## Project Final Report

# Study of Sediment and Nutrients in Pelahatchie Bay and Upland Mill-Pelahatchie Creek- Watershed

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## Abstract

Pelahatchie Bay is located in the northeast section of Jackson, the capital city of Mississippi. Its upland watershed, Mill-Pelahatchie Creek Watershed contains a high percentage of construction sites and developed areas, causing a lot of sediment and associated pollutants to discharge into the bay through runoff. In addition, sediment, nutrients, and other pollutants may also flow into Pelahatchie Bay from the upstream Pelahatchie Creek.

This project studied the response of water quality in Pelahatchie Bay to the sediment and pollutant loads from upland watersheds. The hydrodynamics, sediment transport, and water quality processes were studied using numerical simulations. The Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant loading watershed management model, developed at the USDA ARS, National Sedimentation Laboratory (NSL), was applied to simulate the loads of runoff, sediment and nutrients from the upland watershed. The simulated results were used as boundary conditions for CCHE, a free surface flow, sediment and water quality model developed at the National Center for Computational Hydroscience and Engineering (NCCHE), to simulate flow, sediment transport and water quality processes in the bay. The effectiveness of implemented best management practices (BMPs) in the upland watershed on the water quality in the bay were also evaluated.

## 1. INTRODUCTION

Ross Barnett Reservoir (RBR) is the largest drinking water source in the state of Mississippi. The water quality in RBR is generally affected by the physical, chemical and bio-chemical processes in the reservoir, and is also significantly influenced by the Upper Pearl River watershed and Ross Barnett Reservoir Watershed. Six priority issues in the reservoir and its watershed have been identified and recommended for reducing and controlling: 1) watershed erosion/sedimentation; 2) nutrient enrichment and algal growth; 3) pathogens; 4) invasive aquatic plant species; 5) pesticides; and 6) litter/trash in the reservoir and around the shoreline (FTN 2011).

Pelahatchie Bay (PB) is a part of RBR, located in the southeast corner of the reservoir. The bay is separated with RBR by the "Northshore Parkway", and only a limited amount of water flows in/out of RBR through a relatively narrow opening under a bridge of the parkway. The upland watershed, Mill-Pelahatchie Creek Watershed (MCW) contains a high percentage of construction sites and developed areas, causing a lot of sediment and associated pollutants to discharge into the bay through runoff (Figure 1). In addition, sediment, nutrients, and other pollutants may also flow into Pelahatchie Bay from the upstream Pelahatchie Creek.

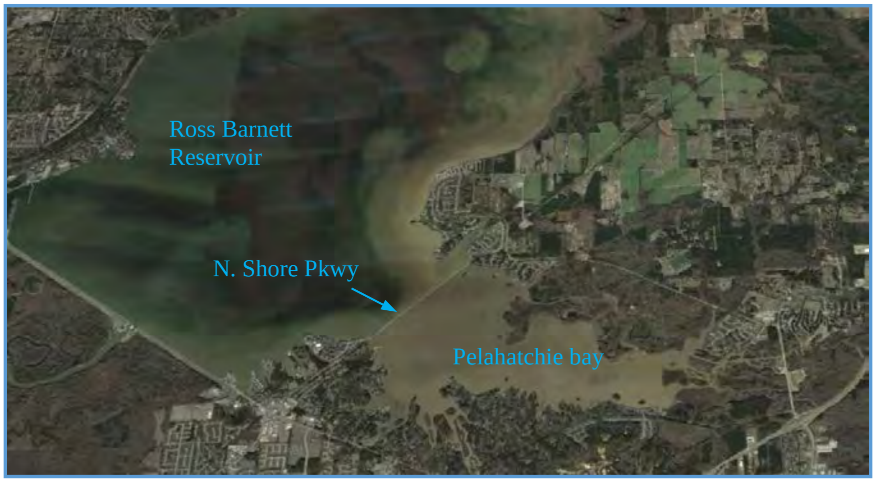


Figure 1. High sediment concentrations in Pelahatchie Bay (google earth)

The major water quality problem in PB is sedimentation, which causes high turbidity and limits boat navigation in the bay. The levels of nitrogen and phosphorus in the bay are relatively high and cause excessive growth of aquatic plants. The dense aquatic vegetation may reduce the water surface area, cause more sediment deposition and affect boat navigation. The pathogen level in the bay is also relatively high, which may influence the recreational value of the PB and RBR.

To better understand the water quality conditions in PB, the loads of runoff, sediment and nutrients from the upland watershed are simulated using the AnnAGNPS watershed model. The simulated results are used as boundary conditions for CCHE model to simulate the flow, sediment and water quality in the bay.

The research results help understand the water quality processes affected by anthropogenic and natural factors in the Pelahatchie Bay. Information obtained from this research can be used by decision makers to develop improved watershed management plans to achieve maximum water quality benefits to Pelahatchie Bay. The technical approach in this research can also be used to evaluate the best management practices (BMPs) implemented in other watersheds.

## 2. OBJECTIVES

In this research, a coupling approach is developed to integrate the AnnAGNPS watershed model and CCHE model to study sediment and water quality distribution in PB of RBR (Figure 2). The AnnAGNPS model is applied to simulate the daily loads of runoff, sediment and nutrients from MCW under alternative BMPs. The simulation results are used as boundary conditions for the CCHE model which includes the sediment-associated water quality processes to predict the sediment and water quality concentrations in the water column. The watershed model and surface water model are integrated together to study sediment and water quality distribution in PB, and the effects of hydrodynamics and upland BMPs on the water quality in the bay.

To reach this goal, the following objectives are designed: (1) application of the AnnAGNPS model for simulating runoff, sediment and nutrient loads in the Mill-Pelahatchie Creek Watershed; (2)

application of the CCHE model to simulate flow, sediment and water quality in PB; (3) analyzing the response of water quality in PB to the implementation of BMPs in MCW.

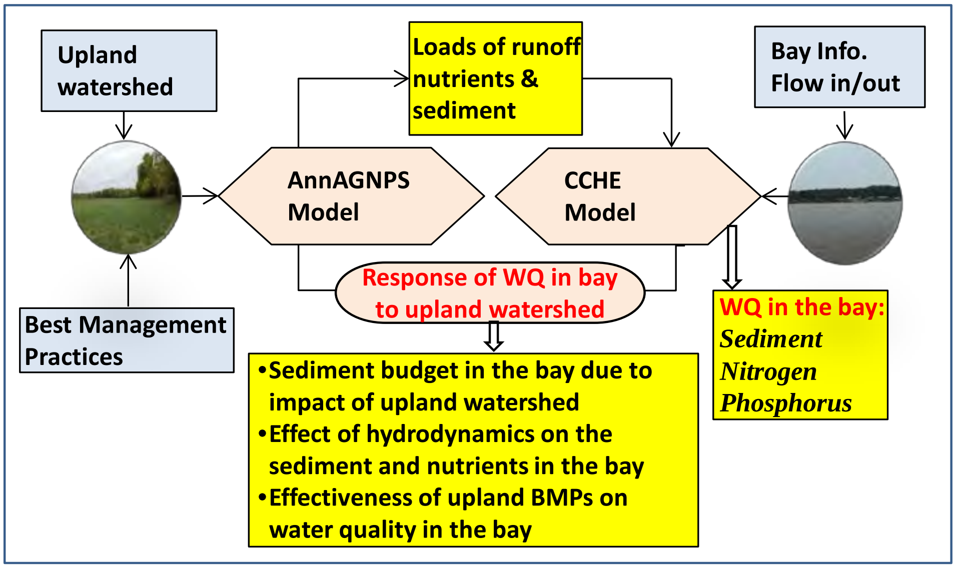


Figure 2. Proposed response system of WQ in surface water to the loads of upland watershed

## 3. RESEARCH METHODS

### 3.1. Study Site

The Ross Barnett Reservoir (RBR) is the largest drinking water source and an important recreation area in the state of Mississippi. The water quality in RBR is significantly affected by the Upper Pearl River watershed and Ross Barnett Reservoir Watershed.

In this research, Pelahatchie Bay (PB) and the surrounding Mill-Pelahatchie Creek Watershed (MCW) is selected as the study site (Figure 3). PB is located in the southeast corner of RBR. The water quality in PB is affected by the physical, chemical and biochemical processes in the bay; the loads of runoff, sediment and nutrient of the surrounding Mill-Pelahatchie Creek Watershed (MCW); and the inflow from upstream Pelahatchie Creek.

The MCW watershed has a total drainage area of approximately 18,176 acres, and the surface area of the PB bay is about 9% of the area of MCW. The averaged water depth of the bay is about 7 feet. The wind is the major driving force of the flow hydrodynamics in the bay. The upland runoff and flow in the upstream Pelahatchie Creek may also affect the flow field in the bay. In addition, the wind induced waves may cause sediment resuspension near the shoreline.

The water surface elevations of RBR and PB, the flow discharge in Pelahatchie Creek can be obtained from USGS gage stations. Water quality concentrations can be obtained from the MDEQ station (Figure 3).

Figure 4 shows the land use and land cover of the upland MCW watershed. This watershed contains pasture, forest, wetland, agricultural land, and a high percentage of developed area. It is found that the developed areas are primarily around Pelahatchie Bay, which may cause lots of sediment and associated pollutants discharge into the bay (Figure 4). In addition, some sediment, nutrients, and other pollutants may also flow into PB through the upstream Pelahatchie Creek. To improve the water quality in PB, BMPs have been implemented or designed in the upland watershed, including the establishment of grassed buffers, and water / sediment retention ponds; stabilization of disturbed surface soil and channel banks.

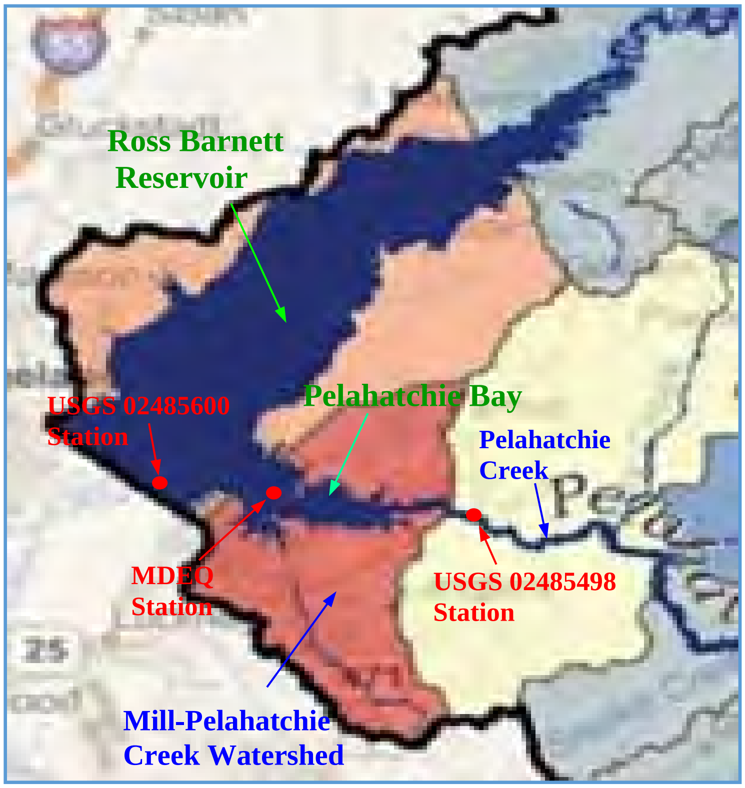


Figure 3. Pelahatchie Bay and the surrounding watershed

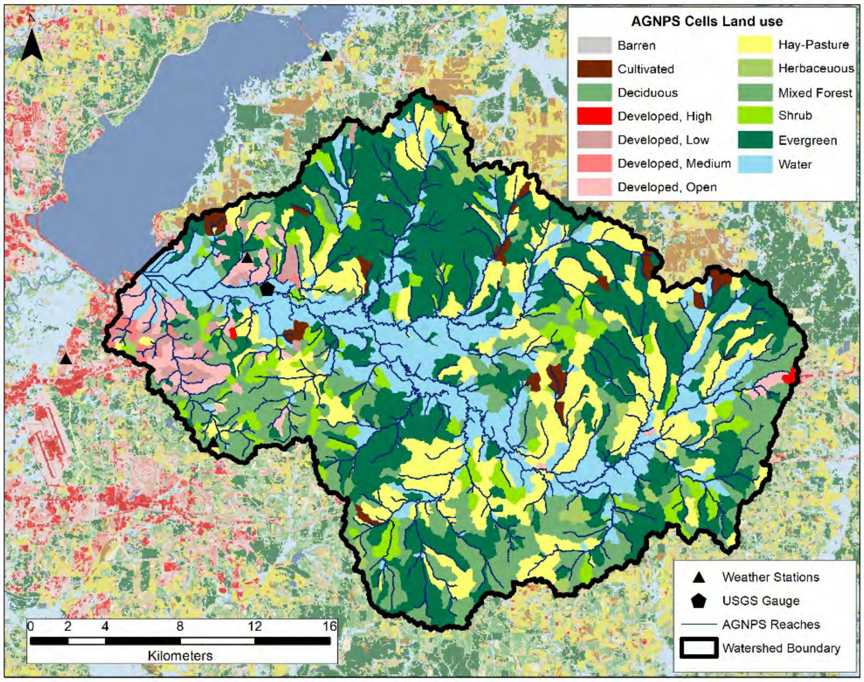


Figure 4. Land use/land cover of Mill-Pelahatchie Creek Watershed

## 3.2. Field Measurements and Data Collections

In this research, the flow, sediment and water quality data in Pelahatchie Bay needed to be measured and/or collected for model simulation. The climate data, such as wind, solar radiation, air temperature, and precipitation in the study area was also collected.

### *a. Flow data*

The observed water surface elevation and flow discharge in Pelahatchie Creek were obtained from USGS 02485498 Station. The observed water surface elevations of RBR and PB were also obtained from USGS 02485600 Station.

### *b. Climate data*

The climate data, including wind, solar radiation, air temperature, relative humidity, and precipitation were obtained from NOAA National Climatic Data Center at Jackson Station.

### *c. Water quality data*

The water quality data, such as nutrients and chlorophyll in RBR and PB were obtained from MDEQ.

### *d. Sediment data*

The suspended sediment (SS) samples in the PB were collected after a storm event on April 4, 2018. The size and concentration of SS were measured by NSL. Figure 5 shows the SS sampling locations in PB, including the North Shore Parkway, North Shore Parkway (under bridge), Highway 25 USGS Gage (Pelahatchie Creek), and Mill Creek.

