LAKE ALTO AND LAKE SANTA FE WATER BUDGET MODELING – ASSESSMENT OF HYPOTHETICAL WATER RESOURCE DEVELOPMENT FOR LAKE SANTA FE

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Prepared for:

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Document Review

The technical contents of the Lake Alto and Lake Santa Fe Water Budget Modeling – Assessment of Hypothetical Water Resource Development for Lake Santa Fe represent our professional interpretations and are arrived at in accordance with generally accepted hydrologic, hydrogeologic, hydraulic, and engineering practices. The findings and results of this report are for the sole use and benefit of Suwannee River Water Management District. Utilization of this report by other parties is at their risk, and Environmental Consulting & Technology, Inc. is not liable for consequences or damages extending therefrom.

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List of Acronyms and Abbreviations

°F	degree Fahrenheit
cfs	cubic feet per second
DEM	digital elevation model
ECT	Environmental Consulting & Technology, Inc.
EPA	U.S. Environmental Protection Agency
ET	Evapotranspiration
FAS	Floridan Aquifer System
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FFWCC	Florida Fish and Wildlife Conservation Commission
ft	Foot
HSG	hydrologic soil group
GFY	George F. Young, Inc.
GPI	Greenman-Pedersen, Inc
ICPR	Interconnected Pond Routing
in	Inch
LiDAR	Light Detection and Ranging
FH	minimum frequent high
FL	minimum frequent low
MA	minimum average
MFLs	minimum flows and levels
NAVD88	North American Vertical Datum of 1988
NEXRAD	Next-Generation Radar
NFSEG	North Florida Southeast Georgia Groundwater Model
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
ORNL	Oak Ridge National Laboratory
PET	potential evapotranspiration
PRISM	PRISM Climate Group
RET	reference evapotranspiration
RMSE	root mean square error
RTF	reference timeframe (for level/flow)
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
SWMM	Storm Water Management Model
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
yr	year

1.0 Executive Summary

In support of the establishment of Minimum Flows and Levels (MFLs) at Lake Alto and Lake Santa Fe, a water budget model is desired by the Suwannee River Water Management District (SRWMD or District) to assess hydrologic changes in these two lake systems. The complexity of the lake hydrologic system, especially as it relates to the upper Floridan aquifer system (FAS) and surface water connection between these two lake systems, requires a predictive computer model to adequately examine the effects of hydrologic changes. The selected modeling tool, Storm Water Management Model (SWMM) Version 5.1, has been successfully employed as a useful tool for the water budget modeling of Lake Butler and Lake Hampton by the District and Environmental Consulting & Technology, Inc. (ECT) in 2016. The SWMM model is capable of performing long-term continuous simulation that involves a full hydrologic cycle, such as rainfall, evapotranspiration (ET), surface runoff, infiltration/percolation, and surface water/groundwater flow exchange.

The District has authorized ECT to undertake the water budget modeling project. Based on results of data collection/review and site visits, a lake water budget model was developed and calibrated to be used to predict hydrologic changes in various water resources development scenarios. The major modeling tasks included model development, calibration, and long-term model simulation.

Groundwater level data sets were developed for the measured, no-pumping, and current pumping scenarios based on the reference timeframe (RTF) analysis methodology and results provided by the District. An RTF of groundwater levels includes an addition to the water levels to adjust for the effect of groundwater pumping over time, creating an estimated “pumps off” or natural condition with respect to withdrawals. The existing water budget model, previously developed under Work Order 14/15-050.06 in 2018, was updated and used to simulate current and predicted pumping scenarios. The updated model results were used to assess the current pumping and predicted pumping scenarios in the context of MFLs for Lake Santa Fe, where MFLs were recommended by the District in 2022.

The Lake Alto and Lake Santa Fe Water Budget Modeling Technical Report – Final was updated to include the RTF analysis results and modeling update efforts for the current pumping scenario. A separate status assessment memo was developed to evaluate compliance with MFLs for Lake Santa Fe.

A brief description of the major modeling tasks performed is provided below.

<u>Model Development</u>

The SWMM Version 5.1 developed by the U.S. Environmental Protection Agency (EPA) was selected by the District and ECT staff to assess long-term hydrologic changes at Lake Alto and Lake Santa Fe.

The Light Detection and Ranging (LiDAR) topographic data in the digital elevation model (DEM) format was provided by the District and used to develop the required model parameters, with the supplementation of the topographic survey at various cross-sections and drainage structures. The model was geo-referenced to the projection coordinate system “NAD_1983_HARN_StatePlane_Florida_North_FIPS_0903_Feet”, as specified in the project scope of work.

<u>Model Calibration</u>

The water budget model was calibrated by comparing the model-simulated lake stage against the known gage data. The calibration model was developed based on 2004/2006 land use and it runs from 2006 through 2015 on a sub-minute timestep. Multiple model parameters were adjusted within reasonable ranges to achieve the best overall fit of the model estimate with the observed data at Lake Alto and Lake Santa Fe.

The lake stage gage data from 2006 through 2015 was used in the model calibration task. Based on the comparison of simulated and observed lake stage hydrographs, the model calibration was successfully executed. The primary criterion for acceptable model calibration is 0.5 foot or less root mean square error (RMSE).

<u>Long-term Model Simulation and Assessment of Current and Predicted Pumping Scenarios</u>

Once the District accepted the model calibration of the water budget model, the model was updated to 2016 land use to perform a long-term simulation of an extended period of approximately 55.7 years from 4/25/1960 through 12/31/2015. It was assumed the2016 land use has stayed the same throughout the entire simulation span.

A long-term groundwater well station at Lake Brooklyn near Keystone Heights, FL (SJRWMD ID: 70078104), approximately 3 miles east of Lake Santa Fe, was used to estimate the historic groundwater level data (4/25/1960 through 4/27/1983) at the USGS Melrose groundwater well station (USGS Melrose station, USGS ID: 294313082024601 / SRWMD ID: S092307001), which is located within the lake watershed and provide daily groundwater level data in the upper FAS since 4/28/1983. The estimated groundwater level data set at the USGS Melrose station was used to assess the groundwater conditions beneath the major lakes and sinkholes. The estimated groundwater level data set extends the simulation period of the water budget model and allows for a more robust and defensible MFLs analysis.

Based on the recent RTF analysis results provided by the District, the groundwater level data sets for the "no-pumping" and "current pumping" scenarios were created using the "measured" groundwater data set estimated for the major lakes and sinkholes.

Based on the event-based MFLs method developed by St. Johns River Water Management District (SJRWMD), frequency analysis of the 55.7-year long-term model results was conducted to determine whether the lake MFLs recommended by the District are being met at Lake Alto and Lake Santa Fe. The current pumping scenario refers to a hypothetical case where the long-term model simulation assumes land use at the 2016 conditions and groundwater withdrawals under the current pumping scenario. Results of the frequency analysis are presented in a separate status assessment memo.

The Lake Alto and Lake Santa Fe water budget model was used to determine the limit of the upper FAS potentiometric elevation at which the recommended MFLs will no longer be achieved for Lake Santa Fe. For this determination, model simulations were performed assuming the upper FAS potentiometric elevation to be lower than that under the no-pumping scenario. Model simulations were made to gradually lower the upper FAS potentiometric elevation value until each of the recommended MFLs were tripped, i.e., not met.

Based on the frequency analysis results, the recommended MFLs for Lake Santa Fe would be met with a freeboard or maximum potentiometric elevation decline of 28.0, 29.7, and 22.0 ft in the upper FAS beyond the no-pumping scenario, for the minimum frequent high (FH), minimum average (MA), and minimum frequent low (FL) levels, respectively. The FL level is the constraining level at Lake Santa Fe since it allows the smallest upper FAS drawdown.

2.0 Watershed Description

2.1 General Description

Lake Alto and Lake Santa Fe are located in northeastern Alachua County, Florida (Figure 2-1). Lake Alto, also known as Lake Altho, has an area of approximately 573 acres at typical water level elevations (Alachua County, 2014). Lake Alto is bounded by Lake Alto Swamp to the north. The eastern part of Lake Alto Swamp, named as Lake Alto Preserve, is currently co-owned by SRWMD and Alachua County. A county-owned park, Lake Alto Park, is located at the east lake bank, just south of Lake Alto Preserve. A boat ramp in this park can provide access to the lake for boats. Another public access point is the boat ramp located in Waldo Canal Park through the Waldo Canal that was originally dredged in the 1880s. Another man-made canal, the Santa Fe Canal, was dredged in the 1870s and 1880s to connect Lake Alto into Lake Santa Fe to the east (Figure 2-1). The Waldo Canal and Santa Fe Canal were primarily used to connect Waldo, the railroad terminal, and Melrose (at the time the center of a thriving citrus and tourist industry).

Lake Santa Fe is the headwater of the Santa Fe River and is designated as an Outstanding Florida Water. It has an area of approximately 5,200 acres at a water elevation of 139.47 ft NAVD88, according to the bathymetric map created by SRWMD in 1976. The "little" northern area of Lake Santa Fe is also referred to as Little Lake Santa Fe, which is separated from its "big" southern arm by a pass that is just 1,000 feet in width and approximately 10 feet in depth. Little Lake Santa Fe has an area of approximately 1,135 acres or 22% of the overall lake surface of Lake Santa Fe. Little Lake Santa Fe is bounded by Santa Fe Swamp to the north. Santa Fe Swamp has an area of approximately 6,227 acres (USF Water Institute, 2021). A majority of Santa Fe Swamp, also known as Santa Fe Swamp Conservation Area, is managed by SRWMD in cooperation with the Florida Fish and Wildlife Conservation Commission (FFWCC). The SRWMD management activities include small scale prescribed burning in the growing seasons on the west and east sides of the Santa Fe Swamp tract, as well as timber harvesting during most months of the year.

Several small lakes and wetland areas, such as Hickory Pond, Bonnet Lake, and Black Lake, discharge to Lake Santa Fe through streams, culverts, and/or overland flows (Figure 2-1). Santa Fe Lake Park, managed by Alachua County, is located at the south lake bank near Melrose, Florida. A boat ramp at the north side of the park can be used to launch boats.

To avoid further confusion, Lake Santa Fe at this point and thereafter refers to the "big" southern portion of the lake system, unless otherwise specified in this section.

The Lake Alto and Lake Santa Fe watershed (the lake watershed), including the three major lakes and their contributing drainage areas, encompasses a total area of approximately 37,484 acres. Note that the lake watershed is primarily located in Alachua and Bradford counties and only the small eastern portion is within Clay and Putnam counties (Figure 2-1).

The Santa Fe River, originating from Lake Santa Fe and Little Lake Santa Fe, is the surface water outfall of the lake watershed. Near its headwaters, the river has not developed a well-integrated surface water drainage system. Instead, the upper most reaches of the river and its tributaries are characterized by broad shallow lakes (i.e., Lake Alto, Lake Santa Fe, and Little Lake Santa Fe) and swamps (i.e., Lake Alto Swamp and Santa Fe Swamp). The Santa Fe River empties into the Suwannee River near Branford, Florida.

Figure 2-1. Lake Alto and Lake Santa Fe Watershed Map.

2.2 Climate

The climate in the lake watershed can be characterized by long, warm summers and relatively mild winters. In summer, the temperature is fairly uniform, in the upper 80s and lower 90s in the afternoon, and in the upper 60s to upper 70s late at night and early in the morning. In winter, the temperature varies considerably. When cold fronts pass, the temperature often drops to 32 degrees or less late at night and early in the morning. Warm air from the south can raise the temperature to 80 °F or more for several days (USDA, 1991).

The average annual rainfall in Bradford County is approximately 54.2 inches with a large part of this rainfall occurring in summer as locally heavy afternoon thundershowers. As much as 2 to 3 inches of rain can fall in an hour. Daylong rains in the summer are rare but occasionally occur when accompanying tropical depressions. These rains can be heavy and of long duration. As much as several inches of rain can fall in a 24-hour period. The annual frequency of tropical depressions ranges from none to several. Rainfall during the winter generally is more moderate. This precipitation usually occurs as cold fronts pass and can last from a few hours to a few days (USDA, 1991).

2.3 Topography

Topography in the lake watershed can be characterized as mildly sloping and poorly drained, as graphically presented in the topographic DEM and contour maps (Figures 2-2A and 2-2B). The topographic DEM and contours were developed based on the Light Detection And Ranging (LiDAR) topographic survey data provided by U.S. Geographical Survey (USGS) (NGC, 2011), St. Johns River Water Management District (SJRWMD), and SRWMD.

The highest land surface elevation of approximately 233 ft NAVD88 is observed at northeast corner of the watershed. Isolated high land elevations of 170 ft NAVD88 or greater are observed in the areas located south of the Santa Fe Canal and west of Lake Santa Fe (Figures 2-2A and 2-2B).

The bathymetric map of Lake Alto was provided in triangulated irregular network (TIN) format by SRWMD (Figure 2-2C). The bathymetric TIN data at Lake Alto was originally developed by Greenmen-Pedersen, Inc. (GPI) in 2014, based on their interior lake survey points and other related topographic data, such as the lake shoreline elevation estimated at 138.85 ft NAVD88. The lowest point is approximately 122.0 ft NAVD88 at the south center of Lake Alto (Figure 2-2C).

The bathymetric maps of Lake Santa Fe and Little Lake Santa Fe were originally provided in scanned .TIFF format by SRWMD, on the basis of the survey data collected in 1976. The maps were georeferenced and digitized to ESRI shapefile format by ECT (Figure 2-2D). The shoreline of these two lakes was set at 140.32 ft NGVD29 or 139.47 ft NAVD88. The lowest point at Lake Santa Fe is below 113.0 ft NGVD29 or 112.15 ft NAVD88 at the lake center and the lowest point at Little Lake Santa Fe is below 119.0 ft NGVD29 or 118.15 ft NAVD88. The deepest point at the saddle point separating these two lakes was estimated at 131.0 ft NGVD29 or 130.15 ft NAVD88, i.e., the water depth at this location is approximately 10 feet.

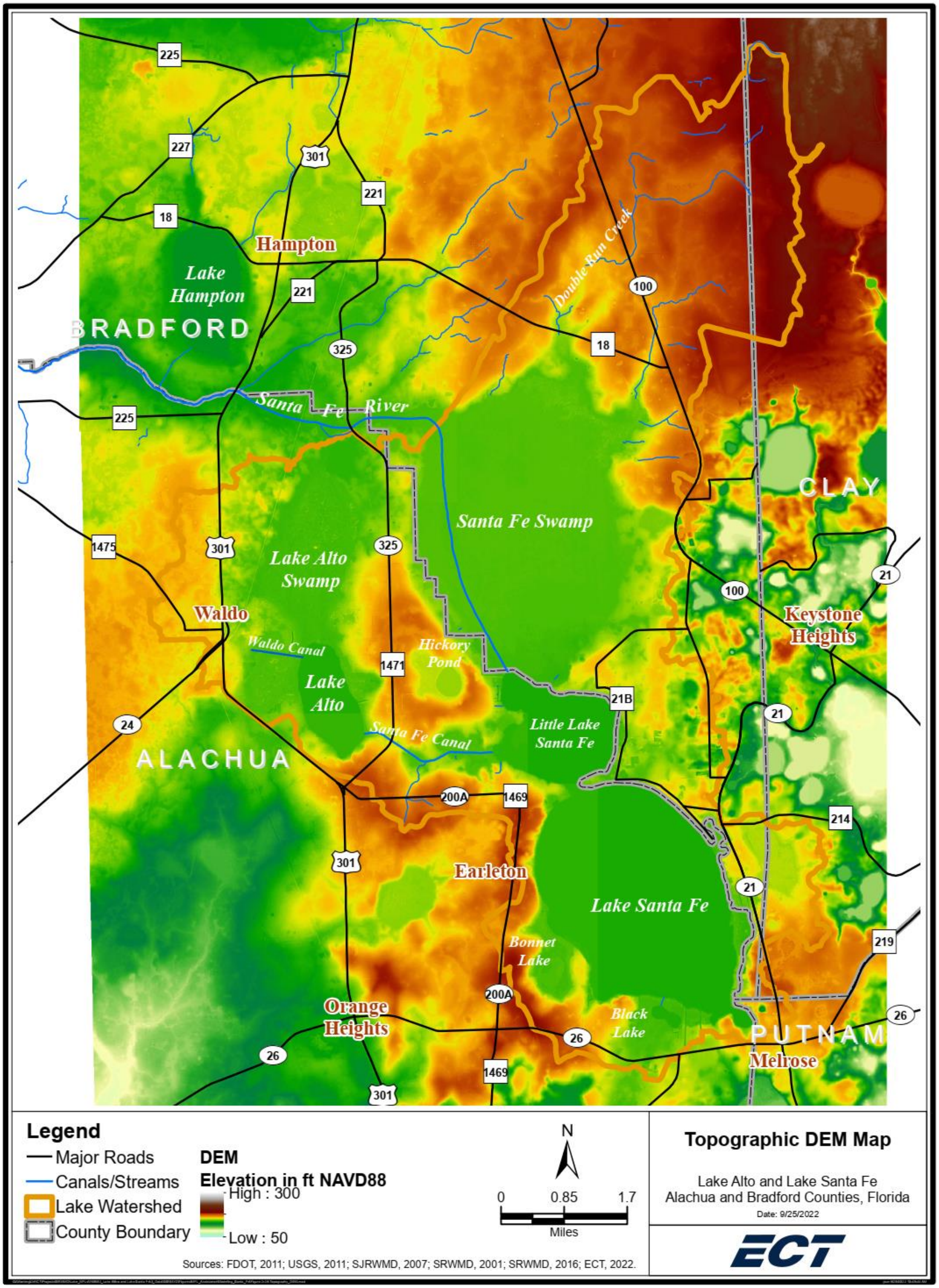


Figure 2-2A. Topographic DEM Map.

Figure 2-2B. Topographic Contours Map.

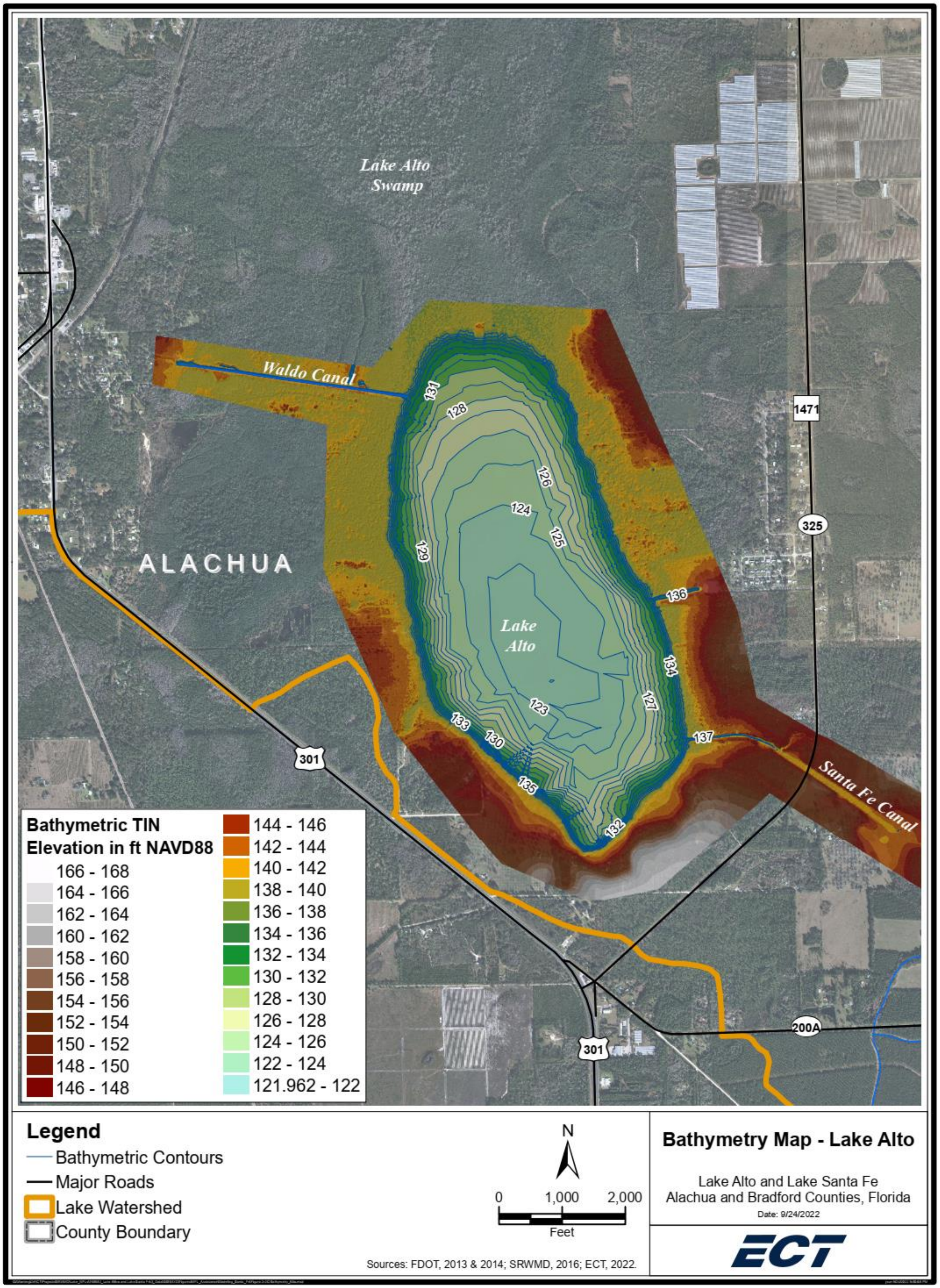


Figure 2-2C. Bathymetry Map - Lake Alto.

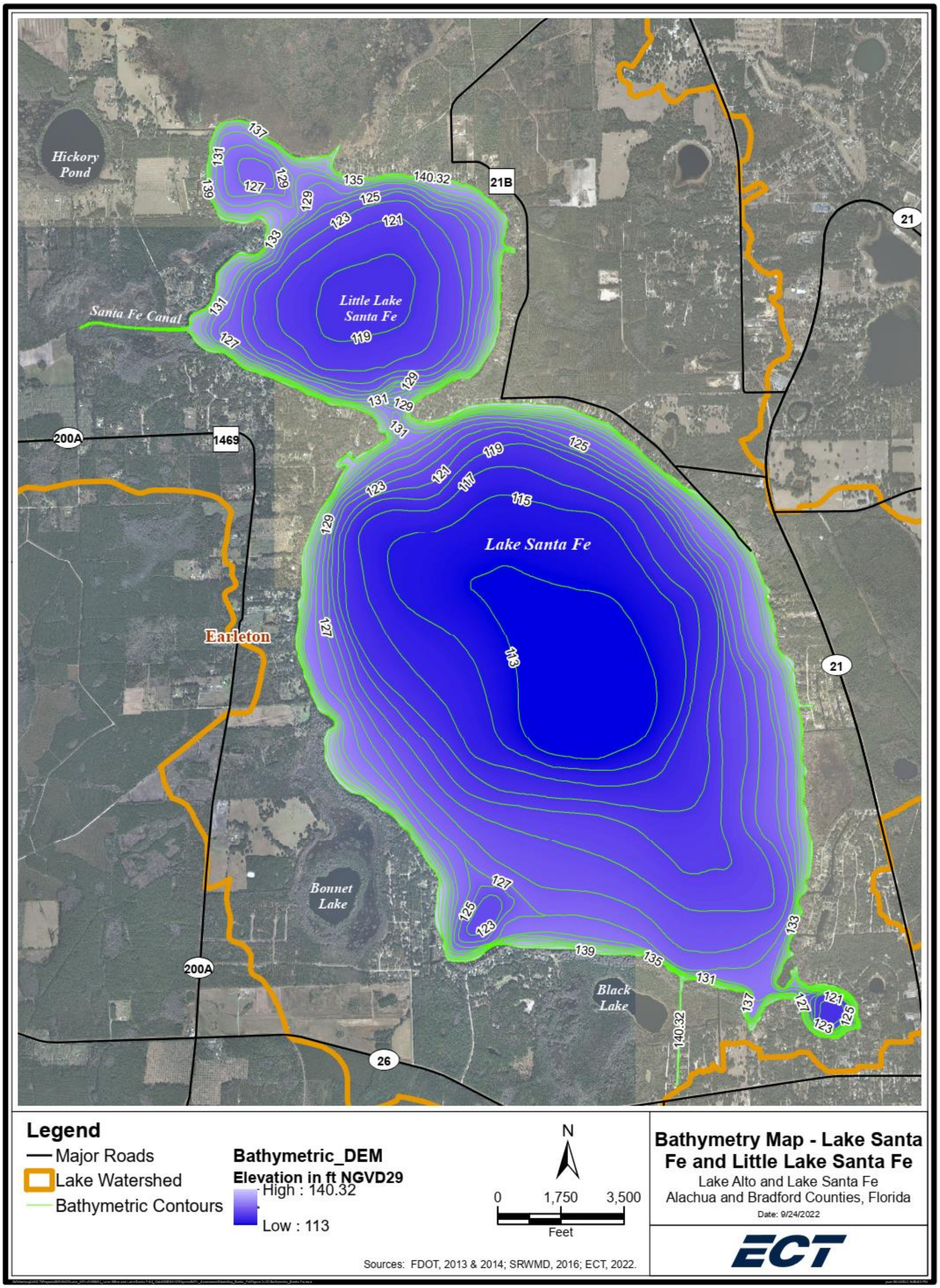


Figure 2-2D. Bathymetry Map – Lake Santa Fe and Little Lake Santa Fe.

2.4 Soils

The most current soils data of Alachua, Bradford, Clay, and Putnam counties was directly downloaded from the Natural Resource Conservation Service (NRCS). The soils map for the lake watershed was created by assembling the soils data in these four counties (Figure 2-3). The various types of soils have been grouped into three soil texture classes, including Sand, Loamy Sand, and Sandy Loam. These soil texture classes are used in the hydrologic modeling analysis to estimate infiltration from rainfall, see Section 3.2.5 for details. The Lake Alto and Lake Santa Fe watershed is classified as 49.4% for Sand, 15.5% for Loamy Sand, 18.2% for Sandy Loam, and the remaining 16.9% for water. A majority of the watershed is classified as Sand (Table 2-1 and Figure 2-3).

Table 2-1. Statistical summary of soil texture classes in Lake Alto and Lake Santa Fe watershed.

Soil Texture Class	Area (acre)	Percentage
Sand	18,511.0	49.4%
Loamy Sand	5,813.5	15.5%
Sandy Loam	6,818.5	18.2%
Water	6,340.9	16.9%
Total	**37,483.8**	**100.0%**

Source: NRCS, 2016.

2.5 Land Use/Land Cover

The SRWMD 2006 land use coverage and SJRWMD 2004 land use coverage are both based on the Florida Land Use and Cover Classification System (FLUCCS, Florida Department of Transportation [FDOT], 1999). The 2004/2006 land use map for the lake watershed was created by merging these land use coverages in the SRWMD and SJRWMD jurisdictional limits (Figure 2-4).

The lake watershed is generally rural with limited developed land (residential, transportation, etc.), most of which is located surrounding the lakes and along the U.S. Hwy 301 corridor. As summarized in Table 2-2, the top three land uses in the lake watershed are upland forests (31.1%), wetlands (25.7%), and waters (15.6%).

Table 2-2. Statistical summary of 2004/2006 land use in Lake Alto and Lake Santa Fe watershed.

FLUCCS	Description	Area (acre)	Percentage
1000	Urban & Built-up	3,138.0	8.4%
2000	Agriculture	3,025.7	8.1%
3000	Rangeland	783.2	2.1%
4000	Upland Forests	11,668.8	31.1%
5000	Waters	5,849.2	15.6%
6000	Wetlands	9,651.9	25.7%
7000	Barren Lands	3,029.4	8.1%
8000	Transportation, Communication & Utilization	337.5	0.9%
	Total	**37,483.8**	**100.0%**

Source: SRWMD, 2006; SJRWMD, 2004.

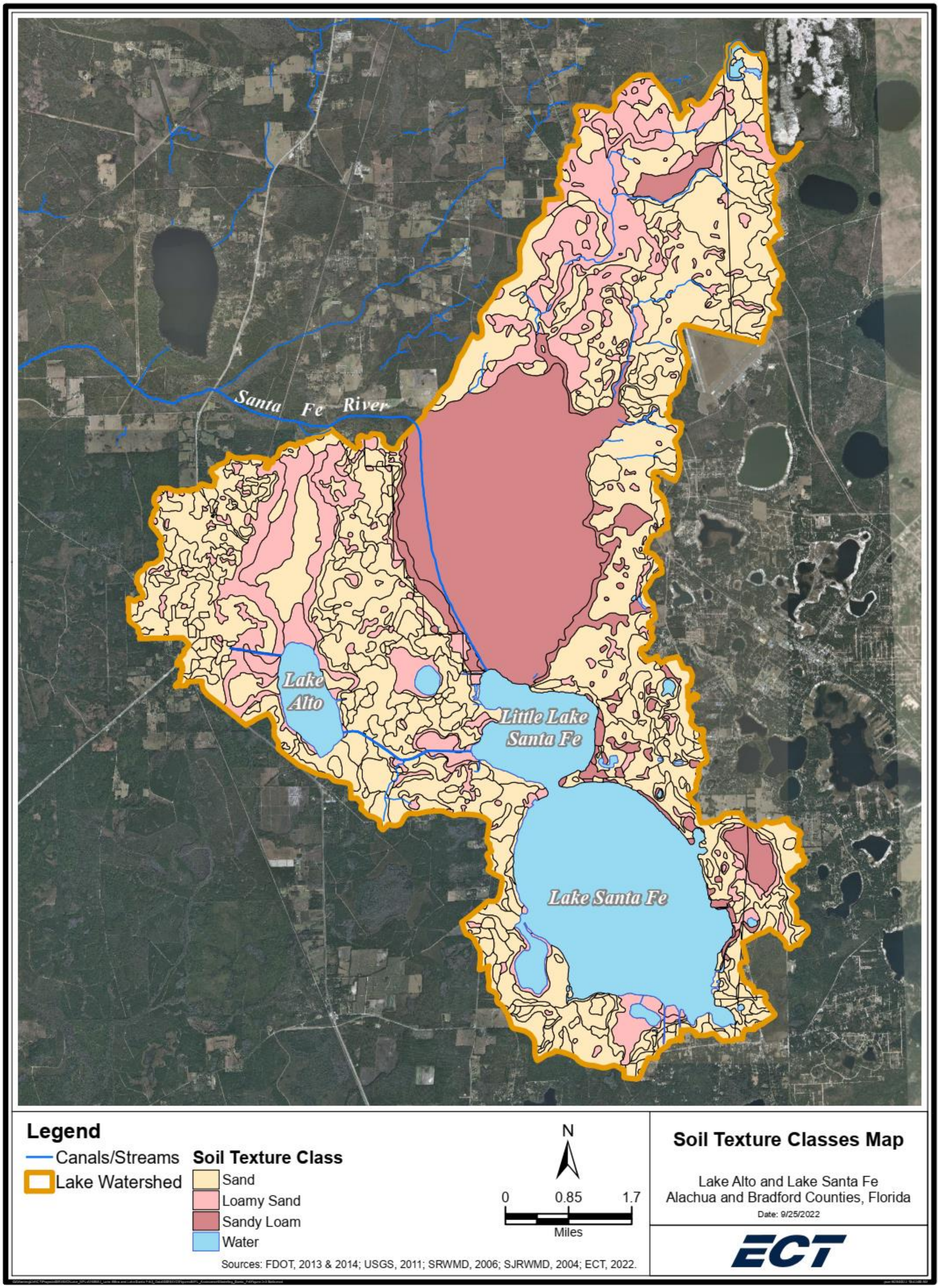


Figure 2-3. Soil Texture Classes Map.

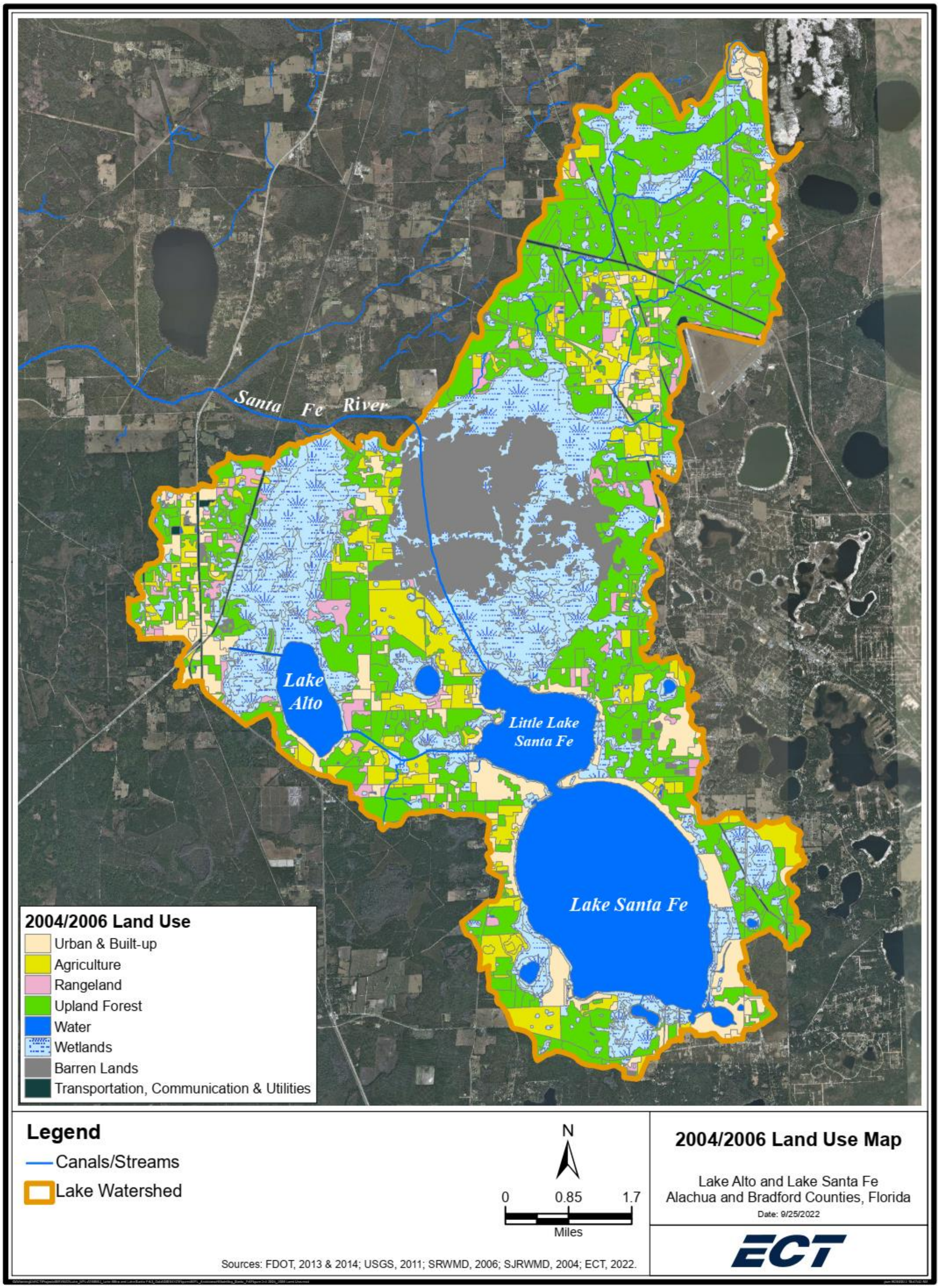


Figure 2-4. 2004/2006 Land Use Map.

2.6 Major Conveyance System

Lake Alto, Lake Santa Fe, and Little Lake Santa Fe receive surface flows from a watershed covering approximately 37,484 acres or 58.6 square miles, by means of flows emerging from the extensive forested wetlands that fringe the lakes, by direct precipitation and stormwater runoff from surrounding developed/undeveloped lands (Figure 2-4). The lake watershed can be further subdivided into five subwatersheds (Figure 2-5) including:

- Lake Alto Swamp
- Lake Alto
- Santa Fe Swamp
- Little Lake Santa Fe
- Lake Santa Fe

The major conveyance system for each of these five subwatersheds is briefly described in the subsequent sections.

2.6.1 Subwatershed: Lake Alto Swamp

The Lake Alto Swamp subwatershed is located in the northeast portion of Alachua County between Lake Alto and the Santa Fe River (Figure 2-5). This subwatershed encompasses a total area of approximately 4,905 acres or 7.7 square miles.

