CHAPTER 3: WATERSHED HYDROLOGY

APPENDIX 3.E: CALIBRATION AND SIMULATION FOR WATER QUALITY: CASE STUDY

During the presentations on the hydrology of the St. Johns River, the National Research Council (NRC) had a question concerning the increased watershed runoff and water quality loadings to the river due to the increase of urban land uses under the 2030 conditions. This section of the WSIS report addresses the NRC question, however, it should be stated that the purpose of the WSIS is to evaluate the potential impacts resulting from proposed water withdrawals, and is not intended to comprehensively address water quality changes associated with future land use changes. Specifically, the NRC questioned whether the implicit approach of modeling Best Management Practices (BMPs) in the existing WSIS HSPF models would affect the accuracy of model predictions in watershed runoff and pollutant loadings under the 2030 conditions. The hydrologic parameters in the existing WSIS HSPF models were calibrated to the 1995 land use conditions, and therefore, reflected the hydrologic responses of the land uses with existing BMPs in 1995. The 2030 scenario HSPF model used the 1995 calibrated parameters to generate the future watershed flows. This approach assumed that the future BMP implementation would not change the hydrologic responses of the land uses under the 2030 conditions. The NRC suggested that a test case should be developed, which would incorporate BMPs explicitly in the HSPF model and compare the loadings of watershed runoff and pollutants, such as nutrients and heavy metals, under the 1995 and 2030 conditions.

The Little Econlockhatchee River watershed is selected for this case study. The Econlockhatchee River watershed is a subbasin of the middle St. Johns River Basin (MSJRB), including parts of Orange County, Seminole County, and Osceola County, Florida. The 15-mile long Little Econlockhatchee River is the largest tributary to the Econlockhatchee River and has a drainage area of approximately 90 square miles. The Little Econlockhatchee River watershed, subwatersheds 11–13 of the Econlockhatchee River watershed, is a highly urbanized watershed (see Figure 3.E.1 and Table 3.E.1). Urban areas, including residential areas, industrial areas, and commercial areas, make up 51% of the watershed under the 1995 land use conditions. This increases to 67% in 2030, which should be sufficient to allow for a valid comparison. Numerous lakes and wetlands cover 21% of the watershed. Forest and rangeland are other major land uses in the watershed. This case study applies the HSPF model to estimate the loadings of flow, total nitrogen (TN), total phosphorus (TP), and zinc from the Little Econlockhatchee River to the Econlockhatchee River under 1995 and 2030 conditions. Zinc is chosen as a representative of heavy metals. The estimated loadings of flows under the 1995 and 2030 conditions in this case study are compared to those estimated by the existing WSIS HSPF models to show the impact of different BMP modeling approaches on model predictions.