Figure 5. Sampling locations of SS in PB

## 3.3. Numerical Modeling of Upland Watershed Using AnnAGNPS Model

### *3.3.1 AnnAGNPS watershed model*

The Annualized Agricultural Nonpoint Source Pollution (AnnAGNPS) model is an advanced technological watershed evaluation tool that has been developed through a partnership between two

US Department of Agriculture (USDA) agencies – the Agriculture Research Service (ARS) and the Natural Resources Conservation Service (NRCS) to aid in the evaluation of watershed responses to agricultural management practices (Bingner and Theurer, 2001). AnnAGNPS is a continuous-simulation, daily time-step, pollutant loading model designed to simulate long term chemical and sediment movement from agricultural watersheds (Bingner and Theurer, 2005). The spatial variability of soils, land use, and topography within a watershed are accounted for by dividing the watershed into many user-specified, homogeneous, drainage-area-determined cells. For individual fields (cells), runoff, sediment, and pollutant loadings can be predicted from precipitation events that include rainfall, snowmelt, and irrigation.

In this model, the watershed cells and stream networks are generated from a watershed DEM using the topographic tools available in the TOPAGNPS module; the soil property information is obtained from NRCS Soil Survey databases; the management operations and schedule data associated with the land use are obtained from the RUSLE database; the climate information can be obtained from a local weather station or generated using the agGEM model.

The model routes the physical and chemical constituents from each cell into the stream network and finally to the watershed outlet using a daily time step approach. The model outputs include runoff, sediment, nutrient and pesticide at a temporal scale ranging from daily to yearly. All model outputs can be obtained at any desired location such as specific cells, stream reaches, feedlots, gullies, or point sources.

The model is currently utilized in many locations around the world and in the U.S. by the Environmental Protection Agency, NRCS, and others to estimate the impact of best management practices (BMPs) including changes of upland land use/land cover (LU/LC) on stream and water quality. As demonstrated in many applications (Shrestha et al., 2006; Licciardello et al., 2007; Yuan et al., 2006), the model can evaluate the impacts of management practices on runoff, sediment and nutrient loadings from agricultural and mixed land use watersheds.

### *3.3.2 Simulation of Mill-Pelahatchie Creek Watershed (MCW) using AnnAGNPS*

AnnAGNPS simulations were developed to evaluate the loads of runoff, sediment and nutrients from MCW into the PB Bay under current conditions and after BMP implementation. In the model, the land use /land cover (LU/LC) parameters were modified based on the implemented BMPs, included the establishment of stabilization measures of disturbed soil on urban construction sites that included water and sediment retention ponds. Based on the DEM of MCW, the computational reaches were generated using the TOPAGNPS module (Figure 6). Through the use of climate data, soil properties and management information in the watershed, the runoff, sediment and nutrient loads in MCW were simulated. The simulated results were used as boundary conditions for CCHE model.

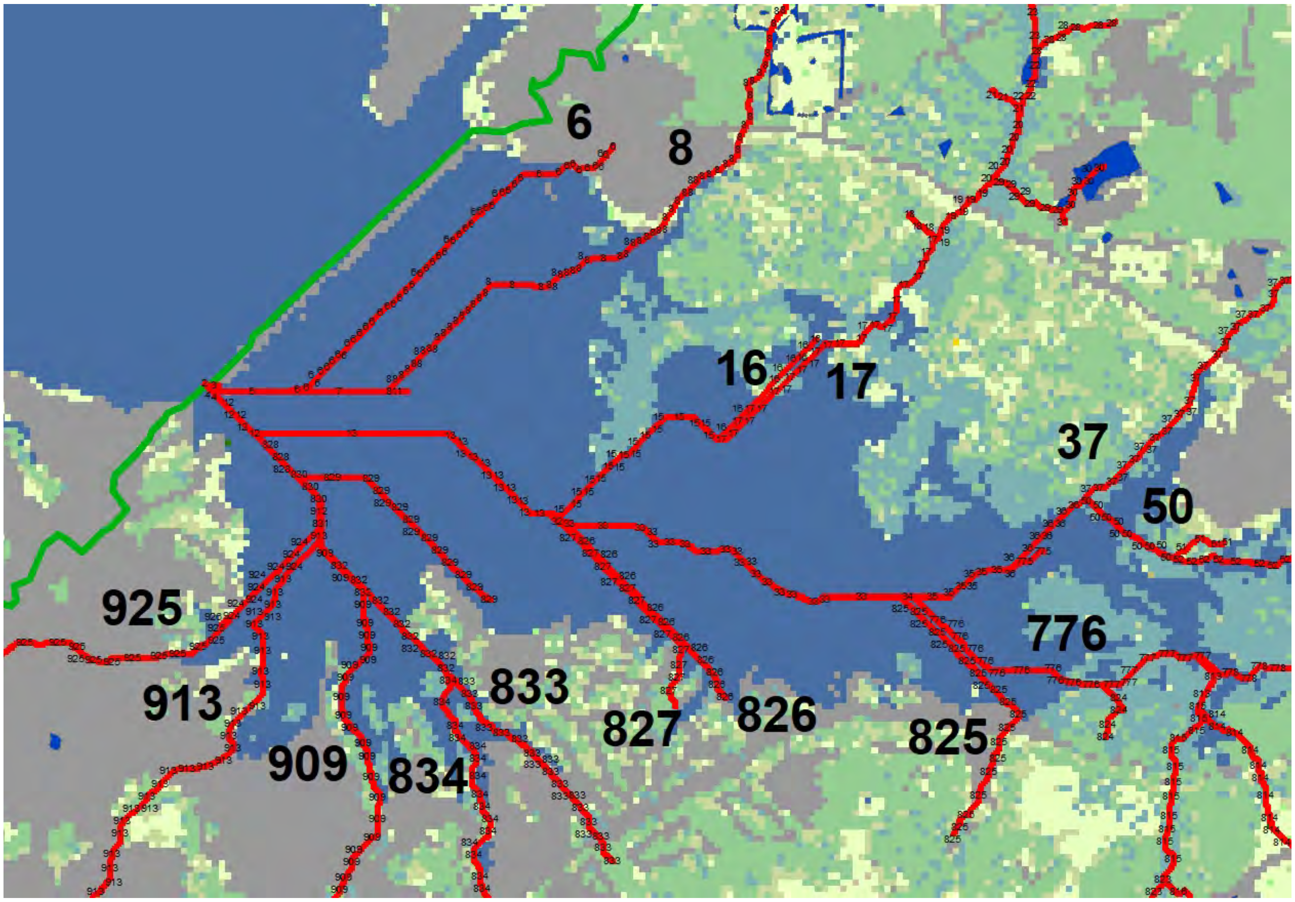


Figure 6. The computational reaches of MCW for AnnAGNPS simulation

## 3.4. Generation of Computational Mesh of PB for CCHE Model Simulation

In computational fluids dynamics (CFD) analysis the governing equations are discretized on the computational meshes, whose qualities play an important role in the convergence process and solution accuracy. However, mesh generation need experiences and is often labor-intensive for complex shaped physical domains. Typically, a mesh generation takes up to one-half of the time for a case study. In this study, the advancing extraction method (Zhang and Jia, 2018), which has been integrated into CCHE-MESH (Zhang, 2017), was used for automatic structured mesh generation in the study domain, the Pelahatchie Bay, with complex geometries (Figure 5).

### *3.4.1 Available data*

In this study, the bathymetric data, in the form of the ERSI shape file with contour lines, for the whole RBR and PB was available (Figure 7).

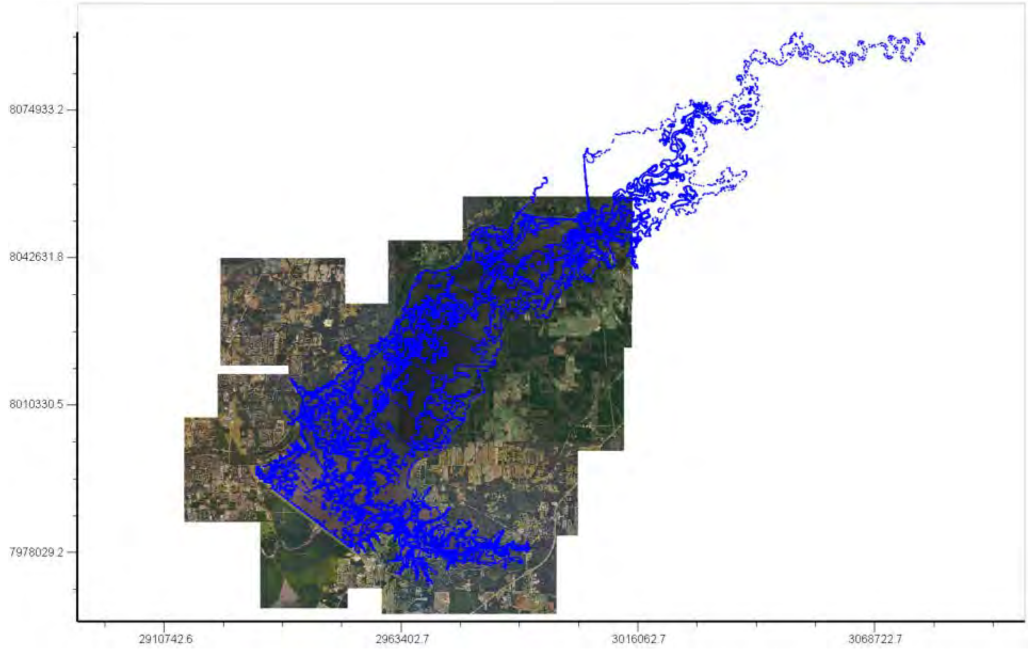
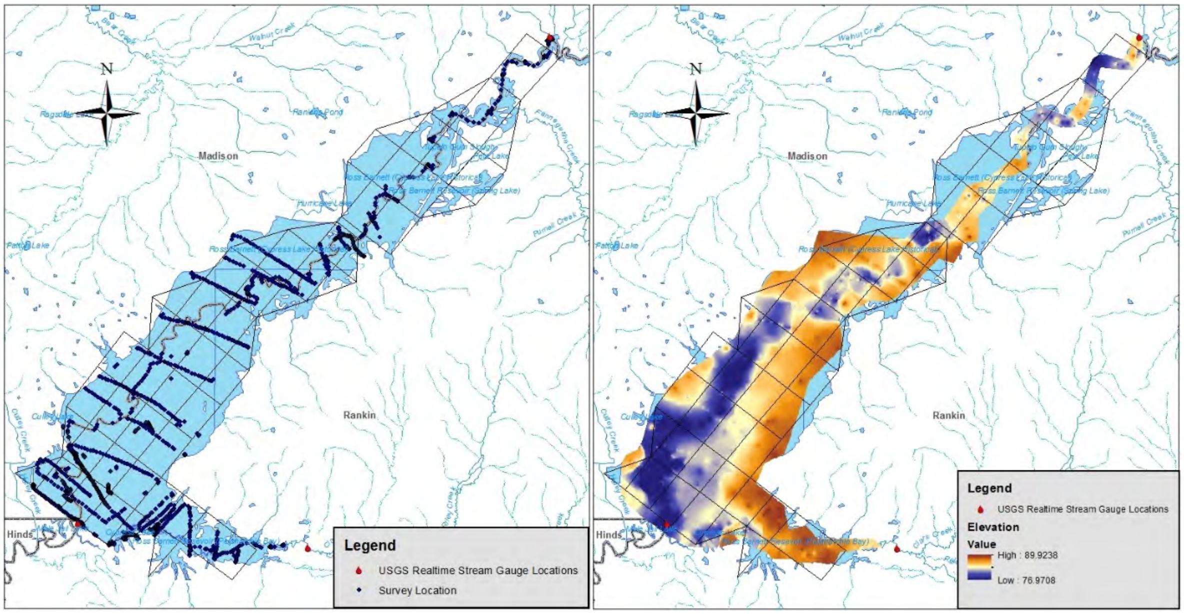


Figure 7. Shape file with bathymetric contour lines

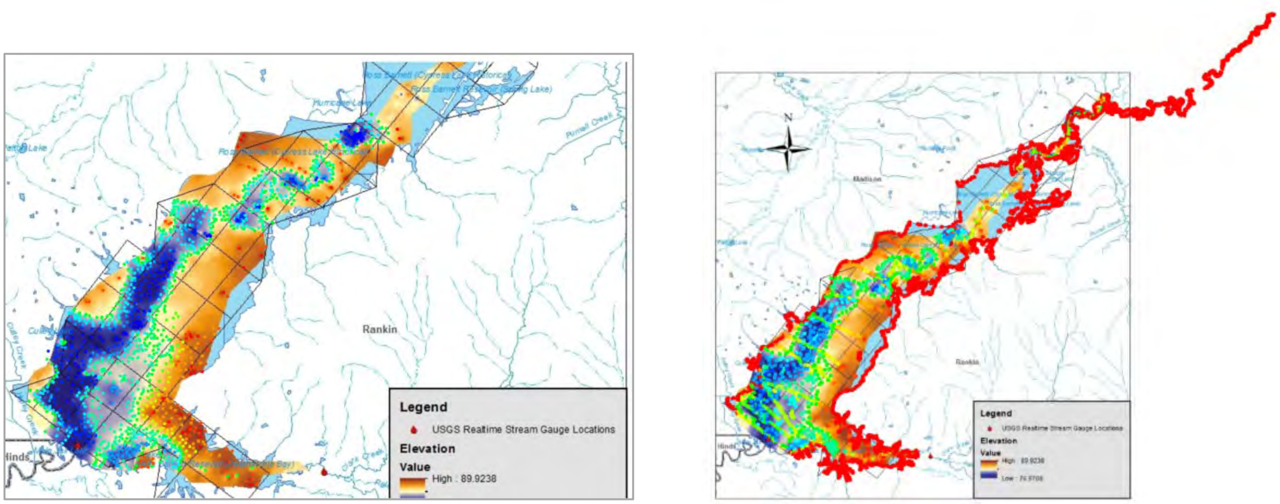
In addition, the surveyed bathymetric data by USGS was available as well. As shown in Figure 8, the scattered survey data (Figure 8a) was processed into the shaded bathymetric data covering the whole RBR and PB (Figure 8b), which is in the form of the image and cannot be used directly.



(a) Survey Data (b) Processed Survey Data in Image Format

Figure 8. Survey Data by USGS

To make use of the processed data, the survey data by USGS was first digitized by using CCHE-MESH and then combined with other data (Figure 7) to form a comprehensive bathymetric data set, as shown in Figure 9.