Inflow to the west side of the swamp is contributed by several major drainage systems that discharge the developed/undeveloped areas within the City of Waldo and unincorporated Alachua County. These drainage systems consist of dredged ditches and canals through the wetland areas between U.S. Hwy 301 and the railroad, as well as the roadway drainage systems of U.S. Hwy 301 and the railroad. The developed areas in the southern portion of the subwatershed, mostly located in the city, are discharged through a dredged canal between the railroad and Doan Road. Selected culverts along the major conveyance systems were inspected by ECT and the District staff and surveyed by George F. Young, Inc. (GFY) in the spring of 2017.

On the east side of the swamp, the contributing areas are mostly classified as undeveloped lands, including agriculture lands and upland forests that are drained through sheet flow, ditches, and/or the cross drains under County Road (C.R.) 325. Selected culverts across C.R. 325 were also surveyed by GFY.

The swamp primarily discharges to the Santa Fe River to the north by means of an outfall canal dredged through its lower northern portion. The southern portion of the swamp may also drain to Lake Alto directly through sheet flow and/or small defined flow paths during a major storm event (Figure 2-2A).

Note that a wildfire occurred in May 2007 in the north portion of the swamp, approximately 172 acres in size.

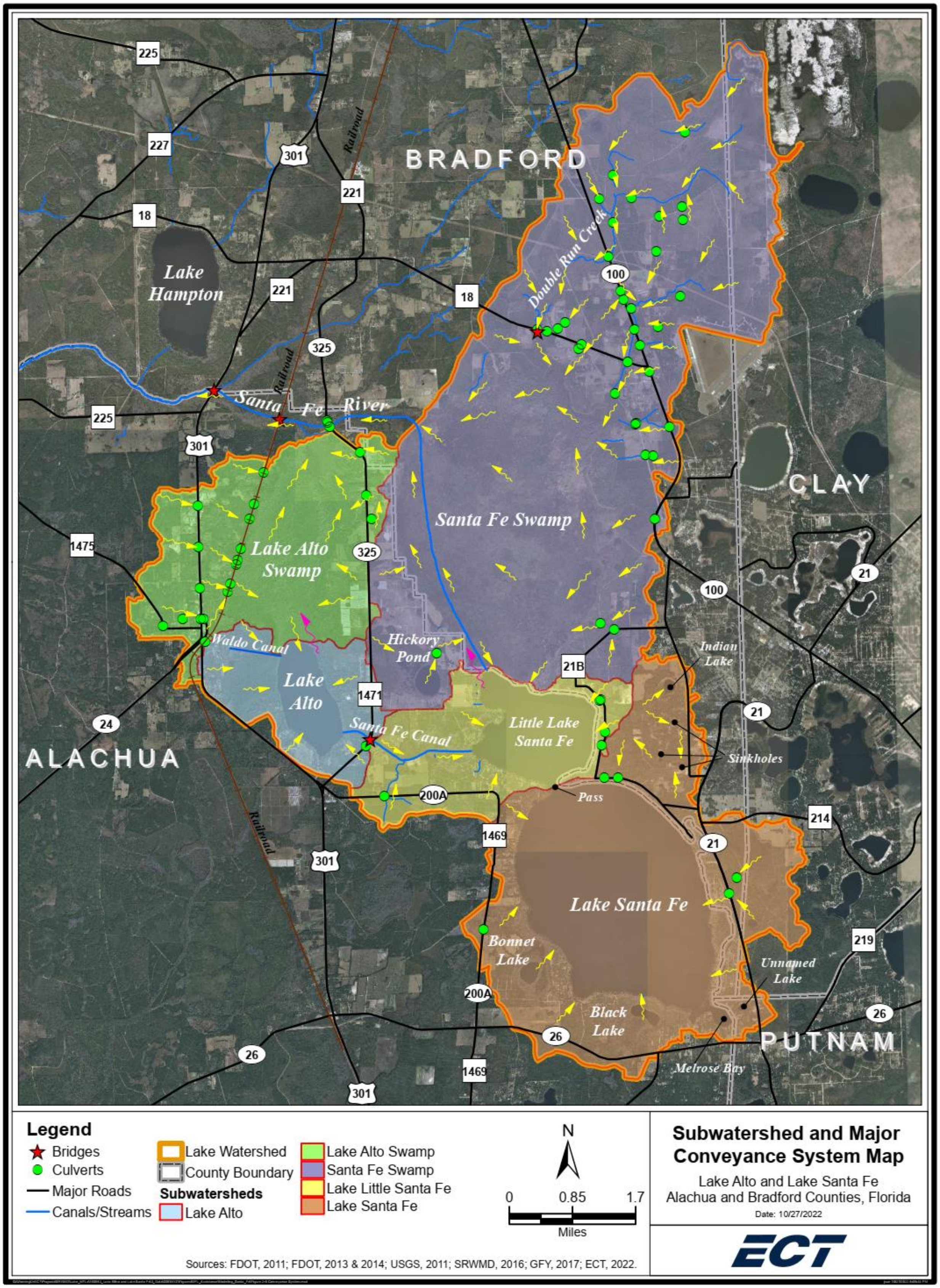


Figure 2-5. Subwatersheds and Major Conveyance System Map.

2.6.2 Subwatershed: Lake Alto

The Lake Alto subwatershed is located south of Lake Alto Swamp and west of Lake Santa Fe/Little Lake Santa Fe (Figure 2-5). This subwatershed encompasses a total area of approximately 2,184 acres or 3.4 square miles.

The southeast portion of the City of Waldo and Waldo Canal Park drains to the wetland areas adjacent to the west lake bank. The Waldo Canal, primarily used for navigation, conveys stormwater runoff from the wetland area to the north into the lake.

Inflows to the south and east sides of the lake are contributed primarily by means of sheet flow, except for the low-density residential area to the west of the lake, where the stormwater runoff discharges through a secondary roadway drainage system and empties into a wetland area adjacent to the lake.

As described previously, the Santa Fe Canal was dredged to link Lake Alto to Little Lake Santa Fe. Depending on the lake levels in these two lakes, Lake Alto may discharge into or receive surface water from Little Lake Santa Fe. As this canal is not currently used for navigation purposes, vegetation overgrowth and siltation were observed at some shallow canal segments during a field trip conducted by ECT and SRWMD in December 2016. Upon evaluation of the cross-section and bridge survey data collected at this canal, the highest point of the canal is likely located east of the C.R. 325 bridge.

During high water conditions, the lake may discharge to Lake Alto Swamp to the north, by means of sheet flow over the north lake bank.

2.6.3 Subwatershed: Santa Fe Swamp

The Santa Fe Swamp subwatershed is located north of Little Lake Santa Fe and east of Lake Alto Swamp. The subwatershed is mostly located in the southeast portion of Bradford County, with small portions in Alachua County and Clay County (Figure 2-5). This subwatershed encompasses a total area of approximately 17,590 acres (27.5 square miles), or 47% of the entire lake watershed.

Inflow to the north and northeast side of the swamp is contributed by Double Run Creek, an unnamed creek, and several small drainage systems that discharge mostly undeveloped contributing areas. These drainage systems consist of natural creeks and dredged ditches through the wetland areas north of C.R. 18 and east of State Road (S.R.) 100. Selected culverts along the major conveyance systems were surveyed by GFY.

On the east side of the swamp, the contributing areas are mostly undeveloped lands, including agriculture lands and upland forests, which are drained through sheet flow, ditches, and/or the roadway drainage system of S.R. 100 and C.R. 21B. Selected culverts along the drainage systems were surveyed by GFY.

On the west side of the swamp, the contributing areas are mostly agriculture lands and upland forests that are drained through sheet flow and ditches. Hickory Pond empties into the swamp through an outfall ditch and various culverts. One culvert in the outfall ditch was surveyed by GFY.

The swamp primarily discharges to the Upper Santa Fe River to the northwest by means of sheet flow through forested wetland areas. No well-defined flow paths were identified near the outfall location. The southern portion of the swamp may drain into Little Lake Santa Fe through sheet flow and an unnamed stream located at the southeast corner of the swamp per the topographic map (Figure 2-

2A). During a major storm event, Lake Santa Fe and Little Lake Santa Fe could drain to the Upper Santa Fe River through the swamp.

Note that the north and central portions of the swamp, approximately 2,899 acres in size, were classified as burned areas with a FLUCCS code of 7450 (Figure 2-4). The burned areas are likely caused by the large scale wildfire occurred in 2004. Small scale prescribed burning periodically occurred on the east and west sides of the swamp when vegetation regrowth is well established. The last prescribed burning was done on the east side of the swamp in March 2021.

2.6.4 Subwatershed: Little Lake Santa Fe

The Little Lake Santa Fe subwatershed is located between Santa Fe Swamp and Lake Santa Fe. Most of the subwatershed is located in the northeast portion of Alachua County, with a small portion in Bradford County (Figure 2-5). This subwatershed encompasses a total area of approximately 3,291 acres or 5.1 square miles.

Inflow to the east side of the lake is contributed by several roadway drainage systems that discharge to the wetland areas on the east side of C.R. 21B. One culvert under C.R. 21B was surveyed by GFY.

Inflow to the west side of the lake is contributed primarily by the Santa Fe Canal that discharges mostly undeveloped areas. A local drainage system is used to drain a small residential area on the southwest lake bank. A cross drain under S.R. 200A was surveyed by GFY.

As mentioned above, Little Lake Santa Fe exchanges surface water with Santa Fe Swamp to the north, Lake Alto to the west through the Santa Fe Canal, and Lake Santa Fe through the pass.

2.6.5 Subwatershed: Lake Santa Fe

The Lake Santa Fe subwatershed is located south of Little Lake Santa Fe. A majority of the subwatershed, including Lake Santa Fe itself, is located in the northeast portion of Alachua County, with the remaining portions located in Bradford, Clay, and Putnam counties (Figure 2-5). This subwatershed encompasses a total area of approximately 9,513 acres or 14.9 square miles.

Inflow to the east side of the lake is contributed by multiple local drainage systems that discharge the undeveloped areas on the east side of S.R. 21 and C.R. 21B and the residential communities adjacent to the lakeshore. Selected culverts under S.R. 21 and C.R. 21B were surveyed by GFY.

Inflow to the west and south sides of the lake is contributed primarily by sheet flow and several small unnamed streams that discharge lakes (Bonnet Lake and Black Lake), wetlands, agriculture land, and upland forests. One cross drain under S.R. 26 and two channel cross sections at the outfall canals of Bonnet Lake and Black Lake were surveyed by GFY.

Lake Santa Fe and Little Lake Santa Fe to the north are separated by the pass, a 1,000-foot-wide and 10-foot-deep opening, which was submerged throughout the entire stage recording period (1957 to present) at USGS gauge station 02320601 Santa Fe near Earleton, FL.

Several closed drainage basins, encompassing Indian Lake and several wetlands to the south, are located on the northeast portion of the subwatershed between C.R. 21B and the watershed boundary. Another closed drainage basin with an unnamed lake is located near Melrose Bay (a round-shaped bay at southeast corner of the lake). Indian Lake, the unnamed lake, and Melrose Bay are likely created by collapse sinkholes. In general, stormwater runoff in these closed drainage basins is mainly discharged through underground conduits and evaporation/evapotranspiration.

3.0 Water Budget Model Development

3.1 Model Selection

To support the establishment of MFLs in Lake Alto and Lake Santa Fe (including Little Lake Santa Fe), a water budget model was required to be developed and calibrated in order to assess the Lakes' hydrologic changes over a long-term duration and under various water resources development scenarios.

It is important that the water budget model is able to perform long-term continuous simulation of a full hydrologic cycle, including rainfall, evapotranspiration, surface runoff, infiltration/percolation, and surface water/groundwater flow exchange. The complexity of the lake hydrologic system, especially as it relates to the upper FAS and surface water connection between the two lake systems, requires a predictive computer model to adequately examine the effects of hydrologic changes. The candidate model should be capable of performing long-term continuous simulation, coupling groundwater and surface water, and be widely and successfully applied in other similar projects.

The EPA SWMM 5.1 was selected for the water budget modeling of Lake Alto and Lake Santa Fe. Much of the information presented herein is directly extracted from the SWMM User's Manual (Rossman, 2015) and User's Guide to SWMM 5, 13th Edition (James *et al.*, 2010). SWMM, a public domain software developed by EPA, is a physically based, discrete-time simulation model based on rainfall hyetographs, land use, topography, and system characterization to predict outcomes in the form of quality and quantity values. It employs principles of conservation of mass, energy, and momentum wherever appropriate. SWMM is widely used in Florida as well as nationwide. The detailed features of hydrology and hydraulic components are addressed in the following sections.

3.2 Hydrologic Modeling in SWMM

SWMM accounts for various hydrologic processes that produce runoff from the basins. These processes include:

- time-varying rainfall
- evaporation of standing surface water
- snow accumulation and melting
- rainfall interception from depression storage
- infiltration of rainfall into unsaturated soil layers
- evapotranspiration from groundwater layers
- percolation of infiltrated water into groundwater layers
- interflow between groundwater and the drainage system
- nonlinear reservoir routing of overland flow

Note that not all the hydrologic processes were considered equally important in modeling of a single storm event, for example, the evaporation and groundwater components may be considered insignificant for a short duration and hence excluded. However, for a long-term simulation, the evaporation and groundwater components play important roles and are necessary to be simulated along with other components.

3.2.1 Subbasin Delineations

Spatial variability in all of these processes is achieved by dividing a study area into a collection of smaller, homogeneous subbasins, each containing its own fraction of pervious and impervious sub-areas. The subbasin boundaries within the model domain were determined by the data availability of the existing physical features in the watershed, such as the drainage basin areas by topography, depression areas (wetlands, ponds, reservoirs, etc.), and structures (pipes, control structures, etc.), which constitute the conveyance system (Figure 3-1).

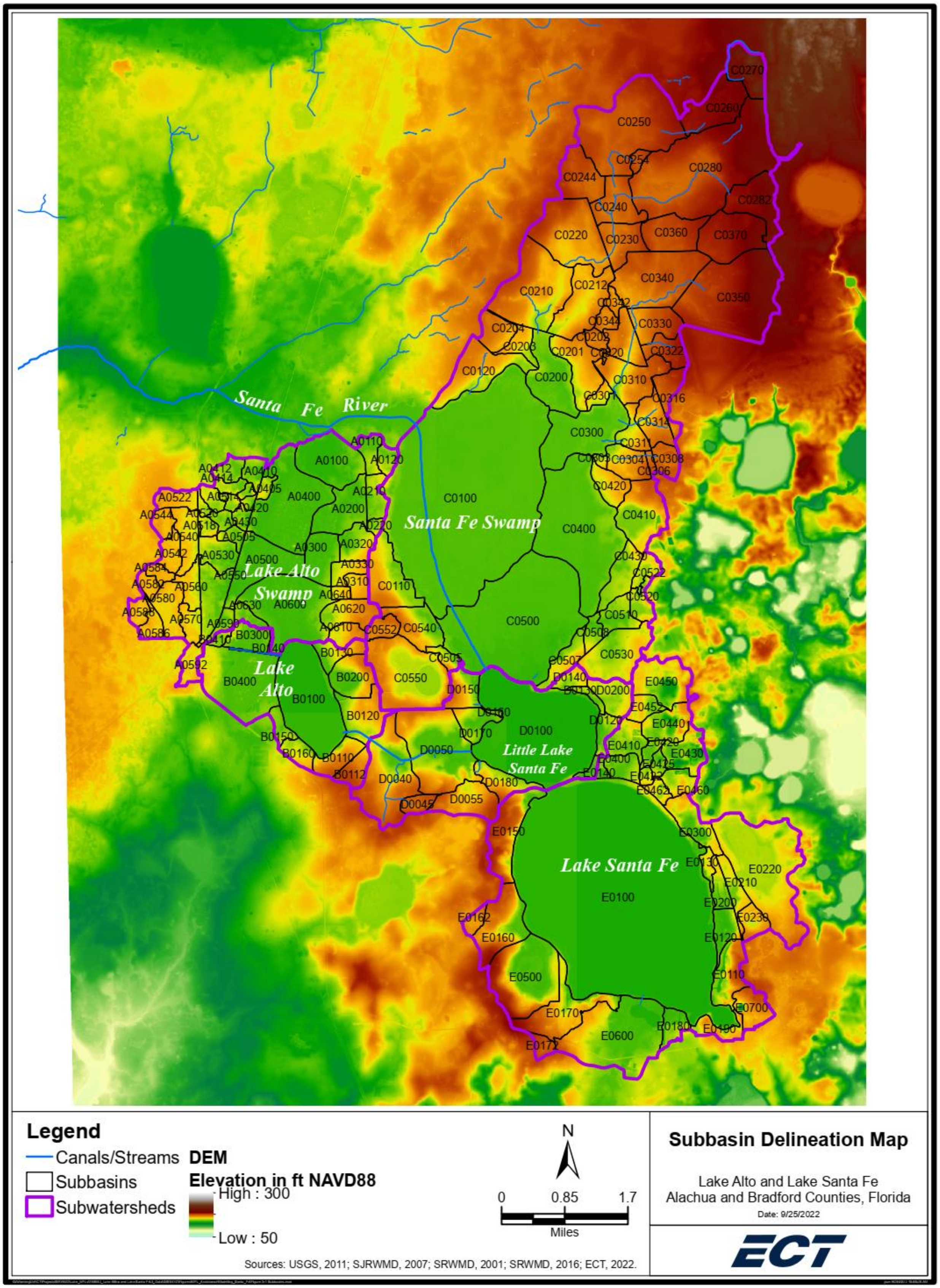
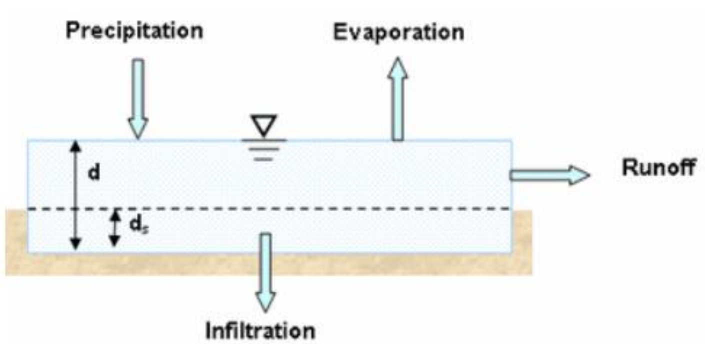


Figure 3-1. Subbasin Delineation Map.

3.2.2 Surface Runoff

The Nonlinear Reservoir Runoff method is used by SWMM, as illustrated in Figure 3-2. Each subbasin surface is treated as a nonlinear reservoir. Inflow comes from precipitation and any designated upstream subbasin. There are several outflows, including infiltration, evaporation, and surface runoff. The capacity of this "reservoir" is the maximum depression storage, which is the maximum surface storage provided by ponding, surface wetting, and interception. Surface runoff per unit area, Q, occurs only when the depth of water in the "reservoir" exceeds the maximum depression storage, d_s, in which case the outflow is given by Manning's equation.



Source: EPA SWMM Help File (V5.1.015)

Figure 3-2. Conceptual View of Surface Runoff Used in SWMM.

Table 3-1 is the lookup table of the hydrologic parameters for different land use categories. It allows the user to assign percentage of average impervious areas, overland Manning's n coefficients and depression storage (abstraction) to various land use categories, which were then applied on an area-weighted basis to each subbasin based on land use coverage. Note that some of the land use categories listed in Table 3-1 may not be present in the Lake Alto and Lake Santa Fe watershed. Other parameters used in the surface non-linear reservoir method, such as average ground slope and watershed width, were derived from the LiDAR-based DEM and subbasin coverage in ArcGIS.

Table 3-1. Lookup table of hydrologic parameters for surface runoff calculation – pre-calibration.

FLUCCS	Description	% Imperv. Area	% Zero Storage Imperv.	Manning n Imperv.	Manning n Perv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)
1100	Residential Low Density <2 Dwelling Units	15	25	0.012	0.1	0.05	0.15
1200	Residential Med Density 2->5 Dwelling Units	30	25	0.012	0.1	0.05	0.15
1300	Residential High Density	50	25	0.012	0.1	0.05	0.15
1400	Commercial and Services	85	25	0.012	0.1	0.05	0.15
1500	Industrial	72	25	0.012	0.1	0.05	0.15
1600	Extractive	65	25	0.012	0.1	0.1	0.15
1650	Reclaimed Land	65	25	0.012	0.1	0.05	0.15
1660	Holding Ponds	65	25	0.012	0.1	0.1	0.15
1700	Institutional	60	25	0.012	0.1	0.05	0.15
1800	Recreational	60	25	0.012	0.1	0.05	0.15
1820	Golf Courses	5	25	0.012	0.1	0.05	0.15
1900	Open Land	0	25	0.012	0.15	0.1	0.1
2100	Cropland and Pastureland	0	25	0.012	0.1	0.05	0.2
2140	Row Crops	0	25	0.012	0.17	0.05	0.2
2200	Tree Crops	0	25	0.012	0.4	0.05	0.2
2300	Feeding Operations	0	25	0.012	0.1	0.05	0.2
2400	Nurseries and Vineyards	0	25	0.012	0.1	0.05	0.2
2500	Specialty Farms	0	25	0.012	0.1	0.05	0.2
2550	Tropical Fish Farms	0	25	0.012	0.1	0.05	0.2
2600	Other Open Lands (Rural)	0	25	0.012	0.13	0.05	0.2
3100	Herbaceous	0	25	0.012	0.24	0.05	0.2
3200	Shrub and Brushland	0	25	0.012	0.4	0.05	0.25
3300	Mixed Rangeland	0	25	0.012	0.13	0.05	0.25
4100	Upland Coniferous Forest	0	25	0.012	0.5	0.05	0.3
4110	Pine Flatwoods	0	25	0.012	0.5	0.05	0.3
4120	Longleaf Pine - Xeric Oak	0	25	0.012	0.5	0.05	0.3
4200	Upland Hardwood Forests	0	25	0.012	0.5	0.05	0.3
4340	Hardwood Conifer Mixed	0	25	0.012	0.5	0.05	0.3
4400	Tree Plantations	0	25	0.012	0.5	0.05	0.3
5100	Streams and Waterways	100	100	0.01	0.1	0	0
5200	Lakes	100	100	0.01	0.1	0	0
5300	Reservoirs	100	100	0.01	0.1	0	0
5400	Bays and Estuaries	100	100	0.01	0.1	0	0
5500	Major Springs	100	100	0.01	0.1	0	0
5600	Slough Waters	100	100	0.01	0.1	0	0

Table 3-1. Lookup table of hydrologic parameters for surface runoff calculation – pre-calibration (cont.).

FLUCCS	Description	% Imperv. Area	% Zero Storage Imperv.	Manning n Imperv.	Manning n Perv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)
6100	Wetland Hardwood Forests	98	75	0.4	0.4	0.1	0.25
6110	Bay Swamps	98	75	0.4	0.4	0.1	0.25
6120	Mangrove Swamps	98	75	0.4	0.4	0.1	0.25
6150	Stream and Lake Swamps (Bottomland)	98	75	0.4	0.4	0.1	0.25
6200	Wetland Coniferous Forests	98	75	0.4	0.4	0.1	0.25
6210	Cypress	98	75	0.4	0.4	0.1	0.25
6300	Wetland Forests Mixed	98	75	0.4	0.4	0.1	0.25
6400	Vegetated Non-Forested Wetlands	98	75	0.24	0.24	0.1	0.25
6410	Freshwater Marshes	98	75	0.24	0.24	0.1	0.25
6420	Saltwater Marshes	98	75	0.24	0.24	0.1	0.25
6430	Wet Prairies	98	75	0.24	0.24	0.1	0.25
6440	Emergent Aquatic Vegetation	98	75	0.24	0.24	0.1	0.25
6500	Non - Vegetated	98	75	0.24	0.24	0.1	0.25
6510	Tidal Flats / Submerged Shallow Platform	98	75	0.24	0.24	0.1	0.25
6520	Shorelines	98	75	0.24	0.24	0.1	0.25
6530	Intermittent Ponds	98	75	0.24	0.24	0.1	0.25
6600	Salt Flats	98	75	0.24	0.24	0.1	0.25
7100	Beaches Other Than Swimming Beaches	0	25	0.012	0.1	0.05	0.1
7400	Disturbed Land	0	25	0.012	0.1	0.05	0.1
7420	Borrow Areas	0	25	0.012	0.1	0.05	0.1
7450	Burned Areas	0	25	0.012	0.1	0.05	0.1
8100	Transportation	50	75	0.012	0.1	0.05	0.15
8200	Communications	85	25	0.012	0.1	0.05	0.15
8300	Utilities	72	25	0.012	0.1	0.05	0.15

Sources: TR-55 (USDA, 1986); Drainage Handbook Hydrology (FDOT, 2012); ECT, 2021.

3.2.3 Rainfall

Rain gages in SWMM supply precipitation data for one or more subcatchments in a study area. Long-term rainfall data was collected from various agencies, including:

- Hourly Next-Generation Radar (NEXRAD) rainfall data by SRWMD (10/1/2007 through 12/31/2015)
- Daily NEXRAD rainfall data by SRWMD (2/1/2001 through 12/31/2015)
- Daily rainfall data (Daymet) by Oak Ridge National Laboratory (ORNL) (1/1/1980 to 12/31/2014) (Thornton *et al.*, 2012)
- Daily rainfall data at Rainfall Station - Starke by SJRWMD (1/1/1941 to 12/31/2012)

Depending on the simulation duration, one or multiple abovementioned data sources may be utilized in the SWMM models.

3.2.4 Evapotranspiration

Evapotranspiration (ET) can occur from standing water on the subcatchment surface, subsurface water in groundwater aquifers, water traveling through open channels, and water held in storage units. In this project, the following two main data sources were considered in the subsequent modeling efforts:

- Daily potential and reference evapotranspiration (PET and RET) data by USGS (6/1/1995 to 12/31/2015)
- Daily Pan Evaporation data by NOAA at three climate stations:
    - USC00084731 – Lake City 2 E FL US (5/1/1965 to 2/26/2011)
    - USC00083322 – Gainesville 11 WNW FL US (2/1/1989 to 12/31/2000)
    - USC00083321 – Gainesville 3 WSW FL US (10/6/1953 to 12/31/1988)

Single or multiple of the abovementioned ET data sources may be utilized in model simulation.

For the ET occurring in the upper zone of groundwater aquifers, a monthly ET pattern was created for each aquifer. Monthly ET coefficients for different land use categories have been developed based on two similar modeling projects, both located in southwest Florida (Table 3-2). The watersheds studied in these projects have a very high similarity in climate, topography, soils, and land use/land cover characteristics compared with the Lake Alto and Lake Santa Fe watershed.

Using an area-weighted method, a monthly ET pattern can be developed for each aquifer in the Lake Alto and Lake Santa Fe watershed. A total of eight lakes, including Lake Alto, Lake Santa Fe, Little Lake Santa Fe, Hickory Pond, Bonnet Lake, Black Lake, Indian Lake, and an unnamed lake near Melrose, were excluded from the estimation of the monthly ET pattern for their corresponding aquifers, since the lakes were treated as storage units in SWMM and the direct evaporation from these lakes was calculated separately in the hydraulic modeling.

Table 3-2. Lookup table of monthly ET coefficients – pre-calibration.

Land Use/Cover	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Urban - Low Density	0.40	0.40	0.60	0.80	0.90	0.84	0.72	0.65	0.65	0.65	0.65	0.50
Urban - Medium Density	0.30	0.30	0.50	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50
Urban - High Density	0.25	0.25	0.30	0.35	0.50	0.50	0.50	0.50	0.35	0.30	0.30	0.30
Pasture / Open Lands	0.60	0.65	0.70	0.85	0.85	0.85	0.85	0.85	0.85	0.75	0.65	0.60
Range Land	0.55	0.60	0.75	0.85	0.85	0.85	0.85	0.85	0.75	0.65	0.60	0.55
Upland Forest	0.55	0.60	0.75	0.85	0.90	0.90	0.85	0.85	0.75	0.65	0.60	0.55
Pine Flatwoods	0.70	0.70	0.85	0.90	0.90	1.00	1.00	1.00	1.00	0.90	0.80	0.70
Open Water	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Forested Wetland	1.00	1.00	1.00	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.00	1.00
Non-Forested Wetland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Burned Areas*	0.78	0.80	0.88	0.98	0.98	0.98	0.98	0.98	0.93	0.88	0.80	0.78

* Coefficients of Burned Areas (Santa Fe Swamp in this project) were estimated by averaging the values for Upland Forest and Forested Wetland.
Sources: Peace River integrated modeling (HGL, 2008) and Myakka River Watershed Initiative (Interflow, 2008).

3.2.5 Infiltration

Infiltration is the process of rainfall penetrating the ground surface into the unsaturated soil zone of pervious subbasin areas. SWMM offers three choices for modeling infiltration: 1) Horton's Equation, 2) Green-Ampt method, and 3) Curve Number method.

In this project, the Green-Ampt method was selected for modeling infiltration, as it accounts for more variables than the other two methods. It assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from the saturated soil above. The two governing equations are Equations A and B. The input parameters required are the initial moisture deficit of the soil ($\Delta\theta$), the soil's saturated hydraulic conductivity, and the suction head at the wetting front.

$$F(t) - \psi\Delta\theta ln\left(1 + \frac{F(t)}{\psi\Delta\theta}\right) = K_t \quad \text{(A)}$$

Where *F* is cumulative infiltration, ψ is wetting front soil suction head, and K_t is hydraulic conductivity in in/hr.

$$f(t) = K\left(\frac{\psi\Delta\theta}{F(t)}\right) + 1 \quad \text{(B)}$$

Where *f* is incremental infiltration.

As there is no site-specific geotechnical investigation available in the study area, the soil parameters were directly derived from the literature, specifically the soil characteristics provided in the SWMM User's Manual (Table 3-3).

Table 3-3. Summary of soil characteristics.

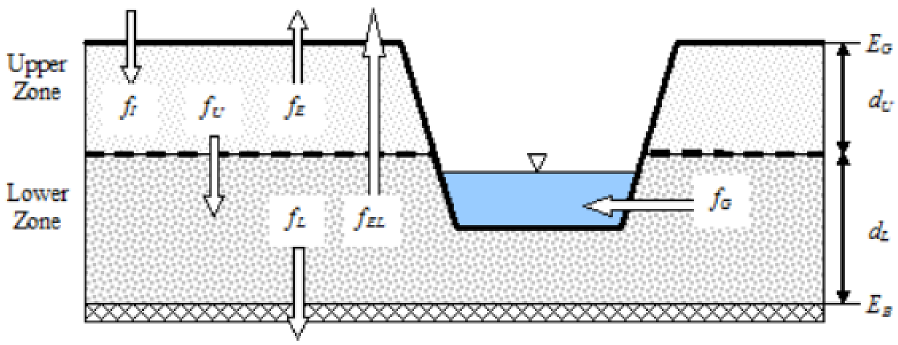
Soil Texture Class	K	Ψ	φ	FC	WP
Sand	4.74	1.93	0.437	0.062	0.024
Loamy Sand	1.18	2.40	0.437	0.105	0.047
Sandy Loam	0.43	4.33	0.453	0.190	0.085
Loam	0.13	3.50	0.463	0.232	0.116
Silt Loam	0.26	6.69	0.501	0.284	0.135
Sandy Clay Loam	0.06	8.66	0.398	0.244	0.136
Clay Loam	0.04	8.27	0.464	0.310	0.187
Silty Clay Loam	0.04	10.63	0.471	0.342	0.210
Sandy Clay	0.02	9.45	0.430	0.321	0.221
Silty Clay	0.02	11.42	0.479	0.371	0.251
Clay	0.01	12.60	0.475	0.378	0.265

K = hydraulic conductivity, in/hr
Ψ = suction head, in.
φ = porosity, fraction
FC = field capacity, fraction
WP = wilting point, fraction
Source: Rawls, W.J. *et al.*, (1983). J. Hyd. Engr., 109:1316.

3.2.6 Groundwater and Aquifers

As represented in SWMM, aquifers are sub-surface groundwater features used to simulate the downward movement of water from the subcatchments that lie above them. Aquifers also allow flow exchange of groundwater with the drainage system, depending on the hydraulic gradient that exists. Aquifers are only required in long-term model simulations that need to explicitly account for the exchange of groundwater with the drainage system or to establish baseflow and recession curves in natural channels and non-urban systems.

Aquifers are represented using two zones - an un-saturated zone and a saturated zone, as illustrated in Figure 3-3. Their behavior is characterized using such parameters as soil porosity, hydraulic conductivity, ET depth, aquifer bottom elevation, and a constant groundwater loss rate to deep aquifer. Some of the required hydrologic parameters were derived from the soil characteristics table discussed in Section 3.2.5 above. The saturated hydraulic conductivity, ET depth, aquifer bottom elevation, and groundwater loss rate to deep aquifer were developed based on the 2016 North Florida Southeast Georgia (NFSEG) Groundwater Flow Model data developed by SJRWMD (Durden *et al*., 2013; SJRWMD, 2016).



Source: EPA SWMM Help File (V5.1.015)

Figure 3-3. Conceptual View of Two-Zone Groundwater Model Used in SWMM.

3.3 Hydraulic Modeling in SWMM

SWMM contains a flexible set of hydraulic modeling capabilities used to route runoff and external inflows through the conveyance system of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

- handle networks of unlimited size
- use a wide variety of standard closed and open conduit shapes and natural channels
- model special elements such as storage/treatment units, flow dividers, pumps, weirs, and orifices
- apply external flows and water quality inputs from surface runoff, groundwater interflow, rainfall-dependent infiltration/inflow, dry weather sanitary flow, and user-defined inflows
- utilize either kinematic wave or full dynamic wave flow routing methods
- model various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding
- apply user-defined dynamic control rules to simulate the operation of pumps, orifice openings, and weir crest levels

Flow routing within a conduit/link network is governed by the conservation of mass and momentum equations for gradually varied, unsteady flow. Dynamic wave routing was selected for the flow routing computation. Dynamic wave routing can account for channel storage, backwater, entrance/exit losses, flow reversal, and pressurized flow. It is the most accurate solution but comes with a price of having to use a smaller time step to overcome the numerical instability.

3.3.1 Channels/Ditches

In SWMM, a channel/ditch is modeled as an open geometry conduit with regular or irregular cross sections. The data for the irregular channel geometry was derived mostly from the survey data by GPI and GFY as well as the LiDAR-based DEM data. The upstream and downstream elevations were mostly taken from the LiDAR-based DEM when land survey data was not available.

Natural channel reaches were evaluated for out of bank conveyance capability using LiDAR-based DEM data, aerial photographs, and field evaluations. Channel roughness (Manning's coefficients) values were derived from the SWMM User's Manual and the Hydraulic Reference Manual for HEC-RAS (Brunner, 2010).

3.3.2 Pipes/Culverts

SWMM offers a variety of standard closed geometries for pipes/culverts. The parameters of the pipes, such as length, type, material, and geometry, were either field surveyed or derived from the aerial photographs and LiDAR-based DEM data, at various major crossings within the lake watershed. For the un-surveyed culverts, the parameters were estimated by the modeler based on the aerial photos, LiDAR-based DEM, Google Streetview, and other surveyed culverts.

The friction loss calculation for the pipes is part of the total head loss, as are minor losses such as entry, exit, and culvert transitions. The Manning's n values, or the roughness of the pipes, were obtained from the SWMM User's Manual. The entry and exit loss coefficients for each pipe were evaluated using survey data and aerial photos. In addition, if a conduit experienced instability during a simulation, an equivalent conduit (elongated) was automatically generated in SWMM.

3.3.3 Outlet

Outlets are flow control devices that are typically used to control outflows from storage units. They are used to model special head-discharge relationships that cannot be characterized by pumps, orifices, or weirs. Outlets are internally represented in SWMM as a link connecting two nodes.

Because SWMM is incapable of simulating time-variant groundwater loss rates to deep aquifer, an "outlet" link was used to calculate the groundwater loss rates at the surficial aquifer beneath various lakes and sinkholes. In SWMM, a user-defined rating curve determines an outlet's discharge flow as a function of the head difference across it (i.e., the difference between the water table elevations in the lakes/sinkholes and potentiometric surface elevations in the upper FAS was used in this model).