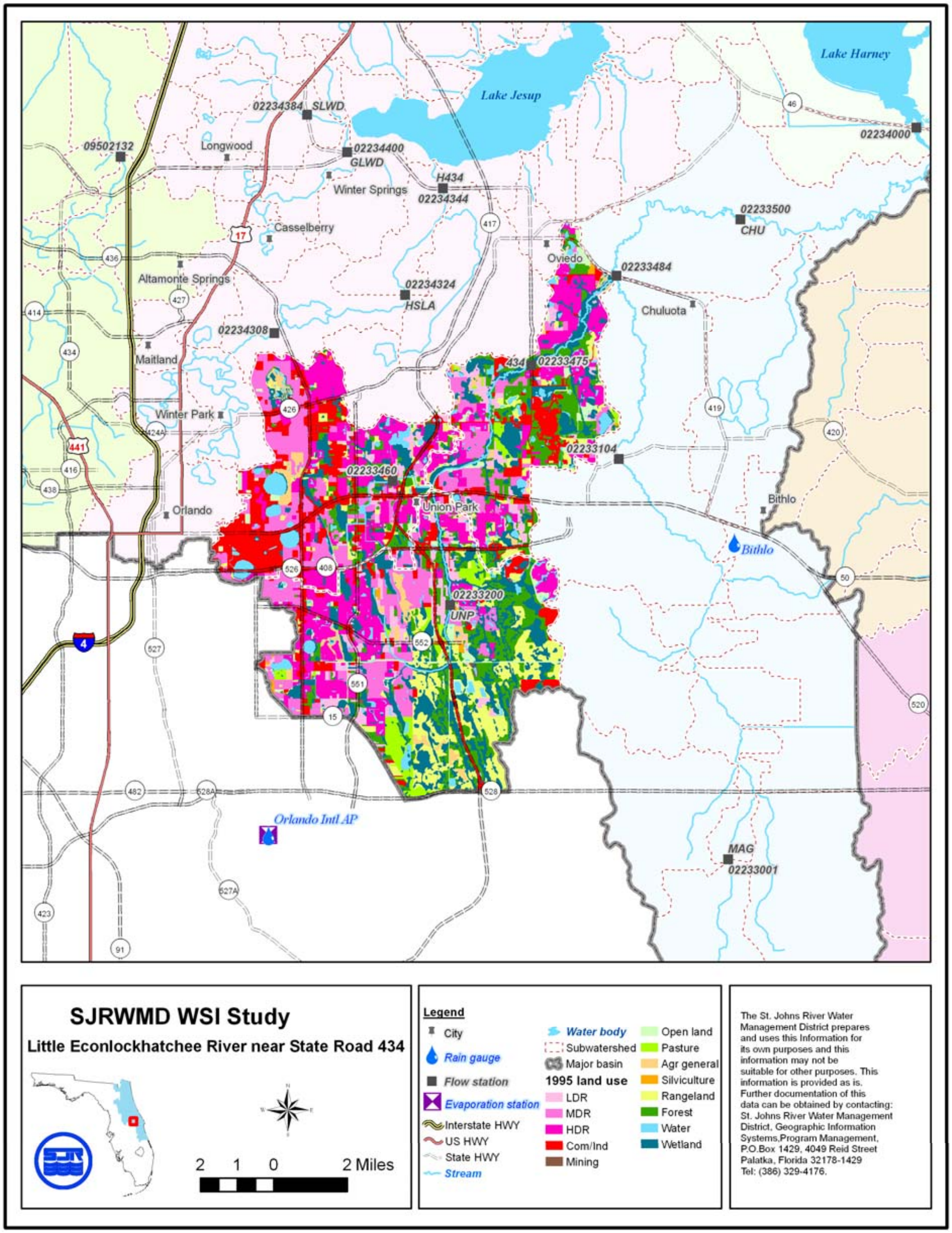

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Figure 3.E.1. Little Econlockhatchee River watershed land use

Table 3.E.1. Little Econlockhatchee River 1995 and 2030 land use comparison

	1995 Land Use (acres)		2030 Land Use (acres)	
Low Density Residential	2,874	5.0%	3,223	5.6%
Medium Density Residential	7,851	13.7%	10,432	18.2%
High Density Residential	10,153	17.8%	14,235	24.9%
Industrial and Commercial	8,169	14.3%	10,420	18.2%
Mining	61	0.1%	35	0.1%
Open and Barren Land	1,426	2.5%	569	1.0%
Pasture	1,366	2.4%	500	0.9%
Agriculture General	1,359	2.4%	617	1.1%
Agriculture Tree Crops	185	0.3%	63	0.1%
Rangeland	4,808	8.4%	2,309	4.0%
Forest	6,883	12.0%	2,733	4.8%
Water	2,957	5.2%	2,956	5.2%
Wetlands	9,068	15.9%	9,068	15.9%
Total	57,160	100.0%		

MODELING APPROACH

The existing WSIS HSPF model is modified to explicitly incorporate the BMPs to create the case study HSPF model. The spatial distribution of existing BMPs under the 1995 conditions is identified using a GIS mapping analysis by Huang et al. (2007). The calibrated hydrologic model parameters are retained in the case study HSPF model. For the 2030 scenario model, all the future development will receive stormwater treatment through BMPs as required by Florida Statute Chapter 403. It is assumed that all the increased urban land uses under the 2030 conditions will be treated by wet detention ponds. Characterization of BMPs in the HSPF model is described in the next section.

Water quality simulation considers the following water quality constituents: total suspended solids (TSS), water temperature, dissolved oxygen (DO), biological oxygen demand (BOD), total ammonia (TAM), nitrite (NO2), nitrate (NO3), organic nitrogen (OrgN), total nitrogen (TN), orthophosphate (PO4), organic phosphorus (OrgP), total phosphorus (TP), phytoplankton, benthic algae, and zinc.

