Baldwin County Commission

& Highway Department

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Wolf Bay Watershed Study

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Prepared By:

HYDRO ENGINEERING SOLUTIONS

A DIVISION OF TRIMBLE

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1. Executive Summary

The study on the Wolf Bay watershed was performed to gain an understanding of the watershed and determine its sensitivity to land use changes in areas expecting growth in the near future. The information obtained can be used for future stormwater planning and management. The study was accomplished by looking at the basin as a whole and identifying areas were regional detention may or may not be needed. The method of analysis used for the study employed the use of the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) system. The two-dimensional overland flow model was calibrated to historic events for use in predicting watershed reaction to various land use changes.

Results of the findings for the Wolf Bay watershed indicates that undetained development in the headwaters of the sub-watersheds cause a greater impact to the peak discharges at the model outlet of the bay those in the lower part of the basin. For the watershed, regional ponds on the major creeks of the watershed provide regional stormwater management benefits for low-density development. The ponds would be ineffective at reducing increased discharges produced by commercial / high-density residential development back down to pre-development discharges.

The study also finds that development within the lower third of the watershed can be left undetained and cause no increased discharge at the selected outlet of the bay. Local streams experiencing increased discharges from the undetained areas must be examined further to ensure there is no stream degradation or increased flooding of adjacent property owners. Local detention may also be warranted to ensure the streams and habitat are not affected by accelerated runoff and volume increases.

Measures presented in this report are a solution to one conservative scenario. For actual future developments, the calibrated GSSHA model can be used as a dynamic management tool in which to analyze the impacts of these developments. Further studies outside of the model can also be performed on a smaller sub-basin level and then reintroduced back into the calibrated model to determine any possible impacts.

2. Introduction

2.1. Description

Wolf Bay is an estuary located in the southeastern part of Baldwin County, AL (Figure 2-1). Wolf Bay drains through a series of other bays and ultimately drains into the Gulf of Mexico. The portion of the watershed that is being analyzed for this study drains approximately 56 square miles. There are generally 5 sub-basins that make up the drainage area for Wolf Bay being studied (Figure 2-2). The major creeks that make up these sub-basins include Wolf Creek, Sandy Creek, Miflin Creek, Hammock Creek, Owens Bayou, and Graham Bayou. The southern end of the creeks experience daily tidal fluctuations with about 2 feet of change. There are two municipalities found within the study area. The first is Foley, which is located on the northwestern boundary of the Wolf Creek sub-basin. The second is Elberta, which is located in the northern part of the Miflin Creek Sub-basin. The municipalities of Gulf Shores and Orange Beach also drain into Wolf Bay, however this is below the area of interest.

The ADEM classification for Wolf Bay and all connecting coves and bayous is OAW / S / F&W / SH. The OAW (Outstanding Alabama Water) classification is the highest level of waterbody classifications. It indicates "high quality waters that constitute an outstanding Alabama resource of exceptional recreational and ecological significance." The OAW designation was granted in 2007. The other classifications indicate that the waterbody is also used for swimming (S), fish and wildlife (F&W), and shellfish harvesting (SH).

Figure 2-1
Location Map and Watershed Boundary

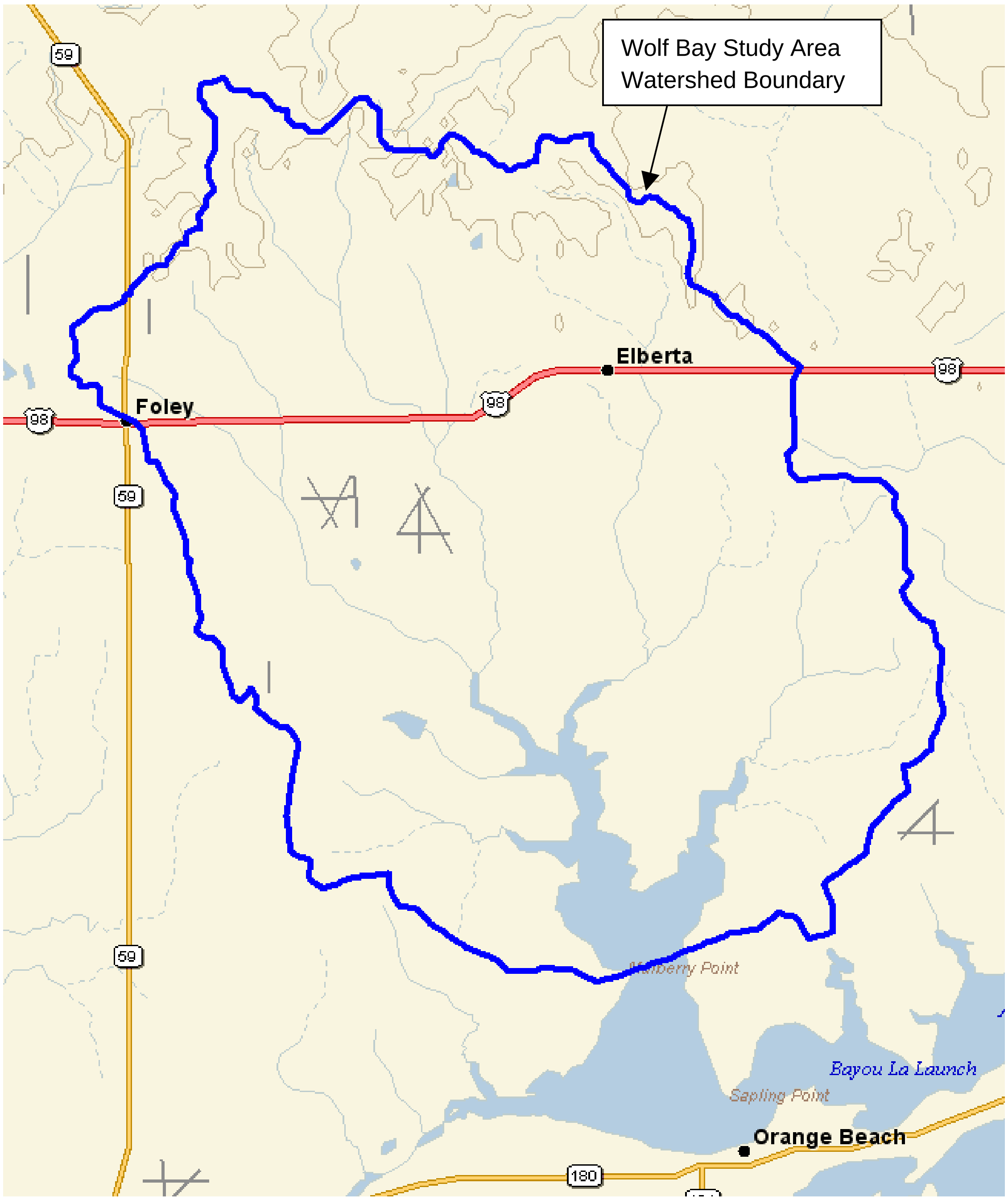
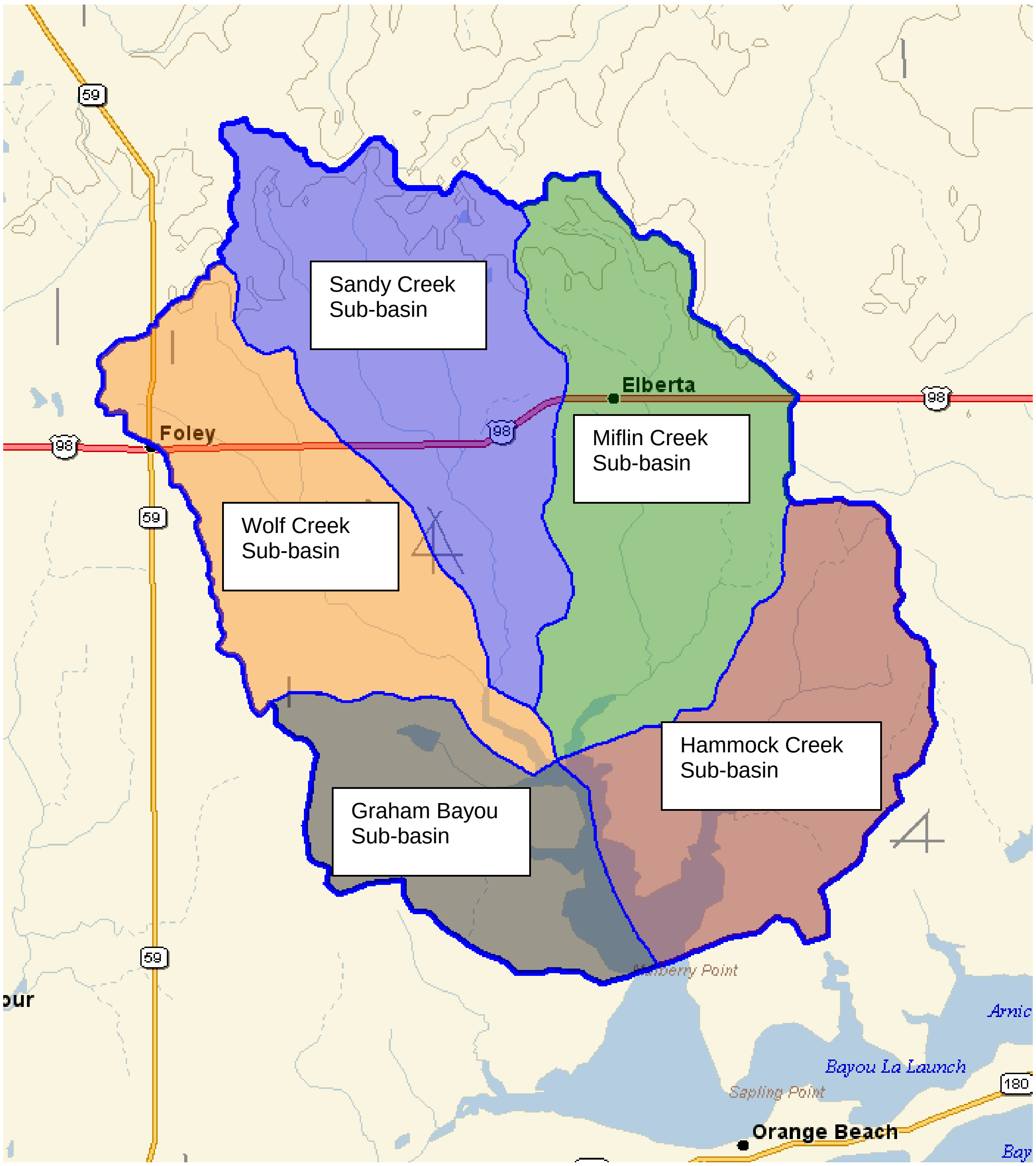


Figure 2-2
Wolf Bay Sub-basins



2.2. Climate

Baldwin County has a mild but humid climate. Data obtained from "weatherdb.com" indicates the average annual rainfall for Baldwin County (Foley and Elberta area) is around 61 inches. The summer months are typically the wettest with the winter typically being the driest months. The average high and low temperatures are 77 degrees and 55 degrees respectively. The warmest month is typically July with the coldest month being January.

Although the yearly rainfall is generally well distributed, significant rain events can be experienced in the watershed due to proximity to the coast and exposure to hurricanes. The hurricane season usually occurs in the late summer to early fall. Table 2-1 lists select hurricanes indicated by the date of occurrence, the hurricane name, and the range of rainfall related to the storm.

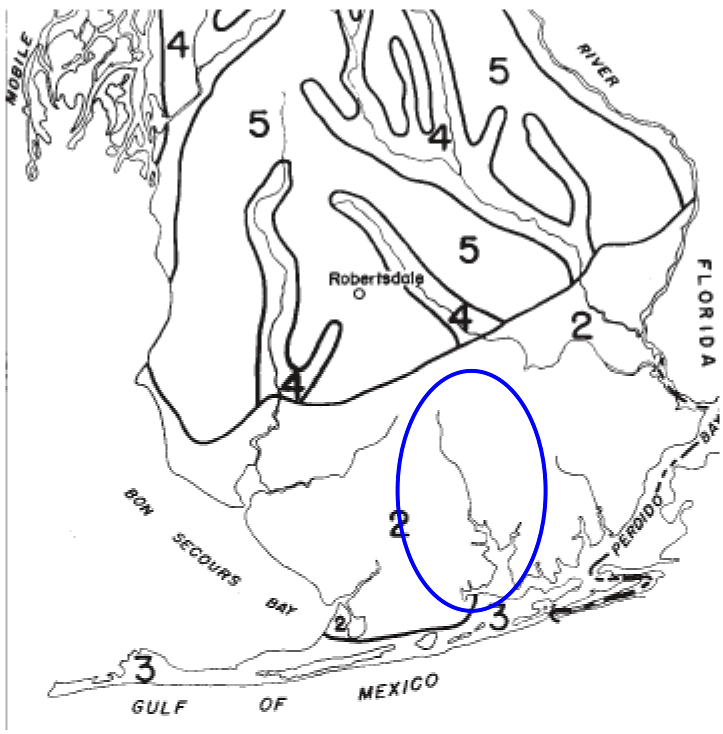
Table 2-1
Hurricane Event and Related Precipitation

Date	Hurricane	Precipitation (inches)
Oct 3-5, 1995	Opal	9-12
July 18-25, 1997	Danny	18-24
Sept 21-Oct 1, 1998	Georges	9-18
Sept 13-26, 2004	Ivan	7-10
July 5-13, 2005	Dennis	3-4
Aug 23-31, 2005	Katrina	2-3
Sept 1-4, 2011	Tropical Storm Lee	7-11

2.3. Physiography

According to the *Soil Survey of Baldwin County*, "Baldwin County is a part of the Gulf Coastal Plain physiographic region known as the Lower Coastal Plain. The county is underlain by five different kinds of deposits or geologic formations…" These are 1) River floodplains and terraces 2) Marine terraces 3) Areas of coastal beaches 4) Areas underlain by Hattiesburg clay and 5) Plateaus and ridgetops underlain by the Citronelle formation. The Wolf Bay watershed falls within area 2. Area 2 is underlain by deposits on marine terraces. This area is nearly level to gently sloping and is at an elevation that ranges from 10 to 100 feet above sea level. Figure 2-3 indicates the physiographic area of the study.

Figure 2-3
Physiographic areas of Wolf Bay Watershed



2.4. Land Use

According to *Baldwin County Profile – An Analysis of the Demographics and Other Characteristics that Constitute Baldwin County* published by the Planning and Zoning Department of the Baldwin Count Commission May 2008, the majority of Baldwin County is made up of agriculture, upland forested areas, and wetlands. These three land uses make up approximately 83.06% of the land use. Residential land use accounts for about 8.88% and commercial and industrial accounts for about 0.75%.

According to *Citizen Volunteer Water Monitoring on Wolf Bay* published by the Alabama Water Watch in 2008, the majority of the Wolf Bay Watershed is made up of agriculture, upland forested areas, and urban development. From 2005 data, these three land uses make up approximately 27%, 23%, and 27% of the land use respectively. As compared to 1992, agricultural and forested areas have decreased while urban development has increased. The percentages of land use in 1992 for agriculture, forests, and urban are 46%, 32%, and 4%. Water and wetlands for the area account for approximately 18% of the land use.

