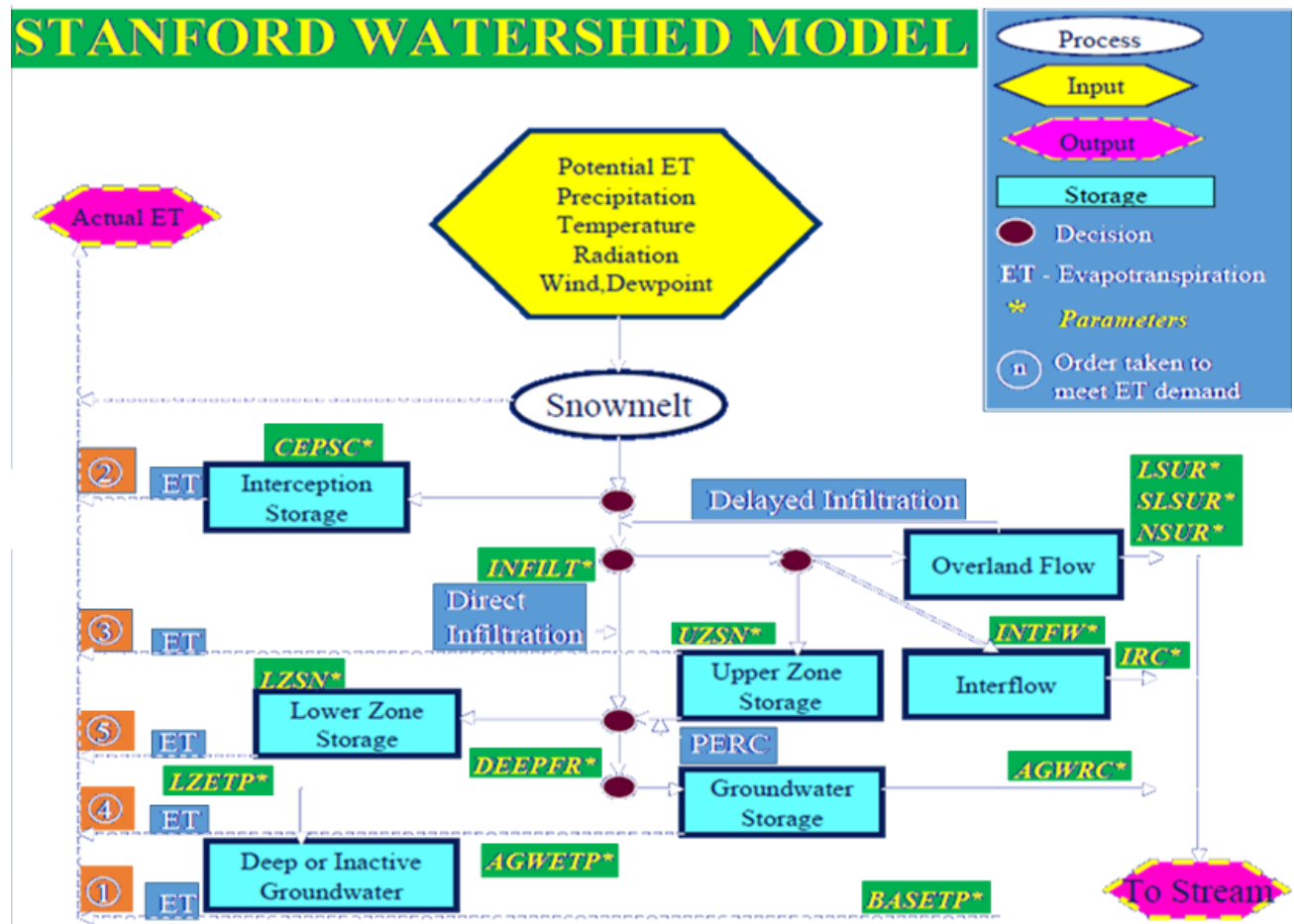


Figure 3.5 Schematic Diagram of Stanford Watershed Model Showing Different Hydrologic Processes and Inter-Connections

The precipitation that occurs during a storm event can be intercepted by vegetation or leaf litter, falls into a water body, or falls on the land surface. The part of precipitation intercepted by vegetation is removed by evapotranspiration. The precipitation falling on land surface is either lost through evaporation, soil infiltration, or gets converted into overland flow. The remaining small portion of rainfall falling on a waterbody is lost through evaporation or directly reaches the stream

channel. The fraction of infiltrated precipitation is either discharged quickly through interflow or is percolated downward to the groundwater and then reaches the stream channel through the slow process of base flow. This is the general process of non-urban (pervious) environments. For more urban (impervious) areas there is little or no vegetation for evapotranspiration to occur. In addition, little exposed soil allows for only a small fraction to be infiltrated. However, due to the impervious nature of the environment, the runoff and surface storage is far greater.

Table 3.1 HSPF PWAT-Parm2 Parameter Ranges

			RANGE OF VALUES					
NAME	DEFINITION	UNITS	TYPICAL		POSSIBLE		FUNCTION OF ...	COMMENT
			MIN	MAX	MIN	MAX		
<b>PWAT - PARM2</b>								
FOREST	Fraction forest cover	none	0.0	0.50	0.0	0.95	Forest cover	Only impact when SNOW is active
LZSN	Lower Zone Nominal Soil Moisture Storage	inches	3.0	8.0	2.0	15.0	Soils, climate	Calibration
INFILT	Index to Infiltration Capacity	in/hr	0.01	0.25	0.001	0.50	Soils, land use	Calibration, divides surface and subsurface flow
LSUR	Length of overland flow	feet	200	500	100	700	Topography	Estimate from high resolution topo maps or GIS
SLSUR	Slope of overland flow plane	ft/ft	0.01	0.15	0.001	0.30	Topography	Estimate from high resolution topo maps or GIS
KVARY	Variable groundwater recession	1/inches	0.0	3.0	0.0	5.0	Baseflow recession variation	Used when recession rate varies with GW levels
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	Baseflow recession	Calibration

Table 3.2 HSPF PWAT-Parm3 Parameter Ranges

			RANGE OF VALUES					
NAME	DEFINITION	UNITS	TYPICAL		POSSIBLE		FUNCTION OF ...	COMMENT
			MIN	MAX	MIN	MAX		
<b>PWAT - PARM3</b>								
PETMAX	Temp below which ET is reduced	deg. F	35.0	45.0	32.0	48.0	Climate, vegetation	Reduces ET near freezing, when SNOW is active
PETMIN	Temp below which ET is set to zero	deg. F	30.0	35.0	30.0	40.0	Climate, vegetation	Reduces ET near freezing, when SNOW is active
INFEXP	Exponent in infiltration equation	none	2.0	2.0	1.0	3.0	Soils variability	Usually default to 2.0
INFILD	Ratio of max/mean infiltration capacities	none	2.0	2.0	1.0	3.0	Soils variability	Usually default to 2.0
DEEPPFR	Fraction of GW inflow to deep recharge	none	0.0	0.20	0.0	0.50	Geology, GW recharge	Accounts for subsurface losses
BASETP	Fraction of remaining ET from baseflow	none	0.0	0.05	0.0	0.20	Riparian vegetation	Direct ET from riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0.0	0.05	0.0	0.20	Marsh/wetlands extent	Direct ET from shallow GW

Table 3.3 HSPF PWAT-Parm4 Parameter Ranges

			RANGE OF VALUES					
NAME	DEFINITION	UNITS	TYPICAL		POSSIBLE		FUNCTION OF ...	COMMENT
			MIN	MAX	MIN	MAX		
<b>PWAT - PARM4</b>								
CEPSC	Interception storage capacity	inches	0.03	0.20	0.01	0.40	Vegetation type/density, land use	Monthly values usually used
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1.0	0.05	2.0	Surface soil conditions, land use	Accounts for near surface retention
NSUR	Manning's n (roughness) for overland flow	none	0.15	0.35	0.05	0.50	Surface conditions, residue, etc.	Monthly values often used for croplands
INTFW	Interflow inflow parameter	none	1.0	3.0	1.0	10.0	Soils, topography, land use	Calibration, based on hydrograph separation
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	Soils, topography, land use	Often start with a value of 0.7, and then adjust
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	Vegetation type/density, root depth	Calibration

Table 3.4 HSPF IWAT-Parm2 and IWAT-PAR3 Parameter Ranges

			RANGE OF VALUES					
NAME	DEFINITION	UNITS	TYPICAL		POSSIBLE		FUNCTION OF ...	COMMENT
			MIN	MAX	MIN	MAX		
<b>IWAT - PARM2</b>								
LSUR	Length of overland flow	feet	50	150	50	250	Topography, drainage system	Estimate from maps, GIS, or field survey
SLSUR	Slope of overland flow plane	ft/ft	0.01	0.05	0.001	0.15	Topography, drainage	Estimate from maps, GIS, or field survey
NSUR	Manning's n (roughness) for overland flow	none	0.03	0.10	0.01	0.15	Impervious surface conditions	Typical range is 0.05 to 0.10 for roads/parking lots
RETSC	Retention storage capacity	inches	0.03	0.10	0.01	0.30	Impervious surface conditions	Typical range is 0.03 to 0.10 for roads/parking lots
<b>IWAT - PARM3</b>								
PETMAX	Temp below which ET is reduced by half	deg. F	35.0	45.0	32.0	48.0	Climate, vegetation	Reduces ET near freezing, when SNOW is active
PETMIN	Temp below which ET is set to zero	deg. F	30.0	35.0	30.0	40.0	Climate, vegetation	Reduces ET near freezing, when SNOW is active

All HSPF parameters have default values that the model starts out using. Most parameters were adjusted during the calibration process. However, some have special cases where the default value was used, or had a certain value chosen that was used for all models.

‘FOREST’ is the fraction of the watershed which is covered by forest which will continue to transpire in winter (Table 3.1). The default is set to 1; it was left at default, due to it only mattering to snow calculations. ‘LSUR’ is the length of the assumed overland flow plane (Table 3.1, 3.4). The default is 350 ft. and every HSPFParm model was between 325—400 ft., so it was left at default. ‘SLSUR’ is the slope of the assumed overland flow plane (Table 3.1, 3.4). This value is pulled from the BASINS file, so it was not calibrated.

‘PETMAX’ is the air temperature below which E-T will arbitrarily be reduced below the value obtained from the input time series. ‘PETMIN’ is the temperature below which E-T will be zero regardless of the value in the input time series. The defaults is set to 40° and 30°, respectively;



these were left at default, due to it only mattering to snow calculations (Table 3.2, 3.4). ‘INFEXP’ is the exponent in the infiltration equation. ‘INFILD’ is the ratio between the maximum and mean infiltration capacities. Both of these coefficients use default values at 2. All HSPFParm models used values between 2—2.5, so these were left at default (Table 3.2).

‘AGWS’ is the initial active groundwater storage. ‘GWVS’ is the index to groundwater slope; it is a measure of antecedent active groundwater inflow. These both have default values of 0.01. However, they were changed to 1 and 0, respectively. This is due to guidance in the HSPF manual for how to adjust HSPF models that poorly predict during the first few months/years of simulation.

### 3.1.5 Major HSPF Formulas

The infiltration capacity, the maximum rate at which soil will accept infiltration, is a function of both the fixed and variable characteristics of the watershed. Fixed characteristics include primary soil permeability and land slopes. Variable characteristics are soil surface conditions and soil moisture content. Fixed and variable characteristics vary spatially over the land segment. A linear probability density function is used in HSPF to account for areal variation (Deliman, 2002).

The infiltration distribution is focused around the two lines which separate the moisture available to the land surface (MSUPY), into what infiltrates, and what goes to interflow (Figure 3.6). A number of the variables that are used to determine the location of lines I and II are calculated in subroutine SURFAC (Johanson, 1980). They are calculated by the following relationships:

$$IBAR = (INFILT / (LZS / LZSN) \cdot INFEXP) \cdot INFFAC \quad (3.1)$$

$$IMAX = INFILD \cdot IBAR \quad (3.2)$$

$$IMIN = IBAR - (IMAX - IBAR) \quad (3.3)$$

$$RATIO = INTFW \cdot (2.0 \cdot (LZS/LZSN)) \quad (3.4)$$

IBAR = mean infiltration capacity over the land segment in in. /interval

INFILT = infiltration parameter in in. /interval

LZS = lower zone storage in inches

LZSN = parameter for lower zone nominal storage in inches

INFEXP = exponent parameter greater than one

INFFAC = factor to account for frozen ground effects, if applicable

TMAX = maximum infiltration capacity in in. /interval

INFILD = ratio parameter of maximum to mean infiltration capacity over the land segment

IMIN = minimum infiltration capacity in in. /interval

RATIO = ratio of the ordinates of line II to line I

INTFW = interflow inflow parameter

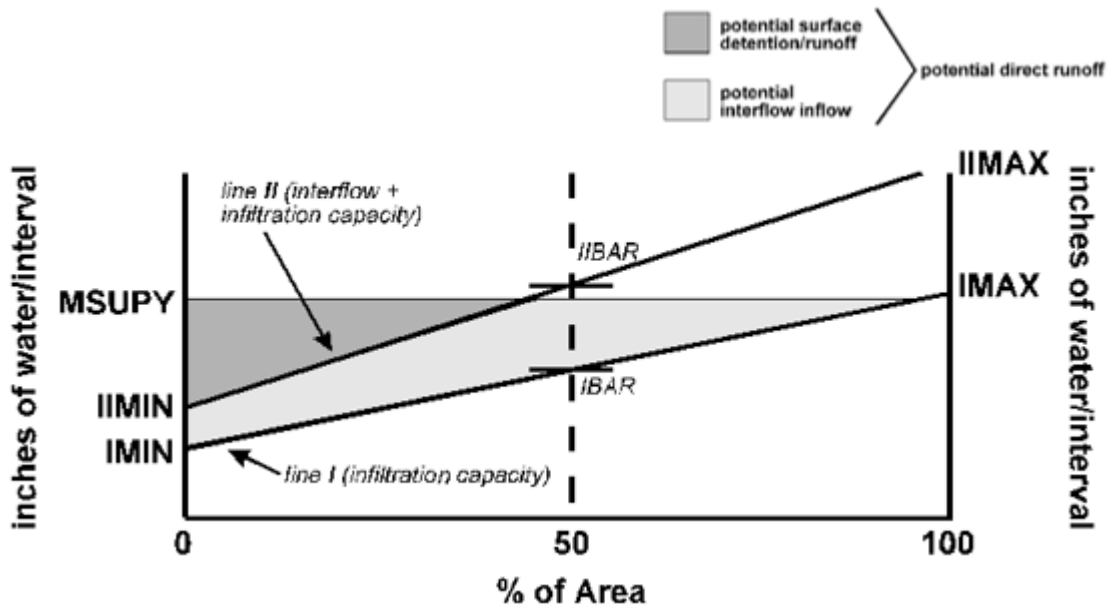


Figure 3.6 Soil Moisture, Infiltration, Interflow Curves

The factor that reduces infiltration (and also upper zone percolation) and accounts for the freezing of the ground surface (INFFAC) is 1.0 if icing is not simulated. When icing occurs, the factor is 1.0 minus the water equivalent of ice in of the snowpack to a minimum of 0.1.

The parameter INTFW can be input on a monthly or seasonal basis to allow for variations throughout the year. When the land segment is separated into conceptual areal blocks as designated by the vertical subdivisions, corresponding IMAX and IMIN values must be determined for each block:

$$IMNB = IMIN + (BLK - 1) \cdot (IMAX - IMIN) / NBLKS \quad (3.5)$$

$$IMXB = IMNB + (IMAX - IMIN) / NBLKS \quad (3.6)$$

IMNB= minimum infiltration capacity for block BLK in in. /interval

BLK = block number

NBLKS = total number of blocks being simulated

IMXB = maximum infiltration capacity for block BLK in in. /interval

As HSPF is a mathematical based model that relays on physically based inputs, each section of the model has multiple equations that use the input parameters. Only the main runoff, infiltration, and interflow equations are shown to demonstrate the complexity of HSPF computations and help us to understand the calibration process and certain model results. The details of the calculations for each section of the model (groundwater, temperature, etc.) can be found in the manual and “help” tab within HSPF itself (Johanson, 1980).

### 3.2 Model Assessment

The performance of the HSPF model was evaluated using both graphical and statistical measures (Al-Abed, 2002). Moriasi et al. (2007) recommends that performance of a model can be evaluated based on three quantitative statistics; Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS) and  $R^2$ , in addition to graphical techniques. This is based on the reports of five models (APEX, DHM, HSPF, SAC-SMA, and SWAT) over nine different studies. The recommended quantitative statistics between simulated ( $Y_{i \text{ sim}}$  or  $S_i$  in Table 3.5) and observed ( $Y_{j \text{ obs}}$  or  $O_j$  in Table 3.5) were computed as well as  $R^2$ .

Nash–Sutcliffe efficiency (Equation 3.7) is the comparison of the sum of squared difference between the modeled value ( $S_i$ ) and the observed value ( $O_i$ ), to the sum of squared difference between the observed value and the average observed value ( $\bar{O}$ ). When the variance of observed is small, the Nash–Sutcliffe efficiency can be low even if the model performs reasonably. This would not happen for discharge simulation, because discharges due to rainfall events and base flows under no-rain seasons typically have large variance. At the same time, Nash–Sutcliffe efficiency puts more weight on matching observed high flows. An efficiency of 1 corresponds to a perfect match, while an efficiency of 0 to  $-\infty$  indicates that the observed mean (constant) is a better predictor than the model. Or in other words, when the residual variance (numerator) is larger than the data (observed) variance (denominator).

The coefficient of determination (Equation 3.8) is similar to the correlation coefficient,  $r$ . The correlation coefficient formula will show the strength of a linear relationship between two variables (here observed and simulated discharge).  $R^2$  is the square of the correlation coefficient,  $r$ , and often called goodness of fit.

The percent bias calculation (Equation 3.9) shows the difference in the modeled value and the observed value as a percentage of the sum of observed values. Values can range for -100% to 100%. The closer to 0, the more accurate the modeled values are to the observed values.

Table 3.5 Equations to Compute Model Efficiency Measures

Name	Formula	Name	Formula
Nash-Sutcliffe modelling efficiency (3.7)	$EF = \frac{\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}$	Goodness of fit (3.8)	$R^2 = \left[ \frac{\sum_{i=1}^n (O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (S_i - \bar{S})^2}} \right]^2$
PBIAS (3.9)	$PBIAS = \frac{\sum_{i=1}^n (O_i - S_i)}{\sum_{i=1}^n O_i} \times 100$		

$O_i$ : observed streamflow ( $m^3/s$ );  $S_i$ : simulated streamflow ( $m^3/s$ );  $\bar{O}$ : mean observed streamflow during evaluation period ( $m^3/s$ ).

### 3.2.1 Calibration Criteria

In Wolf Bay watershed, the only recorded flow data were from the USGS station on the upstream portion of Wolf Creek. While both Wolf Creek and Sandy Creek were modeled through one HSPF model, HSPF output for both the connection to the bay and at the gage location was calculated. The gage location output was isolated and used to calibrate the rest of the model. Gage details are in section 2.3.5. An overview of many studies into the calibration of watershed models (Moriassi, 2007) was used to determine ranges of model efficiency values for the model to determine if the efficiency measures from the model were sufficient. The ranges from the overview that are compared with the model can be found in Table 3.6.

Table 3.6 Summary Statistics from NSE and PBIAS Values <sup>(a)</sup>

Constituent	Statistic	Calibration		Validation	
		NSE	PBIAS	NSE	PBIAS
Streamflow	n	92	72	128	82
	Minimum	-0.23	-91.7	-1.81	-155.6
	Maximum	0.95	26.5	0.89	47.18
	Median	0.89	1.3	0.67	-1.9
Sediment	n	2	0	2	0
	Minimum	-2.5	n/a	-3.51	n/a
	Maximum	0.11	n/a	0.23	n/a
	Median	-1.2	n/a	-1.64	n/a

(a) n= number of reported values for the studies reviewed, NSE = Nash-Sutcliffe Efficiency, PBIAS = percent

bias, n/a = not available (when n=0), models reported Daily values

### 3.2.2 Flow Calibration and Validation

The Wolf Creek simulation was run from 1995- 2009 for calibration with a three year warm-up period. Then for validation it was run from 2004-2009. See Figure 3.7 for a graphical representation of the HSPF model and parameters.

Table 3.7 Wolf Creek Model Simulation Years

Calibration	Validation
Run: 95-09	Run: 04-09
3 yr warm-up	3 yr warm-up
12 yr simulation	3 yr simulation

To start the calibration, other watershed models were examined. For Wolf Creek, the initial active groundwater storage (AGWS) and groundwater slope index (GWVS) were set to 1 and 0, respectively. The infiltration capacity of the soil (INFILT) was increased to match the primary soil types in each land use type. Next the lower nominal zone storage (LZSN) and initial lower zone storage (LZS) were increased to match a high precipitation region. Then the fraction of inactive groundwater inflow that is lost (DEEPPFR) was reduced to more accurately match a coastal system with a shallow groundwater table and quick recharge. Both pervious and imperious manning's

overland flow coefficients (NSUR), as well as lower zone evapotranspiration (LZETP) were adjusted to match the land use. Because the slopes throughout the watershed are very low, the interflow recession parameter (IRC) was increased. Both the initial retention storage (RETS) and initial surface/overland storage (SURS) were increased due to urban storage such as retaining ponds. Lastly the interflow inflow parameter (INTFW) was increased to better match stormflow. A representation of the HSPF Wolf-Creek model and calibrated model parameters can be seen in Figure 3.7. The watershed has a total area of 2.3 mi<sup>2</sup>, and has elevations ranging from 38 to 0 ft. and includes 12 delineated catchments (sub-watersheds) with drainage areas of 0.07—4.96 mi<sup>2</sup> with an average area of 2.01 mi<sup>2</sup>.

The efficiency values for Wolf Creek HSPF model are shown in Table 3.8. While the result is within the ranges of other previous studies (Table 3.6), the values are not as high as desired (Table 3.7). Reasons for this are given in the next section.

Table 3.8 Wolf Creek Efficiency Values

	Uncalibrated	Calibration	Validation
Nash-Sutcliffe:	-22.28	0.177	0.147
Percent Bias:	-196.95	8.23	-46.49
R <sup>2</sup> :	0.019	0.231	0.230

Graphically, the general trend of the Wolf Creek model with the USGS gage was excellent (Figure 3.8). While the estimated WWTP does cause the model to often over predict. The average flows for both modeled and observed were very close. The gage data ranged from 4.5 cfs to 300 cfs with an average of 10 cfs. While the HSPF simulated ranged from 3.5 cfs to 314 cfs with an average of 10 cfs. When the flow during rainfall events are observed the matches are even better. Figure 3.9 shows 30 days of simulation with multiple rainfall events.

When just one month of data is selected (Figure 3.9) for closer inspection, the model preforms even better. During January and February of 2008, there were multiple rainfall events and HSPF was able to simulate them with a NSE of 0.719.

# Wolf Creek HSPF Model Details

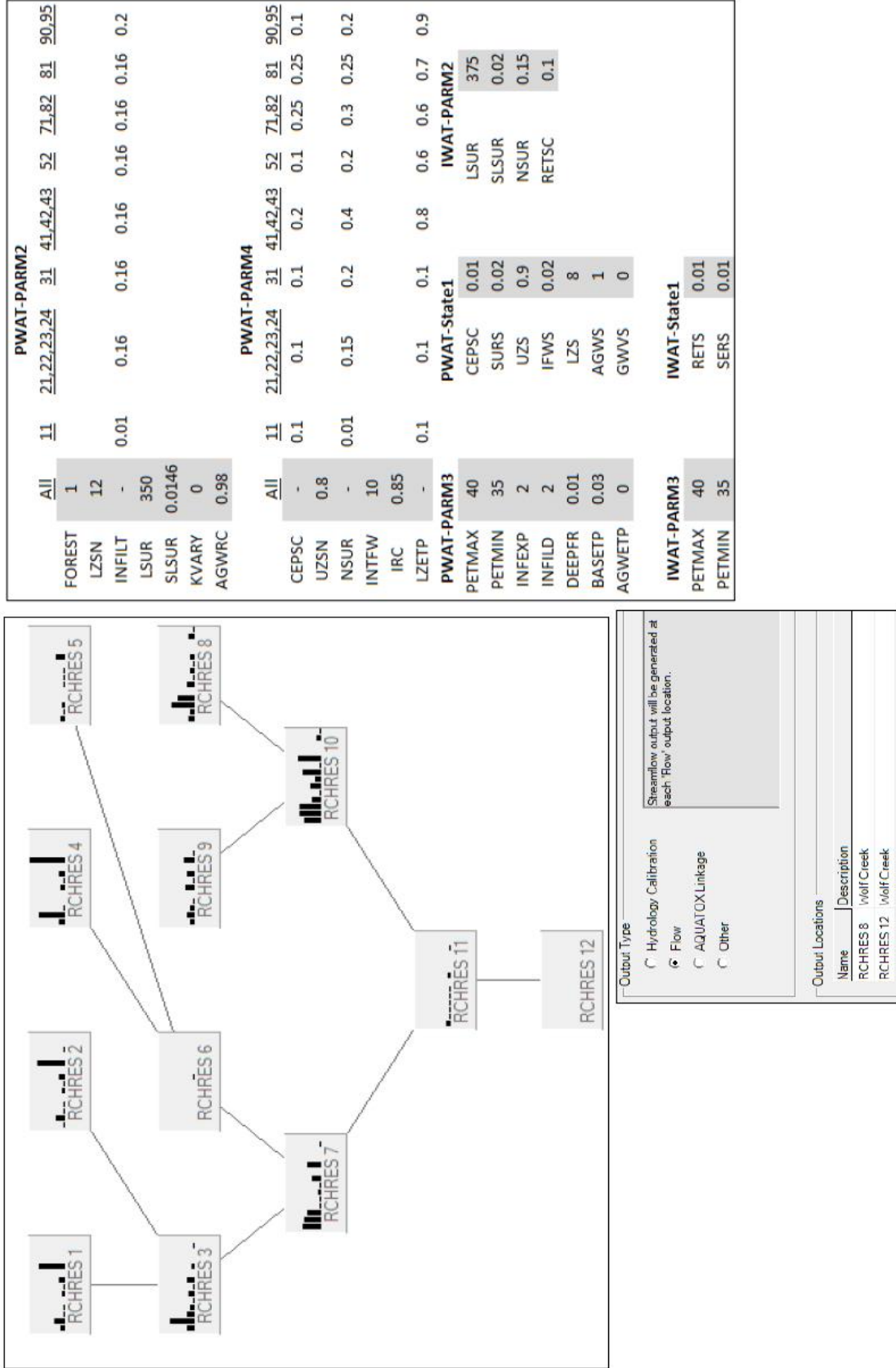


Figure 3.7 Wolf Creek HSPF Model Details

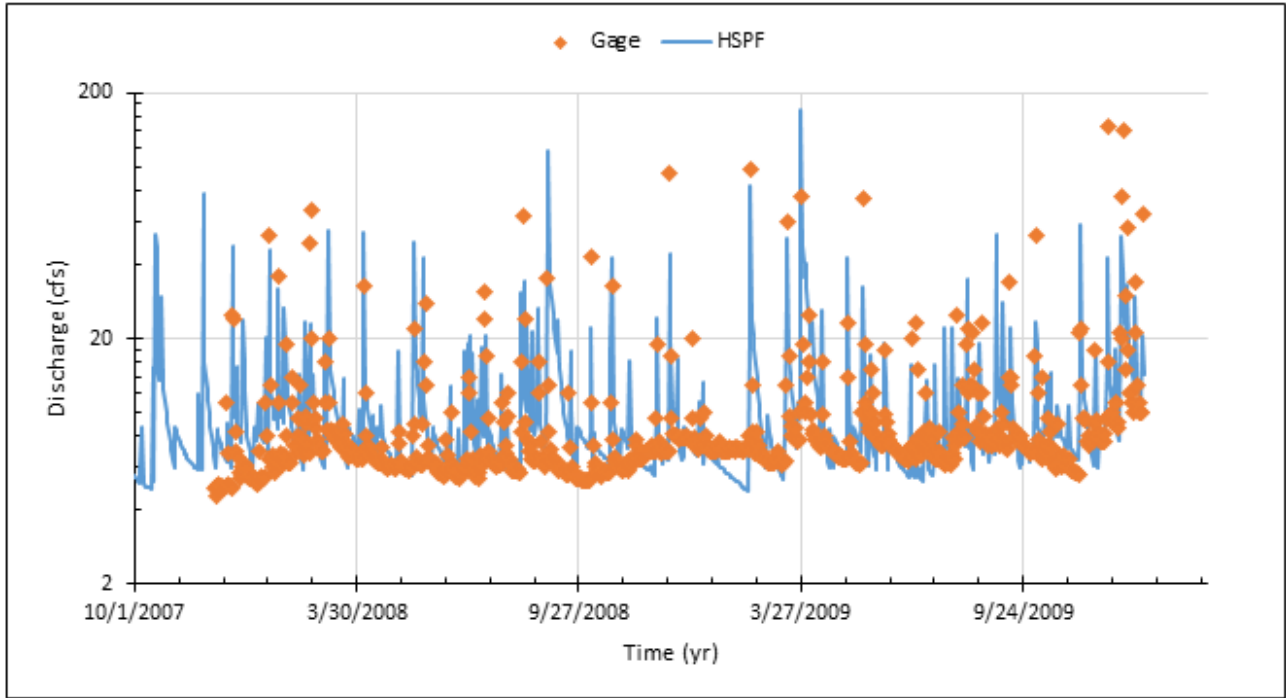


Figure 3.8 Observed and Simulated Daily Discharges (cfs) at the Wolf Creek USGS Gage Station

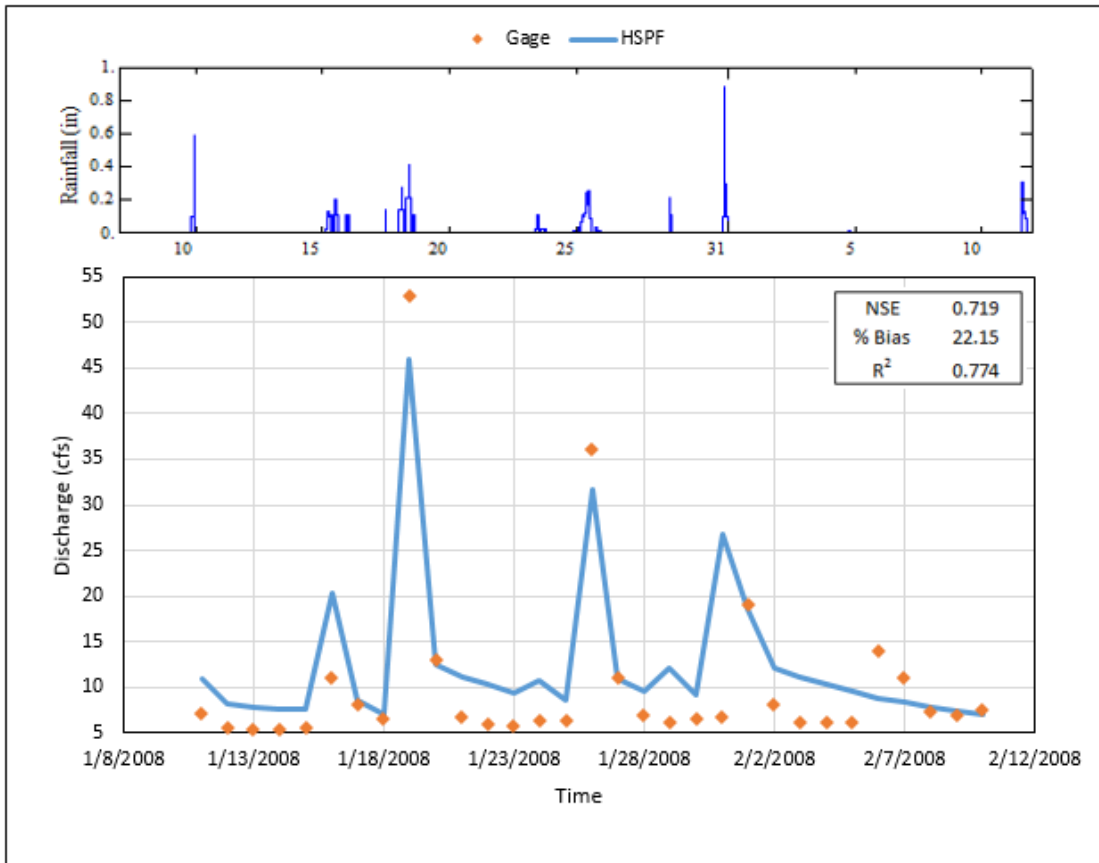


Figure 3.9 One Month of Modeled and Observed Wolf Creek Streamflow



However, the baseflow is consistently too high. This is an issue with the accuracy of the assumed flow from the WWTP.

Overall the data matched fairly well when directly compared to each other as seen in Figure 3.10. Again, this shows that the model tended to overestimate during low flow conditions and be very similar or underestimate during larger flows.

The overall volume (accumulated water) comparison shows that the model tracks with the observed data (Figure 3.11). The model only over predicted by 8.23% for over two years of comparison. Around March 2009, a major uptick occurs in both modeled and observed, so while it is over predicting, it matches the general trend well.

For Wolf the runoff generation was considered (Figure 3.12). Here the model showed that 66.96% of the rainfall generated discharge in the creek, while the gage data showed 61.86% becoming runoff. These are within 5% point from each other, so this was considered satisfactory. These high runoff volumes may seem strange when the landuse is considered (Figure 2.14). However, Perdido is in a coastal area with a shallow groundwater table. This causes higher than usual runoff generation (Sklash, 19759; Hewlett, 1965).

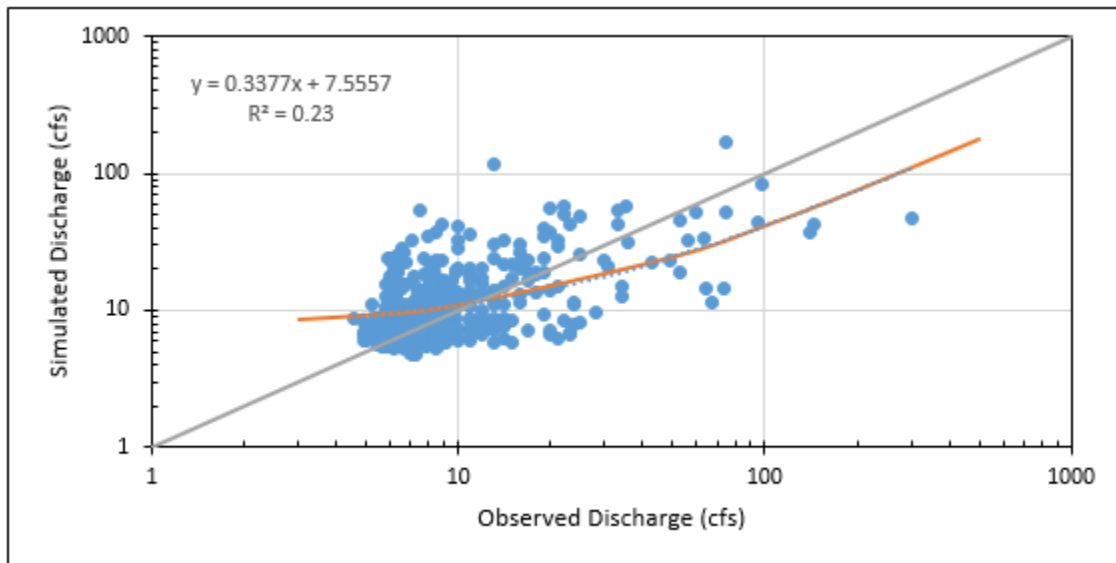


Figure 3.10 Wolf Creek Observed vs. Simulated Discharge

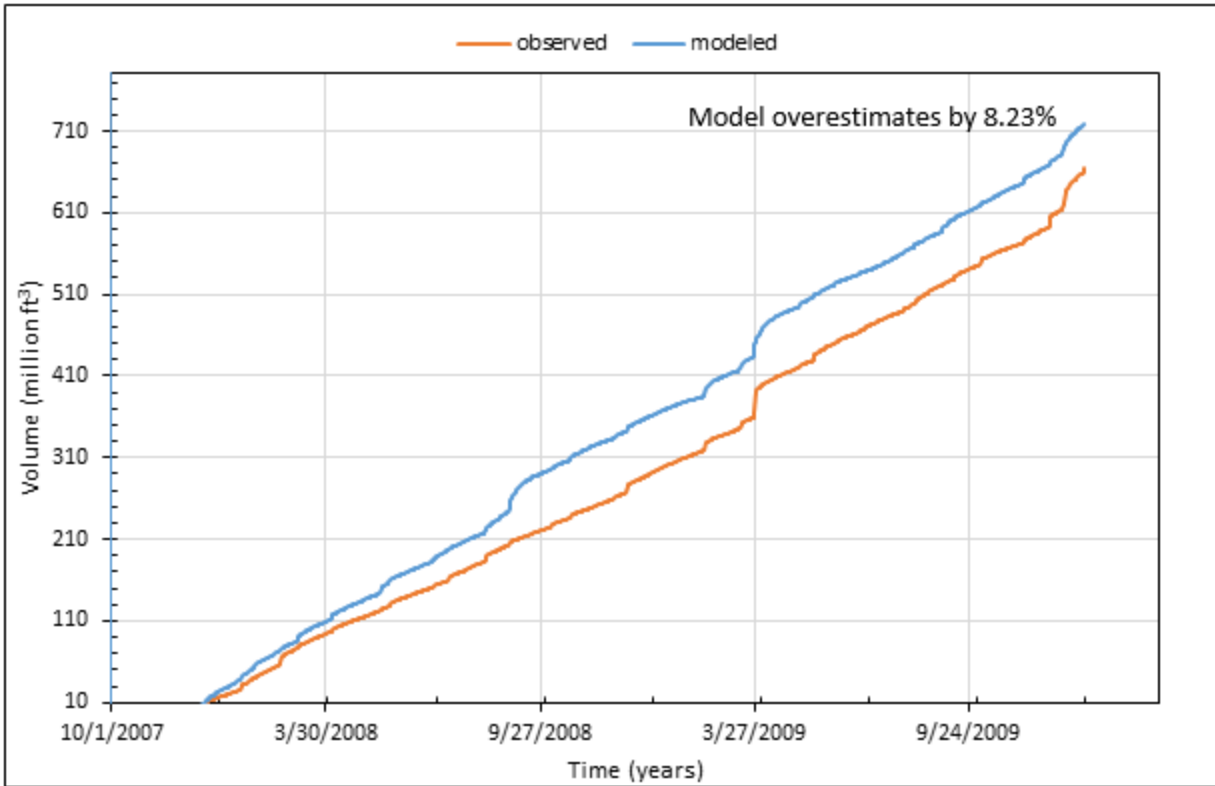


Figure 3.11 Wolf Creek Observed vs. Simulated Cumulative Volume

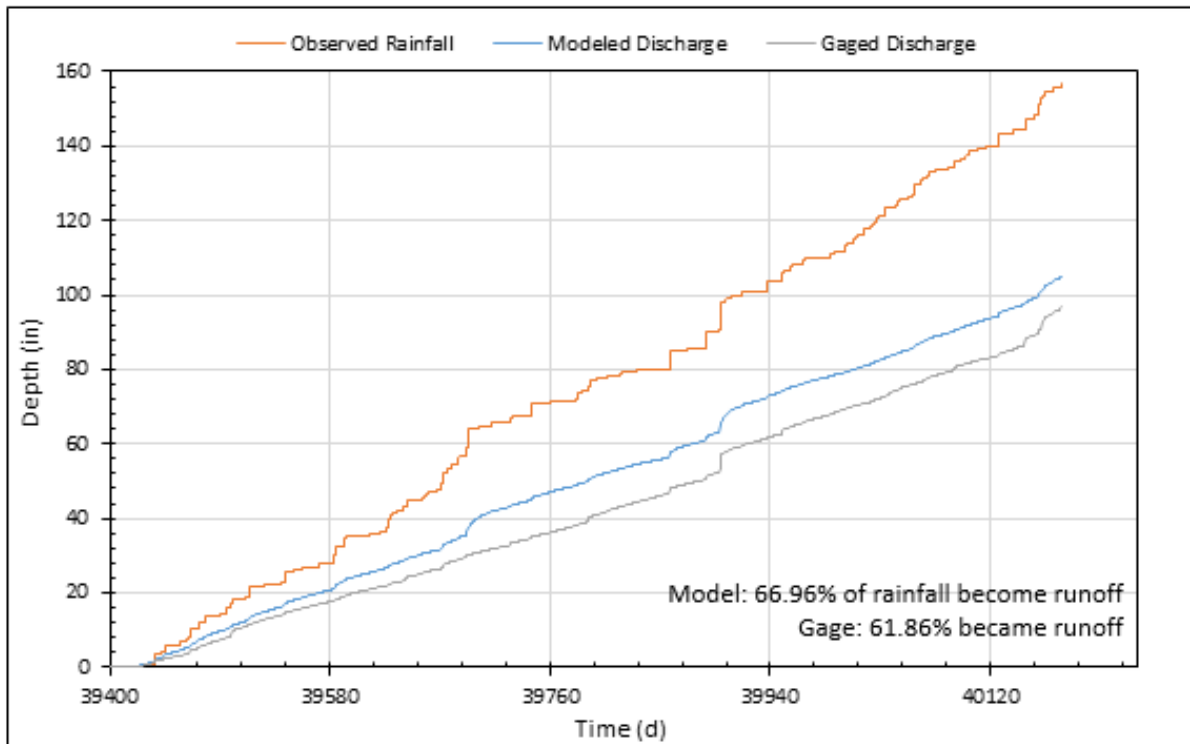


Figure 3.12 Wolf Creek Observed vs. Simulated Runoff

### **3.2.3 Water Quality Calibration and Validation**

Currently the water quality calibration cannot be done since there is no reliable water quality data. This is discussed in section 2.3.6. Multiple professors at Auburn University are currently working on water quality projects within the Perdido Bay basin. Dr. Hayworth's team has collected sediment samples in Perdido Bay in the past, and water samples in 2017. Dr. Wilson's students at the School of Fisheries, Aquaculture and Aquatic Sciences began regular water quality testing of water samples at the Elevenmile Creek and Marcus Bayou entrances to Perdido Bay in January 2017. There will soon be data that can be used, just not at the current time.

A baseline water quality run was performed in HSPF for water temperature and DO. However, with no data to calibrate it against, it has little value.

### **3.3 Summary**

This stage of physical parameter selection was a success. Few errors were encountered and the maps that were produced matched what was expected based on the physical layout of the site as seen visually. The watershed area and DEM all match how the natural streams flow. This adds to their accuracy. The land-use map looks similar to what can be seen visually by visiting the site. Soil data was taken from the USGS, and since this team has no ability to take soil cores throughout the watershed, we are relying on the accuracy of their data. All the needed inputs for HSPF are ready for the next stage of the research. It is believed that the reason the model did not perform as well as desired is that the actual WWTP discharge is unknown (Figure 3.13). When the model output is compared with and without the WWTP discharge the importance of acquiring this data (section 2.3.4) is obvious since without any additional discharge graphically the model barely matches the gage.

The results from the physical parameter selection will help to ensure the accuracy of the remainder of the research project. Because HSPF is a mathematical based model that relies heavily on the physical inputs to be correct, it was necessary to create as accurate as possible the watershed sub-basins areas. However, the graphical data match was conclusive enough to show that the process was correct. Therefore, the model should be able to scale up to a larger watershed within the Perdido Bay watershed.