(a) Digitization (b) Combined Database

Figure 9. Comprehensive Database

### *3.4.2 Automatic Mesh Generation*

As shown in Figure 5, there are many tributaries in the PB, which makes it difficult for structured mesh generation in this domain. To alleviate the difficulties in structured mesh generation in complex geometries, conventionally a multi-block scheme was used so that a complex domain may be decomposed into multiple sub-domains with simpler shapes. The conventional multi-block mesh generation algorithm is interactive, especially the domain decomposition steps, which are the most time-consuming and require modeling experience. In this study, an automatic mesh generation algorithm, the so-called the Advancing Extraction Method (AEM), proposed by Zhang and Jia (2018) was used for mesh generation in the PB with many tributaries.

In the AEM, any domain without holes or islands is to be decomposed into a main Domain Block plus multiple intrusion-like (dikes) and extrusion-like (branches) sub-domain Blocks. Mesh nodes in dikes are considered as external non-computation nodes in numerical model, while those in branches are internal computation nodes. The main domain and the sub-domains are organized in a hierarchical way like a tree structure so that any sub-domain may have its own dikes and branches, and so on. For the PB, the mesh generation procedure was basically divided into the following four steps:

#### a. Define the boundary of the study domain

In CCHE-MESH, the boundary of the study domain is represented by a closed polygon either in clock-wise or anti-clockwise order. For the PB, a polygon with 172 points was defined (Figure 10).

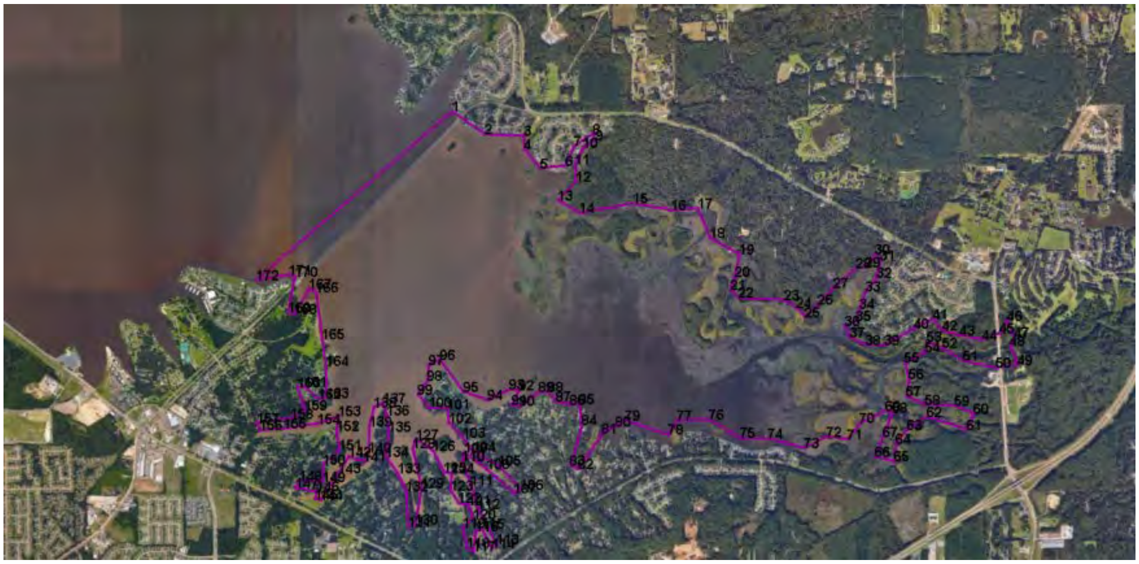


Figure 10. Define boundary

### b. Automatic domain decomposition using AEM

Based on the defined boundary (which was triangulated by Delaunay triangulation algorithm) and the competition rules designed for identifications of dike blocks and branch blocks, the domain was automatically decomposed into multiple dike blocks and branch blocks, which were organized into a hierarchical structure from the base level to the highest level (Figure 11).

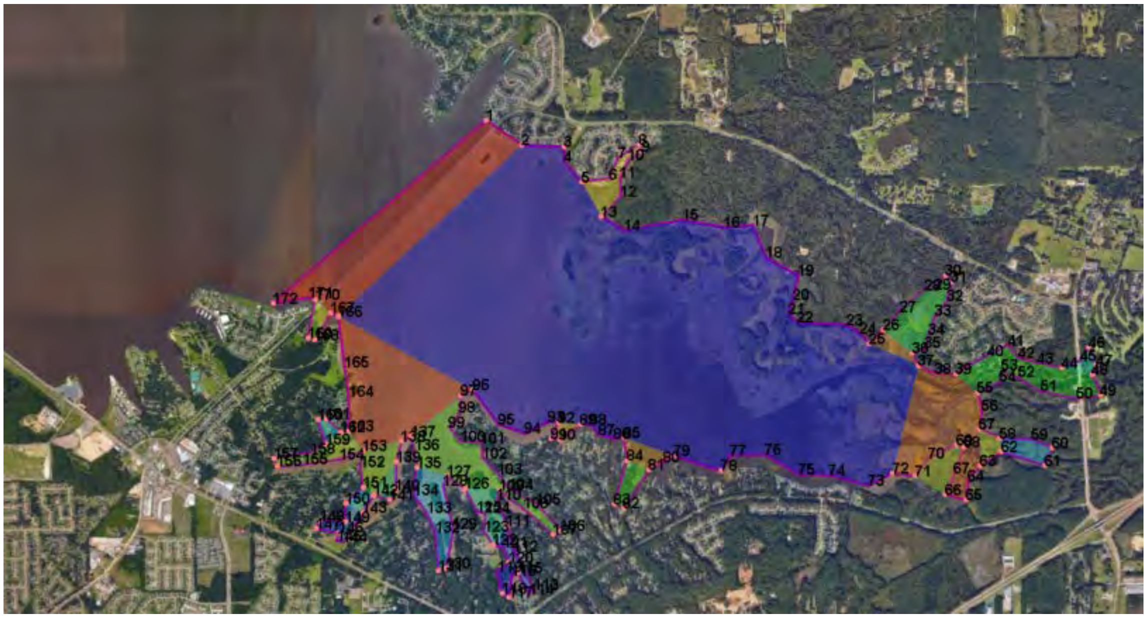


Figure 11. Automatic Domain Decomposition

### c. Automatic mesh generation using AEM

For each block, the (I, J) orientation and the associated four corner nodes were identified, and mesh generation was carried out block by block from the base level to the highest level. The blocked meshes were then automatically assembled into a globally structured mesh (Figure 12).

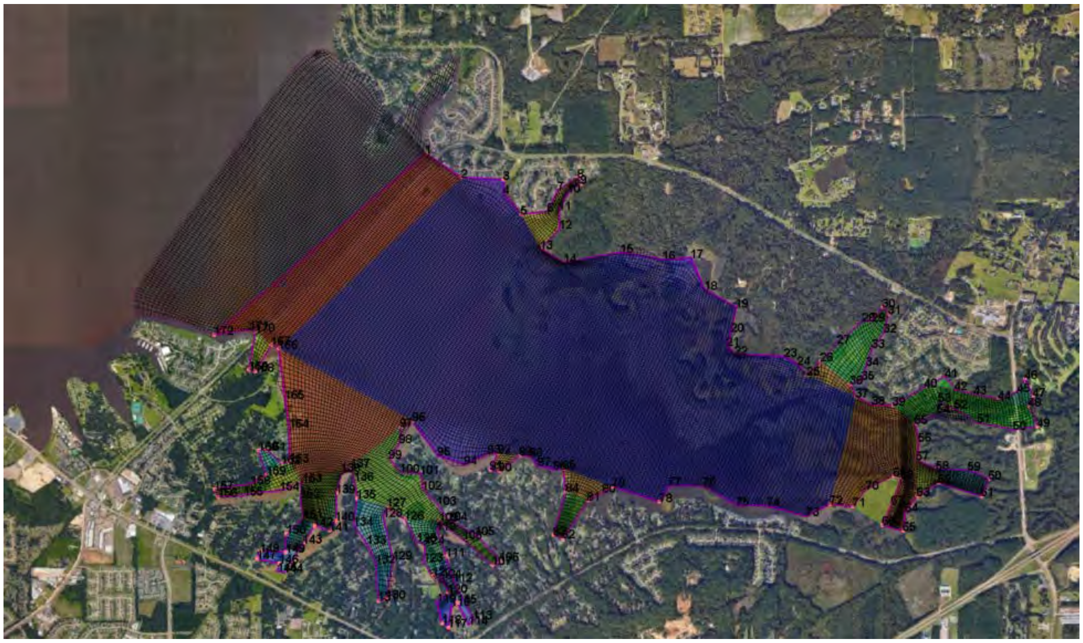


Figure 12. Automatic Mesh Generation in PB

### d. Bed interpolation using the comprehensive database

The final mesh used the comprehensive database (Figure 9) for bed interpolation (Figure 13). The generated mesh was used for CCHE model simulations.

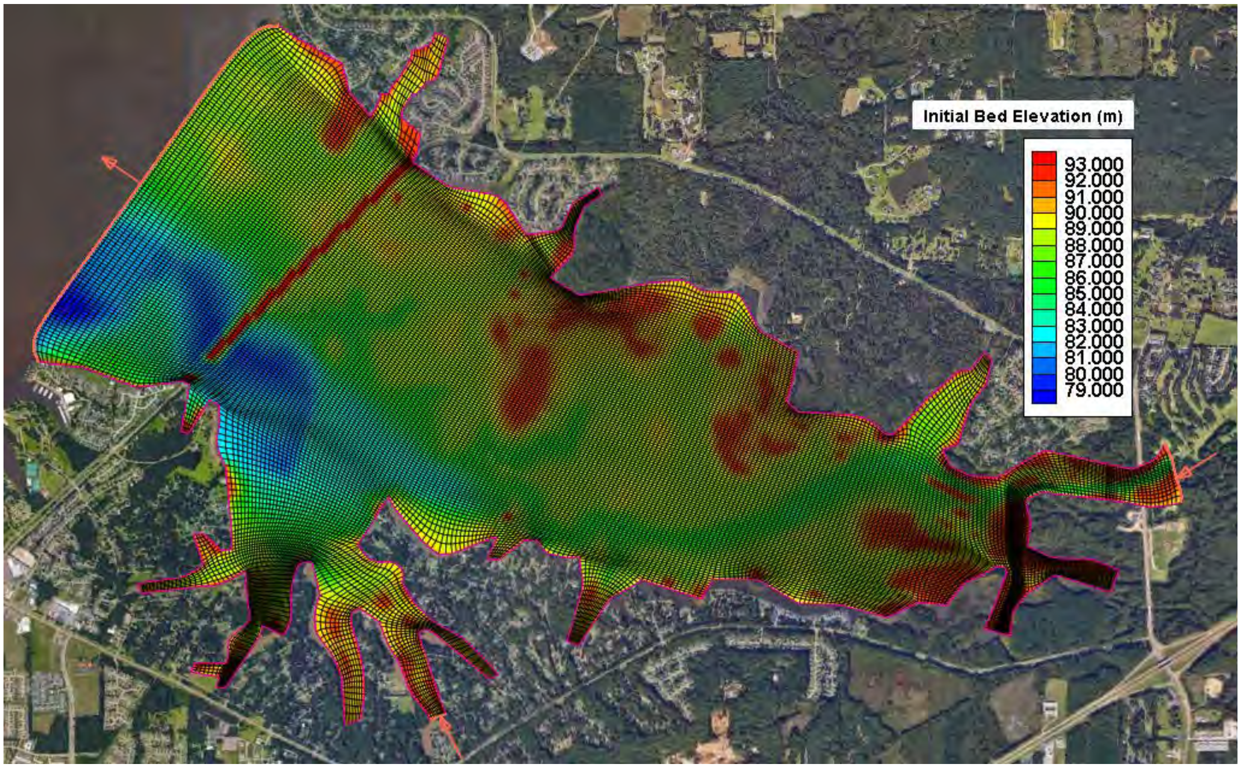


Figure 13. Final Mesh with Bed Interpolation

## 3.5. Numerical Simulation of Pelahatchie Bay (PB) Using CCHE Model

To understand the distributions of sediment and water quality in PB, CCHE was applied in this research to simulate the flow, sediment and water quality. CCHE model includes several modules, such as CCHE2D, CCHE3D, CCHE_WQ, CCHE_Chem, etc. In the study, CCHE3D module and CCHE_Box module were used from numerical simulation.

For short term simulations, such as a storm event, a large amount of water and sediment discharged into the bay within a short period. To study this case, the CCHE3D module was used to simulate the free surface hydrodynamics and sediment transport in the bay. The flow patterns as well as the concentration distributions of sediment were obtained.

Pelahatchie Bay is a shallow and relatively closed bay. For long term simulation, it can be considered as a well-mixed lake system. To study the concentration distribution of water quality in PB over a couple of years, the CCHE Box module was used to simulate the time series concentration of water quality in the bay.

### *3.5.1 CCHE3D module*

CCHE3D has been developed by NCCHE to simulate the flow hydrodynamics, sediment transport, water quality and pollutant transport (Jia et al. 2013, Chao et al. 2010, 2018).

### a. Flow modeling

The governing equations of continuity and momentum of the three-dimensional unsteady hydrodynamic model can be written as follows:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left( \nu \frac{\partial u_i}{\partial x_j} - \overline{u_i' u_j'} \right) + f_i \tag{2}$$

where $u_i$ ($i$=1,2,3) are Reynolds-averaged flow velocities ($u$, $v$, $w$) in Cartesian coordinate system ($x$, $y$, $z$); $t$ is the time; $\rho$ is the water density; $p$ is the pressure; $\nu$ is the fluid kinematic viscosity; $-\overline{u_i' u_j'}$ is the Reynolds stress; and $f_i$ are body force terms.

The free surface elevation ($\eta_s$) is computed using the following equation:

$$\frac{\partial \eta_s}{\partial t} + u_s \frac{\partial \eta_s}{\partial x} + v_s \frac{\partial \eta_s}{\partial y} - w_{sf} = 0 \tag{3}$$

where $u_s$, $v_s$ and $w_{sf}$ are surface velocities in $x$, $y$ and $z$ directions; $\eta_s$ is the water surface elevation.

Wind stress is one of the most important driving forces for lake water movement. The wind shear stresses ($\tau_{wx}$ and $\tau_{wy}$) at the free surface are expressed by

$$\tau_{wx} = \rho_a C_d U_{wind} \sqrt{U_{wind}^2 + V_{wind}^2} \tag{4}$$

$$\tau_{wy} = \rho_a C_d V_{wind} \sqrt{U_{wind}^2 + V_{wind}^2} \qquad (5)$$

where where $\rho_a$ is the air density; $U_{wind}$ and $V_{wind}$ are wind velocity components at 10 m elevation in $x$ and $y$ directions, respectively. Although the drag coefficient $C_d$ may vary with wind speed, for simplicity, many researchers assumed the drag coefficient was a constant on the order of $10^{-3}$ (Rueda and Schladow 2003). In this study, $C_d$ was set to$1.0\times10^{3}$, and this value is applicable for simulating the wind driven flow in Deep Hollow Lake in the Mississippi Delta (Chao et al 2010).