3. Model

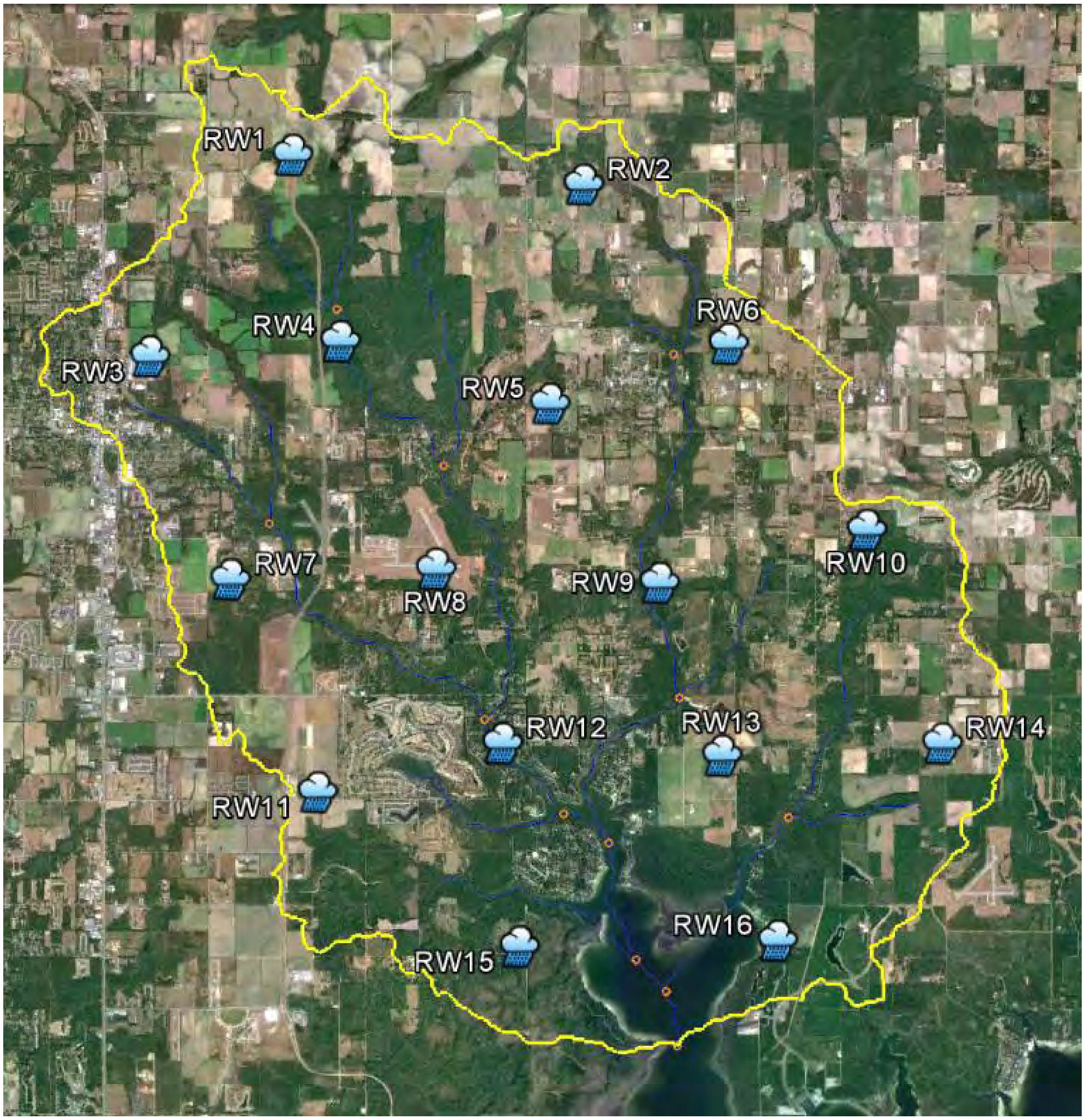
3.1. General

The hydrologic model used to evaluate the Wolf Bay watershed is the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model. GSSHA is a U.S. Army Corps of Engineers (USACE) physically-based, distributed parameter hydrologic model with sediment and constituent fate and transport capabilities. Features include two dimensional (2-D) overland flow, 1-D stream flow, 1-D infiltration, 2-D groundwater, and full coupling between the groundwater, shallow soils, streams, and overland flow. Sediment and constituent fate and transport are simulated in the shallow soils, overland flow plane, and in streams and channels. GSSHA can be used as an episodic or continuous model where soil surface moisture, groundwater levels, stream interactions, and constituent fate are continuously simulated. Parameters used to generate a GSSHA simulation include rainfall data, digital terrain data, land use data, and soils data. The Watershed Modeling System (WMS v8.4) was used as the graphical user interface for entering data in the hydrologic model.

3.2. Rainfall Data

One of the strengths of the GSSHA model is the ability to perform long-term simulations. A key element in forecasting discharges for future storm occurrences depends upon good rainfall data. For the rainfall component used in the simulations, Hydro-Engineering Solutions (HES) employed the use of RainWave. RainWave offers precipitation-monitoring services that allow a user to enter a latitude and longitude for a point of interest. Once this point is entered into the system, various rainfall data can be obtained. For the modeling simulations 5-minute rainfall intervals were utilized. This data can then be formatted for a GSSHA long-term simulation. Figure 3-1 indicates the RainWave point locations used for gathering rainfall distribution data.

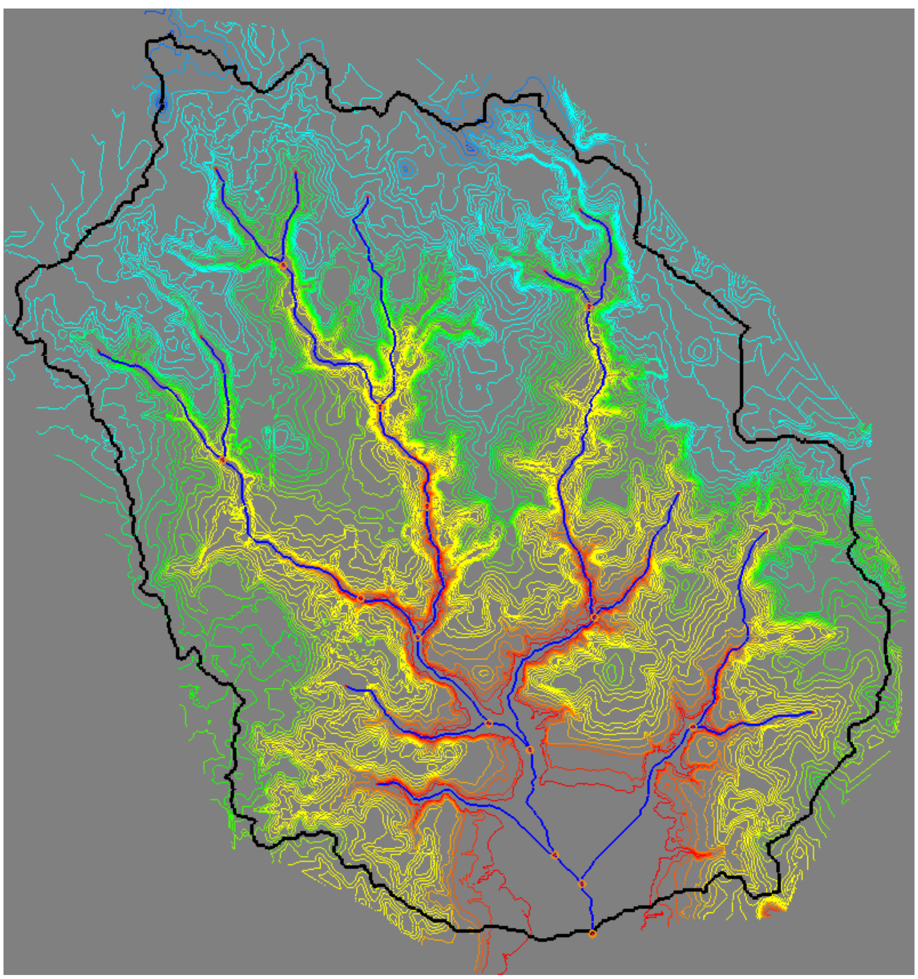
Figure 3-1
Wolf Bay Watershed with RainWave Point Locations



3.3. Digital Terrain Data

The GSSHA model uses digital terrain data to incorporate topography into the hydrologic model. For the model one-foot Light Detection and Ranging (LiDAR) data provided by Baldwin County was used to generate the digital elevation model (DEM). Due to the size of the drainage area, the file size of the LiDAR contours was too large for WMS to process. Contour intervals within the steep sections of the watershed that would not effect creation of the DEM were removed in order to reduce file size. Once the DEM was built, it was used for basin delineation. The DEM data was also used for generating cell elevations for the gridded model. Figure 3-2 indicates the topographic data that was used in the model.

Figure 3-2
Wolf Bay Watershed with Topographic Data



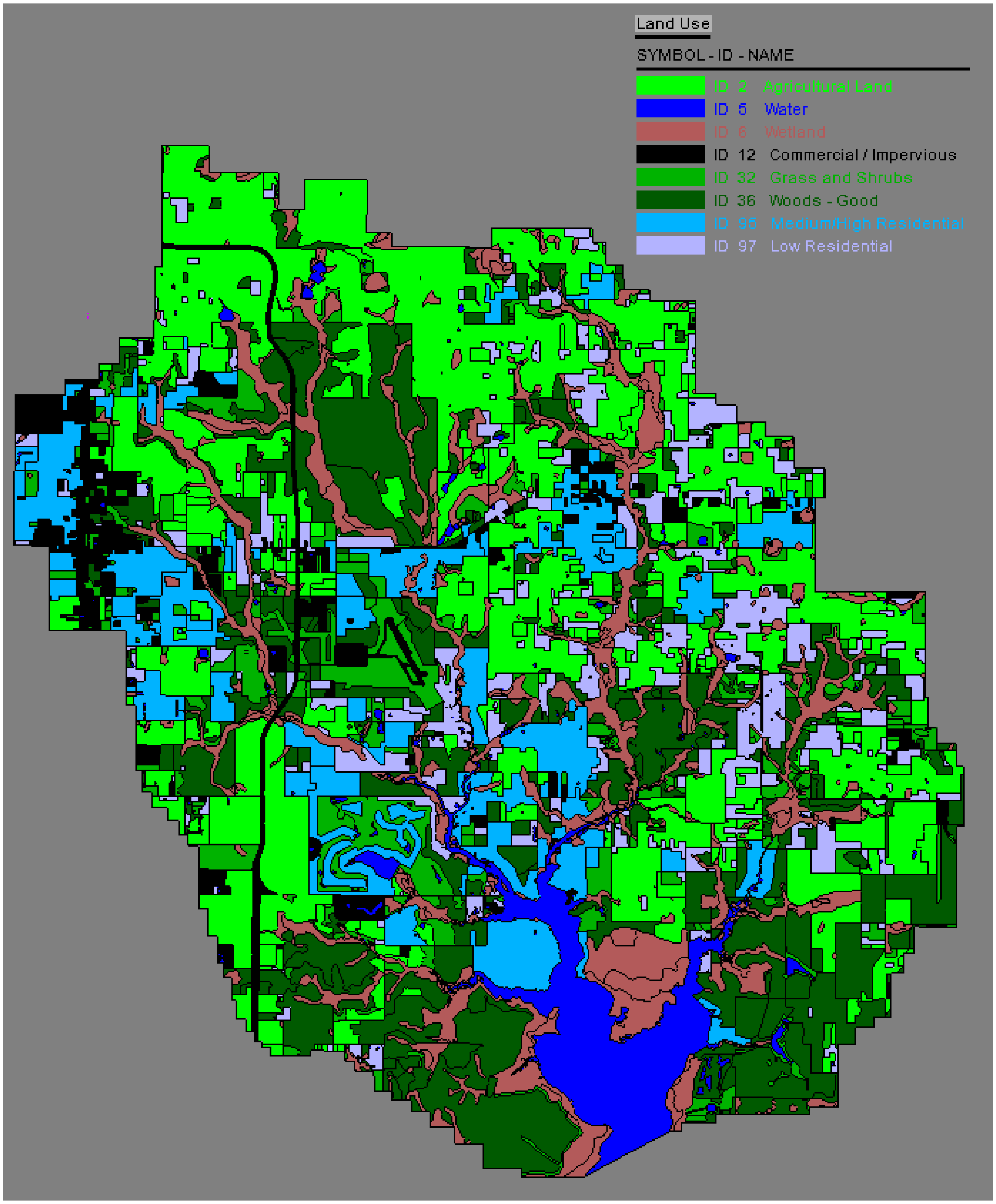
3.4. Land Use

The land use component of the model is necessary to define the various overland flow types throughout the basin. The roughness of each land use type is described by a Manning's 'n' value. A shapefile of the land use was provided by Baldwin County. The shapefile was converted to feature objects to be used in the model. It was necessary to simplify some of the land use descriptions for calibration purposes. Using geo-referenced aerial photography provided by Baldwin County, land use was checked to ensure all areas were properly assigned. Table 3-1 lists the land use types and the respective calibrated 'n' values assigned to them. Figure 3-3 indicates the land use assignments.

Table 3-1
Land Use and Calibrated Manning's 'n' Values

GSSHA ID	Land Use	Calibrated Manning's n
2	Agriculture	0.250
5	Water	0.150
6	Wetlands	0.180
12	Commercial	0.011
32	Grass / Brush / Shrubs	0.260
36	Woods – Good	0.320
95	Med Residential	0.090
97	Low Residential	0.110

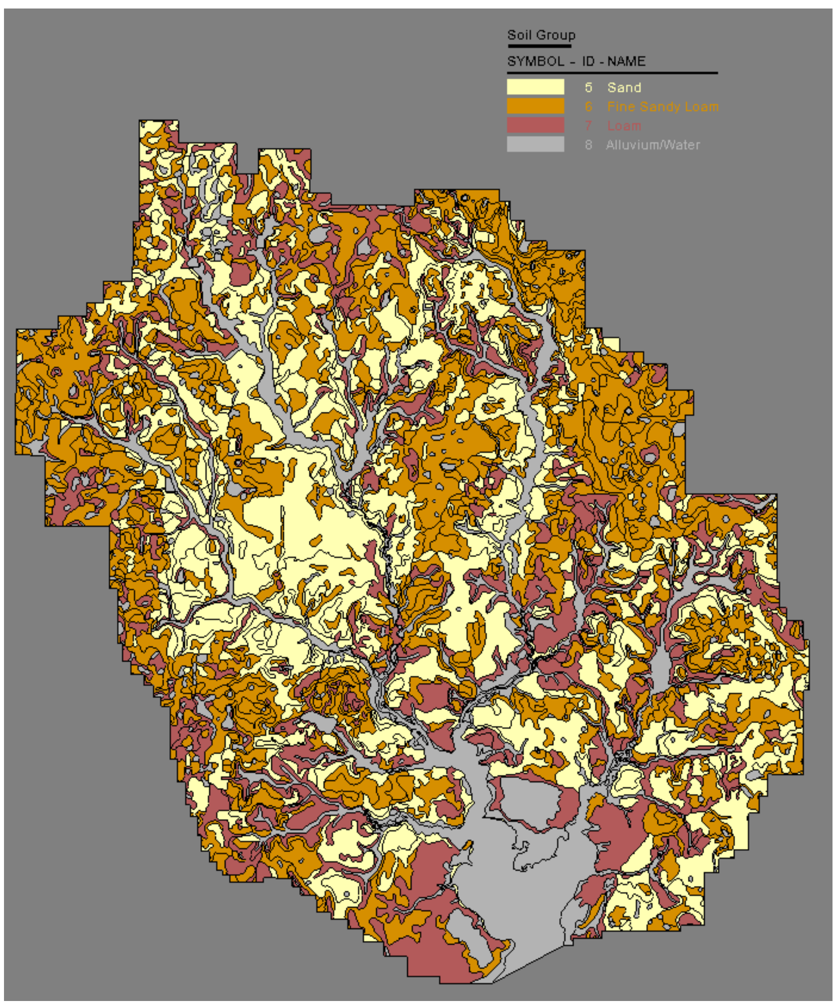
Figure 3-3
Wolf Bay Watershed with Digitized Land Use



3.5. Soils

Similarly to the land use, the GSSHA model has the capability to incorporate specific characteristics of the soils located within a drainage basin. The soils coverage is used for defining infiltration into the soil. The infiltration method used is Green and Ampt (G&A) with soil moisture redistribution. Soil parameters used by the G&A method include hydraulic conductivity, porosity, capillary head, pore distribution index, residual saturation, and field capacity. This allows the GSSHA model to evaluate the soil's ability to infiltrate stormwater runoff in determining the peak discharge and volume of storm events. Soils data shapefiles provided by Baldwin County were converted to feature objects to be used in the model. Figure 3-4 indicates the soil data that has been incorporated into the model.