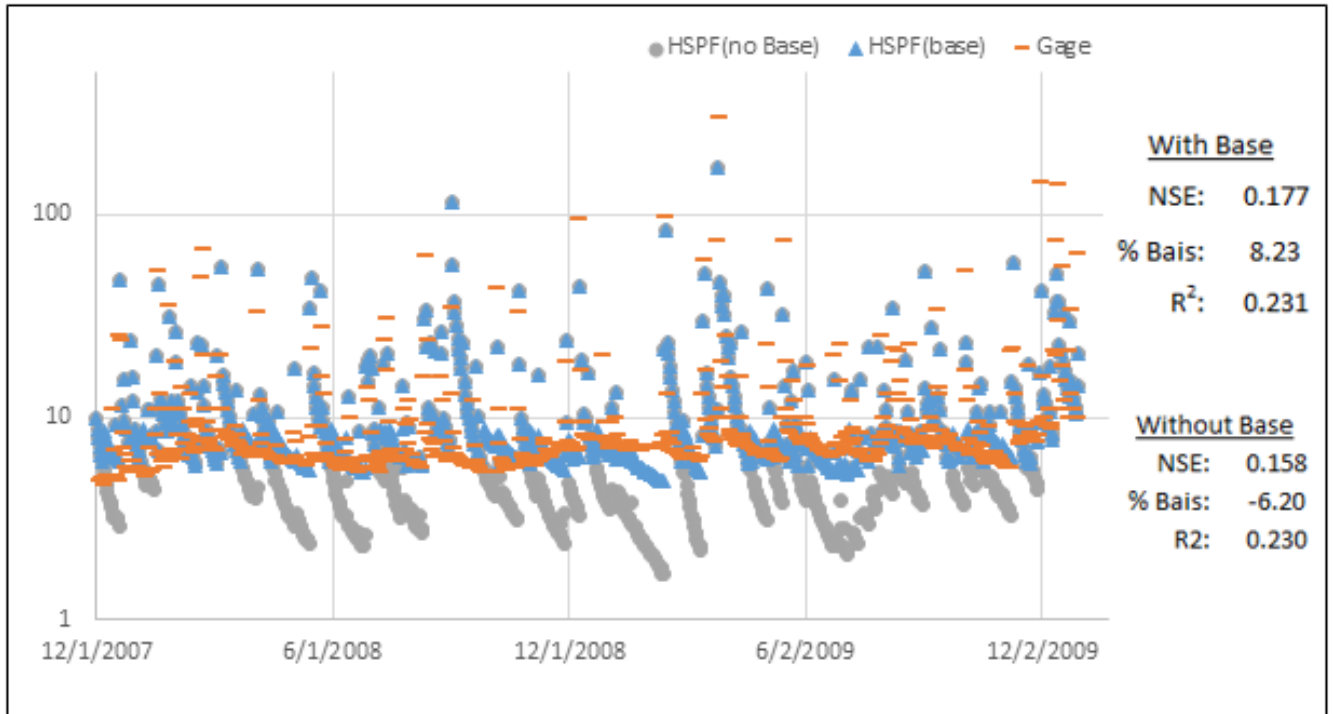


Figure 3.13 Simulated discharges (cfs) with and without Assumed Base Flow from WWTP and Observed Discharges at the Wolf Creek Gage Station

## **CHAPTER 4 MODEL EXPANSION**

### **4.1 Additional Watershed Models**

Once the Wolf Creek model was calibrated, the model development and calibration processes were then applied to the remaining areas of the Perdido Bay watershed, which is about 1000 mi<sup>2</sup>. The bay, along with the Perdido River, forms the border between Florida and Alabama. It can be broken down into sections along its major rivers as seen in Figure 4.1. Much of the bay's watershed includes the cities of Pensacola, Seminole, Foley, Orange Beach, Bay Minette, and others. It connects to the Gulf of Mexico at Perdido Pass between Orange Beach and Perdido Key, and westwards to Mobile bay and eastwards to Pensacola Bay through the GIWW.

#### **4.1.1 Perdido Bay Inflows**

There are several rivers and creeks that flow into Perdido Bay. The major ones include Perdido River, Styx River, Blackwater River, Elevenmile Creek, and Marcus Bayou. A map showing the delineated watersheds are in Figure 4.2, including watersheds of the eight modeled streams, and areas of the unmodeled watersheds. As was done with Wolf Bay, there are areas of marsh and bayou surrounding Perdido Bay that were left un-modeled. The extent of these areas can be seen by the gap between the models and the bay in Figure 4.1. In addition, those areas labeled in pink area are 'Perdido Swamp' in Figure 4.2, which shows the extent of the stream network within the Perdido Bay watershed. Those areas that are not modeled in this study, are discussed further in section 4.3.

For each of these rivers a new DEM, Land use, Basin, and Stream map had to be created. The new DEMs, Basins, and Streams can be found in each separate model's map. The full Perdido

land use map is in Figure 4.3. The process of creating these files was the same as the method used for Wolf Creek as described in Chapter 2. HSPF can only be linked to one WDM file, and the process for retrieving meteorological data and creating a new WDM file is arduous. Therefore, the weather data for each new model was the same WDM file used for Wolf Bay as was described in section 2.3.1. How the WDM file is linked with HSPF is described in Appendix B.

For the four models with a gage station (Figure 4.4), the calibration period was done for 1995—2006 and the validation was done for 2004—2009. This is slightly different from the time period for Wolf Creek, since the Wolf Creek gage only started in 2007. A warm-up period of three years was used for all models.

Table 4.1 Additional Model Time Periods

Calibration	Validation
Run: 95-06	Run: 04-09
3 yr warm-up	3 yr warm-up
9 yr simulation	3 yr simulation

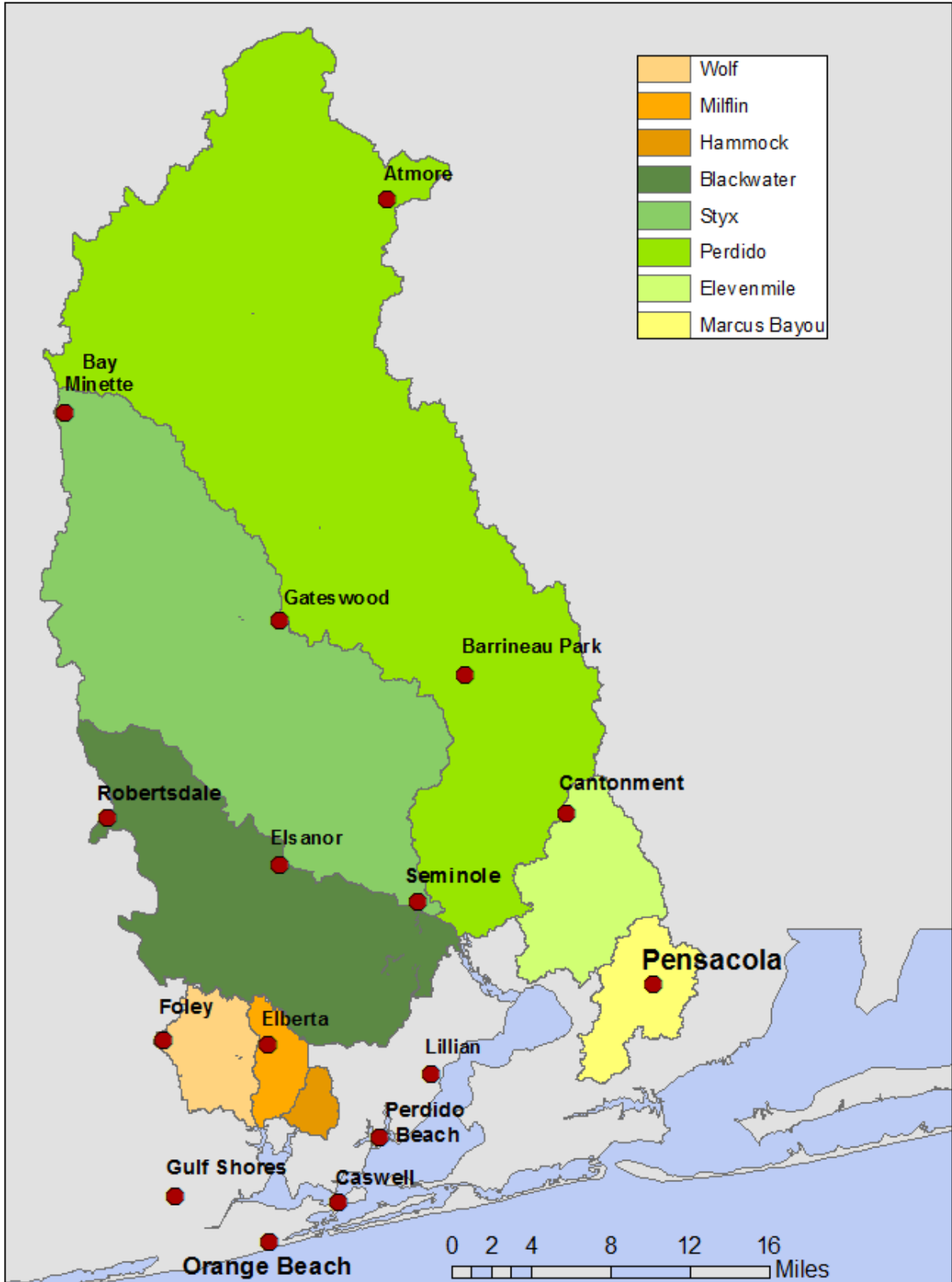
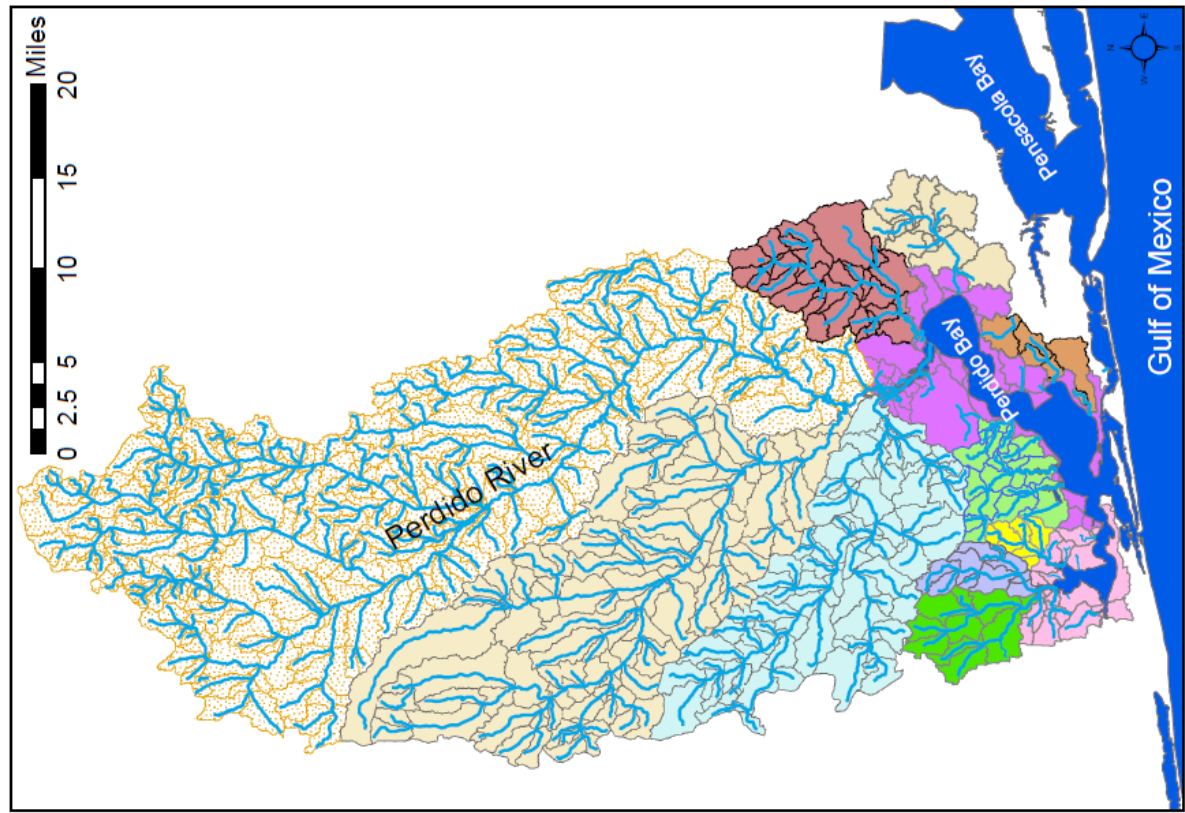
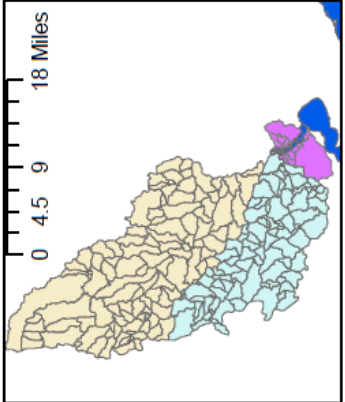


Figure 4.1 Eight Watersheds modeled with HSPF and Cities within the Study Area

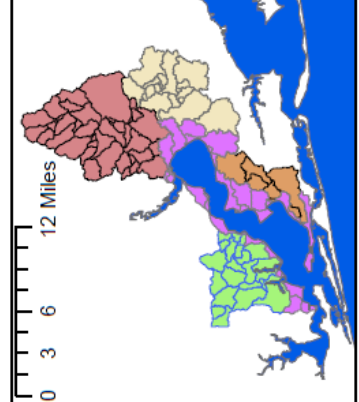
# Perdido River Watershed



- ### Upper Perdido Basins
-  Blackwater River Subbasin
  -  Perdido Marsh
  -  Perdido River Subbasin
  -  Styx River Subbasin



- ### Lower Perdido Basins
-  Beach Area Subbasin
  -  Elevenmile River Subbasin
  -  Marcus Bayou Subbasin
  -  Perdido Marsh
  -  Tarkiln Bayou Subbasin



- ### Wolf Bay Basins
-  Hammock Creek Subbasin
  -  Lower Subbasin
  -  Milfin Creek Subbasin
  -  Wolf Creek Subbasin

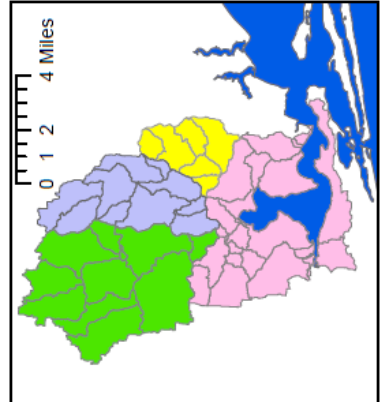


Figure 4.2 Delineated Basins and Subbasins in Perdido Bay Watershed



# Perdido River Watershed Landuse

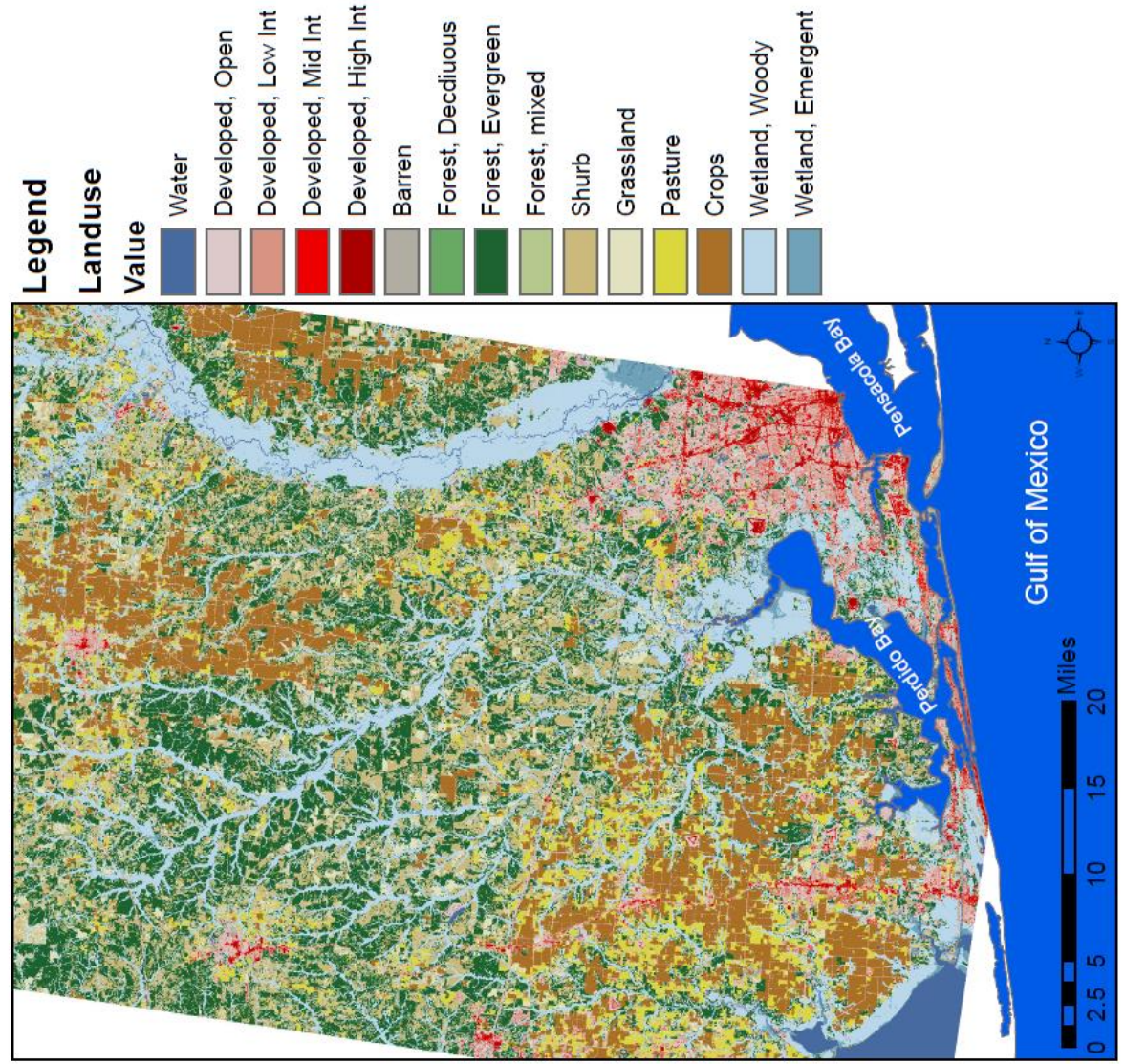


Figure 4.3 Land Use Distribution Used in HSPF for Perdido Bay Watershed

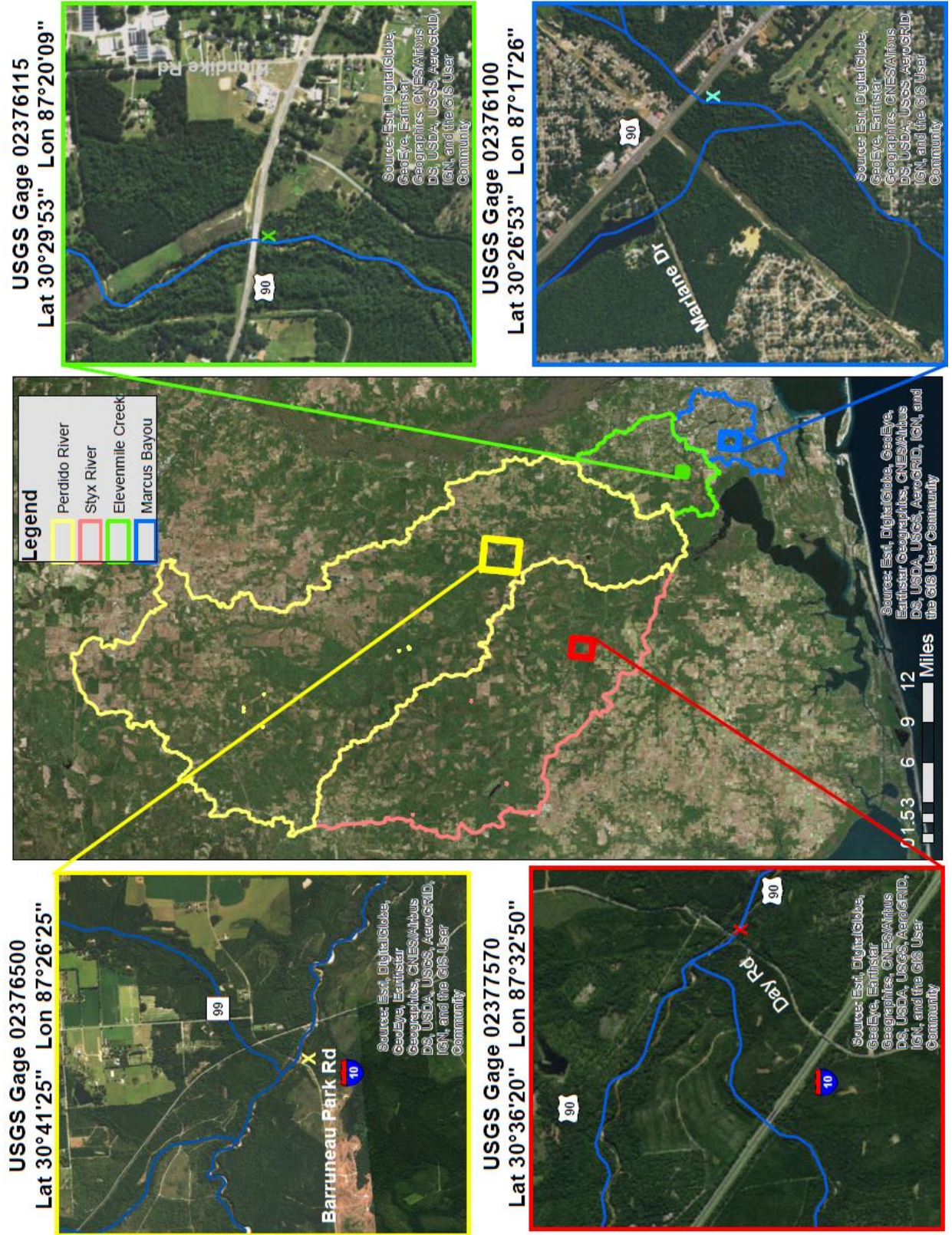


Figure 4.4 Location of USGS Discharge Gages in Perdido, Styx, Elevenmile and Marcus Watersheds

### 4.1.2 Milflin Creek Model

The Milflin Creek model has land use and catchments as shown in Figure 4.5. The main land uses are shown in Table 4.2. The watershed has a total area of 13 mi<sup>2</sup>. The basin has elevations ranging from 1.2 to 31.9 ft. and includes 10 delineated catchments with drainage areas of 0.33—2.59 mi<sup>2</sup> with an average area of 1.32 mi<sup>2</sup>. There is no USGS gage within the watershed. Because of this, while the model was created, it cannot be calibrated.

Table 4.2 Primary Land uses in Milflin Creek Land Use (NLCD 2011)

<b>% of area</b>	<b>Milflin Creek Land use</b>
33.36%	Cultivated Crops
22.45%	Grassland
14.52%	Wetlands
11.75%	Forest
9.33%	Developed, Open Space

For the Milflin Creek watershed, the same process for model development done to Wolf Creek was used. This is due to the watersheds sharing similar characteristics. The model was run successfully (Figure 4.6) and simulated discharges were similar to ones from Wolf Creek, but with a higher base flow. This makes physical sense. While it has less drainage area than Wolf Creek., this model was run for the entire watershed, not just to a gage station. However, with no gage to check against, there is no way to assess model accuracy.

For Milflin Creek the runoff volume in inches over the whole simulation period (1995–2009) was calculated (Figure 4.6). Here the model showed that 51% of the rainfall generated discharges in the creek.

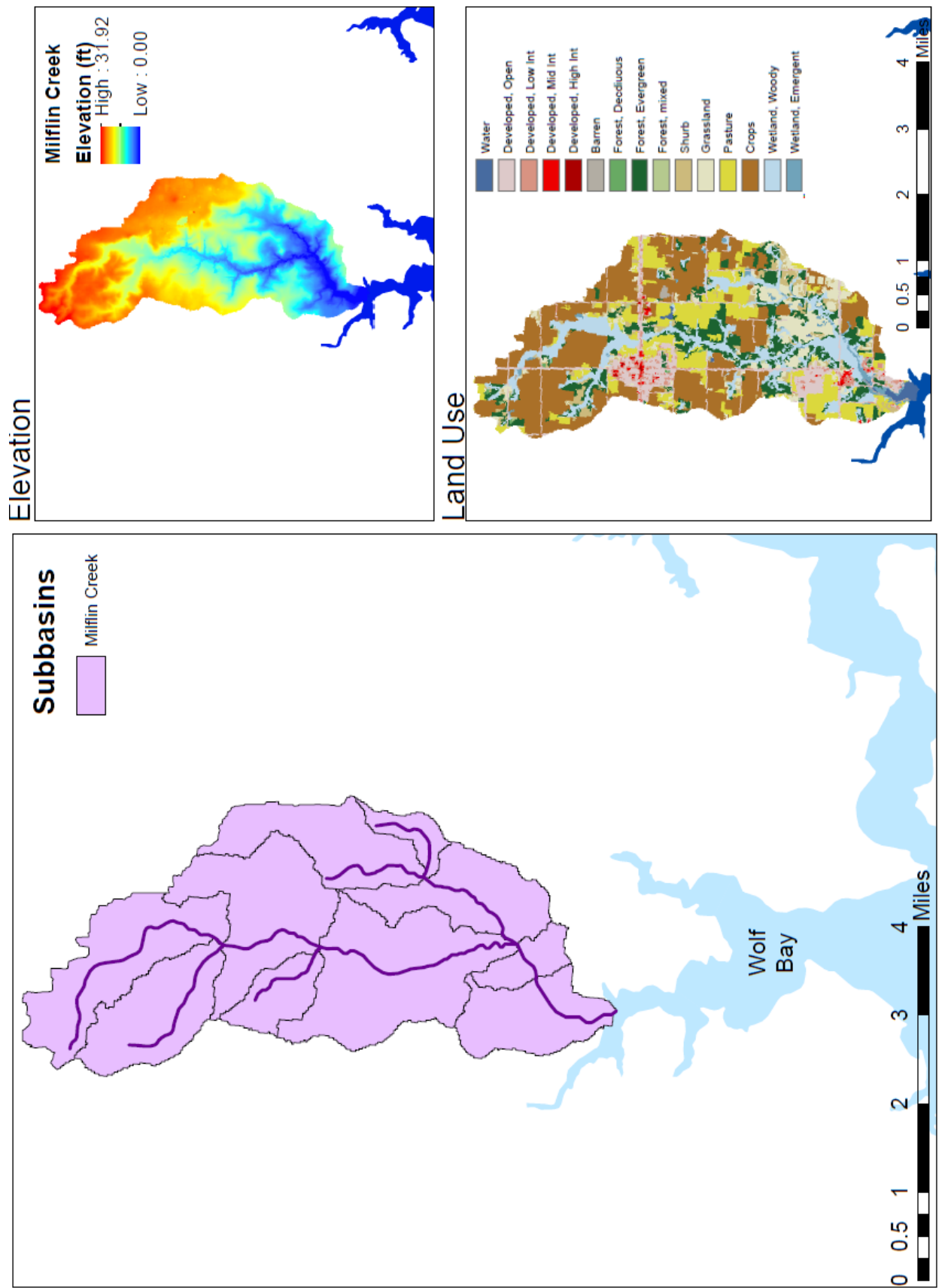


Figure 4.5 Milflin Creek Watershed including elevation and land use maps

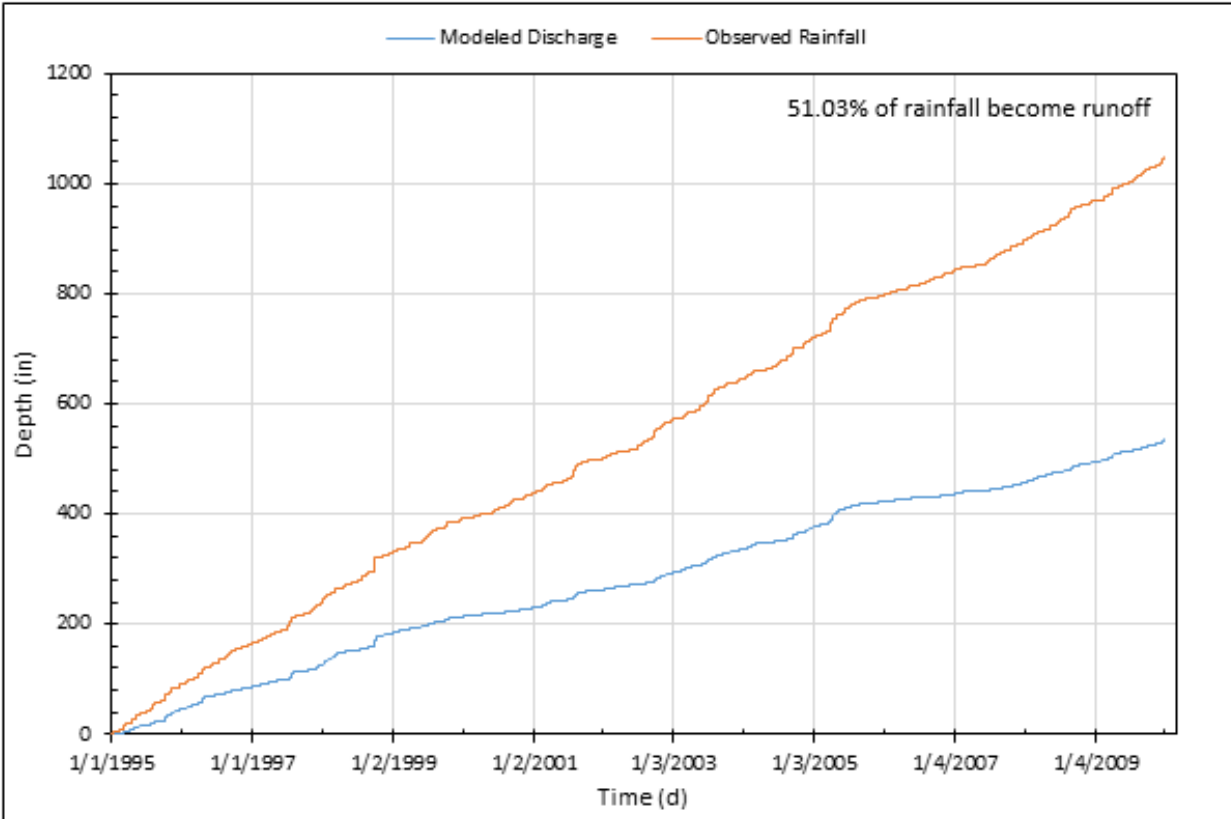
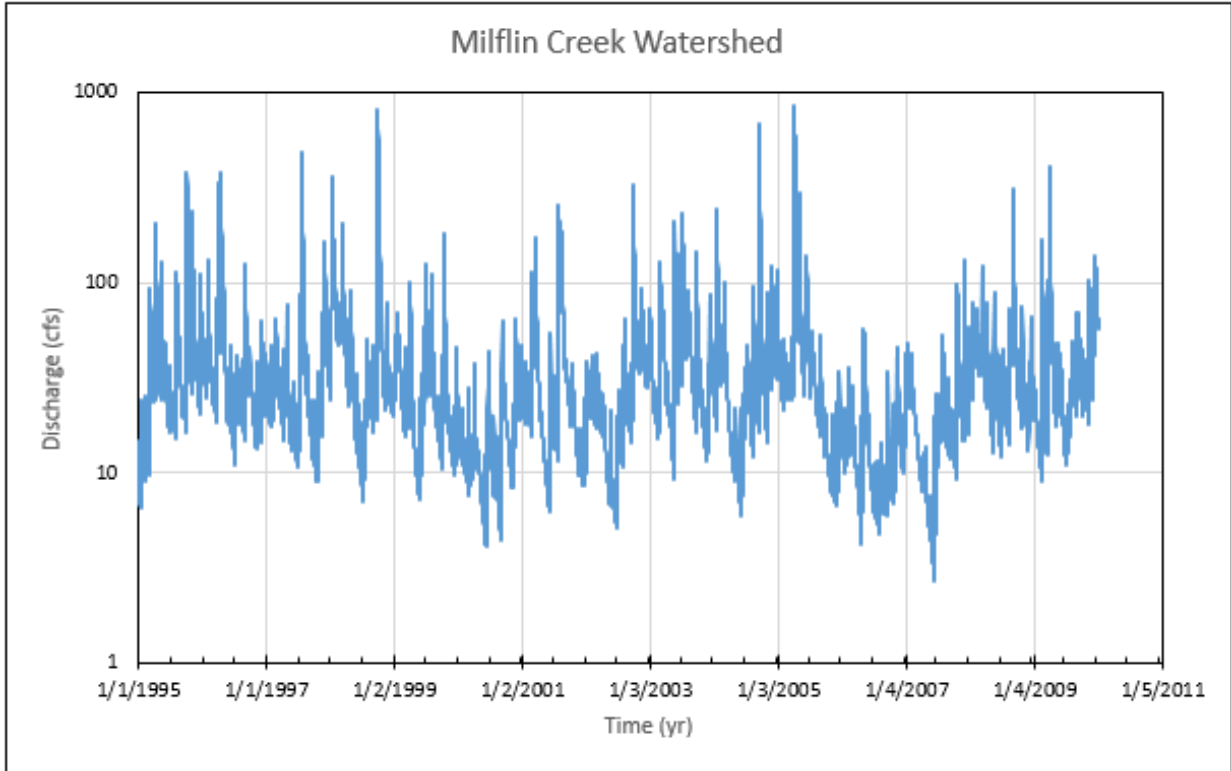


Figure 4.6 Simulated Discharges (cfs) and Simulated Cumulative Runoff for Milflin Creek

### 4.1.3 Hammock Creek Model

The Hammock Creek model has land use and catchments as shown in Figure 4.7. The main land uses are shown in Table 4.3. The watershed has a total area of 6 mi<sup>2</sup>. The basin has elevations ranging from 1.2 to 26.3 ft. and includes 6 delineated catchments with drainage areas of 0.46—1.73 mi<sup>2</sup> with an average area of 1.05 mi<sup>2</sup>. There is no USGS gage within the watershed. Because of this, while the model was created, it cannot be calibrated.

Table 4.3 Primary Land uses in Hammock Creek Land Use (NLCD 2011)

% of area Hammock Creek Land use	
37.37%	Cultivated Crops
22.05%	Forest
15.38%	Wetlands
9.50%	Shrub
9.35%	Grassland

For the Hammock Creek watershed, the same process was done to Wolf Creek. This is due to the watershed sharing similar characteristics. However, with no gage to check against, there is no way to assess model accuracy. The model was run successfully (Figure 4.8) and simulated discharges were similar to discharges in Milflin Creek, but with a lower base flow. This makes physical sense. While it has less drainage area than Wolf Creek (23 mi<sup>2</sup>) or Milflin Creek (13 mi<sup>2</sup>), this model was run for the entire watershed, not just to a gage station.

For Hammock Creek the runoff generation was considered (Figure 4.8). Here the model showed that 41% of the rainfall generated discharge in the creek.

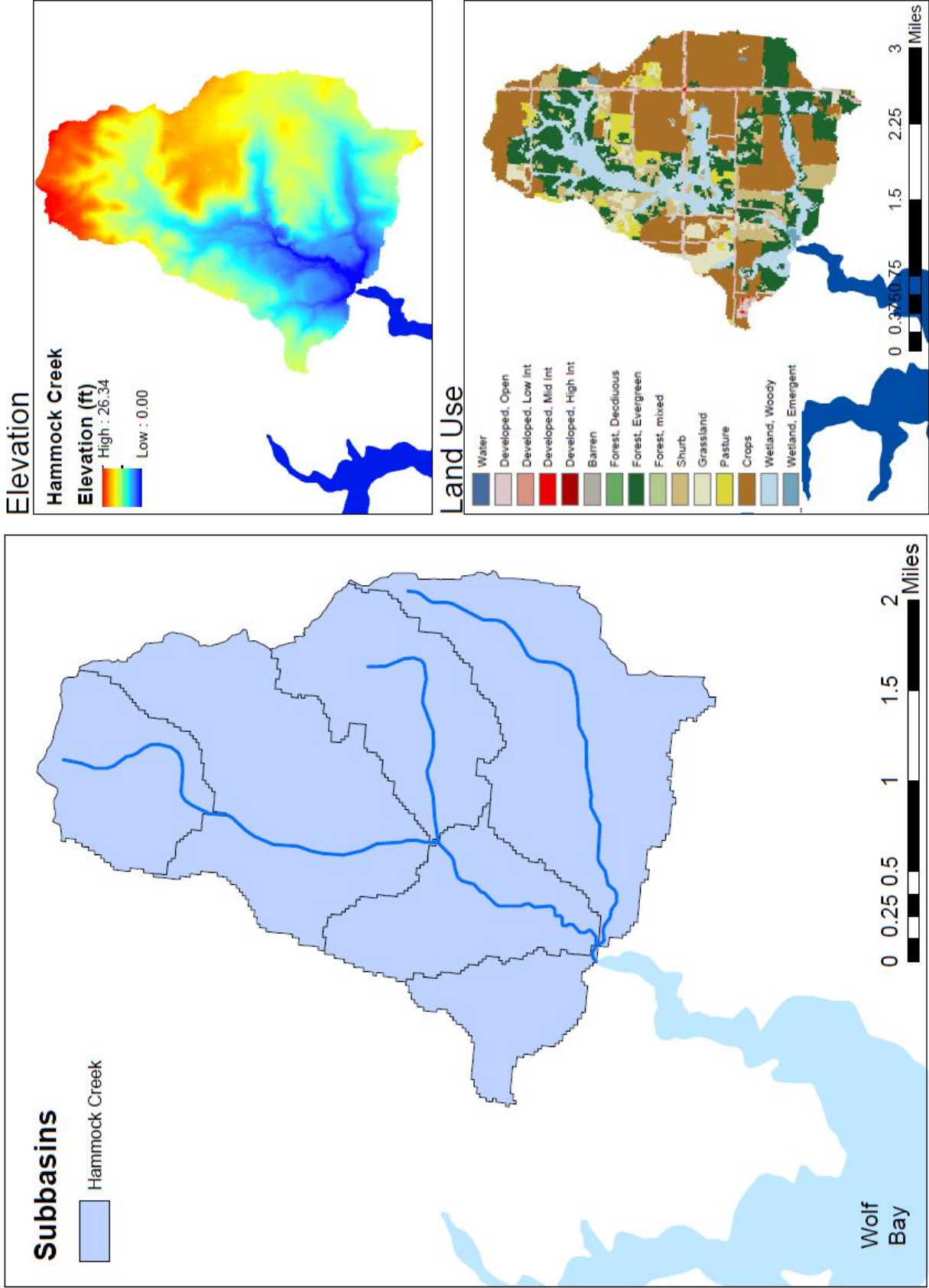


Figure 4.7 Hammock Creek Watershed including Elevation and Land Use Maps

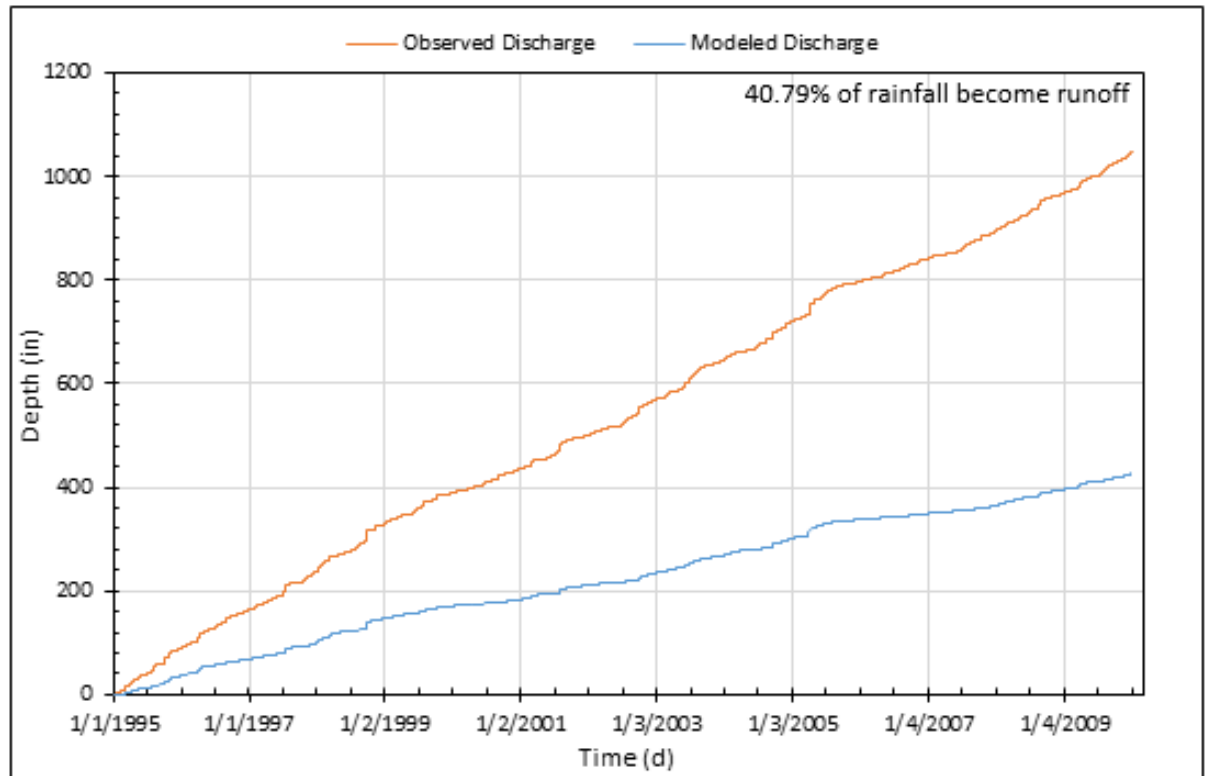
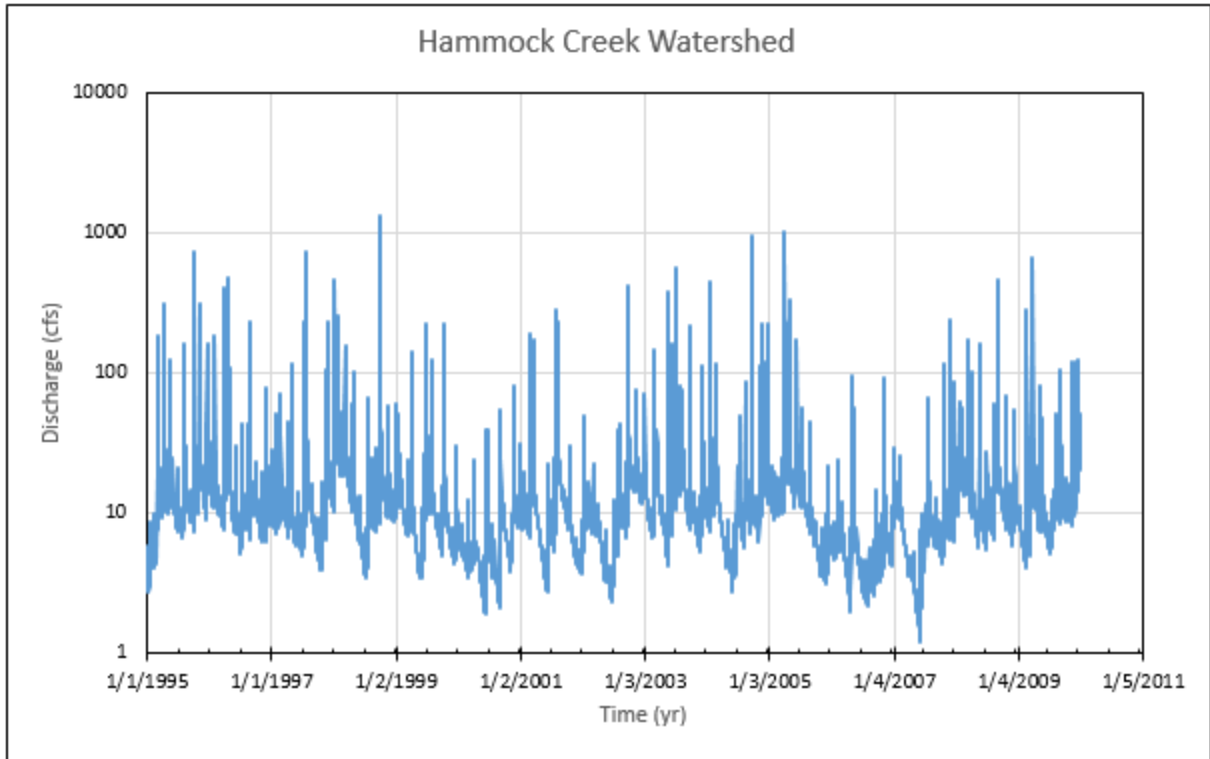


Figure 4.8 Simulated Daily Discharges (cfs) and Cumulative Runoff for Hammock Creek



#### 4.1.4 Perdido River Model

The Perdido River model has land use and catchments as shown in Figure 4.9. The main land uses are shown in Table 4.4. The watershed has a total area of 495 mi<sup>2</sup>, which is the largest subbasin. The watershed has elevations ranging from 1.2 to 101.2 ft. and includes 41 delineated catchments with drainage areas of 2.10–40.04 mi<sup>2</sup> with an average area of 12.37mi<sup>2</sup>. There is one USGS gage (#02376500) near Barrineau Park, FL. It has data from 1951, with only a few months of missing data in the beginning of 2004.