### b. Suspended sediment transport modeling

Sediment transport is one of the special features of the CCHE3D module. Because of the three-dimensionality, sediment particles' movements are highly affected by vertical motion of fluid flows in addition to horizontal movements. Suspended sediment transport in natural rivers, lakes and estuaries is a very common event, and the impact of the suspended sediment on water quality in the water bodies is significant. The governing equation of suspended sediment transport can be expressed as:

$$\frac{\partial s}{\partial t} + \frac{\partial (us)}{\partial x} + \frac{\partial (vs)}{\partial y} + \frac{\partial (w - w_s)s}{\partial z} = \frac{\partial}{\partial x}(D_x \frac{\partial s}{\partial x}) + \frac{\partial}{\partial y}(D_y \frac{\partial s}{\partial y}) + \frac{\partial}{\partial z}(D_z \frac{\partial s}{\partial z}) \qquad (6)$$

where in which $s$ is the concentration of cohesive sediment; $D_x$, $D_y$ and $D_z$ are mixing coefficients in $x$, $y$ and $z$ directions, respectively; and $w_s$ is the settling velocity.

To solve the 3D sediment transport equation, the boundary conditions at the free surface and bottom are needed. At the free surface, the vertical sediment flux is zero and the following condition is applied:

$$\omega_s s + \frac{\nu_t}{\sigma_s} \frac{\partial s}{\partial z} = 0 \qquad (7)$$

At the bottom, the following condition is applied:

$$\omega_s s + \frac{\nu_t}{\sigma_s} \frac{\partial s}{\partial z} = D_b - E_b \qquad (8)$$

where $D_b$ and $E_b$ = deposition rate and erosion (re-suspension) rate at bottom, respectively (kg/m$^2$/s). For non-cohesive sediment transport problems the erosion rate and deposition rate are the same, Eq.(8) becomes

$$\omega_s s_a + \frac{\nu_t}{\sigma_s} \frac{\partial s}{\partial z} = 0 \qquad (9)$$

$s_a$ is a reference concentration near the bed surface above the bedload layer with a reference height $a$. Currently, the reference concentration formula by Von Rijn (1989) is selected.

### c. Numerical method

CCHE is a finite element model. In this model, the staggered grid is adopted. The grid system in the horizontal plane is a structured conformal mesh generated on the boundary of the computational domain. In vertical direction, either uniform or non-uniform mesh lines are employed.

The unsteady equations are solved using the time marching scheme. A second-order upwinding scheme is adopted to eliminate oscillations due to advection. In this model, a convective interpolation function is used for this purpose. This function is obtained by solving a linear and steady convection-diffusion equation analytically over a one-dimensional local element. Although there are several other upwinding schemes, such as the first order upwinding, the second order upwinding and Quick scheme, the convective interpolation function is selected in this model due to its simplicity for the implicit time marching scheme.

The velocity correction method is applied to solve the pressure and enforce mass conservation. Provisional velocities are solved first without the pressure term, and the final solution of the velocity is obtained by correcting the provisional velocities with the pressure solution. The system of the algebraic equations is solved using the Strongly Implicit Procedure (SIP) method. In the model, the flow fields and sediment transport are solved at each time step.

### *3.5.2 CCHE_WQ water quality module*

NCCHE has developed a water quality module, CCHE_WQ for simulating temporal and spatial variations of water quality with respect to phytoplankton, nutrients, and dissolved oxygen. The interactions of water quality constituents in the water column and sediment layer are shown in Figure 14. Four major interacting systems have been simulated, including the phytoplankton kinetics, the nitrogen and phosphorus cycles, and the dissolved oxygen balance. The effects of suspended and bed sediment on the water quality processes are also considered. The model has been verified and validated using multiple sets of analytical solutions and physical model data, respectively. It has been applied to studies of water quality and pollutant transport problems in nature lakes (Chao et al. 2010). This module has been integrated into CCHE receiving water model to simulate the water quality concentration.

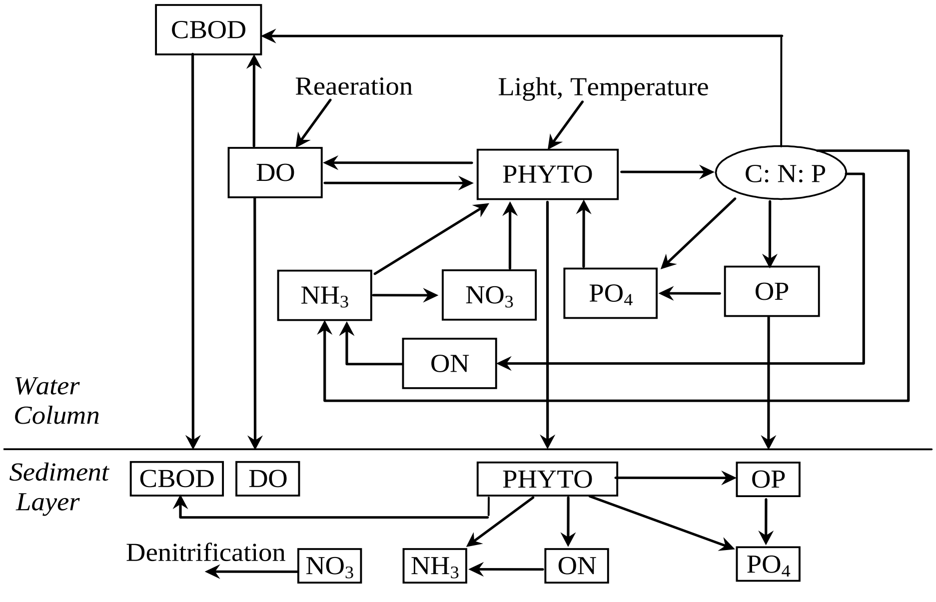


Figure 14. Chemical and bio-chemical processes included in CCHE_WQ

### a. Processes of adsorption-desorption of nutrients by suspended sediment

Adsorption and desorption are important processes between dissolved nutrients and suspended sediment (SS) in the water column. In water quality processes, the reaction rates for adsorption-desorption are much faster than that for the biological kinetics, an equilibrium assumption can be made (Wool et al. 2001). Many experimental results show the Langmuir equilibrium isotherm is a better representation of the relations between the dissolved and particulate nutrient concentrations (Bubba et al. 2003, Chao et al 2010), and can be calculated by

$$C_p = \frac{1}{2}\left[\left(C_0 + \frac{1}{K} + sQ_m\right) - \sqrt{\left(C_0 + \frac{1}{K} - sQ_m\right)^2 + \frac{4sQ_m}{K}}\right] \tag{10}$$

$$C_d = \frac{1}{2}\left[\left(C_0 - \frac{1}{K} - sQ_m\right) + \sqrt{\left(C_0 + \frac{1}{K} - sQ_m\right)^2 + \frac{4sQ_m}{K}}\right] \tag{11}$$

where $C_p$ and $C_d$ are particulate and dissolved nutrient concentrations, respectively; $C_0$ is the initial concentration of nutrients; $K$ and $Q_m$ are adsorption constants; and $s$ is the suspended sediment concentration.

### *b. Release of Dissolved Nutrients from Bed Sediment*

Bed release is an important source of inorganic and organic nutrients in the water column. In many models, the release rate of nutrients from bed sediment is determined based on the concentration gradient across the water-sediment interface. In fact, the bed release rate is also affected by pH, temperature and dissolved oxygen concentration (Romero 2003, Chao et al. 2010), and can be calculated by

$$S_{diff} = \theta_{sed}^{T-20} S_c \left( \frac{K_{dos}}{K_{dos} + DO} + \frac{|pH - 7|}{K_{pHs} + |pH - 7|} \right) \tag{12}$$

where $S_c$ is the diffusive flux of nutrients ($mg/m^2 day$); $K_{dos}$ ($mg/l$)and $K_{pHS}$ are the values that regulate the release of nutrient according to the dissolved oxygen ($DO$) and $pH$ in the bottom layer of the water column of depth $\Delta z_b$ ($m$); $\theta_{sed}$ is the temperature coefficient. The diffusive flux $S_c$ can be calculated using Fick's first law which expresses that the flux is directly proportional to the concentration gradient and the porosity of sediment (Loeff et al, 1984; Moore et al 1998):

$$S_c = -\phi D_m \frac{dC}{dz} \approx \frac{\phi D_m}{\Delta z_b}(C_b - C_w) = \frac{D_{bc}}{\Delta z_b}(C_b - C_w) = k(C_b - C_w) \tag{13}$$

where $D_m$ is the molecular diffusivity ($m^2/day$); $\phi$ is the porosity of sediment; $\Delta z_b$ is the diffusive sub-layer thickness near the bed ($m$); $D_{bc}$ and $k$ are the diffusion coefficient ($m^2/day$) and diffusive exchange coefficient ($m/day$) at the water-sediment interface; $C_w$ and $C_b$ are the concentration of nutrients in water and water-sediment interface, respectively.

### *3.5.3 CCHE_Box Module*

### a. The water balance equation

PB is a relatively shallow and closed bay. For long term simulation, it can be considered as a well-mixed lake system. The water balance equation of a well-mixed lake can be written as:

$$\frac{dV}{dt} = Q_{in} - Q_{out} - Q_e + Q_p + Q_g \tag{14}$$

where $V$ is the volume of the lake water; $t$ is the time; $Q_{in}$ is the inflow discharge; $Q_{out}$ is the outflow discharge; $Q_e$ is the flow decreasing rate due to the evaporation; $Q_p$ is the flow increasing rate due to the precipitation; $Q_g$ is the groundwater discharge.

### b. Water quality mass balance equation

The water quality mass balance equation can be written as

$$\frac{d(CV)}{dt} = Q_{in}C_{in} - Q_{out}C + V\sum S \tag{15}$$

where $C$ is the concentration of water quality constituents in water, including ammonia (NH4), nitrite (NO3), phosphate (PO4), phytoplankton (as chlorophyll a), dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), organic nitrogen (ON), organic phosphorus (OP); $t$ is the time; $V$ is the volume of the water; $Q_{in}$ is the inflow discharge; $Q_{out}$ is the outflow discharge; $C_{in}$ is the concentration of water quality constituents in the inflow; $\sum S$ is the source term of water quality constituents. For each water quality constituents, $\sum S$ can be calculated using the formulas presented in CCHE Water Quality Module (Chao et al. 2006a, 2006b)

### c. Temperature balance equation

The temperature is one of the most important factors in the chemical and bio-chemical reactions of water quality processes. The heat balance equation of a well-mixed lake can be written as:

$$C_p\rho\frac{d(TV)}{dt} = Q_{in}C_p\rho T_{in} - Q_{out}C_p\rho T_{out} + AJ_s \tag{16}$$

$$\frac{d(TV)}{dt} = Q_{in}T_{in} - Q_{out}T_{out} + \frac{AJ_s}{C_p\rho} \tag{17}$$

where $T$ is the water temperature in the lake; $T_{in}$ is the water temperature of inflow; $T_{out}$ is the water temperature of outflow; $C_p$ is the specific heat of water; $\rho$ is the density of water; $J_s$ is the heat exchange flux with atmosphere, including: net short wave radiation (solar radiation) $J_{so}$, net long wave radiation (atmospheric radiation) $J_{am}$, heat flux due to evaporation $J_e$ and convection $J_c$ (Chapra 1997)

The solar radiation $J_{so}$ can be expressed as:

$$J_{so} = 0.94J_{sc}(1 - 0.65C_f^{\,2}) \tag{18}$$

in which $J_{sc}$ is the clear sky solar radiation; and $C_f$ is the fraction of sky covered by clouds.

Net long wave radiation $J_{am}$ can be expressed as:

$$J_{am} = 0.97\varepsilon_{air}\sigma(T_a + 273)^4(1 + 0.17C^2) - \varepsilon_w\sigma(T_{ws} + 273)^4 \tag{19}$$

where σ is the Stefan-Boltzman constant ($5.669\times10^{-8}$); $T_a$ is the atmospheric temperature in $^oC$; $T_{ws}$ is the water surface temperature in $^oC$; C is the fraction of sky covered by clouds; $\varepsilon_{air}$ and $\varepsilon_w$ are the emissivity of air and water. The water emissivity ($\varepsilon_w$ = 0.96) for an approximation for normal and hemispherical emissivity, while the air emissivity is a function of air temperature and is determined by

$$\varepsilon_{air} = 0.938\times10^{-5}(T_a + 273)^2 \tag{20}$$

The evaporative heat flux $J_e$ can be written as:

$$J_e = f(U_w)(e_{air} - e_s) \tag{21}$$

in which $f(U_w)$is a function of wind; $e_s$ is the saturation vapor pressure at the water surface; $e_{air}$ are the vapor pressure in the overlying air.

$$f(U_w) = 6.9 + 0.345U_w^2 \tag{22}$$

$$e_s = 6.108\exp\left(\frac{17.27T_{ws}}{T_{ws} + 237.3}\right) \tag{23}$$

$$e_{air} = 6.108\exp\left(\frac{17.27T_d}{T_d + 237.3}\right) \tag{24}$$

in which $U_w$ is the wind speed at 7 m above the water surface; $T_{ws}$ and $T_d$ are water surface temperature and dew point temperature in $^o$C, respectively.