Figure 3-4
Wolf Bay Watershed with Digitized Soil Type



3.6. Gridded Model

Once all of the variables mentioned above have been incorporated into the model, it was necessary to divide the model into individual grid cells. For the Wolf Bay model a 70 meter x 70 meter (230 feet x 230 feet) grid size was utilized (Figure 3-5). The settings for GSSHA require the units to be in the International System of Units (SI). The total drainage area to the designated outlet is approximately 56 square miles. Over the entire watershed this generates approximately 25,900 grid cells. Figures 3-6 and 3-7 indicate the gridded land use and gridded soil types.

Figure 3-5
Wolf Bay Gridded Watershed - 230' x 230' Grid Cell Size

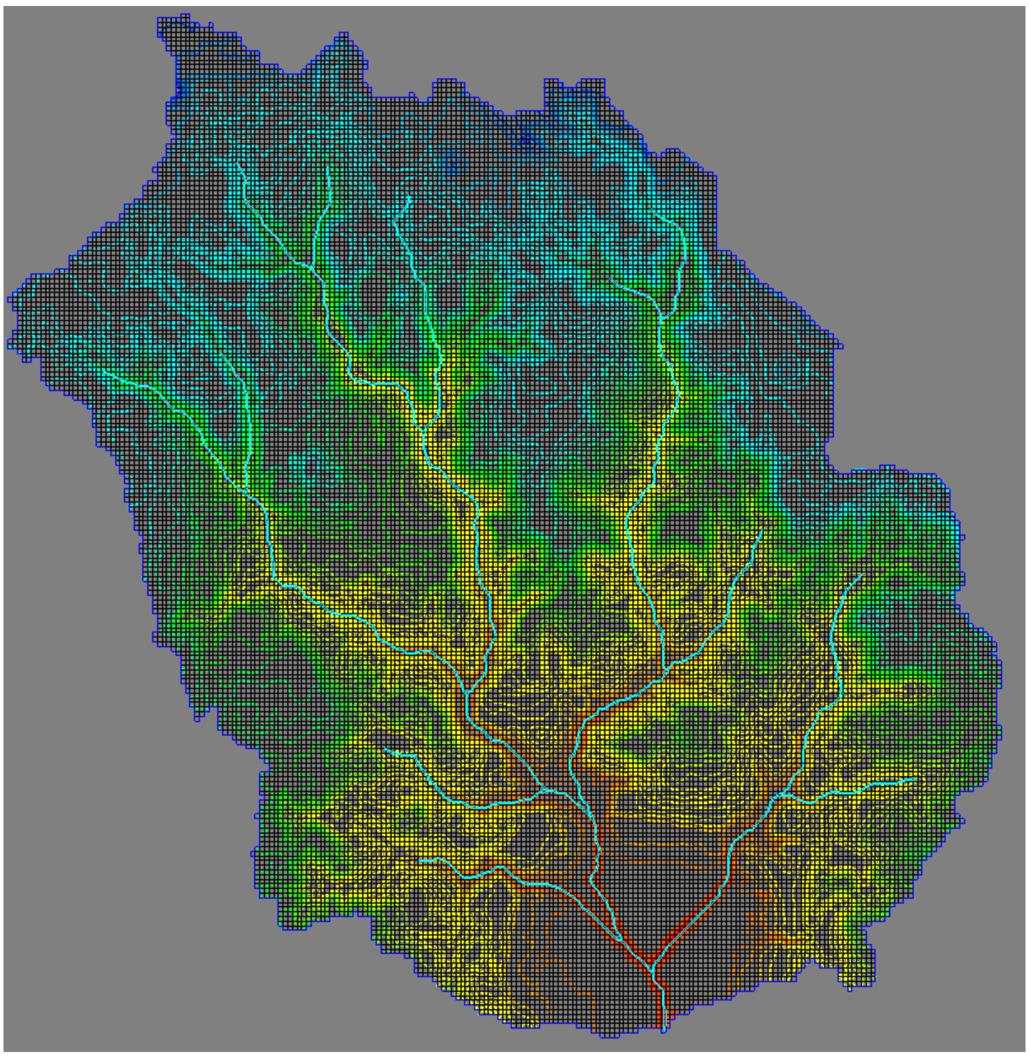


Figure 3-6
Wolf Bay Watershed Gridded Land Use

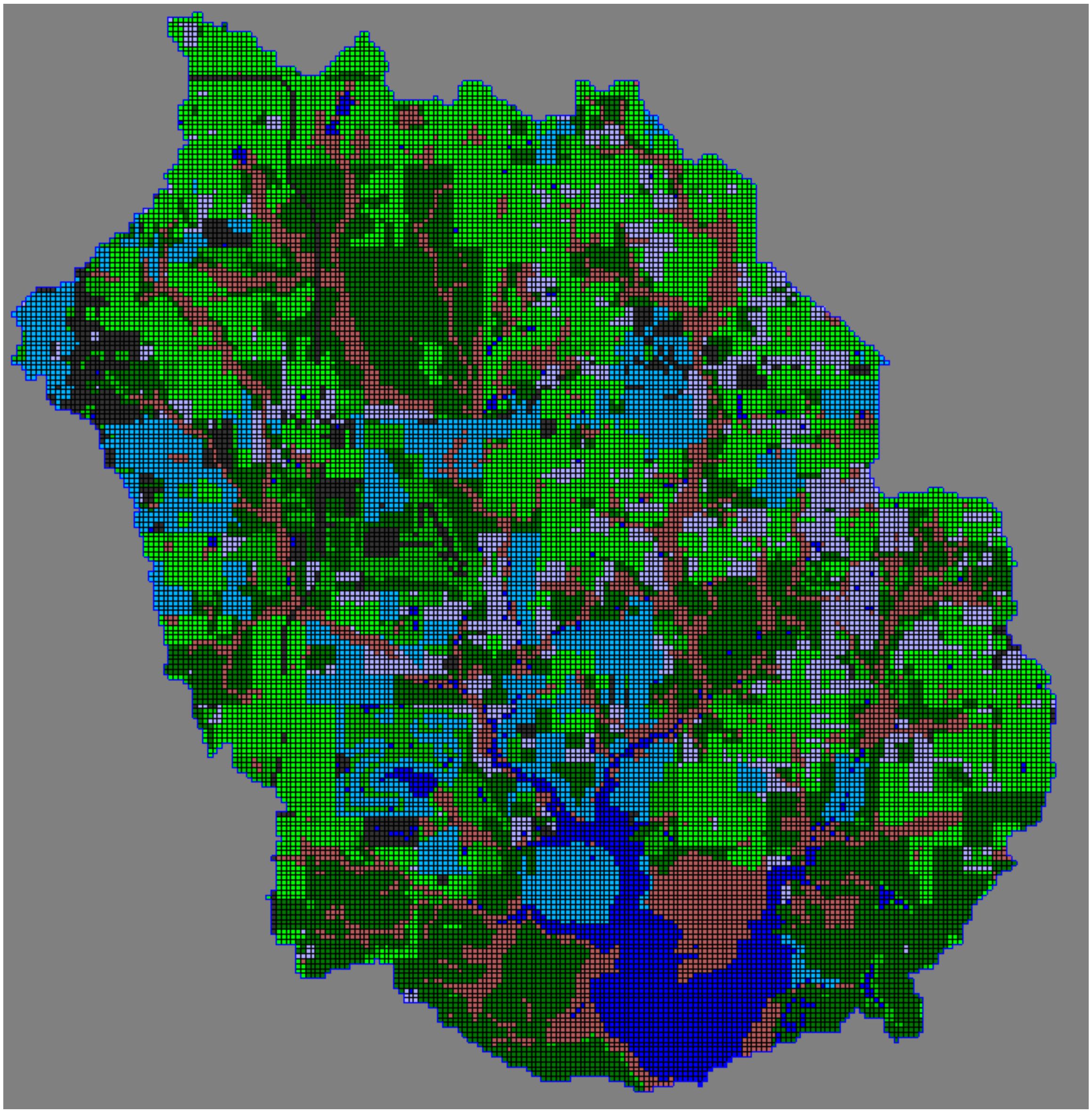
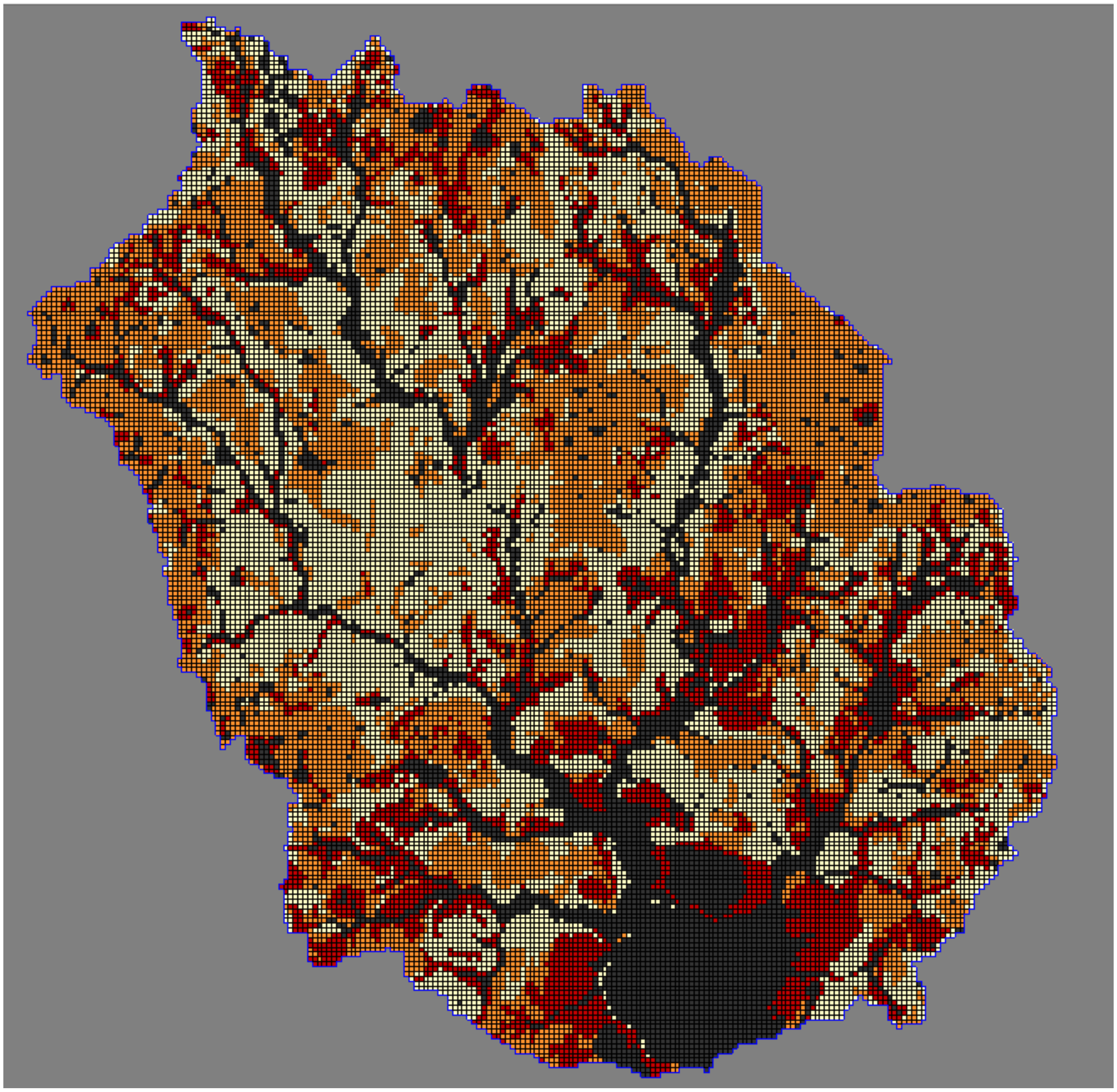


Figure 3-7
Wolf Bay Watershed – Gridded Soil Types

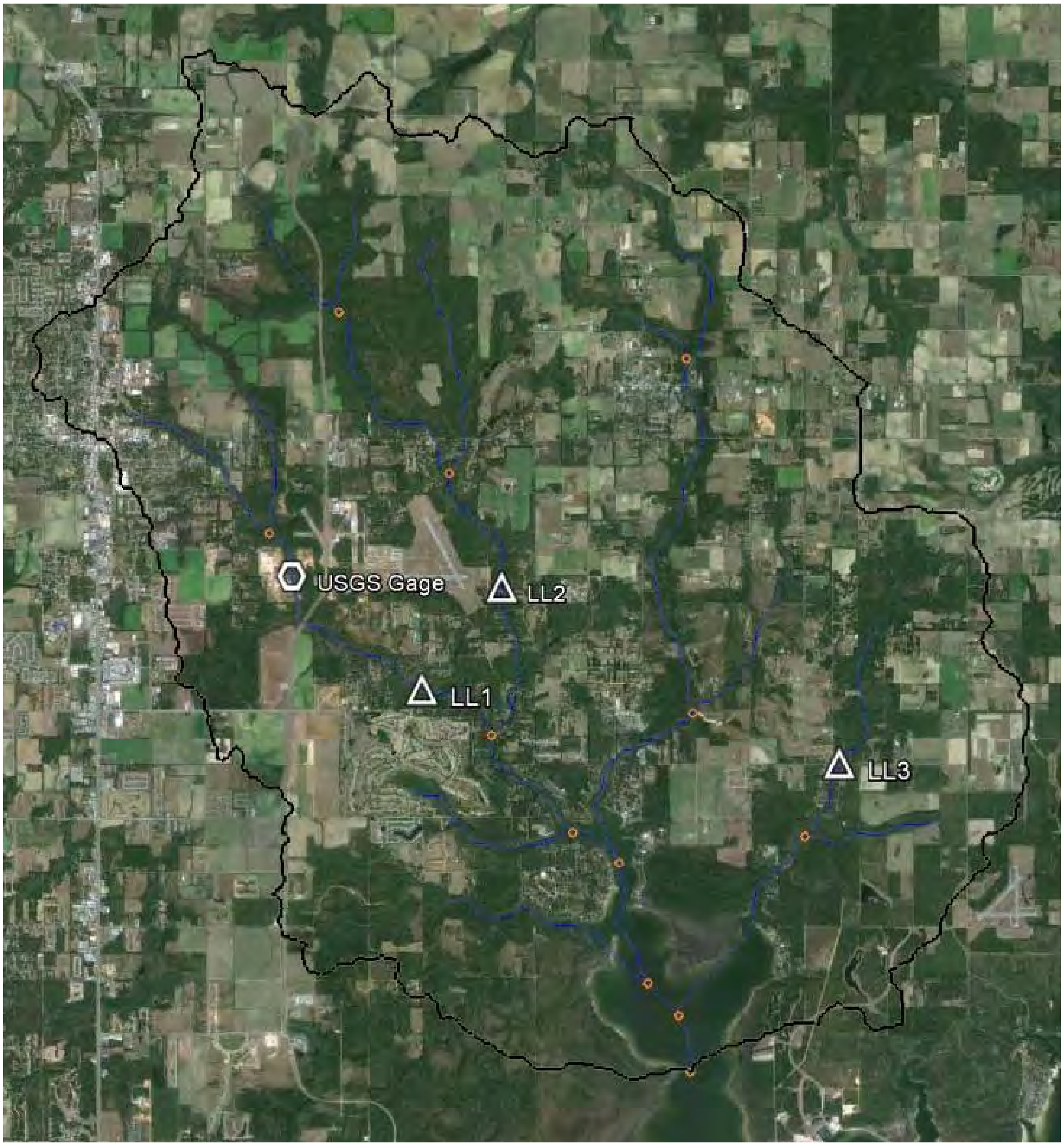


3.7. Calibration

For a model to be used for forecasting it is best to calibrate to real world storm events. Calibration requires both historic rainfall data and river water surface elevations (stages) or discharges during the rain event. With the rainfall being obtained by RainWave, it was necessary to find or install gauges in the watershed to determine stream stages. A site visit was performed in order to determine the best location for installing the monitoring gauges. The USGS currently has an operating gauge on Doc McDuffie Road over Wolf Creek (USGS 02378170). Available parameters for this site are discharge and gage height. Three Solinst Leveloggers were installed throughout the Wolf Bay Watershed (Figure 3-8). The first gauge was installed on Swift Church Road over Wolf Creek. The second gauge was installed on Sandy Creek located in the property boundary of the Barin Nolf Naval Airfield. The last gauge was installed on CR 20 over Hammock Creek. These locations were chosen in order to maximize the drainage area in which to calibrate, for ease of access, and for limiting the possibility of being tampered with. Due to the very flat topography, these sites experience tidal influence.