To simulate TSS loadings from the watershed, the SEDMNT sub-module (for PERLND) and the SOLIDS sub-module (for IMPLND) are used. SEDMNT and SOLIDS simulate many sediment processes, including detachment/attachment of sediment particles from/to the soil matrix, attachment of sediment particles, and wash off of detached sediment. Instream sediment transport is handled by SEDTRN, which considers scour, deposition and advection processes. Because transport characteristics of sediment vary significantly with different particle sizes, HSPF simulates three fractions of TSS: sand, silt, and clay. This study assumes that the sediment loads from the watershed contain 20% sand, 40% silt, and 40% clay. Each fraction of sediment is simulated separately in SEDTRN. Sediment-nutrient interactions are not simulated in this study because there are few stormwater sediment samples for calibration of sediment simulation.

Zinc is modeled as a constituent associated with sediments. PQUAL (for PERLND) and IQUAL (for IMPLND) are used to estimate zinc loadings from watershed land uses. Zinc loadings from land surface are calculated as a multiplier of sediment loading rates. Instream transport of zinc is simulated in GQUAL, which considers adsorption/desorption between dissolved and sediment-associated phase, advection of adsorbed suspended material, and deposition and scour of adsorbed material with sediment.

Water temperature and DO concentration of runoff are simulated in PWTGAS (for PERLND) and IWTGAS (for IMPLND). Water temperature of each runoff type (surface runoff, interflow, or base flow) is equal to soil temperature in the layer where the runoff originates. That is, water temperature of surface runoff equals the surface layer soil temperature, water temperature of interflow equals the upper layer soil temperature, and the temperature of base flow equals the lower layer and groundwater layer soil temperature. Soil temperature in HSPF is simulated based on a linear regression relationship with air temperature. DO concentration in surface runoff is assumed to be saturated. DO concentrations in interflow and base flow vary monthly and are specified by the modeler.

Instream water temperature is simulated in HTRCH, which calculates the heat budget in a reach segment. The major processes considered in HSPF include advection, absorption of solar radiation, absorption of long wave radiation, conduction-convection, emission of long wave radiation, conduction-convection, and evaporation. Instream DO processes are simulated in the RQUAL sub-module, which will be discussed shortly.

PQUAL and IQUAL are used to estimate loads of TAM, NO3, PO4, and BOD from watershed land uses. Surface loadings of these water quality constituents are associated with surface runoff and are modeled using a first-order wash off approach. The pollutants stored on land surface are calculated based on monthly-varied accumulation and removal rates; and subsequent wash off of pollutants is calculated as a first order function of surface runoff. Subsurface pollutant contributions to the stream associate with interflow and base flow. The pollutant concentrations in interflow and base flow are assumed constant throughout the year.

To model various species of nitrogen and phosphorus and their interactions with other water quality constituents, the RQUAL sub-module of HSPF is used. RQUAL simulates the fate and transport of various water quality constituents in the water column and quantifies the impacts on instream water quality by the following processes:

- Processes affecting BOD and DO: reaeration, BOD decay, benthic oxygen demand, nitrification/denitrification, benthic release of BOD, sinking of BOD material, photosynthesis, respiration, and depth of phytoplankton and benthic algae.

- Processes affecting nitrogen and phosphorus: nitrification/denitrification, BOD decay, benthic release of ammonia (NH4) and PO4, sinking of organic nitrogen and phosphorus, sinking of phytoplankton, growth/respiration/depth of phytoplankton and benthic algae.

- Processes affecting phytoplankton and benthic algae: sinking, growth, respiration, and depth.

It should be noted that TN and TP are not modeled directly in RQUAL. TN and TP concentrations are calculated based on the concentrations of inorganic nitrogen, inorganic phosphorus, refractory organic N, refractory organic P, BOD, and phytoplankton. Non-refractory organic N and P are also not modeled directly. BOD in the water column serves as a surrogate for non-refractory organic N and organic P.

CHARACTERIZATION OF BEST MANAGEMENT PRACTICES IN HSPF

Information on BMPs in the Little Econlockhatchee River watershed came from a GIS mapping analysis by Huang et al. (2007), which estimated the spatial distribution of several major BMPs across the whole St. Johns River basin. The BMP maps in Huang et al. (2007) were based on the 2000 land use data. For this case study, these BMP maps are overlaid with the 1995 land use map to estimate the existing BMPs under the 1995 conditions. Three types of BMPs were identified in the study area; including swale, dry detention pond, and wet detention pond. Table 3.E.2 lists the acreage and percentage of watershed area served by each of these BMPs. Figure 3.E.2 shows the spatial distribution of BMP treatment areas in the Little Econlockhatchee River watershed.