The convective heat flux $J_c$ can be expressed as:

$$J_c = 0.62f(U_w)(T_a - T_{ws}) \tag{25}$$

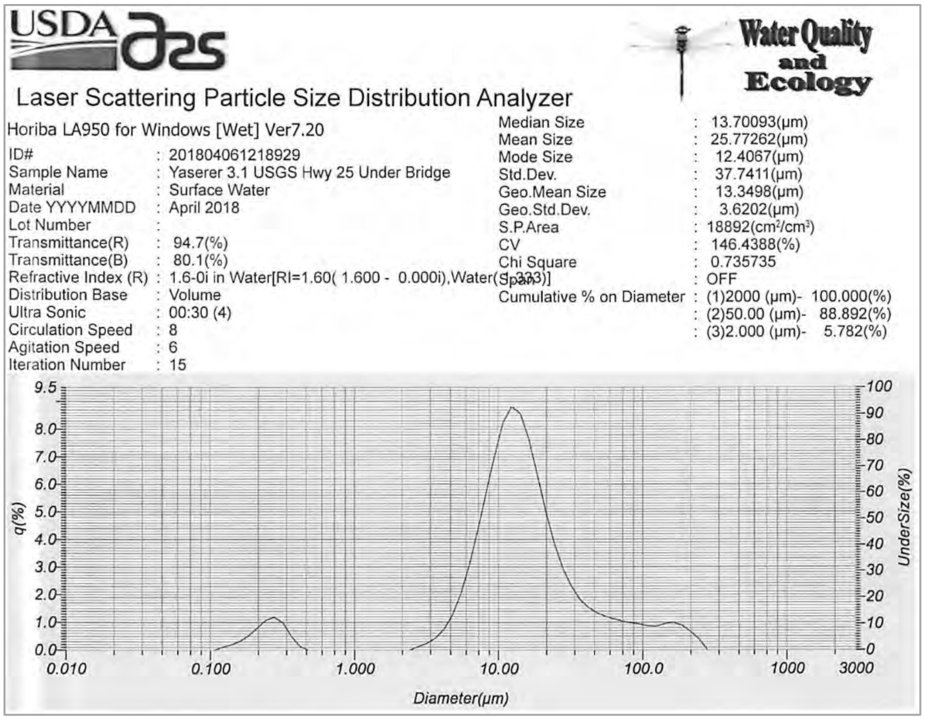
where $T_{ws}$ is the water surface temperature in $^oC$; and $T_a$ is the atmospheric temperature in $^oC$.

In the receiving waterbody model, the water surface elevation, temperature and water quality constituents are solved simultaneously.

## 4. RESEARCH RESULTS

### 4.1. Field Measured Data

In this project, one field trip were taken on April 4, 2018. The suspended sediment samples in the PB were collected after a storm event. Figure 5 shows the SS sampling locations in PB. Figure 15a and b show the size distributions at two major inlets: Highway 25 USGS Gage (Pelahatchie Creek), and Mill Creek. The measured SS concentration at these two stations were 88 mg/l and 117 mg/l, respectively. The measured median sizes and SS concentrations at these two stations are used for model simulation.



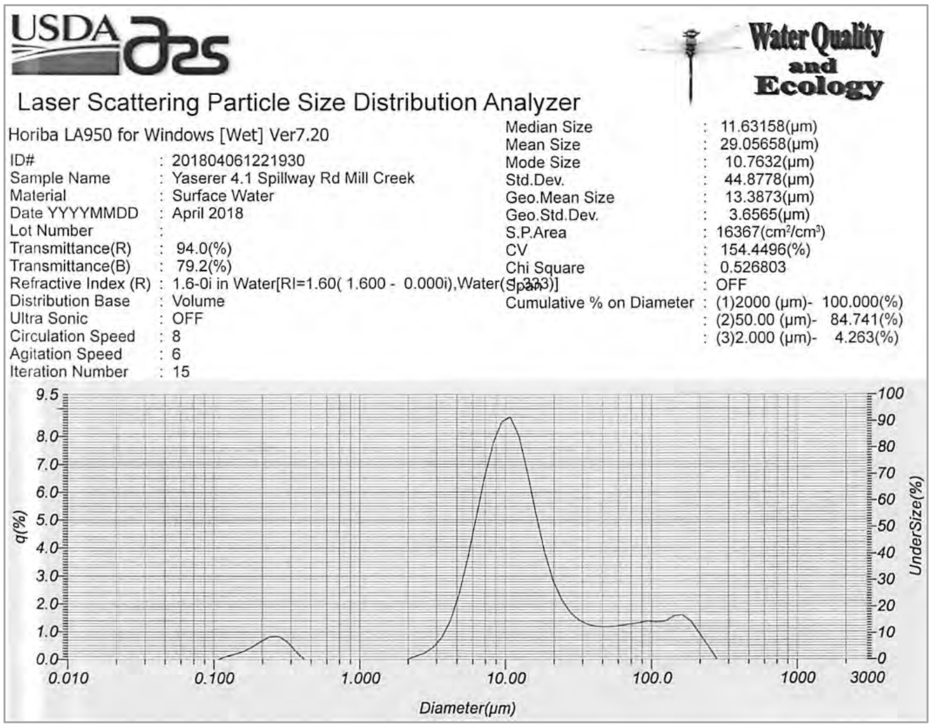
Laser Scattering Particle Size Distribution Analyzer

Horiba LA950 for Windows [Wet] Ver7.20

ID# : 201804061218929
Sample Name : Yaserer 3.1 USGS Hwy 25 Under Bridge
Material : Surface Water
Date YYYYMMDD : April 2018
Lot Number :
Transmittance(R) : 94.7(%)
Transmittance(B) : 80.1(%)
Refractive Index (R) : 1.6-0i in Water[RI=1.60( 1.600 - 0.000i),Water(1.333)]
Distribution Base : Volume
Ultra Sonic : 00:30 (4)
Circulation Speed : 8
Agitation Speed : 6
Iteration Number : 15

Median Size : 13.70093(μm)
Mean Size : 25.77262(μm)
Mode Size : 12.4067(μm)
Std.Dev. : 37.7411(μm)
Geo.Mean Size : 13.3498(μm)
Geo.Std.Dev. : 3.6202(μm)
S.P.Area : 18892(cm²/cm³)
CV : 146.4388(%)
Chi Square : 0.735735
Span : OFF
Cumulative % on Diameter : (1)2000 (μm)- 100.000(%)
: (2)50.00 (μm)- 88.892(%)
: (3)2.000 (μm)- 5.782(%)

Figure 15a. Suspended sediment size distributions at Highway 25 USGS Gage Station



Laser Scattering Particle Size Distribution Analyzer

Horiba LA950 for Windows [Wet] Ver7.20

ID# : 201804061221930
Sample Name : Yaserer 4.1 Spillway Rd Mill Creek
Material : Surface Water
Date YYYYMMDD : April 2018
Lot Number :
Transmittance(R) : 94.0(%)
Transmittance(B) : 79.2(%)
Refractive Index (R) : 1.6-0i in Water[RI=1.60( 1.600 - 0.000i),Water(1.333)]
Distribution Base : Volume
Ultra Sonic : OFF
Circulation Speed : 8
Agitation Speed : 6
Iteration Number : 15

Median Size : 11.63158(μm)
Mean Size : 29.05658(μm)
Mode Size : 10.7632(μm)
Std.Dev. : 44.8778(μm)
Geo.Mean Size : 13.3873(μm)
Geo.Std.Dev. : 3.6565(μm)
S.P.Area : 16367(cm²/cm³)
CV : 154.4496(%)
Chi Square : 0.526803
Span : OFF
Cumulative % on Diameter : (1)2000 (μm)- 100.000(%)
: (2)50.00 (μm)- 84.741(%)
: (3)2.000 (μm)- 4.263(%)

Figure 15b. Suspended sediment size distributions at Mill Creek

## 4.2. AnnAGNPS Watershed Model Simulation

The AnnAGNPS watershed model was applied to simulate the loads of runoff, sediment and nutrients from MCW into the PB Bay under current conditions defined as for 2016 that included water and sediment retention pond BMP implementation in the urban areas of the watershed. The impact of changing land use from 2006 to 2016 was also studied, including the impact of water and sediment retention ponds in urban areas. The simulated results are used as boundary conditions for the CCHE model.

Figure 16 shows the simulated runoff in Mill-Pelahatchie Creek Watershed. Figure 17 shows the simulated sediment loads in MCW watershed.

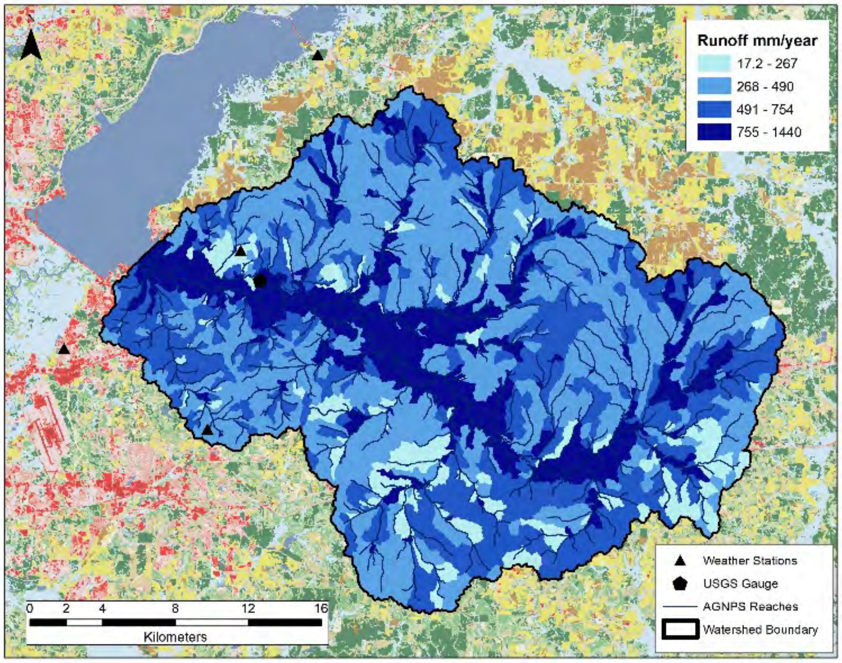


Figure 16. Simulated runoff in Mill-Pelahatchie Creek Watershed

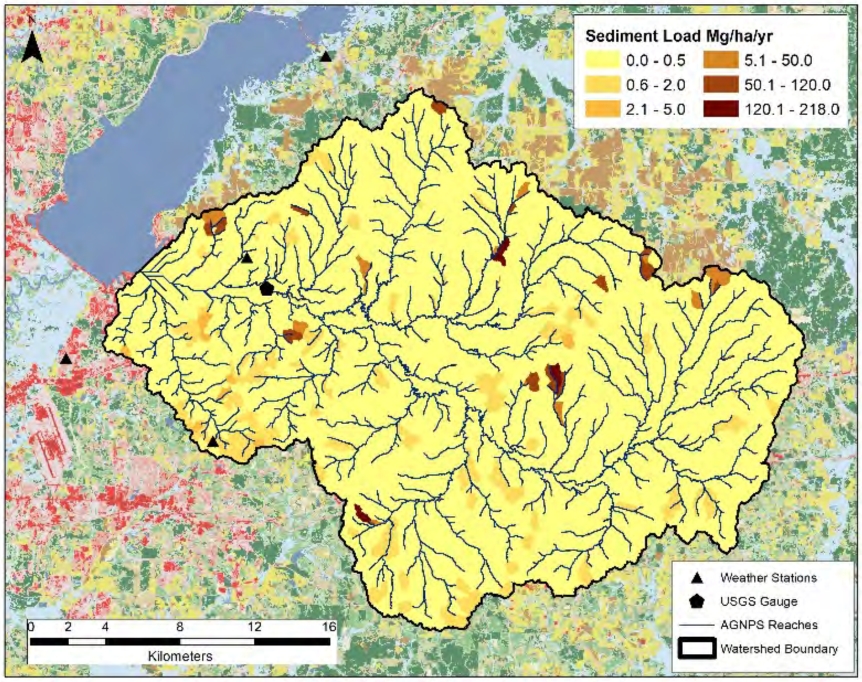


Figure 17. Simulated sediment loads in Mill-Pelahatchie Creek Watershed

Figure 18 shows a comparison of flow discharge between the AnnAGNPS model results and measured data at Highway 25 USGS Gage station. The simulated flow peaks are generally in good agreement with field measurements. The correlation coefficient $r^2$=0.94.

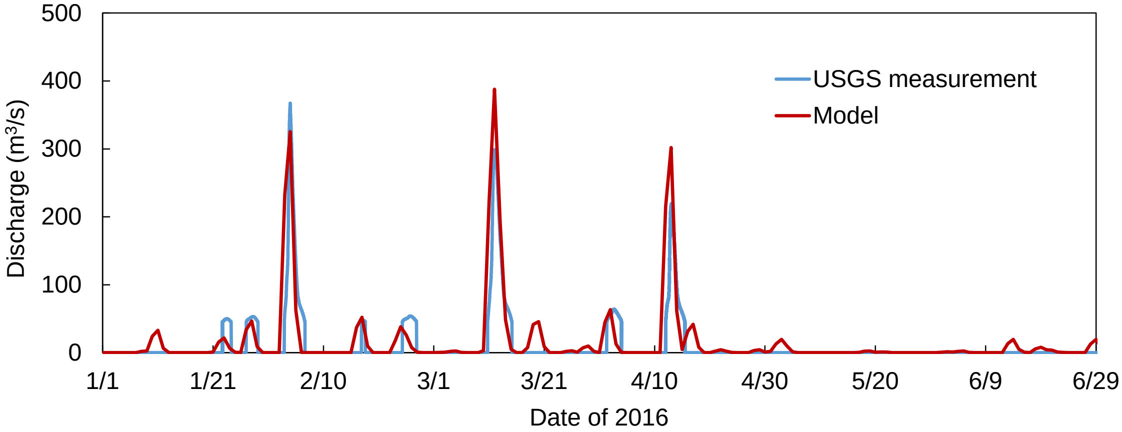


Figure 18. Comparison of flow discharge between AnnAGNPS results and USGS measurements

Urban land use increased 508 hectares within the watershed from 2006 to 2016 resulting in a minor increase in watershed runoff of 0.15%, a decrease in sediment of 0.07%, and a very small change in total nitrogen from all watershed loads into the lake. The impact of water and sediment retention ponds applied as a best management practice in the urban areas of the watershed on total watershed load helped decrease runoff by 0.05% and sediment by 0.13%.

The local impact of the increase of urban areas from 2006 to 2016 was greater in areas associated with computational reach 913 from Figure 6 where runoff increased 10%, sediment decreased 18%, and nitrogen increased 16%. The impact of implementing retention ponds as a best management practice reduced runoff by 1%, sediment by 2%, and nitrogen by 25% from what the loads would be without the retention ponds in place. The impact of urban growth in computational reach 834 from 2006 to 2016 resulted in an increase in runoff of 1%, a decrease in sediment of 2%, and a decrease in nitrogen of 5% with an impact of retention ponds in decreases of 0.5% on runoff, 0.3% on sediment, and a decrease of nitrogen by 7% if the ponds were not in place.

## 4.3. CCHE Model Simulation

In this project, CCHE3D and CCHE_Box modules were applied to simulate the flow, sediment and water quality.

### *4.3.1 CCHE3D module simulation*

Based on initial bed elevation data, the computational domain was discretized into a structured finite element mesh using the CCHE Mesh Generator (Zhang, 2017). In the horizontal plane, the computational domain was represented by a mesh with 213x255 nodes. In the vertical direction, the domain was divided into 8 uniform layers (Figure 13). A simulation period from Feb. 1 to April 20, 2016, was selected for model simulation.

