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HYDROLOGIC AND WATER QUALITY MODELING OF THE LAKE JESUP WATERSHED USING HYDROLOGICAL SIMULATION PROGRAM – FORTRAN (HSPF)

Hydrologic and Water Quality Modeling of the Lake Jesup Watershed Using Hydrological Simulation Program – Fortran (HSPF)

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Executive Summary

The Lake Jesup watershed is a subbasin of the Middle St. Johns River Basin located in Seminole County, Florida, including a small portion of Orange County. The total drainage area of the Lake Jesup watershed is approximately 152 square miles, of which about 17 square miles are the water surface of Lake Jesup. This study applies a Hydrological Simulation Program – Fortran (HSPF) model to the drainage basin of Lake Jesup, which includes four major subbasins: Howell Creek watershed, Gee Creek watershed, Soldier Creek watershed, and Ungauged watershed.

The primary purpose of developing the HSPF watershed model is to support the development of Pollutant Load Reduction Goals of total nitrogen (TN) and total phosphorus (TP) for Lake Jesup. The HSPF watershed model estimates the loadings of flow and nutrients (TN and TP) from the watershed to Lake Jesup under existing and future conditions and evaluates the effects of watershed management scenarios on the watershed loadings.

Modeling Process

Hydrologic calibration of HSPF is performed for Howell Creek, Gee Creek, and Soldier Creek over the simulation period from 10/1997 to 09/2003. The accuracy of HSPF flow predictions is evaluated using several statistical measures recommended by HSPEXP, an expert system for calibration of HSPF. These statistical measures are also suggested in the Technical Memorandum No. 47 of the St. Johns River Water Management District for HSPF hydrologic calibration. The results show a good agreement between the simulated flows and the observed flows in terms of water mass balance, high and low flow distributions, seasonal flow distribution, and low flow recession. Water quality

calibration of HSPF is performed at several water quality sampling sites across the watershed. The results of water quality calibration show that the simulated land use loadings are generally within their expected ranges reported in the literature and HSPF adequately reproduces the observed water quality data, including water temperature, dissolved oxygen, total suspended solids, TN, and TP. Overall, the calibration results indicate that the HSPF model adequately represents the hydrologic and water quality processes in the Lake Jesup watershed. Therefore, the calibrated HSPF model can be used to evaluate the hydrologic and water quality responses to potential management scenarios, and the loads generated by the HSPF model can be used as inputs for the future Lake Jesup eutrophication model.

Current Conditions

The watershed loadings of flow, TN, and TP are summarized in Tables ES.1 – ES.3. On average, the annual flow contributions from the watershed to Lake Jesup is 95,482.0 acre-ft/yr, of which 50% is contributed from the Howell Creek watershed, 12% from the Gee Creek watershed, 12% from the Soldier Creek watershed, and 26% from the Ungauged watershed. The average annual watershed loadings of TN and TP are 140.7 metric ton N/yr and 18.7 metric ton P/yr. The Howell Creek watershed contributes 42% of the nutrient loads, the Gee Creek watershed 12%, the Soldier Creek watershed 12%, and the Ungauged watershed 34%. There is significant variation between the watershed loadings in the three dry years (10/1998 – 09/2001) and those in the three wet years (10/1997 – 09/1998 and 10/2001 – 09/2003). The average dry year watershed loadings of flow, TN, and TP are 63,286.2 acre-ft water/yr, 95.5 metric ton N/yr, and 12.9 metric ton P/yr, respectively. The average wet year watershed loadings are 127,677.7 acre-ft water/yr, 185.8 metric ton N/yr, and 24.6 metric ton P/yr, which are approximately 2 times of the dry year watershed loadings.

Table ES.1. Contributions of flow from the watershed (acre-ft/yr).

Water Year	Howell	Gee	Soldier	Ungauged	Total
1998	61720.2	15880.7	15202.3	32574.2	125377.4
1999	30345.7	7371.7	6723.2	9616.3	54056.9
2000	29310.1	6813.2	6299.4	16804.3	59227.0
2001	38027.4	9037.9	8156.1	21353.2	76574.6
2002	47325.3	11750.9	11088.4	33807.0	103971.6
2003	78452.8	20382.0	19953.4	34896.0	153684.2
Average	47530.3	11872.7	11237.1	24841.8	95482.0

Table ES.2. Contributions of TN from the watershed (metric ton N/yr).