Table 3.E.2. Treatment areas served by BMPs in the Little Econlockhatchee River watershed

BMP Type	Acreage Served	Percent of the watershed
Swale	631	1.1
Dry Detention Pond	1,745	3.1
Wet Detention Pond	9,864	17.3
No BMPs	44,920	78.6

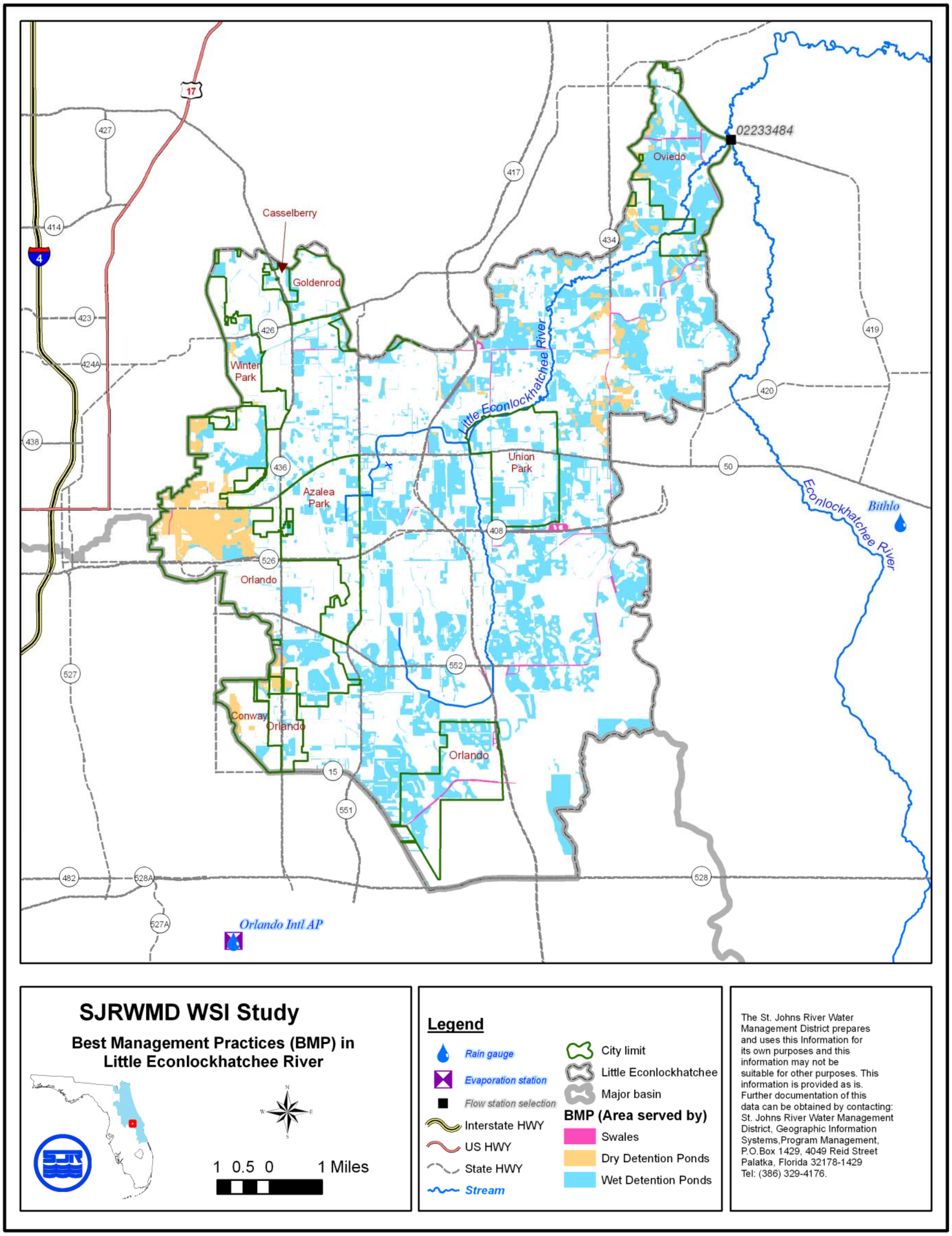

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Figure 3.E.2. Spatial distribution of BMP treatment areas in the Little Econlockhatchee River watershed