3.3.4 Weirs

The overtopping of roadways at channel crossings was simulated as broad crested weirs. The weir invert elevations were derived from the ground survey and/or LiDAR-based DEM. The width of the weir was scaled from the aerial photographic maps, as well as the LiDAR-based DEM data. After preliminary simulations were made, the weir widths were evaluated and modified, as necessary. Weir coefficients of 2.6, 2.2, and 2.0 were assigned to the paved roads, rail roads, and unpaved roads, respectively, based on our past modeling experience in the District (ECT, 2021).

Broad crested weirs were also used to simulate flow that may occur in an overland fashion from subbasin to subbasin. Modeling overland flow as a one-dimensional broad crested weir has been widely applied in many similar stormwater models (e.g., EPA SWMM, HEC-RAS, and ICPR), at subbasin scales in urban and rural areas. Also note that there have been similar recent studies in Florida to use weir coefficients much lower than published values for broad crested weirs (CH2M, 2016). The weir invert elevations were estimated from the LiDAR-based DEM data. Weir coefficients of 1.6, 1.0, and 0.6 were initially assigned to all the overland flow weirs with land cover of grass, upland wood, and wetland swamp, respectively.

3.3.5 Storage Calculations

In SWMM, a depth-area relationship is assigned to a specific node/storage within the model schematic. In this project, the depth-area relationships were established primarily by using the LiDAR-based DEM data.

In addition, the depth-area relationships were modified in the storage nodes for the lakes and several large wetland areas. The LiDAR-based DEM data does not offer a reliable estimate of the wetland or lake bottom elevations due to intense vegetation cover and/or standing water. For example, the bathymetry survey data collected by GPI was used to modify the depth-area relationship representing the storage at Lake Alto in the SWMM model.

3.3.6 Initial Conditions

The node initial elevations in the lakes and their adjacent lakes/wetland areas were adjusted to match stage data measured at the three major lakes (Lake Alto, Lake Santa Fe, and Little Lake Santa Fe). Three lake stations (USGS 02320601 Santa Fe Lake near Earleton, USGS 02320611 Little Santa Fe Lake, and USGS 02320630 Lake Alto at Waldo) currently operated by the District, were used to establish the initial stage at these lakes. The initial stage values in other storage areas, junction nodes, and groundwater tables in aquifers were adjusted accordingly.

3.3.7 Boundary Conditions

In SWMM, outfalls are terminal nodes of the drainage system used to define most downstream boundary under dynamic wave flow routing. The outfall for surface water was defined as the Santa Fe River, located north of Santa Fe Swamp and Alto Swamp. As no stage data is available at this location, the outfall stage was determined by the minimum of the critical flow depth and normal flow depth in the connecting canal/conduit.

To simulate time-variant groundwater loss rates to deep aquifer of the surficial aquifer directly beneath the lakes and sinkholes, various outfalls were added to represent the groundwater level in the upper FAS. A long-term USGS groundwater well station (USGS ID: 294313082024601 / SRWMD ID: S092307001), located approximately 2,000 feet east of Lake Santa Fe near Melrose, provides daily average groundwater level data measured in the upper FAS. The data gaps in the groundwater database were filled using a linear interpolation method, prior to being utilized in the SWMM model.

3.3.8 Numerical Instability

SWMM is based on the solution of the Saint-Venant equations for unsteady state flow in a conveyance system. Due to the explicit nature of the numerical methods used for Dynamic Wave routing, the flows in some links or water depths at some nodes may fluctuate or oscillate significantly at certain periods of time as a result of numerical instabilities. Adjustments of model parameters include the use of equivalent pipes, adjusting storage junction values, adjusting pipe lengths, adjusting weir lengths, adjusting routing time steps, and selecting to ignore the inertial terms of the momentum equation. In this project, combinations of techniques were employed to achieve model stability.

3.3.9 Model Schematic

The hydraulic model consists of all the components that make up the primary conveyance system. These may include lakes, ponds, wetlands, pipes, natural channels, weirs, pumps, and control structures. SWMM uses a node/reach concept to idealize the hydraulics of the system. The nodes within the model are the discrete locations within the watershed boundary where the conservation of mass is maintained. These represent the storage and stage related elements of the model. The reaches are the connections between the nodes. These represent the flow and conveyance related elements of the model.

3.4 Preliminary Model Development and Simulation

The water budget model of Lake Alto and Lake Santa Fe was developed based on the 2004/2006 land use and land cover data, existing topographic data, and other available information that is considered appropriate to characterize the existing conditions in the lake watershed and hence was also used in the model parameterization in this task.

3.4.1 Hydrologic Model Parameterization

Based on the latest LiDAR-based DEM and contour maps (Figures 2-2A and 2-2B) and the major conveyance system map (Figure 2-5), the lake watershed was subdivided into a total of 157 subbasins (Figure 3-1).

Table 3-4 summarizes the hydrologic parameters for each subbasin or subcatchment for the existing conditions. The Green-Ampt method was used in the hydrologic modeling and the values of Capillary Suction Head, Saturated Hydraulic Conductivity, and Initial Moisture Deficit are also listed in this table.

Based on the similarities of the topographic and subsurface character of the 157 subbasins, the subbasin features were further grouped to create a total of 123 aquifers (Figure 3-4). Hydrologic parameters for each aquifer are summarized in Table 3-5.

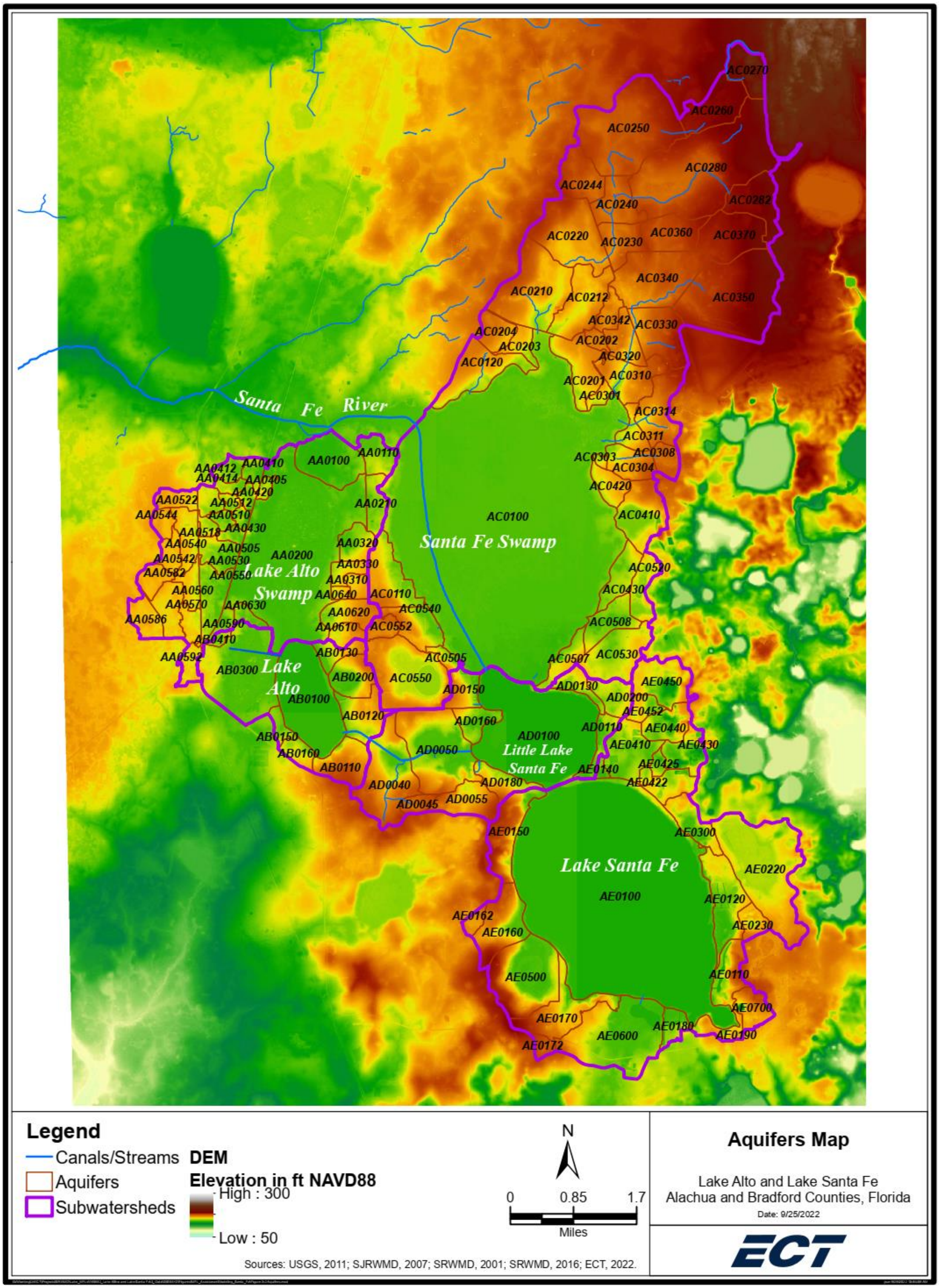


Figure 3-4. Aquifers Map.

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration.

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
A0100	318.63	3812	1.60	73.69	62.52	0.088	0.258	0.300	0.406	2.1	3.2045	0.363
A0110	78.98	1611	1.70	38.79	43.74	0.069	0.239	0.155	0.334	2.1	3.5499	0.366
A0120	57.04	1550	1.90	25.88	37.47	0.062	0.243	0.098	0.331	2.0	4.1364	0.371
A0200	239.74	5636	2.50	61.48	55.92	0.081	0.251	0.252	0.385	2.1	3.7545	0.368
A0210	96.33	2118	1.60	4.88	25.61	0.051	0.219	0.017	0.230	1.9	4.6378	0.375
A0220	25.79	1182	2.40	4.59	26.85	0.052	0.256	0.026	0.345	2.0	4.1193	0.371
A0300	177.98	5764	2.80	80.22	65.86	0.091	0.252	0.291	0.353	1.9	4.6292	0.375
A0310	61.53	1612	1.90	12.65	31.25	0.056	0.288	0.049	0.458	1.9	4.6378	0.375
A0320	126.09	2786	1.80	17.30	33.68	0.059	0.249	0.079	0.317	2.0	4.3068	0.372
A0330	73.41	1263	1.70	1.28	25.00	0.050	0.235	0.012	0.259	1.9	4.6378	0.375
A0400	581.87	7933	2.70	92.01	72.18	0.097	0.252	0.369	0.397	2.1	3.4348	0.365
A0405	33.60	2197	2.00	59.99	58.44	0.078	0.232	0.227	0.367	1.9	4.6378	0.375
A0410	65.73	2153	2.10	13.13	32.78	0.056	0.260	0.043	0.307	1.9	4.6378	0.375
A0412	68.06	1404	1.60	18.31	34.33	0.059	0.276	0.073	0.413	2.0	4.1600	0.371
A0414	44.20	991	1.70	11.51	30.49	0.055	0.242	0.055	0.304	1.9	4.6378	0.375
A0420	19.40	866	2.30	6.34	31.34	0.050	0.279	0.012	0.441	1.9	4.6378	0.375
A0422	19.90	1336	1.80	7.32	28.73	0.054	0.272	0.041	0.371	2.0	4.0432	0.37
A0430	38.70	1082	1.90	13.10	33.04	0.055	0.286	0.053	0.462	2.0	4.0803	0.37
A0500	308.05	3923	2.90	90.45	71.80	0.095	0.251	0.348	0.381	2.1	3.2376	0.364
A0505	45.87	851	1.80	24.39	38.67	0.061	0.260	0.092	0.357	1.9	4.6378	0.375
A0510	43.28	1767	1.80	14.14	32.08	0.057	0.289	0.067	0.476	2.1	3.7286	0.368

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
A0512	24.31	1221	1.50	16.39	33.36	0.058	0.274	0.077	0.430	1.9	4.6378	0.375
A0514	7.59	748	1.40	26.21	38.37	0.063	0.260	0.116	0.404	2.1	3.7444	0.368
A0516	51.01	1241	1.60	47.17	33.08	0.054	0.208	0.041	0.247	2.0	4.5597	0.374
A0518	37.53	1228	1.80	16.62	31.39	0.054	0.243	0.044	0.337	2.0	4.2237	0.372
A0520	23.50	1376	2.30	54.36	48.13	0.055	0.173	0.050	0.166	2.0	4.3190	0.372
A0522	89.61	1102	2.00	25.65	32.11	0.056	0.209	0.056	0.255	2.0	4.2096	0.372
A0530	131.87	2008	2.10	22.04	36.91	0.060	0.248	0.079	0.354	2.0	4.1780	0.371
A0540	144.23	2291	2.40	18.49	30.79	0.049	0.206	0.013	0.220	1.9	4.6378	0.375
A0542	82.52	2491	2.30	37.48	31.82	0.053	0.207	0.038	0.243	2.0	4.6253	0.375
A0544	64.43	1823	2.90	16.67	33.71	0.058	0.290	0.059	0.463	2.0	4.2953	0.372
A0550	196.40	2566	2.60	38.17	40.75	0.062	0.230	0.085	0.298	1.9	4.6378	0.375
A0560	88.87	2147	2.20	20.67	29.66	0.050	0.228	0.013	0.290	1.9	4.6378	0.375
A0570	78.82	1737	2.00	37.04	27.56	0.050	0.175	0.012	0.178	2.0	4.5278	0.374
A0580	153.79	1732	1.80	25.48	33.77	0.059	0.239	0.080	0.329	1.9	4.6378	0.375
A0582	47.16	1486	1.30	7.74	26.34	0.051	0.247	0.022	0.303	1.9	4.6378	0.375
A0584	44.00	875	2.10	18.67	34.37	0.058	0.261	0.068	0.347	2.0	4.0252	0.37
A0586	67.68	1423	1.90	10.95	28.12	0.053	0.232	0.032	0.264	1.9	4.6378	0.375
A0588	56.24	1548	1.70	15.38	32.02	0.057	0.266	0.065	0.403	2.0	4.4979	0.374
A0590	46.41	1775	2.70	18.48	35.72	0.056	0.223	0.059	0.331	2.0	4.5893	0.375
A0592	84.34	1024	2.70	28.67	34.98	0.049	0.178	0.012	0.172	1.9	4.6378	0.375
A0600	546.57	9938	2.80	87.01	69.39	0.094	0.253	0.343	0.387	2.0	4.0456	0.370

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
A0610	75.83	1376	3.20	22.65	36.56	0.062	0.285	0.085	0.431	1.9	4.6378	0.375
A0620	155.69	1708	2.60	12.15	31.20	0.056	0.266	0.052	0.327	1.9	4.6378	0.375
A0630	54.02	1015	3.90	67.53	59.45	0.084	0.266	0.279	0.431	1.9	4.6378	0.375
A0640	28.78	977	2.10	0.00	25.00	0.050	0.299	0.012	0.493	1.9	4.6378	0.375
B0100	627.14	98284	0.40	98.25	96.82	0.008	0.023	0.039	0.125	2.0	4.0332	0.370
B0110	121.43	3431	2.40	3.66	25.97	0.051	0.253	0.019	0.319	1.9	4.6378	0.375
B0112	93.09	1186	2.40	0.20	25.00	0.050	0.287	0.012	0.443	1.9	4.6378	0.375
B0120	215.95	3053	2.50	12.41	30.98	0.054	0.263	0.045	0.367	1.9	4.6378	0.375
B0130	103.57	1364	3.40	26.46	38.50	0.063	0.287	0.107	0.463	2.0	4.5700	0.374
B0140	14.35	9975	7.70	61.61	65.94	0.040	0.164	0.092	0.307	1.9	4.6348	0.375
B0150	58.85	2852	2.00	1.45	25.01	0.050	0.282	0.012	0.431	1.9	4.6378	0.375
B0160	82.30	2381	1.50	6.58	27.24	0.052	0.229	0.029	0.386	1.9	4.6378	0.375
B0200	184.79	3697	2.70	42.61	41.26	0.066	0.230	0.138	0.324	1.9	4.6378	0.375
B0300	118.84	3068	2.80	64.30	57.23	0.082	0.257	0.262	0.406	2.0	4.5372	0.374
B0400	538.11	5309	2.70	65.95	57.12	0.081	0.236	0.190	0.291	2.0	4.3011	0.372
B0410	25.98	1104	2.00	25.40	32.75	0.058	0.226	0.072	0.315	2.0	3.9943	0.370
C0100	3282.25	20036	1.50	61.70	56.13	0.098	0.250	0.276	0.286	4.2	0.6285	0.306
C0110	286.32	3197	1.70	17.43	33.79	0.064	0.224	0.085	0.211	1.9	4.6336	0.375
C0120	304.79	3765	1.90	5.23	27.59	0.053	0.280	0.029	0.404	2.0	3.9130	0.369
C0200	303.41	4240	3.00	73.90	62.70	0.088	0.261	0.275	0.391	3.8	1.0073	0.317
C0201	247.97	2984	1.60	3.62	26.33	0.051	0.244	0.020	0.301	2.2	3.1028	0.363

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
C0202	45.77	1201	1.90	15.21	32.72	0.058	0.277	0.069	0.403	2.0	4.0478	0.370
C0203	86.49	1604	2.10	4.24	27.11	0.052	0.263	0.028	0.336	2.2	3.0854	0.362
C0204	123.80	2062	2.20	18.71	34.55	0.060	0.280	0.085	0.458	2.1	3.6599	0.367
C0210	539.07	2767	2.20	12.80	30.88	0.056	0.286	0.053	0.459	2.1	3.3150	0.364
C0212	313.58	1856	1.90	10.96	30.24	0.054	0.253	0.048	0.357	2.2	2.8304	0.360
C0220	459.79	3156	2.00	14.90	30.77	0.056	0.286	0.054	0.463	2.3	2.2328	0.356
C0230	171.71	2356	2.30	16.11	30.20	0.055	0.282	0.052	0.456	2.3	1.9945	0.354
C0240	202.32	2205	2.10	10.31	29.61	0.055	0.293	0.045	0.481	2.3	1.8948	0.353
C0244	218.63	2186	2.00	14.28	31.03	0.056	0.256	0.058	0.380	2.3	1.7515	0.352
C0250	773.85	4065	1.90	27.82	39.06	0.064	0.282	0.120	0.458	2.3	2.2511	0.356
C0254	32.65	1244	1.70	8.88	29.53	0.055	0.295	0.047	0.491	2.0	4.3354	0.373
C0260	263.04	2027	2.30	42.05	46.44	0.071	0.278	0.150	0.428	2.1	3.3036	0.364
C0270	176.00	3466	3.80	54.52	33.71	0.065	0.195	0.049	0.223	1.9	4.6378	0.375
C0280	1175.20	4055	2.40	31.89	40.44	0.065	0.280	0.117	0.442	2.4	3.6807	0.361
C0282	243.25	3088	2.50	28.01	33.70	0.058	0.262	0.074	0.404	2.0	4.5743	0.374
C0300	443.32	5361	2.90	83.21	67.13	0.095	0.250	0.329	0.359	4.0	0.9642	0.311
C0301	45.77	1961	1.80	2.72	25.01	0.050	0.254	0.012	0.340	2.0	4.3418	0.372
C0303	17.43	811	2.20	19.54	34.97	0.060	0.290	0.089	0.480	1.9	4.6378	0.375
C0304	143.90	1659	2.50	12.65	30.77	0.056	0.271	0.057	0.402	2.0	4.5550	0.374
C0306	19.75	645	1.70	13.58	25.00	0.050	0.222	0.012	0.257	1.9	4.6378	0.375
C0308	88.40	2328	2.90	35.69	41.15	0.066	0.238	0.126	0.309	2.0	4.5688	0.374

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
C0310	253.38	3511	1.80	17.78	30.91	0.055	0.204	0.051	0.189	2.2	4.0189	0.366
C0311	95.54	1529	1.40	11.25	27.21	0.052	0.209	0.027	0.178	2.0	4.5701	0.374
C0314	158.85	1939	2.10	10.11	27.11	0.052	0.233	0.028	0.278	2.0	4.3669	0.373
C0316	112.09	877	2.40	9.45	27.55	0.053	0.265	0.032	0.358	2.0	4.4610	0.374
C0320	154.52	1942	2.10	2.01	25.31	0.050	0.226	0.012	0.209	2.0	4.0101	0.370
C0322	115.61	1313	2.10	3.08	25.26	0.050	0.275	0.014	0.407	2.0	4.5619	0.374
C0330	170.25	2295	2.00	10.74	29.05	0.053	0.241	0.032	0.327	2.1	3.7872	0.368
C0340	483.91	2612	1.90	14.03	30.11	0.055	0.251	0.046	0.328	2.0	3.8925	0.369
C0342	36.50	1333	1.80	41.78	45.94	0.071	0.227	0.175	0.259	2.1	3.6633	0.367
C0344	48.87	2478	2.10	20.72	35.57	0.061	0.247	0.094	0.302	2.1	3.2240	0.364
C0350	789.53	4176	2.30	11.09	30.73	0.053	0.284	0.037	0.452	2.0	4.4657	0.374
C0360	223.65	2041	1.80	12.64	31.45	0.056	0.293	0.062	0.487	2.1	3.8679	0.369
C0370	312.88	2223	2.20	10.10	30.15	0.055	0.295	0.050	0.487	2.0	4.4686	0.374
C0400	969.54	10498	1.50	64.24	57.54	0.094	0.255	0.279	0.335	3.9	1.1289	0.314
C0410	296.39	3274	2.70	34.76	40.42	0.064	0.258	0.124	0.365	2.7	3.2627	0.352
C0420	117.48	2211	2.70	8.95	29.57	0.055	0.282	0.047	0.440	2.0	4.4394	0.373
C0430	161.95	2817	2.00	8.35	29.23	0.056	0.291	0.044	0.464	2.2	4.1585	0.367
C0500	1445.33	8622	1.30	91.53	71.67	0.098	0.249	0.361	0.365	4.2	0.6535	0.306
C0505	49.15	1906	1.90	0.87	25.00	0.050	0.204	0.012	0.132	1.9	4.6378	0.375
C0507	120.82	3680	2.30	3.33	26.34	0.051	0.291	0.020	0.473	2.0	4.5737	0.374
C0508	59.41	995	1.70	28.62	39.60	0.065	0.285	0.116	0.462	2.4	3.8150	0.361

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
C0510	117.73	2426	2.10	28.82	39.48	0.064	0.271	0.124	0.435	2.7	3.3673	0.353
C0520	83.05	1386	2.90	32.85	42.00	0.064	0.261	0.114	0.392	2.6	3.4143	0.355
C0522	69.54	1259	2.40	21.50	35.97	0.061	0.270	0.091	0.428	2.1	3.7447	0.368
C0530	312.99	3146	2.00	13.86	32.03	0.057	0.281	0.063	0.431	2.1	4.1152	0.370
C0540	195.52	2789	2.40	9.64	29.92	0.055	0.211	0.044	0.191	2.0	4.3321	0.372
C0550	552.81	5036	1.80	40.53	48.26	0.058	0.221	0.107	0.342	2.1	3.5917	0.367
C0552	74.52	2189	2.30	22.00	36.19	0.061	0.229	0.099	0.268	2.0	4.4880	0.374
D0040	489.56	3901	1.80	10.37	30.02	0.055	0.252	0.048	0.372	2.0	4.4251	0.373
D0045	62.60	1586	1.80	27.11	38.22	0.063	0.269	0.115	0.431	2.0	4.1066	0.371
D0050	581.97	6326	1.80	33.57	41.61	0.067	0.261	0.120	0.390	2.1	3.6985	0.367
D0055	207.44	2915	1.90	9.97	28.86	0.054	0.267	0.042	0.416	2.0	4.2417	0.372
D0100	1224.32	172321	0.30	96.95	95.89	0.008	0.023	0.031	0.119	3.0	2.7165	0.343
D0110	28.94	1212	3.30	75.07	61.95	0.087	0.237	0.299	0.355	3.7	1.4780	0.320
D0120	72.94	1568	2.70	44.35	47.27	0.071	0.265	0.162	0.406	2.9	3.0049	0.347
D0130	33.23	2989	2.20	11.58	28.05	0.053	0.241	0.036	0.342	2.1	4.3188	0.369
D0140	64.23	1345	2.50	2.10	25.00	0.050	0.259	0.012	0.312	2.0	4.1265	0.371
D0150	131.26	2623	2.20	10.97	29.13	0.052	0.211	0.032	0.305	2.0	4.3516	0.373
D0160	9.53	1335	2.10	33.11	32.90	0.058	0.198	0.067	0.227	1.9	4.6378	0.375
D0170	109.94	1582	1.60	31.52	39.08	0.064	0.256	0.093	0.379	2.0	3.9315	0.369
D0180	134.04	3340	1.90	8.13	25.24	0.050	0.223	0.014	0.295	2.0	4.5348	0.374
D0200	140.81	2821	2.00	16.20	33.19	0.058	0.268	0.076	0.386	2.3	4.0754	0.365

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
E0100	4289.98	424660	0.20	97.52	96.56	0.007	0.018	0.028	0.115	2.5	3.2595	0.355
E0110	192.56	3772	2.60	15.08	29.48	0.051	0.216	0.025	0.285	2.1	4.3746	0.370
E0120	103.92	2326	2.80	89.39	70.27	0.095	0.248	0.271	0.300	3.5	1.6125	0.327
E0130	42.25	2054	2.40	30.64	28.62	0.054	0.179	0.040	0.179	2.0	4.5375	0.373
E0140	23.23	541	3.50	94.67	73.13	0.098	0.249	0.385	0.395	3.2	2.4212	0.337
E0150	279.61	6121	1.90	9.50	27.57	0.053	0.222	0.029	0.318	2.0	4.4847	0.374
E0160	301.91	2791	1.60	11.30	30.71	0.055	0.245	0.042	0.317	1.9	4.6372	0.375
E0162	47.66	1281	1.70	23.61	37.04	0.062	0.285	0.105	0.466	2.0	3.9897	0.370
E0170	306.22	2447	2.00	16.88	29.85	0.055	0.212	0.047	0.209	2.0	4.5942	0.375
E0172	47.90	1508	1.40	20.42	35.42	0.060	0.290	0.093	0.479	1.9	4.6378	0.375
E0180	87.91	1559	3.40	48.52	50.62	0.065	0.225	0.138	0.310	2.1	3.4496	0.365
E0190	87.43	3738	2.00	14.98	25.00	0.050	0.199	0.012	0.231	1.9	4.6378	0.375
E0200	76.44	1118	2.80	33.49	27.65	0.053	0.156	0.033	0.117	2.6	3.4517	0.355
E0210	100.14	1473	3.30	22.87	36.40	0.061	0.286	0.100	0.470	2.1	3.7011	0.367
E0220	792.63	8823	1.90	37.23	43.04	0.068	0.255	0.129	0.340	2.6	3.2698	0.354
E0230	86.51	3475	3.00	36.20	45.88	0.058	0.256	0.095	0.413	2.3	3.9847	0.365
E0300	169.49	1998	2.40	34.53	39.91	0.065	0.262	0.126	0.405	2.3	3.8535	0.364
E0400	94.62	2721	2.60	34.10	42.31	0.067	0.281	0.132	0.446	2.4	3.4807	0.360
E0410	134.78	2660	3.20	29.60	40.10	0.065	0.268	0.113	0.420	2.5	3.5793	0.359
E0420	40.78	1226	1.90	25.11	37.23	0.062	0.276	0.107	0.445	2.5	3.6728	0.358
E0422	26.15	1767	2.30	13.24	31.24	0.056	0.272	0.060	0.412	2.1	3.8703	0.369

Table 3-4. Summary table of hydrologic parameters in subbasins – pre-calibration (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% Imperv. Area	% Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
E0425	36.59	1210	1.80	7.61	28.73	0.054	0.293	0.029	0.472	1.9	4.6378	0.375
E0430	165.62	3884	3.20	17.42	26.89	0.060	0.224	0.023	0.285	2.1	4.4412	0.372
E0440	170.18	2894	2.30	5.27	25.00	0.050	0.231	0.012	0.324	2.0	4.2684	0.372
E0450	261.88	3980	1.60	20.64	36.81	0.054	0.245	0.057	0.339	2.1	4.2736	0.369
E0452	78.61	1651	1.80	19.14	34.77	0.060	0.276	0.081	0.424	2.3	3.9096	0.364
E0460	89.23	2369	2.50	0.09	25.00	0.050	0.255	0.012	0.354	1.9	4.6378	0.375
E0462	45.26	1656	1.80	13.23	33.47	0.047	0.206	0.025	0.218	2.2	4.1775	0.367
E0500	523.39	5458	1.50	44.00	47.33	0.063	0.227	0.115	0.298	2.0	4.4685	0.374
E0600	676.82	4326	2.00	46.31	49.76	0.068	0.253	0.151	0.388	2.1	3.6416	0.367
E0700	133.47	2334	2.50	12.49	27.17	0.049	0.236	0.012	0.341	1.9	4.6378	0.375

Table 3-5. Summary table of hydrologic parameters in aquifers – pre-calibration.

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AA0100	0.4104	0.0541	0.1366	18.442	5.2899	15	1	8.42	0.000002	108.93	136.45	0.15
AA0110	0.4131	0.0524	0.1297	17.221	5.1703	15	1	11.36	0.000002	112.44	142.73	0.15
AA0200	0.4128	0.0526	0.1304	17.530	5.1820	15	1	7.54	0.000002	110.08	137.44	0.15
AA0210	0.4165	0.0503	0.1213	15.902	5.0221	15	1	10.89	0.000001	114.46	143.89	0.15
AA0310	0.4170	0.0500	0.1200	14.635	5.0000	15	1	11.71	0.000002	124.03	155.97	0.15
AA0320	0.4155	0.0510	0.1238	15.656	5.0669	15	1	10.93	0.000001	116.47	145.26	0.15
AA0330	0.4170	0.0500	0.1200	15.034	5.0000	15	1	12.02	0.000002	122.14	150.92	0.15
AA0405	0.4170	0.0500	0.1200	19.818	5.0000	15	1	11.34	0.000002	112.36	145.55	0.15
AA0410	0.4170	0.0500	0.1200	20.824	5.0000	15	1	13.75	0.000002	113.72	141.89	0.15
AA0412	0.4148	0.0514	0.1255	21.165	5.0966	15	1	14.27	0.000003	116.07	143.15	0.15
AA0414	0.4170	0.0500	0.1200	21.261	5.0000	15	1	14.44	0.000003	117.32	145.14	0.15
AA0420	0.4156	0.0509	0.1235	19.949	5.0609	15	1	11.92	0.000002	113.05	144.08	0.15
AA0430	0.4144	0.0516	0.1264	19.993	5.1128	15	1	12.39	0.000003	115.41	142.56	0.15
AA0505	0.4170	0.0500	0.1200	19.443	5.0000	15	1	11.14	0.000002	113.36	142.89	0.15
AA0510	0.4128	0.0526	0.1305	20.075	5.1839	15	1	12.57	0.000003	116.09	143.17	0.15
AA0512	0.4160	0.0506	0.1225	20.367	5.0430	15	1	13.02	0.000003	116.45	146.13	0.15
AA0516	0.4163	0.0504	0.1218	21.070	5.0311	15	1	13.70	0.000003	118.81	147.17	0.15
AA0518	0.4151	0.0512	0.1248	20.563	5.0838	15	1	13.34	0.000003	121.33	147.76	0.15
AA0522	0.4150	0.0512	0.1250	21.833	5.0866	15	1	13.41	0.000003	121.16	155.67	0.15
AA0530	0.4149	0.0513	0.1253	19.581	5.0930	15	1	13.78	0.000003	115.56	143.33	0.15
AA0540	0.4170	0.0500	0.1200	20.736	5.0000	15	1	13.59	0.000003	122.23	152.50	0.15

Table 3-5. Summary table of hydrologic parameters in aquifers – pre-calibration (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AA0542	0.4169	0.0500	0.1201	20.883	5.0025	15	1	14.56	0.000003	124.57	155.12	0.15
AA0544	0.4154	0.0510	0.1240	21.873	5.0693	15	1	15.49	0.000004	122.15	157.10	0.15
AA0550	0.4170	0.0500	0.1200	18.918	5.0000	15	1	13.43	0.000003	116.09	142.40	0.15
AA0560	0.4170	0.0500	0.1200	19.744	5.0000	15	1	14.16	0.000003	123.14	151.28	0.15
AA0570	0.4165	0.0503	0.1213	18.799	5.0222	15	1	14.32	0.000003	120.75	152.09	0.15
AA0580	0.4170	0.0500	0.1200	19.801	5.0000	15	1	13.52	0.000004	125.51	153.62	0.15
AA0582	0.4156	0.0509	0.1234	20.619	5.0598	15	1	14.40	0.000004	126.16	156.74	0.15
AA0586	0.4167	0.0502	0.1207	19.959	5.0128	15	1	12.63	0.000005	125.97	154.92	0.15
AA0590	0.4168	0.0501	0.1206	17.983	5.0098	15	1	13.44	0.000003	114.92	142.91	0.15
AA0592	0.4170	0.0500	0.1200	18.180	5.0000	15	1	13.53	0.000004	122.36	152.96	0.15
AA0610	0.4170	0.0500	0.1200	14.102	5.0000	15	1	11.25	0.000003	122.10	155.73	0.15
AA0620	0.4170	0.0500	0.1200	14.257	5.0000	15	1	11.22	0.000002	124.43	155.38	0.15
AA0630	0.4170	0.0500	0.1200	17.734	5.0000	15	1	12.48	0.000003	112.44	140.93	0.15
AA0640	0.4170	0.0500	0.1200	15.169	5.0000	15	1	12.83	0.000002	120.75	151.76	0.15
AB0100	0.4142	0.0517	0.1270	14.727	5.1223	15	1	8.37	0*	108.44	134.30	0.15
AB0110	0.4170	0.0500	0.1200	13.093	5.0000	15	1	14.43	0.000004	120.95	161.89	0.15
AB0120	0.4170	0.0500	0.1200	12.481	5.0000	15	1	13.54	0.000004	121.42	151.42	0.15
AB0130	0.4167	0.0502	0.1208	13.847	5.0137	15	1	10.64	0.000002	120.14	149.31	0.15
AB0150	0.4170	0.0500	0.1200	14.972	5.0000	15	1	13.83	0.000002	109.85	142.68	0.15
AB0160	0.4170	0.0500	0.1200	14.392	5.0000	15	1	12.22	0.000002	118.60	148.47	0.15
AB0200	0.4170	0.0500	0.1200	13.187	5.0000	15	1	10.26	0.000002	119.46	148.98	0.15

Table 3-5. Summary table of hydrologic parameters in aquifers – pre-calibration (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AB0300	0.4157	0.0508	0.1234	16.873	5.0587	15	1	9.62	0.000003	112.20	140.47	0.15
AB0410	0.4140	0.0519	0.1274	18.011	5.1302	15	1	14.48	0.000003	118.13	144.47	0.15
AC0100	0.4122	0.0684	0.2027	11.638	7.2901	15	1	9.92	0.00005	110.30	138.24	0.15
AC0110	0.4170	0.0500	0.1200	13.658	5.0008	15	1	9.51	0.000002	121.30	151.54	0.15
AC0120	0.4136	0.0521	0.1284	18.065	5.1466	15	1	12.32	0.000016	112.45	155.10	0.15
AC0201	0.4099	0.0544	0.1377	13.964	5.3105	15	1	11.41	0.000044	108.43	155.79	0.15
AC0202	0.4143	0.0517	0.1268	13.699	5.1194	15	1	12.58	0.000049	107.14	164.27	0.15
AC0203	0.4098	0.0545	0.1379	18.174	5.3140	15	1	13.37	0.000028	110.91	152.79	0.15
AC0204	0.4125	0.0528	0.1313	19.804	5.1978	15	1	13.58	0.000026	111.33	162.67	0.15
AC0210	0.4109	0.0538	0.1353	21.744	5.2676	15	1	13.69	0.000044	110.69	160.22	0.15
AC0212	0.4086	0.0552	0.1409	16.986	5.3656	15	1	14.00	0.000046	109.45	156.89	0.15
AC0220	0.4059	0.0570	0.1478	20.034	5.4865	15	1	15.20	0.000079	112.11	164.19	0.15
AC0230	0.4048	0.0576	0.1506	14.787	5.5347	15	1	15.54	0.000069	112.24	167.62	0.15
AC0240	0.4043	0.0579	0.1517	15.032	5.5548	15	1	15.81	0.000097	114.93	168.09	0.15
AC0244	0.4037	0.0583	0.1534	18.117	5.5838	15	1	13.79	0.00014	114.48	171.75	0.15
AC0250	0.4064	0.0567	0.1466	13.471	5.4657	15	1	14.41	0.000199	117.16	173.82	0.15
AC0260	0.4108	0.0539	0.1354	7.578	5.2699	15	1	10.92	0.00025	118.21	189.48	0.15
AC0270	0.4170	0.0500	0.1200	5.883	5.0000	15	1	8.47	0.000423	106.88	206.02	0.15
AC0280	0.4150	0.0541	0.1380	8.512	5.4705	15	1	12.46	0.000133	122.24	181.32	0.15
AC0282	0.4167	0.0502	0.1207	5.812	5.0129	15	1	11.22	0.000178	117.56	193.27	0.15
AC0301	0.4157	0.0509	0.1238	11.995	5.0731	15	1	10.89	0.000053	107.18	151.41	0.15