Water Year	Howell	Gee	Soldier	Ungauged	Total
1998	74.5	21.4	22.7	58.7	177.3
1999	38.1	10.1	11.1	21.4	80.6
2000	34.3	9.0	9.4	33.2	86.0
2001	47.4	12.8	13.5	46.3	120.0
2002	57.7	16.8	18.1	67.3	159.9
2003	94.8	29.1	31.7	64.7	220.3
Average	57.8	16.5	17.7	48.6	140.7

Table ES.3. Contributions of TP from the watershed (metric ton P/yr).

Water Year	Howell	Gee	Soldier	Ungauged	Total
1998	10.5	2.6	2.6	7.1	22.8
1999	5.5	1.4	1.4	2.4	10.7
2000	5.1	1.2	1.1	3.9	11.3
2001	7.2	1.8	1.8	5.9	16.6
2002	8.7	2.2	2.2	8.5	21.7
2003	14.0	3.7	3.9	7.6	29.2
Average	8.5	2.2	2.2	5.9	18.7

Scenario Analysis

The calibrated HSPF model is used to assess the impact of various management scenarios on the nutrient loadings to Lake Jesup. A general description of the simulated scenarios is given as follows:

1. Current – current (1997 – 2003) conditions;
2. Future – future land use with 100% Best Management Practice (BMP) implementation for future development (newly increased residential, industrial, and commercial areas);
3. Future + 25% BMP – future conditions + 25% BMP implementation for current land uses without BMPs (excluding forest, water, and wetland);
4. Future + 50% BMP – future conditions + 50% BMP implementation for current land uses without BMPs (excluding forest, water, and wetland);
5. Future + 75% BMP – future conditions + 75% BMP implementation for current land uses without BMPs (excluding forest, water, and wetland);
6. Pristine – all forested (except water and wetland) watershed.

The simulation of these scenarios is performed over the entire simulation period from 10/1997 to 09/2003. It is assumed that all the newly implemented BMPs in scenarios 2 – 5 are wet detention ponds. Figure ES.1 compares the estimated TN and TP loadings to Lake Jesup under these six scenarios. The estimated TP loading under the future scenario is close to the current TP loading level, suggesting that the implementation of BMPs for all the future development and the decrease of the agriculture and pasture areas (as indicated in the future land use map) would effectively control the increase of TP loads. Because the removal efficiencies of BMPs for nitrogen are relatively low compared with those for phosphorus, the implementation of BMPs is less successful in controlling the increase of TN loading from the watershed. The projected future conditions have an 11% increase of TN loading from the current level. Additional reductions of watershed nutrient contributions can be achieved by implementing BMPs to the areas currently without receiving treatment. Implementing BMPs to 25%, 50%, and 75% of the current land uses without BMPs and 100% of future development could reduce nutrient loadings from the projected future levels by 3%, 6%, and 9% for TN and by 6%, 11%, and 17% for TP. Despite implementing BMPs to an extreme level (Future + 75% BMP), the resulting nutrient loadings will still be well above the estimated background loadings under the pristine scenario, which account for only 31% and 32% of the projected future TN and TP levels. To achieve greater nutrient reductions than those in the simulated BMP implementation scenarios, watershed management should focus on implementing nonstructural BMPs (such as better source control and stormwater reuse) to reduce nutrient loading rates from developed areas and using BMP treatment trains to improve nutrient removal efficiencies.