Two inlet boundaries were set for model simulation: Pelahatchie Creek and Mill Creek (Figure 13). The measured flow discharge at USGS 02485498 Station was used as flow boundary conditions for Pelahatchie Creek. The sediment concentration in Pelahatchie Creek, and the flow as well as sediment concentration in Mill Creek were obtained from the simulation results of AnnAGNPS. The outlet water surface elevations were obtained from field measurements of USGS 02485600 Station. The wind speeds and directions during the simulation period were obtained from nearby Jackson Airport. The flow velocity and sediment concentration in Pelahatchie Bay was simulated using CCHE3D module.

Figures 19 and 20 show the flow velocities on the water surface and near the bed during a storm event. The flow patterns are induced by the upstream river discharge as well as the wind forces.

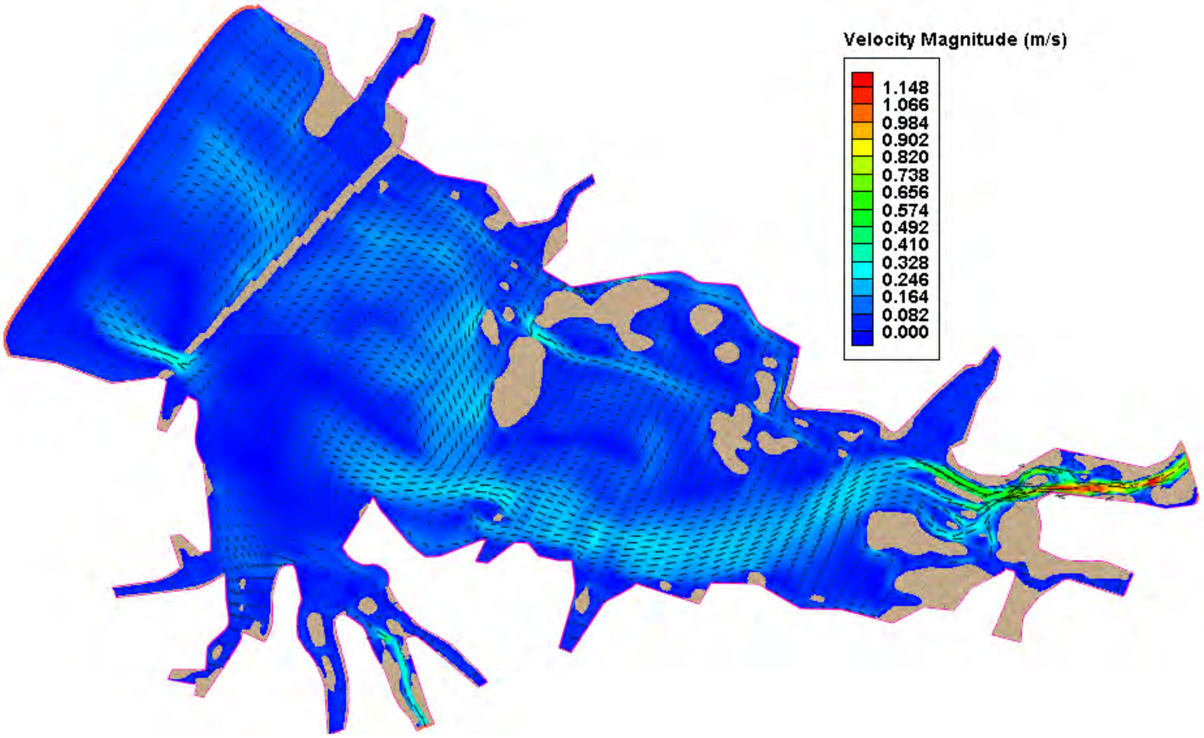


Figure 19. Simulated flow patterns near surface in Pelahatchie Bay

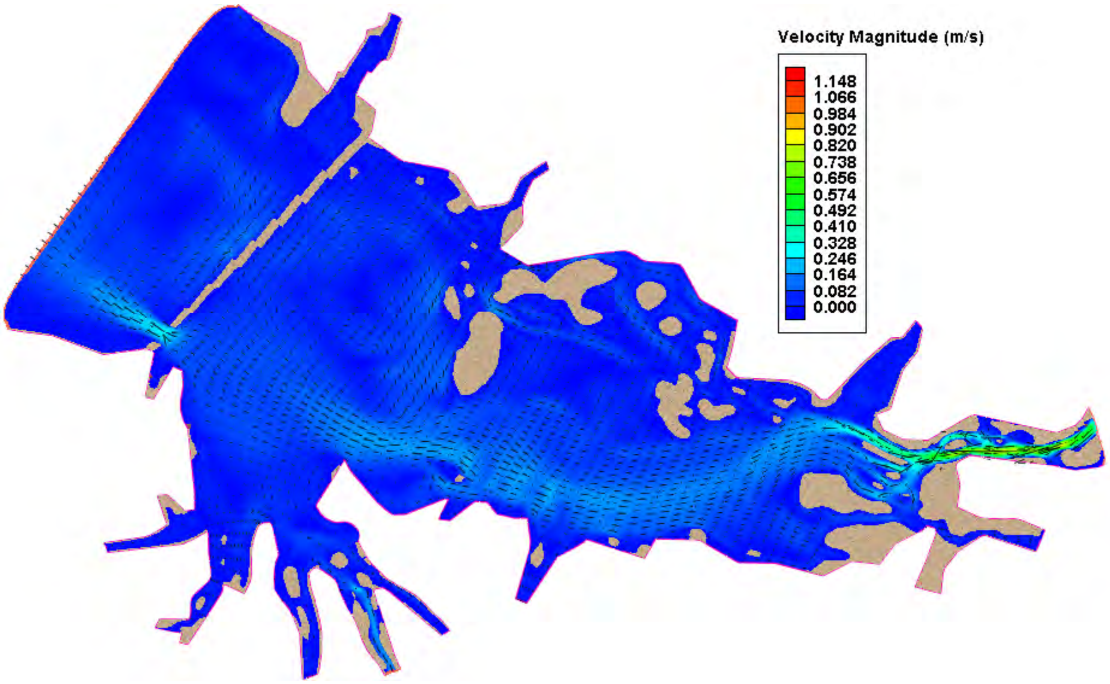


Figure 20. Simulated flow patterns near bottom in Pelahatchie Bay

Figures 21a shows the simulated concentration of SS in the bay when the storm event occurred. It is generally in good agreement with the results obtained based on satellite image (Figure 21b). The two inlets (Pelahatchie Creek and Mill Creek) are the major sources of sediment discharged into the bay (Figure 21a). Due to the storm event, SS transports or diffuses to almost the whole domain of the bay (Figures 22a and 22b).

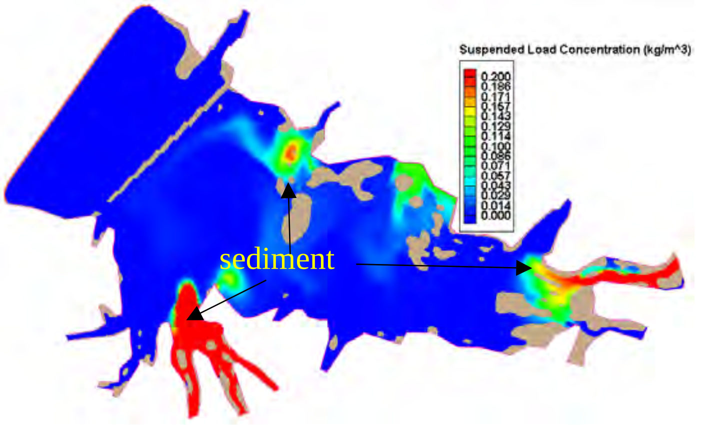


Figure 21a. Simulated sediment concentration in the bay

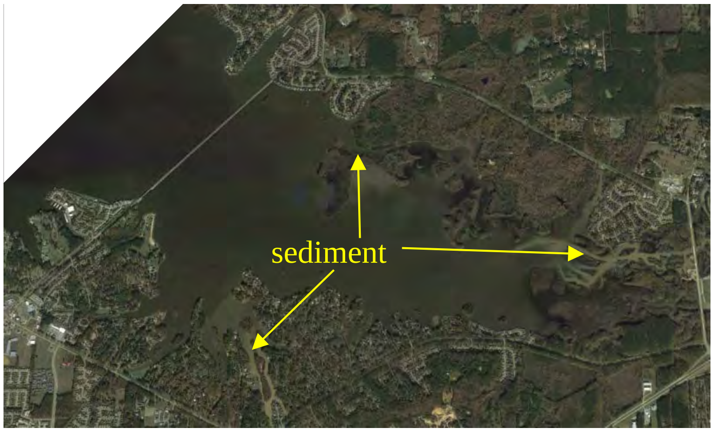


Figure 21b. Concentration of sediment concentration (satellite image)

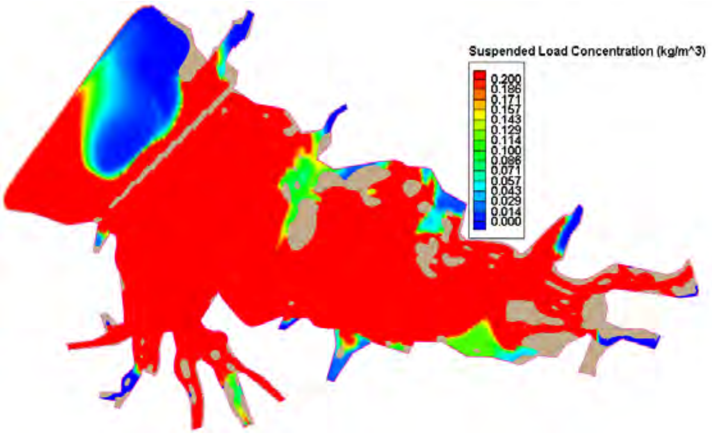


Figure 22a. Simulated sediment concentration in the bay

Figure 22b. Concentration of sediment concentration (satellite image)

### *4.3.2 CCHE_Box module simulation*

To understand the concentration distribution of water quality in PB over a long period from 2014 to 2016, the CCHE_Box module was applied to simulate the time series of water temperature and concentrations of SS and water quality constituents in the bay.

The daily loads of water, sediment, and nutrients in MCW were simulated using the AnnAGNPS model, and the simulated results were used as inflow boundary conditions for the CCHE_Box module. In the AnnAGNPS model, the outputs of daily loads are in the unit of kg, therefore, the runoff needs to be converted to discharge ($m^3/s$), and the sediment and nutrients need to be converted to concentrations (mg/l).

The climate data, including wind, solar radiation, air temperature, relative humidity, and precipitation were obtained from the NOAA National Climatic Data Center at Jackson Station.

The outflow discharge conditions were obtained based on the inflow discharge, water surface elevations, precipitation amount and evaporation rate.

The water quality data, such as nutrients and chlorophyll in PB, were obtained from MDEQ and used for model calibration and validation.

Figure 23 shows the water temperature distribution from 2014 to 2016. It is generally in good agreement with the measured data provided by MDEQ.

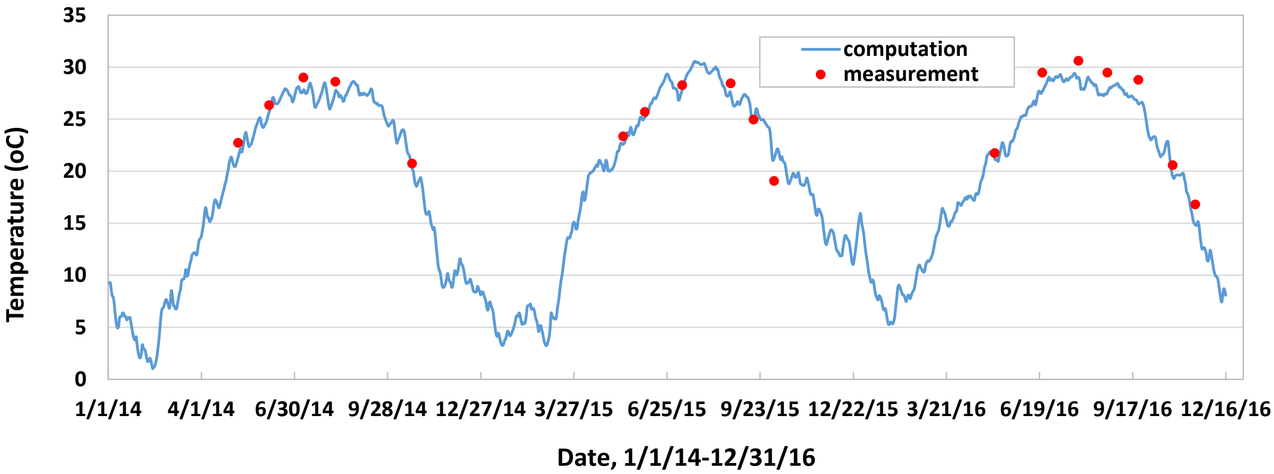


Figure 23. Time series of water temperature distribution in Pelahatchie Bay

Figure 24 shows the concentration of chlorophyll a in the bay from 2014 to 2016. It is generally in agreement with the measured data provided by MDEQ. It can be observed that over time, the chlorophyll concentration in the bay has gradually increased.