Table 3-5. Summary table of hydrologic parameters in aquifers – pre-calibration (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AC0303	0.4170	0.0500	0.1200	9.596	5.0000	15	1	12.02	0.000093	110.55	148.67	0.15
AC0304	0.4167	0.0502	0.1208	8.271	5.0147	15	1	12.37	0.000215	106.94	158.40	0.15
AC0308	0.4167	0.0502	0.1208	6.914	5.0140	15	1	10.80	0.00038	100.73	168.02	0.15
AC0310	0.4157	0.0526	0.1316	10.621	5.3020	15	1	10.39	0.000069	103.86	161.33	0.15
AC0311	0.4169	0.0503	0.1214	8.855	5.0402	15	1	10.66	0.00013	104.84	153.45	0.15
AC0314	0.4159	0.0507	0.1227	8.373	5.0469	15	1	10.76	0.00014	100.31	165.48	0.15
AC0320	0.4141	0.0518	0.1274	12.222	5.1318	15	1	12.02	0.000052	105.45	161.01	0.15
AC0330	0.4145	0.0516	0.1262	10.095	5.1087	15	1	12.00	0.000057	102.34	171.48	0.15
AC0340	0.4136	0.0522	0.1286	11.311	5.1508	15	1	12.77	0.00005	107.64	168.18	0.15
AC0342	0.4113	0.0535	0.1342	14.438	5.2480	15	1	12.95	0.00005	107.79	163.06	0.15
AC0350	0.4162	0.0505	0.1220	6.827	5.0348	15	1	13.41	0.000059	96.07	186.47	0.15
AC0360	0.4134	0.0522	0.1289	10.491	5.1557	15	1	14.76	0.000066	113.14	174.30	0.15
AC0370	0.4162	0.0505	0.1220	6.963	5.0342	15	1	13.36	0.000078	108.05	186.74	0.15
AC0410	0.4150	0.0563	0.1483	6.870	5.7735	15	1	12.50	0.000523	110.61	152.65	0.15
AC0420	0.4161	0.0506	0.1223	8.549	5.0401	15	1	13.28	0.000179	111.08	152.93	0.15
AC0430	0.4161	0.0521	0.1294	6.451	5.2524	15	1	12.09	0.000722	113.91	144.80	0.15
AC0505	0.4170	0.0500	0.1200	10.375	5.0000	15	1	9.45	0.000009	116.43	148.52	0.15
AC0507	0.4169	0.0503	0.1214	6.794	5.0381	15	1	11.57	0.00022	114.09	147.28	0.15
AC0508	0.4157	0.0553	0.1440	6.177	5.6655	15	1	10.12	0.000832	113.98	142.40	0.15
AC0520	0.4141	0.0542	0.1381	5.741	5.4442	15	1	12.98	0.001539	114.62	147.57	0.15
AC0530	0.4149	0.0517	0.1270	5.614	5.1427	15	1	11.35	0.001118	114.72	148.09	0.15

Table 3-5. Summary table of hydrologic parameters in aquifers – pre-calibration (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AC0540	0.4160	0.0511	0.1246	11.808	5.1037	15	1	8.84	0.000006	119.61	151.92	0.15
AC0550	0.4122	0.0530	0.1321	11.478	5.2116	15	1	10.66	0*	124.10	154.42	0.15
AC0552	0.4163	0.0504	0.1217	12.684	5.0303	15	1	11.02	0.000005	126.44	163.98	0.15
AD0040	0.4160	0.0506	0.1225	11.464	5.0430	15	1	12.13	0.000007	123.62	158.71	0.15
AD0045	0.4145	0.0515	0.1261	10.283	5.1075	15	1	12.47	0.000015	124.67	169.07	0.15
AD0050	0.4127	0.0527	0.1309	9.910	5.1900	15	1	11.95	0.00001	123.56	148.56	0.15
AD0055	0.4152	0.0511	0.1246	8.720	5.0801	15	1	13.86	0.000033	123.37	162.15	0.15
AD0100	0.4143	0.0589	0.1599	7.041	6.0929	15	1	10.93	0*	107.15	133.19	0.15
AD0110	0.4145	0.0598	0.1642	5.324	6.2276	15	1	10.52	0.000019	110.04	141.14	0.15
AD0130	0.4153	0.0515	0.1262	6.341	5.1328	15	1	12.42	0.000128	114.10	146.73	0.15
AD0150	0.4157	0.0508	0.1233	9.471	5.0579	15	1	11.37	0.000001	119.72	151.90	0.15
AD0160	0.4140	0.0519	0.1275	8.908	5.1315	15	1	11.70	0.000002	114.32	142.63	0.15
AD0180	0.4165	0.0503	0.1212	7.703	5.0208	15	1	13.28	0.000007	116.33	151.70	0.15
AD0200	0.4163	0.0527	0.1320	5.323	5.3331	15	1	11.15	0.000602	111.20	147.51	0.15
AE0100	0.4139	0.0557	0.1453	4.340	5.6504	15	1	7.62	0*	104.69	133.45	0.15
AE0110	0.4167	0.0513	0.1256	2.188	5.1563	15	1	11.73	0.000316	89.70	153.94	0.15
AE0120	0.4141	0.0545	0.1397	2.429	5.4951	15	1	11.86	0.000271	95.42	144.38	0.15
AE0140	0.4144	0.0605	0.1674	5.079	6.3167	15	1	10.24	0.000002	108.42	139.91	0.15
AE0150	0.4163	0.0504	0.1218	7.313	5.0310	15	1	13.31	0.000011	121.01	163.83	0.15
AE0160	0.4170	0.0500	0.1200	7.575	5.0001	15	1	12.30	0.000065	125.21	160.03	0.15
AE0162	0.4140	0.0519	0.1275	8.641	5.1311	15	1	14.52	0.000058	129.72	162.29	0.15

Table 3-5. Summary table of hydrologic parameters in aquifers – pre-calibration (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AE0170	0.4168	0.0501	0.1205	5.463	5.0088	15	1	13.32	0.000119	113.03	158.26	0.15
AE0172	0.4170	0.0500	0.1200	5.914	5.0000	15	1	13.16	0.000372	112.68	171.76	0.15
AE0180	0.4115	0.0534	0.1337	2.880	5.2403	15	1	10.00	0.00021	94.20	140.47	0.15
AE0190	0.4170	0.0500	0.1200	2.210	5.0000	15	1	12.06	0.00006	84.40	154.39	0.15
AE0220	0.4144	0.0560	0.1465	2.059	5.7014	15	1	10.37	0.00146	89.24	150.34	0.15
AE0230	0.4158	0.0529	0.1328	2.029	5.3431	15	1	11.85	0.001018	88.57	156.71	0.15
AE0300	0.4150	0.0532	0.1338	3.129	5.3470	15	1	12.72	0.000136	101.60	146.73	0.15
AE0410	0.4147	0.0546	0.1401	4.619	5.5247	15	1	12.69	0.000352	107.65	142.84	0.15
AE0422	0.4135	0.0522	0.1289	3.942	5.1553	15	1	12.38	0.000532	104.44	147.35	0.15
AE0425	0.4170	0.0500	0.1200	3.897	5.0000	15	1	12.39	0*	103.21	142.19	0.15
AE0430	0.4168	0.0509	0.1242	3.538	5.1168	15	1	11.85	0*	97.44	141.52	0.15
AE0440	0.4153	0.0511	0.1243	3.988	5.0747	15	1	12.71	0*	101.13	146.71	0.15
AE0450	0.4165	0.0517	0.1275	4.373	5.2046	15	1	12.28	0*	106.57	148.40	0.15
AE0452	0.4156	0.0532	0.1341	4.551	5.3738	15	1	12.45	0.001114	106.63	148.36	0.15
AE0460	0.4168	0.0507	0.1231	3.600	5.0873	15	1	11.74	0.000794	101.38	148.78	0.15
AE0500	0.4162	0.0505	0.1220	6.734	5.0343	15	1	12.05	0.000106	119.69	152.11	0.15
AE0600	0.4124	0.0529	0.1315	3.951	5.2015	15	1	10.77	0.000288	102.97	143.26	0.15
AE0700	0.4170	0.0500	0.1200	1.884	5.0000	15	1	11.88	0*	80.01	160.47	0.15

** Groundwater loss to deep aquifer in Aquifers AB0100, AC0550, AD0100, AE0100, AE0425, AE0430, AE0440, AE0450, and AE0700, beneath lakes and sinkholes, was simulated via an outlet link in the SWMM model, see Section 3.3.3.*

3.4.2 Hydraulic Model Parameterization

There is a total of 166 nodes in the conveyance system, including 118 “storage nodes” representing wetlands, lakes, and ponds, 36 “junction nodes” representing the confluence of natural channels, manholes in a drainage system, or pipe connection fittings, and 12 “outfall nodes” representing the model boundaries in the Santa Fe River, a roadside ditch draining to the Santa Fe River, and the upper FAS (Figure 3-5).

There is a total of 268 reaches, including 51 open channels, 95 pipes or culverts, 113 weirs representing the road overtopping or the sheet flow between subbasins, and nine outlets representing groundwater loss to deep aquifer at the various lakes and sinkholes (Figure 3-5).

3.4.3 Subbasin, Aquifer, Node, and Reach Naming Convention

A total of 5 characters have been dedicated for naming the subbasins. For example, a subbasin name can be designated as “B0100.” The first left character “B” indicates one of the five subwatersheds, , i.e., “Lake Alto.” The remaining four-character fields are reserved for numbering of the subbasins within the major subwatershed (Figure 3-1).

A total of 6 characters have been dedicated for naming the aquifers. The character “A” is used to represent the aquifers. For an aquifer beneath a subbasin, it will use the subbasin name with the character “A” placed at the first left character position. For example, the designated aquifer name “AB0100” would be used for the aquifer that exchanges flow with subbasin “B0100” (Figure 3-4).

A total of 6 characters have been dedicated for naming the nodes and up to 8 characters have been dedicated for naming the reaches in the hydraulic network being modeled. The character “N” is used for the nodes and the character “R” is used for the reaches. For a node receiving runoff directly from a subbasin, it will use the subbasin name with the character “N” placed at the first left character position. For example, the designated node name “NB0410” would be used at the loading node of subbasin “B0410” and its downstream connecting reach would have the name “RB0410XX.” Other nodes and reaches not directly associated with a subbasin will follow in a sequential manner. For example, the next downstream connecting node may be named “NB0400" while the next reach will be named “RB0400XX” due its association. The first character “X” in a reach name is reserved to represent reach type. The character “P” is for pipes or culverts, “C” for channels or ditches, “W” for weirs, and “T” for outlets. The second “X” is used only when there are more than one of the same type of reaches discharging from a node. For example, “RD0200P2” would be used for naming the second culvert that discharge node “ND0200” (Figure 3-5).

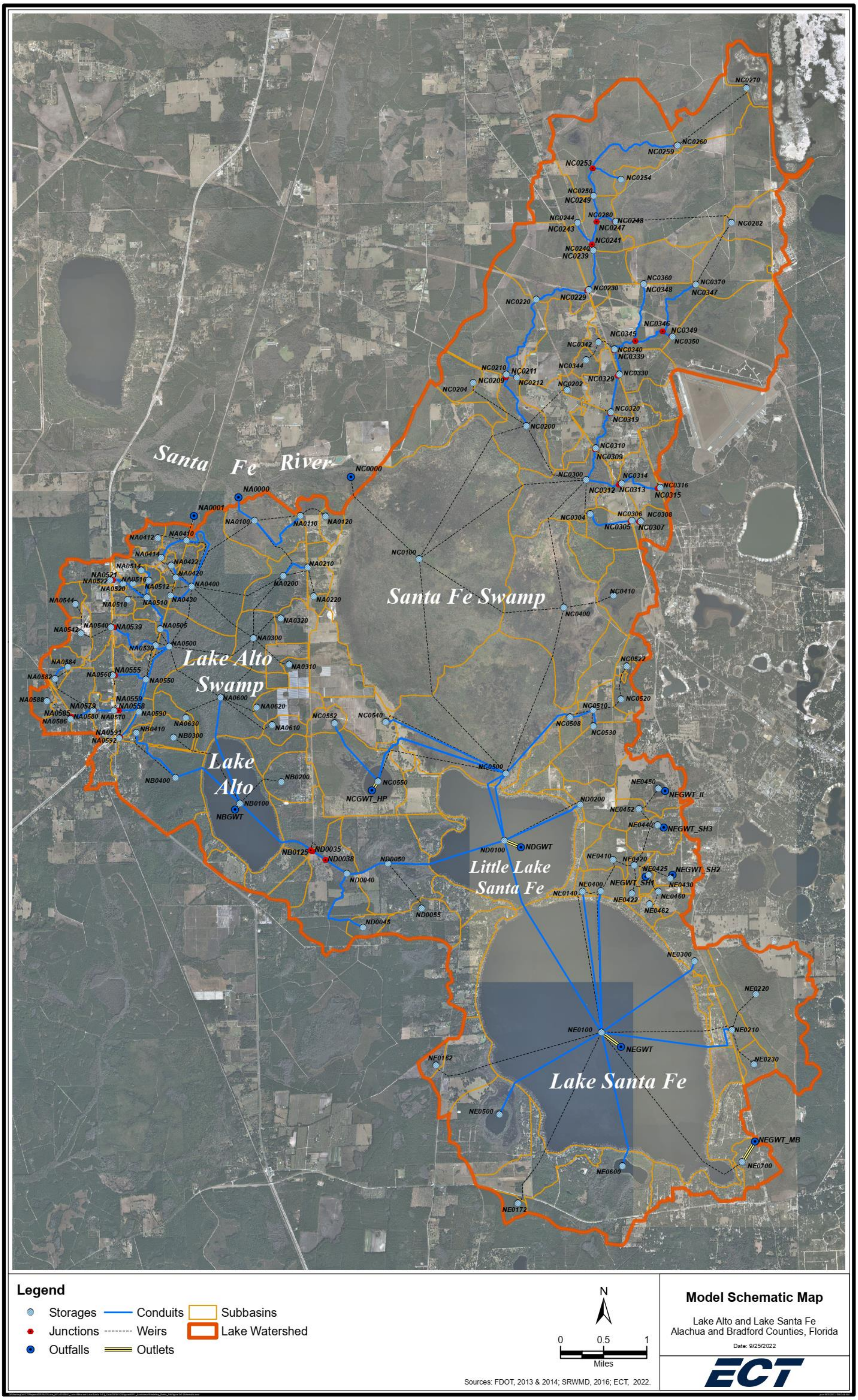


Figure 3-5. Model Schematic Map.

3.4.4 Preliminary Model Simulation

Model parameterization was conducted primarily in ArcGIS, and the resultant parameters for hydrologic and hydraulic features were converted into the input file of the SWMM model. A randomly picked period, from 1/1/2014 through 12/31/2015 in this case, was simulated to identify any potential errors or omissions in this preliminary model.

The preliminary model results were briefly checked by plotting and comparing the simulated and observed node depth hydrographs at Node NB0100 (Lake Alto, Figure 3-6A) and Node NE0100 (Lake Santa Fe, Figure 3-6B). As observed in these comparison plots, the preliminary model appears to be able to capture the hydrologic response to rainfall and ET during the two-year simulation period.

In summary, the preliminary water budget model of Lake Alto and Lake Santa Fe has been developed to simulate the major hydrologic and hydraulic features in the lake watershed. The simulation results for the two-year test run were considered reasonable and adequate.

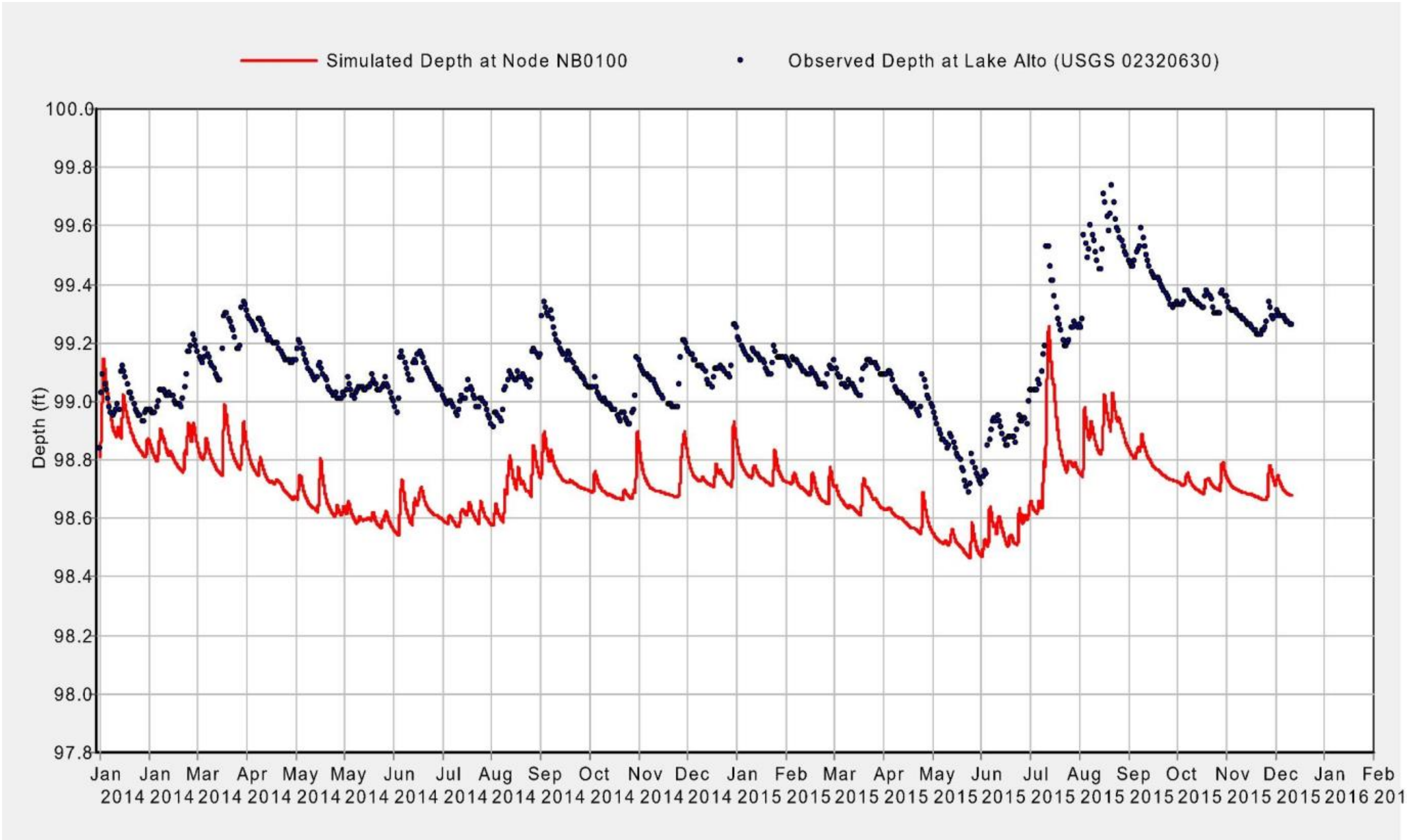


Figure 3-6A. Node Depth Hydrographs Comparison at Lake Alto (2014-2015).

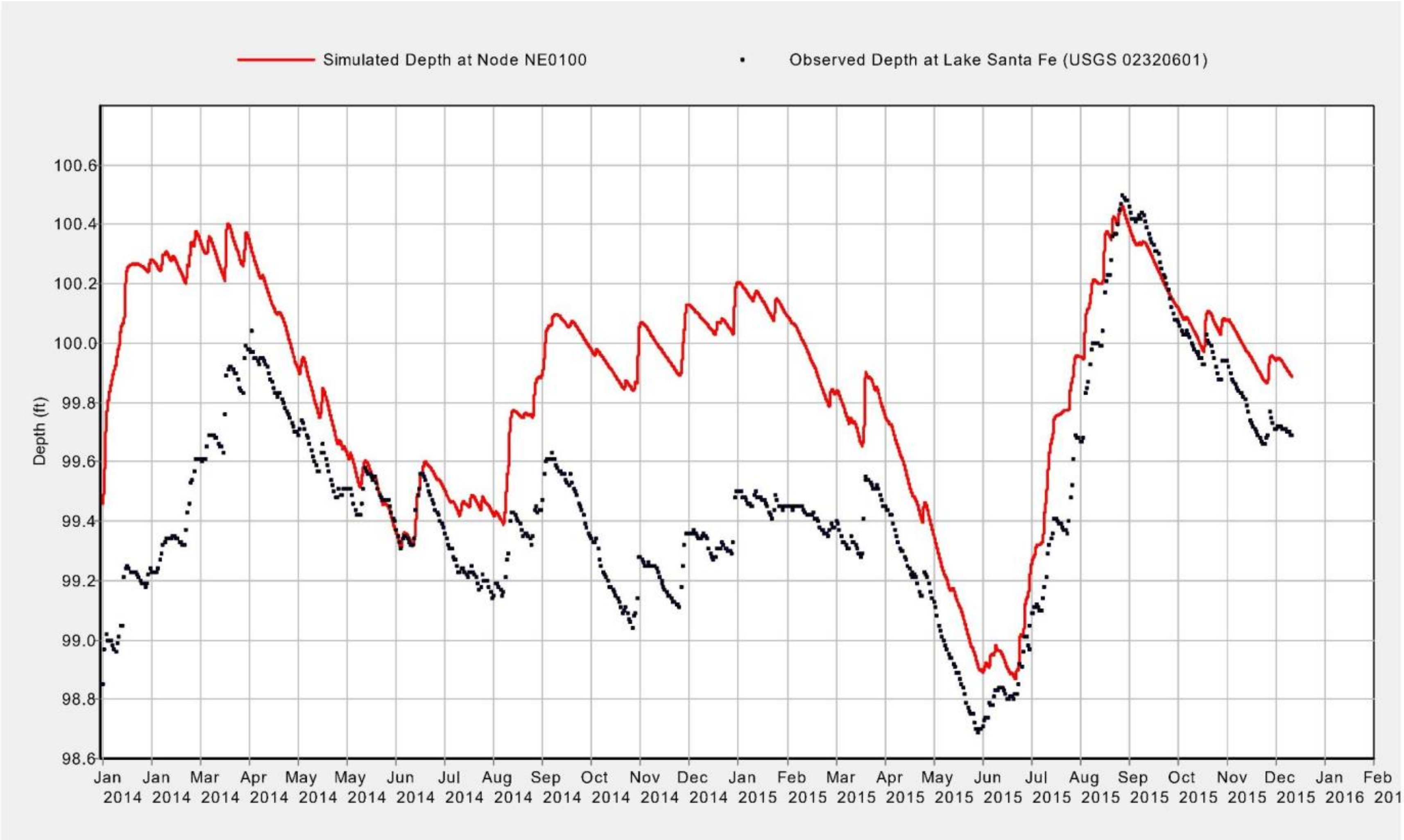


Figure 3-6B. Node Depth Hydrographs Comparison at Lake Santa Fe (2014-2015).

4.0 Water Budget Model Calibration

4.1 Model Calibration Period

The water budget model for Lake Alto and Lake Santa Fe was calibrated with data in a 10-year simulation span from 1/1/2006 through 12/31/2015. This simulation span includes a variety of hydrologic conditions, including two high water (2009-2010 and 2013-2015) and two low water periods (2006-2008 and 2011-2012), from the long-term historical stage records collected at Lake Alto and Lake Santa Fe. The supporting data sources, such as NEXRAD daily rainfall, groundwater well levels, and ET data, were also available in the calibration simulation span.

In addition, the changes in land use/land cover and withdrawals of water during this simulation period are minimal; therefore, the water budget model developed using the 2004/2006 land use/land cover data and other best available data sources is suitable for model calibration for the selected simulation period.

4.2 Model Calibration Criteria

It is a standard procedure in which observed and simulated values are compared for calibration of a water budget model. The water budget model will ultimately be used to determine the effects of consumptive use withdrawals on lake stages. Therefore, the model's capability to predict or simulate lake stages will be assessed by calibration against known gage data. Flow data for lake inflows and outflows could be used to improve the calibration results and verify water balance; however, there is no such flow data available for calibration.

The primary criterion or goal for model calibration has been established by the District, as stated in the project scope of work, i.e., acceptable model calibration is 0.5 foot or less root mean square error (RMSE) of the difference between simulated and observed stage values. This primary goal is to maximize the number of simulated stage values within ±0.5 foot of the corresponding observed stage values at the lakes.

The secondary criteria or goals include: 1) to have at least two thirds or 67% of residuals within ±0.5 foot; 2) to have at least 90% of residuals within ±1.0 foot; and 3) to meet these criteria over a wide range of stages. The secondary criteria were developed based on a hypothetical lake with a 10-ft range of fluctuation. For a lake with 10 ft of total fluctuation, 0.5 foot corresponds to 5% and 1.0 foot corresponds to 10%. These secondary criteria or goals have been employed previously in the Indian Lake System Minimum Flows and Levels Hydrologic Methods Report (Robison, 2014).

4.3 Model Calibration Approach

4.3.1 Time Series Data

Several types of time series data are used as input in the SWMM model. In this project, rainfall, ET, potentiometric surface levels of the upper FAS, as well as lake stage values, were used in the model calibration task.

4.3.1.1 Rainfall

Upon review of the long-term rainfall data collected, the NEXRAD rainfall data provided by the District was considered the best available data and hence used for model calibration (Figure 4-1). Weather radar, when combined with rain gauge records, provided detailed information concerning rainfall densities over specified areas. The entire District is divided into individual 2 km x 2 km pixels, each of which has daily rainfall estimates.

In the SWMM model, a series of rain gages were used to represent the selected NEXRAD pixels and to supply daily rainfall data for one or more subcatchments, if a given pixel polygon contains the centroid point(s) of subcatchments(s).

4.3.1.2 Evapotranspiration

Daily PET data has been developed by USGS for a period from 6/1/1995 through 12/31/2015, based on 15 data collection sites that represent various land cover types in Florida (Jacobs *et al.* 2008). The long-term, accurate, and unbiased PET information meets all the needs for model calibration of the SWMM model. Similar to the NEXRAD rainfall data, the entire State of Florida is divided into individual 2 km x 2 km pixels, each of which has daily PET estimates. The USGS data uses the same pixel polygon features that the NEXRAD rainfall data uses to store and manage the data (Figure 4-1).

Because SWMM can only model one ET time series data source, daily PET data was estimated for the entire lake watershed, by using the area-weighted daily PET data at each of the pixels intersected with the watershed. The estimated daily PET data for the lake watershed (Figure 4-2) was utilized in the SWMM model in two ways: 1) to calculate direct lake evaporation; and 2) to estimate ET occurring in the upper and lower zones of the groundwater aquifers.

Direct evaporation from the lakes can be estimated using PET data multiplied by a coefficient. The average monthly and annual PET values were estimated for the entire lake watershed, based on the area-weighted daily PET data from 1996 through 2015 (Table 4-1). As indicated in the Indian Lake System Minimum Flows and Levels Hydrologic Methods Report (Robison, 2014), the average annual evaporation for shallow lakes in the SJRWMD vary from 45 to 48 inches. Since the average annual PET value of 48.29 inches is close to the upper limit of the annual evaporation range for the SJRWMD lakes, the daily PET data was used to calculate the direct evaporation with a coefficient of 1.0. The methodology for estimation of ET occurring in the upper zone of groundwater aquifers has been previously described in Section 3.2.4.

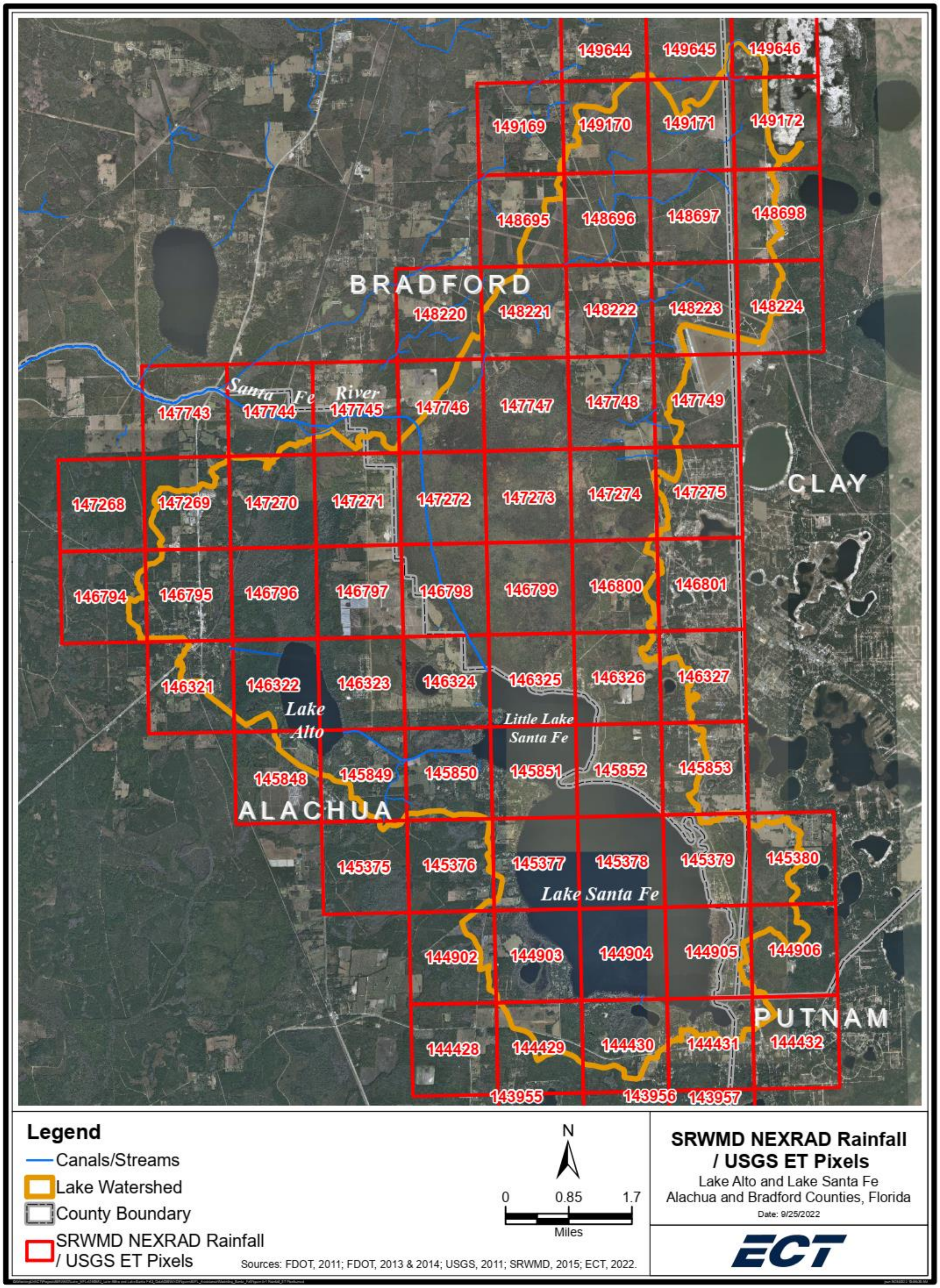


Figure 4-1. SRWMD NEXRAD Rainfall / USGS ET Pixels.

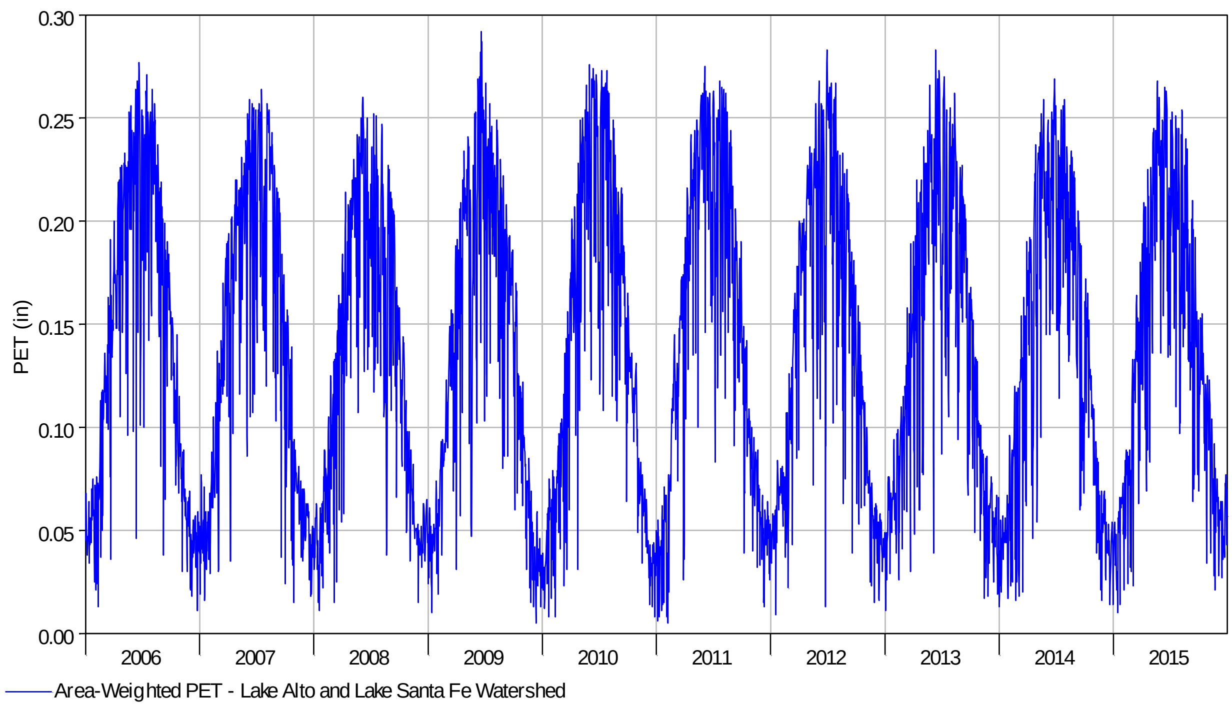


Figure 4-2. Area-Weighted Daily Potential Evapotranspiration (2006-2015).

Table 4-1. Summary table of average monthly PET data for Lake Alto and Lake Santa Fe watershed (1996–2015).

Month	PET Value (inch/month)
January	1.46
February	2.04
March	3.63
April	5.05
May	6.38
June	6.15
July	6.46
August	5.94
September	4.59
October	3.36
November	1.93
December	1.29
Total	**48.29**

Sources: USGS, 2016.

4.3.1.3 Upper FAS Potentiometric Surface Levels

A long-term USGS groundwater well station near Melrose, FL (USGS Melrose station, USGS ID: 294313082024601 / SRWMD ID: S092307001) is located approximately 0.5 miles east of Lake Santa Fe (Figure 4-3). The USGS Melrose station provides daily potentiometric surface levels in the upper FAS since 4/28/1983. The data gaps in the raw data were filled using a linear interpolation method.

Shift factors were estimated for the major lakes and sinkholes, by approximating the groundwater level differences between the USGS Melrose station and these lakes/sinkholes based on the May 2005 potentiometric contour map (Figure 4-3). The estimated shift factors varied from -2.5 feet to -10 feet (Table 4-2).

Table 4-2. Summary table of shift factors to estimate groundwater levels beneath lakes and sinkholes

ID	Location	Shift Factor (ft)
1	USGS Melrose Station	0
2	Lake Santa Fe	-2.5
3	Sinkhole S. of Indian Lake	-4
4	Indian Lake	-4.5
5	Little Lake Santa Fe	-6
6	Hickory Pond	-8
7	Lake Alto	-10

Upon applying the estimated shift factors to the observed/filled daily groundwater well levels at the Melrose station, the new shifted daily groundwater level data would be more representative of the groundwater conditions beneath Lake Alto, Lake Santa Fe, and other lakes and sinkholes.