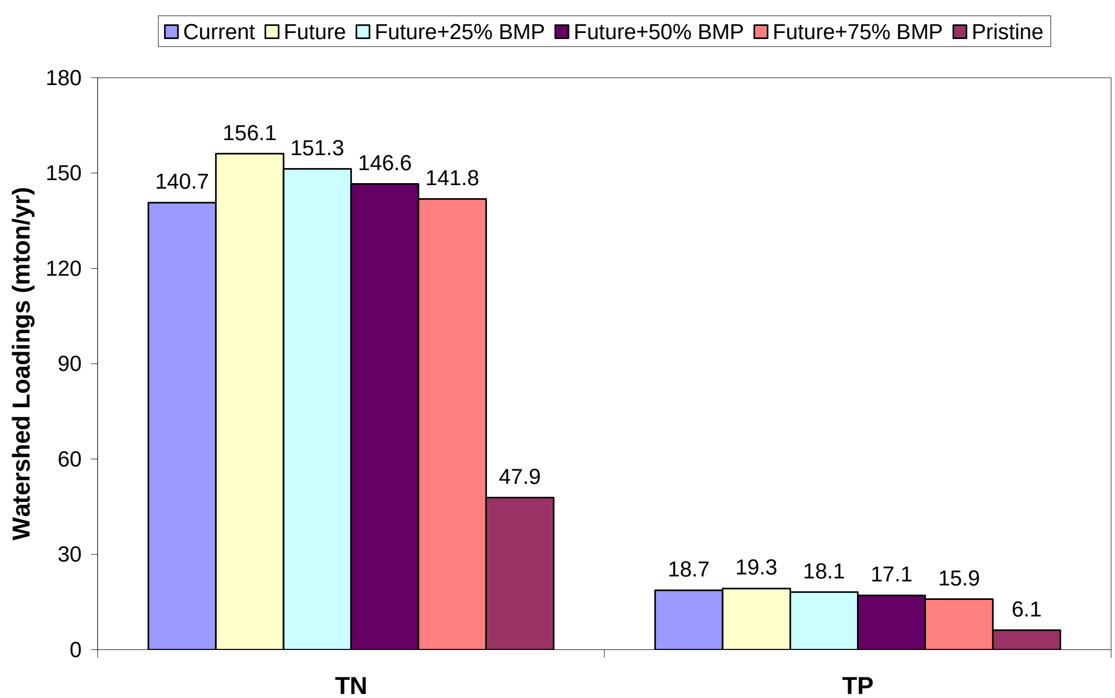

Figure ES.1. Comparison of average annual TN and TP loads to Lake Jesup for the six simulated scenarios.

Future Investigations

This work shows that the HSPF model can adequately predict the flow and water quality concentrations across the Lake Jesup watershed. The accuracy of HSPF predictions could be further improved by collecting additional field data for model calibration and validation. Specific suggestions for future investigations are listed as follows:

- Investigate the interaction between groundwater and surface water in the Lake Jesup watershed. This information is helpful to assess whether the current formulation of HSPF can adequately represent the groundwater processes in the study area.
- Collect additional information on BMPs at the drainage area of Navy Canal (subwatershed 27) and assess the effectiveness of these BMPs on the removal of TN and TP. This will help to explain the observed low TN and TP concentrations in Navy Canal.
- Identify the sources contributing to the observed high TP levels at Sweetwater Creek and Solary Canal.
- Study which nonstructural BMPs could effectively reduce TN and TP loads to Lake Jesup and incorporate their effects in the scenario analysis.
- Conduct field studies to calculate the pollutant removal efficiencies of the existing BMPs in the Lake Jesup watershed. The results of these field studies could help to refine the removal efficiencies used in this study.

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1. Introduction

The Florida Legislature requires the Water Management Districts to develop Pollutant Load Reduction Goals (PLRGs) for the impaired water bodies within their boundaries (Florida Administrative Code 62-40). In 2002, the St. Johns River Water Management District (SJRWMD) adopted the Surface Water Improvement and Management (SWIM) plan and began the PLRG process for the Middle St. Johns River Basin (MSJRB). In 2004, the SJRWMD contracted with BCI Engineers and Scientists, Inc. to provide the engineering services for the development of watershed models for the MSJRB.

Lake Jesup, Florida, is a hyper-eutrophic lake in the MSJRB. To support the development of PLRGs for total nitrogen (TN) and total phosphorus (TP) at Lake Jesup, this study applies a mechanistic watershed simulation model to estimate the loadings of flow and nutrients (TN and TP) from the watershed to Lake Jesup under existing and future conditions and to evaluate the effects of various watershed management scenarios on the watershed loadings. This chapter describes the study area, introduces the modeling approach, and overviews the organization of this report.