Table 4.4 Primary Land uses in Perdido River Land Use (NLCD 2011)

<b>% of area</b>	<b>Perdido River Land use</b>
33.78%	Forest
20.58%	Wetlands
18.52%	Shrub
11.07%	Grassland
9.74%	Cultivated Crops

For the Perdido River watershed, the initial active groundwater storage (AGWS) and groundwater slope index (GWVS) were set to 1 and 0, respectively, as discussed in section 3.1.4. The infiltration capacity of the soil (INFILT) was increased to match the primary soil types in each land use type. Next, the lower nominal zone storage (LZSN) and initial lower zone storage (LZS) were increased to match a high precipitation region. Then the fraction of inactive groundwater inflow that is lost (DEEPPFR) was reduced to more accurately match a coastal system with a shallow groundwater table and quick recharge. Both pervious and imperious manning's overland flow coefficients (NSUR), as well as lower zone evapotranspiration (LZETP) were adjusted to match the land use. Because the slopes throughout the watershed are very low, the interflow recession parameter (IRC) was increased. Lastly, the interflow inflow parameter (INTFW) was increased to better match streamflow. Details about the HSPF model are given in Figure 4.10.

From Figure 4.11, it can be seen that the general trend with the USGS gage was excellent. From Table 3.6, we can see that the NSE for hydrological models should average between -0.23 and 0.95 (Moriasi, 2007) with 0.99 being the ultimate goal. The model efficiency values are shown in Table 4.5. This indicates that similar model parameter values for the Wolf Bay model could be transferred to the Perdido River model.

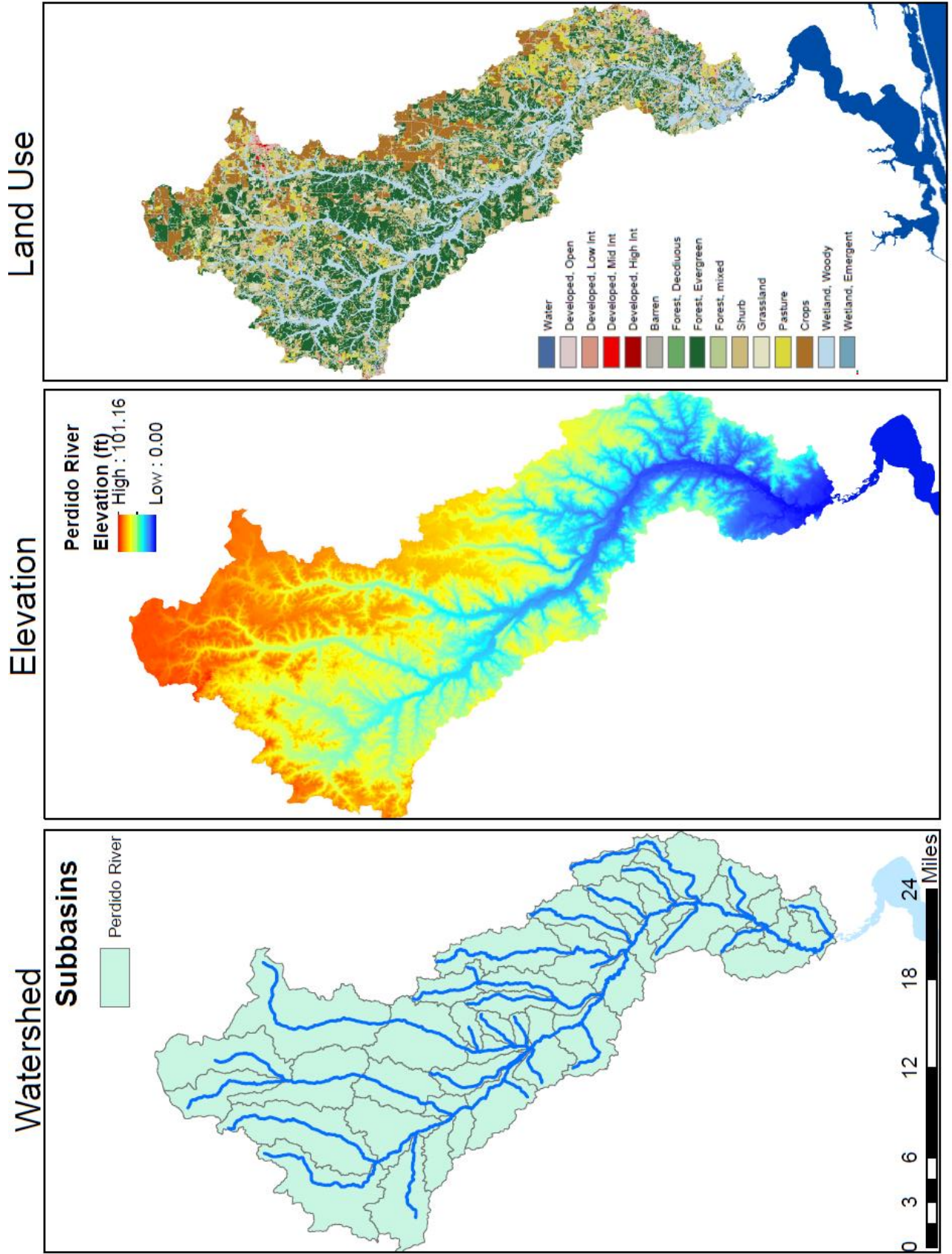


Figure 4.9 Perdido River Watershed including Elevation and Land Use Maps

# Perdido River HSPF Model Details

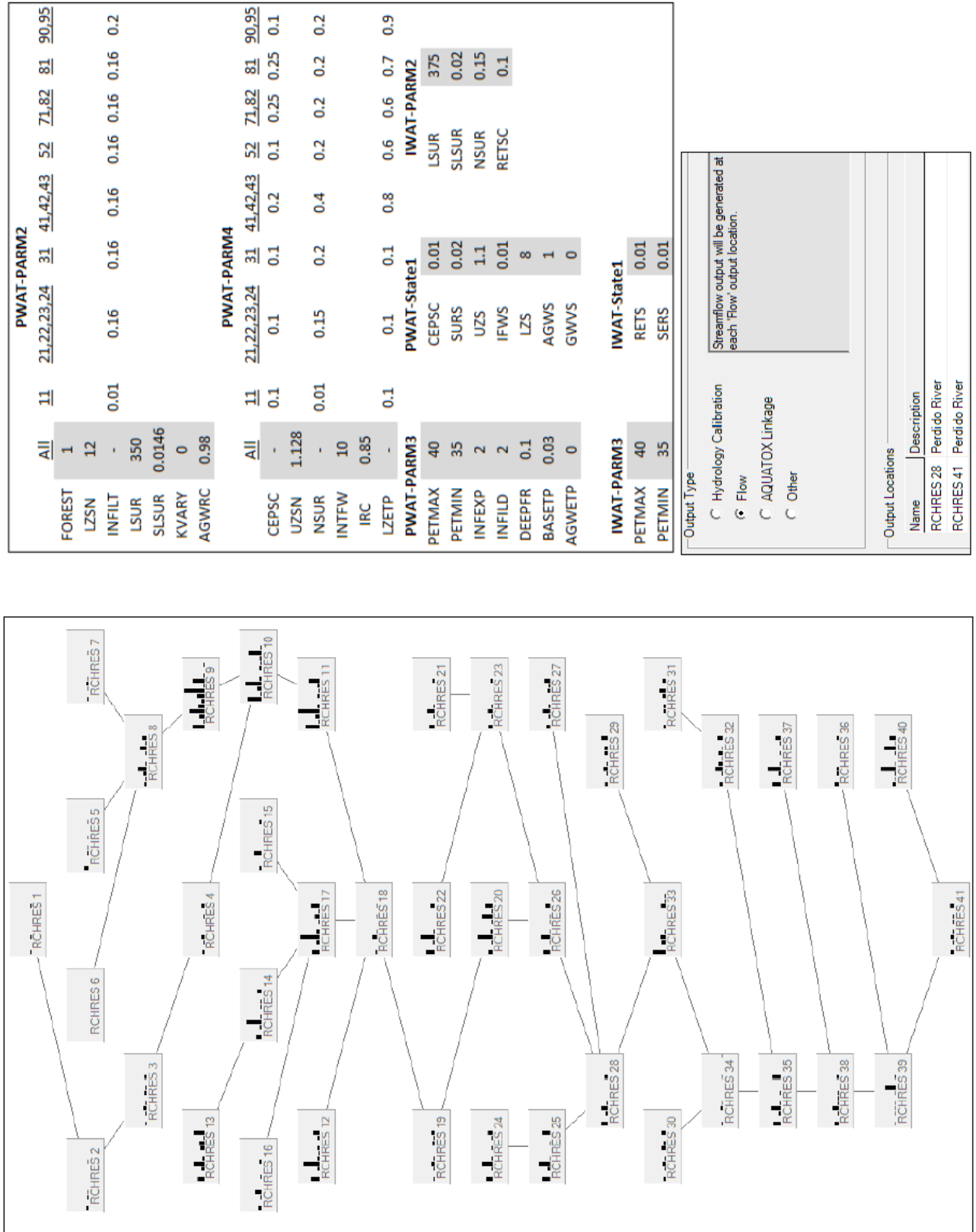


Figure 4.10 Perdido River HSPF Model Details

Table 4.5 Perdido River Model Efficiency Values

	Uncalibrated	Calibration	Validation
Nash-Sutcliffe:	-2.76	0.363	0.337
Percent Bias:	1.13	-6.25	-14.64
R <sup>2</sup> :	0.124	0.444	0.351

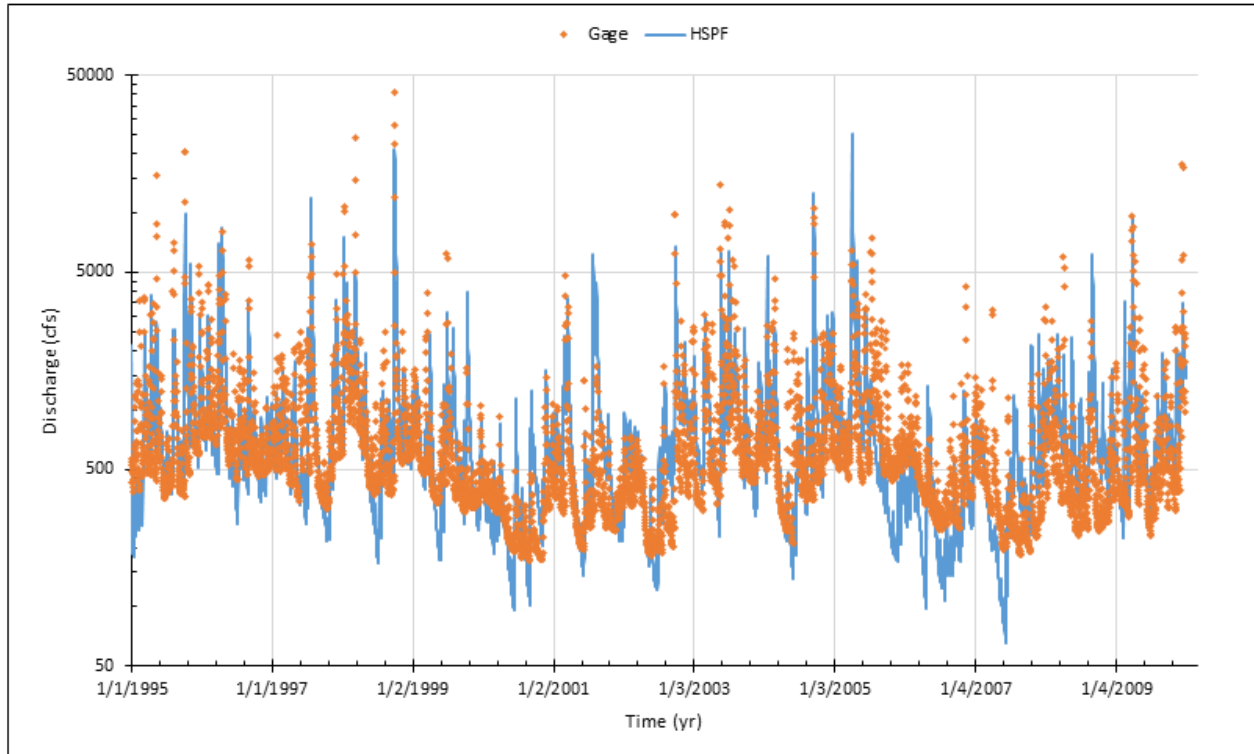


Figure 4.11 Simulated and Observed Daily Discharges (cfs) for Perdido River

This model was more successful than the Wolf Creek model was, when only efficiency is considered. However, there is much more variation in the flow data. While Wolf Creek’s largest discharge was 314 cfs, the maximum flow for the Perdido River was 40,800 cfs. Here the gage ranged from 171 cfs to 40,800 cfs with an average of 820 cfs. While the HSPF modeled discharges ranged from 67 cfs to 30,000 cfs with an average of 878 cfs. Overall the model and gage data match very well, except for the years 2005—2007. This change was examined, however, neither the gage nor the weather station was altered during this time period. However, there was a major drought during this time frame, and records show that 2006—2008 were the driest back-to-back calendar years Florida has experienced (Figure 4.12), based on precipitation data dating back to

1932 ([www.dep.state.fl.us/drought/](http://www.dep.state.fl.us/drought/)). This large precipitation deficit, may have caused HSPF to not model the soil moisture, or evapotranspiration correctly thus affecting the model output.

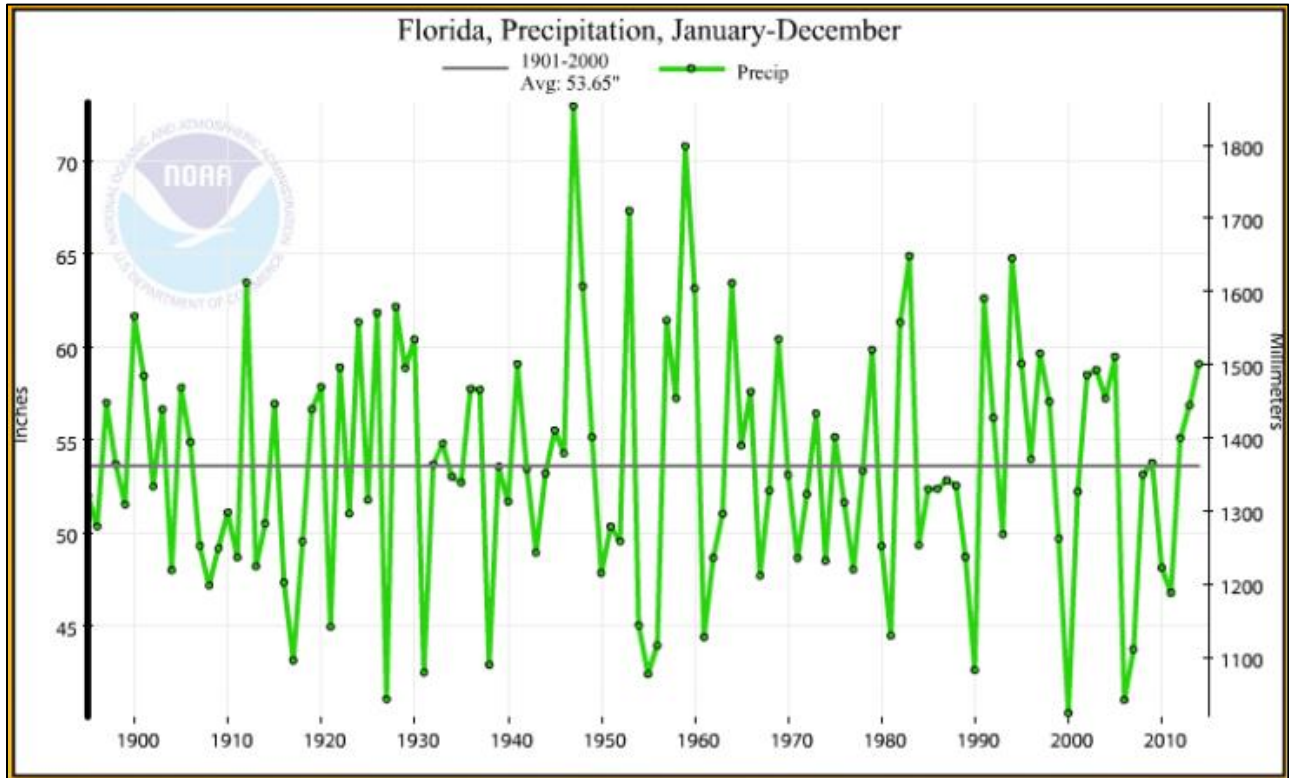


Figure 4.12 Annual Precipitation, Florida 1950-2013, National Climatic Data Center (NCDC)

A 30-day period in spring of 2002 is shown in Figure 4.13 to compare simulated and observed discharges under six rainfall events. Here the simulated streamflow matches very well for two of the three peaks.

When the direct comparison of simulated and observed discharges over the whole simulation period are made in Figure 4.13 it looks very good. The larger flows tend to be further under or overestimated than the smaller flows and are usually underestimated. This matches what was seen in Figure 4.11.

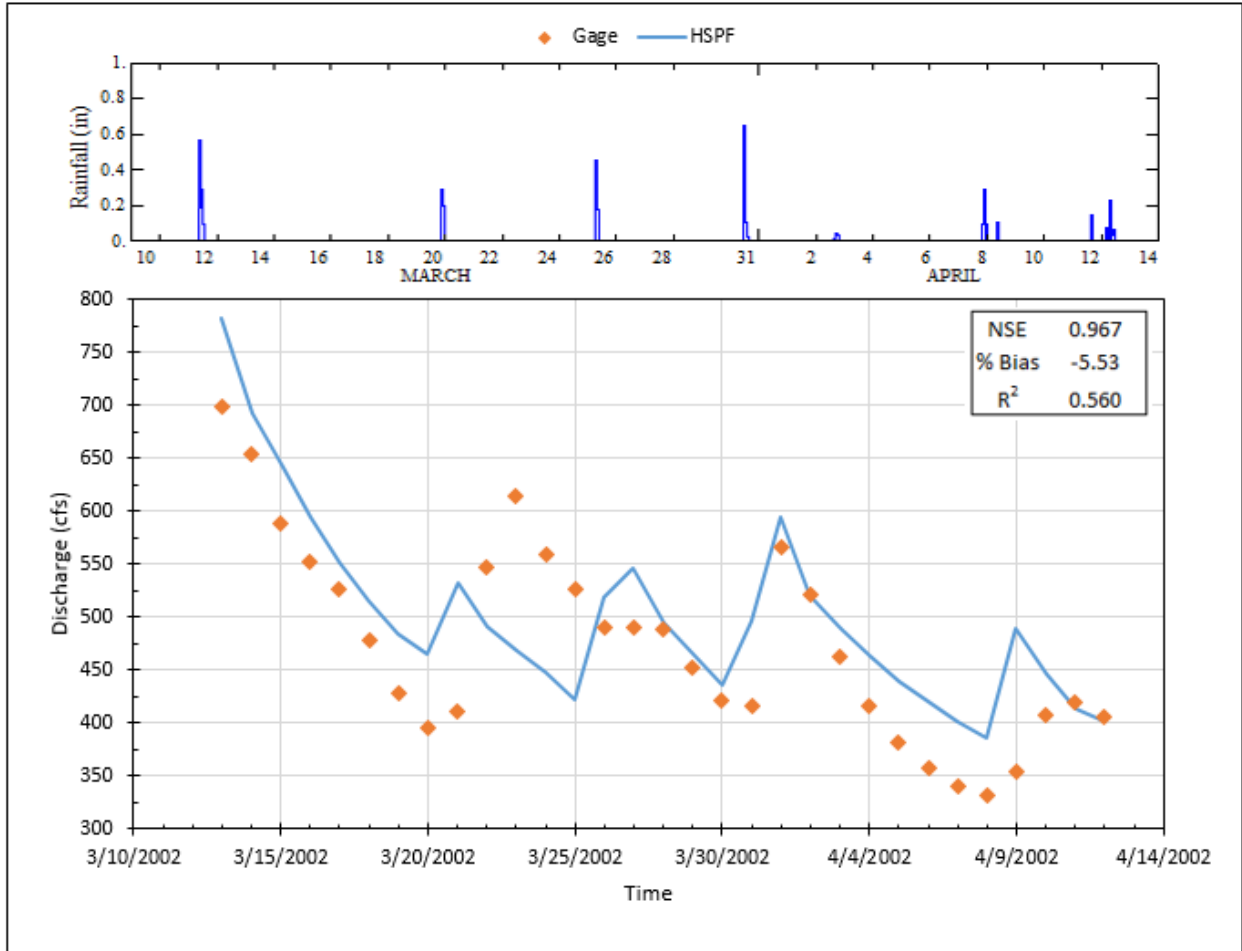


Figure 4.13 One Month of Modeled and Observed Perdido River Streamflow

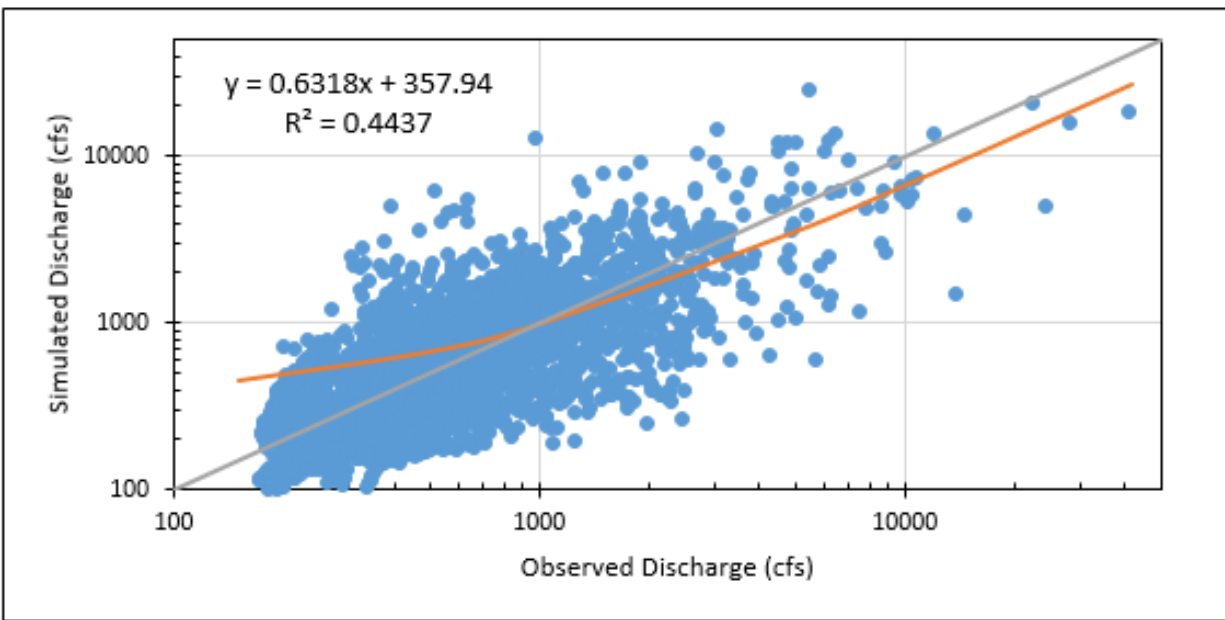


Figure 4.14 Perdido River Observed vs. Simulated Discharge

The volume comparison between the gage and modeled data is excellent, especially before 2001. While the direct comparison shows an even split for over/under estimating, Figure 4.15 shows that this difference nearly evens itself out, due to the low 6.86% error. The two curves track very nicely, both spiking and plateauing together. However, just like in Figure 4.6.2, the years 2005—2007 the difference between the modeled and observed volumes increases, then remains similar for the remainder of the time period.

For the Perdido River watershed the runoff generation from rainfall was calculated and plotted (Figure 4.15). Here the model showed that 62.72% of the rainfall generated discharge in the creek, while the gage data showed 58.70% becoming runoff. These are within a 4% discrepancy from each other, so this was considered satisfactory. These high runoff volumes may seem strange when the landuse is considered (Figure 4.9). However, Perdido is in a coastal area with a shallow groundwater table. This causes higher than usual runoff generation (Sklash, 19759; Hewlett, 1965).

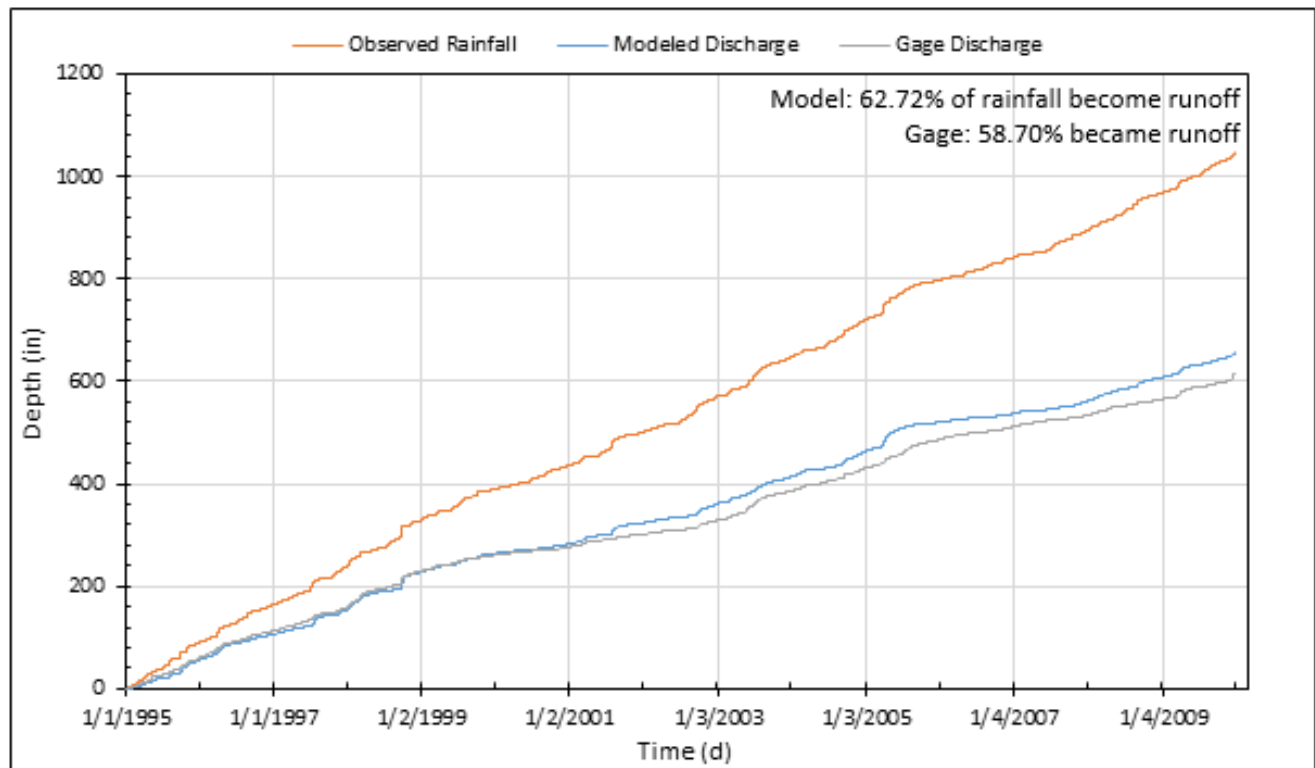
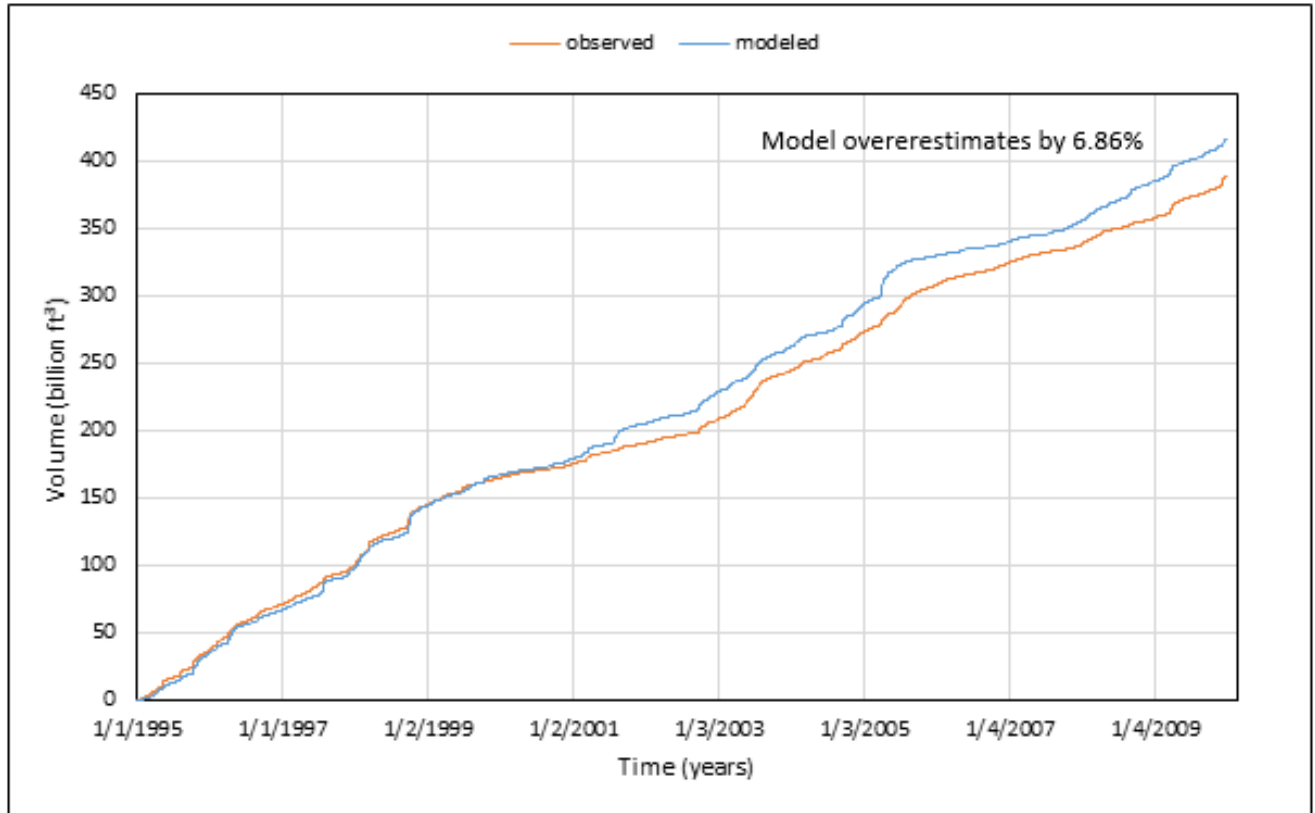


Figure 4.15 Observed vs. Simulated Cumulative Volume and Runoff for Perdido River



#### 4.1.5 Styx River Model

The Styx River model has land use and catchments as shown in Figure 4.16. The main land uses are shown in Table 4.6 (more than 50% are either forest or shrub). The watershed has a total area of 218 mi<sup>2</sup>, making it the second largest watershed model. The basin has elevations ranging from 1.2 to 85.4 m and includes 32 delineated catchments with drainage areas of 1.73—28.15 mi<sup>2</sup> with an average area of 8.33mi<sup>2</sup>. There is one USGS gage (#02377570) near Elsanor, AL. It has data from 1988, with several consecutive months of missing data from 1993 to 1996 and again in 1999. From October 2012 to October 2013 there is a gap in gage data. Since, this is the only gage within the watershed it was the best option for calibration.

Table 4.6 Primary Land Uses in Styx River Land Use (NLCD 2011)

<b>% of area</b>	<b>Styx River Land use</b>
31.50%	Forest
26.31%	Shrub
21.19%	Wetlands
11.25%	Grassland
4.94%	Cultivated Crops

For the Styx River watershed, the AGWS and GWVS were adjusted just like the Perdido model. The INFILT was increased to match the primary soil types in each land use type. Next the LZSN and LZS were increased to match a high precipitation region. Then the DEEPFR was reduced to more accurately match a coastal system with a shallow groundwater table and quick recharge. Both pervious and imperious NSUR as well as LZETP were adjusted to match the land use. Because the slopes throughout the watershed are very low, the IRC was increased. Lastly the INTFW was increased to better match stormflow. Details about the Styx River HSPF model are given in Figure 4.17.

From Figure 4.18, it can be seen that the general trend with the USGS gage was excellent. The model efficiency values are shown in Table 4.7.

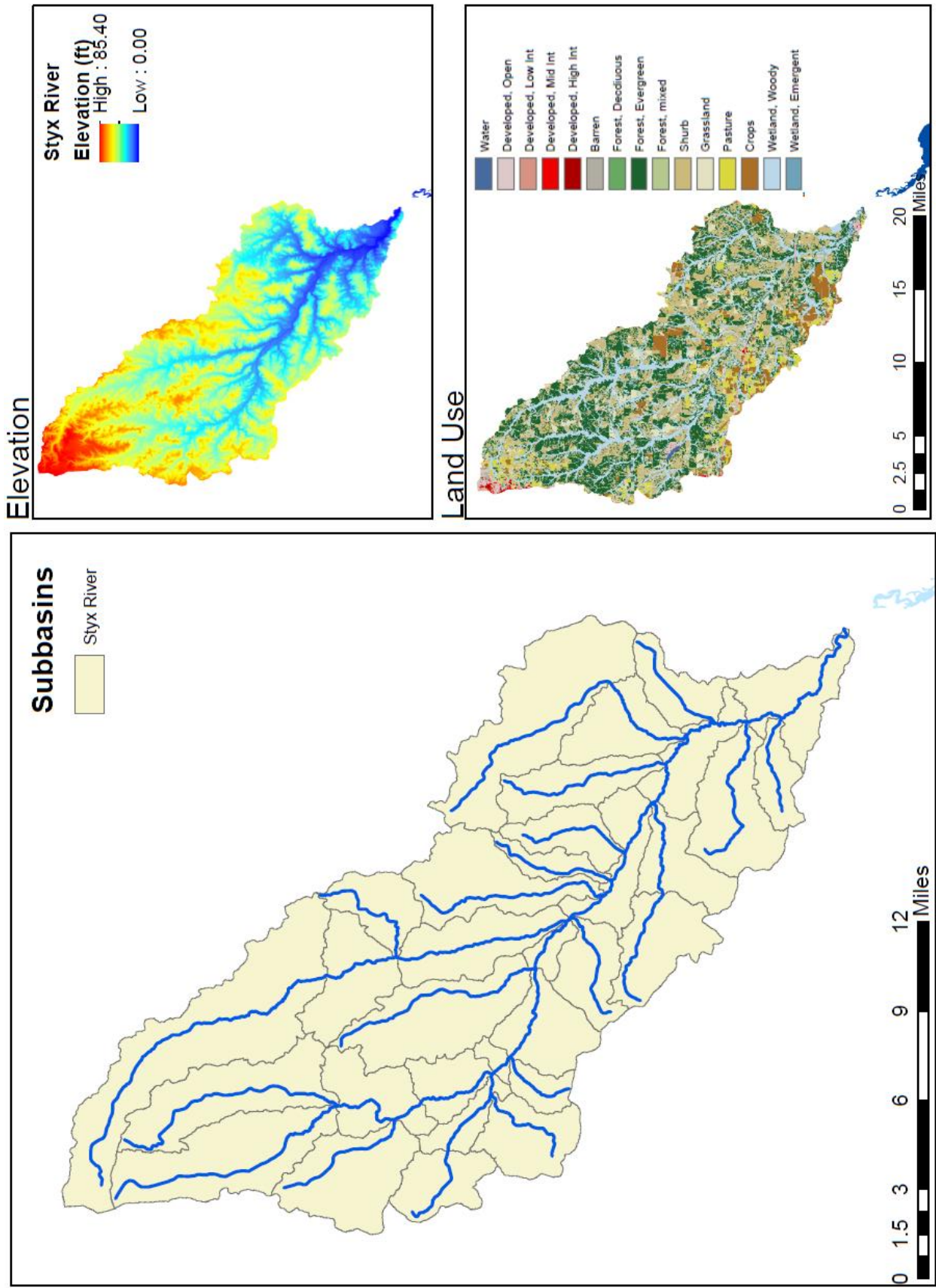


Figure 4.16 Styx River Watershed including Elevation and Land Use Maps

## Styx River HSPF Model Details

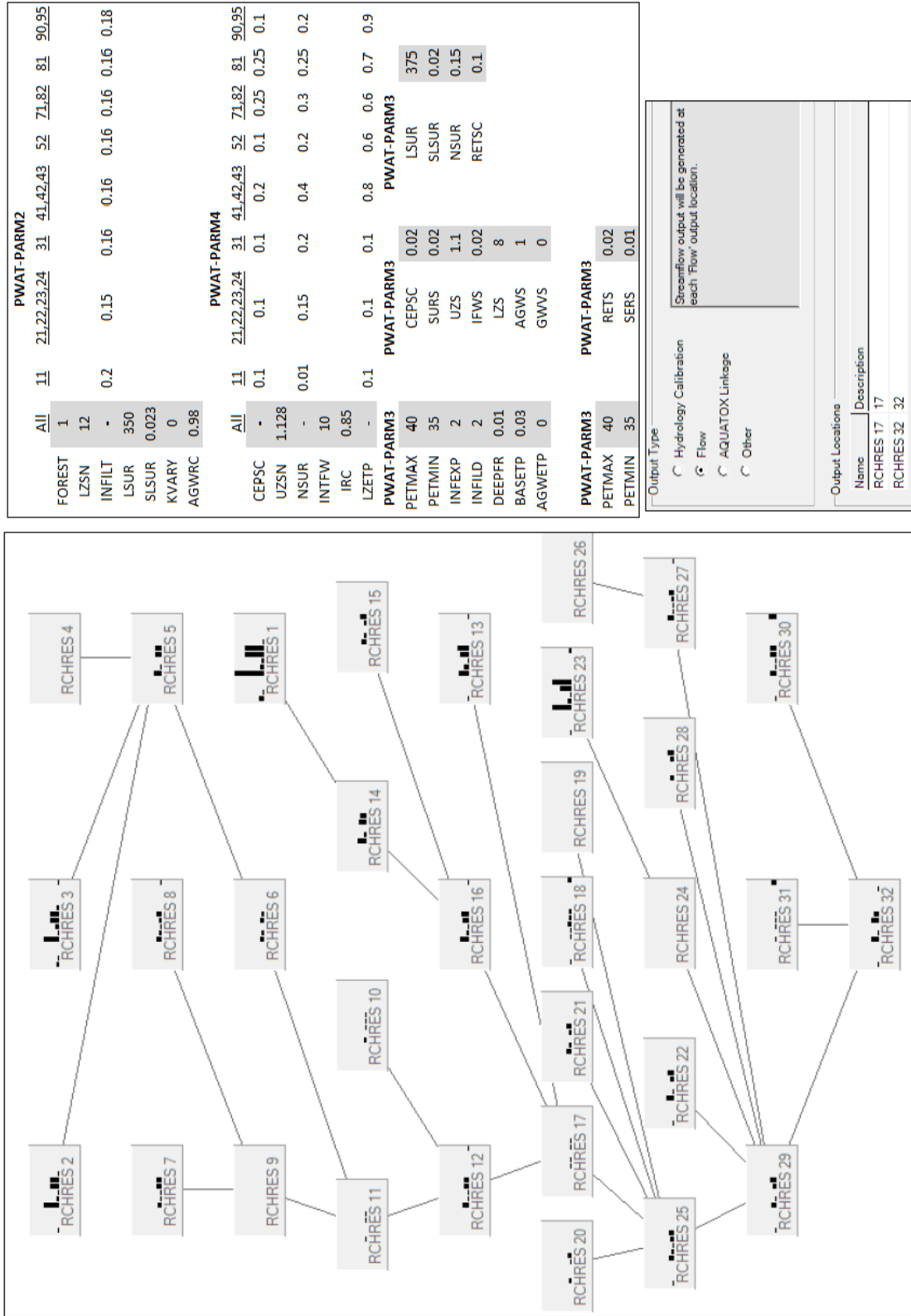


Figure 4.17 Styx River HSPF Model Details

Table 4.7 Styx River Model Efficiency Values

	Uncalibrated	Calibration	Validation
Nash-Sutcliffe:	-0.398	0.472	0.432
Percent Bias:	25.79	7.29	4.81
R <sup>2</sup> :	0.221	0.356	0.485

The Styx model was one of the best models in terms of the efficiency values. Visually the HSPF simulated discharges (Figure 4.18) track well with the observed gage discharges. The gage data range from 70 cfs to 17,200 cfs with an average of 409 cfs. The HSPF simulated discharges range from 32 cfs to 97200 cfs with an average of 369 cfs. Only for the years 2005—2006, do the two fail to match. This is the same time period that the Perdido model loses efficiency (section 4.1.4). However, the Robertsdale station is located closest the Styx River watershed (out of the gaged watersheds), so Styx should have the closest match to the weather data even with the possible change in parameters do to the drought.