The available BMP data do not support detailed modeling of BMPs in the Little Econlockhatchee River watershed. The BMPs in the watershed are mostly on-site BMPs and serve relatively small areas. The efforts involved in compiling related information and performing detailed simulations for each individual BMP in the watershed would be time-consuming. Therefore, the focus of this case study is to simulate the effects of various BMPs on peak flow attenuation and pollutant load reduction at subwatershed levels.

A RCHRES is used in the HSPF model to represent all the dry detention ponds or all the wet detention ponds in a subwatershed. HSPF routes surface runoff, interflow, and their associated water quality constituents generated from the contributing areas through the dry pond RCHRES and routes surface runoff, interflow, base flow, and their associated water quality constituents generated from the contributing areas through the wet pond RCHRES. Table 3.E.3 lists the assumptions used for the FTABLE development. These assumptions are generally based on SJRWMD’s permitting rules and typical design procedures for detention ponds in the study area.

Table 3.E.3.Summary of the assumptions used to develop FTABLEs for dry and wet detention pond RCHRES in the HSPF model

	Assumptions
Dry Detention Pond RCHRES	The surface area of dry pond RCHRES in a subwatershed is 6% of its total contributing area; Dry detention pond side slope is 3 horizontal to 1 vertical; Dry detention pond depth is 5 feet, including 2 feet for water quality treatment, 2 feet for peak flow attenuation, and 1 foot for free board; The recovery time for a half of water quality treatment volume is 24 hours and the recovery time for a half of peak flow attenuation volume is 12 hours.
Wet Detention Pond RCHRES	The surface area of wet pond RCHRES in a subwatershed is 6% of its total contributing area; Wet detention pond side slope is 3 horizontal to 1 vertical; Wet detention pond depth is 13 feet, including 8 feet for permanent pool, 2 feet for water quality treatment, 2 feet for peak flow attenuation, and 1 feet for free board; The recovery time for a half of water quality treatment volume is 48 hours and the recovery time for a half of peak flow attenuation volume is 12 hours.

To make the HSPF model relatively simple and efficient, complex water quality processes in detention ponds are not simulated in the HSPF model. Instead, most water quality constituents are routed through the pond RCHRES as conservative constituents and a set of removal efficiencies are applied to various constituent outflows from the RCHRES. The pollutant removal efficiencies used in the HSPF model are presented in Table 3.E.4. The removal efficiencies for dry detention pond, wet detention pond, and swale are mainly based on the median values of the reported ranges in *Preliminary Data Summary of Urban Storm Water Best Management Practices* (U.S. Environmental Protection Agency 1999), *National Pollutant Removal Database for Stormwater Treatment Practice, 2nd Edition* (Center for Watershed Protection, Tetra Tech, Inc, and USEPA 2000), and *Literature Review of Stormwater Best Management Practices* (CDM 2002). These median values are considered reasonable to represent the average performance of individual BMPs at subwatershed levels. It should be noted that the removal efficiencies are not applied to the loadings of TSS and zinc for detention ponds. TSS and zinc in detention ponds are simulated using the SEDTRN and GQUAL modules discussed in the previous section. The simulated removal rates of dry and wet detention ponds for TSS and zinc are roughly 65% and 80%, which are considered reasonable given the reported removal efficiencies in the literature.

Table 3.E.4. Pollutant removal efficiencies used in the HSPF model (%)

Pollutant	Dry detention pond	Wet detention pond	Swale
TSS	NA	NA	80
Zinc	NA	NA	80
Total Ammonia	5	25	15
Nitrate + Nitrite	5	25	15
PO4	20	55	30
Organic N & P	20	35	30

WATER QUALITY CALIBRATION

Water quality calibration of HSPF is performed at several water quality sampling sites across the watershed over the calibration period between Oct 1995 and Sep 2006. Water quality calibration involves two major steps: (1) adjusting the land use-specific parameters (e.g. accumulation rates, depletion/removal rates, wash-off rates, sub-surface concentrations) to match land use loadings with the expected loadings reported in the literature; (2) selecting the instream water quality parameters (e.g. reaeration rate, nitrification rate, phytoplankton growth rate) to reproduce the observed water quality concentrations at calibration sites. These two steps are performed adaptively in the calibration process. If good agreement between the simulated and observed instream water quality data cannot be achieved in the second step while maintaining the instream water quality parameters within the realistic ranges, the land use-specific parameters determined in the first step will be re-adjusted.