1.1 Study Area

The Lake Jesup watershed is a subbasin of the MSJRB located in Seminole County, Florida, including a small portion of Orange County (Figure 1.1). The total drainage area of the Lake Jesup watershed is approximately 152 square miles, of which about 17 square miles are the water surface of Lake Jesup. Lake Jesup is connected to St. Johns River through a narrow channel at the northern end of the lake. The watershed is drained to Lake Jesup through three large tributaries (Howell Creek, Gee Creek, and Soldier Creek) and a number of smaller tributaries and canals (e.g. Six Mile Creek, Salt Creek, Sweetwater Creek, Navy Canal, Kentucky Canal, and Cameron Canal). In addition, many lakes, including Lake Virginia, Lake Maitland, and Lake Howell, and detention ponds exist within the watershed. They serve as storage facilities for stormwater runoff and provide significant benefits for the improvement of water quality.

The Lake Jesup watershed is a highly urbanized watershed. Urban areas, including residential areas, industrial areas, and commercial areas, make up 46% of the watershed. Numerous lakes and wetlands cover 33% of the watershed. Open areas, pasture, rangeland, forest, and agriculture areas make up the other major land uses in the watershed.

The climate of the study area is humid subtropical. Based on the climatologic data compiled from the National Oceanic and Atmospheric Administration over the period 10/1997 – 09/2003, the temperature ranges from an average of 61 Degrees Fahrenheit (degF) in January to an average of 81 degF in July. The average annual rainfall over this period is about 54 inches. Approximately 60% of the annual rainfall occurs in the summer season from June to September. Average monthly rainfall ranges from 2 inches to 8 inches, and annual rainfall ranges from 41 inches to 66 inches.

Lake Jesup and its adjacent surrounding drainage areas overlie the Eastern Plain physiographic area, and the remaining areas of the watershed overlie the Osceola Plain physiographic area (Schellentrager and Hurt 1990). The Eastern Plain and the Osceola Plain are both broad and flat areas. Elevations of the study area range from 5 feet to 125 feet above sea level, with an average elevation of 46 feet. Soils of the watershed are generally sandy and well-drained, with the exception of some large marsh areas adjacent to Lake Jesup (Schellentrager and Hurt 1990; Keesecker 1992).