The leveloggers were installed on May 28, 2013. After installation, the watershed experienced a rain event on June 9, 2013. This rainfall event was used for the initial calibration. The maximum average rainfall over a 24-hour period was around 3.0 inches. This occurred between 7:00 p.m. on June 8th to 7:00 p.m. on June 9th. The maximum rainfall during that time was 4.3 inches, which occurred at RainWave gauge points 5 and 6. After downloading the levelogger data, the rainfall was not significant enough to generate high enough stages at the three leveloggers in which to calibrate. The USGS gauge located on Doc McDuffie road was used for calibration.

Figure 3-8
Wolf Bay Watershed with Levelogger Locations



An individual model was built just to this gauge and an auto-calibration was performed through GSSHA. Calibration of the model requires adjustment of the key parameters that affect infiltration, overland flow, and channel routing. The variables that are usually examined are hydraulic conductivity, overland roughness, soil moisture depth, top layer depth, and channel roughness. These values were adjusted until the model output best fit the observed data. The parameters were taken from this smaller model and entered back into the large model.

A month later the watershed experienced a larger more significant event on July 4, 2013 (Figure 3-9). For this storm the maximum average rainfall over a 12-hour period was around 5.7 inches. This occurred between 7:00 p.m. on July 3rd to 7:00 a.m. on July 4th. The maximum rainfall during that time was 6.8 inches, which occurred at RainWave gauge point 10. The parameters from the original calibration were used to run the model with the new rainfall event. Adjustments were made to the variables in order to better match storm peaks and volumes to the larger rain. Plots of the 5-minute rainfall and the cumulative rainfall for the July 4th event can be found in Figures 3-10 and 3-11. Figures 3-12 to 3-15 indicate discharges associated with the July 4th event verses the calculated GSSHA model discharges. It should be noted that the leveloggers experience tidal fluctuations. In order to simplify boundary conditions as well as reduce computation time, downstream stages representing tidal fluctuations were not coded into the model. The model was adjusted to best match the peak discharge as well as the timing of the peak discharge to the levelogger data.