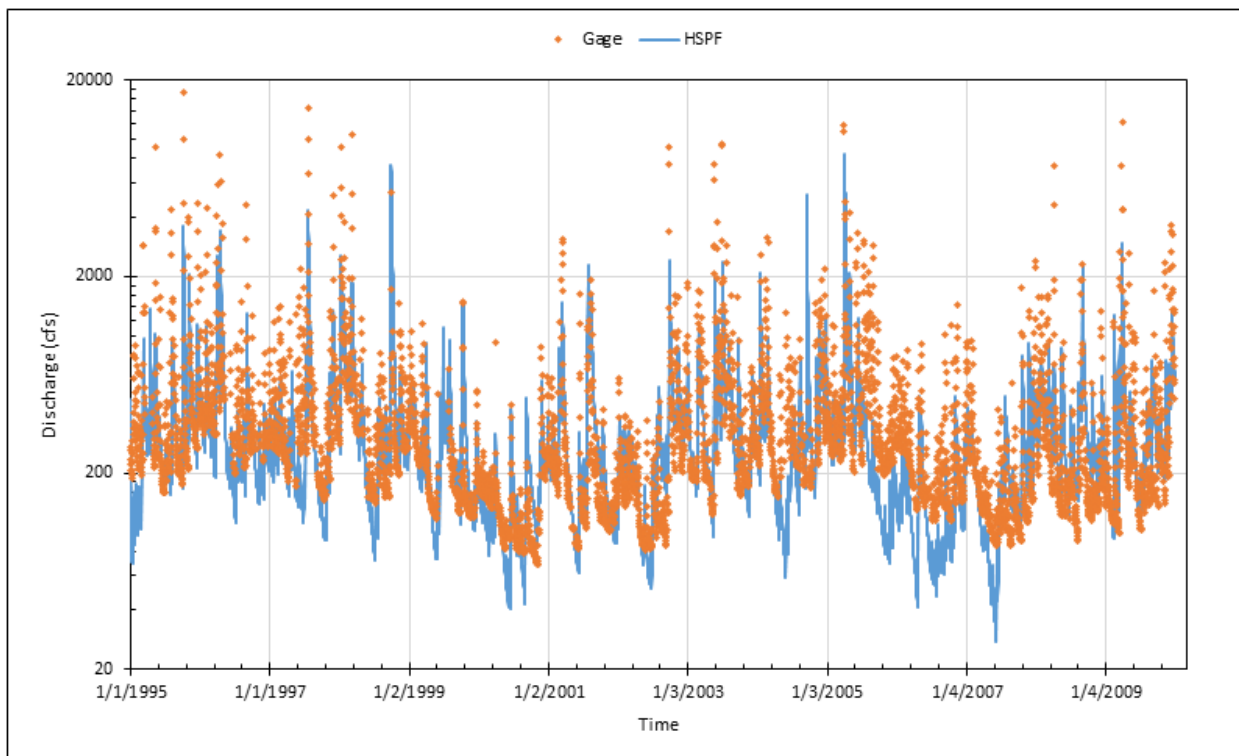


Figure 4.18 Simulated and Observed Daily Discharges (cfs) for Styx River

When storm events are looked at more closely. The Styx model performs even more efficiently. In Figure 4.19, part of March and April 2002 is shown and the model is nearly perfect with an NSE of 0.976. In Figure 4.20 the trends are even better for the winter of 2004. Yet due to the model missing one storm event (December 6), the NSE is only 0.796. However, this time period shows much more variation in the discharge data, so visually the match is much better.

For the direct comparison of the modeled to gage data, the Styx model did about as well as the other models, as it also tends to underpredict larger flows. However it does better for the overall flows, which can be seen in the cloud of data points being narrower and clustered closer to the gray 1:1 line (Figure 4.21).

While the Styx River model is better than other models in some ways, it is worse than both Perdido and Wolf models when it comes to the volume (Figure 4.22). With its underestimation of 3.05% it is half out of step with the gage data as are Perdido or Wolf. Styx only mildly shows an issue with the 2005—2006 time period, unlike Perdido.

For the Styx River watershed the runoff generation was considered (Figure 4.22). Here the model showed that 52.22% of the rainfall generated discharge in the creek, while the gage data showed 53.86% becoming runoff. These are within a 2% discrepancy from each other, so this was considered satisfactory. These high runoff volumes may seem strange when the landuse is considered (Figure 4.22). However, Styx is in a coastal area with a shallow groundwater table. This causes higher than usual runoff generation (Sklash, 19759; Hewlett, 1965).

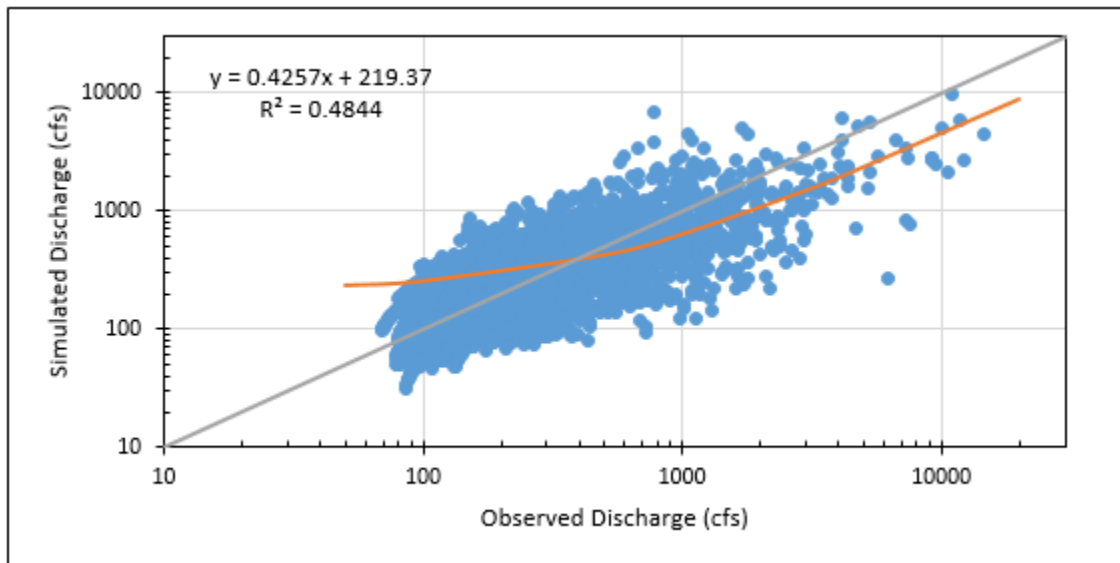


Figure 4.21 Styx River Observed vs. Simulated Discharge

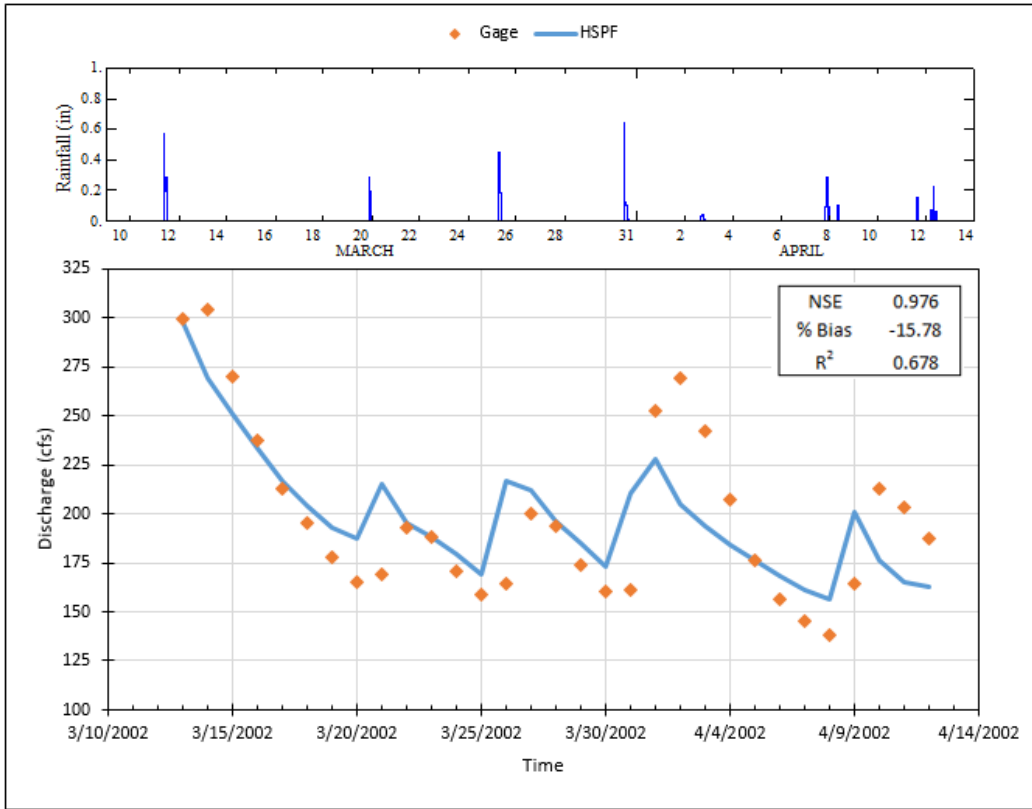


Figure 4.19 30 Days of Spring Rainfall and Observed and Simulated Styx River Streamflow

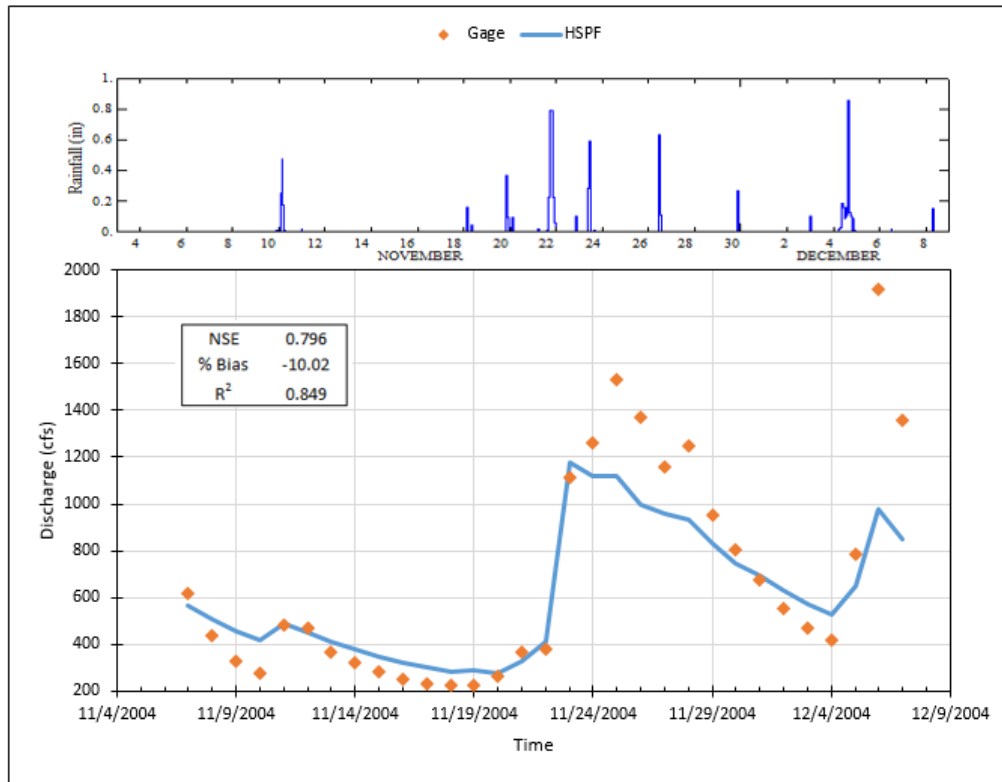


Figure 4.20 30 Days of Winter Rainfall and Observed and Simulated Styx River Streamflow

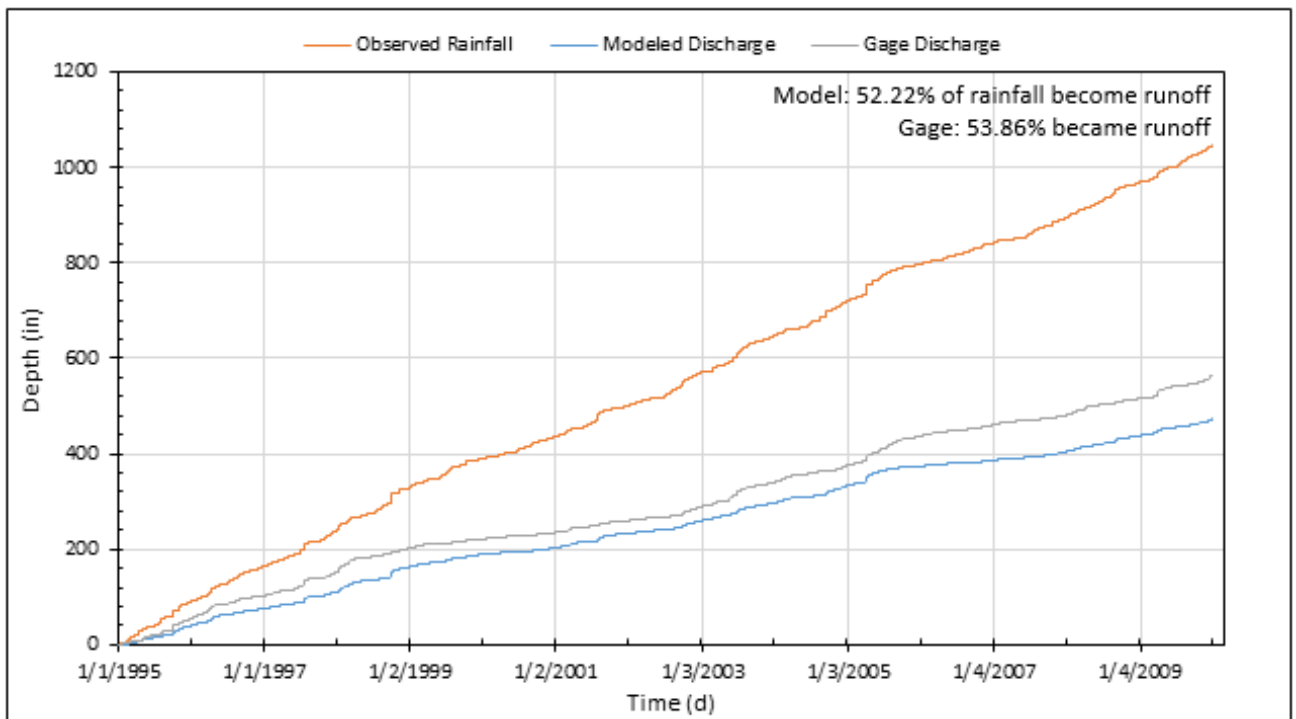
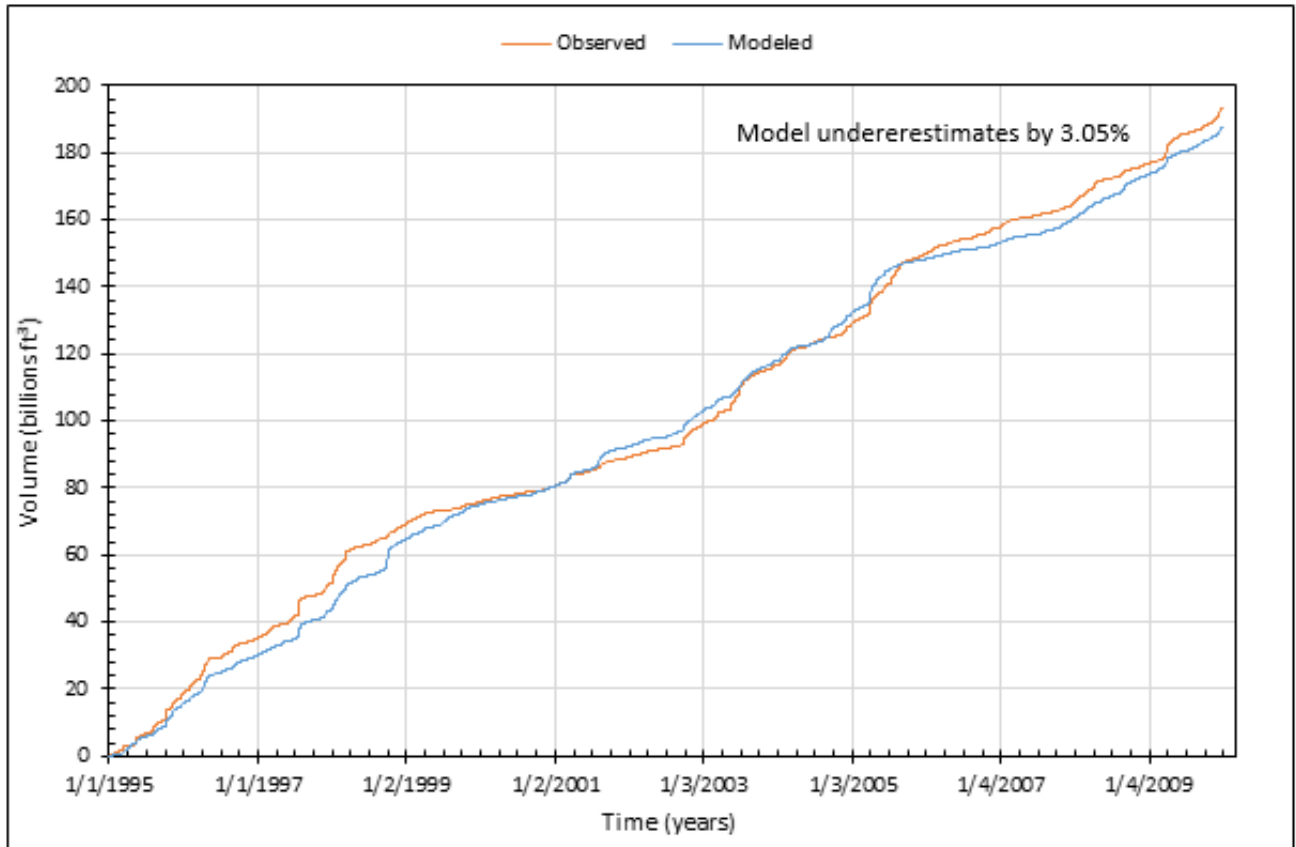


Figure 4.22 Styx River Observed vs. Simulated Cumulative Volume and Runoff

#### 4.1.6 Blackwater River Models

The Blackwater River model has land use distribution and catchments as shown in Figure 4.24. The main land uses are shown in Table 4.8. The watershed has a total area of 100 mi<sup>2</sup>. The watershed has elevations ranging from 1.2 to 61.2 m and includes 35 delineated catchments with drainage areas of 0.01—5.65 mi<sup>2</sup> with an average area of 1.58 mi<sup>2</sup>. There is no USGS gage within the watershed. Because of this, while the model was created, it cannot be calibrated. This is additionally unfortunate, due to the Robertsdale weather station (used for model meteorological data) being located within the watershed. So this model should have been the best match to the weather station.

Table 4.8 Primary Land Uses in Blackwater River Land Use (NLCD 2011)

<b>% of area</b>	<b>Blackwater River Land use</b>
33.13%	Cultivated Crops
18.00%	Wetlands
16.88%	Grassland
14.89%	Forest
10.00%	Shrub

For the Blackwater River watershed, the same process of specifying model parameters was done as for the Styx River. This is due to the watershed sharing similar characteristics. Although, the Blackwater watershed has considerably more cropland than does the Styx watershed. This means a more detailed adjustment to INT(MON) may be needed. The model was run successfully (Figure 4.23) and simulated discharges were similar to ones from the Styx River watershed, but with a lower base flow. This makes physical sense, due to it having less drainage area than does the Styx River. However, with no gage to check against, there is no way to assess model accuracy.

For the Blackwater River watershed the runoff generation was considered (Figure 4.23). Here the model showed that 49% of the rainfall generated discharge in the creek.



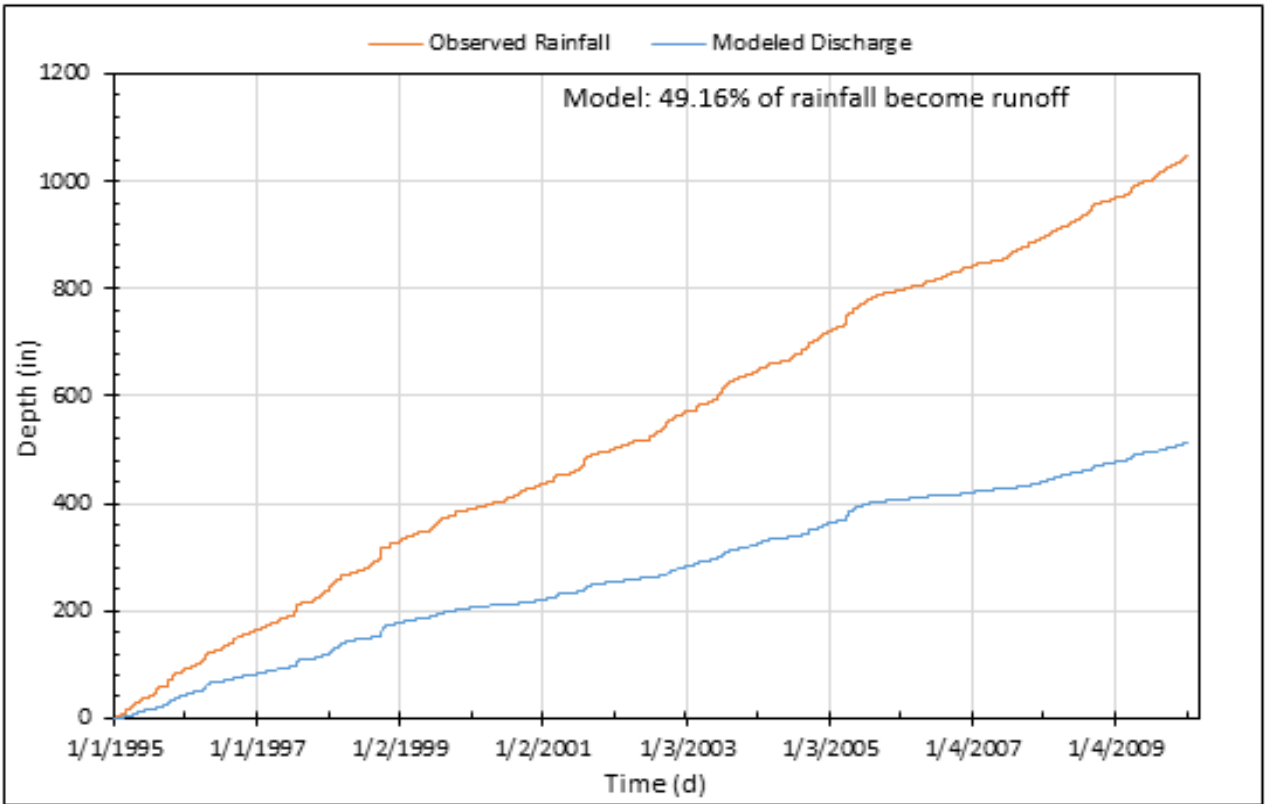
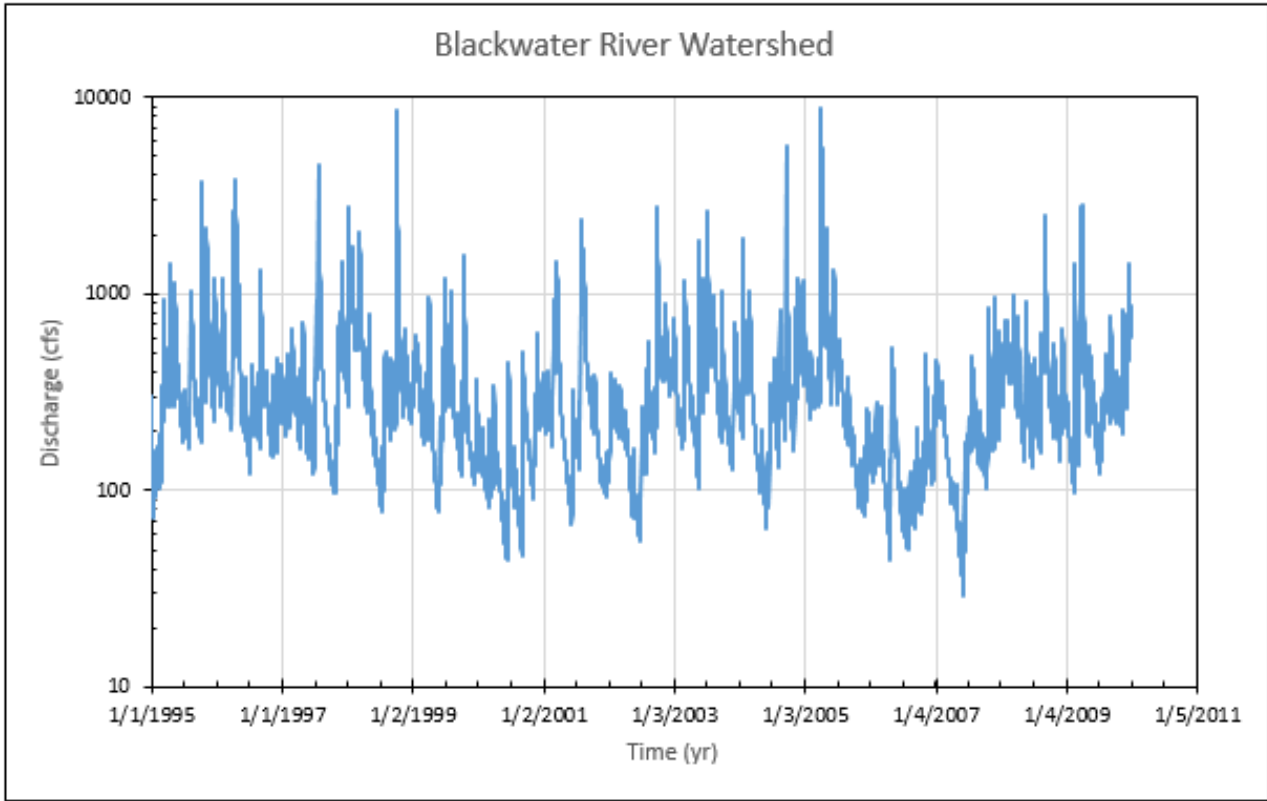


Figure 4.23 Simulated Daily Discharge(cfs) and Runoff for Backwater River Watershed

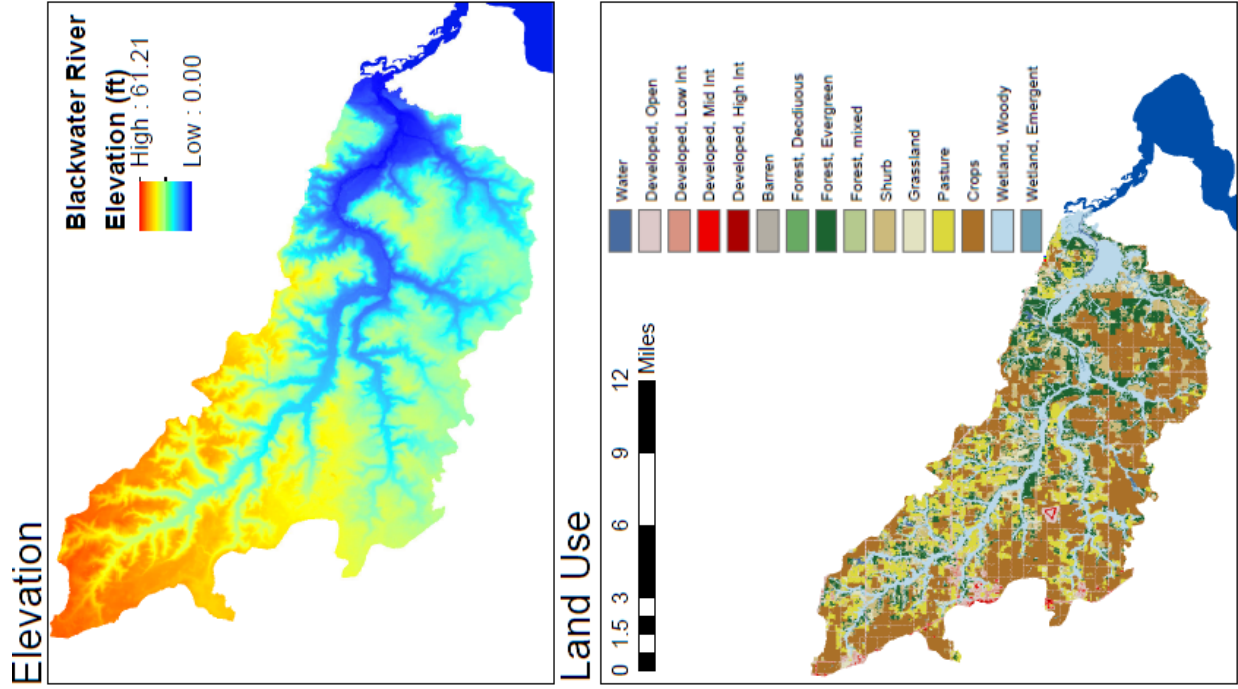
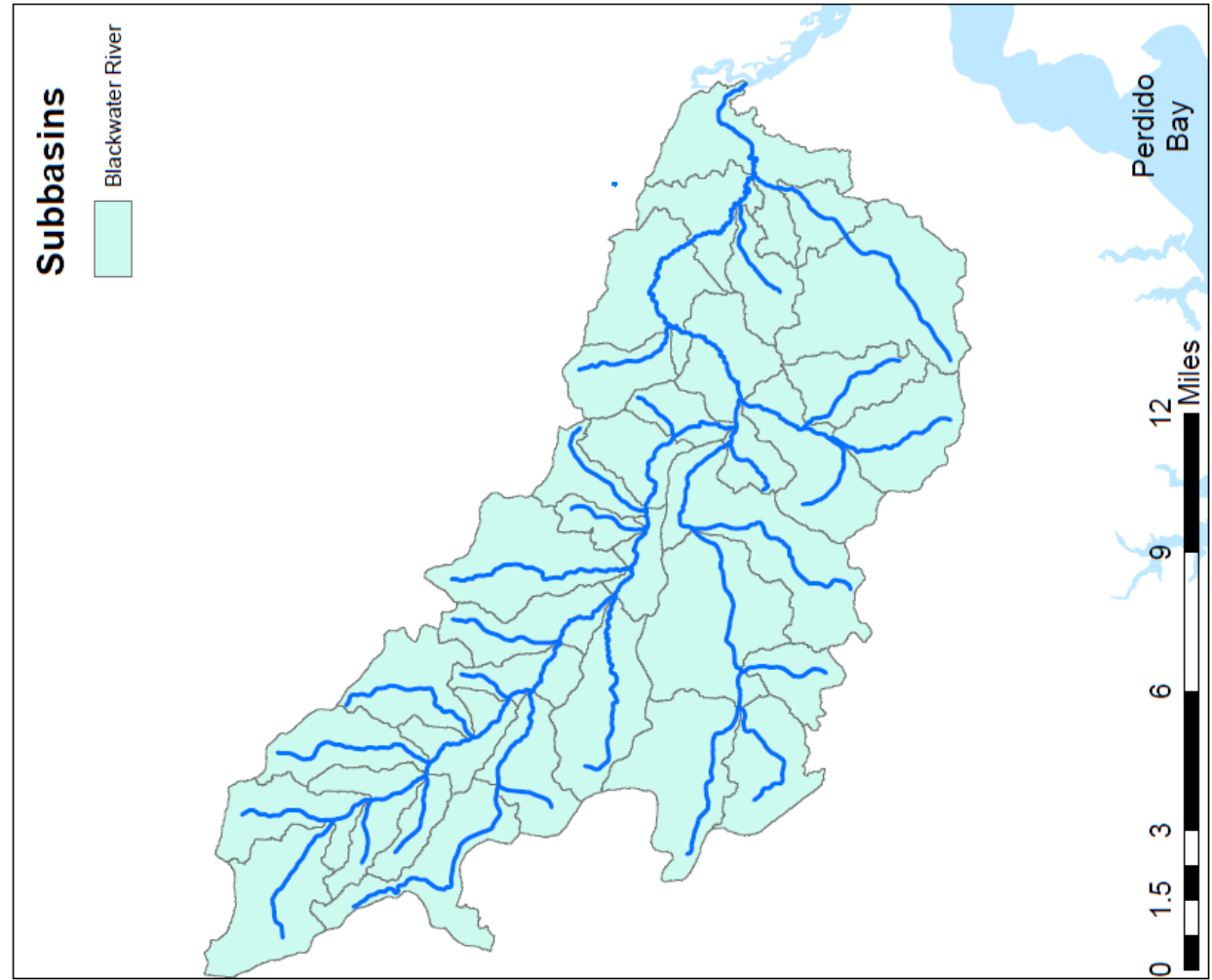


Figure 4.24 Blackwater River Watershed including Elevation and Land Use Maps

#### 4.1.7 Elevenmile Creek Model

The Elevenmile Creek model has land use and catchments as shown in Figure 4.25. The main land uses are shown in Table 4.9. The watershed has a total area of 49 mi<sup>2</sup>. The basin has elevations ranging from -0.3 to 58.3 m and includes 22 delineated catchments with drainage areas of 0.12—3.75 mi<sup>2</sup> with an average area of 1.25mi<sup>2</sup>. The Elevenmile watershed differs from the Perdido or the Styx watersheds in that urban land uses are two of the top five land uses. There is one USGS gage (#02376115) near Pensacola, FL. It has data from 1988 with minor missing data.

Table 4.10 is from a six year algae bloom study (Livingston, 2001). It shows that the Elevenmile creek watershed is degraded in water quality and ecological health. This is due to the International Paper papermill located on the creek. Until 2009 it discharged directly into the creek (www.inweekly.net/article.asp?artID=7240). Between 2009 and 2012 a switch to a discharge pipeline was done to improve the health of the stream. It currently discharges 0% of its wastewater into the creek (www.garney.com/international-paper-48-effluent-pipeline/).

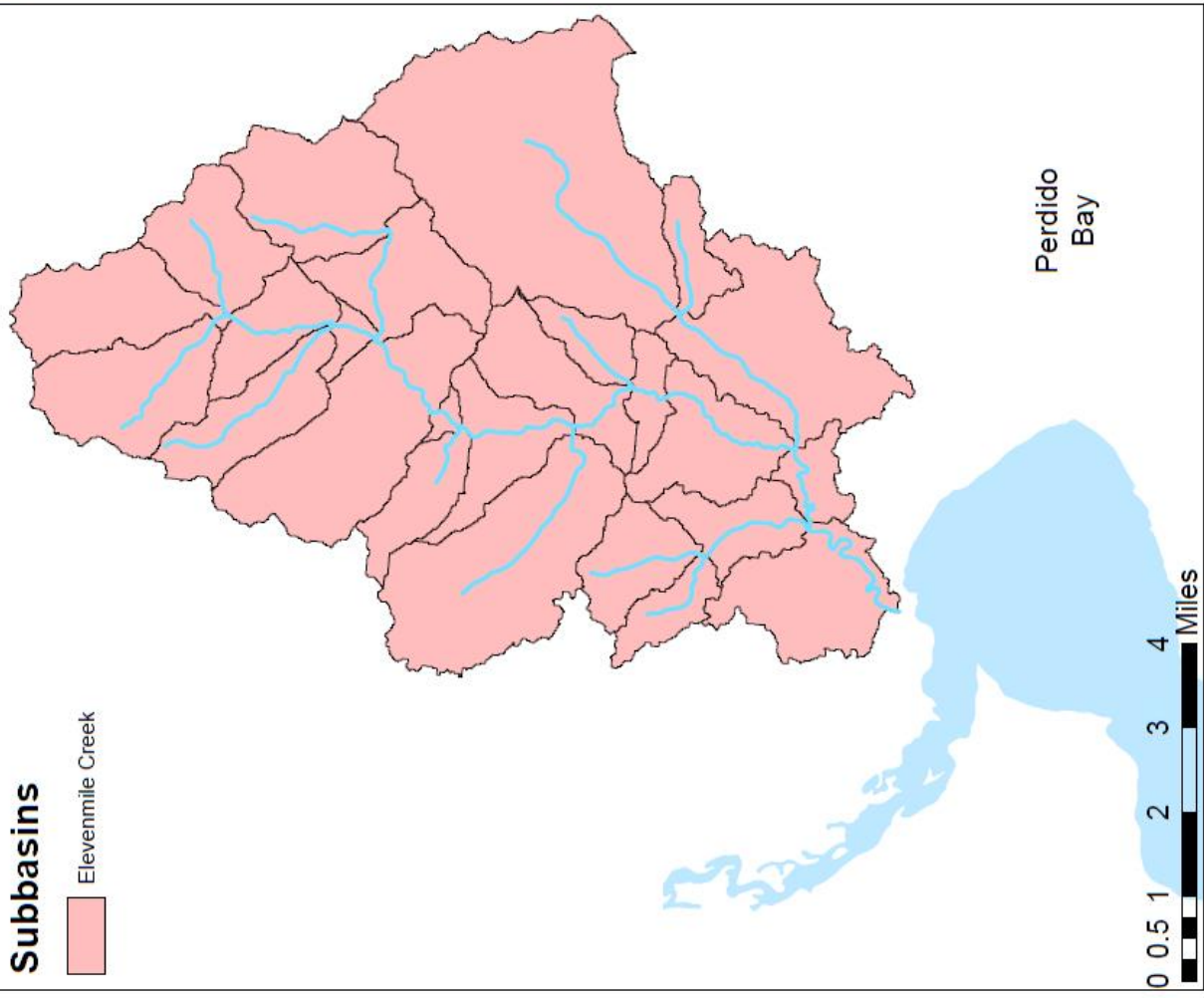
Table 4.9 Primary Land Uses in Elevenmile Creek (NLCD 2011)

% of area Elevenmile Creek Land use	
27.02%	Developed, Open Space
21.68%	Forest
11.81%	Developed, LowInt
11.48%	Wetlands
11.38%	Grassland

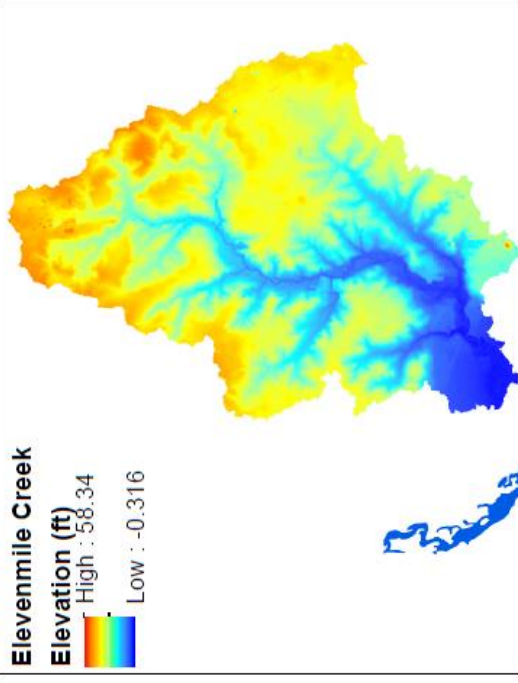
Table 4.10 Elevenmile Creek Algal Blooms

<u>Year</u>	<u>Month</u>	<u>Species</u>
1997	November	M. tenuissima
1998	December	M. tenuissima
1999	January	M. tenuissima
1999	August	M. tenuissima
1999	September	M. tenuissima
1999	October	M. tenuissima
1999	December	M. tenuissima
2000	January	M. tenuissima
2000	Febuary	M. tenuissima
2000	March	M. tenuissima
2000	April	M. tenuissima
2000	July	M. tenuissima
2000	August	M. tenuissima
2000	September	M. tenuissima
2000	October	M. tenuissima
2001	January	M. tenuissima
2001	April	M. tenuissima

# Elevenmile River Watershed



# Elevation



# Land Use

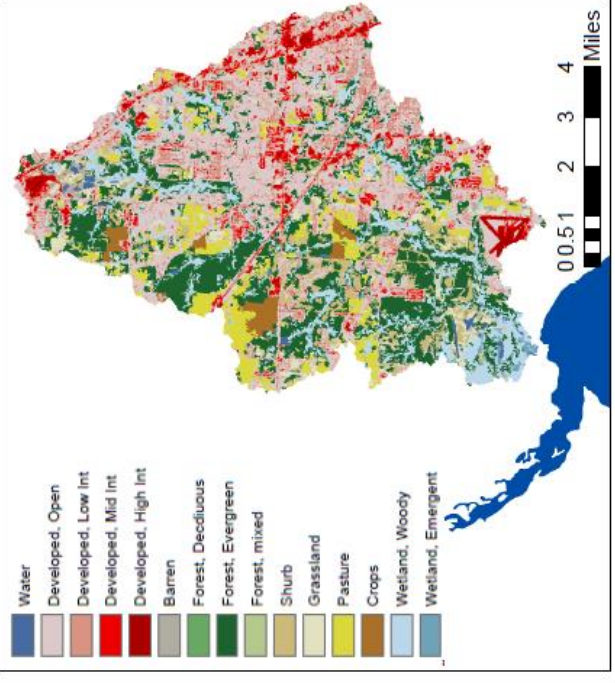


Figure 4.25 Elevenmile Creek Watershed including Elevation and Land Use Maps

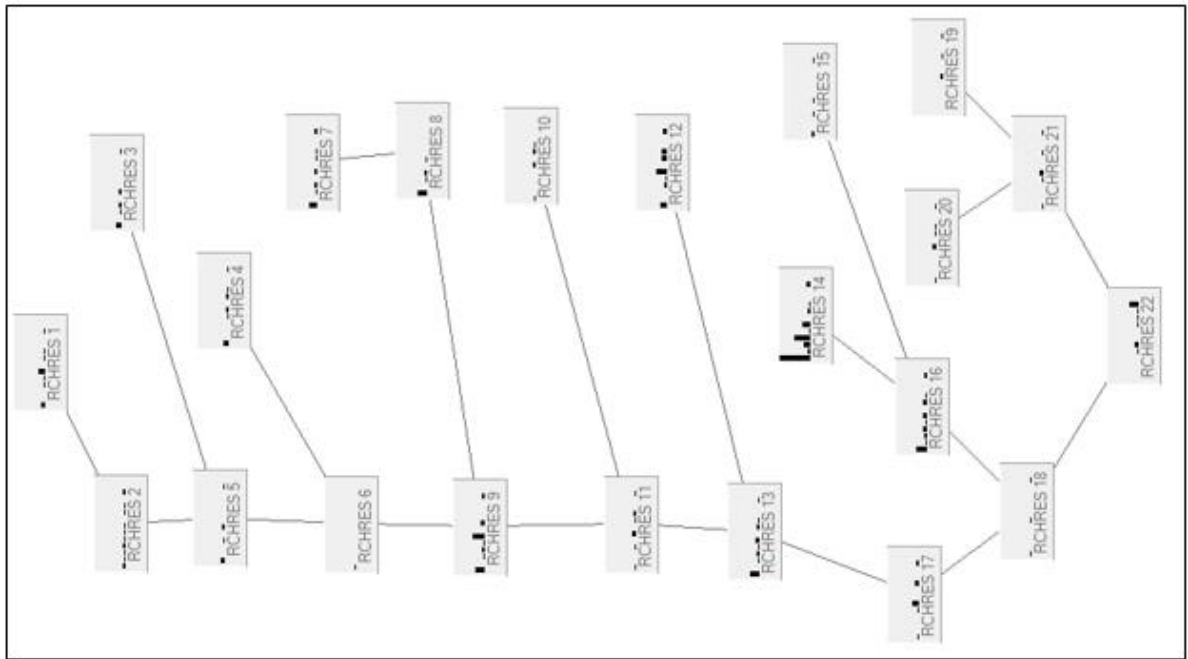
For the Elevenmile Creek watershed, the AGWS and GWVS were adjusted just like the Perdido model. The INFILT was increased to match the primary soil types in each land use type. Next, the LZSN and LZS were increased to match a high precipitation region. Then the DEEPFR was reduced to more accurately match a coastal system with a shallow groundwater table and quick recharge. Both pervious and imperious NSUR as well as LZETP were adjusted to match the land use. Because the slopes throughout the watershed are very low the IRC was increased. Also, RETS and SURS were increased due to the large amount of urban area. Lastly, the INTFW was increased to better match stormflow. Details about the HSPF model are given in Figure 4.26.