The results of water quality calibration shows that the simulated pollutant loadings from land uses are generally within their expected ranges reported in (Harper 1994) and (Bergman 2004). Graphical comparison between simulated and observed TP, TN, and zinc is provided in Figure 3.E.3, Figure 3.E.4, and Figure 3.E.5, respectively. provides a comparison of the flow and water quality loadings between 1995 and 2030 land use scenarios. In general, simulated water quality concentrations closely match the observed values, which indicates that the HSPF model adequately represents the water quality processes in the Little Econlockhatchee River watershed. Therefore, the calibrated HSPF model can be used to evaluate the water quality responses to different land use scenarios.

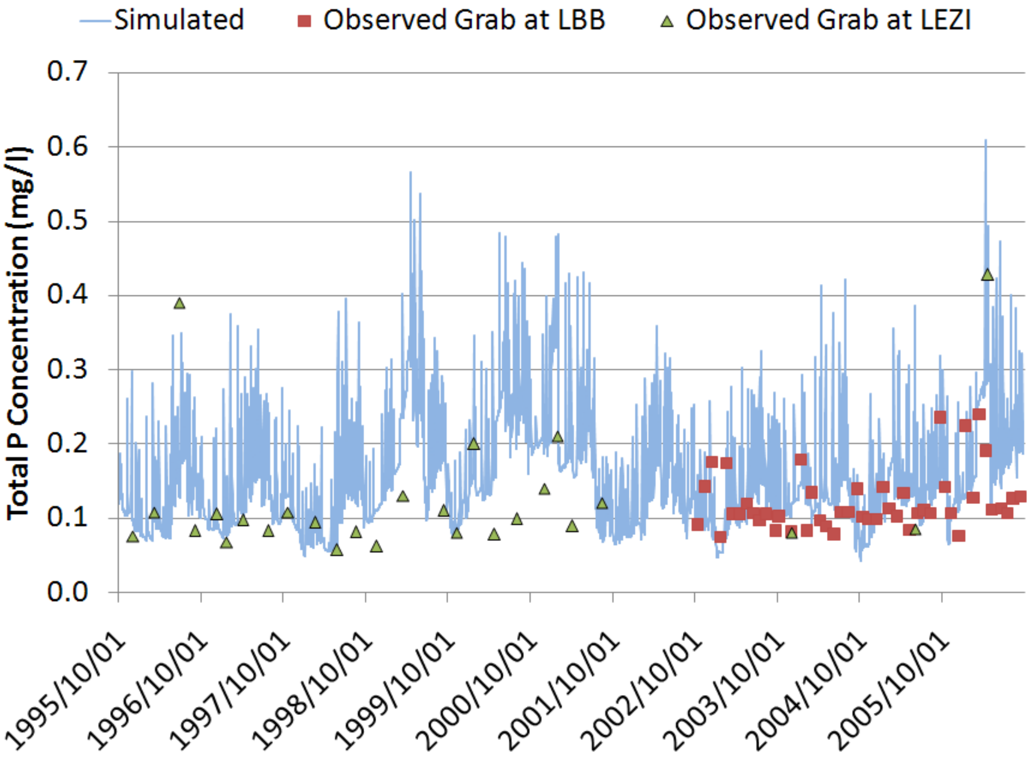

Figure 3.E.3. Simulated and observed total phosphorus concentration

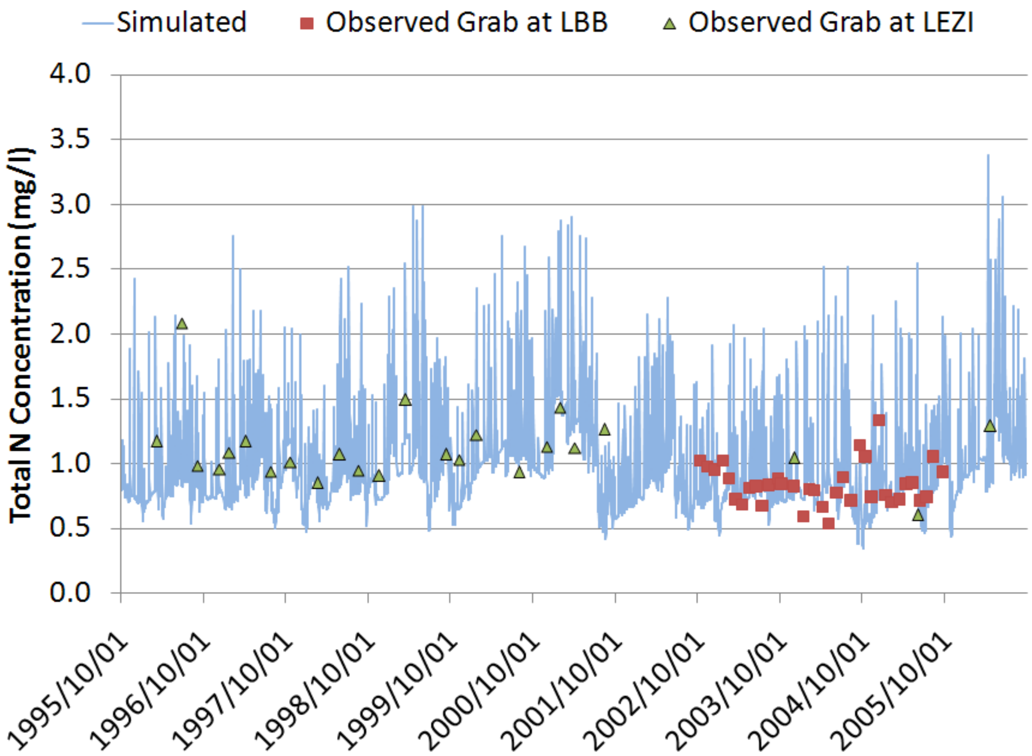

Figure 3.E.4. Comparison of observed and simulated total nitrogen

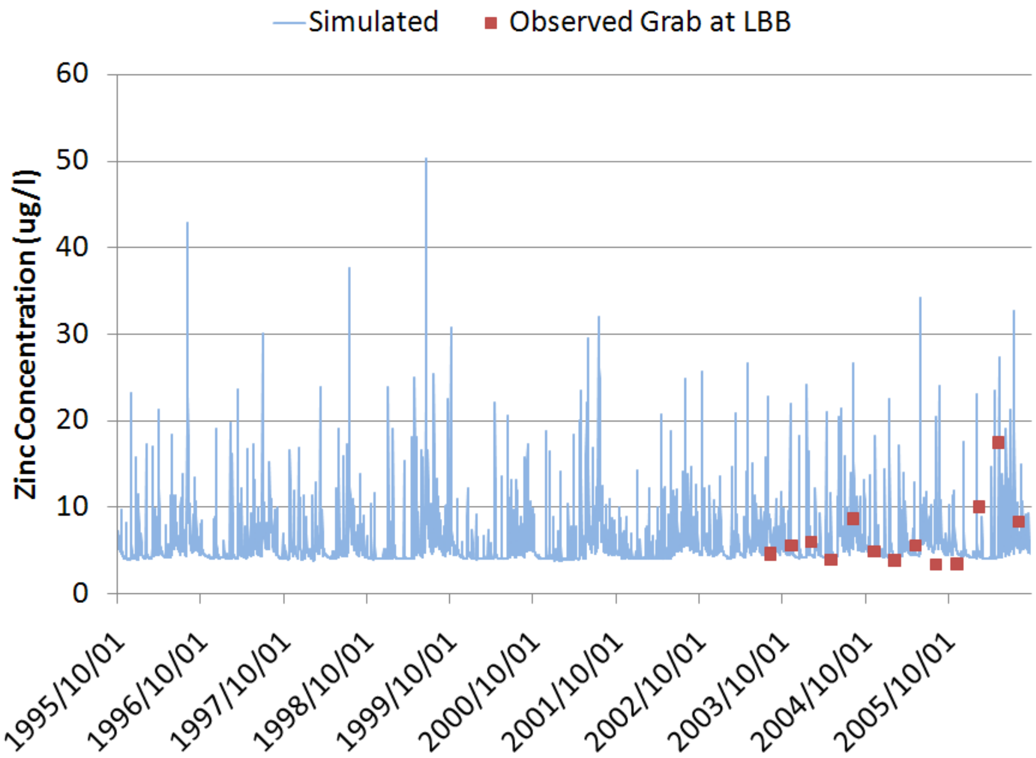

Figure 3.E.5. Comparison of observed and simulated zinc

IMPACT OF BMP MODELING APPROACHES ON FLOW PREDICTIONS

The calibrated hydrologic model parameters in the existing WSIS HSPF model are directly used in the case study model, and no hydrologic calibration is performed. The simulated discharges at the outlet of the Little Econlockhatchee River from the case study HSPF model are compared to those from the existing WSIS HSPF. The Nash-Sutcliffe coefficient for the monthly mean flows of the two flow time series over the period from Jan 1995 to Dec 2006 is 0.99, indicating a good agreement. Table 3.E.5 compares the estimated the mean annual flows over the simulation period between Jan 1995 and Dec 2006 under the 1995 and 2030 land use conditions for the two models. The estimations from