Figure 3-9
Wolf Bay Watershed with Cumulative Rainfall Data for July 4th Event

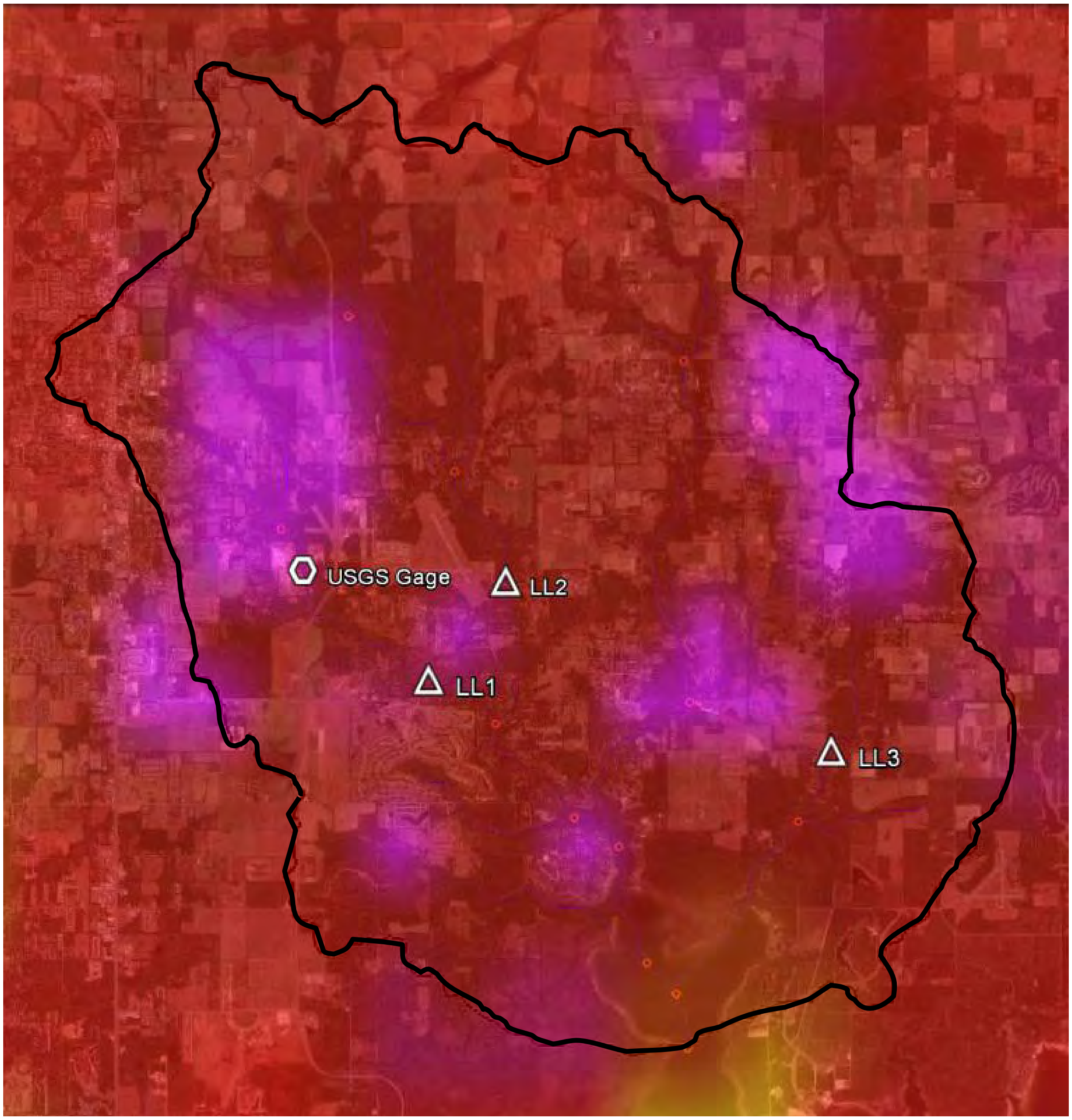


Figure 3-10
Wolf Bay Watershed – Rainfall Distribution

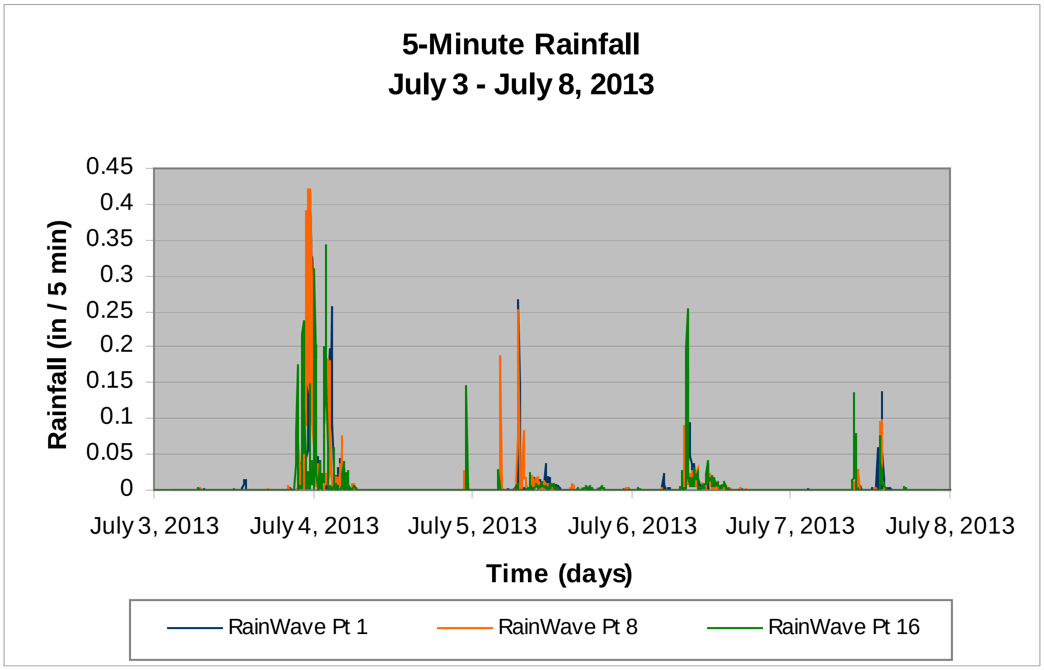


Figure 3-11
Wolf Bay Watershed – Cumulative Rainfall

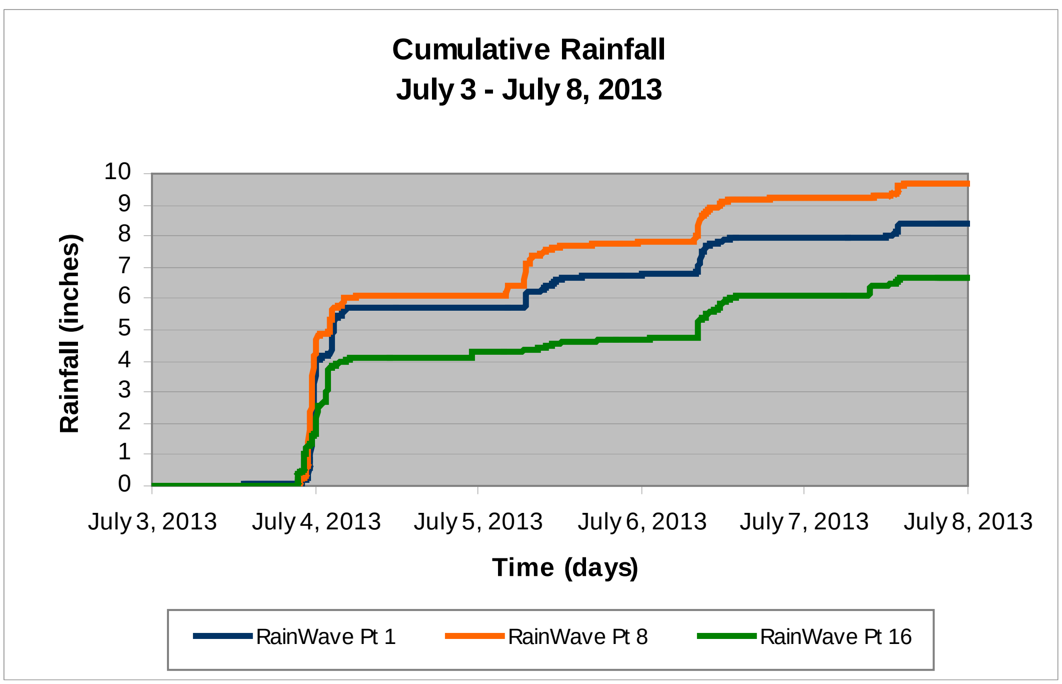


Figure 3-12
Wolf Bay Watershed – Doc McDuffie Road Calibration

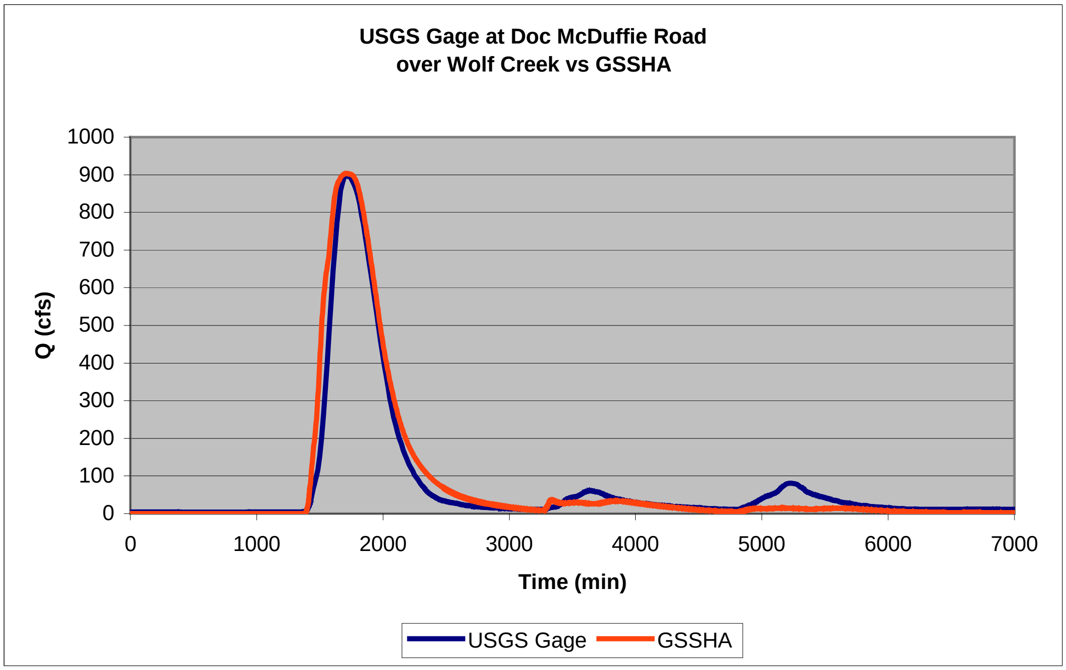


Figure 3-13
Wolf Bay Watershed – Swift Church Road Calibration

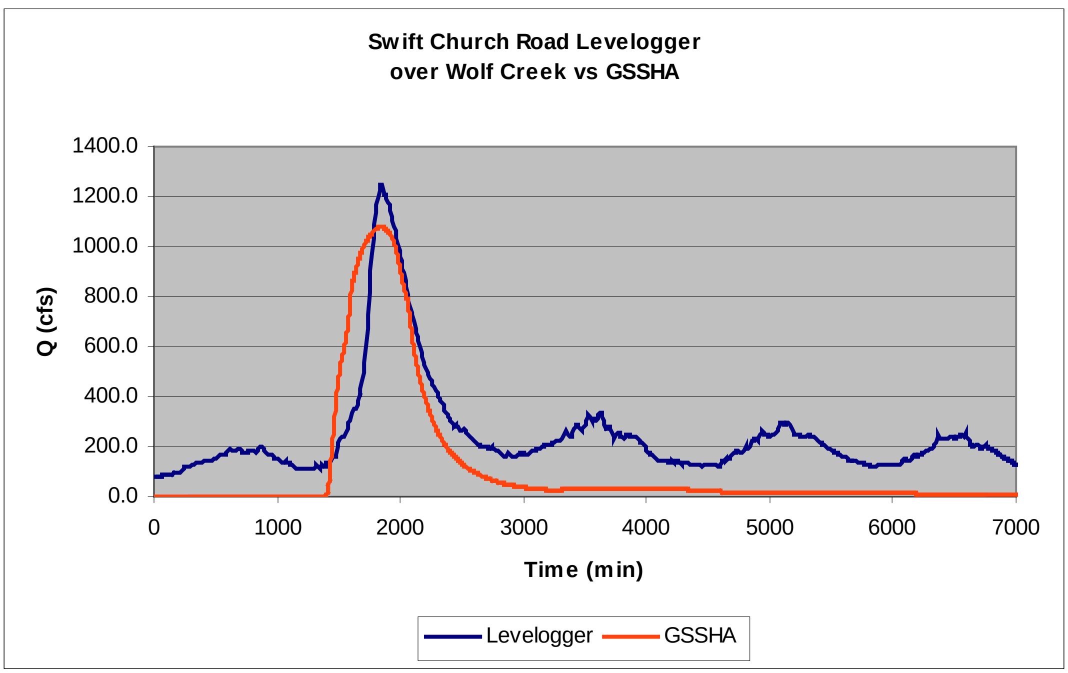


Figure 3-14
Wolf Bay Watershed – Sandy Creek Calibration

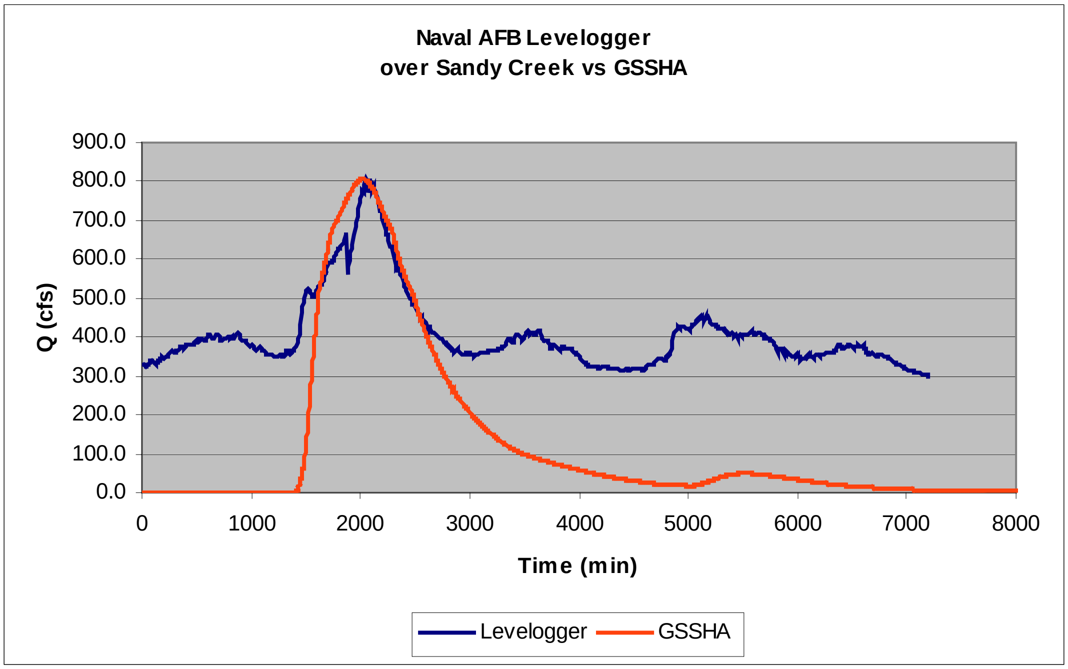
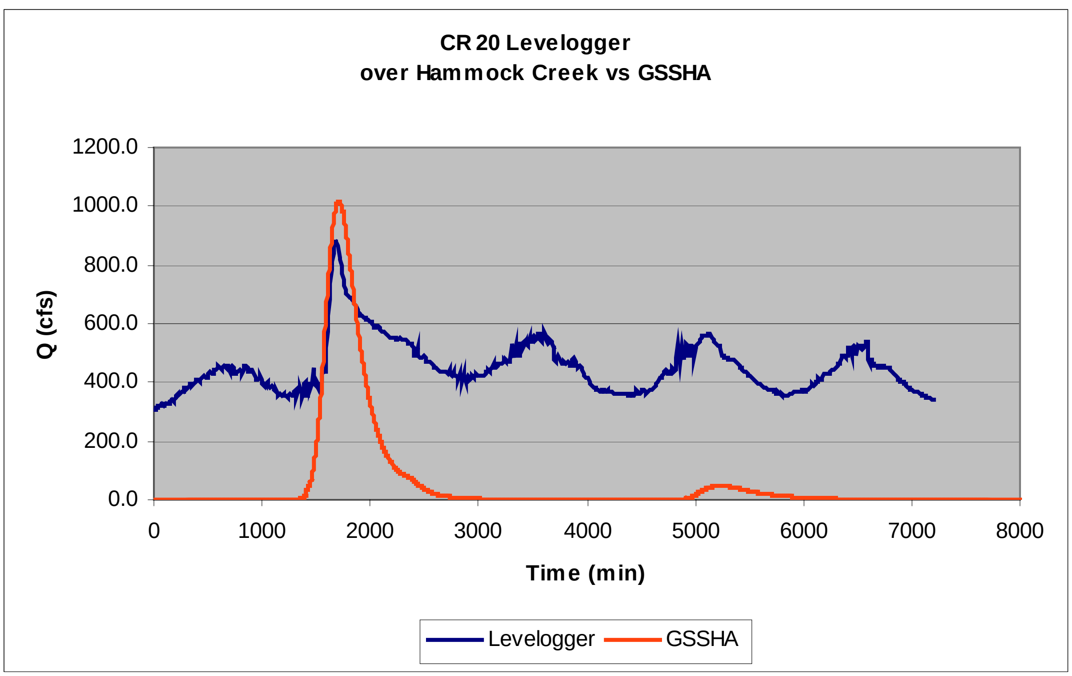


Figure 3-15
Magnolia River Watershed – Hammock Creek Calibration



4. Analysis

4.1. Watershed Analysis

After the model was calibrated, the precipitation and rainfall distribution were changed in order to analyze a 100-yr 24-hour storm event. The 100-year 24-hour rainfall amount for the drainage basin was taken from *Technical Paper No. 40 Rainfall Frequency Atlas of the United States* (TP 40). It was determined the average rainfall amount over the watershed is 14.1 inches or 358 millimeters. The rainfall distribution employed was the SCS Type III distribution. The model was rerun with the previously calibrated parameters and the discharges were examined at the outlet, and other areas of interest throughout the watershed. The publication *Magnitude and Frequency of Floods in Alabama, 2003 USGS Scientific Investigations Report 2007–5204* was used in order to compare the calibrated model discharges to the regression equation discharges. From “Table 2 Regional flood-frequency relations for rural streams in Alabama” the 100 year recurrence interval in years for Region 4 is approximated using the equation $Q=1,036A^{0.578}$. Substituting the drainage area of 56.08 square miles for the Wolf Bay study area into the equation yields a 100-year peak discharge of 10,620 cfs. The 100-year calculated discharge from the model compares favorably with a value of 10,880 cfs.

After verifying the calibrated model with the 100-year discharges, different scenarios were performed to see how the watershed reacted to various changes within the basin. A future land use map provided by Baldwin County was used as an initial guide for the analysis. In order to determine the approximate amount of land use to develop, historical imagery was used to determine the approximate percent developed in the watershed. Using a 1998 and 2013 aerial photograph provided by Google Earth the developed areas were delineated. The percent difference was calculated between the two in order to determine an approximate growth rate. Taking the amount of development used in the GSSHA model and comparing it to the rate of increase listed above, it was determined that the GSSHA model has an increased rate over the 1998 to 2013 rates providing for a conservative model.

The current land use of the basin is indicated in Figure 4-1. Scenarios consisted of adding development to various locations in the watershed (Figures 4-2 through 4-5). The main location of development is projected to occur along the Foley Beach Express. The extents of development were taken approximately 0.4 miles on each side of the road. These extents were run for both an aggressive commercial / high residential buildout as well as a low / medium density residential buildout. Foley and Elberta are the two main municipalities in the watershed. Future land use changes entered into the model for Foley include both commercial and residential development. Only residential development was included around the Elberta area. Low to medium density residential development was also included in the eastern portion of the watershed along Old CR 95.

The next set of objectives was to analyze possible areas for regional detention (Figure 4-6). The drainage to Wolf Bay consists of separate distinct watersheds. As mentioned earlier in the report these sub-watersheds are the Wolf Creek, Sandy Creek, Miflin Creek, Hammock Creek, and Graham Bayou sub-watersheds. Regional ponds were located in each watershed to determine the impact they may have. A pond was not analyzed for the Graham Bayou sub-watershed due to the large existing pond on Owens Bayou as well as the location of the sub-watershed being in the lower quarter of the entire Wolf Bay watershed. Ponds were located based on the location of proposed development, the amount of contributing drainage area to the ponds, and in areas that would not impact adjacent homeowners.