The observed/filled groundwater level hydrograph at the Melrose station as well as the shifted well level hydrographs at the lakes and sinkholes are plotted on Figure 4-4.

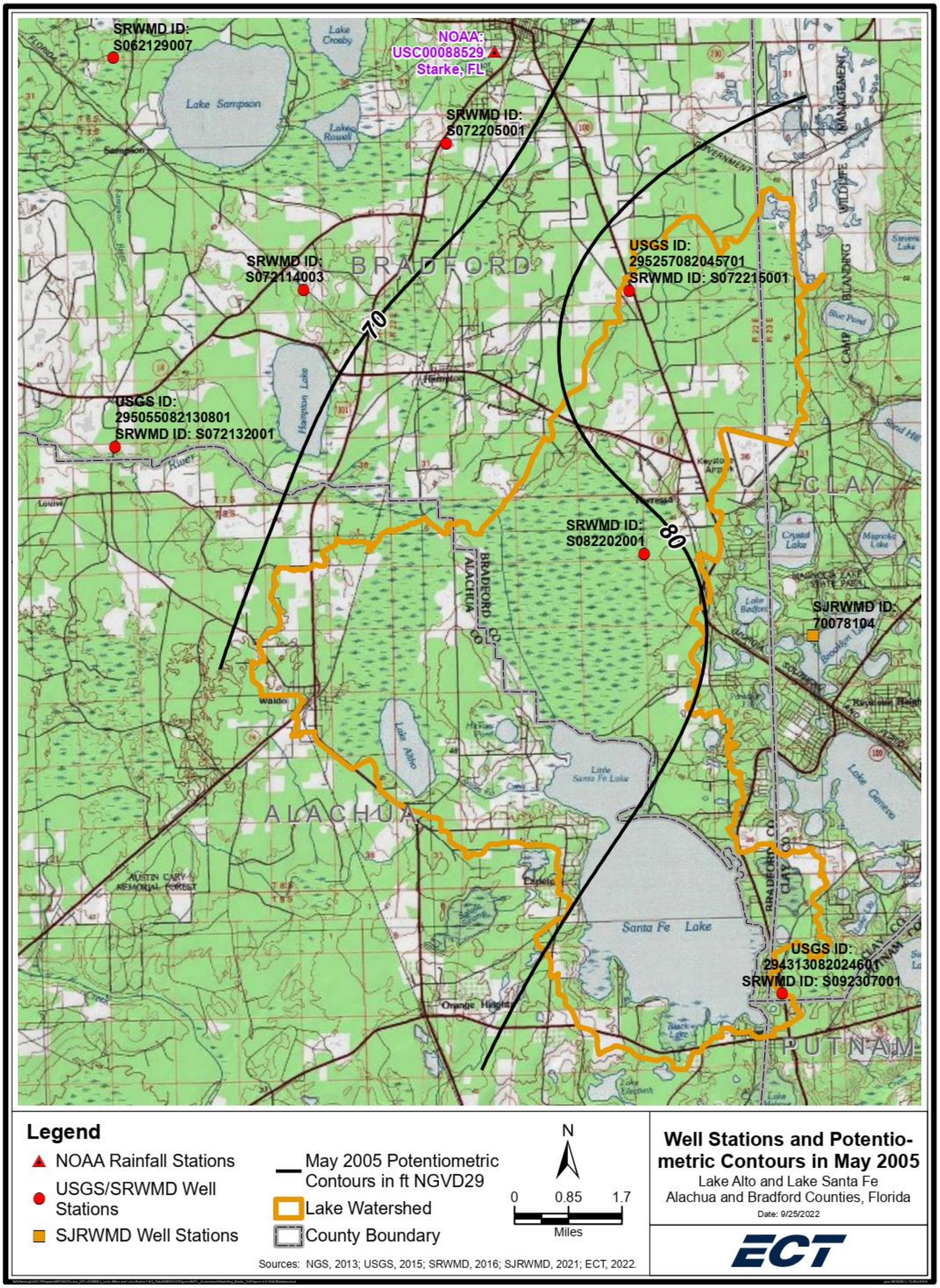


Figure 4-3. Well Stations and Potentiometric Contours in May 2005.

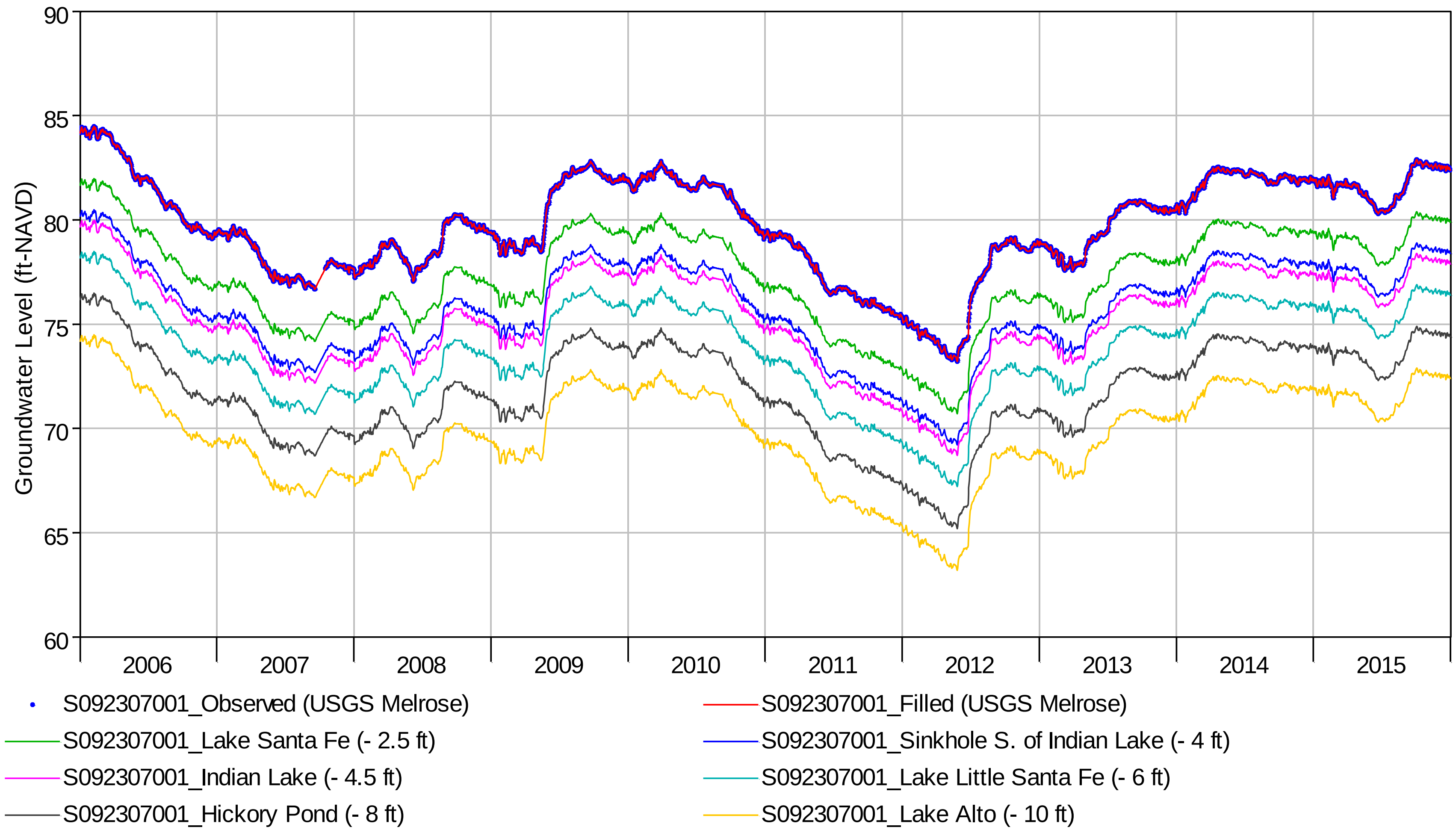


Figure 4-4. Observed/Filled/Shifted Groundwater Level Hydrographs at USGS Melrose Station (2006-2015).

4.3.1.4 Lake Stages

USGS 02320630 Lake Alto at Waldo, FL was a long-term stage gage located at the west end of the Waldo Canal (Figure 4-5). This District-operated lake stage station provided the long-term historical lake stage values in a variety of frequencies from 1976 through 2022 (Figure 4-6A). The lake stage records were used to establish the initial stage value at Lake Alto in the model as well as to compare with the simulated stage values for model calibration. Since the majority of the stage values at this station were provided on a weekly basis, the recently collected daily stage records (3/17/2013 to 12/31/2015) were resampled to weekly stage values (Figure 4-6B). The data resampling was done to eliminate the bias due to the different frequencies in the raw data. The resampled lake stage data was used to compare with the simulated stage values in the model calibration.

A USGS/District-operated long-term stage station USGS 02320601 Santa Fe Lake near Earleton, FL is located on the west lakeshore of Lake Santa Fe (Figure 4-5). This USGS/District-operated lake stage station provides the long-term historical lake stage values in a variety of frequencies from 7/11/1957 to 12/31/2015 (Figure 4-6A). The lake stage records were used to establish the initial stage value at Lake Santa Fe in the model as well as to compare with the simulated stage values for model calibration. Since the lake stage values from 4/27/2006 to current were provided on a daily basis at USGS 02320601, no data resampling was required at this station (Figure 4-6C).

For Little Lake Santa Fe, a USGS/District-operated long-term stage station USGS 02320611 was located on the west lake shore of Little Lake Santa Fe (Figure 4-5). Weekly stage data was manually measured from 2/15/1989 to 11/26/1993 by USGS and from 8/28/2000 to 12/31/2015 by the District (Figure 4-6A). The lake stage data provided at this short-term gage station could be used to validate the stage data measured at USGS station 02320601; however, it will not be used for model calibration purposes due to its shorter data history compared to the USGS station located at the "Big" Lake Santa Fe.

Figure 4-5. USGS/SRWMD Lake Stations.

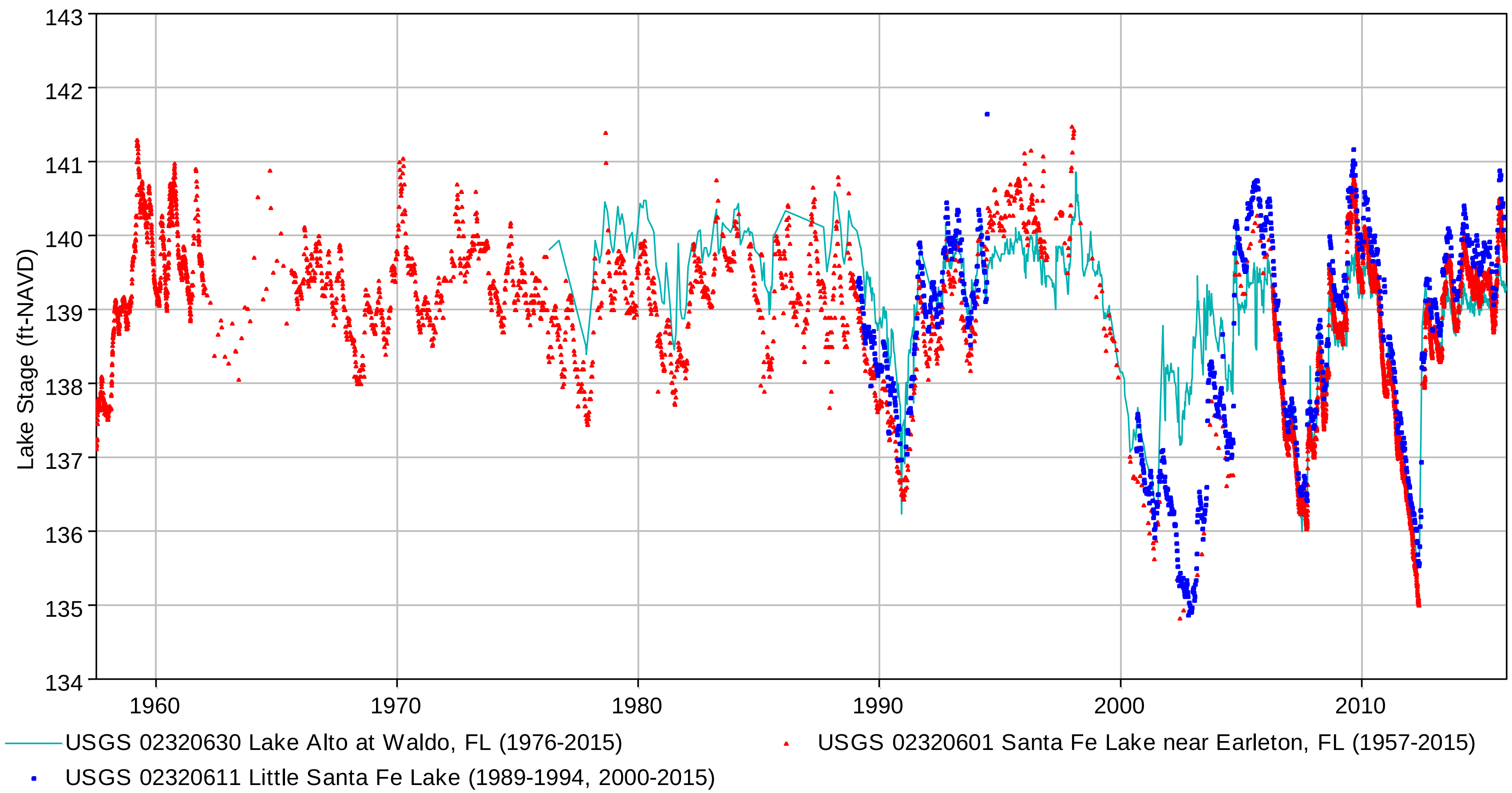


Figure 4-6A. Observed Lake Stage Hydrograph at Lake Alto and Lake Santa Fe (1957-2015).

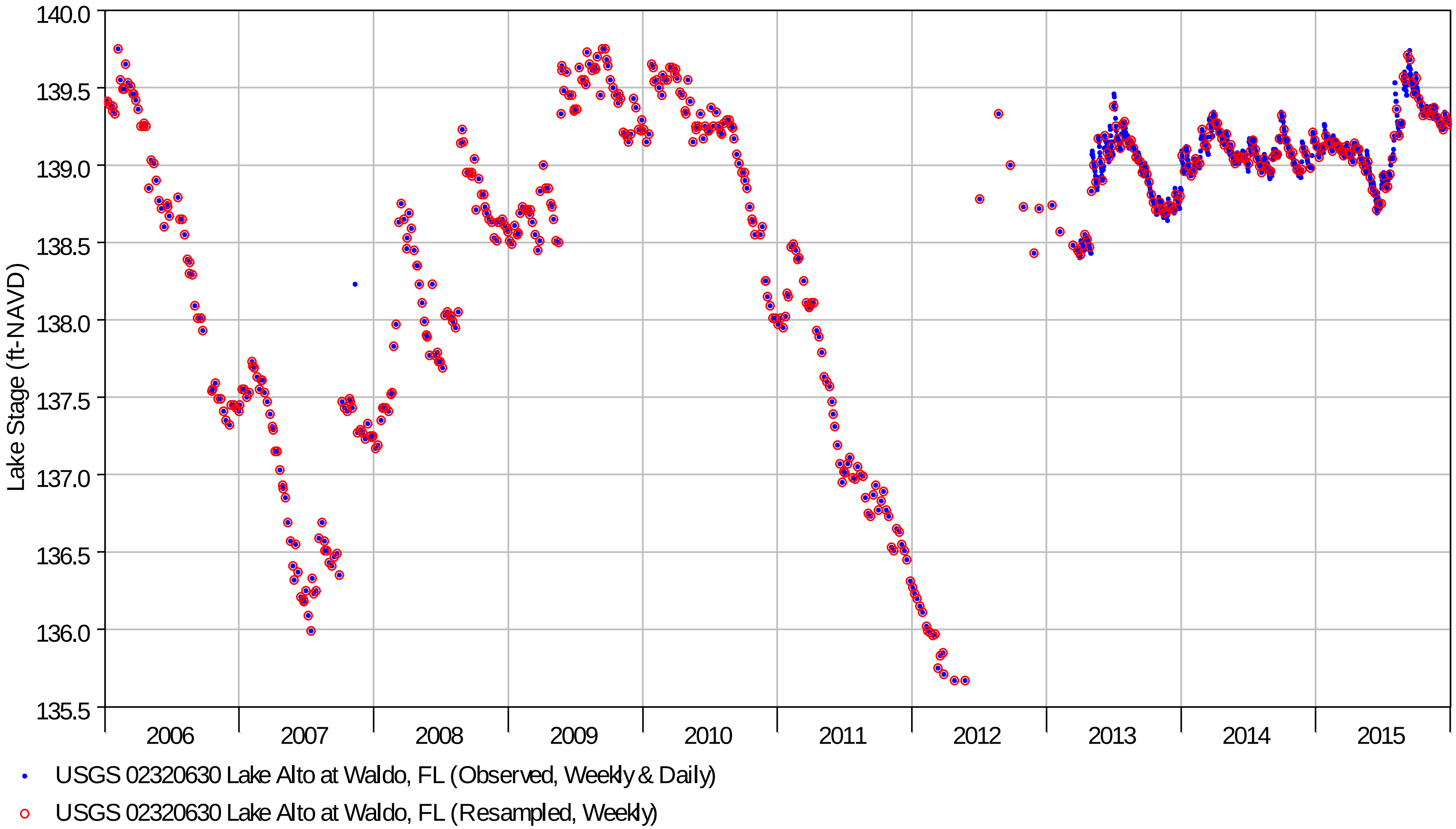


Figure 4-6B. Observed and Resampled Lake Stage Hydrographs at Lake Alto (2006-2015).

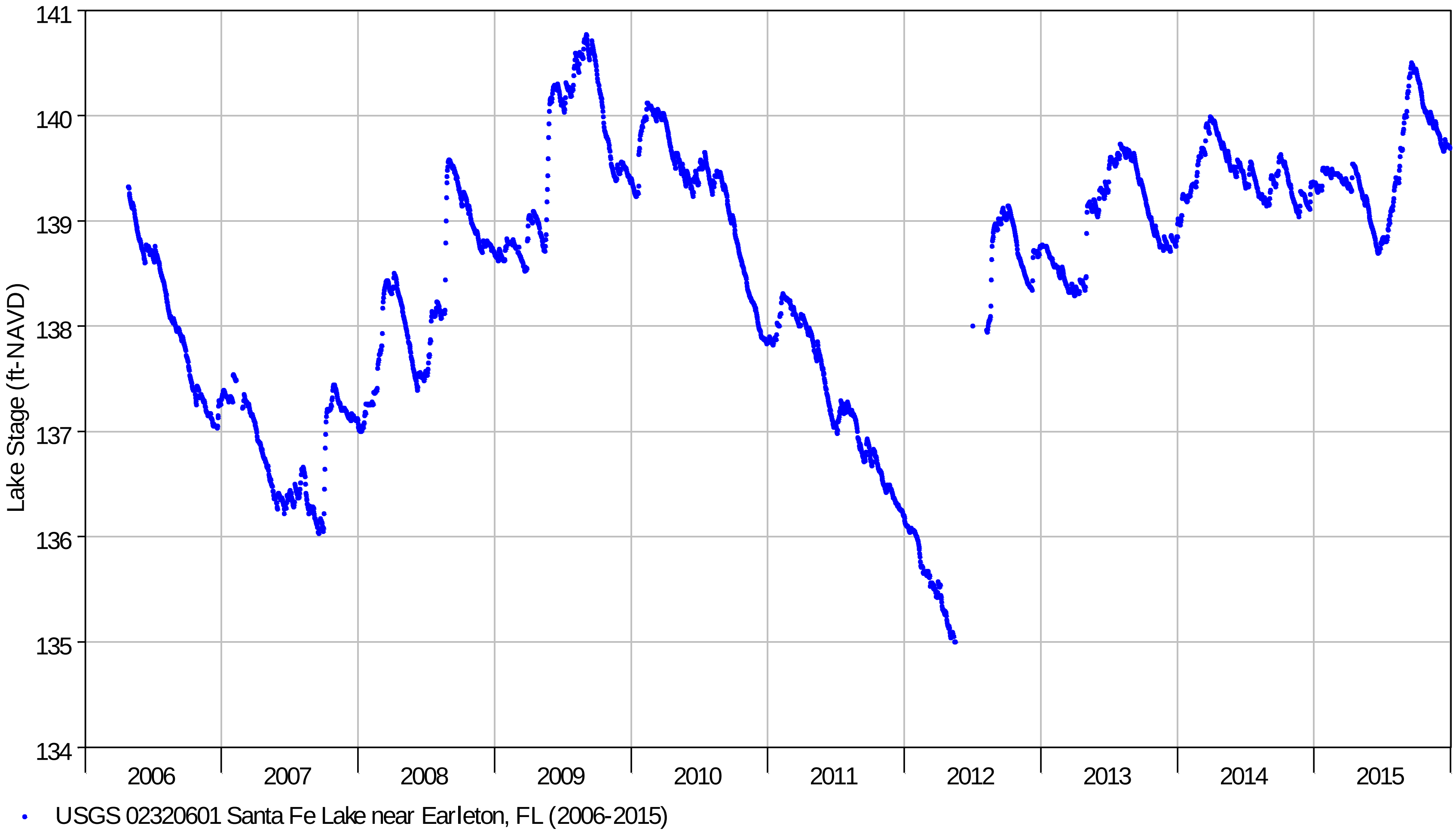


Figure 4-6C. Observed Lake Stage Hydrograph at Lake Santa Fe (2006-2015).

4.3.2 Adjustment of Hydrologic Model Parameters

Various hydrologic model parameters were adjusted during the model calibration process, including impervious percentage, groundwater loss rate to deep aquifer, and other parameters used in groundwater and aquifer components in the SWMM model, as discussed in detail below. Other hydrologic model parameters were held constant in the model calibration process.

4.3.2.1 Land Use/Land Cover

It is common to model wetland areas (FLUCCS 6000) as impervious areas for design storm event simulations; however, for long-term simulations of a water budget model, wetland areas may not hold standing water during dry conditions and infiltration may occur where the soils underneath are unsaturated, and the groundwater table is low. The impervious percentage value of 98%, as originally defined in the model development task, seems inappropriate particularly for the shallow forested wetland areas, e.g., Lake Alto Swamp and Santa Fe Swamp, which dominate the central lake watershed. High impervious percentage results in high surface water runoff volumes and underestimates infiltration and percolation to the surficial aquifer, particularly for the 2006-2008 and 2011-2012 drought periods (Figures 4-6B and 4-6C).

Therefore, impervious percentage values for wetland areas were reduced to 50% to account for low rainfall periods, as highlighted in yellow color in Table 4-3.

For two land use categories: Reclaimed Land (FLUCCS 1650) and Holding Ponds (FLUCCS 1660) classified under Extractive (FLUCCS 1600), the hydrologic parameters were mostly inherited from their parent category. Upon review of the vegetative covers of the reclaimed lands as well as the undisturbed areas with similar land covers, the hydrologic parameters for these two land use categories were adjusted, as highlighted in green color in Table 4-3.

Similarly, the hydrologic parameters for another two land use categories (FLUCCS 7420 – Borrow Areas and FLUCCS 7420 – Burned Areas) were adjusted according to the land covers as presented on the aerial photos and are highlighted in green color in Table 4-3.

Also note that at some developed lands, in addition to a land use code (e.g., FLUCCS 1100 - Residential Low Density), a separate land cover code (e.g., FLUCCS 4200 - Upland Hardwood Forests) was provided in the land use data to describe the vegetative community type of the pervious area (Figure 2.4). For these instances, the hydrologic parameters related to pervious area (e.g., Manning's n for pervious area) should be assigned based on their land cover codes when calculating the hydrologic parameters for subbasins.

Based on the updated lookup table (Table 4-3) as well as the improved approach of using both land use and land cover codes, the hydrologic parameters for each subbasin were recalculated, as highlighted in yellow color in Table 4-4, and updated in the SWMM model. The revised hydrologic parameters for the subbasins were then held constant in the model calibration.

Table 4-3. Lookup table of hydrologic parameters for surface runoff calculation – final.

FLUCCS	Description	% Imperv. Area	% Zero Storage Imperv.	Manning n Imperv.	Manning n Perv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)
1100	Residential Low Density <2 Dwelling Units	15	25	0.012	0.1	0.05	0.15
1200	Residential Med Density 2->5 Dwelling Units	30	25	0.012	0.1	0.05	0.15
1300	Residential High Density	50	25	0.012	0.1	0.05	0.15
1400	Commercial and Services	85	25	0.012	0.1	0.05	0.15
1500	Industrial	72	25	0.012	0.1	0.05	0.15
1600	Extractive	65	25	0.012	0.1	0.1	0.15
1650	Reclaimed Land	0	25	0.012	0.15	0.05	0.2
1660	Holding Ponds	100	100	0.01	0.1	0	0
1700	Institutional	60	25	0.012	0.1	0.05	0.15
1800	Recreational	60	25	0.012	0.1	0.05	0.15
1820	Golf Courses	5	25	0.012	0.1	0.05	0.15
1900	Open Land	0	25	0.012	0.15	0.1	0.1
2100	Cropland and Pastureland	0	25	0.012	0.1	0.05	0.2
2140	Row Crops	0	25	0.012	0.17	0.05	0.2
2200	Tree Crops	0	25	0.012	0.4	0.05	0.2
2300	Feeding Operations	0	25	0.012	0.1	0.05	0.2
2400	Nurseries and Vineyards	0	25	0.012	0.1	0.05	0.2
2500	Specialty Farms	0	25	0.012	0.1	0.05	0.2
2550	Tropical Fish Farms	0	25	0.012	0.1	0.05	0.2
2600	Other Open Lands (Rural)	0	25	0.012	0.13	0.05	0.2
3100	Herbaceous	0	25	0.012	0.24	0.05	0.2
3200	Shrub and Brushland	0	25	0.012	0.4	0.05	0.25
3300	Mixed Rangeland	0	25	0.012	0.13	0.05	0.25
4100	Upland Coniferous Forest	0	25	0.012	0.5	0.05	0.3
4110	Pine Flatwoods	0	25	0.012	0.5	0.05	0.3
4120	Longleaf Pine - Xeric Oak	0	25	0.012	0.5	0.05	0.3
4200	Upland Hardwood Forests	0	25	0.012	0.5	0.05	0.3
4340	Hardwood Conifer Mixed	0	25	0.012	0.5	0.05	0.3
4400	Tree Plantations	0	25	0.012	0.5	0.05	0.3
5100	Streams and Waterways	100	100	0.01	0.1	0	0
5200	Lakes	100	100	0.01	0.1	0	0
5300	Reservoirs	100	100	0.01	0.1	0	0
5400	Bays and Estuaries	100	100	0.01	0.1	0	0
5500	Major Springs	100	100	0.01	0.1	0	0
5600	Slough Waters	100	100	0.01	0.1	0	0

Table 4-3. Lookup table of hydrologic parameters for surface runoff calculation - final (cont.)

FLUCCS	Description	% Imperv. Area	% Zero Storage Imperv.	Manning n Imperv.	Manning n Perv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)
6100	Wetland Hardwood Forests	50	75	0.4	0.4	0.1	0.25
6110	Bay Swamps	50	75	0.4	0.4	0.1	0.25
6120	Mangrove Swamps	50	75	0.4	0.4	0.1	0.25
6150	Stream and Lake Swamps (Bottomland)	50	75	0.4	0.4	0.1	0.25
6200	Wetland Coniferous Forests	50	75	0.4	0.4	0.1	0.25
6210	Cypress	50	75	0.4	0.4	0.1	0.25
6300	Wetland Forests Mixed	50	75	0.4	0.4	0.1	0.25
6400	Vegetated Non-Forested Wetlands	50	75	0.24	0.24	0.1	0.25
6410	Freshwater Marshes	50	75	0.24	0.24	0.1	0.25
6420	Saltwater Marshes	50	75	0.24	0.24	0.1	0.25
6430	Wet Prairies	50	75	0.24	0.24	0.1	0.25
6440	Emergent Aquatic Vegetation	50	75	0.24	0.24	0.1	0.25
6500	Non - Vegetated	50	75	0.24	0.24	0.1	0.25
6510	Tidal Flats / Submerged Shallow Platform	50	75	0.24	0.24	0.1	0.25
6520	Shorelines	50	75	0.24	0.24	0.1	0.25
6530	Intermittent Ponds	50	75	0.24	0.24	0.1	0.25
6600	Salt Flats	50	75	0.24	0.24	0.1	0.25
7100	Beaches Other Than Swimming Beaches	0	25	0.012	0.1	0.05	0.1
7400	Disturbed Land	0	25	0.012	0.1	0.05	0.1
7420	Borrow Areas	10	100	0.012	0.15	0.1	0.15
7450	Burned Areas	50	50	0.24	0.24	0.1	0.25
8100	Transportation	50	75	0.012	0.1	0.05	0.15
8200	Communications	85	25	0.012	0.1	0.05	0.15
8300	Utilities	72	25	0.012	0.1	0.05	0.15

Sources: TR-55 (USDA, 1986); Drainage Handbook Hydrology (FDOT, 2012); ECT, 2022.

Table 4-4. Summary table of hydrologic parameters in subbasins – final.

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
A0100	318.63	3812	1.60	37.77	62.52	0.088	0.258	0.300	0.407	2.1	3.2045	0.363
A0110	78.98	1611	1.70	22.25	43.74	0.069	0.246	0.155	0.353	2.1	3.5499	0.366
A0120	57.04	1550	1.90	14.85	37.47	0.062	0.247	0.098	0.344	2.0	4.1364	0.371
A0200	239.74	5636	2.50	32.39	55.92	0.081	0.254	0.252	0.388	2.1	3.7545	0.368
A0210	96.33	2118	1.60	6.74	25.61	0.051	0.231	0.017	0.234	1.9	4.6378	0.375
A0220	25.79	1182	2.40	3.46	26.85	0.052	0.259	0.026	0.354	2.0	4.1193	0.371
A0300	177.98	5764	2.80	41.09	65.86	0.091	0.252	0.291	0.355	1.9	4.6292	0.375
A0310	61.53	1612	1.90	6.92	31.25	0.056	0.289	0.049	0.458	1.9	4.6378	0.375
A0320	126.09	2786	1.80	9.17	33.68	0.059	0.250	0.079	0.318	2.0	4.3068	0.372
A0330	73.41	1263	1.70	2.13	25.00	0.050	0.239	0.012	0.260	1.9	4.6378	0.375
A0400	581.87	7933	2.70	47.18	72.18	0.097	0.252	0.368	0.398	2.1	3.4348	0.365
A0405	33.60	2197	2.00	33.44	58.44	0.078	0.232	0.227	0.367	1.9	4.6378	0.375
A0410	65.73	2153	2.10	7.78	32.78	0.055	0.262	0.038	0.312	1.9	4.6378	0.375
A0412	68.06	1404	1.60	9.35	34.33	0.059	0.276	0.073	0.413	2.0	4.1600	0.371
A0414	44.20	991	1.70	6.54	30.49	0.055	0.243	0.055	0.304	1.9	4.6378	0.375
A0420	19.40	866	2.30	6.34	31.34	0.050	0.279	0.012	0.441	1.9	4.6378	0.375
A0422	19.90	1336	1.80	3.73	28.73	0.054	0.272	0.041	0.371	2.0	4.0432	0.37
A0430	38.70	1082	1.90	8.04	33.04	0.055	0.288	0.048	0.468	2.0	4.0803	0.37
A0500	308.05	3923	2.90	46.80	71.80	0.095	0.251	0.347	0.382	2.1	3.2376	0.364
A0505	45.87	851	1.80	13.79	38.67	0.061	0.261	0.092	0.359	1.9	4.6378	0.375
A0510	43.28	1767	1.80	7.52	32.08	0.057	0.290	0.067	0.478	2.1	3.7286	0.368

Table 4-4. Summary table of hydrologic parameters in subbasins – final (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
A0512	24.31	1221	1.50	8.36	33.36	0.058	0.274	0.077	0.430	1.9	4.6378	0.375
A0514	7.59	748	1.40	13.37	38.37	0.063	0.260	0.116	0.404	2.1	3.7444	0.368
A0516	51.01	1241	1.60	43.59	33.08	0.054	0.208	0.041	0.247	2.0	4.5597	0.374
A0518	37.53	1228	1.80	14.45	31.39	0.054	0.262	0.044	0.376	2.0	4.2237	0.372
A0520	23.50	1376	2.30	49.98	48.13	0.055	0.174	0.050	0.169	2.0	4.3190	0.372
A0522	89.61	1102	2.00	22.34	32.11	0.056	0.219	0.056	0.285	2.0	4.2096	0.372
A0530	131.87	2008	2.10	13.22	36.91	0.060	0.253	0.079	0.366	2.0	4.1780	0.371
A0540	144.23	2291	2.40	19.00	30.60	0.049	0.215	0.012	0.241	1.9	4.6378	0.375
A0542	82.52	2491	2.30	34.27	31.82	0.053	0.207	0.038	0.243	2.0	4.6253	0.375
A0544	64.43	1823	2.90	7.49	32.37	0.057	0.288	0.049	0.459	2.0	4.2953	0.372
A0550	196.40	2566	2.60	27.49	40.75	0.061	0.237	0.084	0.317	1.9	4.6378	0.375
A0560	88.87	2147	2.20	21.41	29.66	0.050	0.242	0.013	0.325	1.9	4.6378	0.375
A0570	78.82	1737	2.00	37.39	27.56	0.050	0.180	0.012	0.191	2.0	4.5278	0.374
A0580	153.79	1732	1.80	17.39	33.77	0.059	0.242	0.080	0.336	1.9	4.6378	0.375
A0582	47.16	1486	1.30	6.88	26.34	0.051	0.252	0.022	0.313	1.9	4.6378	0.375
A0584	44.00	875	2.10	11.06	34.37	0.058	0.263	0.068	0.347	2.0	4.0252	0.37
A0586	67.68	1423	1.90	8.42	28.12	0.053	0.238	0.032	0.279	1.9	4.6378	0.375
A0588	56.24	1548	1.70	9.11	32.02	0.057	0.270	0.065	0.414	2.0	4.4979	0.374
A0590	46.41	1775	2.70	12.63	35.72	0.056	0.223	0.059	0.331	2.0	4.5893	0.375
A0592	84.34	1024	2.70	28.67	34.98	0.049	0.178	0.012	0.172	1.9	4.6378	0.375
A0600	546.57	9938	2.80	44.39	69.39	0.094	0.253	0.343	0.387	2.0	4.0456	0.37

Table 4-4. Summary table of hydrologic parameters in subbasins – final (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
A0610	75.83	1376	3.20	11.56	36.56	0.062	0.285	0.085	0.431	1.9	4.6378	0.375
A0620	155.69	1708	2.60	6.20	31.20	0.056	0.266	0.052	0.327	1.9	4.6378	0.375
A0630	54.02	1015	3.90	34.45	59.45	0.084	0.266	0.279	0.431	1.9	4.6378	0.375
A0640	28.78	977	2.10	0.00	25.00	0.050	0.299	0.012	0.493	1.9	4.6378	0.375
B0100	627.14	98284	0.40	94.75	96.81	0.008	0.024	0.039	0.129	2.0	4.0332	0.370
B0110	121.43	3431	2.40	3.92	25.97	0.051	0.271	0.019	0.366	1.9	4.6378	0.375
B0112	93.09	1186	2.40	0.34	25.00	0.050	0.289	0.012	0.449	1.9	4.6378	0.375
B0120	215.95	3053	2.50	8.75	30.65	0.054	0.270	0.045	0.385	1.9	4.6378	0.375
B0130	103.57	1364	3.40	13.50	38.50	0.063	0.287	0.107	0.463	2.0	4.5700	0.374
B0140	14.35	9975	7.70	51.74	65.94	0.040	0.166	0.092	0.313	1.9	4.6348	0.375
B0150	58.85	2852	2.00	2.39	25.01	0.050	0.296	0.012	0.469	1.9	4.6378	0.375
B0160	82.30	2381	1.50	5.77	27.24	0.052	0.246	0.029	0.430	1.9	4.6378	0.375
B0200	184.79	3697	2.70	27.10	41.18	0.066	0.230	0.138	0.324	1.9	4.6378	0.375
B0300	118.84	3068	2.80	34.11	57.23	0.082	0.268	0.262	0.436	2.0	4.5372	0.374
B0400	538.11	5309	2.70	36.74	57.12	0.081	0.237	0.190	0.294	2.0	4.3011	0.372
B0410	25.98	1104	2.00	18.69	32.75	0.058	0.237	0.072	0.344	2.0	3.9943	0.370
C0100	3282.25	20036	1.50	48.05	56.13	0.098	0.250	0.276	0.286	4.2	0.6285	0.306
C0110	286.32	3197	1.70	14.03	33.79	0.064	0.224	0.085	0.211	1.9	4.6336	0.375
C0120	304.79	3765	1.90	2.84	27.59	0.053	0.281	0.029	0.407	2.0	3.9130	0.369
C0200	303.41	4240	3.00	37.71	62.70	0.088	0.261	0.275	0.391	3.8	1.0073	0.317
C0201	247.97	2984	1.60	3.46	26.33	0.051	0.251	0.020	0.318	2.2	3.1028	0.363