From Figure 4.27, it can be seen that the general trend with the USGS gage was only fair. The efficiency values are shown in Table 4.11. Just like Wolf Creek there is a point source. However the papermill does not release its outflow due to legal issues. In addition, the papermill no longer discharge into the creek, so for future modeling this point source will no longer exist. Once again, the odd mismatch during the 2005—2007 drought can be observed (section 4.1.4). Other than that time period the modeled and gage dataset track very closely for storm events, but the model nearly always under predicts for lower flows. The gage data range from 30.7 cfs to 8,000 cfs with an average of 106 cfs, and the HSPF simulation results range from 5.5 cfs to 2,840 cfs with an average of 80 cfs.

Table 4.11 Elevenmile Creek Efficiency Values

	Uncalibrated	Calibration	Validation
Nash-Sutcliffe:	-0.031	0.444	0.280
Percent Bias:	28.33	21.43	19.49
R <sup>2</sup> :	0.365	0.474	0.314

### Elevenmile Creek HSPF Model Details



		PWAT-PARM2									
		11	21,22,23,24	31	41,42,43	52	71,82	81	90,95		
FOREST	All	1									
LZSN	12										
INFILT	-	0.2	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.2	
LSUR	350										
SLSUR	0.0146										
KVARY	0										
AGWRC	0.98										
		PWAT-PARM4									
		11	21,22,23,24	31	41,42,43	52	71,82	81	90,95		
CEPSC	All	0.1	0.1	0.1	0.2	0.1	0.25	0.25	0.1		
UZSN	1.128										
NSUR	-	0.01	0.15	0.2	0.4	0.2	0.2	0.2	0.2		
INTFW	10										
IRC	0.85										
LZETP	-	0.1	0.1	0.1	0.8	0.6	0.6	0.7	0.9		
		PWAT-PARM3									
		PWAT-State1									
PETMAX	40										
PETMIN	35										
INFEXP	2										
INFILD	2										
DEEPPR	0.01										
BASETP	0.03										
AGWETP	0										
		IWAT-PARM2									
LSUR	375										
SLSUR	0.02										
NSUR	0.15										
RETSC	0.1										
		IWAT-State1									
CEPSC	0.01										
SURS	0.02										
UZS	1.1										
IFWS	0.02										
LZS	8										
AGWS	1										
GWVS	0										
		IWAT-State1									
PETMAX	40										
PETMIN	35										
RETS	0.02										
SERS	0.02										

Output Type

- Hydrology Calibration
- Flow
- AQUATOX Linkage
- Other

Streamflow output will be generated at each flow output location.

Output Locations	
Name	Description
RCHRES 13	Elevenmile Creek
RCHRES 22	Elevenmile Creek

Figure 4.26 Elevenmile Creek HSPF Model Details

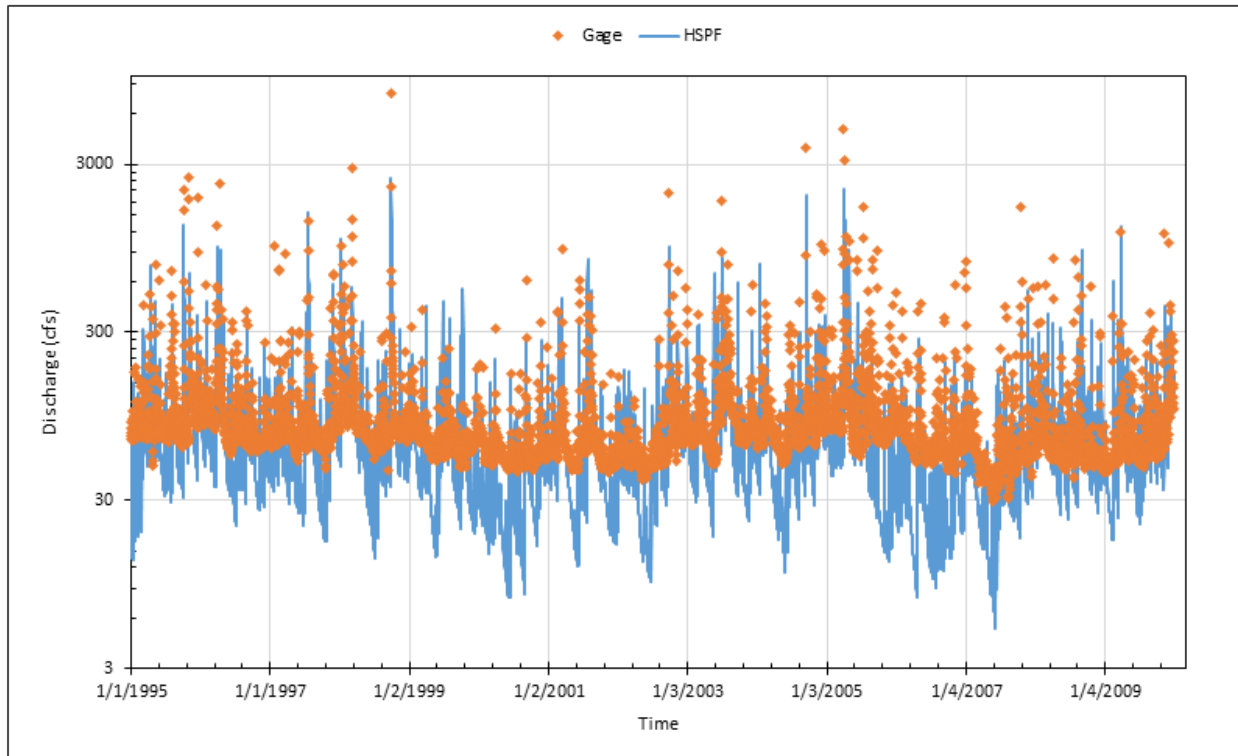


Figure 4.27 Simulated and Observed Daily Discharges (cfs) for Elevenmile Creek

This range agrees with graphical assessment that for low flows the model is not matching. It seems that the model’s rainfall losses are too much. This results in the model missing 20—30 cfs of low flows: the minimum flow difference of 25.2 Cfs (30.7-5.5), the first quantile flow difference of 28.8 cfs (59.0-30.2), and the median flow difference of 22.2 cfs (71.8-49.6) between observed data and simulated by HSPF. The maximum difference was in the highest flow (5520 cfs = 8000 – 2480). This largest difference occurs on September 28, 1998 (Figure 4.28). When the Perdido and Styx models are considered, all three models have their largest (or second largest) discharge on this day.

The National Weather Service records that Hurricane Georges made landfall near Biloxi, MS on the morning of September 28<sup>th</sup> (Figure 4.29) with maximum winds of 110 mph ([www.weather.gov/mob/georges](http://www.weather.gov/mob/georges)). After the landfall, Georges moved very slowly across southern Mississippi and weakened to a tropical depression by the morning of the 29<sup>th</sup>. At that time the center was about 30 miles north northeast of Mobile, AL (just north of the Perdido Bay basin). The storm dissipated near the northeast Florida and southeast Georgia coast by the morning of October 1, 1998.

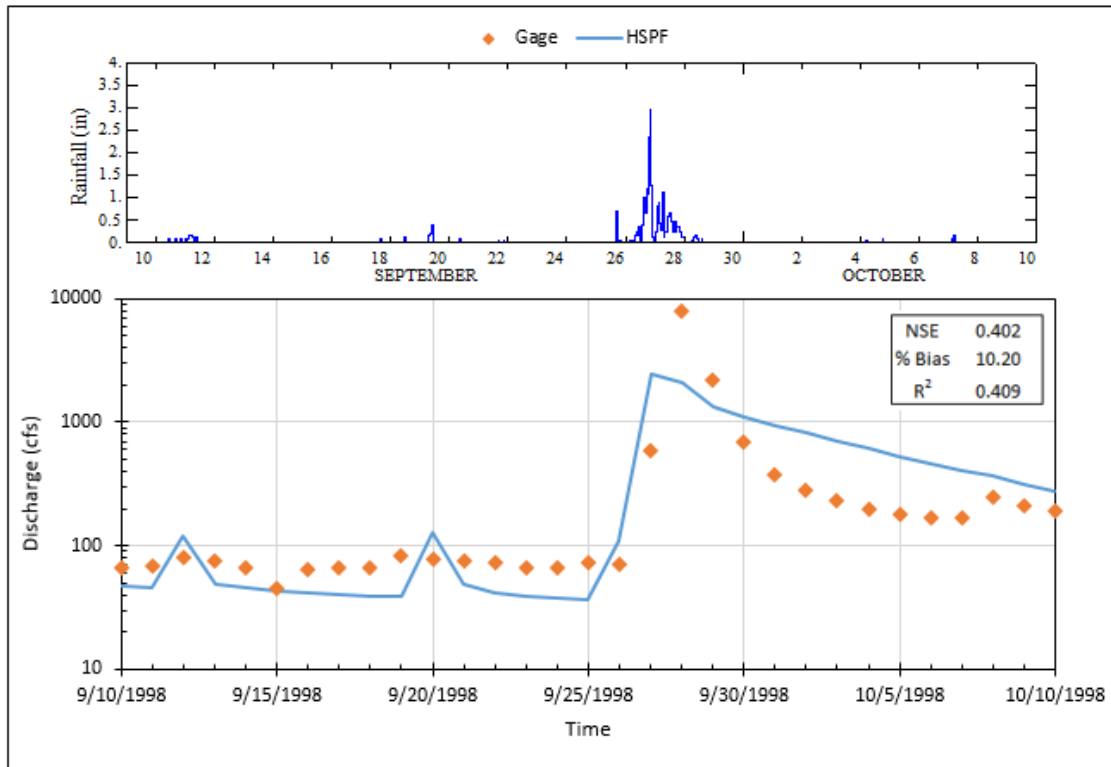


Figure 4.28 Sep 10 – Oct 10, 1998 Discharge Including Hurricane Georges effects on Elevenmile Creek

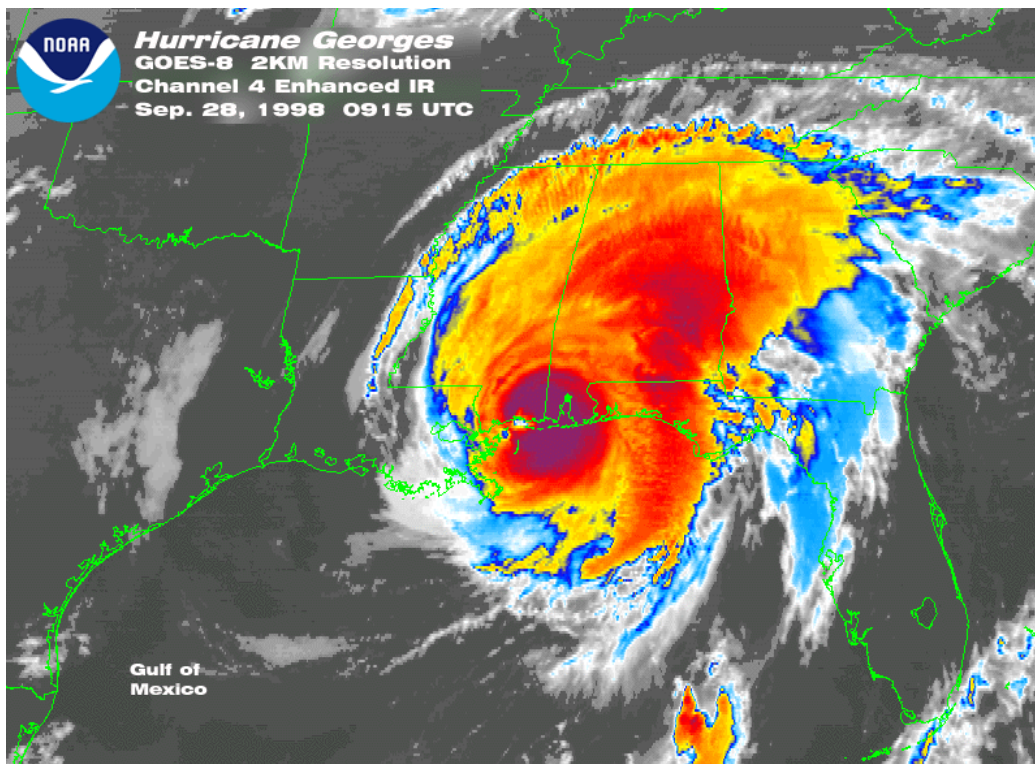


Figure 4.29 National Weather Service's IR Satellite Image of Georges Landfall on the Mississippi Coast ([www.weather.gov/images/mob/events/georges/georges\\_satellite.png](http://www.weather.gov/images/mob/events/georges/georges_satellite.png))



Hurricane Georges produced a 7-12 foot storm surge in Mobile and Baldwin Counties with a 5-10 foot storm surge across the western Florida Panhandle, which caused extensive damage across coastal communities. High water breached Dauphin Island, Pensacola Beach and Navarre Beach in several locations (to the east, within, and west of the Perdido Bay basin). Many bridges in the county were undermined by the high water and had to be closed. I-10 was closed due to high water near the Alabama/Florida state line, which is marked by the Perdido River.

The USGS records that the Perdido River crested at 26.3 feet, which was above the previous record of 23.94 feet ([waterdata.usgs.gov/fl/nwis/uv?site\\_no=02376500](http://waterdata.usgs.gov/fl/nwis/uv?site_no=02376500)). The Escambia River also recorded near record levels with a crest of 23.9 feet on September 30. Rainfall estimates were as high as 20-30 inches across Escambia County, FL (Table 4.12). This shows that while the Elevenmile Creek model underestimated the discharge during the event, the prediction is reasonable considering the magnitude of this storm event.

Table 4.12 Rainfall (in) Totals around Perdido Bay due to Hurricane Georges

<b>City</b>	<b>Storm Total Rainfall</b>
Bay Minette, AL	29.66"
Andalusia, AL	26.90"
Pensacola, FL	26.83"
Gulf Breeze, FL	26.87"
Milton, FL	25.06"
Mobile Regional Airport	15.02"

Figure 4.30 shows rainfall and discharges during a 30-day period in December 2009. This time frame shows how well the HSPF model handles the storm events for Elevenmile Creek. However, Figure 4.31 is a similar time period in the spring of 2007, and it shows how poorly HSPF models base flows for Elevenmile Creek. This mismatch is why, while the NSE was fine, the PBIAS was over 20%.

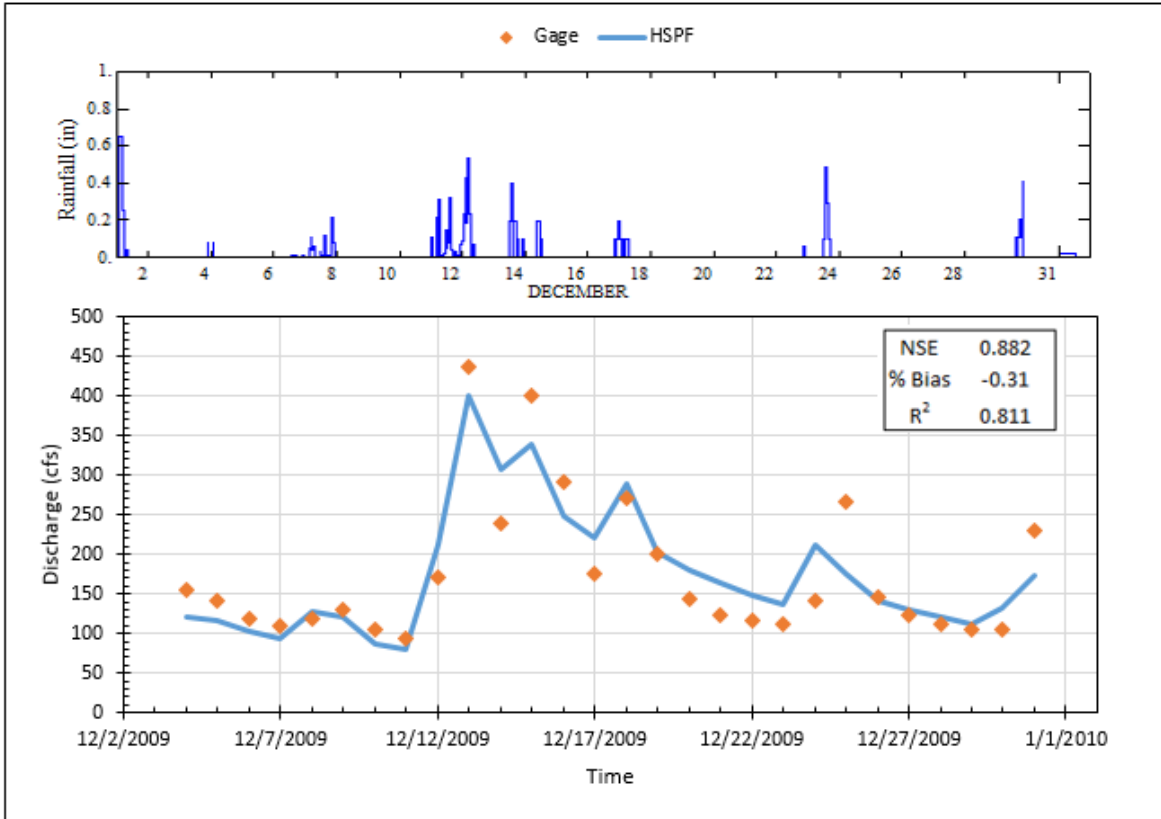


Figure 4.30 One Winter Month of Modeled and Observed Streamflow for Elevenmile Creek

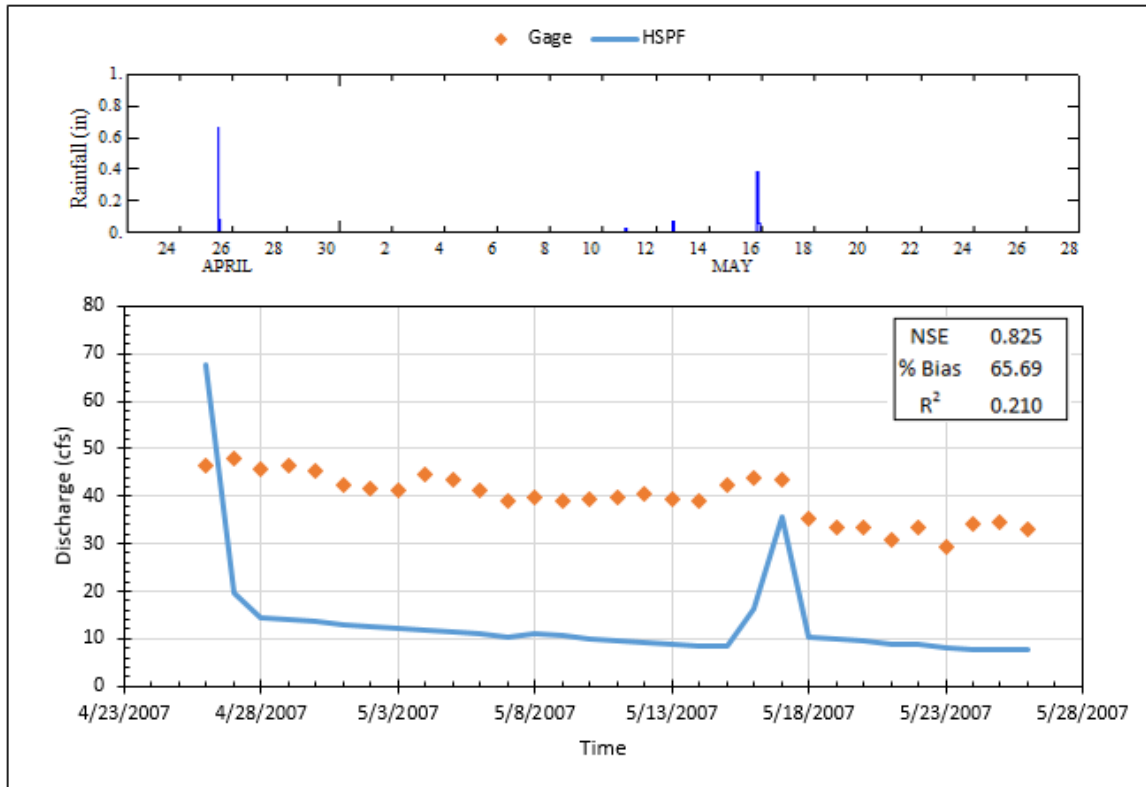


Figure 4.31 One Spring Month of Modeled and Observed Streamflow for Elevenmile Creek

For the direct comparison between the model and gage (Figure 4.32), it is not surprising that the model seems to be under predicting over nearly all base flows. From both Figure 4.30 and Figure 4.31, the fact that the model tends to only match storm events is obvious.

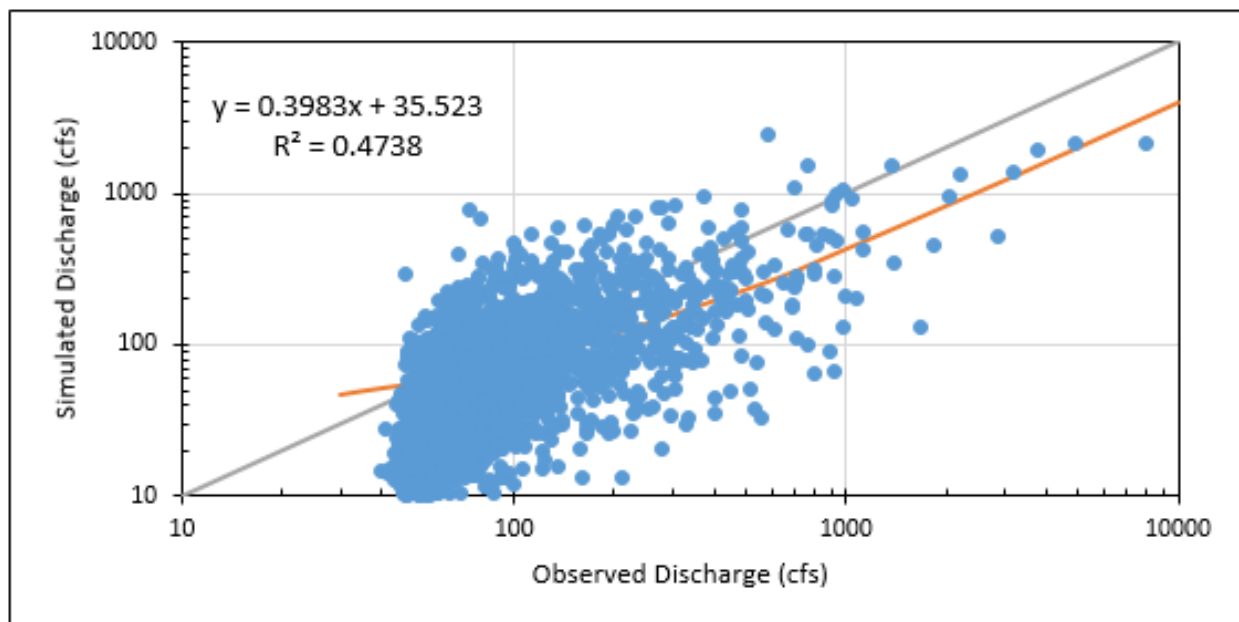


Figure 4.32 Elevenmile Creek Observed vs. Simulated Discharge

Cumulative volumes of observed and simulated discharges (Figure 4.33) show that unlike Perdido and Styx, where the two tracked until 2005, the difference between the model and gage volumes for Elevenmile slowly increases over the entire simulation period. However, the difference does grow faster during 2005—2007, just like the other models. The Elevenmile Creek model has the largest volume deficit of the four models (with gage data) so far with 25.19%.

For the Elevenmile watershed, the runoff generation was considered (Figure 4.33). Here the model showed that 55.16% of the rainfall generated discharge in the creek, while the gage data showed 73.74% becoming runoff. These are within a 19% discrepancy from each other, so parameters that affect the runoff generation may need to be adjusted to increase the model's runoff potential. The discrepancy of the runoff generation is much higher than that of the other models. However, these volumes of runoff are not unexpected when the landuse is considered (Figure 4.24), due to Elevenmile high urban areas.

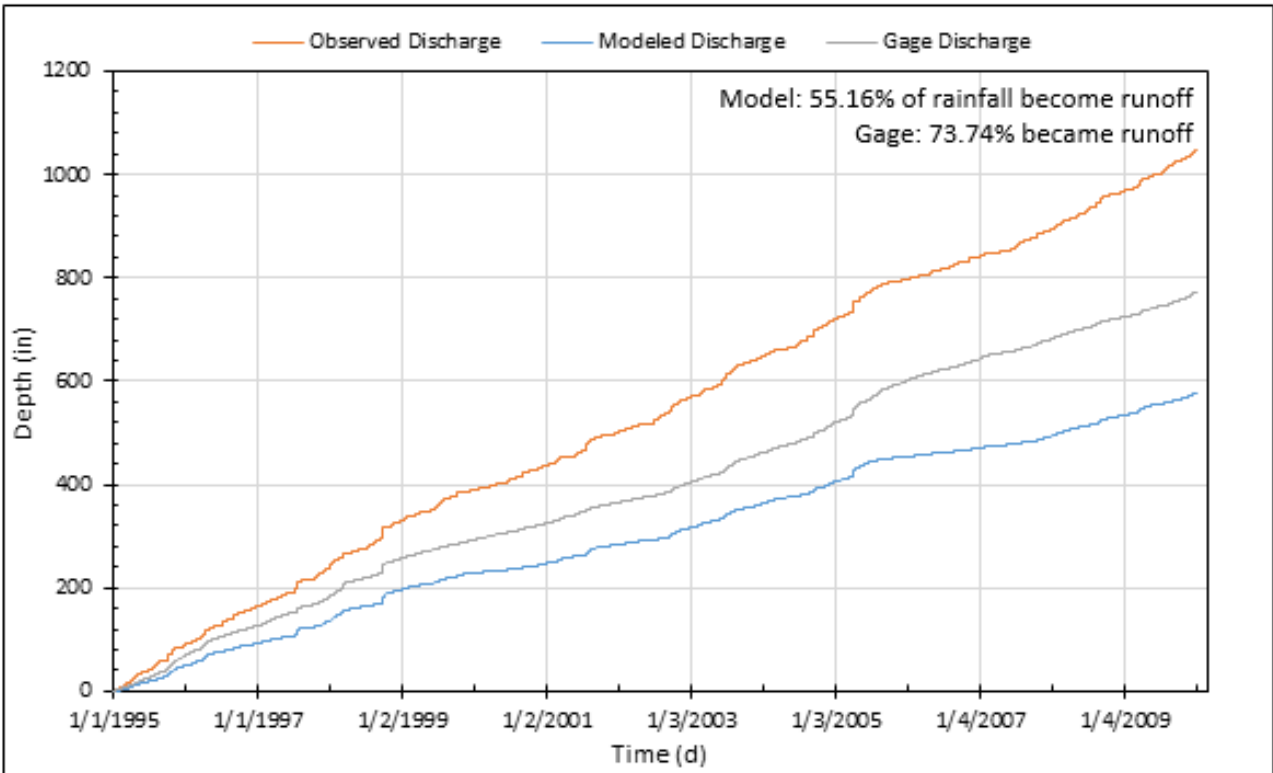
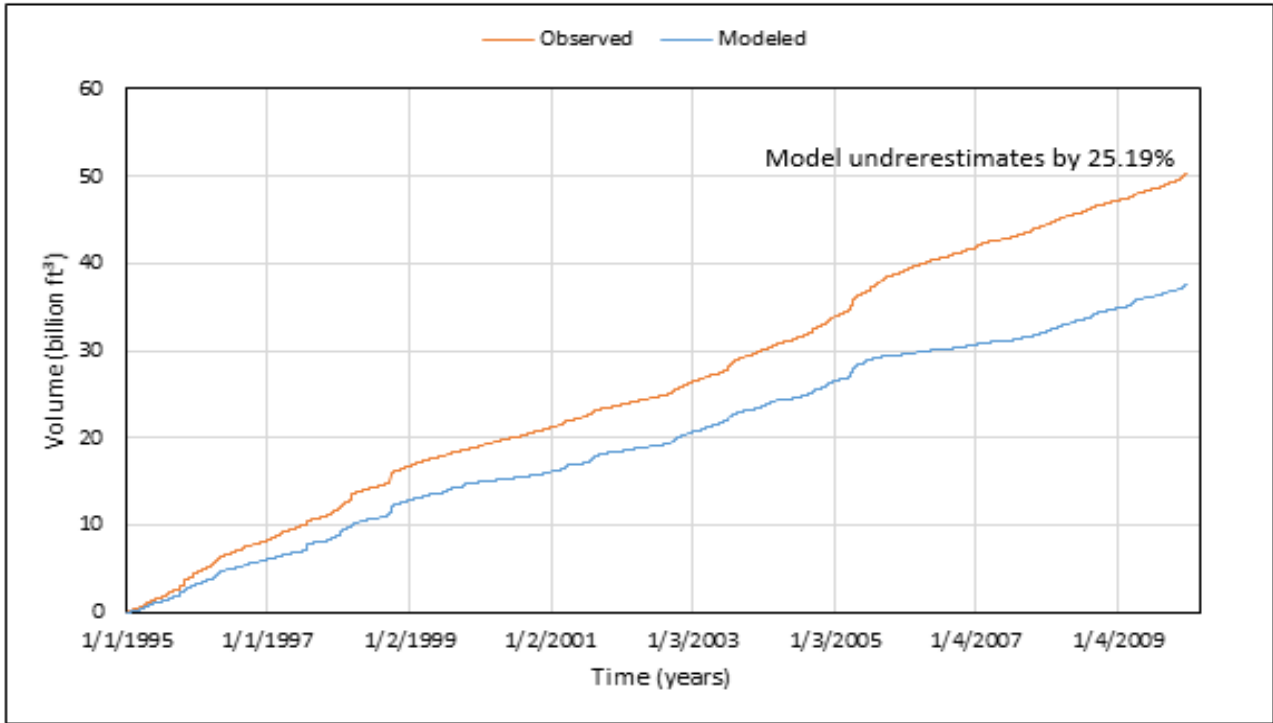


Figure 4.33 Elevenmile Creek Observed vs. Simulated Cumulative Volume and Runoff

#### 4.1.8 Marcus Bayou Model

The Marcus Bayou model has land use and catchments as shown in Figure 4.34. The main land uses are shown in Table 4.13. The watershed has a total area of 28 mi<sup>2</sup>. The basin has elevations ranging from 0.2 to 49.0 m and includes only 9 delineated catchments with drainage areas of 0.07—5.14 mi<sup>2</sup> with an average area of 1.6 mi<sup>2</sup>. The Marcus Bayou watershed differs from the Perdido or the Styx watershed in that urban land uses are three of the top five types. This makes it a closer match to the Elevenmile Creek watershed. There is one USGS gage (#02376100) near Pensacola, FL. It has data from September 1998 with no significant data missing. This is one of the smaller datasets that were used for calibration, but it still has over 20 years of data.

Table 4.13 Primary Land Uses in Marcus Bayou (NLCD 2011)

<b>% of area</b>	<b>Marcus Bayou Land use</b>
30.21%	Developed, Open Space
26.89%	Developed, Low Int
10.10%	Wetlands
9.37%	Developed, Mid Int
7.75%	Cultivated Crops

The ECUA Bayou Marcus Water Reclamation Facility sits nearly 2 miles southwest of Highway 90 and discharges into Marcus Bayou. Because it is downstream of the gage station it should have little effect on the calibration of the model. However, due to the small slope of the watershed (elevation change from gage to WWTP is 1.5 ft.), any backflow could cause a change in flow at the gage. In addition, Marcus Bayou is drastically different from the other watersheds in terms of land use. Both Perdido River and Styx River watersheds have around 5% urban land uses. Elevenmile Creek watershed has just over 45%. Marcus Bayou watershed has over 70%, which is considerably higher. Due to it being a highly developed watershed, urban heat island effects (Jauregui, 1996) could affect the model efficiency. In addition, it is the farthest from the weather station used for the models. This may mean that the precipitation pattern and even the air temperature patterns that fit the other watersheds may not match Marcus Bayou. Examples of precipitation moving around urban areas can be seen in the case studies done by Robert Bornstein (Bornstein, 1999).

For the Marcus Bayou watershed, a similar process of specifying model parameters to Elevenmile was used. However, both UZSN and USZ were increased to decrease simulated dischargers that are consistently above gage flows. Also, RETS and SURS were increased more due to the large amount of urban area. Lastly, the INTFW was increased to better match stormflow. Details about the HSPF model are given in Figure 4.35.

The efficiency values are shown in Table 4.14. The un-calibrated model was very similar to the Wolf Bay uncalibrated run (Table 3.8). This is not surprising since they are very similar watersheds in terms of elevation, streamflow, and size. It was unique however, in that it gave consistently higher results for storm events and lower values for low flow conditions. This is why the UZSN and USZ were increased. The same process was used for each model. Therefore, the GIS based parameters are unlikely to be faulty. It should then be inferred that the weather data may not have been adequate for this watershed.

Table 4.14 Marcus Bayou Efficiency Values

	Uncalibrated	Calibration	Validation
Nash-Sutcliffe:	-20.26	-4.847	-11.286
Percent Bias:	-99.52	-73.32	-120.15
R <sup>2</sup> :	0.333	0.427	0.339

This model does not match well with observed gage streamflow. For Figure 4.35 it can be seen that the model is nearly always over predicting the gage data. The gage data ranges from 3 cfs to 930 cfs with an average of 22 cfs and the HSPF simulation results range from 2 cfs to 1,940 cfs with an average of 48 cfs. Unlike all the other models, simulated discharges of Marcus Bayou does not even match well with observed discharges during the storm events. For all other gaged watersheds, the modeled stream flow tended to match the storm events in the gage data. However, USGS gage 02376100 does not track with the precipitation data from Robertsdale. Marcus Bayou is the watershed that is the farthest away from Robertsville, so the weather data may not be relevant for this watershed

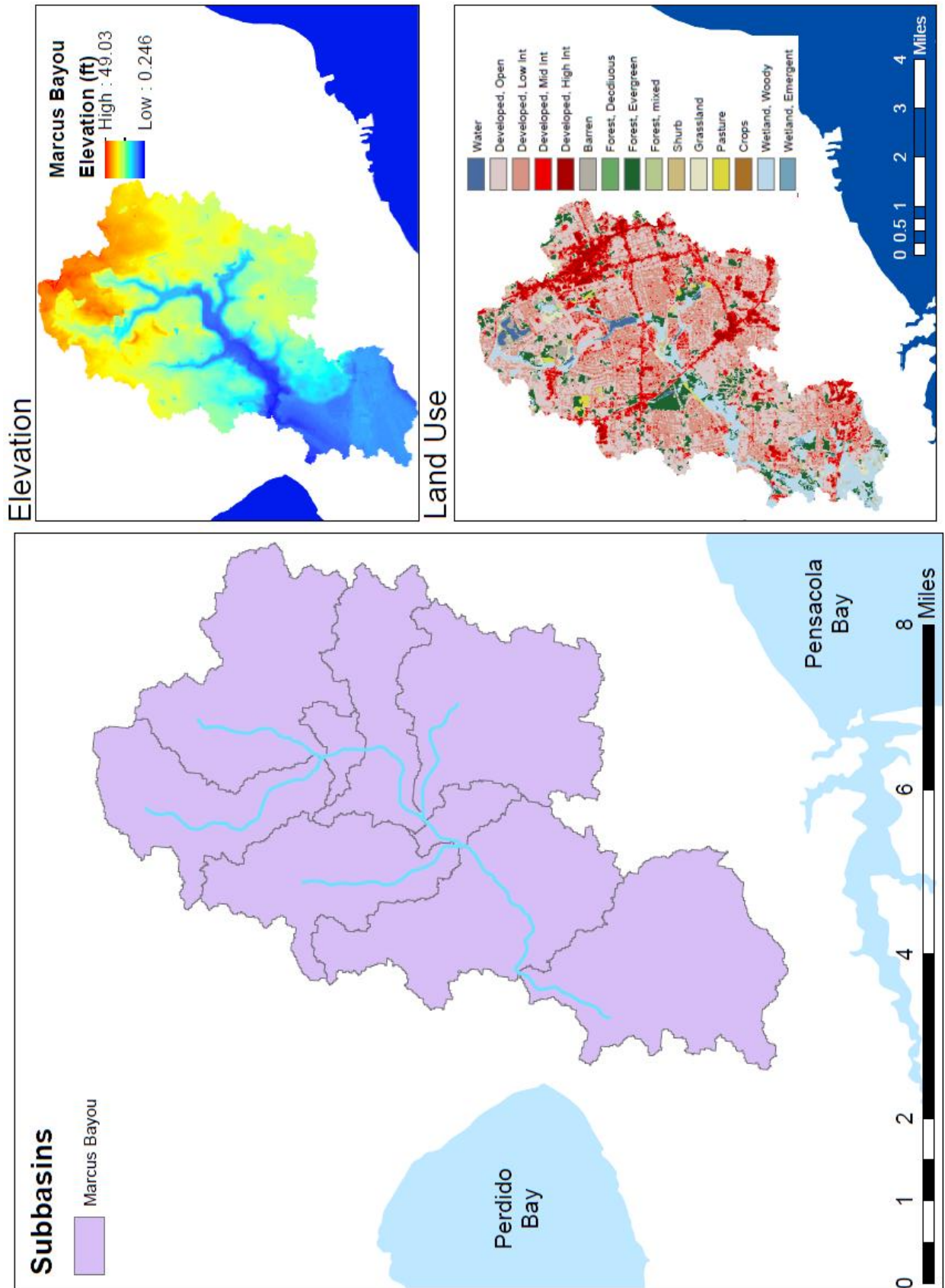


Figure 4.34 Marcus Bayou Watershed including Elevation and Land Use Maps

## Marcus Bayou HSPF Model Details

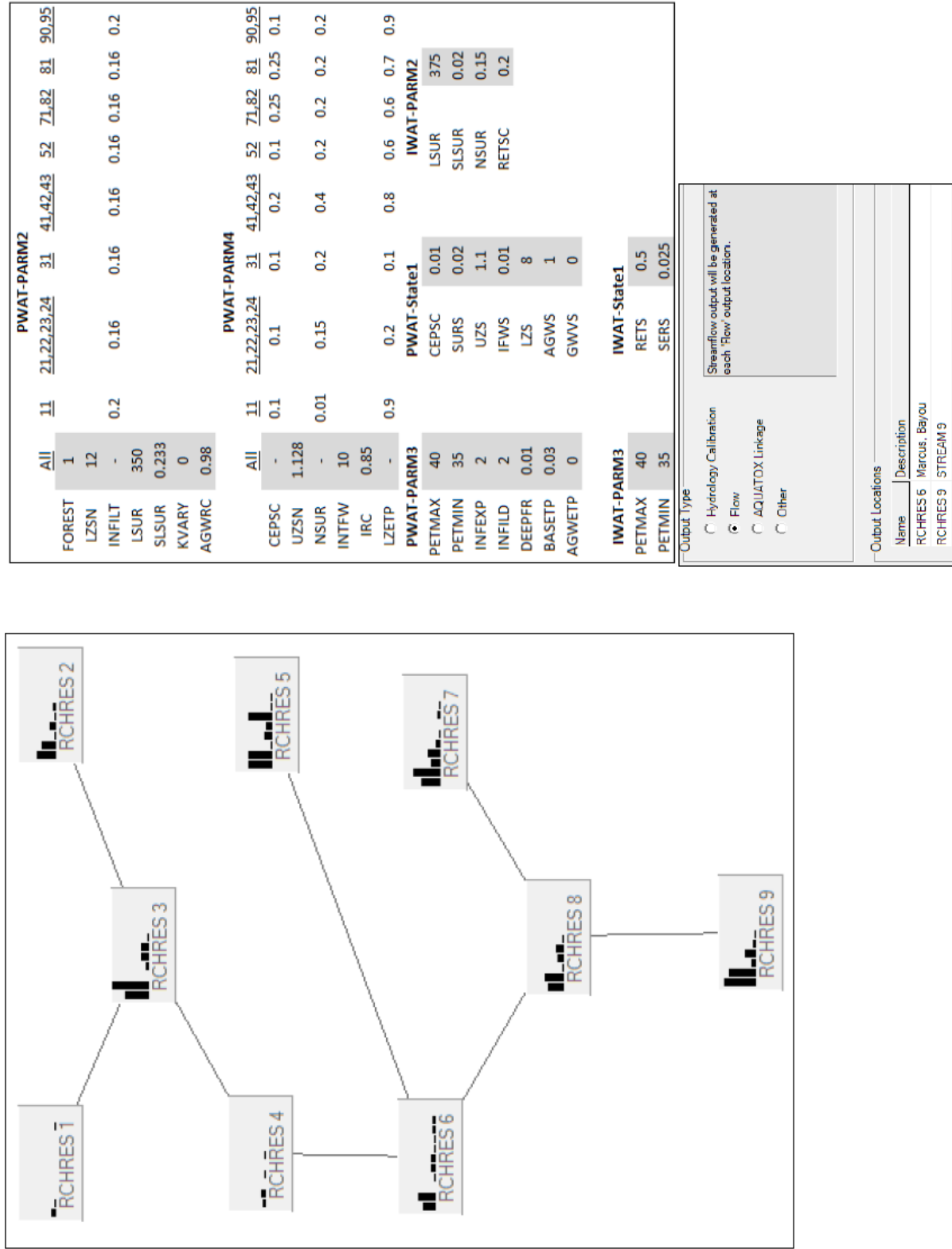


Figure 4.35 Marcus Bayou HSPF Model Details



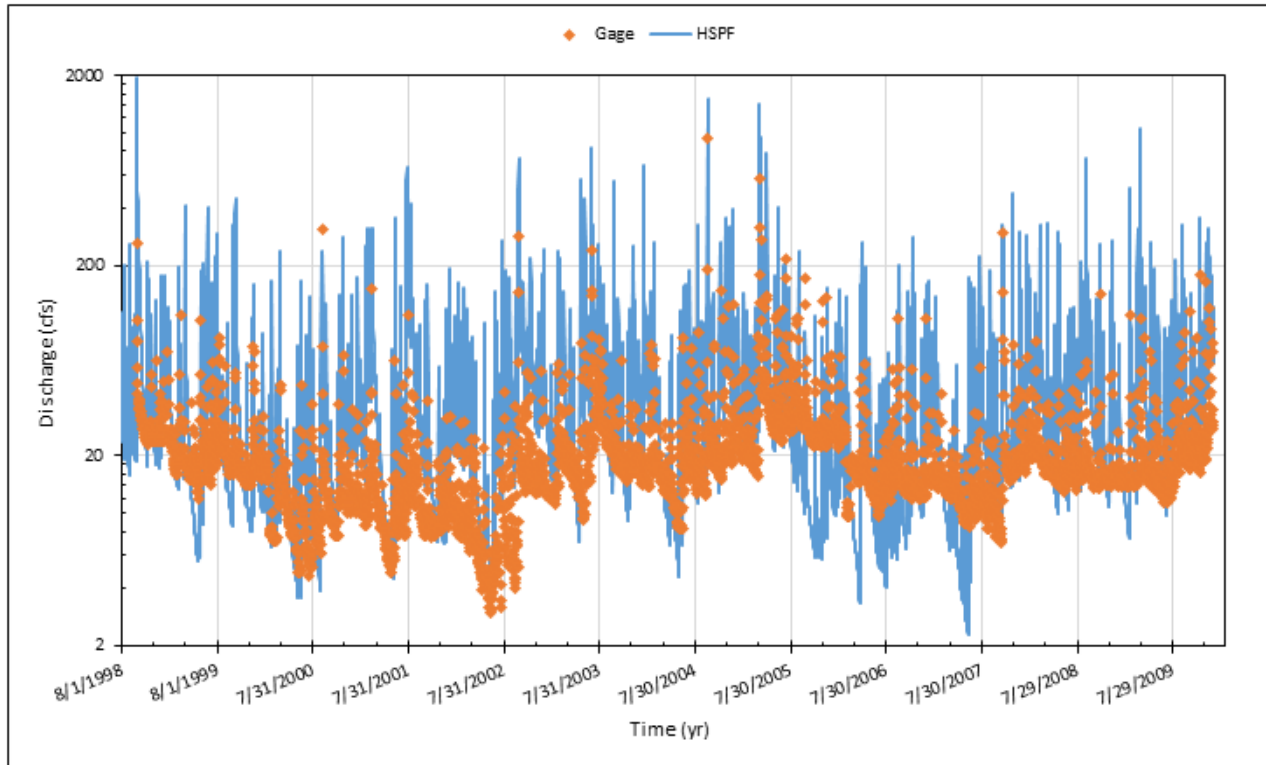


Figure 4.36 Simulated and Observed Daily Dishcarges (cfs) for Marcus Bayou

Figure 4.37 and Figure 4.38 both show the issues with this model. Figure 4.37 shows a month of winter streamflow data. The model matches the gage adequately when there is no rainfall. But as soon as a storm event occurs, the model gives a value 300% more than the gage (November 22). Then in Figure 4.38, which is an autumn streamflow, two of the three rainfall events (November 10 and 15) that the precipitation data shows have zero affect on the gage's streamflow. For the one rainfall that does affect the gage (November 22), HSPF gives a discharge of twice the gage's flow. This gives more evidence that the rainfall data may not be sufficient for this watershed.