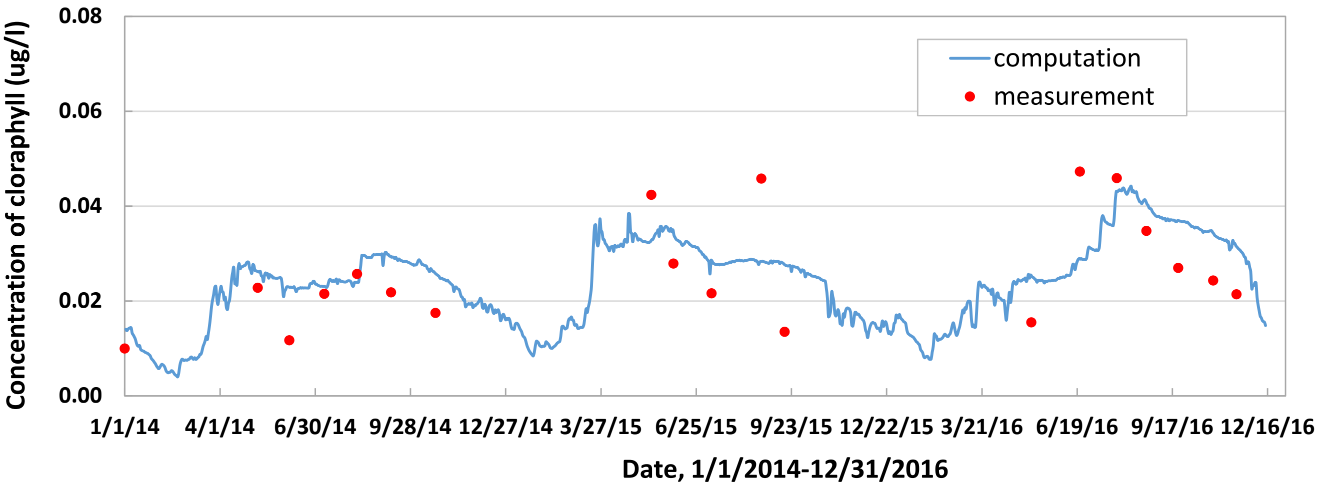


Figure 24. Time series of concentration of chlorophyll a in Pelahatchie Bay

## 4.4. Effects of BMPs on the Loads in the Watershed and Water Quality in the Bay

### *4.4.1 Current conditions of sediment loads*

Figures 25 and 26 show the simulation results of total sediment loads and concentration of sediment discharged into PB from 2014 to 2016. It was estimated that about 372,095 MG (ton) of sediment was discharged into PB during this period. High sediment discharges corresponded to high precipitation storm events. Since the outlet of the bay is very narrow and very little sediment might flow out of the bay, then, almost all the sediment discharged into the bay from the upland watershed may stay in the bay either in the water or bed, for a long time. Over time, nutrients trapped with the sediment in the bay would be released into the water and extensive sedimentation would also affect the navigation of the bay.

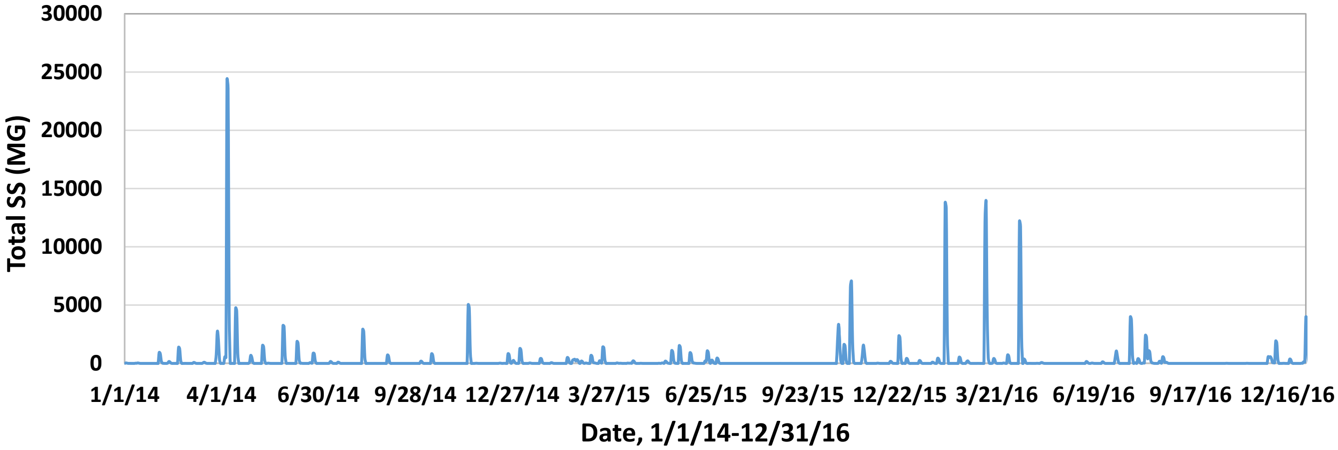


Figure 25. Total suspended sediment loads from upland watershed

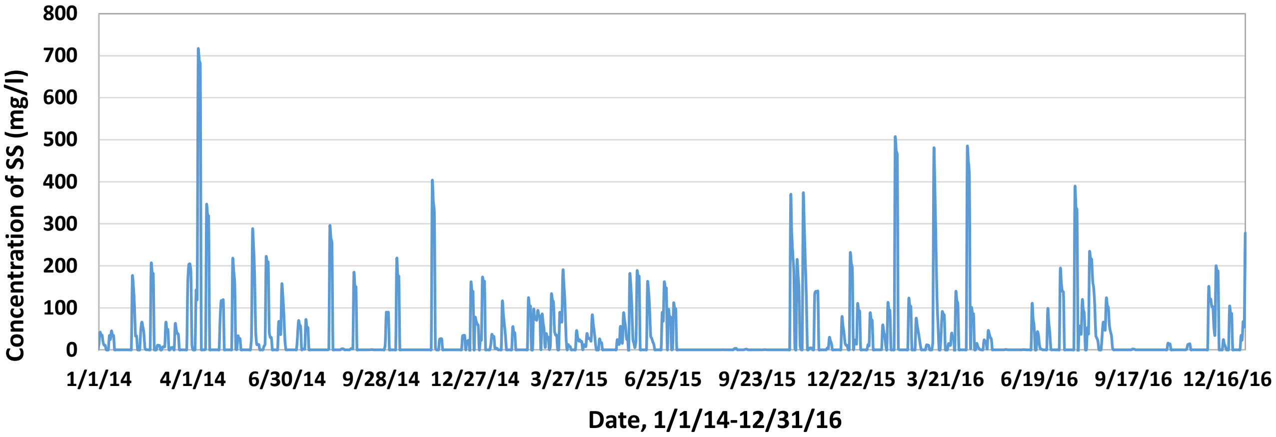


Figure 26. Concentration of suspended sediment discharged into PB from upland watershed

### *4.3.2 Current conditions of nutrients loads*

Figures 27 and 28 show the simulation results of concentrations of nitrogen and phosphorus discharged into PB from upland during 2014 and 2016. Since the outlet of the bay is very narrow and may limit the exchange of nutrients in/out of PB, therefore, the nutrients discharged into the bay from the upland watershed may stay in the bay for a longer time, either in the water or absorbed on sediment.

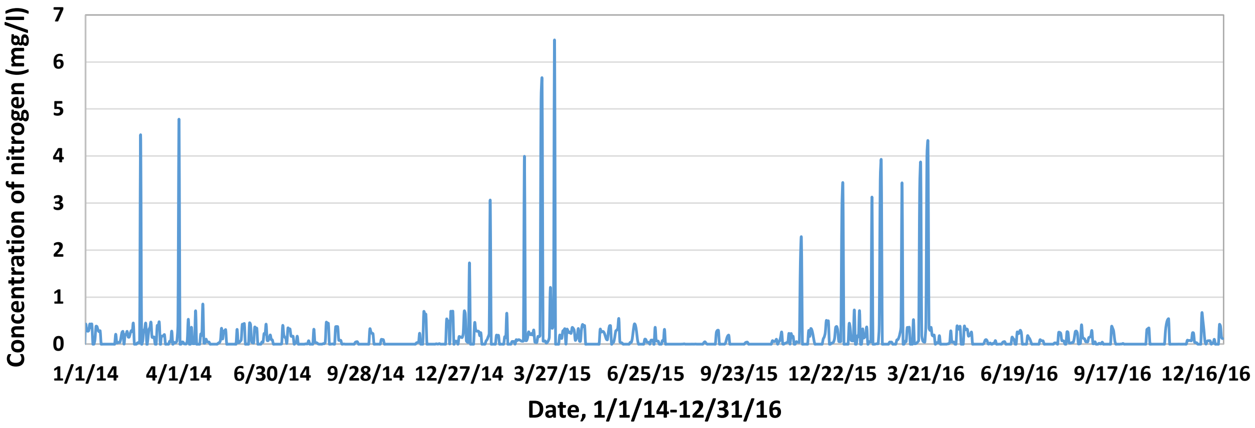


Figure 27. Concentration of nitrogen discharged into PB from upland watershed

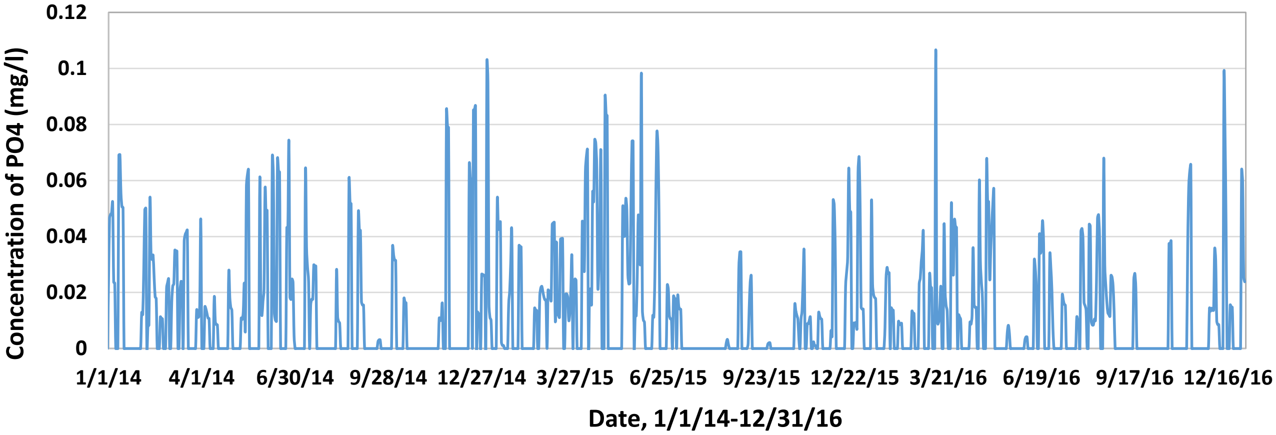


Figure 28. Concentration of phosphate discharged into PB from upland watershed

### *4.3.3 Current conditions of SS and nutrients in Pelahatchie Bay*

The concentrations of SS and nutrients in PB are generally affected by the loads from upland watershed. During the storm events, large amount of sediment and nutrients flow into PB. Figures 21 shows the concentration of SS in the bay when a storm event occurred. The two inlets (Pelahatchie Creek and Mill Creek) are the major sources of sediment discharged into the bay, nearly 90% of total SS loads flow into PB through these two inlets. Simulation results show that every year, about 124,000 tons of SS enter the bay, only 8% may flow out of the bay. More than 90% of sediment still stay in the bay either in water or deposit to bed. Most of the sediment may deposit near the Creek entrance, and in the low flow velocity regions, such as many braches, shore line, etc. Large amount of sediment deposited in the bay may greatly affect the navigation and recreation value of the bay.

The simulation results show that the yearly average concentration of SS in the bay is about 36 mg/l. From May to November, the SS concentration in the bay is relatively small, and the averaged concentration is about 16 mg/l, while during the raining season from December to April, the averaged SS concentration could raise to 67 mg/l. Since the flow in the bay is relatively weak, and the outlet of the bay is also very narrow, most of the sediment may eventually deposit to the bed.

Figures 29, 30 and 31 show the concentrations of ammonia, nitrite and phosphate in PB during 2014 and 2016. The simulated results are generally in agreement with the limited field measurements provided by MDEQ. The high nutrient concentrations are corresponding to the big storm events in winter or spring. In the water, the concentrations of NH4 and PO4 are relatively high, which may promote the growth of algae and aquatic plants.

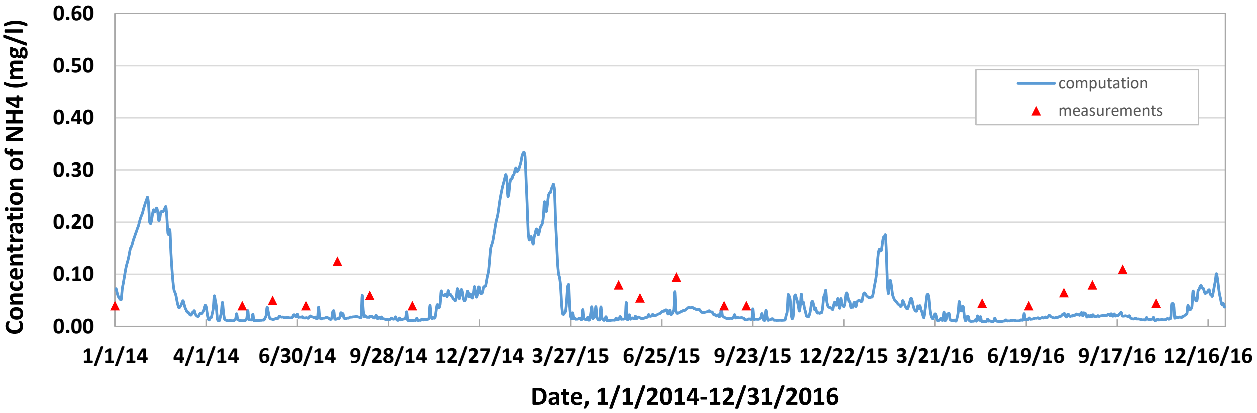


Figure 29. Concentration of NH4 in PB

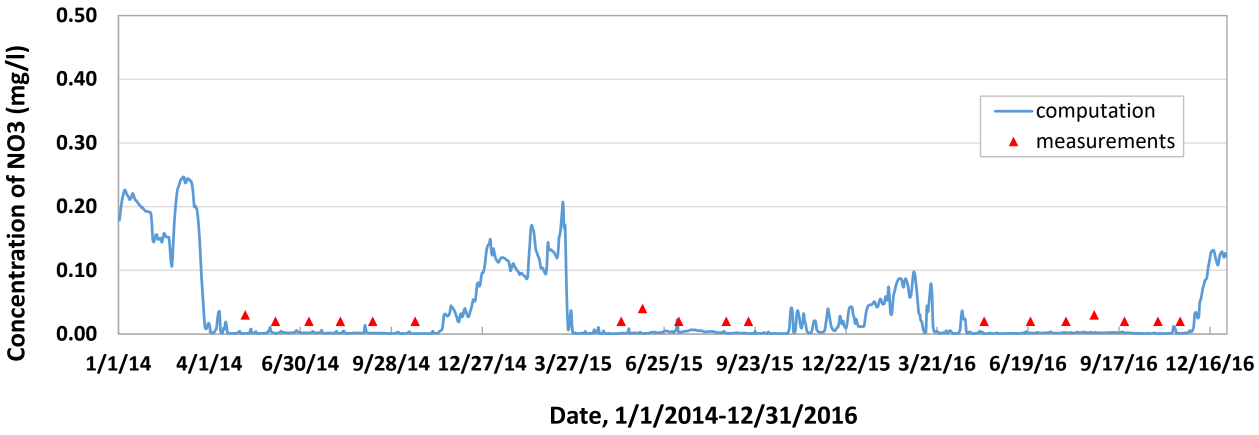


Figure 30. Concentration of NO3 in PB

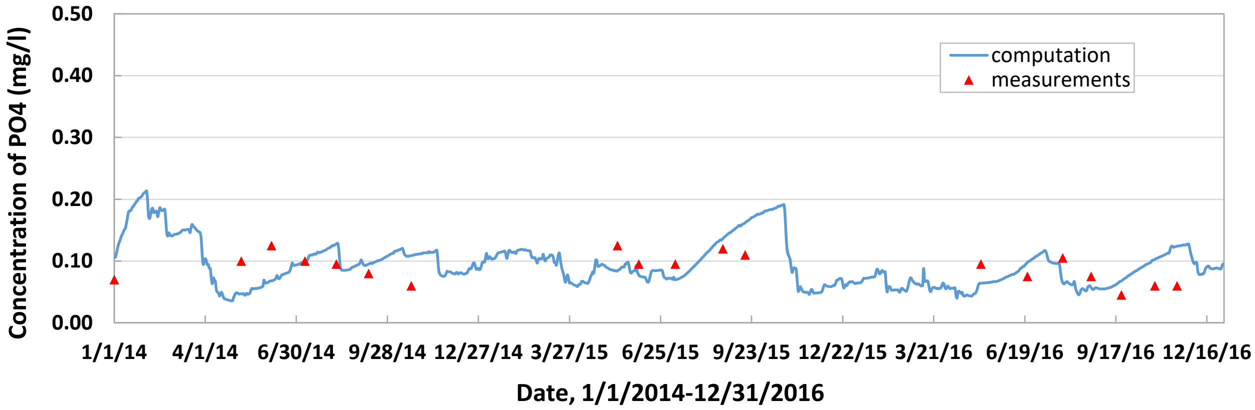


Figure 31. Concentration of PO4 in PB

### *4.3.4 The effects of BMPs on the conditions of sediment and nutrients in Pelahatchie Bay*

To reduce the sediment and nutrients from upland watershed flowed into PB, BMPs have been implemented. In the AnnAGNPS watershed model, the land use /land cover (LU/LC) parameters were modified based on the implemented BMPs, included the establishment of stabilization measures of disturbed soil on urban construction sites that included water and sediment retention ponds.