Table 4-4. Summary table of hydrologic parameters in subbasins – final (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
C0202	45.77	1201	1.90	7.86	32.72	0.058	0.277	0.069	0.403	2.0	4.0478	0.370
C0203	86.49	1604	2.10	2.30	27.11	0.052	0.264	0.028	0.337	2.2	3.0854	0.362
C0204	123.80	2062	2.20	9.55	34.55	0.060	0.280	0.085	0.458	2.1	3.6599	0.367
C0210	539.07	2767	2.20	7.32	30.82	0.056	0.287	0.053	0.460	2.1	3.3150	0.364
C0212	313.58	1856	1.90	6.54	30.19	0.054	0.253	0.048	0.357	2.2	2.8304	0.360
C0220	459.79	3156	2.00	9.43	30.62	0.056	0.287	0.053	0.463	2.3	2.2328	0.356
C0230	171.71	2356	2.30	11.13	30.20	0.055	0.282	0.052	0.456	2.3	1.9945	0.354
C0240	202.32	2205	2.10	4.96	28.70	0.054	0.291	0.040	0.473	2.3	1.8948	0.353
C0244	218.63	2186	2.00	9.17	30.84	0.056	0.260	0.057	0.389	2.3	1.7515	0.352
C0250	773.85	4065	1.90	14.32	39.06	0.064	0.282	0.120	0.458	2.3	2.2511	0.356
C0254	32.65	1244	1.70	4.53	29.53	0.055	0.295	0.047	0.491	2.0	4.3354	0.373
C0260	263.04	2027	2.30	21.44	46.44	0.071	0.279	0.150	0.429	2.1	3.3036	0.364
C0270	176.00	3466	3.80	28.15	47.40	0.044	0.223	0.039	0.379	1.9	4.6378	0.375
C0280	1175.20	4055	2.40	16.07	40.32	0.065	0.282	0.116	0.447	2.4	3.6807	0.361
C0282	243.25	3088	2.50	20.07	33.70	0.058	0.262	0.074	0.404	2.0	4.5743	0.374
C0300	443.32	5361	2.90	45.81	66.97	0.095	0.251	0.328	0.361	4.0	0.9642	0.311
C0301	45.77	1961	1.80	3.81	25.00	0.050	0.259	0.012	0.340	2.0	4.3418	0.372
C0303	17.43	811	2.20	9.97	34.97	0.060	0.290	0.089	0.480	1.9	4.6378	0.375
C0304	143.90	1659	2.50	7.40	30.77	0.056	0.272	0.057	0.402	2.0	4.5550	0.374
C0306	19.75	645	1.70	15.44	25.00	0.050	0.231	0.012	0.264	1.9	4.6378	0.375
C0308	88.40	2328	2.90	20.36	41.15	0.066	0.239	0.126	0.311	2.0	4.5688	0.374

Table 4-4. Summary table of hydrologic parameters in subbasins – final (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
C0310	253.38	3511	1.80	14.78	30.85	0.055	0.215	0.051	0.198	2.2	4.0189	0.366
C0311	95.54	1529	1.40	10.13	27.18	0.052	0.215	0.027	0.182	2.0	4.5701	0.374
C0314	158.85	1939	2.10	8.33	27.11	0.052	0.235	0.028	0.278	2.0	4.3669	0.373
C0316	112.09	877	2.40	7.58	27.51	0.053	0.268	0.031	0.357	2.0	4.4610	0.374
C0320	154.52	1942	2.10	3.08	25.31	0.050	0.231	0.012	0.209	2.0	4.0101	0.370
C0322	115.61	1313	2.10	3.22	25.26	0.050	0.280	0.014	0.419	2.0	4.5619	0.374
C0330	170.25	2295	2.00	9.14	29.05	0.053	0.245	0.032	0.332	2.1	3.7872	0.368
C0340	483.91	2612	1.90	9.64	30.11	0.055	0.254	0.046	0.329	2.0	3.8925	0.369
C0342	36.50	1333	1.80	22.17	45.94	0.071	0.229	0.175	0.259	2.1	3.6633	0.367
C0344	48.87	2478	2.10	10.57	35.57	0.061	0.247	0.094	0.302	2.1	3.2240	0.364
C0350	789.53	4176	2.30	7.77	30.73	0.053	0.284	0.037	0.452	2.0	4.4657	0.374
C0360	223.65	2041	1.80	6.46	31.45	0.056	0.293	0.062	0.487	2.1	3.8679	0.369
C0370	312.88	2223	2.20	5.15	30.15	0.055	0.295	0.050	0.487	2.0	4.4686	0.374
C0400	969.54	10498	1.50	44.17	57.54	0.094	0.255	0.279	0.335	3.9	1.1289	0.314
C0410	296.39	3274	2.70	17.56	40.42	0.064	0.262	0.124	0.374	2.7	3.2627	0.352
C0420	117.48	2211	2.70	4.57	29.57	0.055	0.282	0.047	0.440	2.0	4.4394	0.373
C0430	161.95	2817	2.00	5.87	29.23	0.056	0.291	0.044	0.464	2.2	4.1585	0.367
C0500	1445.33	8622	1.30	48.47	71.67	0.098	0.249	0.361	0.365	4.2	0.6535	0.306
C0505	49.15	1906	1.90	1.45	25.00	0.050	0.208	0.012	0.142	1.9	4.6378	0.375
C0507	120.82	3680	2.30	2.52	26.34	0.051	0.296	0.020	0.488	2.0	4.5737	0.374
C0508	59.41	995	1.70	14.60	39.60	0.065	0.285	0.116	0.462	2.4	3.8150	0.361

Table 4-4. Summary table of hydrologic parameters in subbasins – final (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
C0510	117.73	2426	2.10	15.22	39.48	0.064	0.272	0.124	0.439	2.7	3.3673	0.353
C0520	83.05	1386	2.90	18.98	42.00	0.064	0.269	0.114	0.413	2.6	3.4143	0.355
C0522	69.54	1259	2.40	10.97	35.97	0.061	0.270	0.091	0.428	2.1	3.7447	0.368
C0530	312.99	3146	2.00	7.16	32.03	0.057	0.281	0.063	0.433	2.1	4.1152	0.370
C0540	195.52	2789	2.40	4.92	29.92	0.055	0.211	0.044	0.191	2.0	4.3321	0.372
C0550	552.81	5036	1.80	27.41	48.26	0.058	0.223	0.107	0.348	2.1	3.5917	0.367
C0552	74.52	2189	2.30	11.31	36.19	0.061	0.230	0.099	0.268	2.0	4.4880	0.374
D0040	489.56	3901	1.80	6.17	30.02	0.055	0.255	0.048	0.378	2.0	4.4251	0.373
D0045	62.60	1586	1.80	14.83	38.22	0.063	0.273	0.115	0.443	2.0	4.1066	0.371
D0050	581.97	6326	1.80	18.28	41.61	0.067	0.270	0.120	0.413	2.1	3.6985	0.367
D0055	207.44	2915	1.90	7.89	28.86	0.054	0.292	0.042	0.480	2.0	4.2417	0.372
D0100	1224.32	172321	0.30	93.88	95.77	0.008	0.025	0.031	0.126	3.0	2.7165	0.343
D0110	28.94	1212	3.30	39.68	60.26	0.085	0.261	0.286	0.421	3.7	1.4780	0.320
D0120	72.94	1568	2.70	24.33	47.27	0.071	0.276	0.162	0.436	2.9	3.0049	0.347
D0130	33.23	2989	2.20	12.37	28.05	0.053	0.297	0.036	0.491	2.1	4.3188	0.369
D0140	64.23	1345	2.50	3.51	25.00	0.050	0.274	0.012	0.354	2.0	4.1265	0.371
D0150	131.26	2623	2.20	9.36	29.13	0.052	0.221	0.032	0.332	2.0	4.3516	0.373
D0160	9.53	1335	2.10	26.36	32.90	0.058	0.210	0.067	0.260	1.9	4.6378	0.375
D0170	109.94	1582	1.60	18.23	39.08	0.064	0.260	0.093	0.387	2.0	3.9315	0.369
D0180	134.04	3340	1.90	13.01	25.24	0.050	0.300	0.014	0.499	2.0	4.5348	0.374
D0200	140.81	2821	2.00	8.44	33.19	0.058	0.268	0.076	0.388	2.3	4.0754	0.365

Table 4-4. Summary table of hydrologic parameters in subbasins – final (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
E0100	4289.98	424660	0.20	94.76	96.16	0.006	0.020	0.025	0.121	2.5	3.2595	0.355
E0110	192.56	3772	2.60	17.52	29.48	0.051	0.284	0.025	0.467	2.1	4.3746	0.370
E0120	103.92	2326	2.80	46.38	70.27	0.095	0.255	0.271	0.317	3.5	1.6125	0.327
E0130	42.25	2054	2.40	27.17	28.62	0.054	0.179	0.040	0.179	2.0	4.5375	0.373
E0140	23.23	541	3.50	48.33	72.79	0.098	0.251	0.383	0.403	3.2	2.4212	0.337
E0150	279.61	6121	1.90	8.97	27.57	0.053	0.251	0.029	0.395	2.0	4.4847	0.374
E0160	301.91	2791	1.60	6.32	30.71	0.055	0.248	0.042	0.325	1.9	4.6372	0.375
E0162	47.66	1281	1.70	12.04	37.04	0.062	0.285	0.105	0.466	2.0	3.9897	0.370
E0170	306.22	2447	2.00	12.36	29.69	0.054	0.214	0.045	0.215	2.0	4.5942	0.375
E0172	47.90	1508	1.40	10.42	35.42	0.060	0.290	0.093	0.479	1.9	4.6378	0.375
E0180	87.91	1559	3.40	31.27	50.62	0.065	0.247	0.138	0.367	2.1	3.4496	0.365
E0190	87.43	3738	2.00	19.89	25.00	0.050	0.273	0.012	0.428	1.9	4.6378	0.375
E0200	76.44	1118	2.80	30.95	27.65	0.053	0.156	0.033	0.117	2.6	3.4517	0.355
E0210	100.14	1473	3.30	11.95	36.40	0.061	0.286	0.100	0.471	2.1	3.7011	0.367
E0220	792.63	8823	1.90	20.16	42.79	0.068	0.258	0.128	0.347	2.6	3.2698	0.354
E0230	86.51	3475	3.00	23.40	45.88	0.058	0.256	0.095	0.413	2.3	3.9847	0.365
E0300	169.49	1998	2.40	19.47	38.09	0.063	0.275	0.111	0.442	2.3	3.8535	0.364
E0400	94.62	2721	2.60	17.21	41.93	0.067	0.282	0.129	0.450	2.4	3.4807	0.360
E0410	134.78	2660	3.20	15.10	40.10	0.065	0.268	0.113	0.420	2.5	3.5793	0.359
E0420	40.78	1226	1.90	14.12	37.23	0.062	0.288	0.107	0.476	2.5	3.6728	0.358
E0422	26.15	1767	2.30	7.91	31.24	0.056	0.282	0.060	0.439	2.1	3.8703	0.369

Table 4-4. Summary table of hydrologic parameters in subbasins – final (cont.).

Subbasin Name	Area (Acre)	Width (feet)	% Slope	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.	Suction Head (in)	Conductivity (in/hr)	Initial Moisture Deficit
E0425	36.59	1210	1.80	4.25	28.86	0.054	0.296	0.029	0.480	1.9	4.6378	0.375
E0430	165.62	3884	3.20	18.27	29.77	0.062	0.260	0.023	0.379	2.1	4.4412	0.372
E0440	170.18	2894	2.30	8.78	25.00	0.050	0.283	0.012	0.464	2.0	4.2684	0.372
E0450	261.88	3980	1.60	13.95	36.81	0.054	0.249	0.057	0.348	2.1	4.2736	0.369
E0452	78.61	1651	1.80	9.77	34.77	0.060	0.276	0.081	0.424	2.3	3.9096	0.364
E0460	89.23	2369	2.50	0.96	31.30	0.054	0.259	0.012	0.360	1.9	4.6378	0.375
E0462	45.26	1656	1.80	11.57	32.79	0.046	0.212	0.019	0.233	2.2	4.1775	0.367
E0500	523.39	5458	1.50	27.75	47.33	0.063	0.227	0.115	0.298	2.0	4.4685	0.374
E0600	676.82	4326	2.00	26.62	49.76	0.068	0.256	0.151	0.396	2.1	3.6416	0.367
E0700	133.47	2334	2.50	14.45	27.17	0.049	0.265	0.012	0.419	1.9	4.6378	0.375

4.3.2.2 Groundwater and Aquifers

Most of the parameters associated with groundwater and aquifers were kept constant in the model calibration, e.g., the parameters for soil characteristics (Table 4-5).

Monthly ET coefficients were adjusted for FLUCCS 4000 - Upland Forests (the dominant land use in the watershed, Table 2-2), based on the initial calibration model run results. The ET coefficients were kept constant for the subsequent model calibration runs (Table 4-6).

The coefficients (A1, A2, B1, B2, and A3), used in the equation that computes lateral groundwater flow, were adjusted during the initial model runs to obtain reasonable groundwater levels in the aquifers and flows between the aquifers and the receiving storage nodes. These coefficients were kept constant for the subsequent model calibration runs (Table 4-7).

The groundwater loss rate in aquifers controls deep seepage flow into the upper FAS and is an important part of a lake water budget model. It is one of the few primary parameters that were adjusted in a series of runs during model calibration. The final calibrated groundwater loss rates to deep aquifer are highlighted in yellow color in Table 4-5.

Also note that the groundwater loss to deep aquifer in the aquifer beneath lakes and sinkholes was modeled as an “outlet” link in the SWMM model, as discussed in Section 4.3.3.2 below. Using a constant groundwater loss rate for other aquifers seems reasonable, based on the simulated flows at the modeled outlet links (Figures 4-7A through 4-7C).

Table 4-5. Summary table of hydrologic parameters in aquifers – final.

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AA0100	0.4104	0.0541	0.1366	18.442	5.2899	15	1	8.42	0.000900	108.93	136.45	0.15
AA0110	0.4131	0.0524	0.1297	17.221	5.1703	15	1	11.36	0.000960	112.44	142.73	0.15
AA0200	0.4128	0.0526	0.1304	17.530	5.1820	15	1	7.54	0.000900	110.08	137.44	0.15
AA0210	0.4165	0.0503	0.1213	15.902	5.0221	15	1	10.89	0.001100	114.46	143.89	0.15
AA0310	0.4170	0.0500	0.1200	14.635	5.0000	15	1	11.71	0.001440	124.03	155.97	0.15
AA0320	0.4155	0.0510	0.1238	15.656	5.0669	15	1	10.93	0.000660	116.47	145.26	0.15
AA0330	0.4170	0.0500	0.1200	15.034	5.0000	15	1	12.02	0.001020	122.14	150.92	0.15
AA0405	0.4170	0.0500	0.1200	19.818	5.0000	15	1	11.34	0.001320	112.36	145.55	0.15
AA0410	0.4170	0.0500	0.1200	20.824	5.0000	15	1	13.75	0.001200	113.72	141.89	0.15
AA0412	0.4148	0.0514	0.1255	21.165	5.0966	15	1	14.27	0.001500	116.07	143.15	0.15
AA0414	0.4170	0.0500	0.1200	21.261	5.0000	15	1	14.44	0.001500	117.32	145.14	0.15
AA0420	0.4156	0.0509	0.1235	19.949	5.0609	15	1	11.92	0.001260	113.05	144.08	0.15
AA0430	0.4144	0.0516	0.1264	19.993	5.1128	15	1	12.39	0.001500	115.41	142.56	0.15
AA0505	0.4170	0.0500	0.1200	19.443	5.0000	15	1	11.14	0.001260	113.36	142.89	0.15
AA0510	0.4128	0.0526	0.1305	20.075	5.1839	15	1	12.57	0.001500	116.09	143.17	0.15
AA0512	0.4160	0.0506	0.1225	20.367	5.0430	15	1	13.02	0.001560	116.45	146.13	0.15
AA0516	0.4163	0.0504	0.1218	21.070	5.0311	15	1	13.70	0.001560	118.81	147.17	0.15
AA0518	0.4151	0.0512	0.1248	20.563	5.0838	15	1	13.34	0.001560	121.33	147.76	0.15
AA0522	0.4150	0.0512	0.1250	21.833	5.0866	15	1	13.41	0.002040	121.16	155.67	0.15
AA0530	0.4149	0.0513	0.1253	19.581	5.0930	15	1	13.78	0.001500	115.56	143.33	0.15
AA0540	0.4170	0.0500	0.1200	20.736	5.0000	15	1	13.59	0.001980	122.23	152.50	0.15

Table 4-5. Summary table of hydrologic parameters in aquifers – final (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AA0542	0.4169	0.0500	0.1201	20.883	5.0025	15	1	14.56	0.001980	124.57	155.12	0.15
AA0544	0.4154	0.0510	0.1240	21.873	5.0693	15	1	15.49	0.002400	122.15	157.10	0.15
AA0550	0.4170	0.0500	0.1200	18.918	5.0000	15	1	13.43	0.001800	116.09	142.40	0.15
AA0560	0.4170	0.0500	0.1200	19.744	5.0000	15	1	14.16	0.001920	123.14	151.28	0.15
AA0570	0.4165	0.0503	0.1213	18.799	5.0222	15	1	14.32	0.001980	120.75	152.09	0.15
AA0580	0.4170	0.0500	0.1200	19.801	5.0000	15	1	13.52	0.002220	125.51	153.62	0.15
AA0582	0.4156	0.0509	0.1234	20.619	5.0598	15	1	14.40	0.002340	126.16	156.74	0.15
AA0586	0.4167	0.0502	0.1207	19.959	5.0128	15	1	12.63	0.002880	125.97	154.92	0.15
AA0590	0.4168	0.0501	0.1206	17.983	5.0098	15	1	13.44	0.001860	114.92	142.91	0.15
AA0592	0.4170	0.0500	0.1200	18.180	5.0000	15	1	13.53	0.002580	122.36	152.96	0.15
AA0610	0.4170	0.0500	0.1200	14.102	5.0000	15	1	11.25	0.001500	122.10	155.73	0.15
AA0620	0.4170	0.0500	0.1200	14.257	5.0000	15	1	11.22	0.001440	124.43	155.38	0.15
AA0630	0.4170	0.0500	0.1200	17.734	5.0000	15	1	12.48	0.001560	112.44	140.93	0.15
AA0640	0.4170	0.0500	0.1200	15.169	5.0000	15	1	12.83	0.001080	120.75	151.76	0.15
AB0100	0.4142	0.0517	0.1270	14.727	5.1223	15	1	8.37	0*	108.44	134.30	0.15
AB0110	0.4170	0.0500	0.1200	13.093	5.0000	15	1	14.43	0.002280	120.95	161.89	0.15
AB0120	0.4170	0.0500	0.1200	12.481	5.0000	15	1	13.54	0.002640	121.42	151.42	0.15
AB0130	0.4167	0.0502	0.1208	13.847	5.0137	15	1	10.64	0.001440	120.14	149.31	0.15
AB0150	0.4170	0.0500	0.1200	14.972	5.0000	15	1	13.83	0.001080	109.85	142.68	0.15
AB0160	0.4170	0.0500	0.1200	14.392	5.0000	15	1	12.22	0.001140	118.60	148.47	0.15
AB0200	0.4170	0.0500	0.1200	13.187	5.0000	15	1	10.26	0.001920	119.46	148.98	0.15

Table 4-5. Summary table of hydrologic parameters in aquifers – final (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AB0300	0.4157	0.0508	0.1234	16.873	5.0587	15	1	9.62	0.001560	112.20	140.47	0.15
AB0410	0.4140	0.0519	0.1274	18.011	5.1302	15	1	14.48	0.001800	118.13	144.47	0.15
AC0100	0.4122	0.0684	0.2027	11.638	7.2901	15	1	9.92	0.001004	110.30	138.24	0.15
AC0110	0.4170	0.0500	0.1200	13.658	5.0008	15	1	9.51	0.000046	121.30	151.54	0.15
AC0120	0.4136	0.0521	0.1284	18.065	5.1466	15	1	12.32	0.000310	112.45	155.10	0.15
AC0201	0.4099	0.0544	0.1377	13.964	5.3105	15	1	11.41	0.000880	108.43	155.79	0.15
AC0202	0.4143	0.0517	0.1268	13.699	5.1194	15	1	12.58	0.001230	107.14	164.27	0.15
AC0203	0.4098	0.0545	0.1379	18.174	5.3140	15	1	13.37	0.000550	110.91	152.79	0.15
AC0204	0.4125	0.0528	0.1313	19.804	5.1978	15	1	13.58	0.000522	111.33	162.67	0.15
AC0210	0.4109	0.0538	0.1353	21.744	5.2676	15	1	13.69	0.001100	110.69	160.22	0.15
AC0212	0.4086	0.0552	0.1409	16.986	5.3656	15	1	14.00	0.001374	109.45	156.89	0.15
AC0220	0.4059	0.0570	0.1478	20.034	5.4865	15	1	15.20	0.001574	112.11	164.19	0.15
AC0230	0.4048	0.0576	0.1506	14.787	5.5347	15	1	15.54	0.001382	112.24	167.62	0.15
AC0240	0.4043	0.0579	0.1517	15.032	5.5548	15	1	15.81	0.001461	114.93	168.09	0.15
AC0244	0.4037	0.0583	0.1534	18.117	5.5838	15	1	13.79	0.001402	114.48	171.75	0.15
AC0250	0.4064	0.0567	0.1466	13.471	5.4657	15	1	14.41	0.001391	117.16	173.82	0.15
AC0260	0.4108	0.0539	0.1354	7.578	5.2699	15	1	10.92	0.001250	118.21	189.48	0.15
AC0270	0.4170	0.0500	0.1200	5.883	5.0000	15	1	8.47	0.001269	106.88	206.02	0.15
AC0280	0.4150	0.0541	0.1380	8.512	5.4705	15	1	12.46	0.001332	122.24	181.32	0.15
AC0282	0.4167	0.0502	0.1207	5.812	5.0129	15	1	11.22	0.001782	117.56	193.27	0.15
AC0301	0.4157	0.0509	0.1238	11.995	5.0731	15	1	10.89	0.001066	107.18	151.41	0.15

Table 4-5. Summary table of hydrologic parameters in aquifers – final (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AC0303	0.4170	0.0500	0.1200	9.596	5.0000	15	1	12.02	0.001862	110.55	148.67	0.15
AC0304	0.4167	0.0502	0.1208	8.271	5.0147	15	1	12.37	0.002147	106.94	158.40	0.15
AC0308	0.4167	0.0502	0.1208	6.914	5.0140	15	1	10.80	0.001902	100.73	168.02	0.15
AC0310	0.4157	0.0526	0.1316	10.621	5.3020	15	1	10.39	0.001374	103.86	161.33	0.15
AC0311	0.4169	0.0503	0.1214	8.855	5.0402	15	1	10.66	0.002594	104.84	153.45	0.15
AC0314	0.4159	0.0507	0.1227	8.373	5.0469	15	1	10.76	0.002802	100.31	165.48	0.15
AC0320	0.4141	0.0518	0.1274	12.222	5.1318	15	1	12.02	0.001042	105.45	161.01	0.15
AC0330	0.4145	0.0516	0.1262	10.095	5.1087	15	1	12.00	0.001136	102.34	171.48	0.15
AC0340	0.4136	0.0522	0.1286	11.311	5.1508	15	1	12.77	0.001008	107.64	168.18	0.15
AC0342	0.4113	0.0535	0.1342	14.438	5.2480	15	1	12.95	0.000996	107.79	163.06	0.15
AC0350	0.4162	0.0505	0.1220	6.827	5.0348	15	1	13.41	0.001176	96.07	186.47	0.15
AC0360	0.4134	0.0522	0.1289	10.491	5.1557	15	1	14.76	0.001322	113.14	174.30	0.15
AC0370	0.4162	0.0505	0.1220	6.963	5.0342	15	1	13.36	0.001550	108.05	186.74	0.15
AC0410	0.4150	0.0563	0.1483	6.870	5.7735	15	1	12.50	0.002614	110.61	152.65	0.15
AC0420	0.4161	0.0506	0.1223	8.549	5.0401	15	1	13.28	0.003570	111.08	152.93	0.15
AC0430	0.4161	0.0521	0.1294	6.451	5.2524	15	1	12.09	0.002166	113.91	144.80	0.15
AC0505	0.4170	0.0500	0.1200	10.375	5.0000	15	1	9.45	0.000900	116.43	148.52	0.15
AC0507	0.4169	0.0503	0.1214	6.794	5.0381	15	1	11.57	0.003293	114.09	147.28	0.15
AC0508	0.4157	0.0553	0.1440	6.177	5.6655	15	1	10.12	0.001664	113.98	142.40	0.15
AC0520	0.4141	0.0542	0.1381	5.741	5.4442	15	1	12.98	0.002308	114.62	147.57	0.15
AC0530	0.4149	0.0517	0.1270	5.614	5.1427	15	1	11.35	0.001676	114.72	148.09	0.15

Table 4-5. Summary table of hydrologic parameters in aquifers – final (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AC0540	0.4160	0.0511	0.1246	11.808	5.1037	15	1	8.84	0.002440	119.61	151.92	0.15
AC0550	0.4122	0.0530	0.1321	11.478	5.2116	15	1	10.66	0*	124.10	154.42	0.15
AC0552	0.4163	0.0504	0.1217	12.684	5.0303	15	1	11.02	0.000235	126.44	163.98	0.15
AD0040	0.4160	0.0506	0.1225	11.464	5.0430	15	1	12.13	0.000296	123.62	158.71	0.15
AD0045	0.4145	0.0515	0.1261	10.283	5.1075	15	1	12.47	0.000612	124.67	169.07	0.15
AD0050	0.4127	0.0527	0.1309	9.910	5.1900	15	1	11.95	0.000396	123.56	148.56	0.15
AD0055	0.4152	0.0511	0.1246	8.720	5.0801	15	1	13.86	0.001336	123.37	162.15	0.15
AD0100	0.4143	0.0589	0.1599	7.041	6.0929	15	1	10.93	0*	107.15	133.19	0.15
AD0110	0.4145	0.0598	0.1642	5.324	6.2276	15	1	10.52	0.000386	110.04	141.14	0.15
AD0130	0.4153	0.0515	0.1262	6.341	5.1328	15	1	12.42	0.002566	114.10	146.73	0.15
AD0150	0.4157	0.0508	0.1233	9.471	5.0579	15	1	11.37	0.000060	119.72	151.90	0.15
AD0160	0.4140	0.0519	0.1275	8.908	5.1315	15	1	11.70	0.000115	114.32	142.63	0.15
AD0180	0.4165	0.0503	0.1212	7.703	5.0208	15	1	13.28	0.000138	116.33	151.70	0.15
AD0200	0.4163	0.0527	0.1320	5.323	5.3331	15	1	11.15	0.003010	111.20	147.51	0.15
AE0100	0.4139	0.0557	0.1453	4.340	5.6504	15	1	7.62	0*	104.69	133.45	0.15
AE0110	0.4167	0.0513	0.1256	2.188	5.1563	15	1	11.73	0.003160	89.70	153.94	0.15
AE0120	0.4141	0.0545	0.1397	2.429	5.4951	15	1	11.86	0.001353	95.42	144.38	0.15
AE0140	0.4144	0.0605	0.1674	5.079	6.3167	15	1	10.24	0.000240	108.42	139.91	0.15
AE0150	0.4163	0.0504	0.1218	7.313	5.0310	15	1	13.31	0.000222	121.01	163.83	0.15
AE0160	0.4170	0.0500	0.1200	7.575	5.0001	15	1	12.30	0.001300	125.21	160.03	0.15
AE0162	0.4140	0.0519	0.1275	8.641	5.1311	15	1	14.52	0.001168	129.72	162.29	0.15

Table 4-5. Summary table of hydrologic parameters in aquifers – final (cont.).

Aquifer	Porosity	Wilting Point	Field Capacity	Conductivity (in/hr)	Conductivity Slope	Tension Slope	Upper Evap. Fraction	Lower Eva. Depth (ft)	GW Loss to Deep Aquifer (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AE0170	0.4168	0.0501	0.1205	5.463	5.0088	15	1	13.32	0.002382	113.03	158.26	0.15
AE0172	0.4170	0.0500	0.1200	5.914	5.0000	15	1	13.16	0.001859	112.68	171.76	0.15
AE0180	0.4115	0.0534	0.1337	2.880	5.2403	15	1	10.00	0.002101	94.20	140.47	0.15
AE0190	0.4170	0.0500	0.1200	2.210	5.0000	15	1	12.06	0.001202	84.40	154.39	0.15
AE0220	0.4144	0.0560	0.1465	2.059	5.7014	15	1	10.37	0.002189	89.24	150.34	0.15
AE0230	0.4158	0.0529	0.1328	2.029	5.3431	15	1	11.85	0.002036	88.57	156.71	0.15
AE0300	0.4150	0.0532	0.1338	3.129	5.3470	15	1	12.72	0.002036	101.60	146.73	0.15
AE0410	0.4147	0.0546	0.1401	4.619	5.5247	15	1	12.69	0.001762	107.65	142.84	0.15
AE0422	0.4135	0.0522	0.1289	3.942	5.1553	15	1	12.38	0.001597	104.44	147.35	0.15
AE0425	0.4170	0.0500	0.1200	3.897	5.0000	15	1	12.39	0*	103.21	142.19	0.15
AE0430	0.4168	0.0509	0.1242	3.538	5.1168	15	1	11.85	0*	97.44	141.52	0.15
AE0440	0.4153	0.0511	0.1243	3.988	5.0747	15	1	12.71	0*	101.13	146.71	0.15
AE0450	0.4165	0.0517	0.1275	4.373	5.2046	15	1	12.28	0*	106.57	148.40	0.15
AE0452	0.4156	0.0532	0.1341	4.551	5.3738	15	1	12.45	0.003343	106.63	148.36	0.15
AE0460	0.4168	0.0507	0.1231	3.600	5.0873	15	1	11.74	0.003573	101.38	148.78	0.15
AE0500	0.4162	0.0505	0.1220	6.734	5.0343	15	1	12.05	0.001059	119.69	152.11	0.15
AE0600	0.4124	0.0529	0.1315	3.951	5.2015	15	1	10.77	0.002884	102.97	143.26	0.15
AE0700	0.4170	0.0500	0.1200	1.884	5.0000	15	1	11.88	0*	80.01	160.47	0.15

* Groundwater loss to deep aquifer in Aquifers AB0100, AC0550, AD0100, AE0100, AE0425, AE0430, AE0440, AE0450, and AE0700, beneath lakes and sinkholes, was simulated via an outlet link in the SWMM model, see Section 4.3.3.3.

Table 4-6. Lookup table of monthly ET coefficients – final.

Land Use/Cover	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Urban - Low Density	0.40	0.40	0.60	0.80	0.90	0.84	0.72	0.65	0.65	0.65	0.65	0.50
Urban - Medium Density	0.30	0.30	0.50	0.60	0.60	0.60	0.60	0.50	0.50	0.50	0.50	0.50
Urban - High Density	0.25	0.25	0.30	0.35	0.50	0.50	0.50	0.50	0.35	0.30	0.30	0.30
Pasture / Open Lands	0.60	0.65	0.70	0.85	0.85	0.85	0.85	0.85	0.85	0.75	0.65	0.60
Range Land	0.55	0.60	0.75	0.85	0.85	0.85	0.85	0.85	0.75	0.65	0.60	0.55
Upland Forest	0.65	0.70	0.80	0.90	0.90	0.90	0.90	0.90	0.85	0.75	0.70	0.65
Pine Flatwoods	0.70	0.70	0.85	0.90	0.90	1.00	1.00	1.00	1.00	0.90	0.80	0.70
Open Water	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Forested Wetland	1.00	1.00	1.00	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.00	1.00
Non-Forested Wetland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Burned Areas*	0.78	0.80	0.88	0.98	0.98	0.98	0.98	0.98	0.93	0.88	0.80	0.78

* Coefficients of Burned Areas (Santa Fe Swamp in this project) were estimated by averaging the values for Upland Forest and Forested Wetland.
Sources: Peace River integrated modeling (HGL, 2008); Myakka River Watershed Initiative (Interflow, 2008). ECT, 2021.

Table 4-7. Summary table of hydrologic parameters in groundwater – final.

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
A0100	AA0100	NA0100	138.45	0.02	0.7	0.02	0.7	0	100	138.0
A0110	AA0110	NA0110	143.99	0.02	0.7	0.02	0.7	0	100	140.0
A0120	AA0110	NA0120	145.76	0.02	0.7	0.02	0.7	0	100	141.0
A0200	AA0200	NA0200	140.19	0.02	0.7	0.02	0.7	0	100	139.5
A0210	AA0210	NA0210	145.74	0.02	0.7	0.02	0.7	0	100	139.5
A0220	AA0210	NA0220	146.45	0.02	0.7	0.02	0.7	0	100	139.8
A0300	AA0200	NA0300	139.77	0.02	0.7	0.02	0.7	0	100	139.5
A0310	AA0310	NA0310	157.97	0.02	0.7	0.02	0.7	0	100	153.8
A0320	AA0320	NA0320	147.26	0.02	0.7	0.02	0.7	0	100	139.8
A0330	AA0330	NA0300	152.92	0.02	0.7	0.02	0.7	0	100	139.8
A0400	AA0200	NA0400	138.96	0.02	0.7	0.02	0.7	0	100	138.9
A0405	AA0405	NA0400	147.55	0.02	0.7	0.02	0.7	0	100	139.5
A0410	AA0410	NA0410	143.89	0.02	0.7	0.02	0.7	0	100	139.5
A0412	AA0412	NA0412	145.15	0.02	0.7	0.02	0.7	0	100	141.0
A0414	AA0414	NA0414	147.14	0.02	0.7	0.02	0.7	0	100	140.0
A0420	AA0420	NA0420	145.55	0.02	0.7	0.02	0.7	0	100	139.5
A0422	AA0420	NA0422	146.6	0.02	0.7	0.02	0.7	0	100	140.0
A0430	AA0430	NA0430	144.56	0.02	0.7	0.02	0.7	0	100	139.5
A0500	AA0200	NA0500	139.13	0.02	0.7	0.02	0.7	0	100	139.1
A0505	AA0505	NA0505	144.89	0.02	0.7	0.02	0.7	0	100	139.5
A0510	AA0510	NA0510	145.17	0.02	0.7	0.02	0.7	0	100	140.2

Table 4-7. Summary table of hydrologic parameters in groundwater – final (cont.).