When the direct comparison was done, it showed that the model almost exclusively overestimates the streamflow. For Figure 4.39 it can be seen that the best fix curve is fully above the gray 1:1 line. This is not acceptable for a model, since it shows that the average model streamflow is always higher than the gage's streamflow.

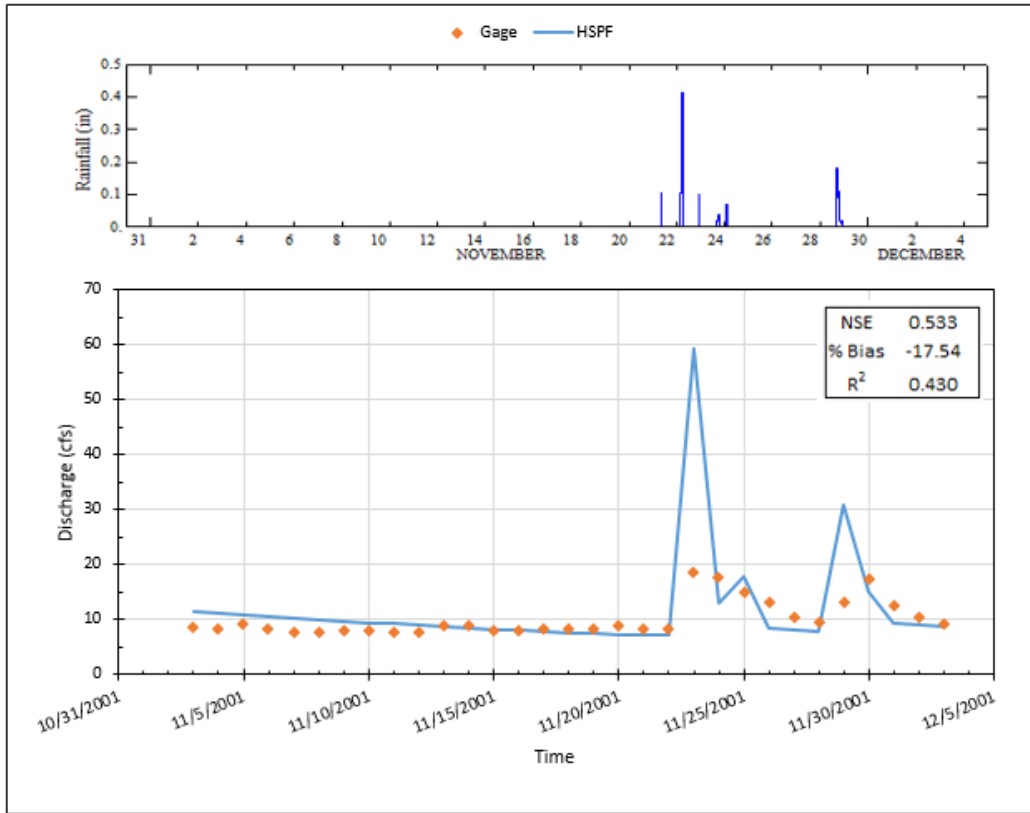


Figure 4.37 One Month of Winter Modeled and Observed Streamflow for Marcus Bayou

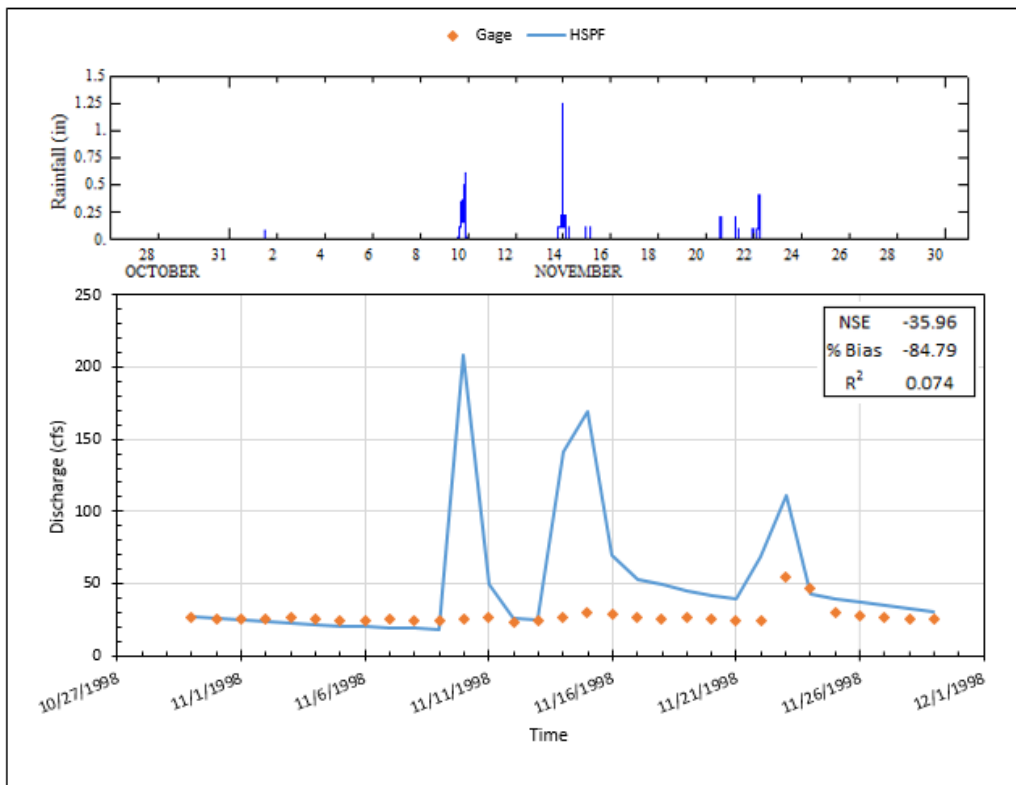


Figure 4.38 One Month Autumn Modeled and Observed Streamflow for Marcus Bayou

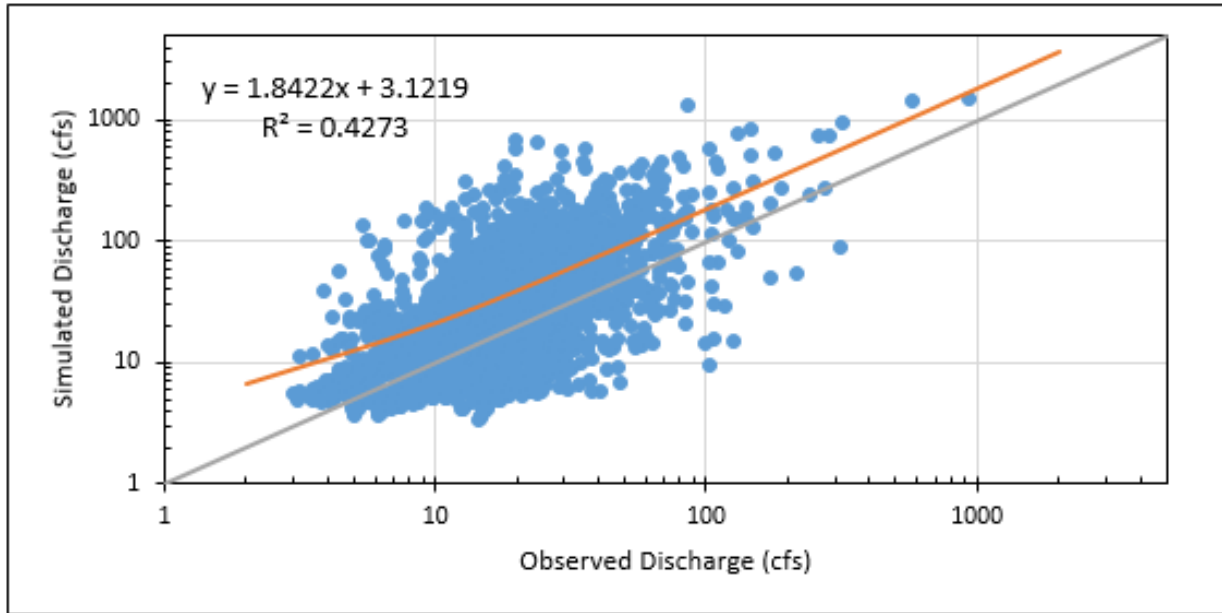


Figure 4.39 Marcus Bayou Observed vs. Simulated Discharge

This model was unsatisfactory. For Figure 4.40 it can be seen that the model is nearly always over predicting the gage data, since the overall model has over predicted by more than 100%. This is expected, due to the unsatisfactory efficiency values.

For Marcus, the runoff generation was considered (Figure 4.40). Here the model showed that 61.54% of the rainfall generated discharge in the creek, while the gage data showed 30.27% becoming runoff. These are within 30% point from each other, so parameters that affect the runoff generation may need to be adjust to increase the model's runoff potential. These values are both much higher and much lower than the other models. However the modeled volumes are not unexpected when the landuse is considered (Figure 4.34), due to Elevenmile high urban areas.

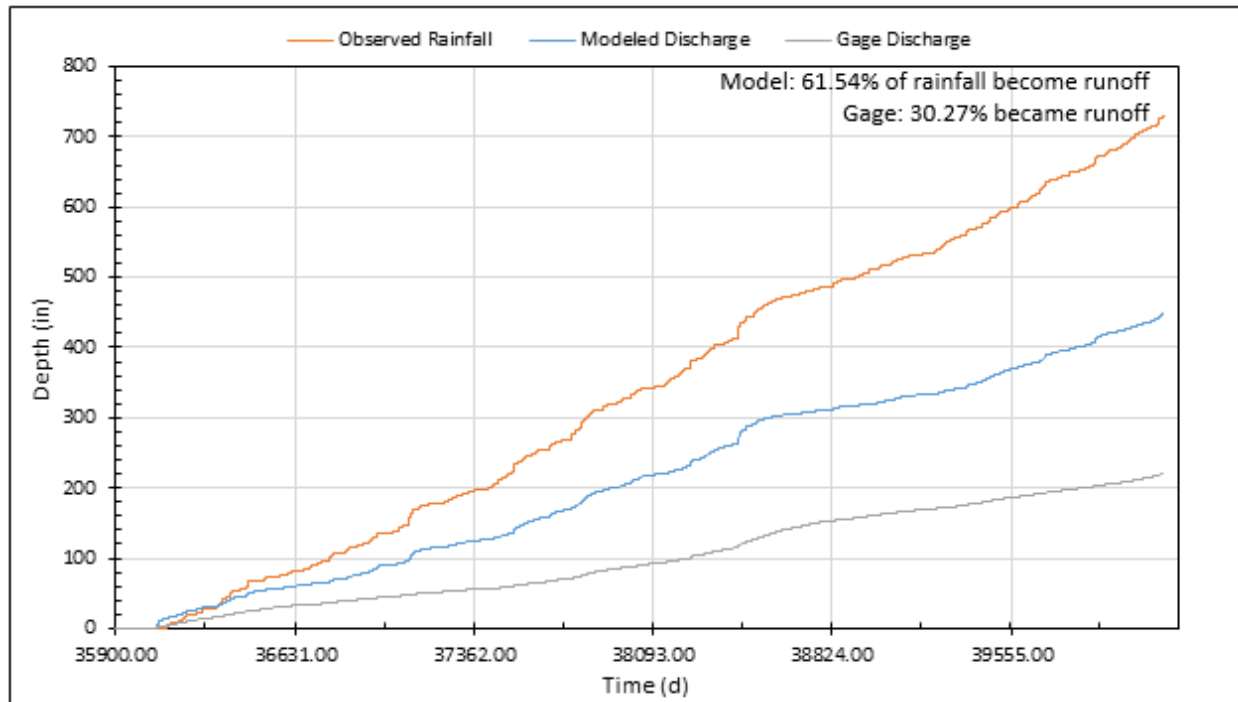
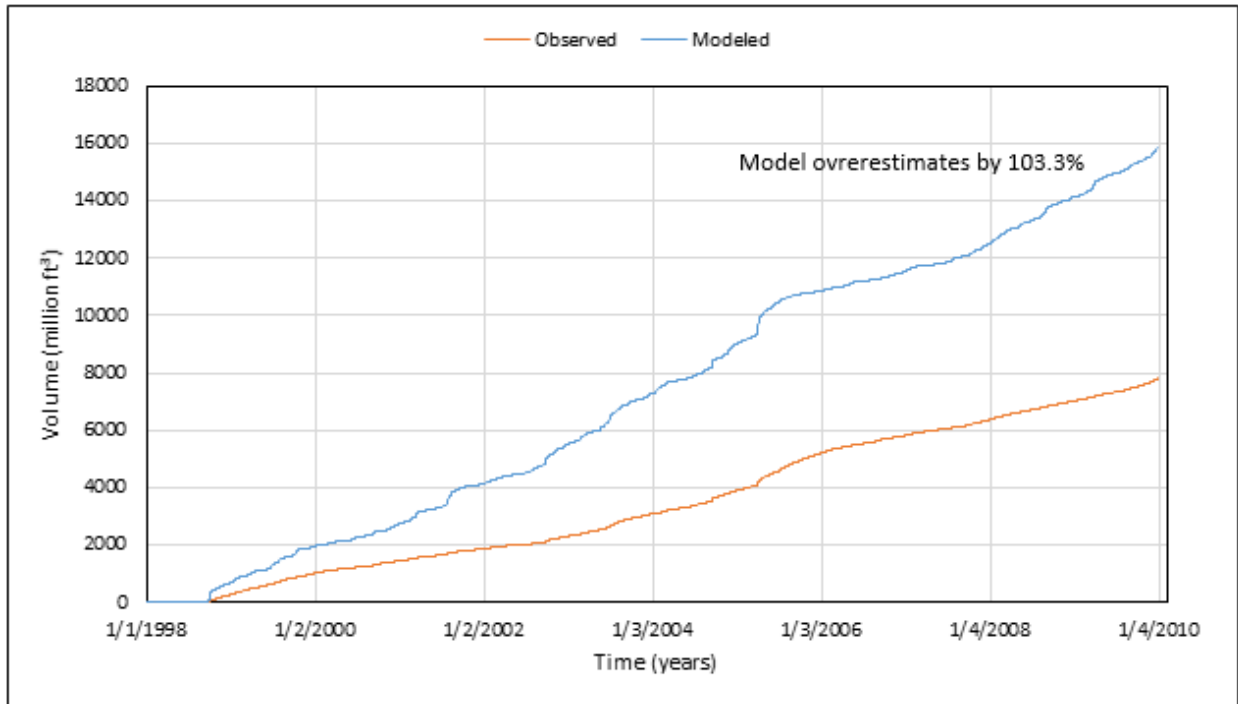


Figure 4.40 Marcus Bayou Observed vs. Simulated Cumulative and Cumulative Runoff

### 4.1.9 Remodeling Marcus Bayou

Unlike all the other models, simulated discharges of Marcus Bayou does not even match well with observed discharges during the storm events, and the USGS gage 02376100 does not track with the precipitation data from Robertsdale. This necessitated that the model be run with different meteorological data.

Marcus Bayou is the watershed that is the farthest away from Robertsville, so the weather data may not be relevant for this watershed. There are only a few EPA BASINS weather stations (Figures 4.41 and 4.42) within 30 miles of the Perdido Bay basin. Figure 4.41 shows yearly precipitation data (1995–2009) for the three stations on the west side of the bay. Figure 4.42 shows the same on the east side. There is a drastic difference for any given year between these stations (Figure 4.43). From the National Weather Service’s (NWS) site, ([www.weather.gov/climate/local\\_data.php?wfo=bmx](http://www.weather.gov/climate/local_data.php?wfo=bmx)) maps of the variation between all NWS stations can be found, and this large variance along the coast can be seen.

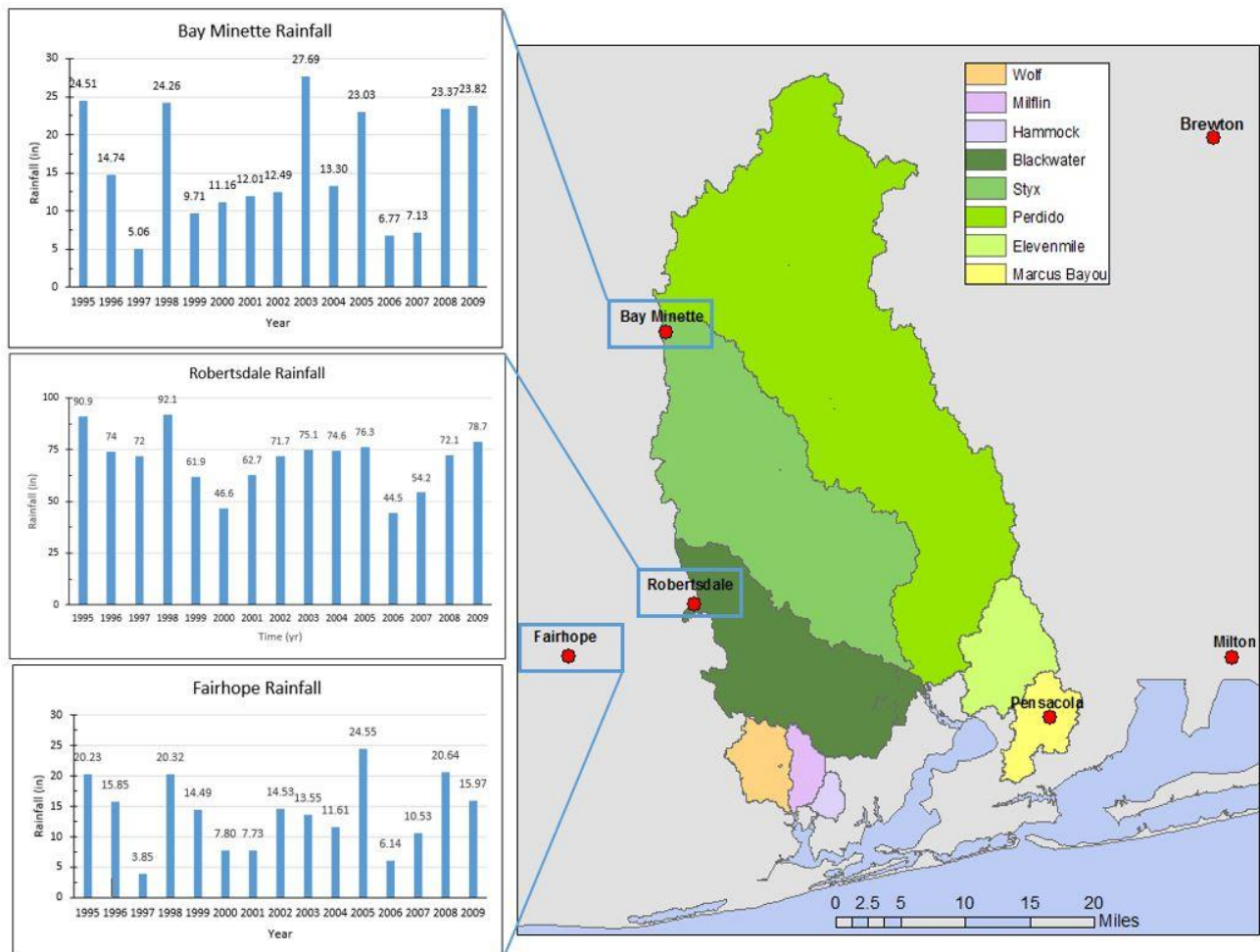


Figure 4.41 Meteorological Stations West of Perdido Bay

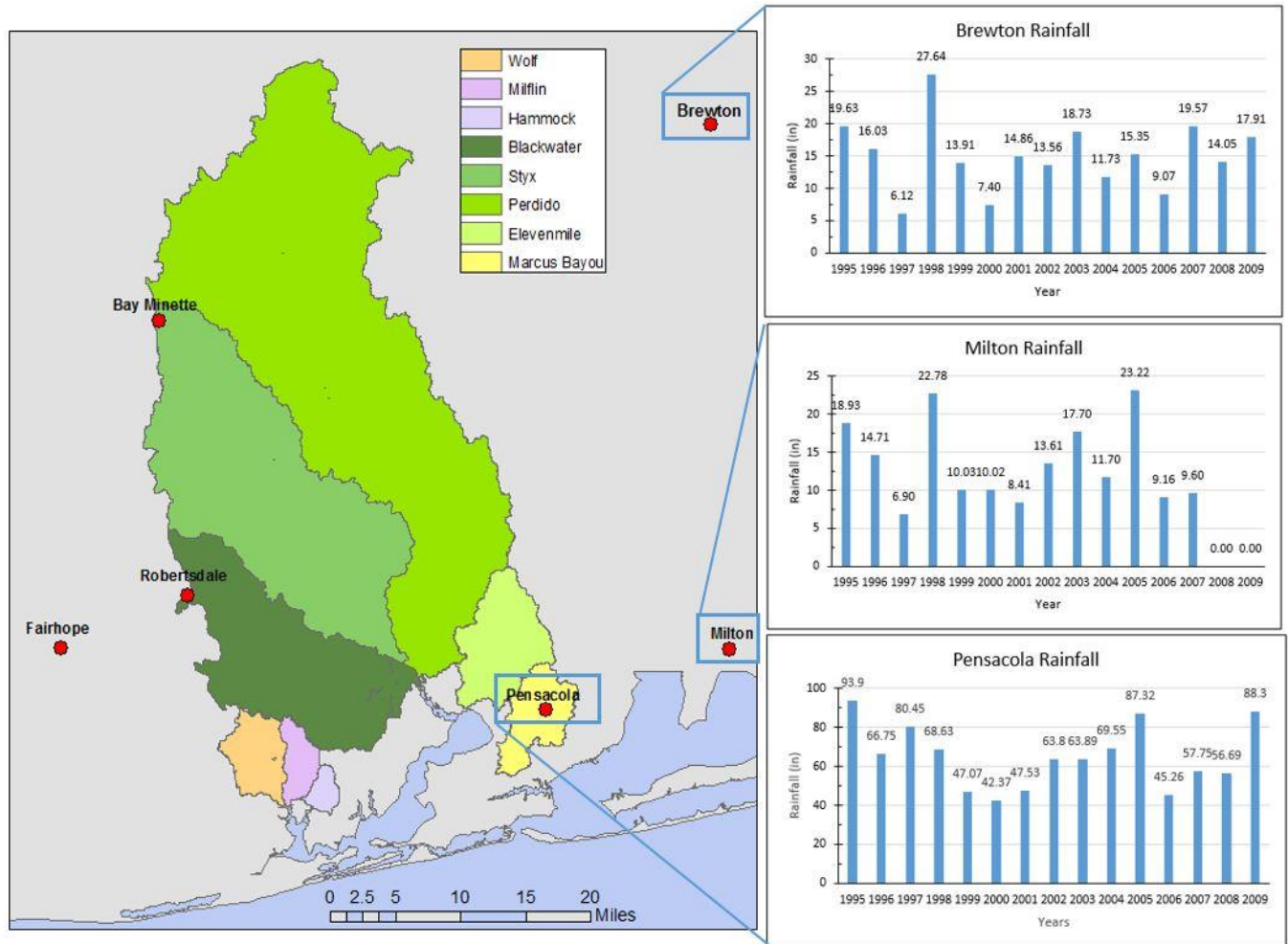


Figure 4.42 Meteorological Stations East of Perdido Bay

From these stations it can be seen that the precipitation varies drastically over the small area between each gage (Figure 4.42). From Table 4.15, it can be seen that the closest two stations (Robertsdale and Fairhope) have over a 40 in. difference in average yearly precipitation between 1995 and 2009.

As a side note, when the NWS weather maps are consulted the large/huge variations in annual average rainfall are concerning. The NWS maps show that this area of coastal AL should have an average of around 60 inches of precipitation each year. Therefore, even if the BASINS weather stations are based on NOAA weather data, they may be unreliable. While there is no ‘missing’ data within these datasets, the fact that Fairhope, Bay Minette, Milton, and Brewton have yearly averages (Table 4.15) in the teens shows that the dataset may not show hourly precipitation accurately.

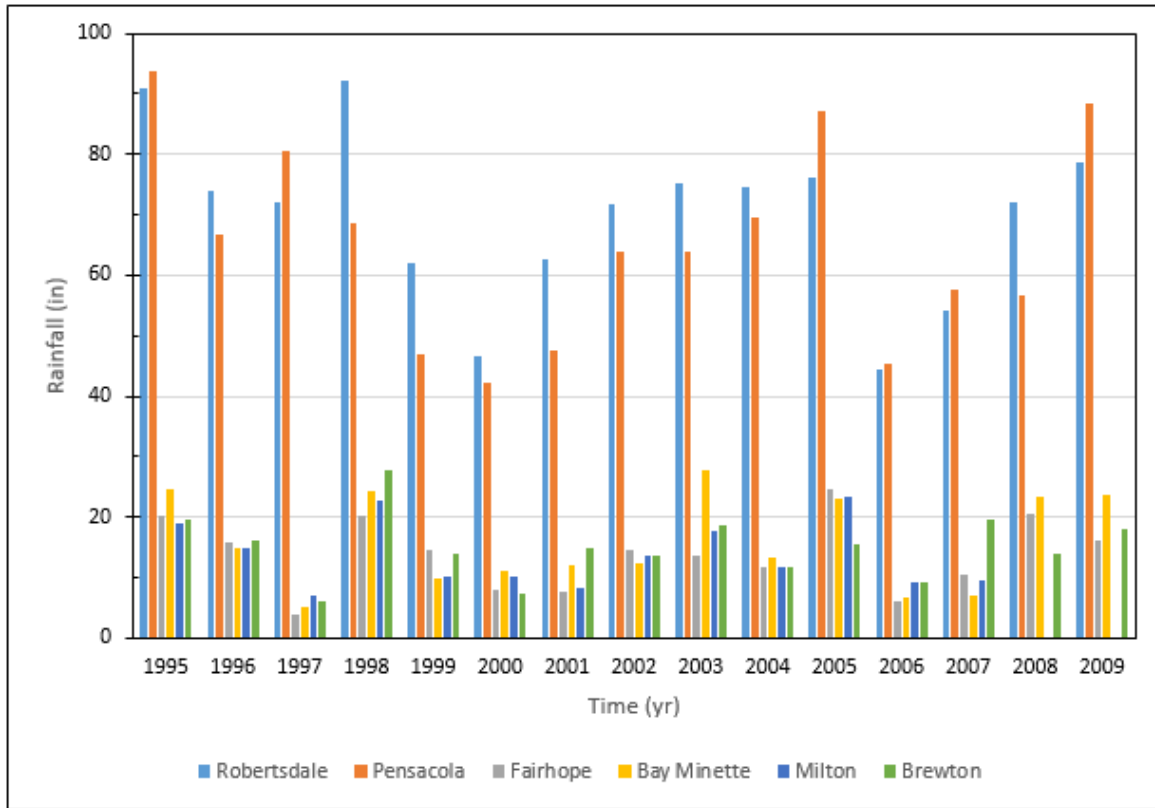


Figure 4.43 All Meteorological Stations within 30 miles of Perdido Bay

Table 4.15 Statistics of annual rainfalls (1995—2009) in six weather stations

	Robertsdale	Pensacola	Fairhope	Bay Minette	Milton	Brewton
Max	92.10	93.90	24.55	27.69	23.22	27.64
Average	69.83	65.29	13.85	15.94	13.60	15.04
Min	44.50	42.37	3.85	5.06	6.90	6.12

With all this variation in precipitation, it is not surprising that the Marcus Bayou USGS gage did not match with the Robertsdale precipitation data. The Marcus Bayou model discussed in section 4.1.8 was recreated with Pensacola weather data. The cumulative volume (Table 4.16) and percent bias greatly improved, while the NSE improved some. None are satisfactory, but this shows that some of the error can be accounted for in the weather data. However, it also shows that not all can be attributed to the weather data.

Table 4.16 Comparison of Marcus Bayou Efficiency Values

	Calibration	Validation	Calibration.2	Validation.2
Nash-Sutcliffe:	-4.847	-11.286	-2.910	-13.034
Percent Bias:	-73.32	-120.15	-44.81	-110.28
R <sup>2</sup> :	0.427	0.339	0.421	0.674
Cumulative Vol	103.3	-	72.3	-

From Figure 4.44 the model stays more accurate with the observed for longer in the Pensacola data (till 2001) than in the Robertsdale data (till 1999). This shows that the Pensacola station is the better station to use for the model.

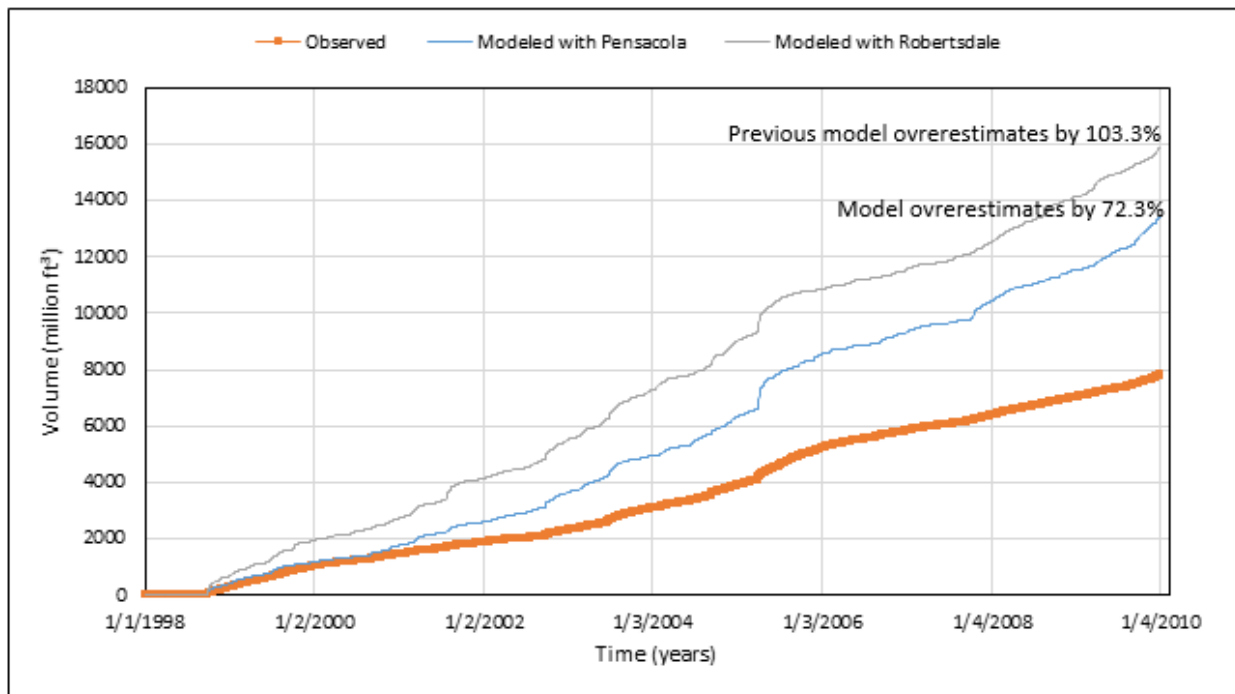


Figure 4.44 Observed and Simulated Cumulative Volumes using Two Weather Stations for Marcus Bayou

It is believed that this additional error can be accounted for in this way. A few of the neighborhoods (Figure 4.45) in the southeast of the Marcus Bayou watershed (dark green) divert and channel storm runoff out of the watershed (to the pink and blue), bypassing the gage’s location (Atkins, 2015). This flood mitigation report created by Atkins for the City of Pensacola deals with how to manage the large volumes of runoff generated in short time periods due to urbanization



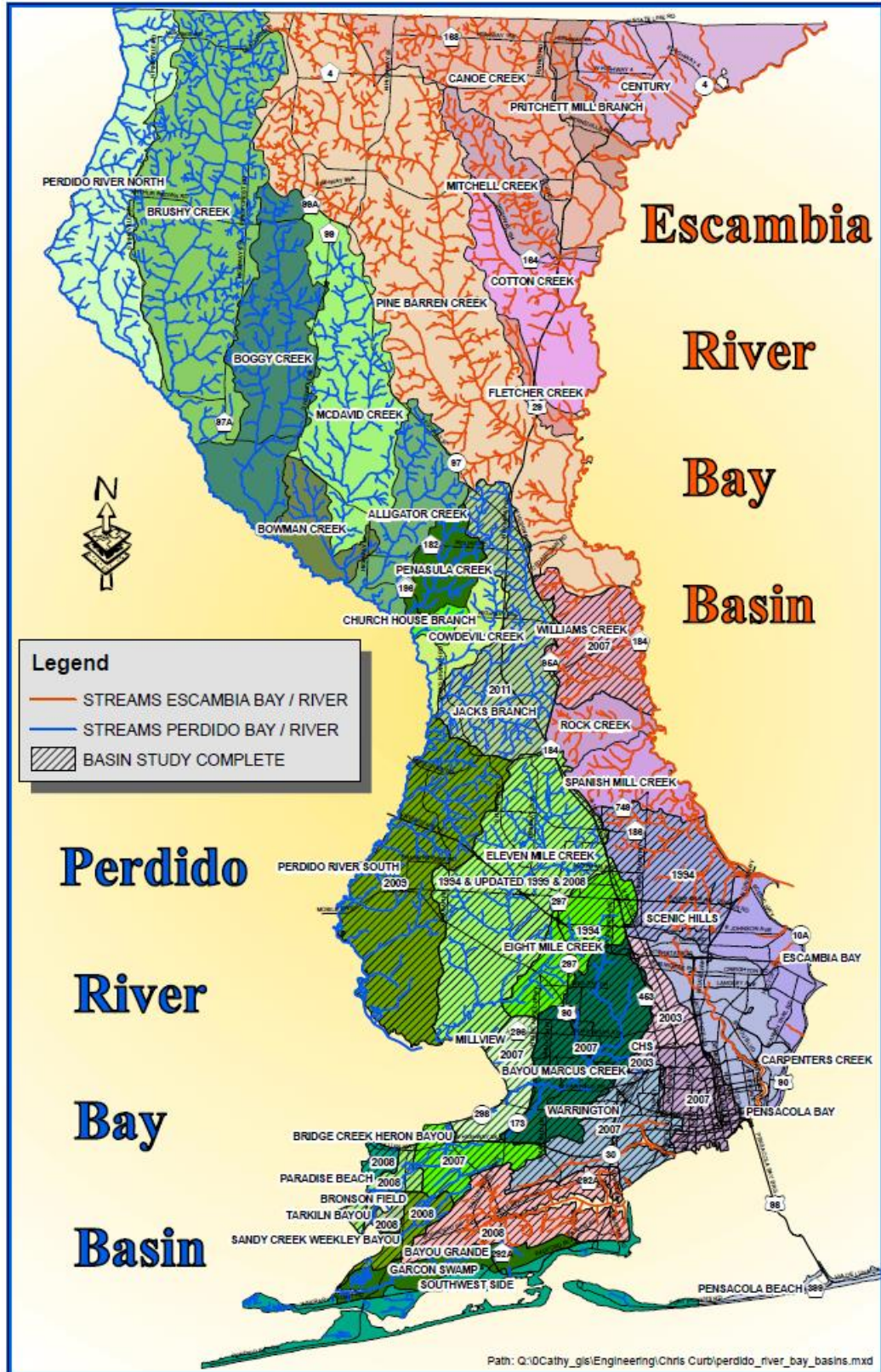


Figure 4.45 Emerald Coast Utilities Authority's Basin Map  
[myscambia.com/docs/default-source/sharepoint-public-works/basin-map.pdf?sfvrsn=12f318cd\\_5](http://myscambia.com/docs/default-source/sharepoint-public-works/basin-map.pdf?sfvrsn=12f318cd_5)

putting substantial pressure on both the natural and manmade hydrologic systems' ability to accommodate increasing amounts of runoff. This report deals with a watershed (Long Hollow) on the other side of Pensacola from Marcus Bayou. However it does demonstrate

Pensacola's use of hydraulic structures in the management of stormwater. To better model Marcus Bayou, a detailed map of Pensacola's storm drains needs to be obtained. At the very least, a better understanding of how Pensacola deals with the flooding of the Bellview and Myrtle Grove neighborhoods (the Marcus Bayou watershed) needs to be researched.

#### 4.1.10 Remodeling Elevenmile Creek

Due to the Marcus Bayou model's improvement when changing to the Pensacola weather station, it was believed that Elevenmile Creek may also benefit from the same adjustment. The same process was done to Elevenmile as was done to Marcus Bayou. The same model parameters were kept, just with new meteorological data.

However, the results were not an improvement to the model, but an impairment (Table 4.17). All the efficiency values of the Elevenmile Creek model using Pensacola's weather data were worse compared to those using Robertsdale's weather data. In addition the cumulative volume the model produced also become worse when compared to the gage and the model based on Robertsdale data (Figure 4.45). This lends further proof that the Marcus Bayou model's issues are not fully related to the meteorological data or the calibration process.

Table 4.17 Comparison of Elevenmile Creek Efficiency Values

	Calibration	Validation	Calibration.2	Validation.2
Nash-Sutcliffe:	0.444	0.280	0.338	0.193
Percent Bias:	21.43	19.49	32.50	23.31
R <sup>2</sup> :	0.474	0.314	0.420	0.295

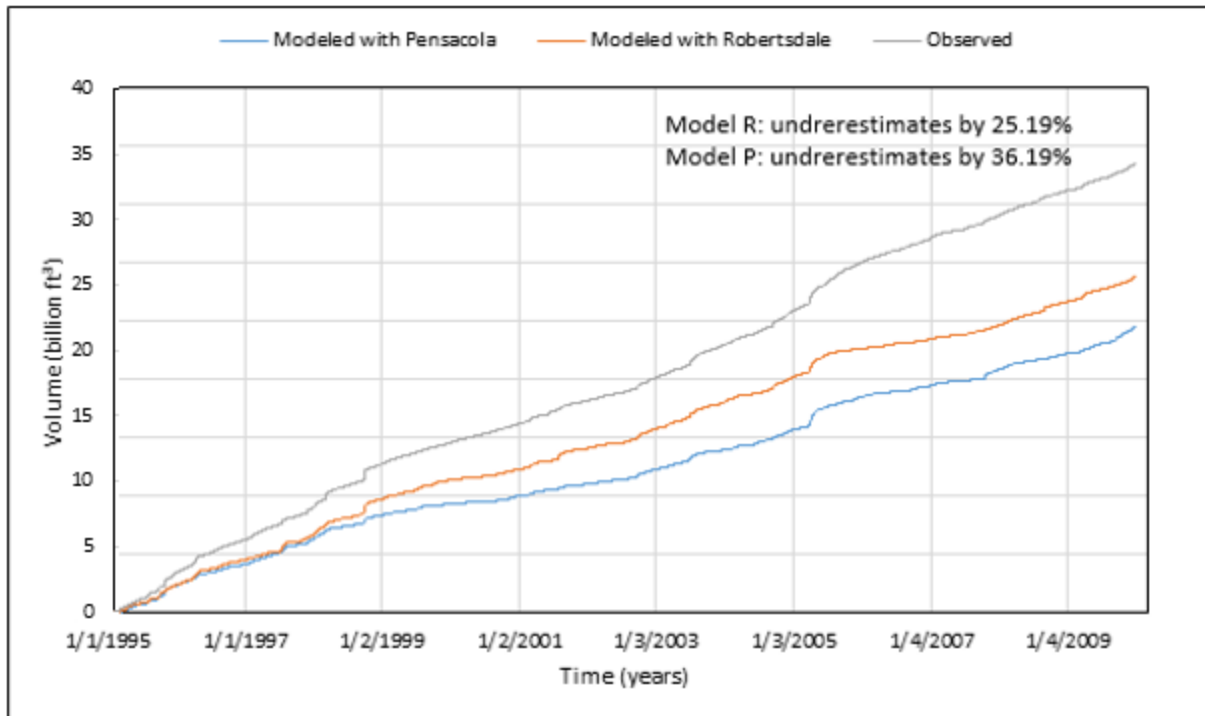


Figure 4.46 Observed and Simulated Cumulative Volumes using Two Weather Stations for Elevenmile Creek

## 4.2 Comparison of Wolf Bay

A graphical comparison of the models can be seen in Figure 4.2. A numerical comparison can be seen in Table 4.18. Wolf, Perdido, and Styx watersheds are fairly similar in terms of land use. Elevenmile and Marcus watersheds share few land use similarities to the Wolf watershed. When elevation change is considered, the Perdido River and Styx River are similar, but are considerably steeper than Elevenmile Creek, Marcus Bayou, or Wolf Creek. However, all are in low laying coastal areas and are similarly steep if average slope is compared. If the average discharge is looked at, the Perdido River is double the flow of the Styx River, which is more than four times larger than the other three models.

If Wolf Creek is ignored, the other models can be compared. For NSE, Styx and Elevenmile were the best two models. For cumulative volume error, Styx and Perdido were the top two. For PBIAS, Perdido and Styx were the best two models. For  $R^2$ , Elevenmile and Perdido were the best two models. For the overall efficiency Styx was the best.

If the Wolf Creek model is compared, Perdido and Styx tie for the overall best model. However, the Wolf Creek model already preforms better than Elevenmile Creek and Marcus Bayou and may have performed better than other models if more accurate WWTP discharge data had been available.

Table 4.18 Comparisons of Calibrated Models

	Wolf	Styx	Perdido	Elevenmile	Marcus
Barren Land (%):	0.53	0.11	0.21	0.91	1.17
Cultivated Crops (%):	23.83	4.94	9.74	1.80	7.75
Developed, High Int (%):	0.52	0.10	0.03	1.62	3.83
Developed, Low Int (%):	5.69	0.71	0.87	11.81	26.89
Developed, Mid Int (%):	2.02	0.21	0.13	4.59	9.37
Developed, Open Space (%):	12.20	3.36	4.72	27.02	30.21
Forest (%):	19.85	31.50	33.78	21.68	6.89
Grassland (%):	19.25	11.25	11.07	11.38	1.86
Open Water (%):	0.55	0.31	0.36	0.70	0.86
Shrub (%):	3.38	26.31	18.52	7.02	1.05
Wetlands (%):	12.17	21.19	20.58	11.48	10.10
Ave. Stream Slope (ft/Kft):	0.332	0.305	0.222	0.391	0.221
Elevation Change (ft):	33.1	85.2	101.1	58.3	49.0
Watershed Area (mi <sup>2</sup> ):	23.85	217.7	494.7	49.23	28.4
Catchment area range (mi <sup>2</sup> ):	0.08-4.96	1.73-28.15	2.10-40.04	0.12-3.75	0.07-5.14
HUC catchments:	14	115	480	39	19
HSPF catchments:	12	30	41	20	10
Discharge range,model (cfs):	3.5-314	32-97200	67-30000	5-2840	2-1480
Discharge range,gage (cfs):	4.5-300	70-17200	171-40800	30-7999	3-931
Ave Discharge,model (cfs):	10	369	878	105	42
Ave Discharge,gage (cfs):	10	409	820	79	22
Cumlative Volume (acreft):	16,512	4,304,243	9,550,350	86,409	308,296
Culm Vol error from gage(%):	8.23	-3.05	6.68	-25.19	72.27
Nash-Sutcliffe	0.177	0.472	0.363	0.444	-2.190
Percent Bias	8.23	7.29	-6.25	21.43	-44.81
R <sup>2</sup>	0.231	0.419	0.444	0.474	0.421

Milflin Creek, Hammock Creek, and Blackwater River watersheds did not have gage sites to calibrate with so similar model parameters were used to create them. The Wolf Creek model was used to create Milflin and Hammock models. Figure 4.47 shows what is expected, that Wolf Creek being the largest model has the most discharge, followed by Milflin, the next largest and

Hammock the smallest. The Styx model was used to create Blackwater model. Figure 4.48 again shows what is expected.