Figure 4-1
Land Use - Existing Conditions

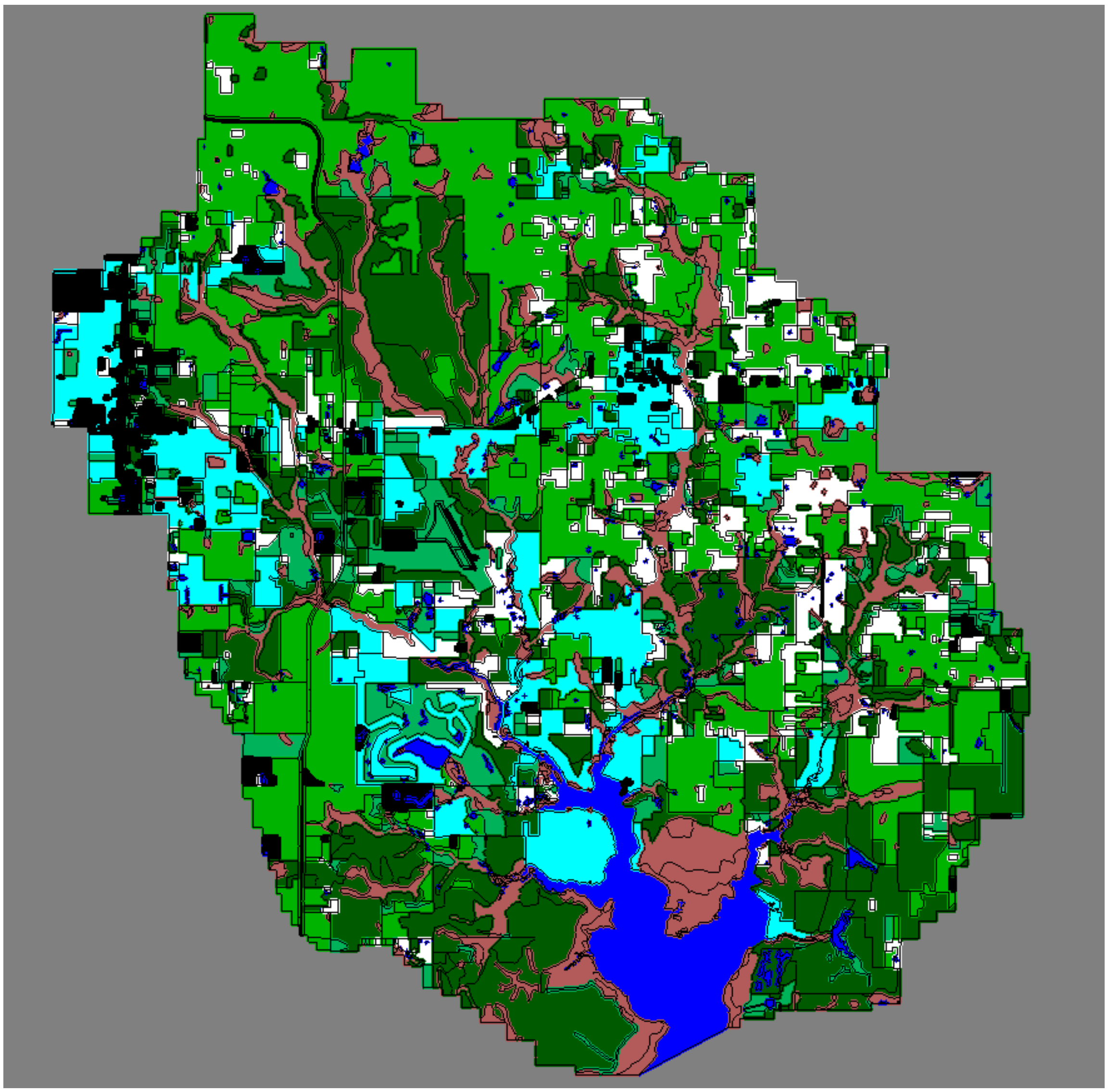


Figure 4-2
Land Use – Foley, Foley Beach Express, Elberta, Old CR 95 Development

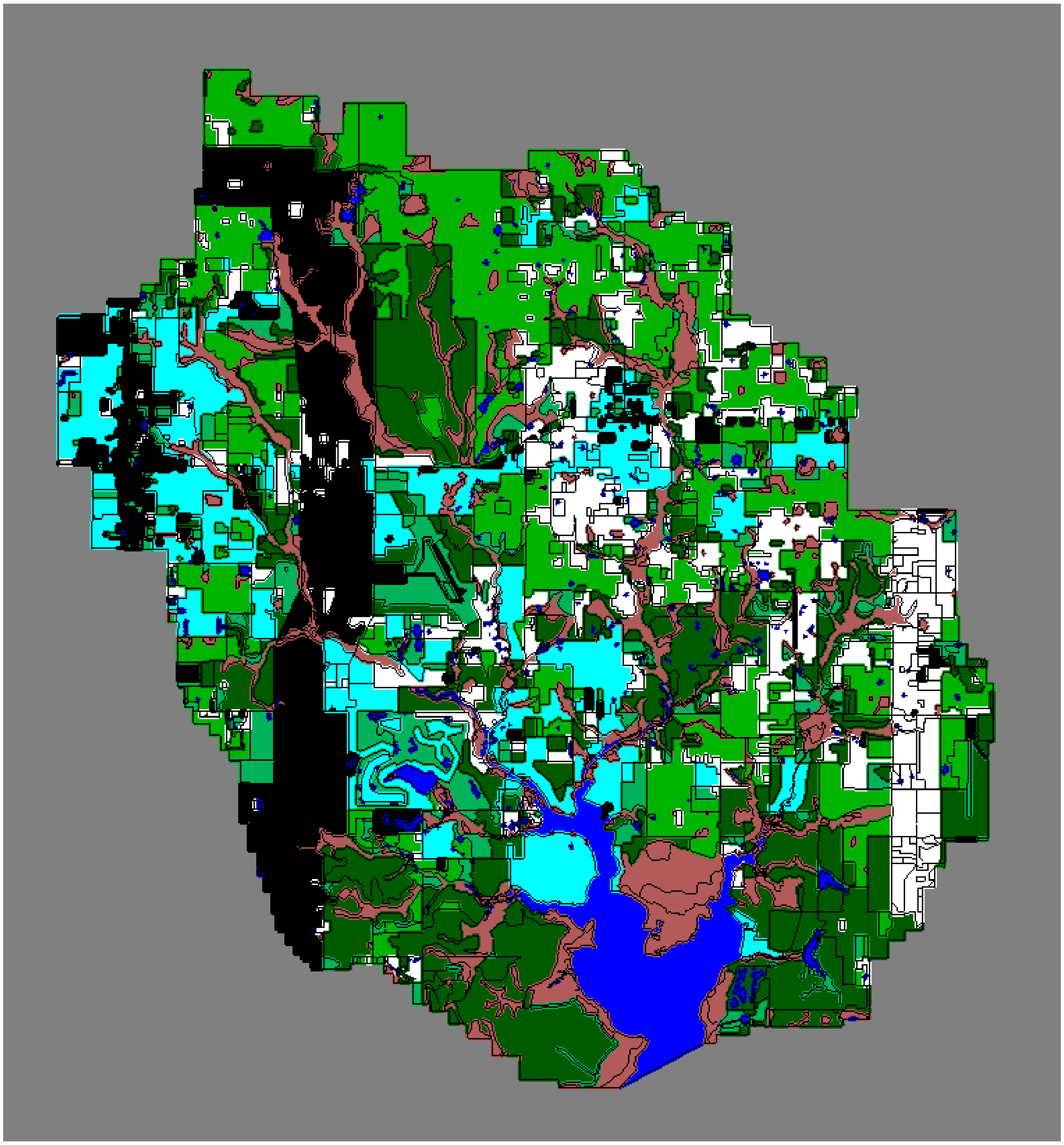


Figure 4-3
Land Use – High Density Lower Basin Development

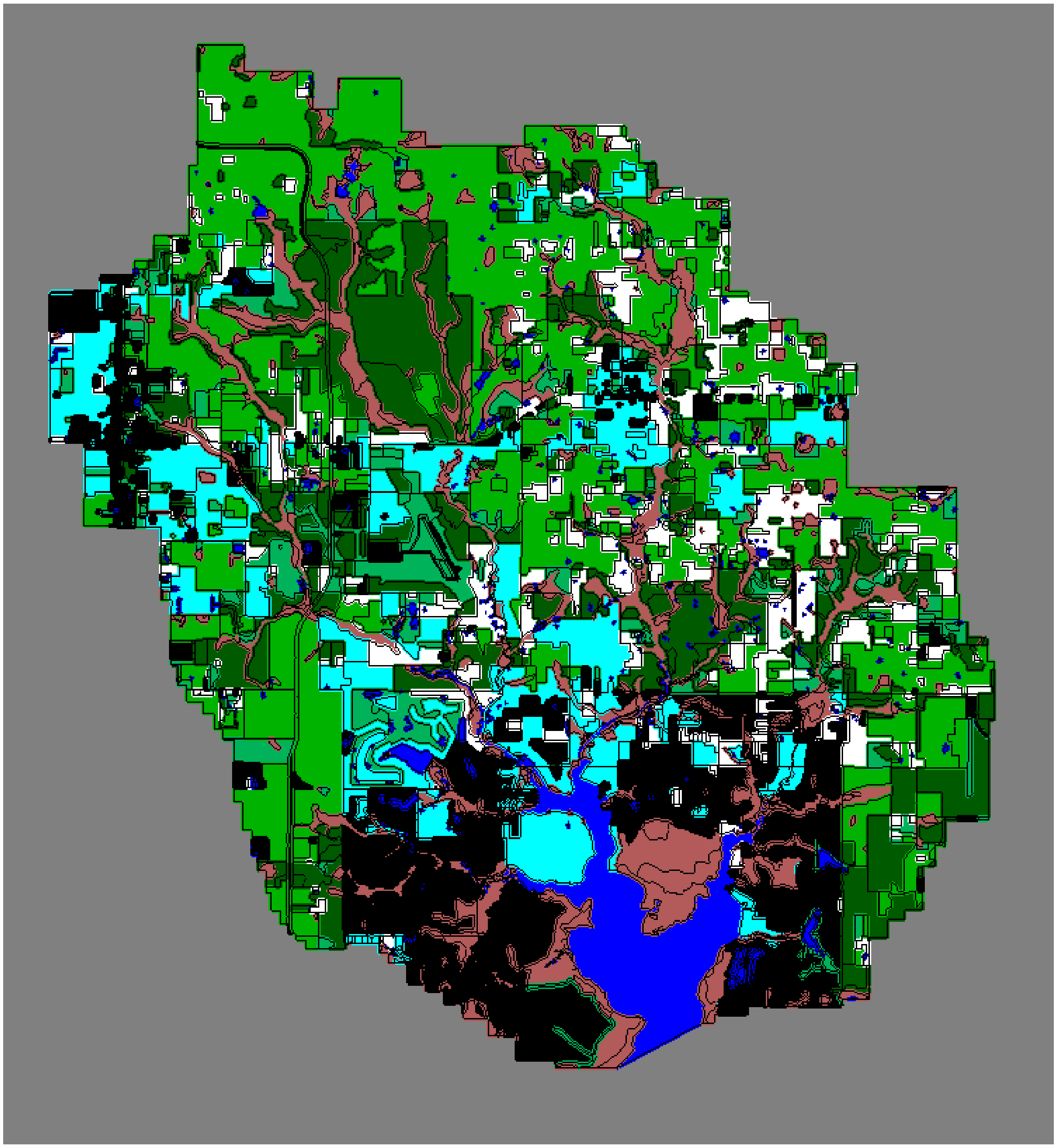


Figure 4-4
Land Use – Low Density Lower Basin Development

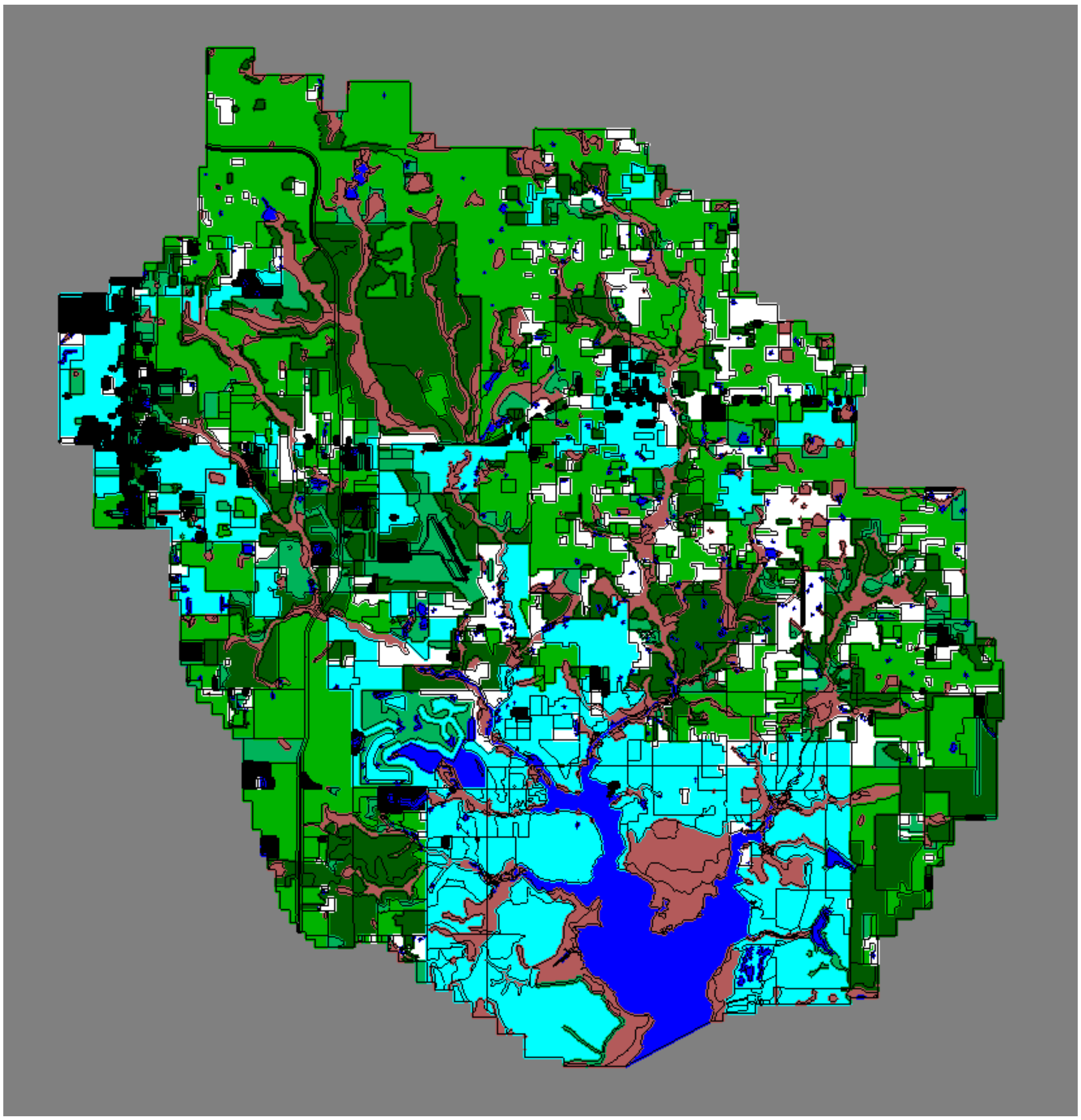


Figure 4-5
Land Use – Expanded Low Density Lower Basin Development

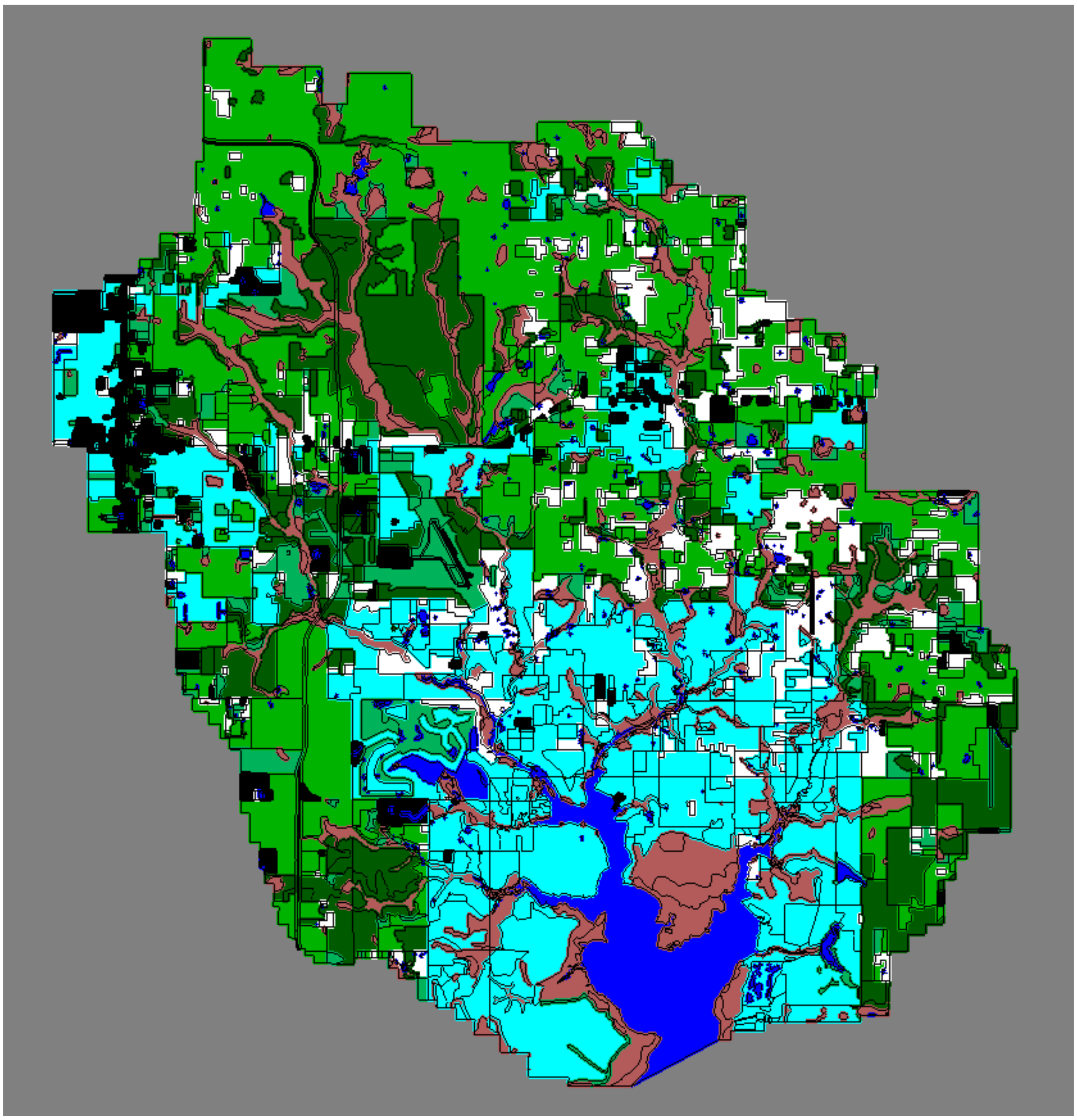


Figure 4-6
Aerial Photograph indicating Pond Locations

5. Results and Conclusions

5.1. Results

Various development scenarios were analyzed for the Wolf Bay watershed. Figure 5-1 indicates the location of the comparison points in the watershed that are summarized in Table 5-1. Results indicate that additional development around the municipalities of Foley and Elberta will increase peak discharges downstream if not detained. Development along the Foley Beach Express corridor as well as the Old CR 95 corridor will result in increased peak discharges downstream. Development in the lower portion of the basin can have different impacts depending on the location and amount of land use change. High-density development decreases runoff time to Wolf Bay, however the amount of runoff is significantly higher than existing conditions. Low density development, however, will increase local discharges, but will not be higher at the outlet.

The analyses indicate that the development of each area of interest would cause a negative impact to the local reach downstream of where the build-out occurred (Figures 5-2 to 5-11). Due to the location of the development near the bottom of the watershed, development without detention would cause peak discharges to occur earlier. The earlier timing of these discharges would not increase the overall discharge at the outlet of Wolf Bay. There is however an increase in the discharge on the local streams leading into the bay. Due to Wolf Bay being an Outstanding Alabama Waterbody the areas designated in the land use as water or wetlands were not developed. This was done in order to help preserve the water quality, habitat, and flora.

Results from the multiple analyses of the regional detention ponds indicate that each pond is only effective for the individual basin in which it is contained. For example, a pond placed along Wolf Creek will not have any impact on Sandy, Miflin, or Hammock Creek. These ponds help reduce discharges along the local branch just downstream. The ponds are insufficient for reducing peak discharges associated with all high-density development back down to existing conditions discharges.

Further analysis of the regional ponds with the addition of development indicates that all four regional ponds by themselves are not sufficient to handle discharge increases at the outlet of Wolf Bay. Local detention also needs to be employed in the upper portions of the watershed. Results for different build-outs, regional pond locations, and local detention are presented in Table 5-1.

Further considerations should be given to the local streams downstream of the undetained developments. Although the discharges at Wolf Bay will not have a negative impact, there will be increased discharge along the local streams. Consideration should be given to local streams to help guard against in-stream erosion. This may be accomplished using local detention on smaller more frequent events. This will help guard against possible stream degradation that could occur with increased runoff.