the case study HSPF model are slightly higher than those from the existing WSIS HSPF model. The difference in the predicted increase in mean annual flows between the WSIS HSPF model and the case study HSPF model is about 1.0%. Given the uncertainties involved in the modeling of the hydrologic processes at watershed scales, the small differences in flow predictions by those two models are not considered significant. This comparison suggests that the implicit modeling of BMPs in the existing WSIS HSPF models is an acceptable simplification of the explicit modeling of BMPs in the case study HSPF model and the difference in BMP modeling approaches will not significantly affect the accuracy of model predictions under the future 2030 land use conditions.

Table 3.E.5. Mean annual flows (mgd) and percent increases in flows

	1995	**2030**	**% increase**
Existing WSIS HSPF (implicit modeling of BMPs)	97.8	105.7	8.1
Case Study HSPF (explicit modeling of BMPs)	100.7	107.9	7.1

SCENARIO ANALYSIS RESULTS

The calibrated HSPF water quality model is used to estimate the loadings of TN, TP, and zinc from the Little Econlockhatchee River to the Econlockhatchee River under the 1995 and 2030 land use scenarios. A general description of the simulated scenarios is given as follows:

1. Current: 1995 land use conditions with existing BMPs
2. Future: 2030 future land use conditions with existing BMPs in 1995 and with 100% BMP implementation for future development (newly increased residential, industrial, and commercial areas)

The simulation is performed over the period from 01/1995 to 12/2006. Table 3.E.6 compares the estimated TN, TP, and zinc loadings under the two scenarios. The projected future conditions will have a 3.9% increase of TN loading, a 7.4% increase of TP loading, and a 5.6% increase of zinc loading from their current levels, suggesting that the implementation of BMPs for all the future development will not be able to effectively control the increase of nutrient and heavy metal loads.