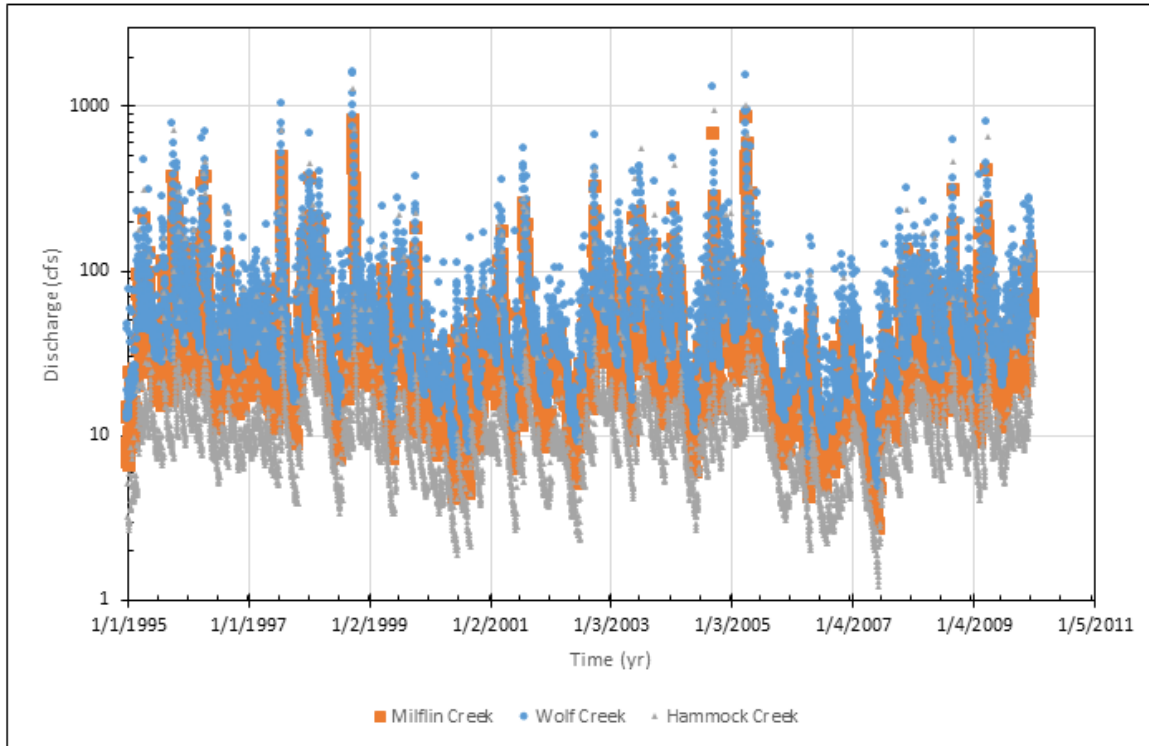


Figure 4.47 Comparison of Discharge (cfs) between Wolf, Milflin, and Hammock Creek Models

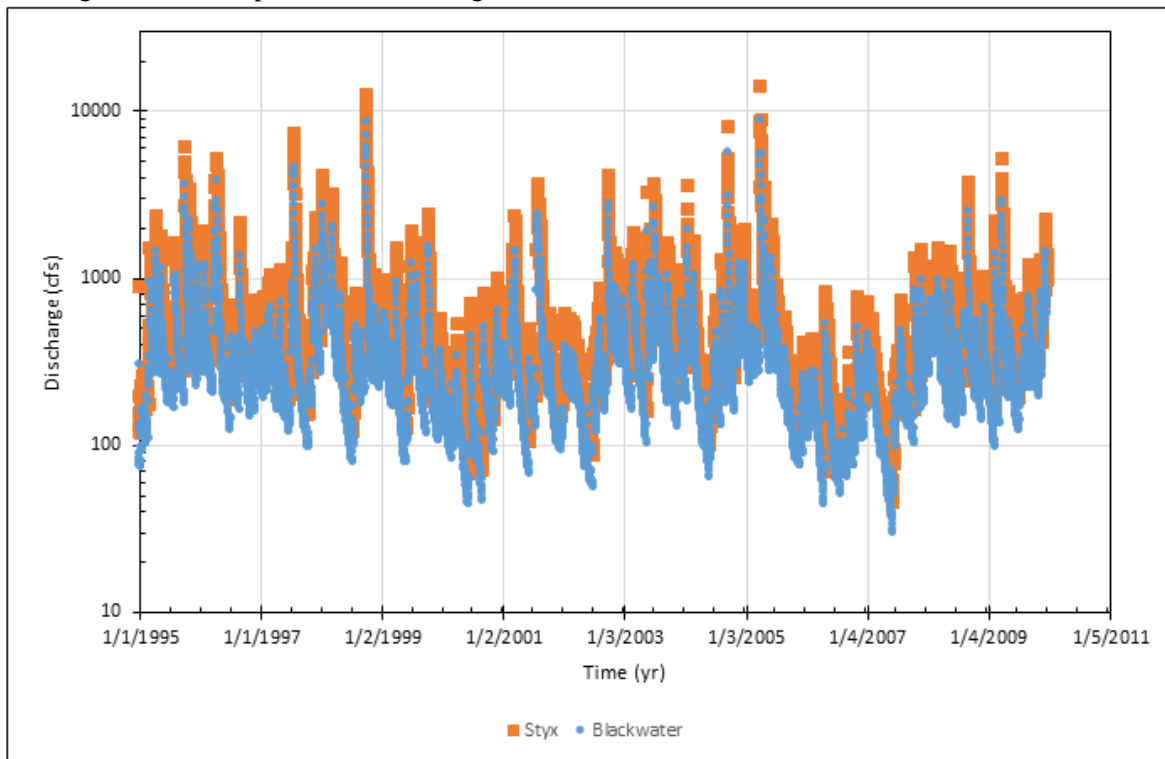


Figure 4.48 Comparison of Discharge (cfs) between Styx and Blackwater River Models

### 4.2.1 Effects of the warm-up period

Because all additional models had better results, we decided to test different warm-up periods to see if that had any effects on the efficiency of the models. The HSPF manual, and other papers recommend warm-up periods that vary for different watershed-scale processes. Warm-up periods in hydrology and water quality studies may range from months to decades, with two to four years being common for watershed-scale hydrologic modeling, and five to ten years being common for sediment, nutrient, and constituent modeling (Lumb, 1944; Daggupti, 2014).

For this analysis, two to six years were chosen to test against the HSPF models. The models were run from 1995-2009. This gives fourteen years of simulation with the warm-up period being adjusted five times. The results are shown in Table 4.19 and are what would be expected for Styx and Elevenmile. Wolf showed little change due to the smaller time period of observed stream flow.

However, the Perdido model's results were unexpected. As the warm-up period increased, the Perdido model had a sharp decrease in efficiency, while the other models only showed minimal improvements. While statically unexpected, when Figure 4.11 is considered, this result is not surprising. For Perdido, 1996—1999 and 2007—2009 are the best fitting times of the model. While 2004—2006 are the worst times. The larger the warm-up period becomes, the less of 1996—1999 is considered, and the more prominently 2004—2006 figures into the efficiency calculation.

Table 4.19 Efficiency due to warm-up period

<b>Wolf</b>					
<b>warm-up:</b>	<u>6 yr</u>	<u>5 yr</u>	<u>4 yr</u>	<u>3 yr</u>	<u>2 yr</u>
<b>NSE:</b>	0.178	0.177	0.177	0.177	0.177
<b>% Bais:</b>	8.36	8.23	8.23	8.23	8.23
<b>R2:</b>	0.23	0.23	0.23	0.23	0.23
<b>Styx</b>					
<b>warm-up:</b>	<u>6 yr</u>	<u>5 yr</u>	<u>4 yr</u>	<u>3 yr</u>	<u>2 yr</u>
<b>NSE:</b>	0.402	0.410	0.407	0.323	0.357
<b>% Bais:</b>	-18.08	-17.21	-14.35	-12.28	-13.98
<b>R2:</b>	0.420	0.427	0.419	0.332	0.363
<b>Perdido</b>					
<b>warm-up:</b>	<u>6 yr</u>	<u>5 yr</u>	<u>4 yr</u>	<u>3 yr</u>	<u>2 yr</u>
<b>NSE:</b>	0.115	0.130	0.122	0.373	0.360
<b>% Bais:</b>	10.74	10.92	11.29	10.08	9.61
<b>R2:</b>	0.332	0.341	0.336	0.426	0.427
<b>Eleven Mile</b>					
<b>warm-up:</b>	<u>6 yr</u>	<u>5 yr</u>	<u>4 yr</u>	<u>3 yr</u>	<u>2 yr</u>
<b>NSE:</b>	0.477	0.473	0.463	0.434	0.432
<b>% Bais:</b>	-26.17	-27.29	-26.08	-25.05	-24.94
<b>R2:</b>	0.51	0.509	0.494	0.461	0.456

### 4.3 Unmodeled Watersheds

As mentioned throughout the thesis, the Perdido Bay basin has a large amount of wetland and marsh. Figure 4.49 shows a call out of the unmodeled areas within the basin. Most areas (pink) are primarily wetland. These areas have little or no stream networks for HSPF to model. There are two areas that do have some network (tan and green). The tan area is the community of Perdido Beach, which has nearly a dozen streams, bays, bayous and inlets. The green area is Tarkiln Bayou Preserve State Park ([www.floridastateparks.org/park/Tarkiln-Bayou](http://www.floridastateparks.org/park/Tarkiln-Bayou)). These areas cause an issue for HSPF modeling, in that each stream connects to the bay directly and may only have one 1—2 mi<sup>2</sup> that drains into it. This would have meant creating several ungagged HSPF models with very small drainage areas.

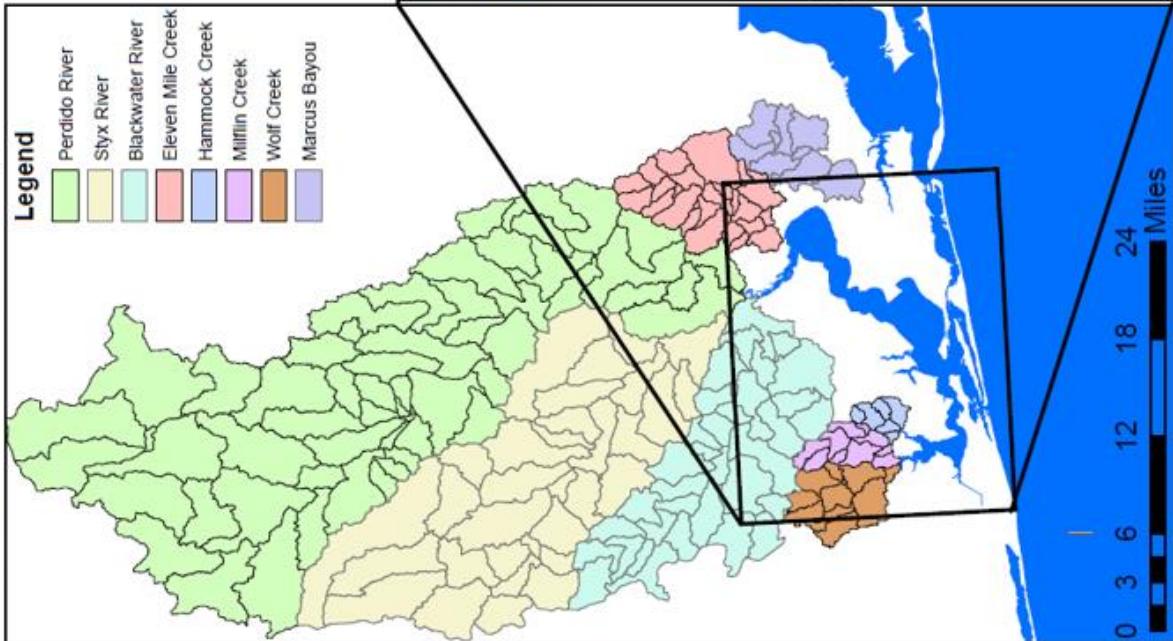
Another obstacle to modeling this region is that flooding plays a major role during winter and early spring. This is partly due to the very low elevation of the bay (Figure 4.50). The dark blue regions of the map show that much of the wetlands in this region are at or below sea level. These areas have an additional challenge, in that tides affect what areas will have what depth of standing water. Astronomical tides in the Perdido Bay system are diurnal, having relatively low amplitudes that range from 2.39 to 1.71 ft. (Livingston, 2001).

While the entire Perdido Bay basin is nearly 1000 mi<sup>2</sup>, all the unmodeled areas combined are less than 120 mi<sup>2</sup> (Figure 4.49). This means that with the eight current HSPF models, only 11% of the basin area is outside of an HSPF watershed model. In addition, much of the area is actually below sea level, so there is little ‘overland’ flow, due to the amount of standing water in the marsh and wetland areas. For these areas of the basin, it can be assumed that a significant fraction of precipitation is going directly to the bay. However, for the Perdido Beach area (Figure 4.49, tan area) this is less true. Here, either multiple small HSPF models must be created or another model that deals better with tidal areas should be used.

The Watershed Analysis Risk Management Framework (WARMF) (Chen et al. 2001) is a physically based, versatile, dynamic watershed model that simulates hydrology and water quality. Originally developed for EPRI (Electric Power Research Institute) by Systech Engineering, WARMF has been endorsed by the EPA as a watershed assessment model for TMDL studies. WARMF is an integrated watershed model that groups simulation models and input databases into a GIS-based user interface. WARMF can simulate point and non-point sources and integrate stream and one-dimensional (1-D) reservoir models into a seamless river basin model. WARMF has been applied for hydrologic and water quality modeling in the Saugahatchee Creek watershed including a 1-D model for Yates Reservoir Embayment (Shrestha, 2011), and in the Bankhead watershed including Bankhead Reservoir and Black Warrior River (Thomas, 2013). The reservoir component in WAMRF is a waterbody and can link multiple sub-watersheds draining through different pour points (outlets) into it. It may be possible to apply WAMRF to connect all watersheds including unmodeled watersheds for the Perdido Bay basin into an integrated modeling system. WAMRF was developed for watersheds with relative large watershed slopes and has not been applied to coastal watersheds with low elevation differences and estuarine bays.



# Unmodeled Perdido Bay Areas



Total Area (mi <sup>2</sup> )	
Unmodeled Area (mi <sup>2</sup> )	1092.14
Unmodeled Percent	10.68%

Watershed	Area (mi <sup>2</sup> )	Elevation Change (ft)	Ave. Stream Slope (ft/Kft)
Wolf Creek	23.85	33.1	0.332
Milfin Creek	13.22	35.0	0.293
Hammock Creek	6.29	24.0	0.278
Perdido River	494.70	101.1	0.222
Styx River	217.70	85.2	0.305
Blackwater River	142.09	50.1	0.255
Elevenmile Creek	49.23	58.3	0.391
Marcus Bayou	28.40	49.0	0.221
Tarklin Park	25.72	14.2	-
Perdido Beach	19.47	36.5	-
Unmodeled basins	71.47	36.5	-

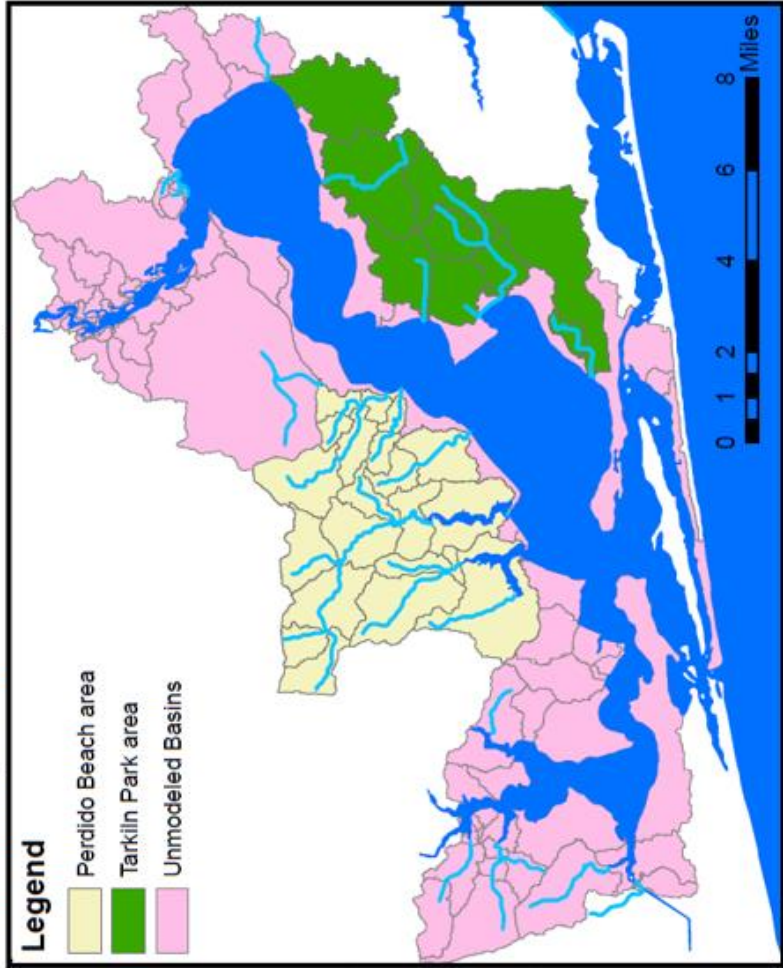


Figure 4.49 Map of Wetland and Marsh within the Lower Perdido Bay Basin

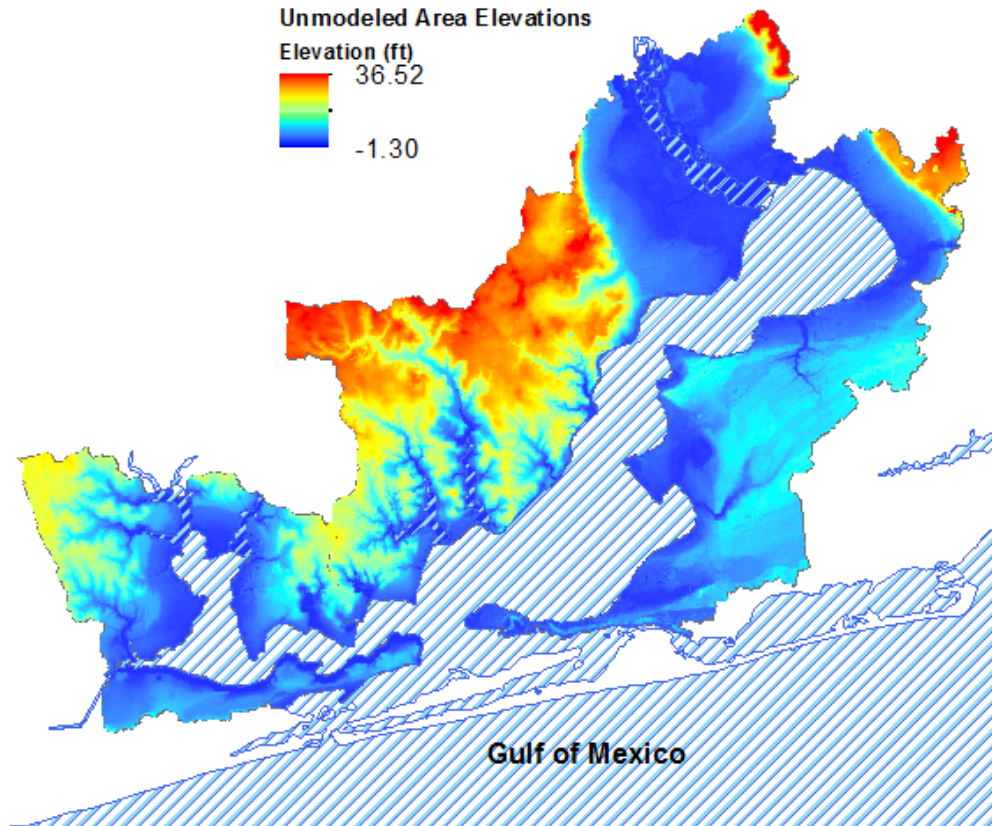


Figure 4.50 Elevations of Unmodeled Areas in the Perdido Bay Basin

### 4.3.1 Estimation of Total Inflows to Perdido Bay

As mentioned throughout the thesis, the models were calibrated to the USGS gage stations within their watersheds (Figure 2.17, Figure 4.4). However, none of the gaged watersheds had the gage station at the final outlet of the corresponding HSPF model. Table 4.21 shows the drainage areas downstream of the gage station and the total drainage areas for the five gaged watersheds. This means that to create an accurate prediction for the total inflow into Perdido Bay or Wolf Bay, the entire watershed discharge for each of the eight models must be combined with the area of unmodeled catchments times the rainfall. HSPF allows the user to output discharge for any catchment inside simulated watershed, so the models had two output locations: the catchment at the gage and the final outlet.

The purpose of the hydrological and water quality modeling in this study is to provide more accurate input for a hydrodynamic and water quality model of Perdido Bay and Wolf Bay using

the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992). The EFDC model is a general purpose modeling package that can be configured to simulate 1D, 2D, and 3D flow, transport, and biogeochemical processes in various surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model previously developed for Perdido Bay and Wolf Bay (Devkota, 2013; Devkota, 2015) ties external inflows and sources to specific cells (Figure 4.51). Figures 4.52 to 4.54 show modeled discharge at the final outlet for each gaged watershed. Total runoff over the simulation periods are 563 in. for the Wolf Creek watershed. Likewise, it is 696 in., for the Perdido River, 547 in. for the Styx River, 585 in. for Elevenmile Creek, and 428 in. for the Marcus Bayou watershed (1995—2005). Perdido had the most area by far and it is no surprise that it has the most runoff. Styx, not having the second largest runoff is unexpected when area alone is considered, however both Elevenmile and Marcus Bayou have far more urban areas where runoff generation is increased. These outflows will be added to the EFDC model for water quality modeling. In addition, EDFC can tie shallow overland to cells in the same way to model the unmodeled HSPF areas.

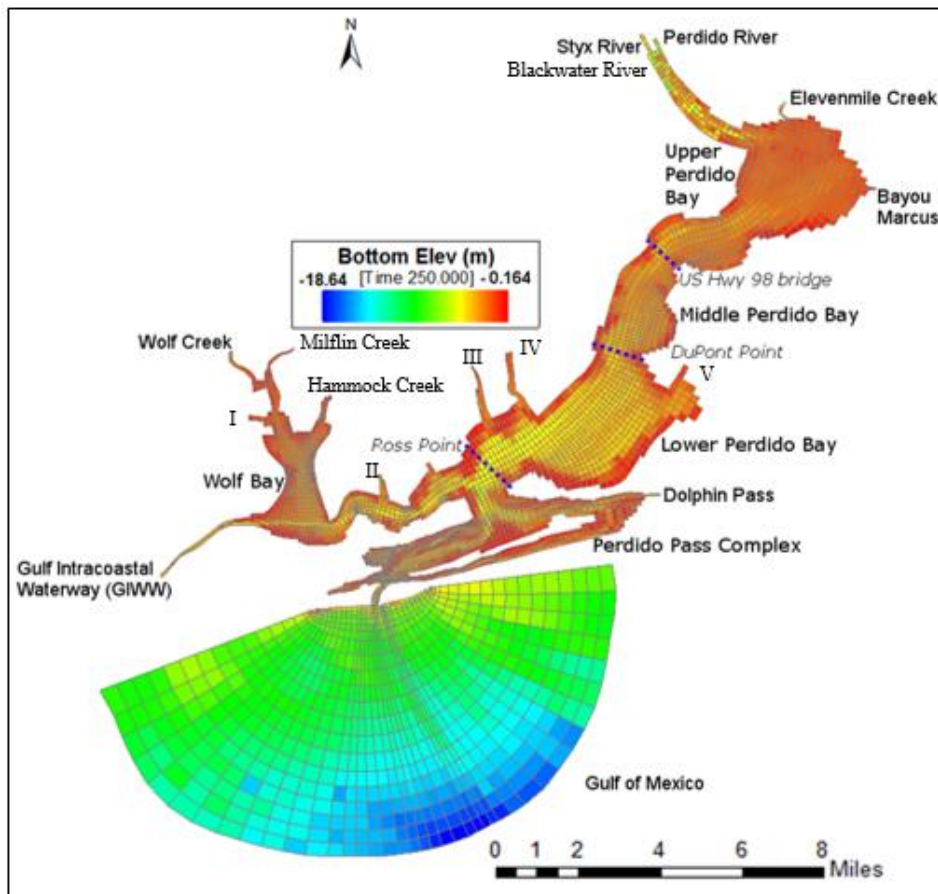


Figure 4.51 Current EFDC Model of Perdido Bay and its Inflow Points

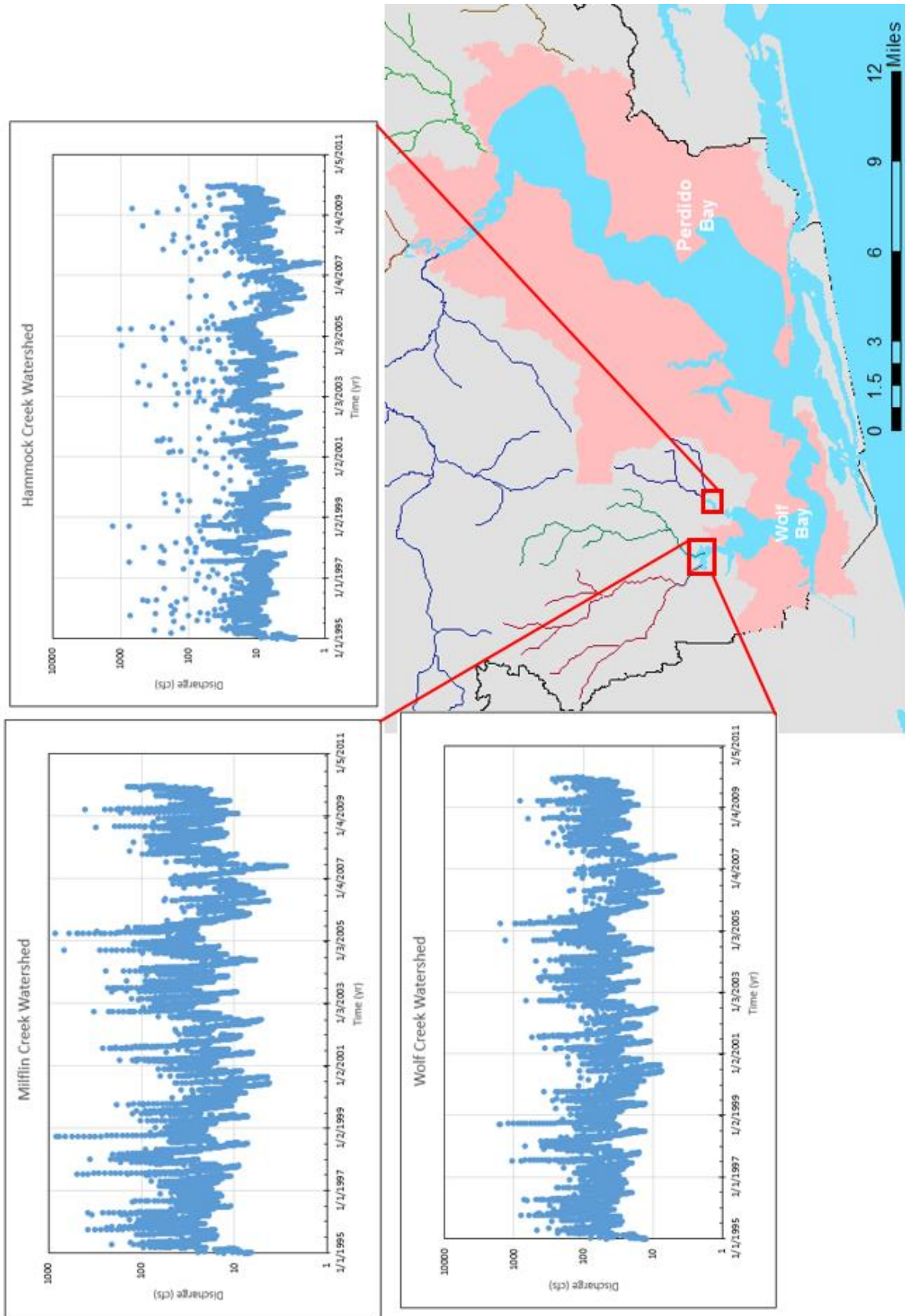


Figure 4.52 Wolf Bay Model's Discharge at the watershed outlet

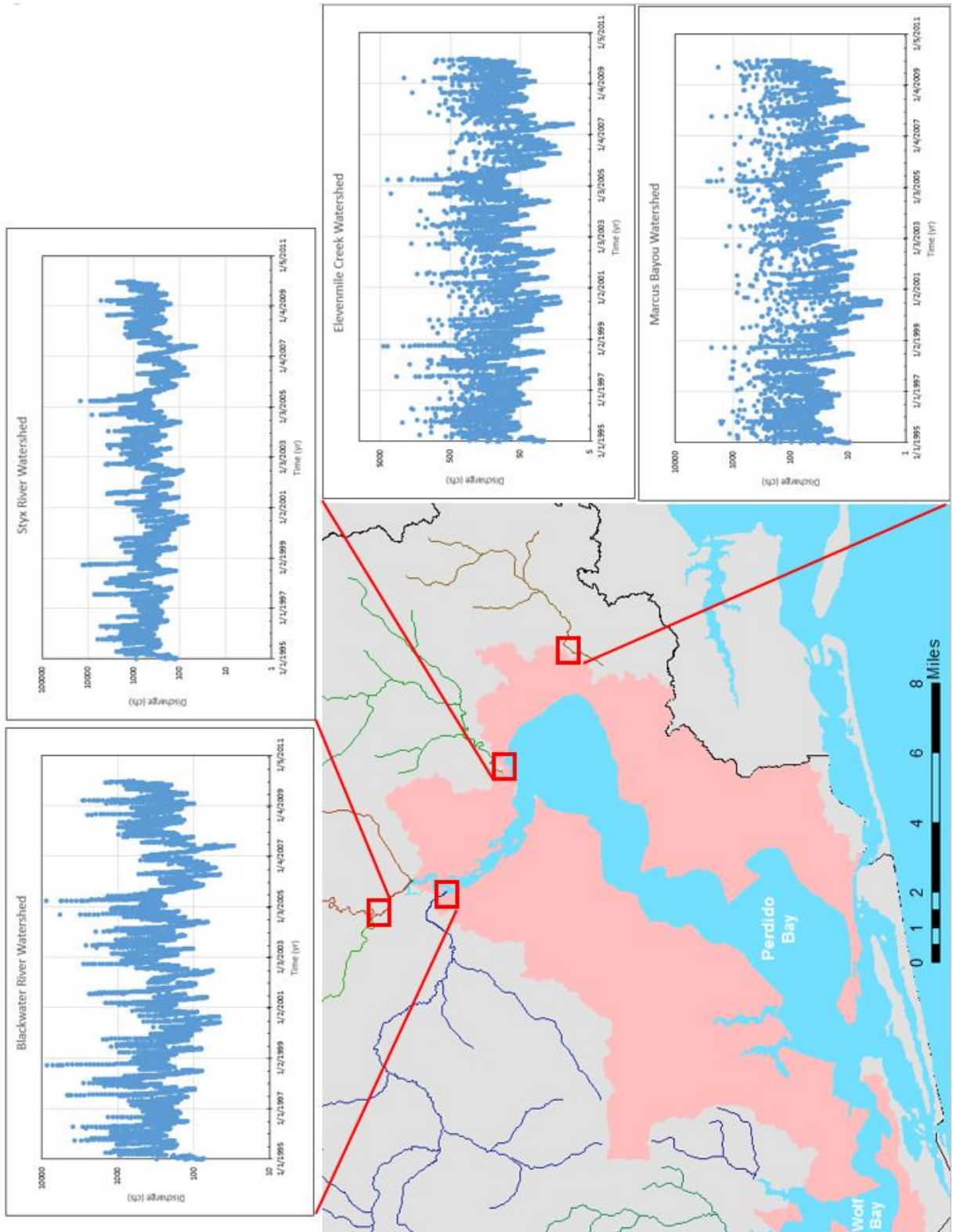


Figure 4.53 Perdido Bay Model's Discharge at the watershed outlet

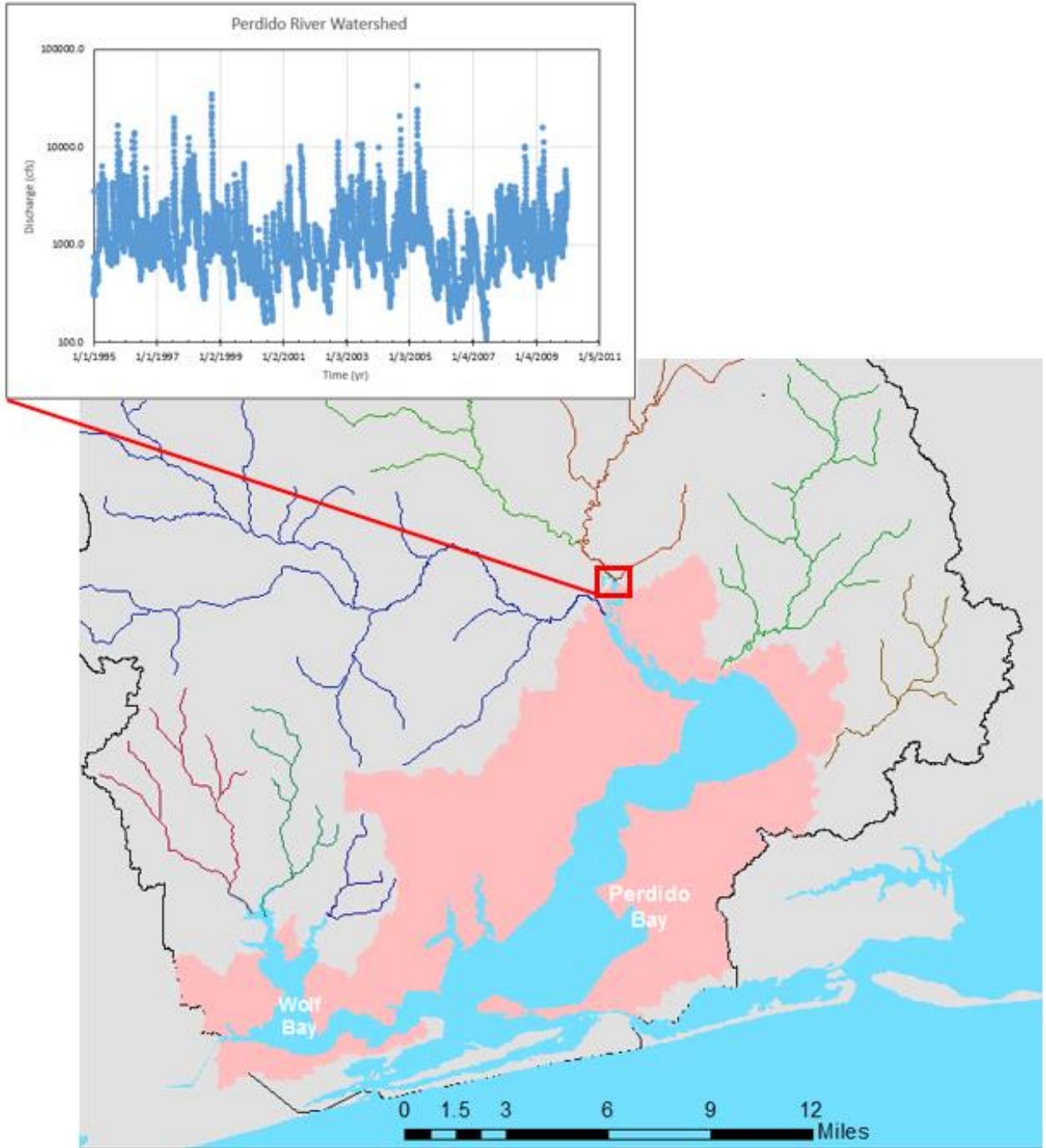


Figure 4.54 Perdido River Model's Discharge at the watershed outlet

Table 4.20 Areas (mi<sup>2</sup>) and Runoff (in.) for Upstream and Downstream of the USGS Gage

	Wolf Creek	Milfin Creek	Hammock Creek	Perdido River	Styx River	Blackwater River	Elevenmile Creek	Marcus Bayou
Area at gage (mi <sup>2</sup> )	3.0	13.2	6.3	272.6	147.6	142.1	28.0	15.2
Area Downstream of gage (mi <sup>2</sup> )	22.5	-	-	150.5	127.6	-	21.2	12.9
Total Area (mi <sup>2</sup> )	25.4	13.2	6.3	423.1	275.1	142.1	49.3	28.2
Area ratio	11.6%	-	-	64.4%	53.6%	-	56.9%	54.0%
Gage runoff (in)	152.2	-	-	657.0	425.0	-	577.7	380.0
Full runoff (in)	562.5	534.5	474.7	695.9	546.9	491.4	584.5	428.2
runoff ratio	27.1%	-	-	94.4%	77.7%	-	98.8%	88.7%

The statistics for each of the full watershed models shown in Figures 4.52-4.54 are given in Table 4.21. For each of the full models the ranges of simulated discharges are larger than those from the models to the gage, however, the averages are very similar. Figure 4.55 shows how the area ratio and runoff ratios (Table 4.20) relate to each other (Hirsch, 1982). Two theoretical data points (0, 0; 1, 1) for the relationship were used for limiting and developing the regression equation. The runoff ratios are assumed to be a function of the area ratios:

$$\frac{\text{Runoff}_{\text{gaged}}}{\text{Runoff}_{\text{full}}} = f\left(\frac{\text{Area}_{\text{gaged}}}{\text{Area}_{\text{full}}}\right) \quad (4.1)$$

There are issues with relating area with runoff. These are the fact that while runoff will certainly increase with area, the type of landuse in the area will affect the rate of increase. Also, the soil type will alter infiltration rates which affect runoff volume. However, this is still useful information that can be applied to the unmodeled areas. Since there are no gages in some areas, the relationships between area and runoff (Figure 4.55) can be used to calculate flow into Perdido Bay from those areas (peach areas, Figure 4.54).

Figure 4.50 also shows four (I-V) small streams flowing into Wolf Bay and Perdido Bay that could be modeled using HSPF at the next step of the project. With additional information of DEM, urban land use, drainage channels, and outlets, stormwater runoff from the City of Orange Beach can be modeled also. In addition to the discharges from streams to the bay, Figures 4.51-4.54 show the unmodeled swamp areas in Perdido Beach, Orange Beach and Tarkiln Bayou. Now that all the major streams are modeled, the swamp area needs to be added. This was done by multiplying the rainfall by the area. Then, we can use the relationship between area and runoff (Figure 4.55) to convert rainfall to discharge, since even in marshland some rain will be lost to infiltration, interflow, and evapotranspiration (Gianfagna, 2015). However, from how wide the precipitation varies from station to station (Figure 4.43), this process will be left for Phase 2 of the

project. Then the user of the EFDC model can determine the best method for modeling surface runoff with the unmodeled areas provided in Figure 4.47.

Table 4.21 Full Model Statistics

	Min	1st Quartile	Medium	3rd Quartile	Max
Wolf Creek	4.8	27.0	43.6	73.6	1600.0
Milfin Creek	2.7	14.7	23.5	38.2	853.0
Hammock Creek	1.2	6.3	9.3	13.3	1303.0
Perdido River	108.0	591.9	958.6	1583.4	41600.1
Styx River	45.1	247.0	392.0	633.0	14100.0
Blackwater River	29.4	156.0	249.0	402.0	8720.0
Elevenmile Creek	8.8	52.6	86.6	156.0	4540.0
Marcus Bayou	4.1	24.7	41.7	81.7	3690.0



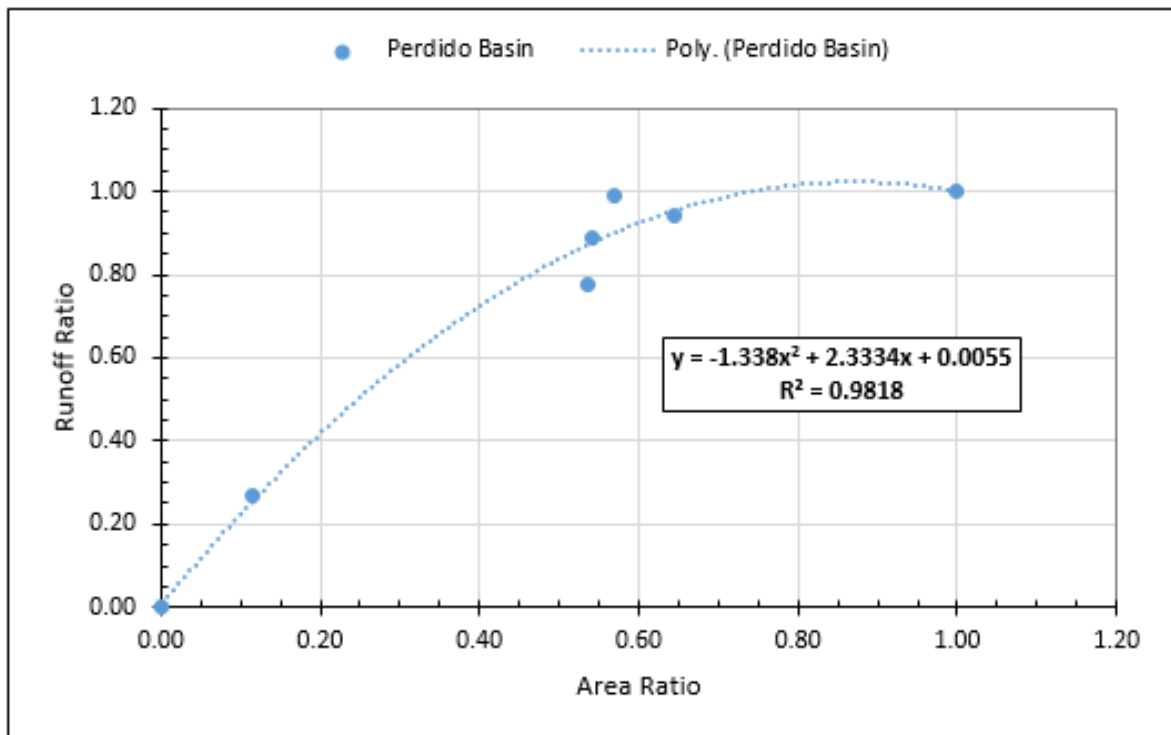
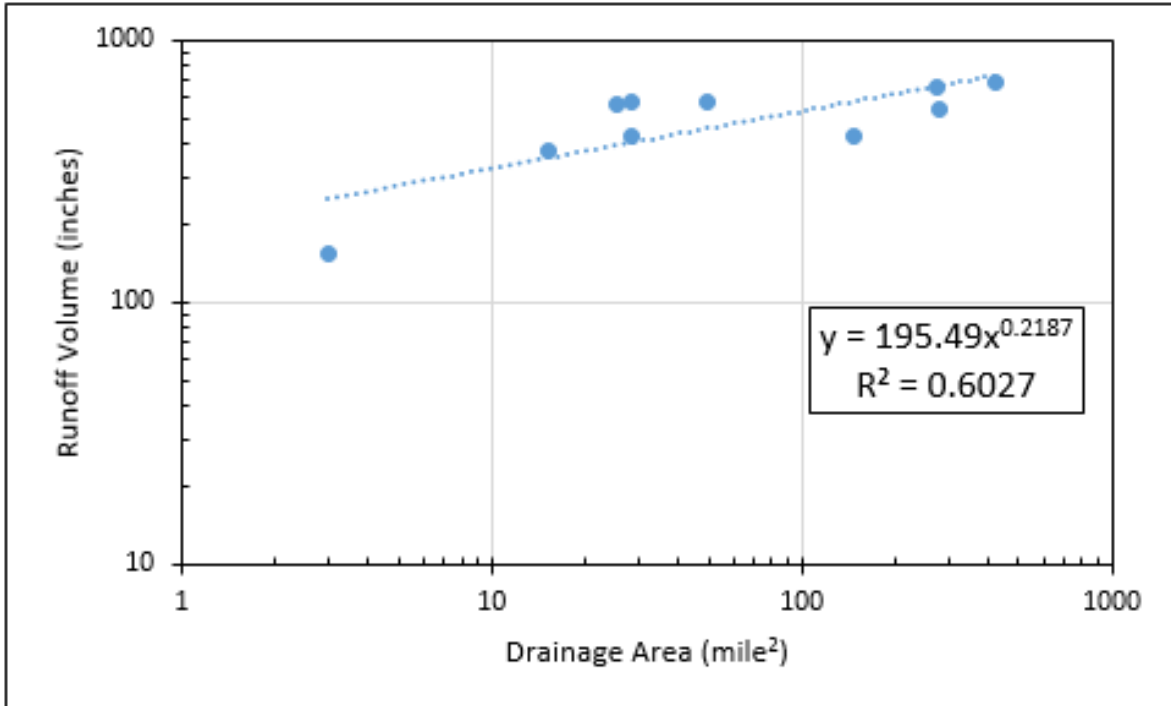


Figure 4.55 Runoff Ratio vs Area Ratio for Gaged and Full Model Areas with Runoff vs Area Comparison

## CHAPTER 5 SUMMARY AND CONCLUSIONS

### 5.1 Summary and Discussions

The study is to develop, calibrate, and validate a series of hydrological models for watersheds in the Perdido Bay basin. The basin includes two estuaries: Perdido Bay and Wolf Bay. The optimum goal was to simulate flows and water quality constituents from upstream and surrounding watersheds into estuaries so that we can model water quality conditions to understand ecological health in these coastal waters. Eight total HSPF watershed models were developed. Five models for watersheds with USGS gage stations were calibrated and validated. All model input data are in hourly time step, and models were run in daily time step for an easier comparison of USGS daily flow data. Meteorological data for the models were primarily obtained from Robertsdale, AL.