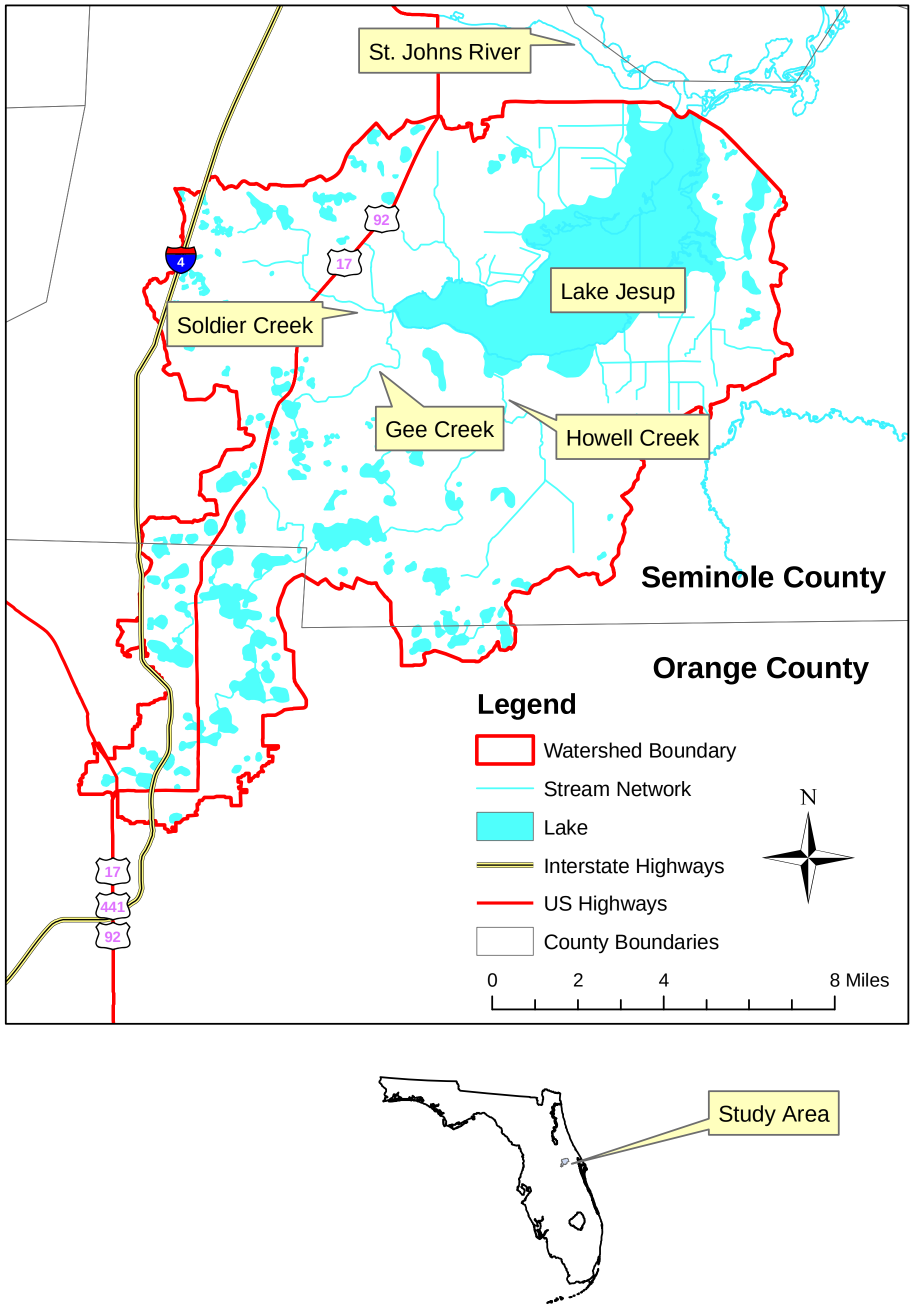

Figure 1.1. The Lake Jesup watershed, Florida.

1.2 Modeling Approach

The Hydrological Simulation Program – Fortran (HSPF) model version 12.0 (Bicknell et al. 2001) is used in this study to simulate the hydrology and water quality in the Lake Jesup watershed. The HSPF model is a lumped-parameter, continuous simulation model that simulates both point and nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates instream water quality processes (Bicknell et al. 2001). This model framework is selected because of its capability to handle a variety of water quality constituents and to represent complex land uses and pollutant sources in the watershed. In addition, HSPF has been incorporated into BASINS (U.S. Environmental Protection Agency (USEPA) 2001b), supported by the USEPA as a standard watershed modeling framework for Total Maximum Daily Load (TMDL) development. Many recent applications of HSPF (e.g. Bergman et al. 2002; Wicklein and Schiffer 2002) have demonstrated that HSPF can accurately predict stream flow and concentrations of various water quality constituents in Florida.

The watershed is conceptually represented in HSPF by a series of storage compartments (e.g. surface depression, soil zone, ground water zone, river segment). Based on the principal of mass conservation, HSPF performs continuous budget analysis of water quantity and quality for these storage compartments. Given the inputs of meteorological time series and the parameter values related to watershed characteristics, HSPF generates time series of runoff, stream flow, loading rates, and concentrations of various instream water quality constituents.

While most parameters of HSPF can be specified by watershed spatial and physical data (e.g. land use, topography, stream characteristics, and soil property), a few parameters, such as those related to infiltration, evaporation, and instream kinetics, need to be determined in the calibration and validation process. Model calibration is the process of adjusting values of model parameters to accurately reproduce the observed flow and water quality data. Validation is the testing of the selected parameter values. In general, the observed flow and water quality data from one time period are used for calibration, and the data from another time period are used for validation. Once calibrated and validated, the HSPF model is considered to be able to accurately represent the hydrologic and water quality processes in the watershed and can be utilized for scenario analysis.