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
A0512	AA0512	NA0512	147.97	0.02	0.7	0.02	0.7	0	100	144.1
A0514	AA0512	NA0514	148.64	0.02	0.7	0.02	0.7	0	100	147.3
A0516	AA0516	NA0516	148.88	0.02	0.7	0.02	0.7	0	100	143.7
A0518	AA0518	NA0518	149.76	0.02	0.7	0.02	0.7	0	100	145.4
A0520	AA0516	NA0520	149.79	0.02	0.7	0.02	0.7	0	100	143.3
A0522	AA0522	NA0522	157.67	0.02	0.7	0.02	0.7	0	100	147.55
A0530	AA0530	NA0530	145.33	0.02	0.7	0.02	0.7	0	100	139.5
A0540	AA0540	NA0540	154.5	0.02	0.7	0.02	0.7	0	100	146.5
A0542	AA0542	NA0542	157.12	0.02	0.7	0.02	0.7	0	100	152.5
A0544	AA0544	NA0544	159.1	0.02	0.7	0.02	0.7	0	100	154.6
A0550	AA0550	NA0550	144.4	0.02	0.7	0.02	0.7	0	100	139.5
A0560	AA0560	NA0560	153.28	0.02	0.7	0.02	0.7	0	100	142.0
A0570	AA0570	NA0570	154.09	0.02	0.7	0.02	0.7	0	100	143.7
A0580	AA0580	NA0580	155.62	0.02	0.7	0.02	0.7	0	100	147.63
A0582	AA0582	NA0582	158.51	0.02	0.7	0.02	0.7	0	100	155.2
A0584	AA0582	NA0584	158.99	0.02	0.7	0.02	0.7	0	100	156.5
A0586	AA0586	NA0586	156.34	0.02	0.7	0.02	0.7	0	100	151.2
A0588	AA0586	NA0588	157.62	0.02	0.7	0.02	0.7	0	100	154.6
A0590	AA0590	NA0590	144.91	0.02	0.7	0.02	0.7	0	100	140.0
A0592	AA0592	NA0592	154.96	0.02	0.7	0.02	0.7	0	100	146.1
A0600	AA0200	NA0600	139.68	0.02	0.7	0.02	0.7	0	100	139.5

Table 4-7. Summary table of hydrologic parameters in groundwater – final (cont.).

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
A0610	AA0610	NA0610	157.73	0.02	0.7	0.02	0.7	0	100	148.5
A0620	AA0620	NA0620	157.38	0.02	0.7	0.02	0.7	0	100	142.0
A0630	AA0630	NA0630	142.93	0.02	0.7	0.02	0.7	0	100	139.5
A0640	AA0640	NA0600	153.76	0.02	0.7	0.02	0.7	0	100	139.8
B0100	AB0100	NB0100	142	0.02	0.7	0.02	0.7	0	100	139.5
B0110	AB0110	NB0100	160.18	0.02	0.7	0.02	0.7	0	100	139.5
B0112	AB0110	NB0100	168.74	0.02	0.7	0.02	0.7	0	100	139.5
B0120	AB0120	NB0100	153.42	0.02	0.7	0.02	0.7	0	100	139.5
B0130	AB0130	NB0100	151.31	0.02	0.7	0.02	0.7	0	100	139.5
B0140	AB0300	NB0100	139.01	0.02	0.7	0.02	0.7	0	100	139.0
B0150	AB0150	NB0100	144.68	0.02	0.7	0.02	0.7	0	100	139.5
B0160	AB0160	NB0100	150.47	0.02	0.7	0.02	0.7	0	100	139.5
B0200	AB0200	NB0200	150.98	0.02	0.7	0.02	0.7	0	100	139.5
B0300	AB0300	NB0300	142.1	0.02	0.7	0.02	0.7	0	100	139.5
B0400	AB0300	NB0400	142.65	0.02	0.7	0.02	0.7	0	100	139.5
B0410	AB0410	NB0410	146.47	0.02	0.7	0.02	0.7	0	100	142.0
C0100	AC0100	NC0100	140.31	0.02	0.7	0.02	0.7	0	100	139.7
C0110	AC0110	NC0100	153.54	0.02	0.7	0.02	0.7	0	100	140.0
C0120	AC0120	NC0100	157.1	0.02	0.7	0.02	0.7	0	100	140.0
C0200	AC0100	NC0200	142.05	0.02	0.7	0.02	0.7	0	100	139.7
C0201	AC0201	NC0200	157.79	0.02	0.7	0.02	0.7	0	100	140.0

Table 4-7. Summary table of hydrologic parameters in groundwater – final (cont.).

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
C0202	AC0202	NC0202	166.27	0.02	0.7	0.02	0.7	0	100	163.5
C0203	AC0203	NC0200	154.79	0.02	0.7	0.02	0.7	0	100	140.0
C0204	AC0204	NC0204	164.67	0.02	0.7	0.02	0.7	0	100	155.3
C0210	AC0210	NC0210	162.22	0.02	0.7	0.02	0.7	0	100	142.0
C0212	AC0212	NC0212	158.89	0.02	0.7	0.02	0.7	0	100	145.5
C0220	AC0220	NC0220	166.19	0.02	0.7	0.02	0.7	0	100	153.1
C0230	AC0230	NC0230	169.62	0.02	0.7	0.02	0.7	0	100	158.6
C0240	AC0240	NC0240	170.09	0.02	0.7	0.02	0.7	0	100	163.8
C0244	AC0244	NC0244	173.75	0.02	0.7	0.02	0.7	0	100	167.1
C0250	AC0250	NC0250	175.89	0.02	0.7	0.02	0.7	0	100	166.7
C0254	AC0250	NC0254	174.22	0.02	0.7	0.02	0.7	0	100	171.8
C0260	AC0260	NC0260	191.48	0.02	0.7	0.02	0.7	0	100	183.9
C0270	AC0270	NC0270	208.02	0.02	0.7	0.02	0.7	0	100	194.9
C0280	AC0280	NC0280	183.32	0.02	0.7	0.02	0.7	0	100	167.7
C0282	AC0282	NC0282	195.27	0.02	0.7	0.02	0.7	0	100	186.0
C0300	AC0100	NC0300	141.09	0.02	0.7	0.02	0.7	0	100	139.7
C0301	AC0301	NC0300	153.41	0.02	0.7	0.02	0.7	0	100	140.0
C0303	AC0303	NC0300	150.67	0.02	0.7	0.02	0.7	0	100	140.0
C0304	AC0304	NC0304	159.09	0.02	0.7	0.02	0.7	0	100	143.2
C0306	AC0304	NC0306	169.92	0.02	0.7	0.02	0.7	0	100	162.0
C0308	AC0308	NC0308	170.02	0.02	0.7	0.02	0.7	0	100	163.6

Table 4-7. Summary table of hydrologic parameters in groundwater – final (cont.).

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
C0310	AC0310	NC0310	163.33	0.02	0.7	0.02	0.7	0	100	142.5
C0311	AC0311	NC0300	155.45	0.02	0.7	0.02	0.7	0	100	140.0
C0314	AC0314	NC0314	163.16	0.02	0.7	0.02	0.7	0	100	148.0
C0316	AC0314	NC0316	173.61	0.02	0.7	0.02	0.7	0	100	162.2
C0320	AC0320	NC0320	163.01	0.02	0.7	0.02	0.7	0	100	149.9
C0322	AC0330	NC0320	178.51	0.02	0.7	0.02	0.7	0	100	149.9
C0330	AC0330	NC0330	170.06	0.02	0.7	0.02	0.7	0	100	152.5
C0340	AC0340	NC0340	170.18	0.02	0.7	0.02	0.7	0	100	156.3
C0342	AC0342	NC0342	163.76	0.02	0.7	0.02	0.7	0	100	158.0
C0344	AC0342	NC0344	166.03	0.02	0.7	0.02	0.7	0	100	162.6
C0350	AC0350	NC0350	188.47	0.02	0.7	0.02	0.7	0	100	172.0
C0360	AC0360	NC0360	176.3	0.02	0.7	0.02	0.7	0	100	170.0
C0370	AC0370	NC0370	188.74	0.02	0.7	0.02	0.7	0	100	177.5
C0400	AC0100	NC0400	140.58	0.02	0.7	0.02	0.7	0	100	139.7
C0410	AC0410	NC0410	154.65	0.02	0.7	0.02	0.7	0	100	142.5
C0420	AC0420	NC0400	154.93	0.02	0.7	0.02	0.7	0	100	140.0
C0430	AC0430	NC0400	146.8	0.02	0.7	0.02	0.7	0	100	140.0
C0500	AC0100	NC0500	140	0.02	0.7	0.02	0.7	0	100	139.7
C0505	AC0505	NC0500	150.52	0.02	0.7	0.02	0.7	0	100	139.7
C0507	AC0507	NC0500	149.28	0.02	0.7	0.02	0.7	0	100	139.7
C0508	AC0508	NC0508	144.55	0.02	0.7	0.02	0.7	0	100	139.7

Table 4-7. Summary table of hydrologic parameters in groundwater – final (cont.).

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
C0510	AC0508	NC0510	144.33	0.02	0.7	0.02	0.7	0	100	140.0
C0520	AC0520	NC0520	148.68	0.02	0.7	0.02	0.7	0	100	142.0
C0522	AC0520	NC0522	150.64	0.02	0.7	0.02	0.7	0	100	144.5
C0530	AC0530	NC0530	150.09	0.02	0.7	0.02	0.7	0	100	140.5
C0540	AC0540	NC0540	153.92	0.02	0.7	0.02	0.7	0	100	140.0
C0550	AC0550	NC0550	156.42	0.02	0.7	0.02	0.7	0	100	147.0
C0552	AC0552	NC0552	165.98	0.02	0.7	0.02	0.7	0	100	163.1
D0040	AD0040	ND0040	160.71	0.02	0.7	0.02	0.7	0	100	139.7
D0045	AD0045	ND0045	171.07	0.02	0.7	0.02	0.7	0	100	165.6
D0050	AD0050	ND0050	150.56	0.02	0.7	0.02	0.7	0	100	139.7
D0055	AD0055	ND0055	164.15	0.02	0.7	0.02	0.7	0	100	149.7
D0100	AD0100	ND0100	142.00	0.02	0.7	0.02	0.7	0	100	139.7
D0110	AD0110	ND0100	140.65	0.02	0.7	0.02	0.7	0	100	139.7
D0120	AD0110	ND0100	144.13	0.02	0.7	0.02	0.7	0	100	139.7
D0130	AD0130	ND0100	144.99	0.02	0.7	0.02	0.7	0	100	139.7
D0140	AD0130	ND0100	150.66	0.02	0.7	0.02	0.7	0	100	139.7
D0150	AD0150	ND0100	153.9	0.02	0.7	0.02	0.7	0	100	139.7
D0160	AD0160	ND0100	142.24	0.02	0.7	0.02	0.7	0	100	140.0
D0170	AD0160	ND0100	144.83	0.02	0.7	0.02	0.7	0	100	139.7
D0180	AD0180	ND0100	153.7	0.02	0.7	0.02	0.7	0	100	139.7
D0200	AD0200	ND0200	149.51	0.02	0.7	0.02	0.7	0	100	140.46

Table 4-7. Summary table of hydrologic parameters in groundwater – final (cont.).

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
E0100	AE0100	NE0100	142.00	0.02	0.7	0.02	0.7	0	100	139.7
E0110	AE0110	NE0100	155.94	0.02	0.7	0.02	0.7	0	100	139.7
E0120	AE0120	NE0100	141.27	0.02	0.7	0.02	0.7	0	100	139.7
E0130	AE0120	NE0100	148.87	0.02	0.7	0.02	0.7	0	100	139.7
E0140	AE0140	NE0140	141.91	0.02	0.7	0.02	0.7	0	100	139.7
E0150	AE0150	NE0100	165.83	0.02	0.7	0.02	0.7	0	100	139.7
E0160	AE0160	NE0100	162.03	0.02	0.7	0.02	0.7	0	100	139.7
E0162	AE0162	NE0162	164.29	0.02	0.7	0.02	0.7	0	100	160.7
E0170	AE0170	NE0100	160.26	0.02	0.7	0.02	0.7	0	100	139.7
E0172	AE0172	NE0172	173.76	0.02	0.7	0.02	0.7	0	100	168.6
E0180	AE0180	NE0100	142.47	0.02	0.7	0.02	0.7	0	100	139.7
E0190	AE0190	NE0100	156.39	0.02	0.7	0.02	0.7	0	100	139.7
E0200	AE0120	NE0100	145.54	0.02	0.7	0.02	0.7	0	100	139.7
E0210	AE0120	NE0210	151.28	0.02	0.7	0.02	0.7	0	100	141.0
E0220	AE0220	NE0220	152.34	0.02	0.7	0.02	0.7	0	100	141.0
E0230	AE0230	NE0230	158.71	0.02	0.7	0.02	0.7	0	100	150.0
E0300	AE0300	NE0300	148.73	0.02	0.7	0.02	0.7	0	100	139.7
E0400	AE0410	NE0400	143.61	0.02	0.7	0.02	0.7	0	100	139.7
E0410	AE0410	NE0410	146.17	0.02	0.7	0.02	0.7	0	100	139.5
E0420	AE0410	NE0420	143.32	0.02	0.7	0.02	0.7	0	100	139.8
E0422	AE0422	NE0422	149.35	0.02	0.7	0.02	0.7	0	100	143.4

Table 4-7. Summary table of hydrologic parameters in groundwater – final (cont.).

Subbasin Name	Aquifer	Node	Surface Elevation (ft NAVD88)	A1	B1	A2	B2	A3	Threshold Water Table Elev. (ft NAVD88)	Ini. Water Table Elev. (ft NAVD88)
E0425	AE0425	NE0425	144.19	0.02	0.7	0.02	0.7	0	100	136.5
E0430	AE0430	NE0430	143.52	0.02	0.7	0.02	0.7	0	100	125.0
E0440	AE0440	NE0440	148.71	0.02	0.7	0.02	0.7	0	100	123.0
E0450	AE0450	NE0450	150.40	0.02	0.7	0.02	0.7	0	100	131.5
E0452	AE0452	NE0452	150.36	0.02	0.7	0.02	0.7	0	100	139.8
E0460	AE0460	NE0460	150.34	0.02	0.7	0.02	0.7	0	100	135.5
E0462	AE0460	NE0462	151.64	0.02	0.7	0.02	0.7	0	100	142.0
E0500	AE0500	NE0500	154.11	0.02	0.7	0.02	0.7	0	100	139.7
E0600	AE0600	NE0600	145.26	0.02	0.7	0.02	0.7	0	100	139.7
E0700	AE0700	NE0700	162.47	0.02	0.7	0.02	0.7	0	100	136.5

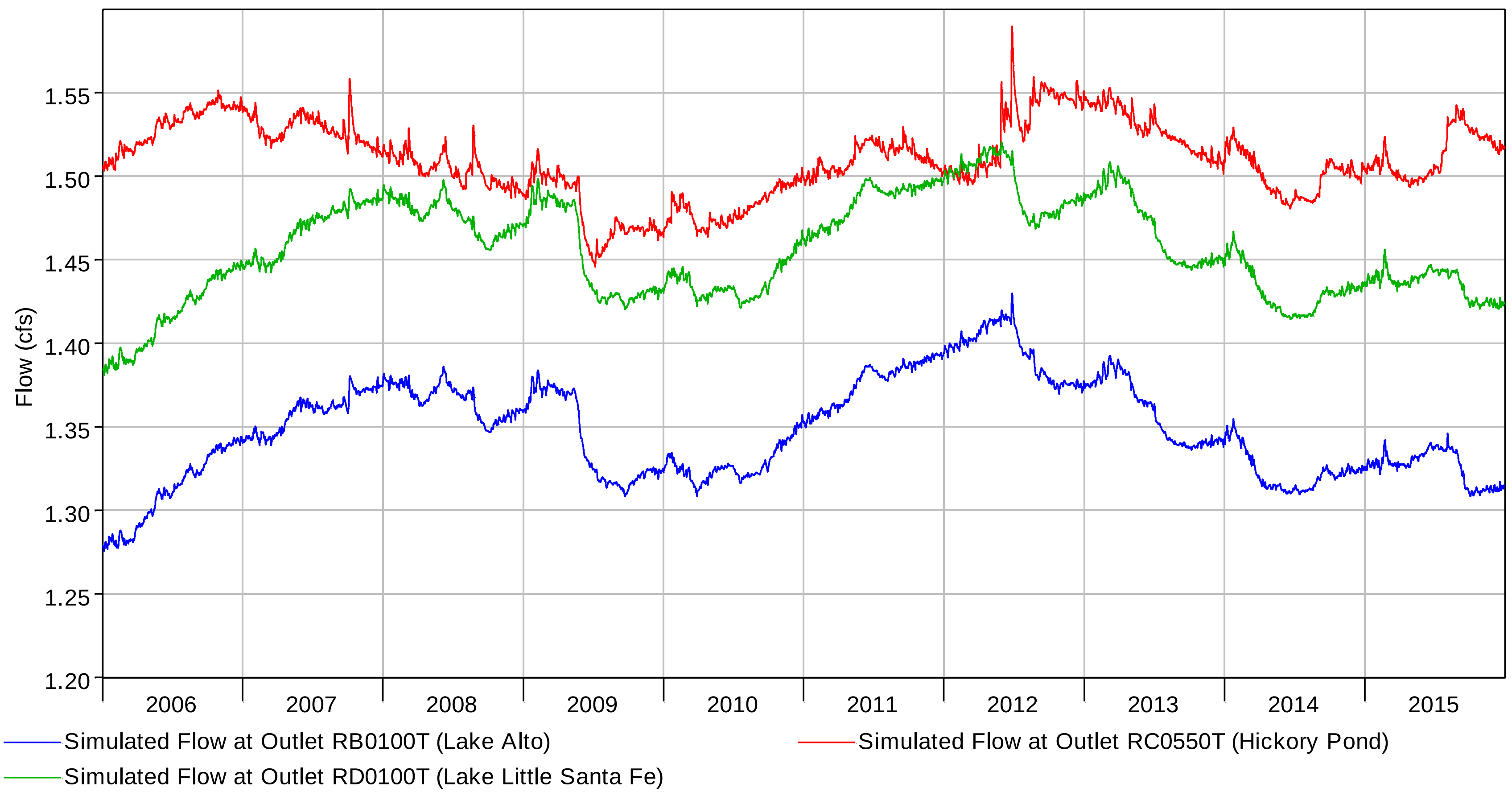


Figure 4-7A. Simulated Groundwater Flow Hydrographs (2006-2015) - 1 of 3.

Figure 4-7B. Simulated Groundwater Flow Hydrographs (2006-2015) - 2 of 3.

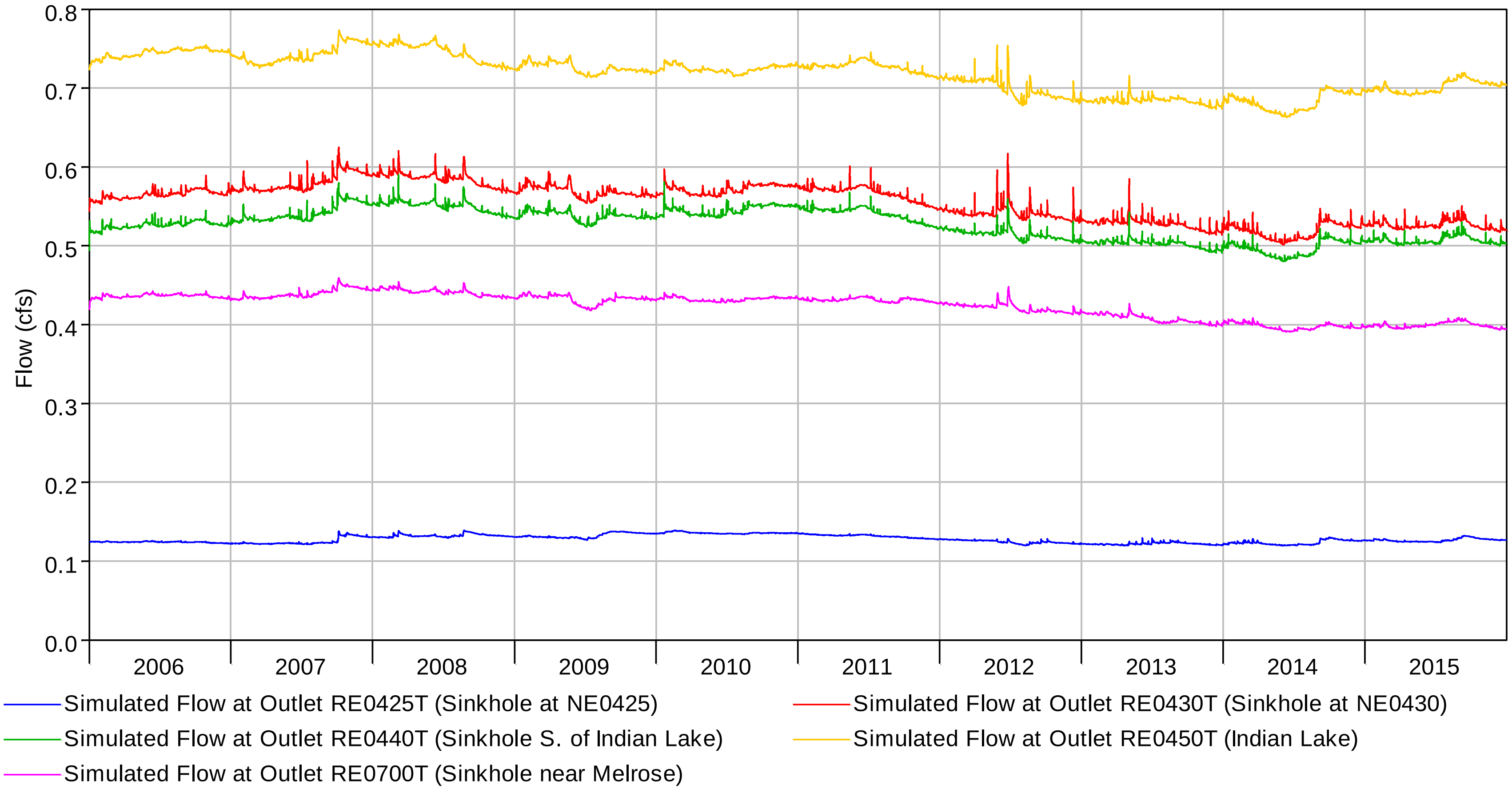


Figure 4-7C. Simulated Groundwater Flow Hydrographs (2006-2015) - 3 of 3.

4.3.3 Adjustment of Hydraulic Model Parameters

Various hydraulic model parameters were adjusted during model calibration, including channel invert elevations, weir crest elevations, weir discharge coefficients, outlet rating curves, and initial conditions, as discussed in detail below. Other hydraulic model parameters were held constant in the model calibration process.

4.3.3.1 Channel Invert Elevations

Surface water flow exchange between Lake Alto and Lake Santa Fe is controlled by the Santa Fe Canal. Based on the ground survey data and LiDAR-based DEM data, the highest point of the Santa Fe Canal is likely located east of the C.R. 325 bridge, which was modeled as Channel RD0038C that connects Nodes ND0038 to ND0035 (Figure 3-5).

The upstream invert of Channel RD0038C was adjusted based on the observed lake stage values (Figures 4-6B and 4-6C) during periods of high lake levels in 2006, 2009-2010, and 2013-2015 when the lake levels exceeded the control elevation in the Santa Fe Canal. The final upstream invert of RD0038C was calibrated to be 138.0 ft NAVD88. The Canal may be silted or partially blocked by man-made low-water crossing or natural debris, upon evaluation of the lake stage data collected at these two lakes and the LiDAR-based DEM data.

Other coefficients (e.g., Manning's n roughness values in channel transects) were adjusted during the initial model runs and held constant in the subsequent model calibration runs.

4.3.3.2 Weir Crest Elevations and Discharge Coefficients

As illustrated on Figure 3-5, the flow paths in Lake Alto Swamp and Santa Fe Swamp were modeled as series of overland flow weirs. The crest elevations and discharge coefficients of the overland flow weirs also control the outfall flow discharge from Lake Alto and Lake Santa Fe to the Santa Fe River.

The weir crest elevations were adjusted based on the observed lake stage values (Figures 4-6B and 4-6C), particularly during the two high water periods of 2009-2010 and 2013-2015 when the lakes may possibly exceed the weir crest elevations and discharge north to the Santa Fe River. The following factors may potentially result in different weir crest or control elevations in the swamp areas: 1) changes in vegetation covers caused by wildfires, e.g., the wildfires that occurred in 2002, 2004, 2007, and 2011 at Santa Fe Swamp and 2007 at Lake Alto Swamp; 2) changes in water flow paths due to sediment deposit/erosion and vegetation growth; and 3) impacts of cyclic wetting and drying on soils and vegetation cover. The weir discharge coefficients for the overland flow weirs through swamps were lowered from 0.6 to 0.3 with consideration of these factors. The weir crest elevations or lake control point elevations were calibrated as listed below.

- Lake Alto Swamp (RA0600W1 & RA0600W2): 139.2 ft NAVD88; and
- Santa Fe Swamp (RC0100W & RC0500W1): 140.2 ft NAVD88.

Other parameters for these overland flow weirs were held constant in the model calibration.

4.3.3.2 Outlet Functional Rating Curves

To simulate the time-variant groundwater loss to deep aquifer, a total of nine "outlet" links were used to calculate the groundwater loss rates from various lakes and sinkholes into the upper FAS. A user-defined functional rating curve determines an outlet's discharge flow as a power function of the head difference across it, i.e., the head difference between the water table elevations in a given lake and groundwater table elevations in the upper FAS (Equation C).

$$Q = A * \Delta H^{B} \quad \text{(C)}$$

where, Q =flow (cfs)
A = coefficient A (ft^2/s)
B = coefficient B (set at 1.0, per Darcy's equation)
ΔH = head difference (ft)

As listed in Table 4-8, the initial coefficient A in this equation was first estimated for each outlet link using Darcy's equation with the following three parameters:

- Saturated vertical hydraulic conductivity of Intermediate Aquifer System/Intermediate Confining Unit (IAS/ICU);
- Surface area of lakes/sinkholes; and
- Distance from the lake/sinkhole bottom to the IAS/ICU bottom.

The saturated vertical hydraulic conductivity values and the IAS/ICU bottom elevations were derived from the 2016 NFSEG model. Seismic profiling of numerous northeast Florida lakes shows a variety of collapse structures providing preferred paths toward the aquifer (Kindinger *et al*. 2000), which may potentially increase groundwater loss rate to deep aquifer. Based on the initial model run results, the initial estimation of coefficient A was not high enough to account for these collapse structures and needed to be further adjusted in the model calibration process.

Coefficient A is one of the few parameters that were adjusted in a series of model runs to match the observed lake stage data and historical aerial imagery if lake gage data was not available. The initial and final coefficient A values were listed in Table 4-8.

Table 4-8. Summary table of initial and final coefficient A values for outlet functional curves.

Outlet Name	Location	Initial Coefficient A (ft^2/s)	Final Coefficient A (ft^2/s)
RB0100T	Lake Alto	0.000014	0.019600
RC0550T	Hickory Pond	0.000005	0.021250
RD0100T	Little Lake Santa Fe	0.000018	0.022500
RE0100T	Lake Santa Fe	0.000161	0.206080
RE0425T	Sinkhole at NE0425	0.000026	0.002210
RE0430T	Sinkhole at NE0430	0.000101	0.012120
RE0440T	Sinkhole S. of Indian Lake	0.000079	0.011455
RE0450T	Indian Lake	0.000399	0.013965
RE0700T	Sinkhole near Melrose	0.000016	0.008000

4.3.3.4 Initial Conditions

The node initial elevations in Lake Alto, Lake Santa Fe, and their adjacent wetland areas were adjusted to match stage data measured at USGS 02320630 Lake Alto at Waldo, FL and USGS 02320601 Lake Santa Fe near Earleton, FL (Figure 4-5). The node initial elevations were set at 139.41 ft NAVD88 and 139.72 ft NAVD88 for Lake Alto and Lake Santa Fe, respectively, by interpolating the observed lake stage values. The initial stage values in other adjacent storage areas, junction nodes, as well as the water elevations in groundwater and aquifers (Tables 4-5 and 4-7) were adjusted accordingly to avoid unreasonable initial flows.

4.4 Model Calibration Results

4.4.1 Model Simulation and Calibration

The Lake Alto and Lake Santa Fe water budget model was calibrated with data from 2006 through 2015, by comparing the observed lake stage values with the simulated stages. A series of model runs were simulated to obtain the closest overall fit to measured values, by adjusting certain model parameters while leaving other parameters constant, as discussed in Section 4.3.

The following model parameters were adjusted initially to make the model ready for calibration, and were held constant thereafter:

- Impervious percentages
- The coefficients used for computing lateral groundwater flow
- Shift factors used to adjust potentiometric surface levels beneath lakes/sinkholes
- Weir discharge coefficients at Lake Alto Swamp and Santa Fe Swamp
- Initial conditions at nodes (lakes, wetlands, and channels) and water tables in aquifers

The following model parameters were adjusted during the model calibration process:

- Channel invert elevations (control elevation at Santa Fe Canal)
- Weir crest elevations (control elevations at Lake Alto Swamp and Santa Fe Swamp)
- Groundwater loss rates from the surficial aquifers to upper FAS
- Outlet functional curves for flow exchange between the lakes/sinkholes and FAS

4.4.2 Model Calibration Results

The simulated and observed lake stage hydrographs are graphically presented on Figures 4-8A and 4-8B for Lake Alto and Lake Santa Fe, respectively. These figures demonstrate that the final calibration model-simulated stage values replicate the trends of the historical data for both lakes. Two scatter plots comparing individual simulated lake stages with corresponding observed values are provided on Figures 4-9A and 4-9B to assist in the model assessment for Lake Alto and Lake Santa Fe, respectively. The statistical analysis results are summarized in these two plots as well.

For Lake Alto, the RMSE of the lake stage residuals was 0.24 (Figure 4-9A), which is less than the 0.5 foot primary goal. 96.6% of the residuals were within ±0.5 foot of the observed values meeting the second goal of 67%. 100.0% of the residuals were within ±1.0 foot of the observed values meeting the third goal of 90%. The agreement between simulated and observed values covers approximately 4 vertical feet, so the final goal of meeting these abovementioned criteria over a wide range of stages is also being met.

For Lake Santa Fe, the RMSE of the residuals was 0.32 (Figure 4-9B), which is less than 0.5 foot as the primary goal. 89.0% of the residuals were within ±0.5 foot of the observed values meeting the second goal of 67%. 100% of the residuals were within ±1.0 foot of the observed values meeting the third goal of 90%. The agreement between simulated and observed values covers approximately 6 feet, so the final goal of meeting these criteria over a wide range of stages is also met.

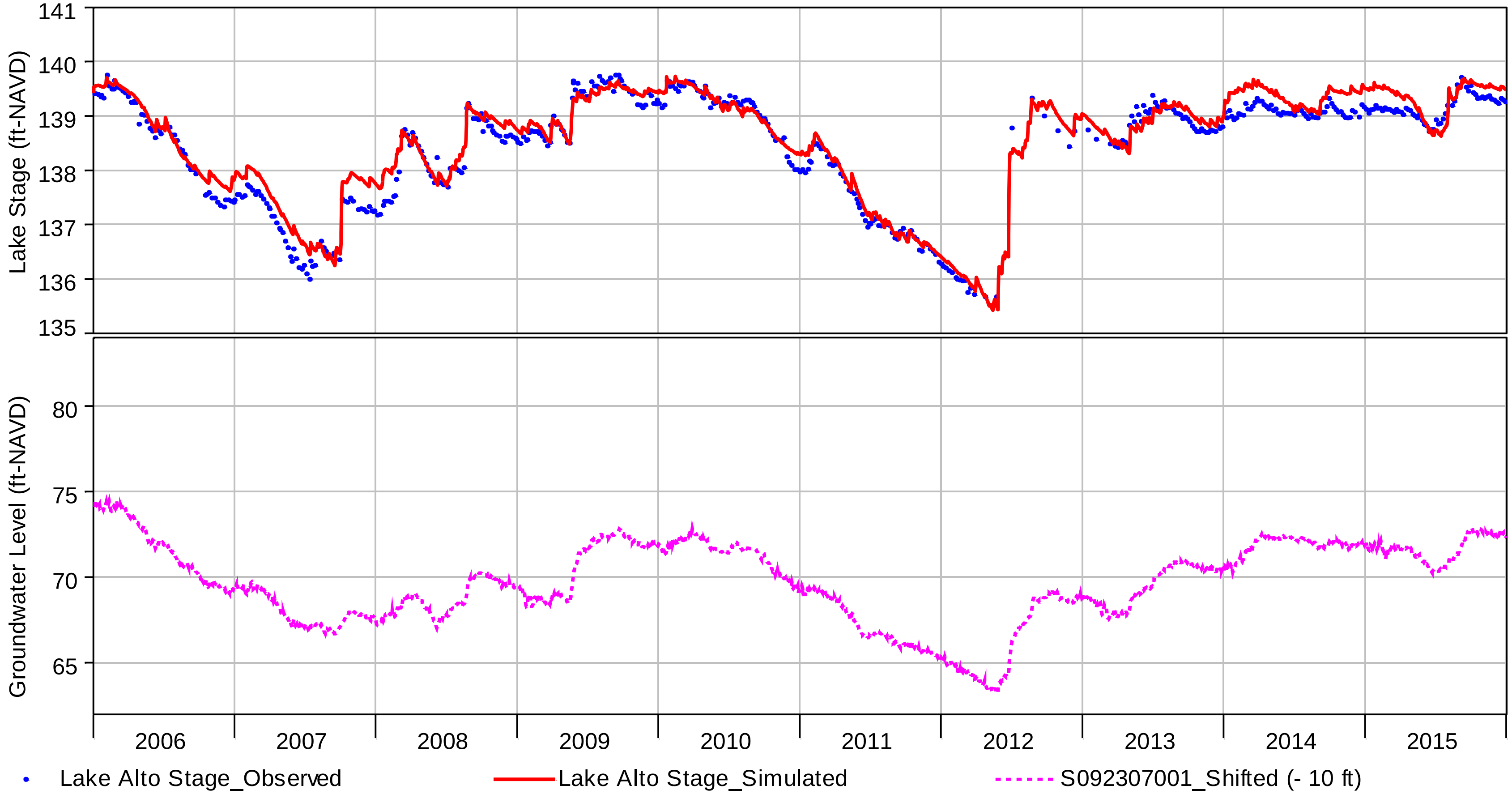


Figure 4-8A. Comparison of Observed and Simulated Lake Stage Hydrographs at Lake Alto (2006-2015).

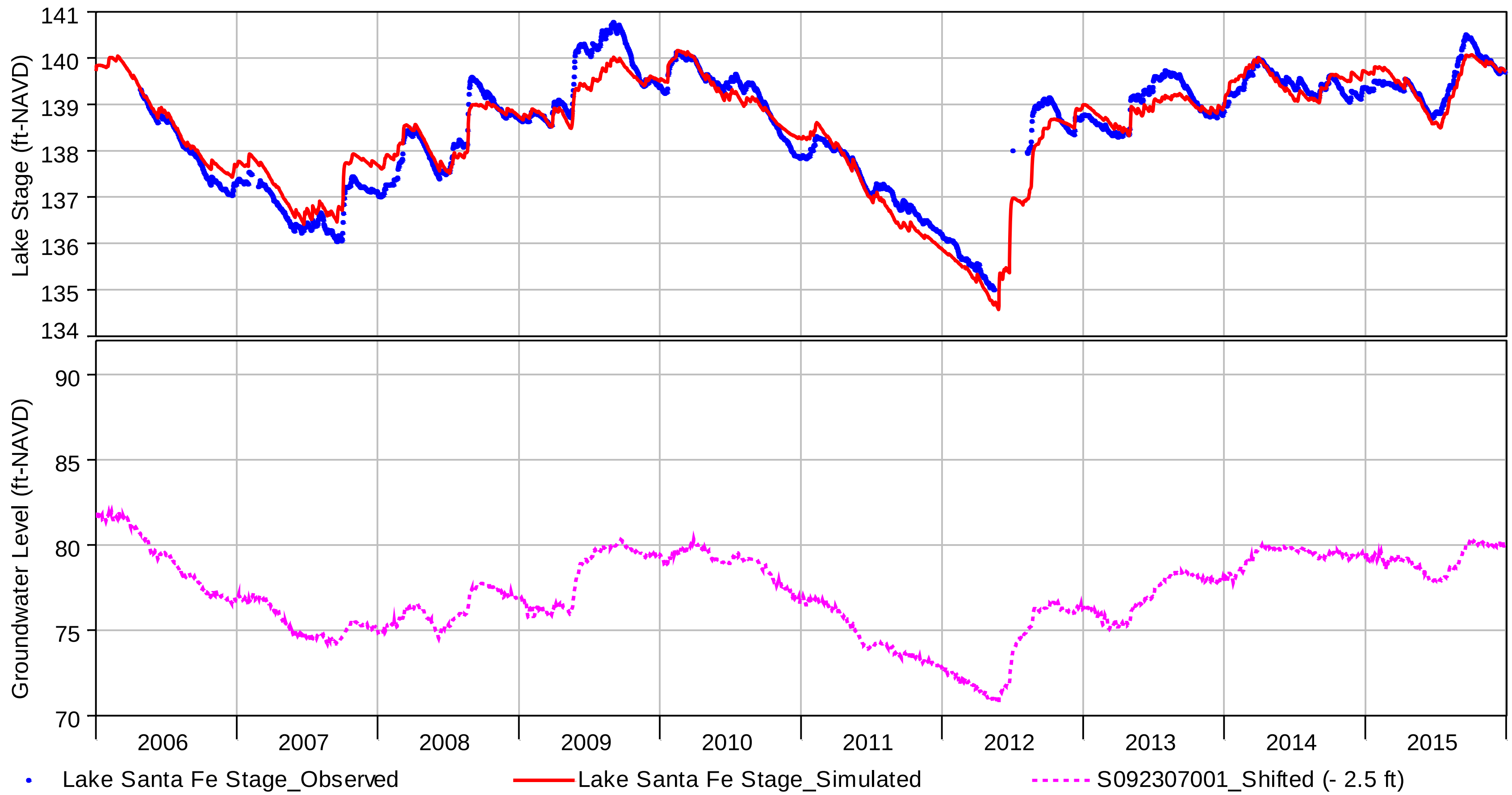


Figure 4-8B. Comparison of Observed and Simulated Lake Stage Hydrographs at Lake Santa Fe (2006-2015).