The simulation results show that the impact of implementing retention ponds as a best management practice reduced runoff by 1%, sediment by 2%, and nitrogen by 25% from what the loads would be without the retention ponds in place.

To estimate the effectiveness of BMPs on water quality in PB, numerical model was applied to simulate the concentrations of nutrients and SS by considering the reductions of their loads from upland watershed. The scenarios consisted of current loads, and 90%, 80%, 70%, 60%, and 50% of current loads.

The model was used to simulate the concentrations of SS and nutrients in the bay under different scenarios. Figures 32 and 33 show the concentrations of ammonia and chlorophyll in PB under those different loads. Table 1 shows the reduced nutrients levels in PB due to the loads reductions of SS and nutrients in the upland watershed. According to model predictions, reducing the upland nutrients and SS loads by 50% would reduce average concentrations of NH4, NO3, PO4 and Chlorophyll a by approximately 40%, 50%, 6% and 55%, respectively.

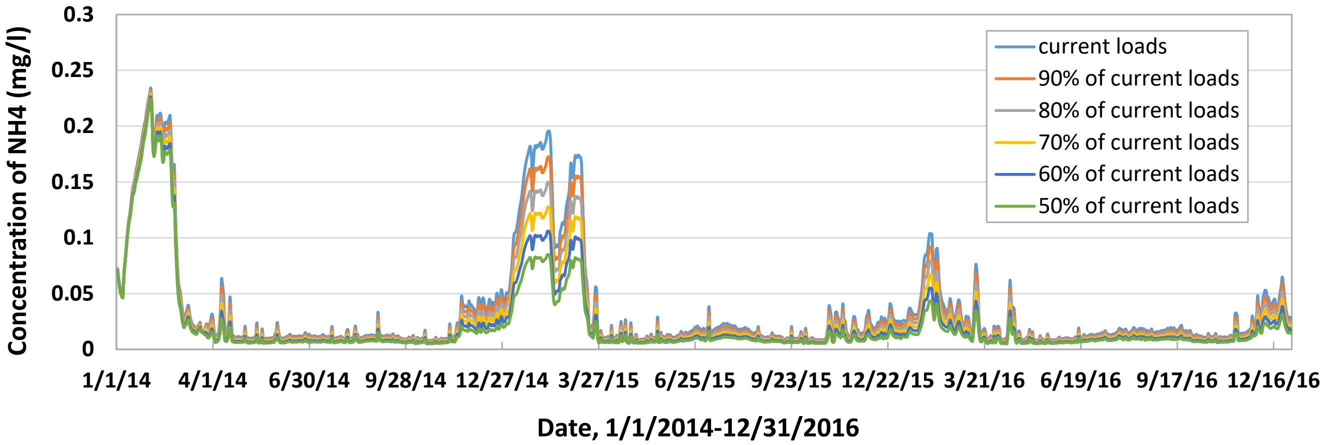


Figure 32. Concentration of NH4 in PB with different loads of nutrients and SS

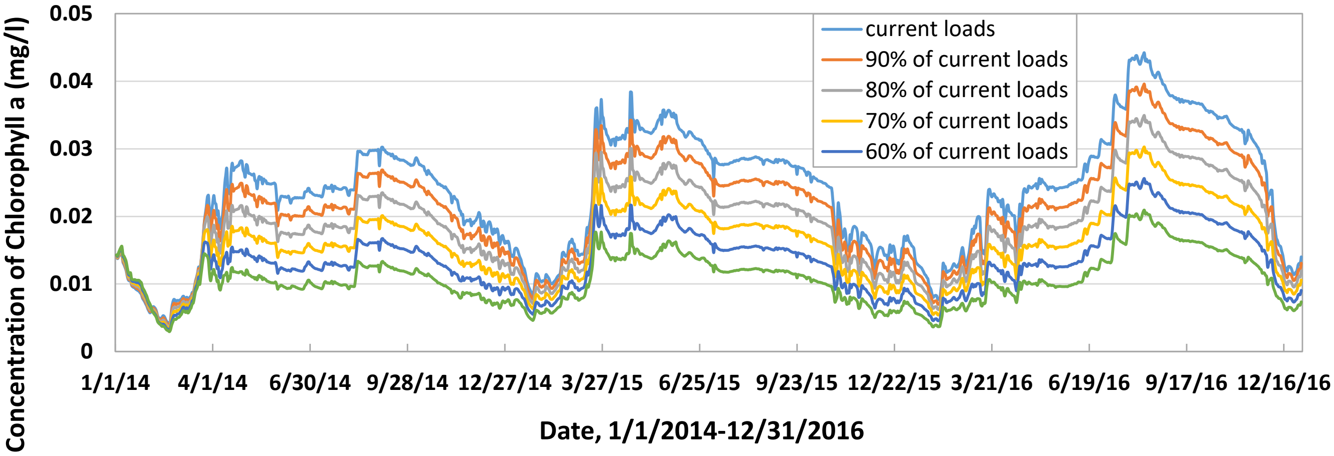


Figure 33. Concentration of chlorophyll a in PB with different loads of nutrients and SS

Table 1. Reduced nutrients levels in PB due to the loads reductions of SS and nutrients in the watershed

| % of Current loads | Reduced % of NH4 | Reduced % of NO3 | Reduced % of PO4 | Reduced % of Chl a |
|---|---|---|---|---|
| 90% | 8.54% | 12.77% | 1.44% | 10.77% |
| 80% | 16.88% | 24.17% | 2.81% | 21.64% |
| 70% | 25.03% | 34.25% | 4.08% | 32.62% |
| 60% | 33.02% | 43.02% | 5.25% | 43.66% |
| 50% | 40.89% | 50.52% | 6.30% | 54.70% |

Table 2 show the sediment budgets in the water, bed, and out of the bay under different scenarios. According to model predictions, reducing the upland SS loads by 50% would reduce the average concentration of SS in water by approximately 50%. More than 90% of sediment may stay in the bay, and eventually deposit to the bed.

Table 2. Reduced SS amounts in PB due to the loads reductions of SS in the watershed

| % of Current loads | SS yearly loads, ton | SS in water, mg/l | SS in water, ton | Sediment in bed, ton | Sediment out of the bay, ton |
|---|---|---|---|---|---|
| 100% | 124,000 | 36.34 | 1,213 | 114,080 | 9,920 |
| 90% | 111,600 | 32.72 | 1,092 | 102,672 | 8,928 |
| 80% | 99,200 | 29.1 | 971 | 91,264 | 7,936 |
| 70% | 86,800 | 25.48 | 850 | 79,856 | 6,944 |
| 60% | 74,400 | 21.86 | 729 | 68,448 | 5,952 |
| 50% | 62,000 | 18.24 | 609 | 57,040 | 4,960 |

## 5. DISCUSSIONS

The distributions of sediment and nutrients in Pelahatchie Bay and upland Mill-Pelahatchie Creek- Watershed have been studied based on field measured data and numerical models. This study indicates that the concentrations of SS and nutrients in PB are greatly affected by the loads of upland watershed.

A coupling approach has been developed to integrate the AnnAGNPS watershed model and CCHE model to simulate the sediment and water quality distribution in PB. The AnnAGNPS model is applied to simulate the daily loads of runoff, sediment and nutrients from MCW. The simulation results are used as boundary conditions for the CCHE model to predict the sediment and water quality concentrations in PB. The integrating system is also applied to analyze the effect of upland BMP on the water quality in the watershed and PB.

The AnnAGNPS model results show that the growth of urban areas of over 500 hectares throughout the watershed from 2006 to 2016 resulted in only a minor increase in total runoff, sediment, and nitrogen. While, the local impact of the increase of urban areas from 2006 to 2016 was greater in areas associated with computational reach 913 where runoff increased 10%, sediment decreased 18%, and nitrogen increased by 16%. Water and sediment retention ponds in this computational reach helped to decrease runoff, sediment, and nitrogen by 1%, 2%, and 25%, respectively.

Pelahatchie Bay is a shallow and relatively closed bay. During storm events, the flow velocities in the bay are greatly affected by the upstream flow discharge as well as the wind force, therefore, the flow patterns show very complex 3D distributions. To study these cases, the CCHE3D module was used to simulate the free surface hydrodynamics and sediment transport in the bay. If there is no storm event, the flow velocities in PB is mainly induced by wind driving, which can be considered as a well-mixed system. To study this case, the CCHE Box module can be used to simulate the concentrations of water quality and SS in the bay over a long time period.

The concentrations of SS and nutrients in PB are generally affected by the loads from upland watershed. During the storm events, nearly 90% of sediments discharge into PB through the two inlets (Pelahatchie Creek and Mill Creek). Simulation results show that every year, about 124,000 tons of SS enter the bay, only 8% may flow out of the bay. More than 90% of sediment still stay in the bay either in water or deposit to bed. Since the flow in the bay is relatively weak, most of the sediment may deposit near the Creek entrance, and in the low flow velocity regions, such as many braches, shore line, etc. Large amount of sediment deposited in the bay may greatly affect the navigation and recreation value of the bay.

The yearly average concentration of SS in the bay is about 36 mg/l. From May to November, the SS concentration in the bay is relatively small, and the averaged concentration is about 16 mg/l, while during the raining season from December to April, the averaged SS concentration could raise to 67 mg/l.

Almost 90% of nutrients are also discharged into PB through the two inlets (Pelahatchie Creek and Mill Creek) due to the storm events. Since the outlet of the bay is very narrow and could limit the exchange of nutrients in/out of PB, therefore, the nutrients discharged into the bay from upland watershed may stay in the bay for a longer time, either in the water or absorbed on bed /suspended sediment. The high nutrient concentrations in PB are corresponding to the big storm events in winter or spring. In the water, the concentrations of NH4 and PO4 are relatively high, which may promote the growth of algae and aquatic plants.

BMPs are effective ways to reduce the loads of sediment and nutrients from upland watershed. According to model predictions, reducing the upland nutrients and SS loads by 50% would reduce average concentrations of SS, NH4, NO3, PO4 and Chlorophyll a in PB by approximately50%, 40%, 50%, 6% and 55%, respectively.

## 6. SIGNIFICANT FINDINGS

- The integrated AnnAGNPS watershed model and CCHE model provides useful tools to study the response of WQ in surface water to the loads of upland watershed, and provides a system analysis approach to evaluate the effectiveness of BMPs on the reduction of nutrients and SS loads.
- Numerical models are effective tools to predict the loads of SS and nutrients from upland watershed and simulate the long term and short term distributions of SS and nutrients in the receiving waterbodies.
- CCHE_MESH is a very effective tool to generate computational mesh for natural water body with complex geometry.
- In Mill-Pelahatchie Watershed, the urban growth increased runoff and nitrogen loads but implementing water retention ponds limited these loads by up to 1% and 25%, respectively, in high urban growth areas.
- The concentrations of SS and nutrients in PB are generally affected by the loads from upland watershed. Nearly 90% of sediments and nutrients are discharged into PB through the two inlets (Pelahatchie Creek and Mill Creek). More than 90% of SS discharged into PB could eventually deposit to the bed.
- The outlet of Pelahatchie Bay is very narrow, which could limit the exchange of SS and nutrients in/out of PB, therefore the nutrients and SS levels in PB are relatively high, which may affect the navigation and recreation value of the bay, and promote the growth of algae and aquatic plants.
- The implementation of BMPs, such as the establishment, stabilization measures of disturbed soil on urban construction sites that included water and sediment retention ponds is very effective to reduce the loads of SS and nutrients in the upland watershed.

## 7. FUTURE RESEARCH

In this project, the proposed research tasks have been successfully studied. Due to the limitations of funds and time, we could not address all the questions we found during the project period. They might be interesting topics for our future research.

Although we have obtained the general distributions of SS and nutrients in the lake, the amount of nutrients absorbed on the SS or bounded with bed sediment is still a question to be answered to assess the nutrient mass balance in the lake. This can be achieved by understanding the nutrient sedimentation processes, such as adsorption/ desorption of nutrient by sediment and biochemical processes of nutrients in bed sediment layer.

The long time deposition of SS, nutrients and other contaminate materials in PB will greatly affect the navigation and recreation value of PB. The impact of contaminates released from the bottom sediment is critical for proper risk assessment of water quality for the lake. In addition to the understanding of the distribution of SS and nutrients in PB, it is also important to provide useful information about the budgets of nutrients, sediment, and other pollutants in the bay, including the amounts in water, suspended sediment and bed sediment, which are very useful for water resources management.

## 8. STUDENT TRAINING

Jiayu Fang, a Ph.D student, has done some model simulation work in this project.

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