1.3 Organization of the Report

To describe the procedures and to present the results for the application of HSPF to the Lake Jesup watershed, this report is organized as follows. Chapter 2 summarizes the data used for HSPF modeling at the Lake Jesup watershed and their sources. Chapter 3 describes the formulation, calibration, and validation of the HSPF model. In addition, a summary of watershed modeling results for existing conditions is presented in Chapter 3. Analysis of management scenarios is described and discussed in Chapter 4. Finally, Chapter 5 summarizes the results of this study and discusses the future effort needed to improve the Lake Jesup watershed HSPF model.

2. Data Collection

The development of HSPF model requires various types of data, including watershed physical and spatial data (subwatershed delineation, land use, etc.), meteorological data, stream flow data, and water quality data. These data and their sources are described bellow.

2.1 Subwatershed Delineation

A Geographic Information System (GIS) layer of subwatershed boundaries for the Lake Jesup watershed was obtained from the SJRWMD. The Lake Jesup watershed is divided into 39 subwatersheds (Figure 2.1) based on the stream network and topography of the watershed. These subwatersheds are grouped into five major subbasins: Howell Creek watershed (subwatersheds 1 - 9), Gee Creek watershed (subwatersheds 10 - 15), Soldier Creek watershed (subwatersheds 16 - 23), Ungauged watershed (subwatersheds 24 - 38), Lake Jesup and its adjacent drainage areas (subwatershed 39), as shown in Figure 2.1. Howell Creek, Gee Creek, and Soldier Creek are major tributaries to Lake Jesup. U.S. Geological Survey (USGS) flow gauges are installed along the main stems of these tributaries. The Ungauged watershed includes the drainage areas of several smaller streams and canals where stream flows are not continuously monitored.

Subwatersheds 3, 11, and 16 are closed drainage areas and do not contribute surface runoff to downstream. No simulation is performed for these subwatersheds. Subwatershed 39 includes Lake Jesup and its adjacent drainage areas. The total acreage of these adjacent drainage areas varies constantly with the change of the surface area of Lake Jesup. To model the loads contributed from these adjacent drainage areas to Lake Jesup, a 10,720-acre area (the average surface area of Lake Jesup in the period from

10/1997 to 09/2003) of water and wetland in subwatershed 39 is counted as Lake Jesup, and the remaining area in subwatershed 39 is counted as the drainage area to Lake Jesup. For simplicity, the adjacent drainage area in subwatershed 39 is not referred as a separate subwatershed and is considered as a part of the Ungauged watershed. This study focuses on the simulation of hydrology and water quality in the Howell Creek watershed, the Gee Creek watershed, the Soldier Creek watershed, and the Ungauged watershed (including the drainage area adjacent to Lake Jesup in subwatershed 39). Analysis of hydrology and water quality processes in Lake Jesup will be conducted as a separate study and will not be described in this report.