Table 3.E.6. Comparison of average annual flow and total nitrogen, total phosphorus, and zinc loadings from the Little Econlockhatchee River to the Econlockhatchee River for the two simulated scenarios

	1995 Land Use Scenario	2030 Land Use Scenario	Change (%)
Total Nitrogen (lbs yr^{-1})	277,968	288,889	3.9
Total Phosphorus (lbs yr^{-1})	43,616	46,853	7.4
Zinc (lbs yr^{-1})	2,557	2,700	5.6

Given the current state of Florida's environmental requlatory climate, the status of stormwater treatment requirements in 2030 is highly uncertain. There are existing Total Maximum Daily Load (TMDL) and Numeric Nutrient Load criteria that have not been implemented. There are also proposed stormwater nutrient rule changes that either EPA or FDEP may be enforcing. However, based on the understanding of the literature, and as this case study confirms, it is relatively certain that pollutant loadings will increase with future land development if changes in the regulatory requirements do not occur. Due to the uncertain nature of these regulations, and the belief that the additional requirements would have greatly reduced or eliminated any water quality degredation associated with new land development, the original scope of the WSIS did not include a watershed wide evaluation of these increases. Additional work is recommended to expand the full suite of HSPF models to include water quality parameters, and that the downstream EFDC models also be expanded to provide a comprehensive analysis of this potential environmental impact, should the environmental protection programs not be implemented.

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