Figure 5-1
Wolf Bay Discharge Comparison Points

Figure 5-2
Discharges at Point 1

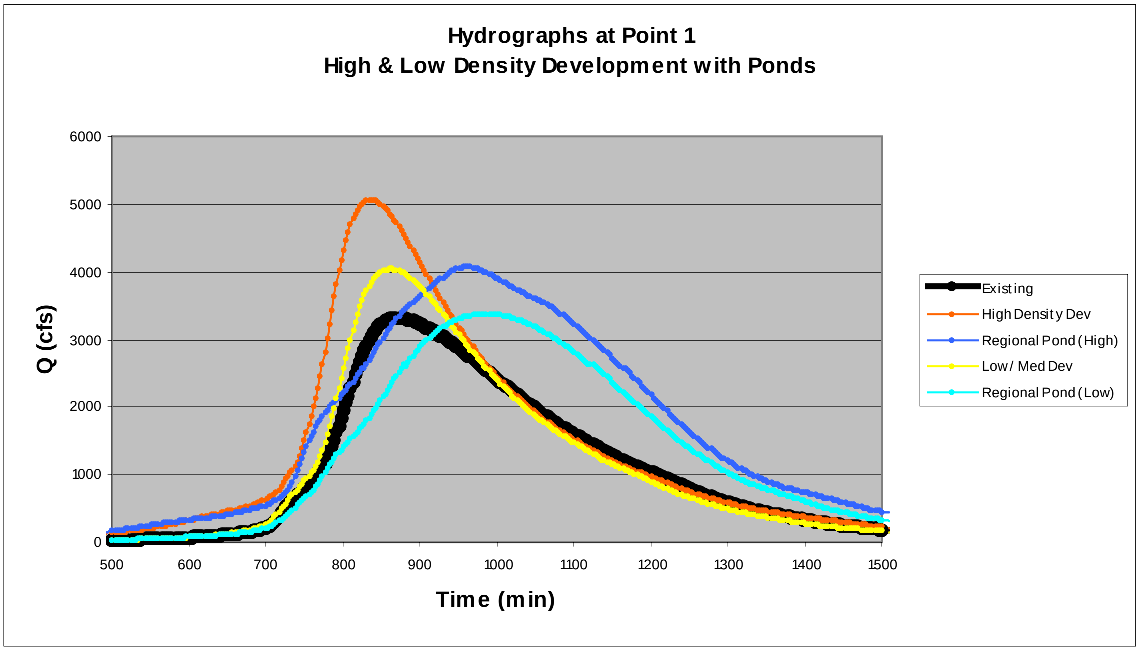


Figure 5-3
Discharges at Point 2

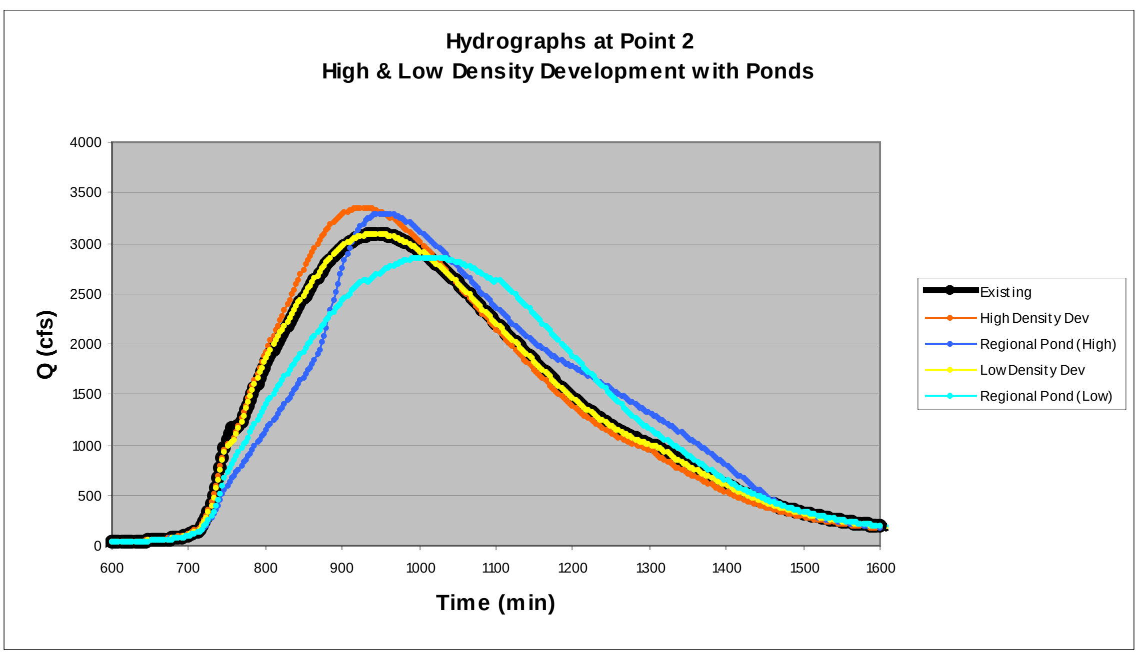


Figure 5-4
Discharges at Point 3

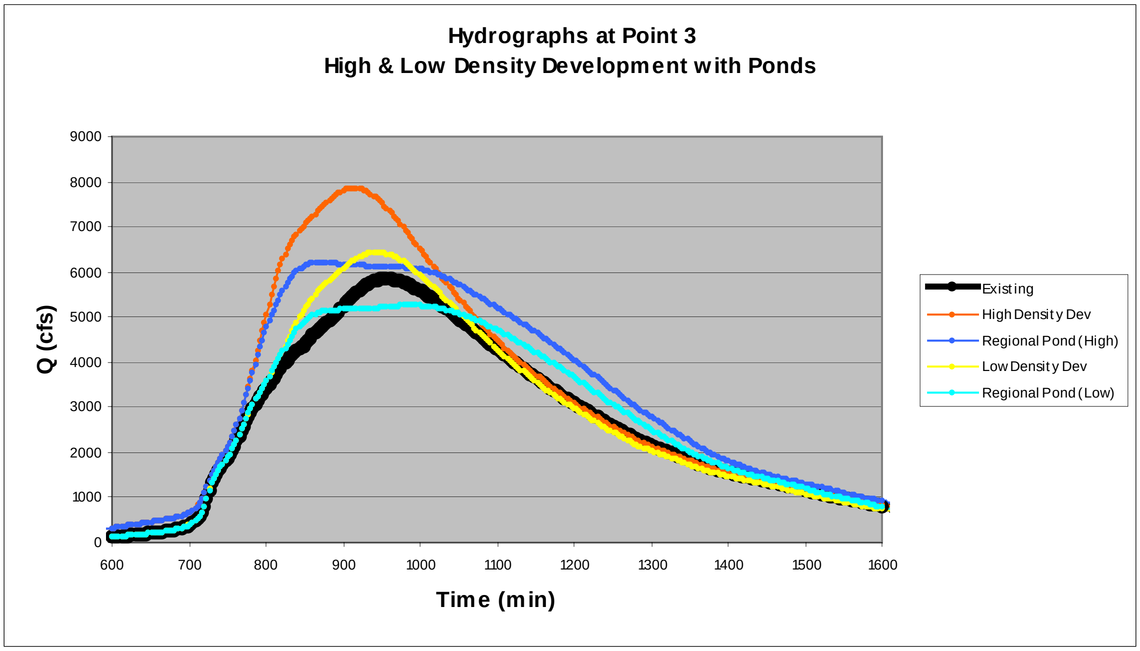


Figure 5-5
Discharges at Point 4

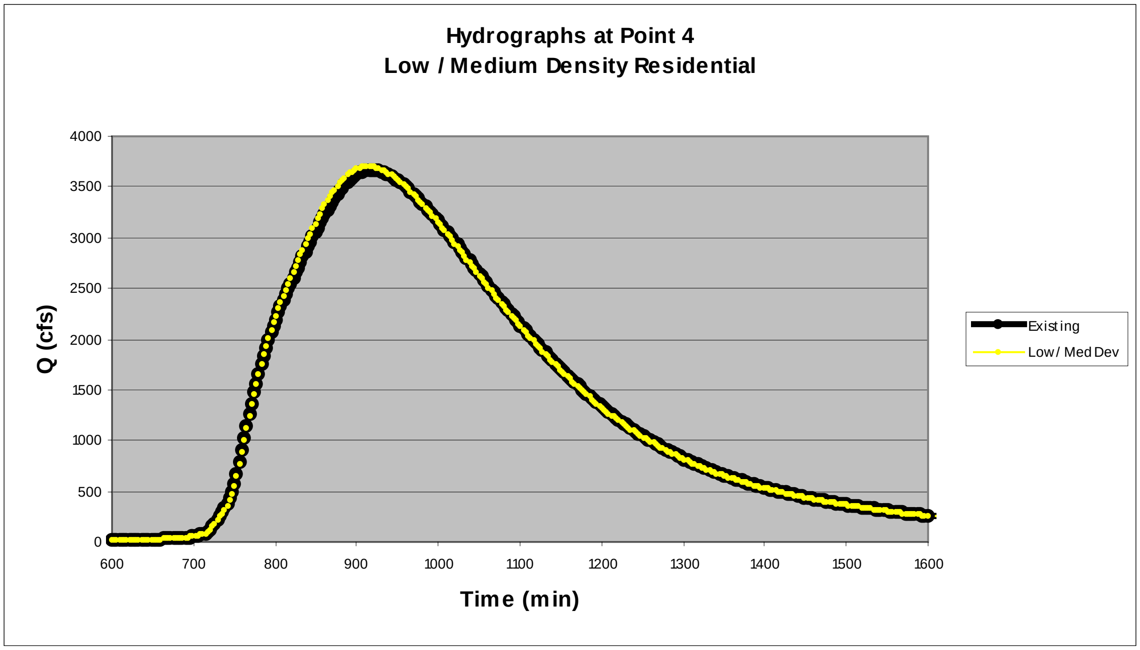


Figure 5-6
Discharges at Point 5

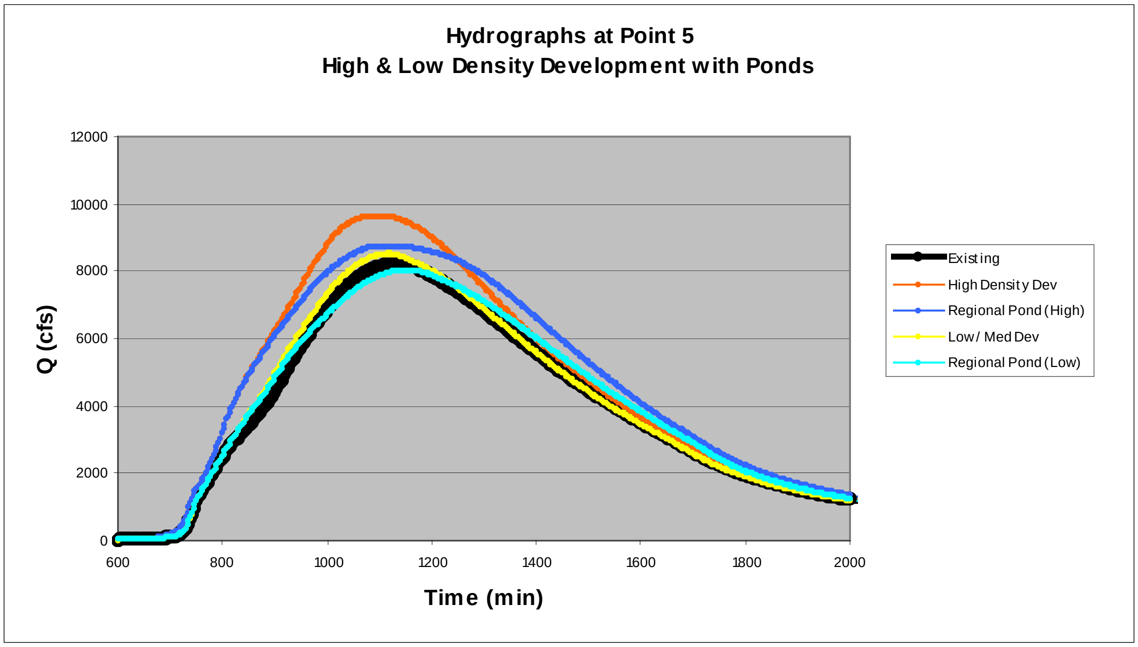


Figure 5-7
Discharges at Point 6

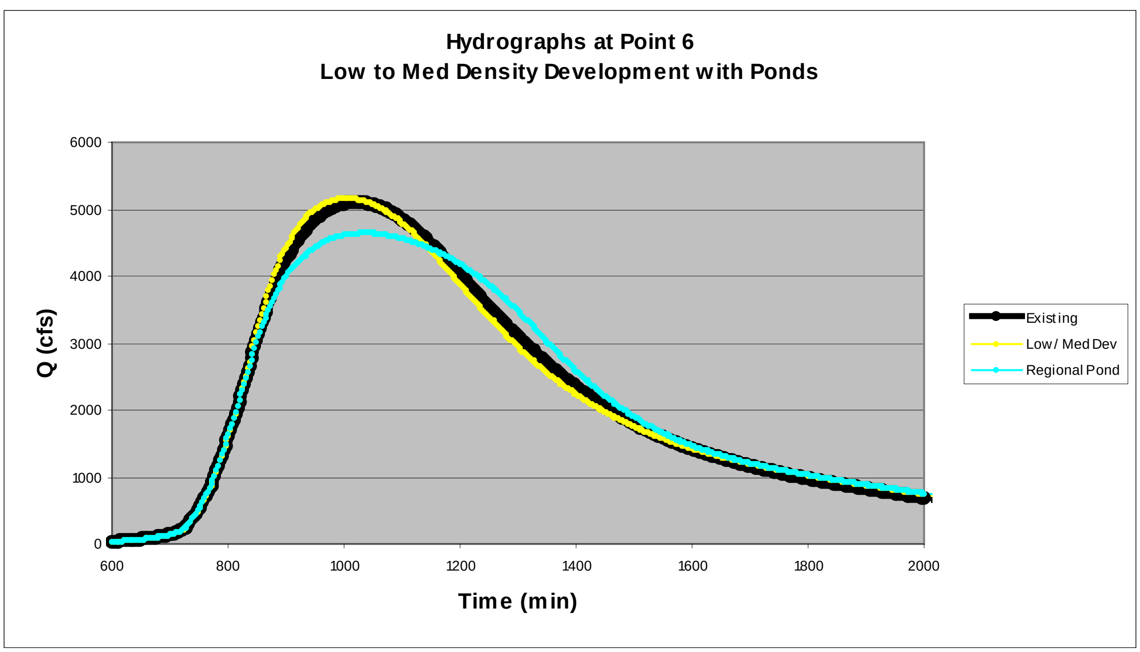


Figure 5-8
Discharges at Point 7

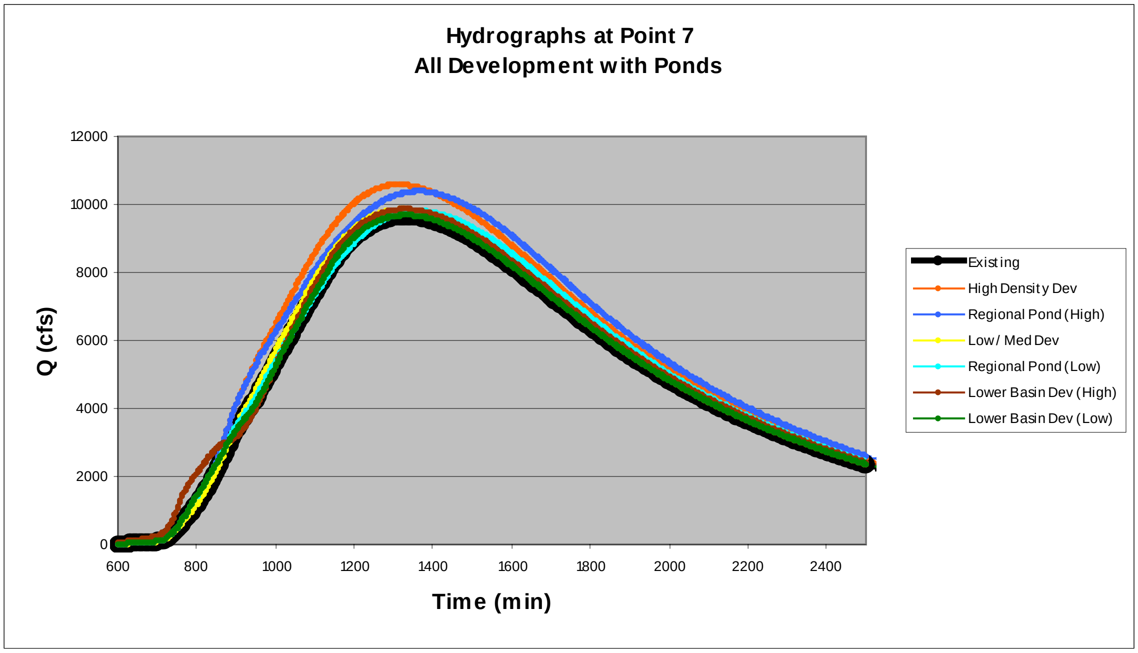


Figure 5-9
Discharges at Point 8

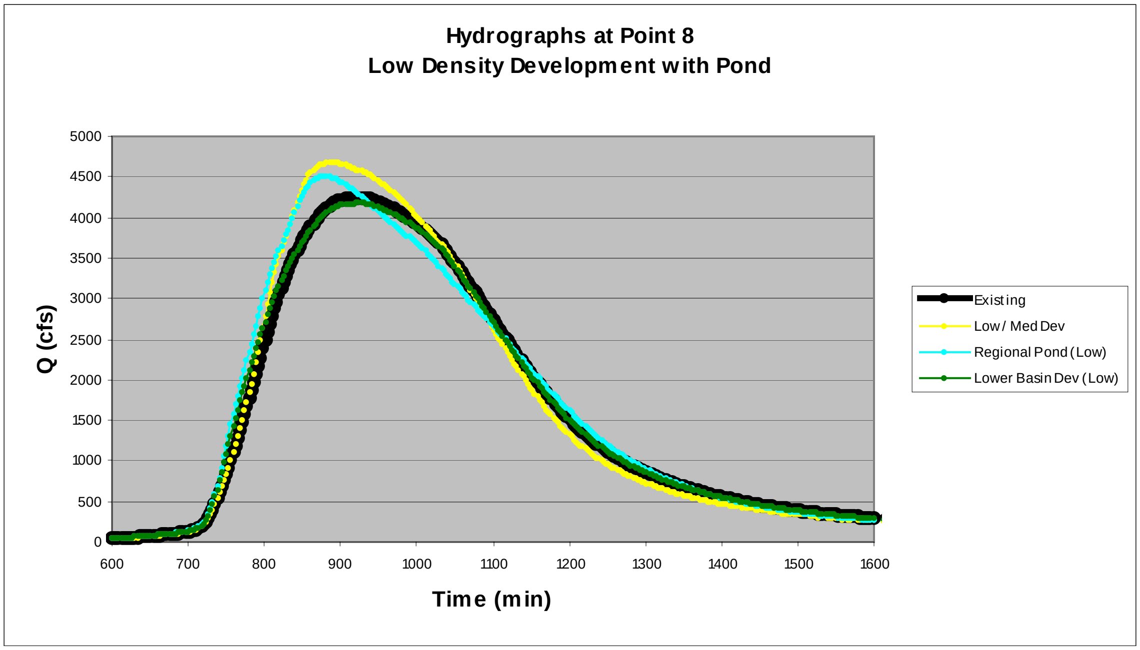


Figure 5-10
Discharges at Outlet

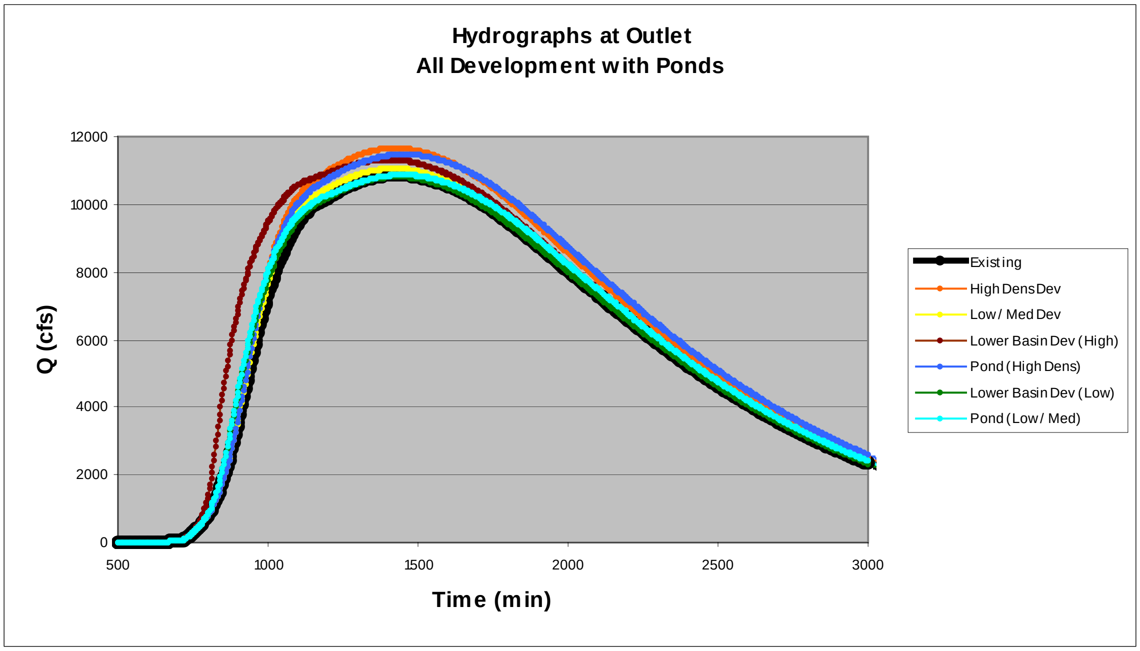


Figure 5-11
Discharges at Outlet (Zoomed in on peak)

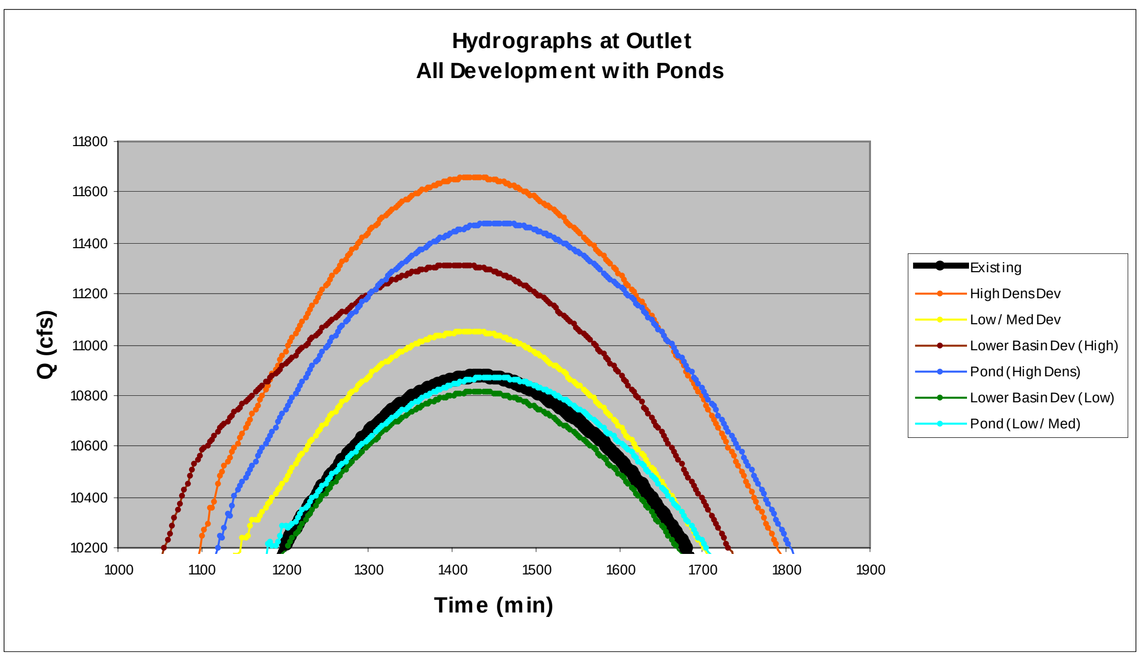


Table 5-1
Wolf Bay Watershed Summary of Discharges

SCENARIO	2	3	5	6	7	8	Outlet
Existing Conditions	3,088	5,843	8,224	5,106	9,662	4,243	10,876
Fol(MD) + FBE(HD) + Elb(LD) + CR95(LD)	3,349	7,860	9,647	5,159	10,584	4,676	11,659
FBE(LD) + Elb(LD) + CR95(LD)	3,093	6,442	8,527	5,170	9,855	4,676	11,052
Und(HD)					9,857	4,163	11,313
Und(LD)					9,686	4,159	10,814
Und Expanded (LD)			8,173	5,033	9,666	4,164	10,825
Fol(MD) + FBE(HD) + Elb(LD) + CR95 (LD) + ALL Ponds	3,295	6,213	8,762	4,647	10,388	4,580	11,480
Fol(MD) + FBE(LD) + Elb(LD) + CR95 (LD) + Und(LD) + ALL Ponds	2,861	5,263	8,046	4,669	9,807	4,505	10,871

Fol = Foley Elb = Elberta FBE = Foley Beach Express CR95=CR95 Und = Undetained Lower Area
(HD) = High Density (LD) = Low Density (MD) = Mixed Use
ALL Ponds = Wolf Creek Pond, Sandy Creek Pond, Miflin Creek Pond, Hammock Creek Pond

5.2. Conclusions

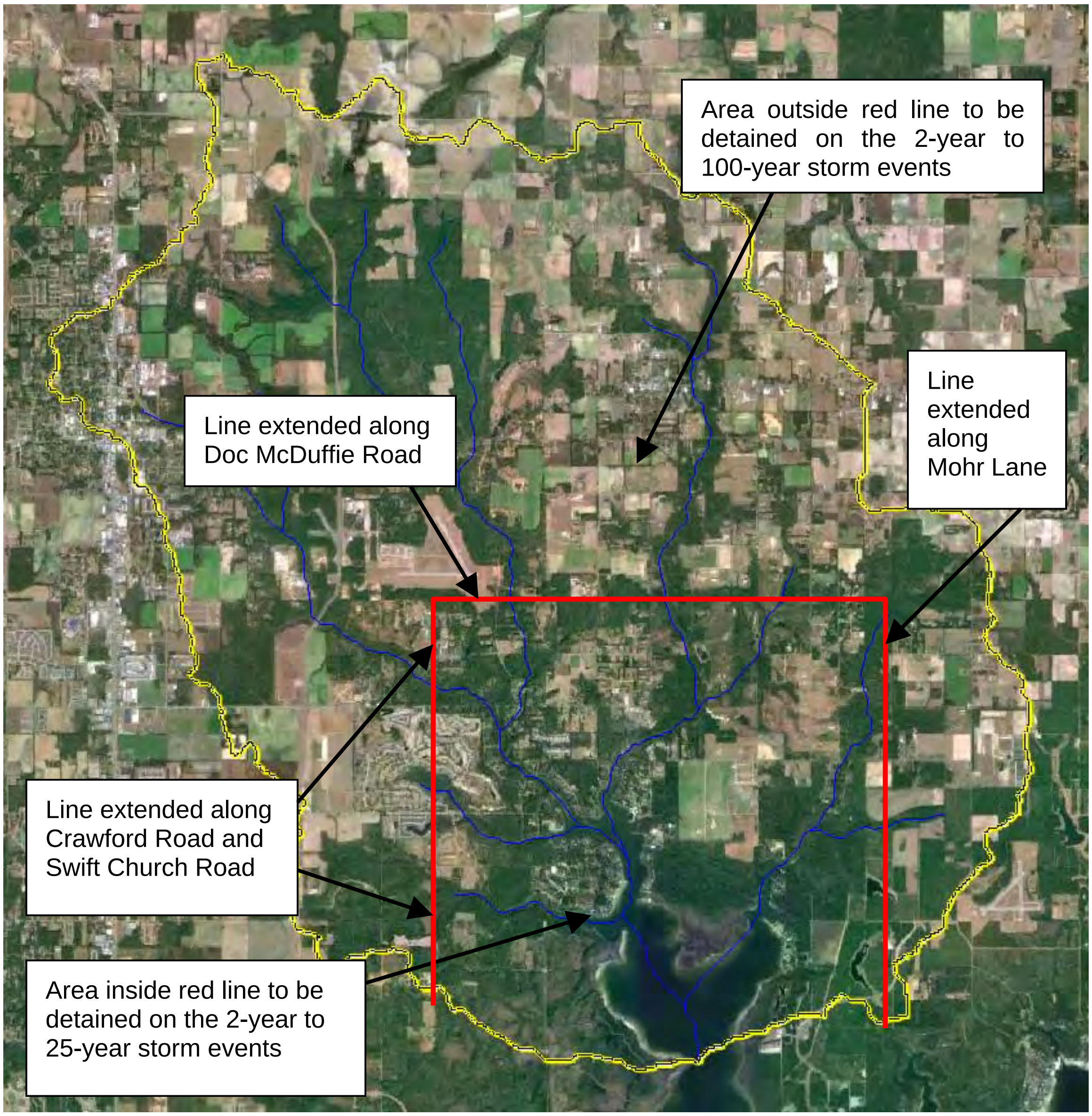
The Wolf Bay watershed is a large drainage system consisting of several distinct sub-watersheds. Based on the results, it has been determined that the development along the corridor of the Foley Beach Express causes the most impact to the basin. The Wolf Creek and Sandy Creek basins are the two sub-watersheds that would experience the most impact from the possible linear development. The impacts to these basins do not have influence on the other sub-basins except at the outlet.