The HSPF model for the Wolf Creek watershed (Figure 3.5) was first developed using publicly downloadable GIS data (digital elevation model, streams, land use, and soil layers) and included 12 catchments. More than 20% of land uses are either crops or wetlands in the Wolf Bay watershed. The model was calibrated in 1995—2004 and validated in 2004—2009, with a three-year model warm-up period. Since the Riviera Utilities WWTP discharge data are currently still not available, assumed base flow of 3.5 cfs from WWTP was used for the model. HSPF model parameters were calibrated based on land use and watershed characteristics.

After the Wolf Creek model was developed and calibrated, the same processes were used for the model development, calibration and validation in the Perdido River, Styx River, Elevenmile Creek, and Marcus Bayou watersheds. The HSPF models for the Milflin Creek, Hammock Creek, and Blackwater River watersheds were also developed but could not be calibrated and validated since there are no gage stations with observed flow data in these watersheds. Eight HSPF models

developed in this study have 6 (Hammock Creek) to 41 (Perdido River) catchments (sub-watersheds) and included 17 land uses.

Table 5.1 summarizes model efficiency parameters (Nash-Sutcliffe efficiency, percent bias, and  $R^2$ ) values for each uncalibrated model, calibration, and validation runs for the five gaged models. These model efficiency parameters were improved from uncalibrated to calibrated model within all five models, indicating that the calibration process was effective. Model efficiency had certain decreases in validation but was still acceptable except the Marcus Bayou model.

As Marcus bayou was the only model that did not have satisfactory calibration and validation results it is believed that the meteorological data from Robertsdale, AL most likely was not as correct for the Marcus Bayou watershed. This may be due to its proximity to Pensacola Bay and the Gulf of Mexico, since the calibration process was similar for all five models, and the fact that HSPF relies heavily on physical parameters. More accurate meteorological data from Pensacola were used, but the model efficiency was still not improved to a satisfactory level. It was found that the City of Pensacola's stormwater structures divert part of stormwater out of the watersheds. The link between the two (diversion and poor model efficiency) makes logical sense, but to fully and more accurately model the Marcus Bayou watershed, more detailed stormwater channel-network maps of Pensacola need to be obtained.

The GIS data, (elevation, land use, soil and stream networks) was obtained and can be used for later Perdido Bay watershed research. While stream gage data was limited, it is enough to fully model the watershed. The only data that was insufficient was water quality parameters. We have started to address this need as discussed in Section 2.3.6.

Due to the satisfactory results of four of the calibrated models, and with Dr. Hayworth and Dr. Wilson collecting water quality samples (section 3.2.2), the research is ready for Phase 2. This will be the predictive modeling of water quality in Wolf and Perdido Bays. The calibrated models can then be used as hydrologic input into the EDFC water salinity and temperature models and can model required quality simulations (DO, Sediment, etc.).

Table 5.1 Model Calibration Results

	Nash-Sutcliffe	Percent Bias	R <sup>2</sup>	Cumulative Volume error
<b>Wolf</b>				
uncalibrated	-22.280	-196.950	0.019	-100.01
calibrated	0.177	-8.231	0.230	8.23
<b>Perdido</b>				
uncalibrated	-2.756	1.131	0.124	-76.69
calibrated	0.363	-3.250	0.444	6.68
<b>Styx</b>				
uncalibrated	-0.398	25.785	0.221	-59.06
calibrated	0.472	7.290	0.356	-3.05
<b>Elevenmile</b>				
uncalibrated	-0.0308	28.33	0.365	-28.33
calibrated	0.444	21.430	0.474	-25.19
<b>Marcus</b>				
uncalibrated	-20.259	-99.520	0.333	99.52
calibrated	-2.910	-44.81	0.421	72.3

### 5.1.1 Recommendations and Lessons Learned

While the EPA had all meteorological datasets before 2009, the web site has not been updated since, so more current meteorological data (2010–2015) had to be obtained from the other sites. It was relatively easy to find weather data from various agencies, but it was quite an effort to convert, format, and integrate weather data into WDM. Unfortunately, the HSPF model only uses/reads the weather data from WDM files.

HSPF is the watershed hydrology and water quality model for total maximum daily load studies. The HSPFParm database contains parameter values for HSPF model applications in over 40 watersheds, 14 states, and 9 HUC’s. For all previous applications of HSPF, none of the watersheds are in coastal areas with small elevation differences like the Perdido Bay watershed. Various applications of HSPF by private consulting firms are not documented or publicly available. Other watershed models (e.g., SWAT) have many applications for numerous watersheds over the world. Due to limited applications, understanding and specifying, model parameters for HSPF is still limited.

While the weather data is likely to blame for some of the HSPF model's faulty results of the Marcus Bayou watershed it is also likely partly due to Pensacola's storm water structures. It is recommended that more detailed maps of Pensacola need to be obtained.

Baldwin County and the city of Foley in Alabama were contacted. However, actual discharges from the Riviera Utilities WWTP have not been received. Due to the lower streamflow in Wolf Creek (average 10 cfs of low flows) any outflow from the WWTP, which is different from assumed 3.5 cfs base flow, could make up a significant portion of the flow. Similarly Elevenmile Creek has the International Paper papermill that discharged into in during the simulation period (but not currently). While the Elevenmile Creek HSPF model was calibrated sufficiently, with more accurate mill discharge data the model will become more accurate.

To begin Phase 2 of the study, water quality data will be needed. As was discussed in Section 2.3.6, a researcher team from the civil engineering department and the School of Fisheries has started to set up water quality stations in Perdido Bay and Wolf Bay (e.g., near Marcus Bayou and Elevenmile Creek). However, these will only have data starting from February 2017. A source of reliable long term water quality data still needs to be found for Perdido Bay and Wolf Bay.

One of the downsides of HSPF is that it requires a stream network to develop a watershed model (one stream in each catchment). While this is fine for the majority of cases, the lower sections of Perdido Bay are primarily marsh and swamp (Figure 4.39). So while water flows to the bay, it is all considered 'overland' flow, even though the amount of standing water for much of the year can negate this. As can be seen for the unmodeled areas in Figure 4.40, this area is significant as a source of inflow to the bay and accounts for more than 10% of the area. If a solution for this can be found (i.e., multiple small models), then HSPF may work. If not, then an additional model may need to be used to assist in modeling these areas.

One possible way to include currently unmodeled watersheds is to develop multiple small HSPF models for them. An alternate method is to use a different model system for modeling these areas. WARMF can integrate stream and one-dimensional (1-D) reservoir models into a seamless river basin model, and it may be possible to apply WAMRF to connect all watersheds including unmodeled watersheds for the Perdido Bay basin into an integrated modeling system. However, WAMRF was also developed for watersheds with relative large watershed slopes and has not been applied to coastal watersheds with low elevation differences and estuarine bays, similar to HSPF.

Both HSPF and LSPC have been endorsed by the EPA as a watershed assessment model, but very limited technical support is available. Various unknown (not documented) difficulties for the tasks or steps using HSPF were encountered. Some issues were resolved after troubleshooting (Appendix B), but some are still clear or full understood.

## **5.2 Conclusions**

Overall the goals of the project to develop and calibrate watershed models for the Perdido Bay basin (including Wolf Bay) were met. However, it is still difficult to more accurately model the Marcus Bayou watershed and those wetland and swamp watersheds adjacent to Perdido Bay and Wolf Bay. A plan to integrate simulated discharges of HSPF models and unmodeled areas with a hydrodynamic model of Perdido Bay and Wolf Bay was developed and discussed. This project is basically ready to begin predictive modeling of water quality in Wolf and Perdido Bays once the recommendations are implemented.

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**APPENDIX A**  
**ArcMap Toolbox Details**



Appendix A provides details of various procedures and gives steps on how to use different tools or Toolboxes in ArcMap to complete various tasks for preparing GIS datasets or layers in order to delineate watersheds/sub-watersheds. These are procedures are required to prepare files necessary for HSPF modeling.

## **A.1 LIDAR to DEM**

Raster elevation models are one of the most common GIS data types (layers). They can be used in many ways for analysis and are easily shared. LIDAR as a remote sensing method provides users with the opportunity to make high-quality elevation models of two distinct types: first return and ground. A first-return surface includes tree canopy and buildings and is often referred to as a DSM (digital surface model). The ground, or bare earth, contains only the topography and is frequently called a DEM.

LIDAR data can produce multiple types of dataset: mosaics, LAS (binary point file) and terrain. Terrain datasets are the most convenient for creating DEMs since they do not deal directly from LAS, have breaklines, require multiuser editing/versioning, or need a z-tolerance based point filtering option. Terrains represent and model the study area by integrating 3D-based mass point observations with other data sources such as 3D features captured using stereophotogrammetry.

Frist the LIDAR point data must be run through the “LAS to Multipoint” tool in the “From File” section of the “Conversion” section of the “3D Analyst” toolbox in ArcMap. The “ASCII 3D To Feature Class” tool may be used; however, the LAS binary format contains more data and can be read more efficiently. Also, a cell assignment of average is best for bare earth points which are used when making DEMs. Once the terrain is created, the “Terrain to Raster” tool in the “From Terrain” section of the “Conversion” section of the “3D Analyst” toolbox can be used to create a raster file.

Converting a LiDAR dataset to a DEM, is taking a set of discrete data points and converting them into a single, continuous dataset. If the average resolution is ~1 meters, the data values will fall within a range around that resolution. In between LiDAR points, an interpolation algorithm has been applied to estimate what reasonable elevation values might be. When choosing the correct interpolation method, setting the proper resolution on that output DEM is important — always set a lower resolution than the resolution of your LiDAR dataset (e.g., for a ~1 meter resolution set a 3 meter resolution for the DEM, in an effort to minimize distortion).

There are of course multiple tools to do any single process in ArcMap. The given link shows other work flows to do similar processing ([desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/lidar-solutions-creating-raster-dems-and-dsms-from-large-lidar-point-collections.htm](http://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/lidar-solutions-creating-raster-dems-and-dsms-from-large-lidar-point-collections.htm))

## A.2 Manual watershed Delineation

The DEM is raster data so processing is computationally demanding. If watershed boundaries can be visually determined, a Clip should be made to shrink the area being processed. First, find the coordinates of the area of interest. The coordinates can then be used to clip out the area of interest from the area of the DEM. Then use the “Clip” tool within the “Raster Processing” section of the “Raster” section in the “Data Management” toolbox. The Clip tool cuts out a portion of a raster dataset, mosaic dataset, or other image layer.

Now that the clip has been made, use the “Fill” tool in the “Hydrology” section in the “Spatial Analyst” toolbox to create a FILL layer. The Fill tool sinks in a surface to remove any small imperfection in the data. The Z-factor (height of fills) must be specified. This scaling factor is used for two purposes: to convert the elevation units to the horizontal coordinate units of the dataset, which may be feet, meters, or degrees, and to add vertical exaggeration for visual effect. Therefore the Z-factor affects how smooth the fill will be, so a small non-negative integer is best. Next, use the FILL layer in the “Flow Direction” tool in the “Hydrology” section in the “Spatial Analyst” toolbox creates a FLOW layer. This creates a drop raster layer that shows the direction from each cell to its steepest downslope neighbor. The output of the Flow Direction tool is an integer raster layer whose values range from 1 to 255. The values for each direction from the center are the following (Figure A.1):

32	64	128
16		1
8	4	2

Figure A.1 Flow Direction Example Cell

For example, if the direction of the steepest drop is to the left of the current processing cell, its flow direction would be coded as 16. If the steepest drop was south, it would be coded as 4. If the steepest drop was northeast, then it would be coded as 128. Now, use the FLOW layer in the “Flow Accumulation” tool in the “Hydrology” section in the “Spatial Analyst toolbox” to create an ACC (accumulation) layer. The Flow Accommodation tool creates a raster layer of accumulated flow into each cell, as determined by accumulating the weight for all cells that flow into each downslope cell. Next, use the ACC layer in the “Basins” tool in the “Hydrology” section in the “Spatial Analyst” toolbox to create the BAS (basin) layer. The flow direction raster is analyzed to find all sets of connected cells. The drainage basins are created by locating the pour points, as well as sinks, then identifying the contributing area above each pour point. This results in a drainage basin for the watershed.

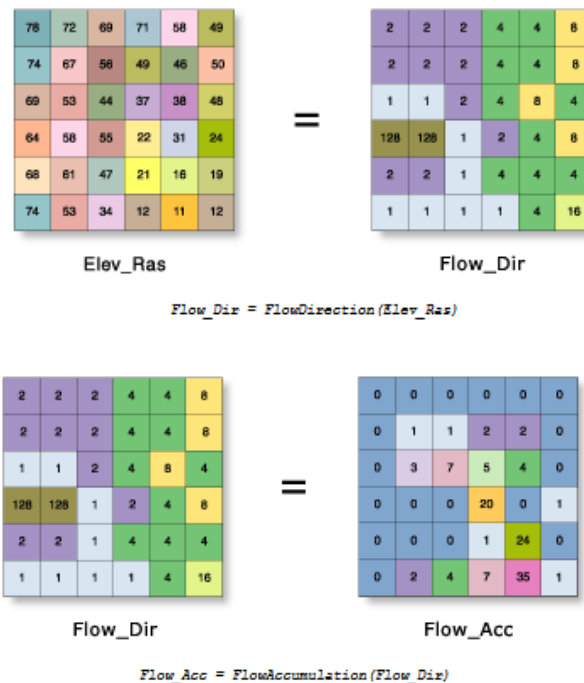


Figure A.2 Elevation to Flow Direction to Flow Accumulation Process

This Basins layer is what will be used to determine the overall watershed. However, as a layer it is difficult to move it to other users. Therefore it can be made into a Shapefile for ease of transfer. Use the BAS layer in the “Raster to Polygon” tool in the “From Raster” section in the “Conversion” toolbox. This converts the Raster data into polygons of similar attributes. Insure that this layer is saved as a Feature class.

Lastly, this feature class can be made into an independent Shapefile by using the “Feature Class to” tool in the “To Shapefile section” in the “Conversion” toolbox. Finally, a Shapefile of the Watershed has been created.

### **A.3 Raster Clip**

First go to the USGS website to download the most current NLCD. At the time of writing the current datasets available were the 1992, 2001, 2006 and 2011 datasets. Each are given at 30 meter resolution. However, the 1992 dataset is divided into 24 different land-uses, while datasets after 2001 are divided into 16 land-use classes. This can cause some issues if an older dataset is compared to a more recent one, since it may look as if land-use had changes when really it could just be a class difference.

The USGS breaks the NLCD into 4 maps: Conterminous US, Alaska, Hawaii, and Puerto Rico. For some reason, their data set does not include the names of the land-use classes. The 16 current land-use classes are summarized in the table below. This means that the names must be added into the Attribute Table manually. This is fairly easy, since the attribute table is so simple. Usually the Select by attribute would be used, however since there are only 14 rows and two columns that is unnecessary. Just add a new field and name it Land-use. Then start an edit session and type in the land-use name for each numbered category. The Land-use names and other parameters can be found in the metadata that comes with the raster download.

Once the data is download there are two ways to cut the rest of the data into just the needed area. Since this is a raster dataset the Geoprocessing Clip will not work, so the Spatial Analysis tool can be used. Go to the “Clip” tool within the “Extract” section in the “Spatial Analysis” toolbox. Just input the NLCD and clip it to the needed area. The Data management tool could also be used by using the “Clip” tool within the “Raster Processing” tool of the “Raster” section in the “Data Management” toolbox.

Now that the dataset is of a more manageable size, other processing can be done. In the properties tab the symbology can be changed to make the data easier to understand. Under Unique values, each land-use type can be given a different color using a color ramp. Then the water can be changed to blue and each Developed land type can be a different shade of the same color.

Additionally, there are other ways to get land-use data than from USGS. Their 30 meter grids are fine for most purposes, however local agencies sometimes have better resolutions or more

detailed land-uses for their regions. For this study, the Baldwin County Planning and Zoning Dept. has Land-use maps available for download. Their maps are all from 1994 and have a resolution of 0.125 miles (660 ft.). This puts their maps a few years out of date with a worse resolution. However, the same land-use categories are used at the NLCD, so a good comparison can be made for past conditions. Also their maps are more detailed about city uses and local features such as canals and locations of county roads.

#### A.4 Soil data

The USDA and the USCS manage the SSURGO which can be accessed through the Web Soil Survey (WSS). This online interactive soil map gives the most recent soil type locations for the entire US. The interface is very similar to ArcMap. The most important aspect is the Area of Interest (AOI). This is the area from where soil data will be pulled. The rest of the map interface is only there as background to assist with the section of the AOI.



Figure A.3 Interface of Web Soil Survey

There are multiple ways to find the soil map for an AOI. One way is to load a Shapefile of the AOI. This is very accurate, however it doesn't show trends that could be seen just outside the AOI which might be important.

Another way is to zoom into the needed area or use the Quick navigation tab to enter location information. Then select it through the AOI by Polygon or the AOI by Rectangle. These are easy to use since it only requires an approximate knowledge of the needed area. These selection methods have the benefit that they include more applicable data, but a downside that if an AOI that is too small is chosen the process would have to be repeated once the mistake is caught.

Once an AOI is selected, a Soil Report can be generated that provides all Soil Types within the AOI, as well as each type's area, % of total area, drainage characteristics, and many other parameters about the AOI. Some of the other parameters are given in the table below. Then the Soil Map can be download as a geodatabase for easy use. Once the data is downloaded and opened

in ArcMap, it is quite simple to process. All that is needed is to change the symbology to display unique values for the MUSYM data. This is done in the Symbology tab in the properties.

### A.5 National Land Cover Dataset (NLCD) Classification Table

The NLCD covers the entire USA at a 10m cell resolution. There are available land use datasets from 1992, 2001, 2006, and 2013 ([www.mrlc.gov/nlcd2011.php](http://www.mrlc.gov/nlcd2011.php)). The maps from 2001 use the land use codes found in Table A.1, however the 1992 map uses an older set of codes.

Table A.1 NLCD Land Use Code Descriptions

11	<b>Open Water</b> - areas of open water, generally with less than 25% cover of vegetation or soil.
12	<b>Perennial Ice/Snow</b> - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
21	<b>Developed, Open Space</b> - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	<b>Developed, Low Intensity</b> - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	<b>Developed, Medium Intensity</b> -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	<b>Developed High Intensity</b> -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
31	<b>Barren Land (Rock/Sand/Clay)</b> - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
41	<b>Deciduous Forest</b> - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.

- 42 **Evergreen Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
- 43 **Mixed Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
- 51 **Dwarf Scrub**- Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
- 52 **Shrub/Scrub**- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
- 71 **Grassland/Herbaceous**- areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
- 72 **Sedge/Herbaceous**- Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
- 73 **Lichens**- Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
- 74 **Moss**- Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
- 81 **Pasture/Hay**-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
- 82 **Cultivated Crops** -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
- 90 **Woody Wetlands**- areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

95 **Emergent Herbaceous Wetlands**- Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.



**APPENDIX B:**  
**Common HSPF Error Details**

Appendix B contains information about how the HSPF and BASINS function together. Several errors and how to fix them are included, as well as details about the BASINS technical notes and where to download them. In addition, the code used to calculate cloud cover data from solar data. This code was created with the assistance of Sagar Tamang.

## B.1 Solar Code

For this code to function, the set-up in Excel (or other database) need to be as shown. Both the latitude and longitude of the station and time step of the data need to manually edited.

Enter your hourly measured solar radiation data here:		Enter the value of longitude and latitude in decimal degrees:	
Julian day	Measured solar radiation	longitude	-88.0681
0.041666667	0	latitude	30.62639
0.083333333	0	Select the type of output for cloud cover here and then hit Calculate:	
0.125	0	daily	
0.166666667	0	CommandButton1	
0.208333333	0		
0.25	0		
0.291666667	0		
0.333333333	20		
0.375	55		
0.416666667	106		
0.458333333	162		
0.5	474		
0.541666667	393		
0.583333333	508		
0.625	411		
0.666666667	236		

Figure B.1 Excel Solar Set-up

```
Private Sub CommandButton1_Click()
```

```
Dim phis As Single, ao As Single, h As Single, hour As Integer, slong As Single, slat As Single, eqt As Single, phi As Single, del As Single, taud As Single
```

```
Dim i As Long, j As Integer, jday As Integer, pi As Single, hh As Single, jd As Integer, storage As Single
```

```
Dim variations As String, dvalue(1000) As Single, count As Integer, hour1 As Integer, jday1 As Single
```

```
Range("C4:J9000").Clear
```

```
pi = 3.1416
```

```
slong = Cells(4, 13)
```

```
slat = Cells(5, 13)
```

```
variations = Cells(6, 27)
```

```
phi = 15# * Int(slong / 15#)
```

```
If variations = "daily" Then
```

```
For i = 1 To 365
```

```

jday = i
eqt = 0.17 * Sin(4 * pi * (jday - 80) / 373) - 0.129 * Sin(2 * pi * (jday - 8) / 355)
storage = 0
'this step accounts for hourly values and sums them up
For hour = 1 To 24
    dvalue(i) = dvalue(i) + Cells(24 * (i - 1) + 4 + hour, 2)
    hh = 2 * pi / 24 * (hour - ((slong - phi) * 24 / 360) + eqt - 12#)
    taud = 2 * pi * (jday - 1) / 365
    del = 0.006918 - 0.399912 * Cos(taud) + 0.070257 * Sin(taud) - 0.006758 * Cos(2 * taud)
+ 0.000907 * Sin(2 * taud) - 0.002697 * Cos(3 * taud) + 0.00148 * Sin(3 * taud)
    ao = Application.Asin(Sin(slat * 0.01743) * Sin(del) + Cos(slat * 0.01743) * Cos(del) *
Cos(hh))
    ao = ao * 180 / pi
    If ao < 0 Then
        phis = 0
    Else
        phis = 24 * (2.044 * ao + 0.1296 * ao ^ 2 - 1.941 * 0.001 * ao ^ 3 + 7.591 * 0.000001 *
ao ^ 4) * 0.1314
    End If
    storage = storage + phis 'storage refers to clear sky solar radiation
Next hour
If dvalue(i) > storage Then
    Cells(i + 4, 7) = 0
ElseIf dvalue(i) < 0.35 * storage Then
    Cells(i + 4, 7) = 1
Else
    Cells(i + 4, 7) = ((1 - dvalue(i) / (storage)) / 0.65) ^ 0.5

End If
Cells(i + 4, 6) = storage
Cells(i + 4, 5) = dvalue(i)
Cells(i + 4, 4) = i
Cells(4, 4) = "Julian Day"
Cells(4, 5) = "measured daily"
Cells(4, 6) = "simulated daily"
Cells(4, 7) = "cloud cover"
Next i

ElseIf variations = "hourly" Then
For i = 1 To 8760
    jday1 = Cells(i + 4, 1)
    eqt = 0.17 * Sin(4 * pi * (Int(jday) - 80) / 373) - 0.129 * Sin(2 * pi * Int((jday) - 8) / 355)
    storage = 0
    hour1 = 24 * (jday1 - Int(jday1))
    hh = 2 * pi / 24 * (hour1 - ((slong - phi) * 24 / 360) + eqt - 12#)

```

```

    taud = 2 * pi * (Int(jday1) - 1) / 365
    del = 0.006918 - 0.399912 * Cos(taud) + 0.070257 * Sin(taud) - 0.006758 * Cos(2 * taud) +
0.000907 * Sin(2 * taud) - 0.002697 * Cos(3 * taud) + 0.00148 * Sin(3 * taud)
    ao = Application.Asin(Sin(slat * 0.01743) * Sin(del) + Cos(slat * 0.01743) * Cos(del) *
Cos(hh))
    ao = ao * 180 / pi
    If ao < 0 Then
        phis = 0
    Else
        phis = 24 * (2.044 * ao + 0.1296 * ao ^ 2 - 1.941 * 0.001 * ao ^ 3 + 7.591 * 0.000001 * ao
^ 4) * 0.1314
    End If

    If phis = 0 Then
        Cells(i + 4, 4) = 0
    Else

        If Cells(i + 4, 2) > phis Then
            Cells(i + 4, 4) = 0
        ElseIf Cells(i + 4, 2) < 0.35 * phis Then
            Cells(i + 4, 4) = 1
        Else
            Cells(i + 4, 4) = ((1 - Cells(i + 4, 2) / (phis)) / 0.65) ^ 0.5

        End If
    End If
    Cells(i + 4, 3) = phis
    Cells(4, 4) = "Cloud cover"
    Cells(4, 3) = "simulated solar radiation"
Next i
End If
End Sub

```

If the code is use correctly, the output will be as shown; giving simulated solar radiation and computed cloud cover.

Enter your hourly measured solar radiation data here:				Enter the value of longitude and latitude in decimal degrees:	
Julian day	Measured solar radiati	simulated solar radiati	Cloud cover	longitude	latitude
0.04166667	0	0	0	-88.0681	30.6264
0.08333333	0	0	0		
0.125	0	0	0		
0.16666667	0	0	0	Select the type of output for cloud cover here and then hit Calculate:	
0.20833333	0	0	0		
0.25	0	0	0		
0.29166667	0	0	0	hourly	
0.33333333	20	91.19425964	1		
0.375	55	237.7188721	1		
0.41666667	106	377.2812195	1		
0.45833333	162	477.0912781	1		
0.5	474	519.9765015	0.36882421		
0.54166667	393	500.0063171	0.57379966		
0.58333333	508	419.8338318	0		
0.625	411	292.006073	0		
0.66666667	236	143.0782623	0		

Figure B.2 Excel Solar Output

## B.2 EPA Advice

If there are any questions with the operation of BASINS or HSPF, the first place to check for answers should be the EPA's BASINS Technical notes. The EPA has developed several technical notes that provide in depth information on a specific function in BASINS. Technical notes can be used to answer questions users may have, or to provide additional information on the application of features in BASINS.

These notes can be found in PDF form from [www.epa.gov/exposure-assessment-models/basins-technical-notes](http://www.epa.gov/exposure-assessment-models/basins-technical-notes). There are 12 in total and the titles are given below. These guides are highly useful and should be consulted before any HSPF work is to be done.

- 1- Creating Hydraulic Function Tables (FTABLES) for Reservoirs in BASINS
- 2- Two Automated Methods for Creating Hydraulic Function Tables FTABLES
- 3- WinHSPF Simulation Module Matrix
- 4- Incorporating Upstream Flow and Water Quality Time Series in the Source Model
- 5- Using HSPEXP with BASINS
- 6- Estimating Hydrology and Hydraulic Parameters for HSPF
- 7- Addendum: Additional Notes for HSPF Users
- 8- Matching STORET Parameters with HSPF Output
- 9- Sediment Parameter and Calibration Guidance for HSPF

- 10- Web Based HSPF Toolkit to Support Low Impact Development LID and Other Urban Stormwater Modeling Applications
- 11- Using the BASINS Meteorological Database Version 2006
- 12- Infiltration BMP Tutorial for HSPF

### B.3 Summary of Data Import Scripts

Both HSPF and WDMUtil only allow certain data to be input into them in certain file formats. Most can be created in Excel, then saved as a .csv to be input into the program. Below are some formats (Table B.1) that the programs can accept. If you have download BASINS, samples of these formats can be found in the model’s subfolder as shown below (Figure B.3).

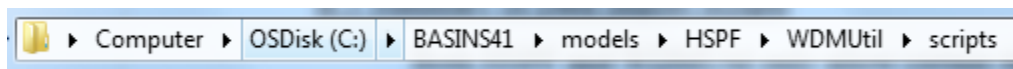


Figure B.3 Location of Import Sample Scripts

Table B.1 Data Format Descriptions for WDMUtil

Script File Name	Description of Data Format Script Reads	Sample Data File
<u>HPCP_NCDC_Arch.ws</u>	Hourly Precip, Archive Format, TD-3240	lthaca_prec.ncd, ncdc.ncd
<u>HPCP_NCDC_OL.ws</u>	Hourly Precip, On-Line Format, NCDC TD-3240	aberdeen.ncd
<u>IdStMet_DLY.ws</u>	Idaho State Climate Services Daily Format	fennrs.log
<u>MultiCol7_Wid10_Mon.ws</u>	Multi-Columns (7) of Width 10, Monthly Values	acpoint.prn
<u>SimpDly_MDY.ws</u>	Simple Daily Value Format-mm/dd/yyyy	usgsfecal.prn
<u>SimpDly_YMD.ws</u>	Simple Daily Value Format-yyyy/mm/dd	
<u>SimpHrly_YMDH.ws</u>	txtScriptDesc	
<u>SOD_OL.ws</u>	Summary of the Day TD-3210	Bing_SOD.ncd
<u>SOD_OL_Coop.ws</u>	Summary of the Day, On-Line, Coop	Amherst.ncd
<u>SurfAir_Hrly_Arch.ws</u>	Surface Airways Hourly Data, Archive Format, TD-3280	surface.ncd
<u>UsgsDvWeb_MDY.WS</u>	USGS Daily Web Values (mm/dd/yyyy)	hist_littleyellow.cgi
<u>UsgsDvWeb_YMD.ws</u>	USGS Daily Web Values (yyyy/mm/dd)	tendall.rdb

<u>WDMUtil_Dly.ws</u>	WDMUtil Export Format - Daily Values	tmax.exp
<u>WDMUtil_Hrly.ws</u>	WDMUtil Export Format - Hourly Values	prec.exp

#### B.4 BASINS File Attribute Tables

When using the Models:HPSF tool (Figure B.4), check to insure Basin # and Basin Downstream # are sequential.

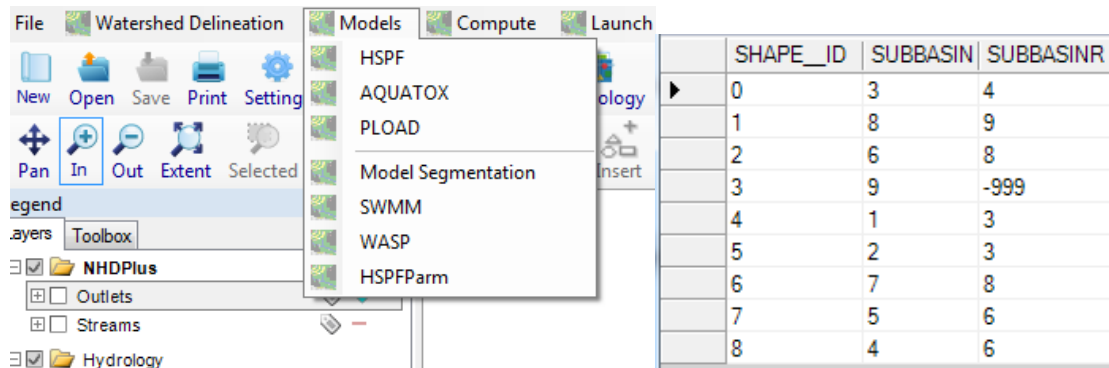


Figure B.4 HSPF Tool in the Models Tab and Attribute Table for Streams

No large value basins can flow to a lesser valued basin. (e.g. Subbasin 4 flows to Subbasin 5 is good, Subbasin 6 flows to Subbasin 2 will crash). This data is found in the Stream file, however the streams match with a corresponding catchment, so if the Stream file is altered, the Watershed file must be also. The Outlet file is just a point file that contains latitude and longitudes for the catchment outflow points. This file is less of a challenge than the other two. As long as the point corresponds to the correct catchment there are no problems, a few feet off will not cause a crash, however 100 ft wrong in any direction will.

	SHAPE_ID	ID	PCSID	Xpr	Ypr
	0	1		-130982.58	3379693.27
	1	2		-131332.32	3377828.91
	2	3		-131332.3	3377828.91
	3	4		-132334.28	3376425.98
	4	7		-133145.62	3374447.52
	5	6		-132475.66	3376446.89
	6	5		-132334.29	3376425.98
	7	8		-133145.6	3374447.49
*					

Figure B.5 BASINS Outlet point file

## B.5 Stream File Attribute Table

For a stream file, the first column to check is the SUBBASINR. This is the catchment directly downstream of the current catchment. While BASINS usually gets this right, if it does not, the watershed model will be very incorrect. Also, sometimes the Final outlet values will not be -999 (HSPF requires this value), so ensure that it is correct.

Elevation values for Max must match the Min of the upstream basin. Elevation values for Min must match the Max of the downstream basin. It can be considered obvious that BASINS will use the DEM to correctly input this field into the Stream file, since the DEM is physically only elevation data. However, this is wrong. BASINS uses the DEM for this, but there are rounding errors. Below is an example (Table B.2) where the elevations of this stream file don't match. Subbasin 3 goes from 21 to 20 ft. and flows to Subbasin 4. However, Subbasin 4 starts at 21 ft. Water cannot flow uphill, so the HSPF tool will crash.

Table B.2 Example Stream File with a Max/Min Elevation Error

SUBBASIN	SUBBASINR	LEN2	LAREA	TAREA	WID2	DEP2	MINEL	MAXEL	SLO2	SNAME
1	2	1966.03496	1879011.78	1879011.78	1.88342	0.16731	25	26	0.050865	Hammock Creek
2	4	1999.38106	4170918.68	6049930.46	3.79874	0.26708	21	25	0.2001	Hammock Creek
3	4	2176.74110	2493627.02	2493627.02	2.23197	0.18736	20	21	0.045935	Branch 1
4	-999	2023.06650	2066140.95	10609698.43	5.32122	0.33437	8	21	0.64259	Hammock Creek

This error results from some strange rounding issue. All the other fields are float values (many decimals places), but the elevations are integers. To fix the error an adjustment to the elevation in the problem catchment needs to be made. This will not affect the HSPF model because you can readjust the adjustment in the Reaches Tab in HSPF itself once BASINS creates the HSPF file. This is because the value is not 'wrong', just rounded.



ID	Description	Length (mi)	Delta H (ft)	DownstreamID	N Exits	Lake Flag
1	STREAM 1	1.65	3	3	1	0
2	Sandy Creek	1.97	30	3	1	0
3	Sandy Creek	2.03	39	7	1	0
4	STREAM 4	1.84	98	6	1	0
5	STREAM 5	1.15	69	6	1	0
6	STREAM 6	0.26	33	7	1	0
7	Sandy Creek	2.91	30	11	1	0
8	Wolf Creek	2.38	39	10	1	0
9	STREAM 9	2.74	52	10	1	0
10	Wolf Creek	3.08	43	11	1	0
11	Wolf Creek	1.15	23	12	1	0
12	Wolf Creek	0.15	7	0	1	0

Figure B.6 HSPF Reach Tab

### B.6 BASINS to HSPF error

Once the Model:HSPF tool is complete within BASINS 4.1, it will attempt to open the new .uci file in HSPF. It will appear that BASINS has failed to create the required HSPF file. However the .uci can't be opened in this way, due to some error in BASINS 4.1 coding (which may be fixed in future updates). To solve this error, just open HSPF or WinHSPF directly, then navigate to the .uci file directly, and it will open as expected.

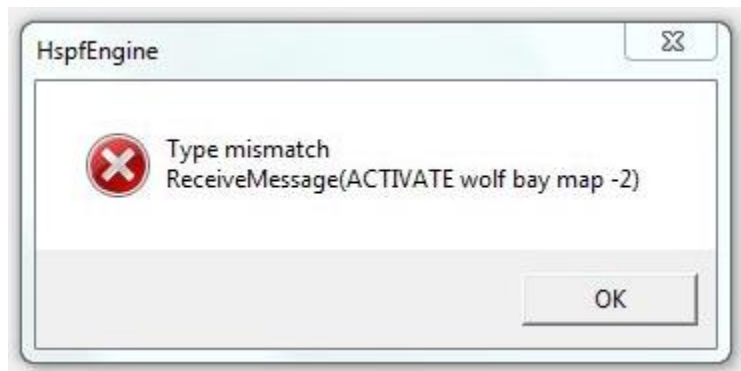


Figure B.7 BASINS to HSPF Creation Error

## B.7 HSPF File Locations

The HSPF .uci uses the file directory to find all the other files associated with it. This means that any change in file location will cause HSPF to crash due to a lack of required data.

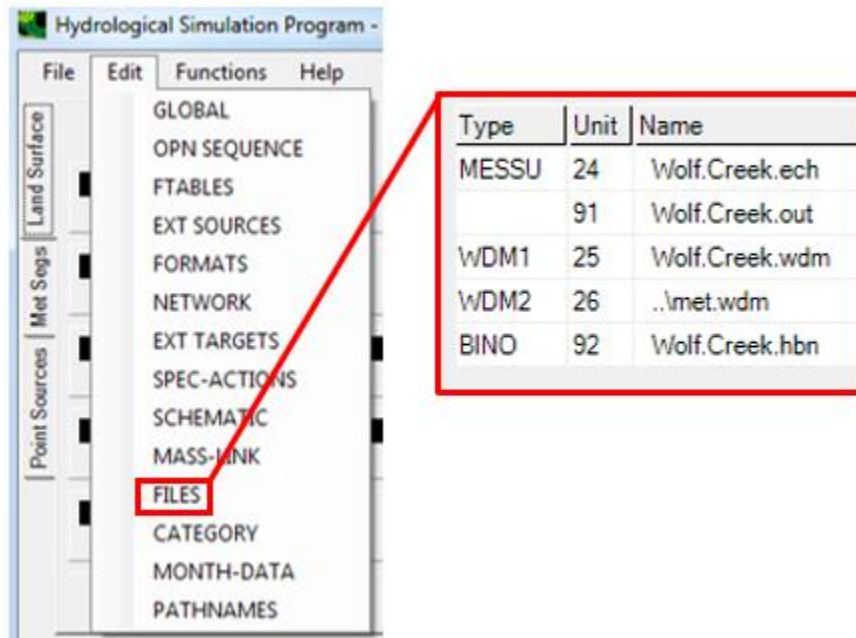


Figure B.8 Location and Content HSPF File Tab

This is usually not an issue to the Watershed, Outlet, or Stream files. However, it can become an issue for the WDM and Point source files. This is because these files are more likely to be edited and changed. Therefore, be very careful about changing these data files. The new file must already be created in the new location to change the Files Link in HSPF.

In addition, if the Folder with the HSPF files is moved, HSPF will no longer be able to open, due to a missing data error. All needed files must be moved to the new folder location first. Only then can the HSPF .uci file can be saved in the new location.

## B.8 HSPFParm function in WinHSPF

When trying to use HSPFParm to add parameters from previous studies to a new HSPF, the HSPF manual says that you can access HSPFParm from BASINS 4.1 and can export txt and .uci files. When this HSPFParm function is used in WinHSPF (Figure B.9) it asks for the location of HSPFParm.exe file, however, the executable is not provided with the Basins 4.1 installation.

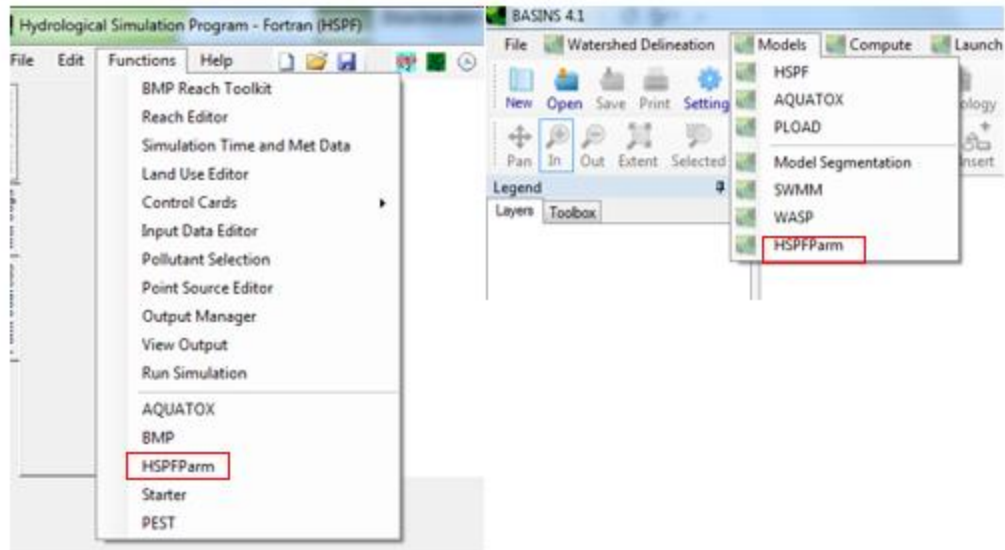


Figure B.9 Location of HSPFParm within BASINS and HSPF

The 'HSPFParm' button in WinHSPF is outdated; an earlier version of HSPFParm linked with a separate executable file, but now HSPFParm is a BASINS plug-in. The current intended workflow is to select your parameters in BASINS first and saving them to a report file. Then within WinHSPF, using the HSPFParm linkage you can open that report file and assign the values to your UCI.