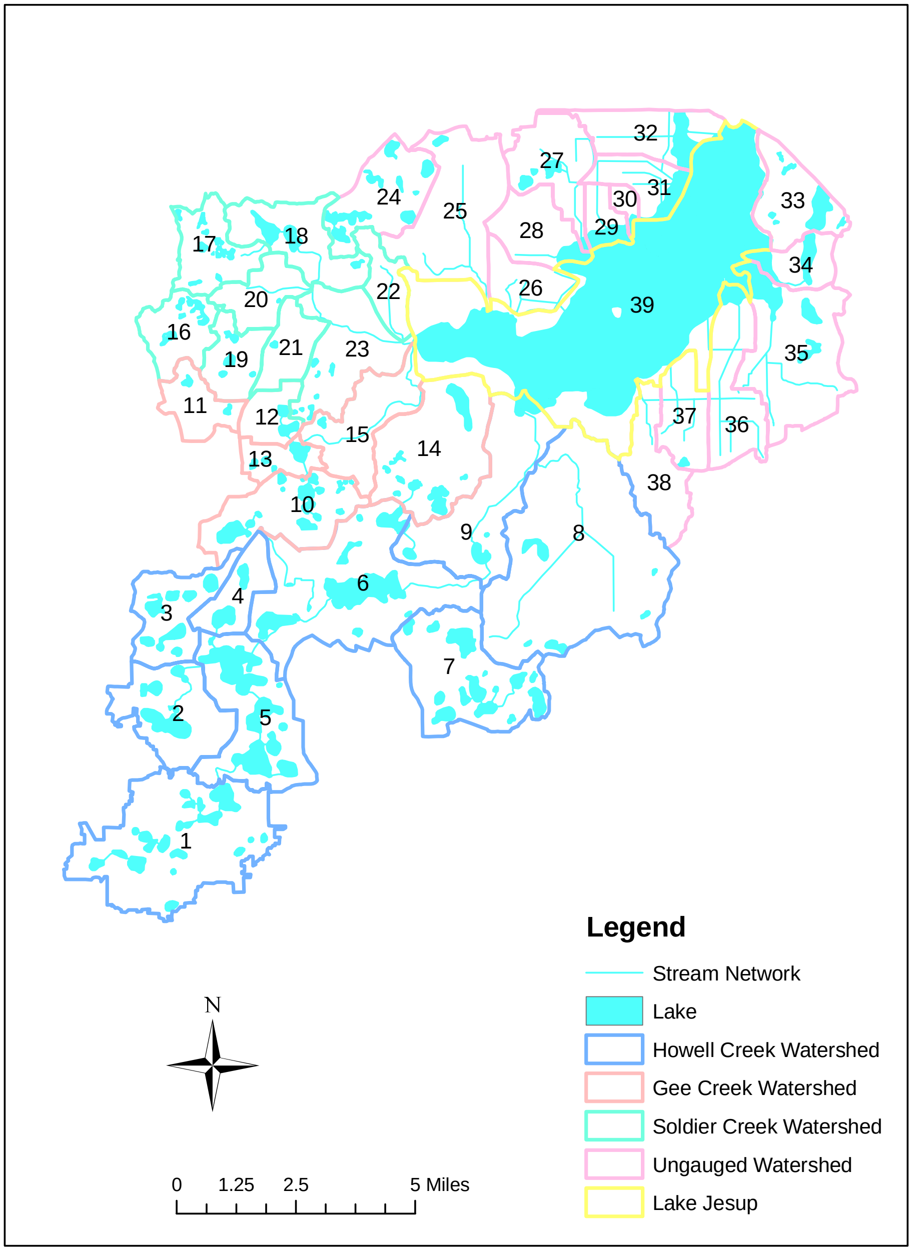

Figure 2.1. Subwatersheds, stream network, major subbasins in the Lake Jesup watershed.

2.2 Land Uses

A GIS land use map for the Lake Jesup watershed was obtained from the SJRWMD. The land use information is primarily based on aerial photographs taken in 1999 and 2000. The SJRWMD identified over 100 different land use classes within the watershed based on the Florida Land Use Classification Code System (FLUCCS). For modeling purposes, these land use classes are grouped into 13 major land uses following the Land Use Classification Table developed by the engineering division of SJRWMD (Bergman 2004). Consolidation of the original land use classes is mainly based on similarities in hydrologic properties and nutrient loads. Table 2.1 and Figure 2.2 show the distribution of these aggregated land uses in the Lake Jesup watershed.

Table 2.1. Distribution of consolidated land uses in the Lake Jesup watershed.

Land Use	Acreage	Percent of the Lake Jesup watershed
Low Density Residential (LDR)	5742	5.9
Medium Density Residential (MDR)	22494	23.1
High Density Residential (HDR)	5024	5.1
Industrial and Commercial (IND)	12060	12.4
Mining (MIN)	117	0.1
Open Land (OPE)	2332	2.4
Pasture (PAS)	4521	4.6
Agriculture General (AGG)	3129	3.2
Agriculture Tree Crop (AGT)	1947	2.0
Rangeland (RAN)	2285	2.3
Forest (FOR)	5482	5.6
Water (WAT)	13974	14.3
Wetland (WET)	18455	18.9