Results indicate that the placement of regional ponds can provide a benefit to the local stream on which the pond is located. These ponds will reduce discharges, however they are not effective enough to be used as stand-alone detention for high-density development. For the existing conditions and low-density residential development the ponds can provide discharge reduction benefit.

It has been determined that development within the lower portion of the basin can be performed without any detention. It is recommended that development be avoided in the wetlands, marshlands and other critical areas that could affect the OAW status of Wolf Bay. Analysis would need to be performed locally to determine if any undetained property would cause increased flooding on adjacent properties; or cause other impacts such as stream erosion and degradation. In such cases it may be necessary to install local detention for smaller events to safeguard property, streams, and habitat.

Based upon a conservative build-out scenario including the municipalities, the corridor along the Foley Beach Express, the corridor along Old CR 95, and the lower portion of the basin, the following items would be needed in order to have post development match pre development discharges on Wolf Bay. Regional ponds can be used to offset peak discharge increases associated with low-density residential development. These ponds need to be designed to handle all flood events including the 100-year event. All flood events would need to also be locally detained above the line defined by Crawford Road to the east, Doc McDuffie Road to the north, and Mohr Lane to the west (Figure 5-12). This is just one solution to a conservative scenario. These measures may not be essential initially, but should be based on how the actual development occurs in the watershed. The calibrated GSSHA model can therefore be used as a dynamic management tool in which to analyze future developments. Outside analysis at a smaller sub-basin level can also be performed and reintroduced into the model to determine possible impacts.

Figure 5-12
Designation of Areas Requiring All Event Detention



6. **References**

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