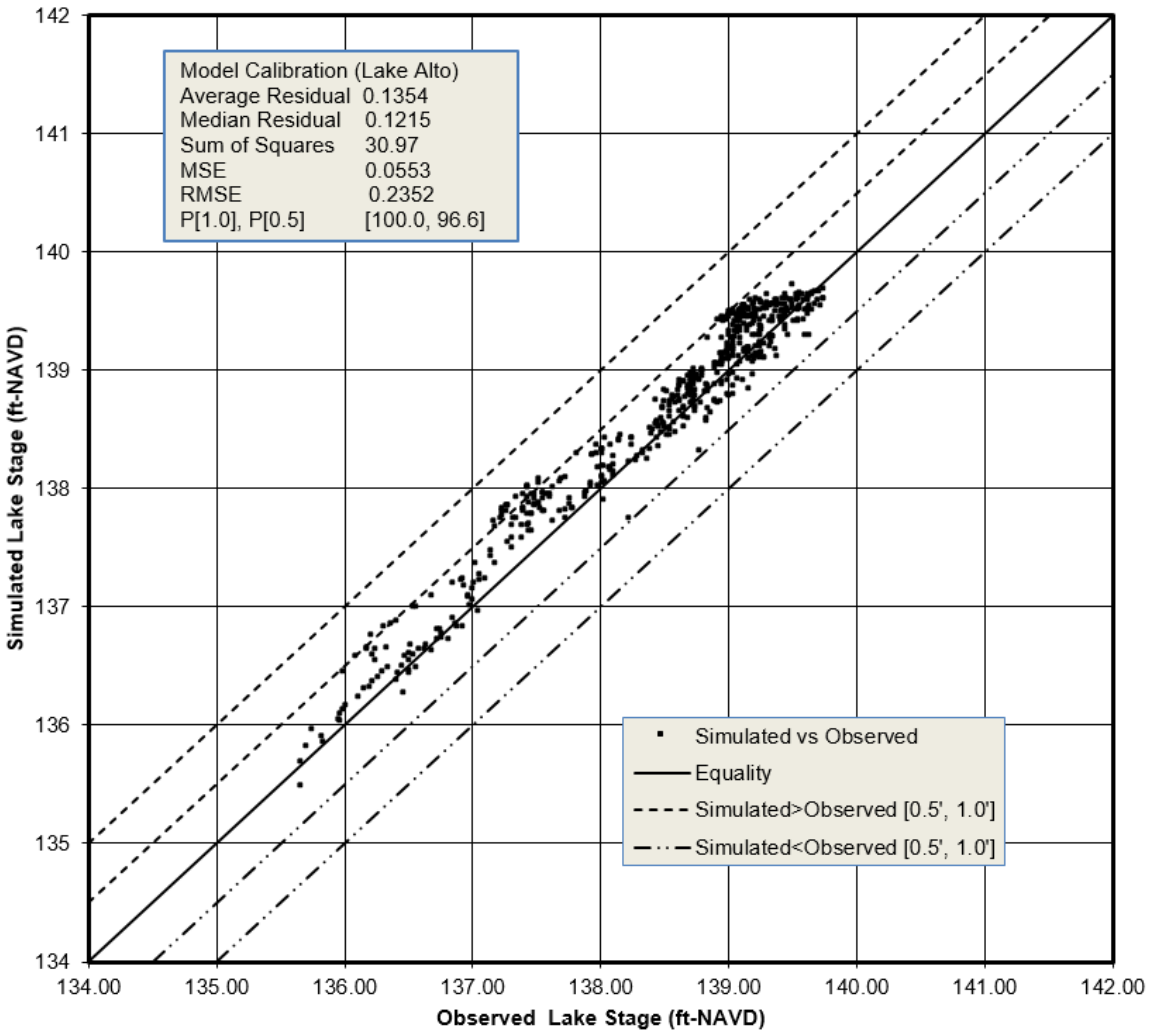


Figure 4-9A. Scatter Plot Comparing Simulated and Observed Stages at Lake Alto (2006-2015).

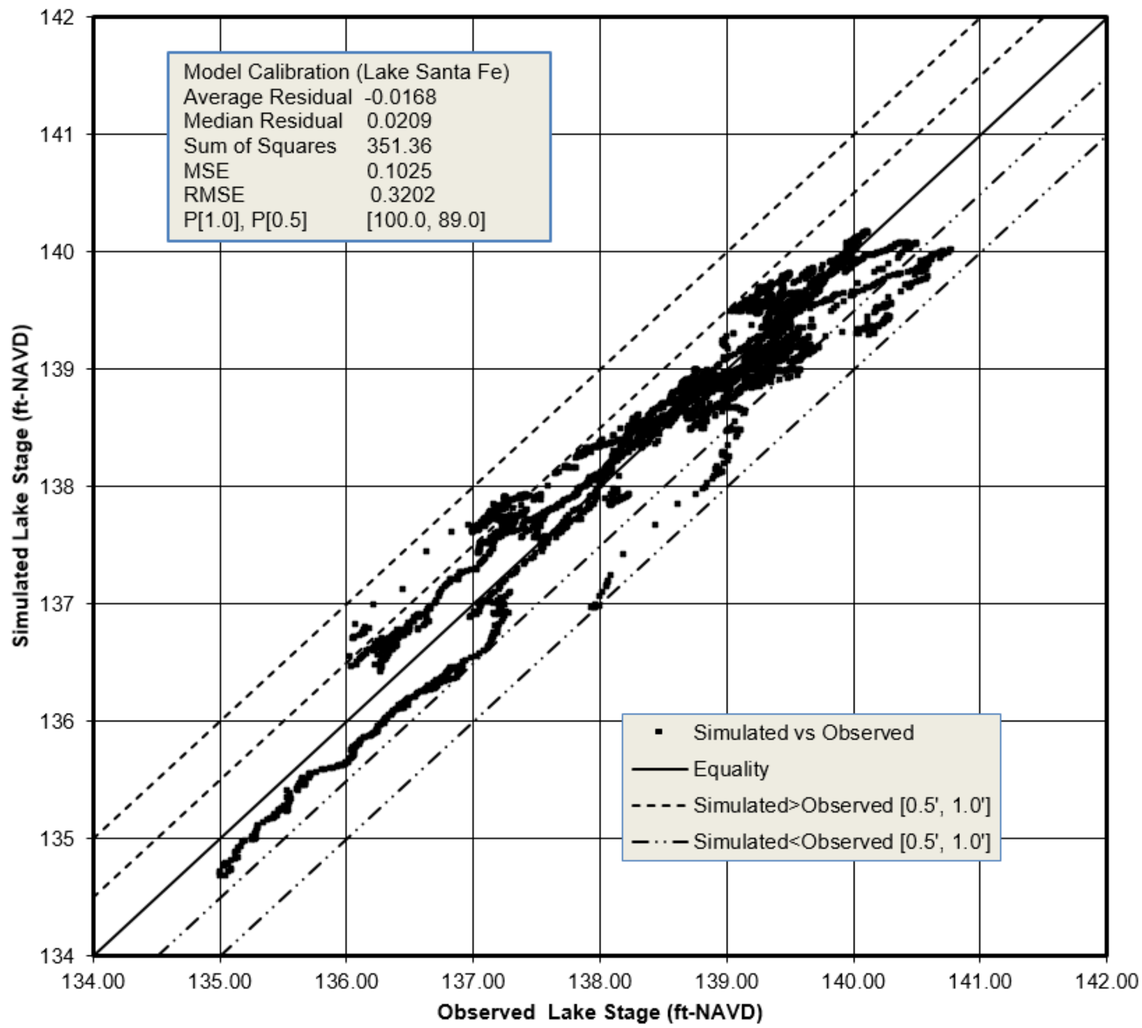


Figure 4-9B. Scatter Plot Comparing Simulated and Observed Stages at Lake Santa Fe (2006-2015).

4.4.3 Water Budget Results

The water budgets of the Lake Alto and Lake Santa Fe watershed, as simulated in the SWMM model, can be grouped into three categories: runoff quantity in subcatchments, groundwater in aquifers, and flow routing in conveyance systems. Each category consists of multiple components, as summarized below:

- Runoff Quantity
    - Precipitation
    - Evaporation
    - Infiltration
    - Surface Runoff
- Groundwater
    - Infiltration
    - Upper Zone ET
    - Lower Zone ET
    - Deep Percolation to Upper FAS
    - Groundwater Flow
    - Storage Change in Aquifers
- Flow Routing
    - Surface Runoff
    - Groundwater Flow
    - Evaporation
    - External Outflow (to Downstream Canal and Upper FAS)
    - Storage Change in Conveyance System

The water budget results of the 10-year calibration simulation were provided in the model output report file. The results of the model calibration simulation indicate that the lake watershed has on average, precipitation of 47.69 in/yr, evaporation (from land surface and conveyance system) and ET of 33.24 in/yr, deep percolation of 12.13 in/yr, outflow to the downstream canal of 2.45 in/yr, and storage change in aquifers and conveyance system of -0.13 in/yr in the 10-year simulation period from 2006 through 2015 (Table 4-9).

In the SWMM model, it is assumed that the lake watershed or model domain boundary is a no-flow boundary that has a flux of zero for both surface water and groundwater flow simulation. The simulated deep percolation to the upper FAS of 12.13 in/yr may consist of three components that were not distinguished in the model: 1) the lateral groundwater flow away from the surficial aquifer to its surrounding areas; 2) the lateral groundwater flow away from the intermediate aquifer system; and 3) the deep recharge from the intermediate aquifer system to the upper FAS. In addition, the high deep percolation rates simulated may also be attributed to various collapse structures providing preferred flow paths toward the intermediate aquifer system and/or the upper FAS (Kindinger *et al.*, 2000).

Table 4-9. Summary table of water budget results in Lake Alto and Lake Santa Fe watershed (2006-2015).

Runoff Quantity

Items	Total Volume (acre-ft)	Total Depth (in)	Average Depth (in/yr)
Precipitation	1,489,629.1	476.9	47.69
Evaporation	164,269.1	52.6	5.26
Infiltration	927,332.0	296.9	29.69
Surface Runoff	398,115.8	127.5	12.75
Final Storage	5.8	0.0	0.00

Groundwater

Items	Total Volume (acre-ft)	Total Depth (in)	Average Depth (in/yr)
Initial Storage	576,500.6	184.6	18.46
Infiltration	927,332.0	296.9	29.69
Upper Zone ET	473,988.9	151.7	15.17
Lower Zone ET	12,625.6	4.0	0.40
Deep Percolation	239,264.7	76.6	7.66
Groundwater Flow	205,301.4	65.7	6.57
Final Storage	572,355.4	183.2	18.32
Storage Change	-4,145.3	-1.3	-0.13

Flow Routing

Items	Volume (acre-ft)	Volume (10^6 Gal)	Average Depth (in/yr)
Initial Storage	107,133.2	34,911.0	3.43
Surface Runoff	398,100.8	129,727.1	12.74
Groundwater Inflow	205,301.7	66,900.6	6.57
External Outflow*	216,275.6	70,476.6	6.92
Evaporation	387,383.8	126,234.8	12.40
Final Storage	107,085.5	34,895.4	3.43
Storage Change	-47.7	-15.5	0.00
* External Outflow includes:			
To Upper Santa Fe River	76,572.9	24,951.4	2.45
To Upper Floridan Aquifer	139,695.7	45,520.0	4.47

4.4.4 Summary of Model Calibration

Based on the model calibration results for the 10-year simulation span, the Lake Alto and Lake Santa Fe water budget model has been successfully calibrated and meets both the primary and secondary goals and criteria as discussed previously. Thus, the approach and assumptions utilized in the model development and calibration tasks appear to be appropriate.

In summary, the calibrated Lake Alto and Lake Santa Fe water budget model will provide a useful tool for comparing water management alternatives in the context of MFLs.

5.0 Development of No-pumping and Current Pumping Scenarios

5.1 Introduction

The purpose of long-term continuous simulations is to assess the characteristics of a water body over a wide variety of hydrologic conditions. The MFLs establishment also relies on results of the long-term continuous simulations to determine if MFLs are being met.

The calibrated Lake Alto and Lake Santa Fe water budget model was used to run long-term simulations for a total of 55.7 years from 4/25/1960 through 12/31/2015, which is limited by the available groundwater well data at the USGS Melrose station (USGS ID: 295055082130801 / SRWMD ID: S051933001) and SJRWMD Lake Brooklyn Wells (SJRWMD ID: 70078104) (Figure 4-3).

Based on the recent reference timeframe (RTF) analysis results provided by the District, the groundwater level data set for the no-pumping and current pumping scenarios were created using the "measured" groundwater data set estimated for the major lakes and sinkholes, which is described in Section 5.2.3.

In this report, the term RTF data set is referred to as the "no-pumping" groundwater levels, which was created by adding the RTF adjustment factors to the measured groundwater level data set. "Current," as used here, refers to the end of the hydrologic record utilized to develop the MFLs, in this case, 2015. Current pumping groundwater level data set represents a 2015 average water use for the District and a 2011-2015 average water use for the SJRWMD portions in the model domain of a groundwater model used for the RTF analysis by the District.

The 55.7-year model period includes four low lake stage events and over ten high periods (Figure 4-6A). All the low lake stage periods occur between 1990 and 2012 and coincide with decreased rainfall at those times, as illustrated in Figures 5-1A and 5-1B that were developed by the District. The lake stages have since rebounded to pre-drought levels. The lake stage data during the 55.7-year model period appears to be representative of the longer lake stage data history. It was assumed that this period of record is a reasonable representation of the long-term lake hydrology for use in MFL development. The use of the simulated lake stage data sets also allows for analysis over a greater portion of the Atlantic Multidecadal Oscillation (Enfield *et al.*, 2001).

In subsequent sections, the calibrated model was updated to 2016 land use conditions for MFL evaluation as it is the most recent land use data.

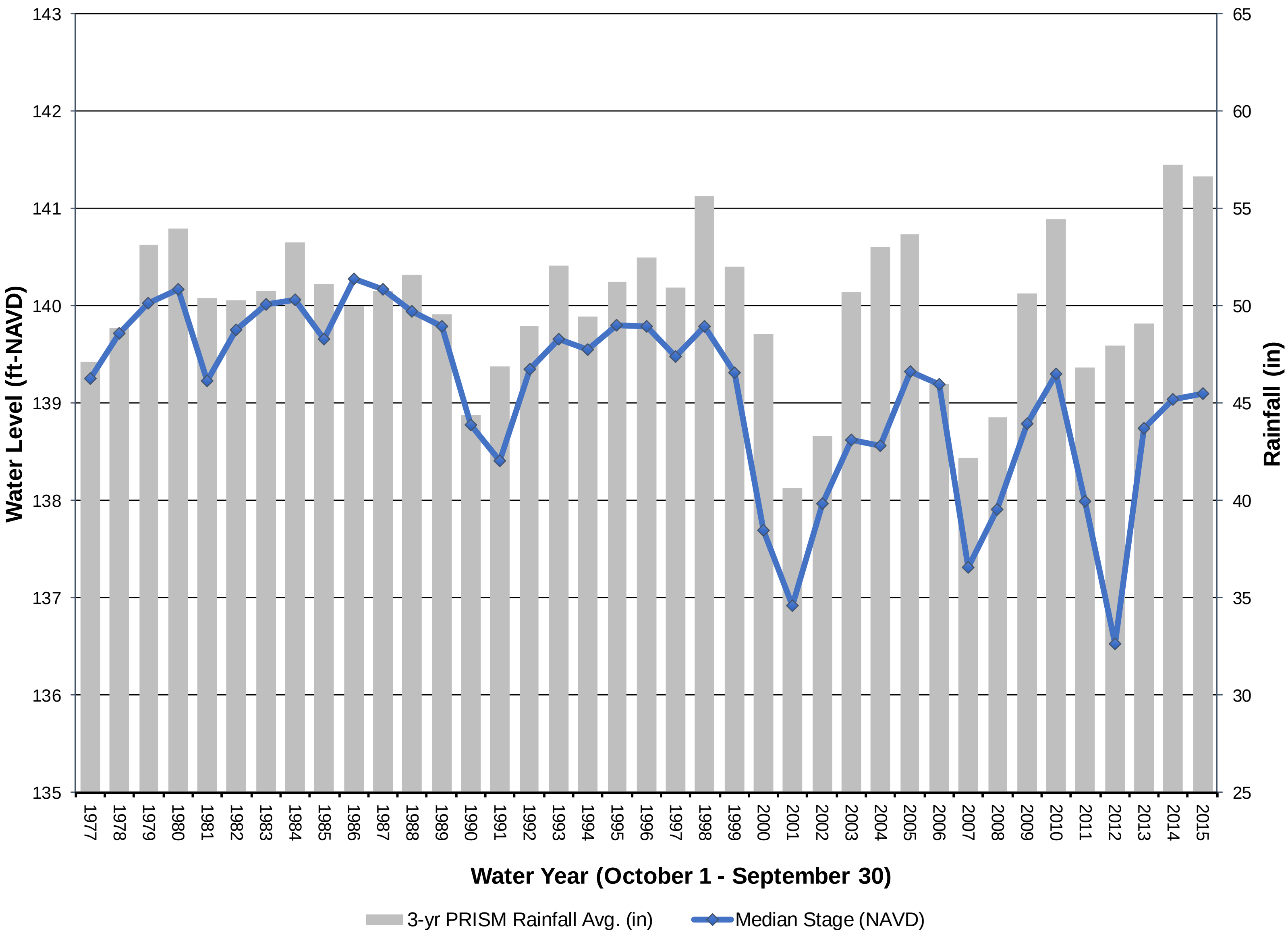


Figure 5-1A. Annual Median Lake Stage vs. PRISM Rainfall (3-Yr Average) (WY 1977-2015) at Lake Alto.

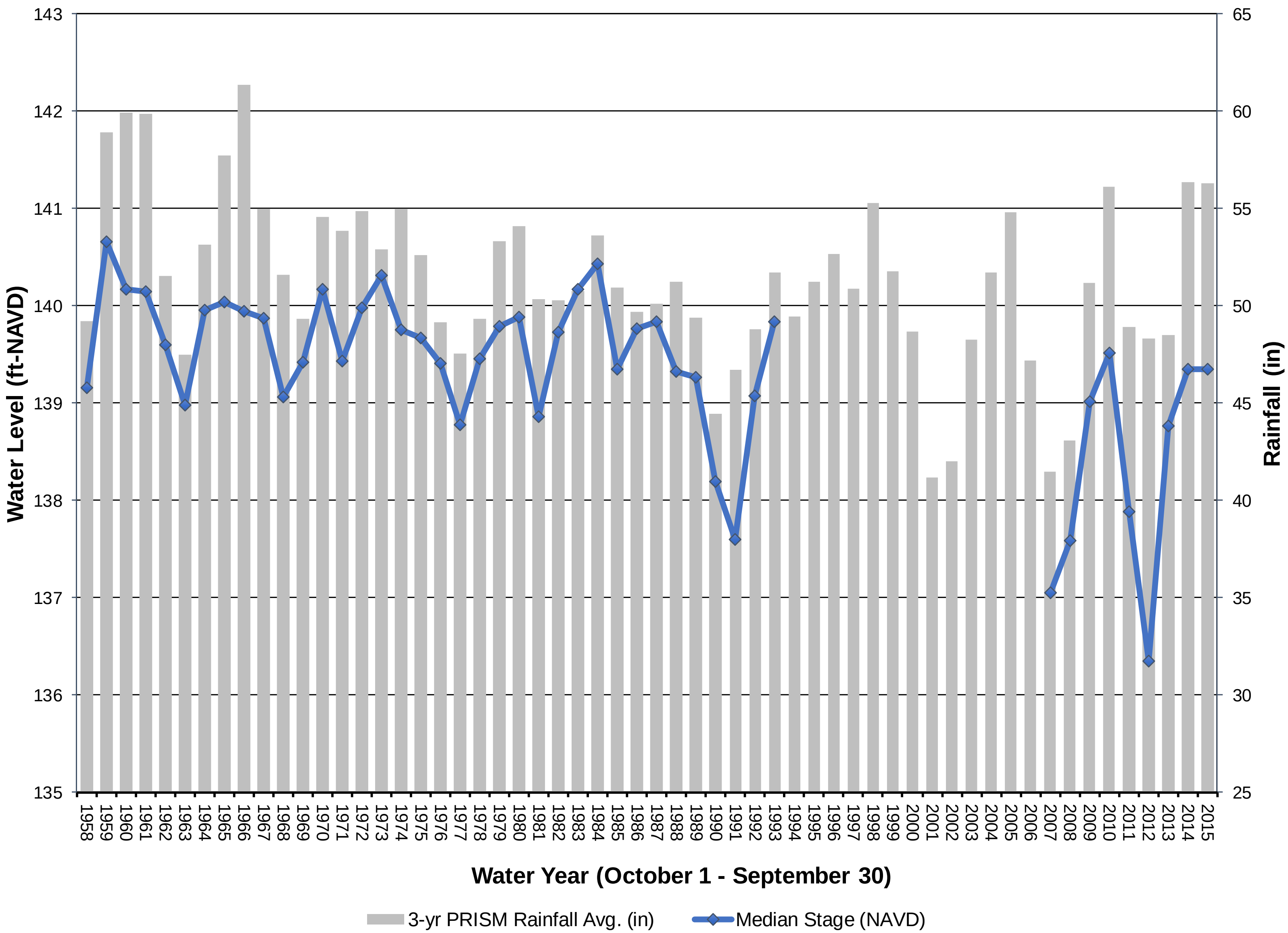


Figure 5-1B. Annual Median Lake Stage vs. PRISM Rainfall (3-Yr Average) (WY 1958-2015) at Lake Santa Fe.

5.2 Long-term Model Data Assembling and Evaluation

Expansion of the model simulations from the 10-year calibration period to a long-term simulation requires assembling and evaluation of additional time series data, including rainfall, ET, and potentiometric surface levels of the upper FAS (Table 5-1). The data used for the model calibration, as discussed in Section 4.3.1, were retained for use in the long-term simulations.

Table 5-1. Time series data used in model calibration and long-term simulations.

Simulation	Rainfall	Evapotranspiration	FAS Well Level
Calibration (2006-2015)	NEXRAD (1/1/2006 - 12/31/2015)	USGS PET (1/1/2006-12/31/2015)	SRWMD S092307001 (1/1/2006 – 12/31/2015)
Long-term Simulations (1960-2015)	SJRWMD at Starke station (4/25/1960 – 12/31/1979) Oak Ridge National Laboratory (ORNL) Daymet (1/1/1980 - 1/31/2001) NEXRAD (2/1/2001 - 12/31/2015)	NOAA Pan Evaporation at Gainesville and Lake City stations (1/1/1960 – 8/24/2015) USGS PET (6/1/1995-12/31/2015)	SRWMD S092307001 (5/1/1983 – 12/31/2015) SJRWMD 70078104 (4/25/1960 – 3/30/2015)

Source: ORNL, 2016; NOAA, 2016; USGS, 2016; SRWMD, 2016 & 2021.

In addition, the 2016 land use map was collected and utilized in the subsequent long-term modeling analysis, to be consistent with the current pumping conditions to be assessed in this project,

5.2.1 Rainfall

As NEXRAD rainfall data previously used for the model calibration is only available after February 2001, the Daymet daily rainfall data developed by ORNL was employed to extend the rainfall records used in the model calibration. Similar to the NEXRAD rainfall data, the Daymet rainfall data was organized in individual 1 km x 1 km pixels, each of which has daily rainfall estimates (Figure 5-2). A long-term NOAA rainfall station is located near Starke, FL, approximately 10 miles north of Lake Santa Fe (Figure 4-3). SJRWMD has assembled daily rainfall data at the NOAA Starke station for a period from 1/1/1941 to 12/31/2012, filled with data collected at several rainfall stations in the vicinity.

The rainfall data from 4/25/1960 to 12/31/1979 at the NOAA Starke station, the Daymet rainfall data from 1/1/1980 to 1/31/2001, and the NEXRAD rainfall data from 2/1/2001 to 12/31/2015 (Table 5-1), were assembled to be used in the long-term model simulations.

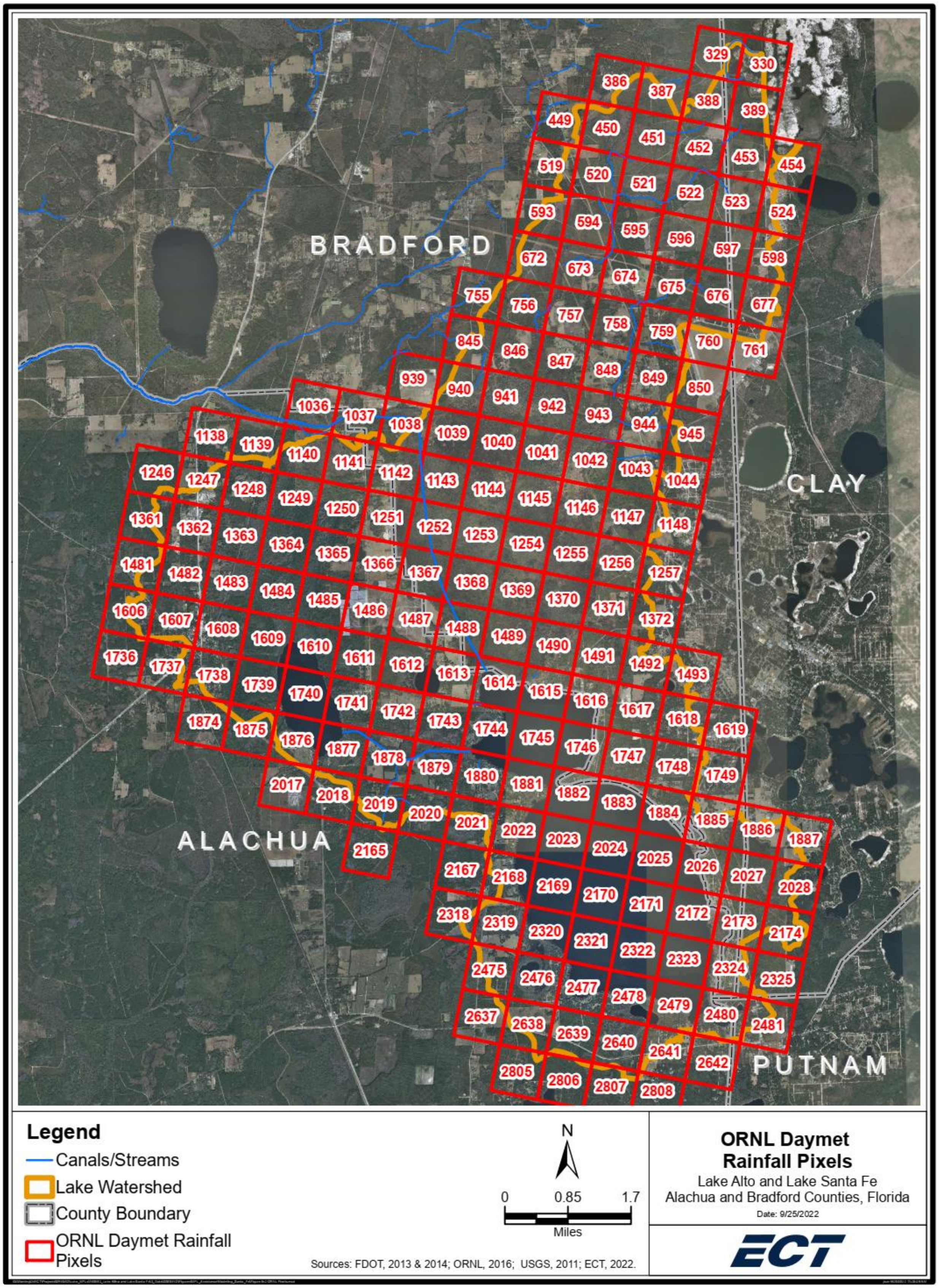


Figure 5-2. ORNL Daymet Rainfall Pixels.

5.2.2 Evapotranspiration

The daily PET data developed by the USGS in individual 2 km x 2 km pixels (Figure 4-1) has a period of record from 6/1/1995 to 12/31/2015.

The daily pan evaporation data collected at three NOAA weather stations, including two at Gainesville, FL and one at Lake City, FL, was used to extend the PET record back to 1960. Upon review of the pan evaporation data at these three stations, the two Gainesville stations (USC00083321 and USC00083322) were selected to estimate the PET data prior to 6/1/1995 since these two Gainesville stations are closer to the lake watershed compared to the Lake City station. The following data processing steps were involved to accomplish this task:

1. The daily pan evaporation data at the two Gainesville stations were first combined as one Gainesville station with a period of record (POR) from 1960 through 2000. The missing data at the Gainesville (combined) station and Lake City station (with a POR from 1960 through 2015) were filled using a linear interpolation method;
2. The annual pan evaporation values for Years 1982 to 2000 were generated for these two stations. The average ratio of the Lake City / Gainesville (combined) annual pan evaporation data was estimated at 1.095;
3. The annual pan evaporation values for Years 1996 to 2008 were generated for the Lake City station. The annual PET values for the same period were created based on the USGS area-weighted daily PET Data (Figure 4-2). The average ratio of the USGS / Lake City annual PET/pan evaporation data was estimated at 0.712; and
4. A transfer factor of 0.78 (1.095 x 0.712) was calculated and used to convert pan evaporation data at the Gainesville (combined) station to PET for a POR from 1/1/1960 to 5/31/1995.

In summary, the daily PET data required for the long-term model simulation with a span of 55.7 years (Table 5-1 and Figure 5-3A) were developed by combining the USGS PET data with the PET values estimated from the NOAA pan evaporation data. The annual PET data for Years 1960 through 2015, as illustrated in Figure 5-3B, were created based on the abovementioned daily PET data. The annual PET appears to coincide with decreased rainfall (Figures 5-1A and 5-1B).

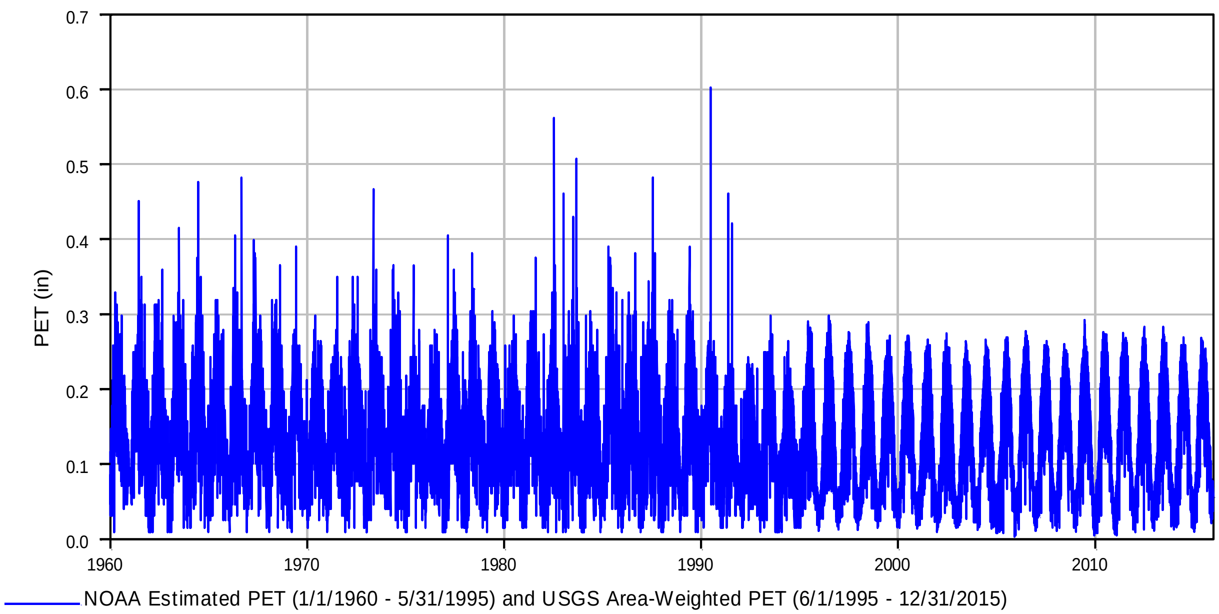


Figure 5-3A. Daily NOAA and USGS Potential Evapotranspiration Data (1960-2015).

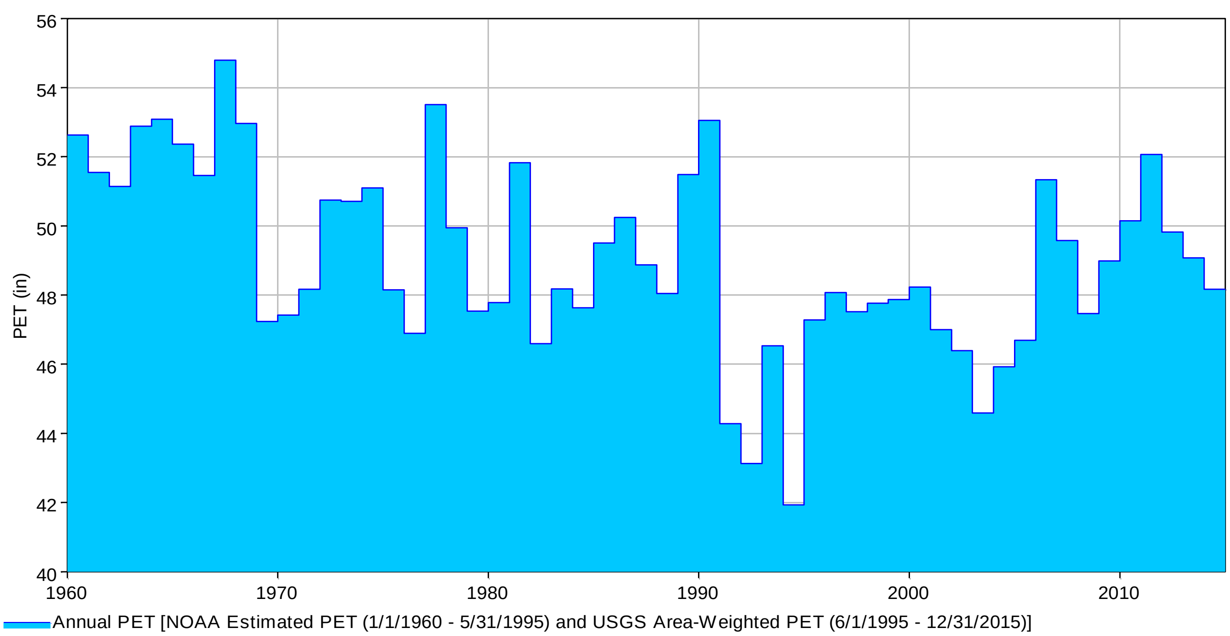


Figure 5-3B. Annual NOAA and USGS Potential Evapotranspiration Data (1960-2015).

5.2.3 Upper FAS Potentiometric Surface Levels

The groundwater level data collected at the USGS Melrose station (USGS ID: 294313082024601 / SRWMD ID: S092307001, data record starting on 4/28/1983) and the SJRWMD Lake Brooklyn Wells near Keystone Heights, FL (SJRWMD ID: 70078104, data record starting on 4/25/1960) was used to estimate the groundwater conditions beneath the major lakes and sinkholes (Table 5-1 and Figure 5-4A), by applying the method discussed in Section 4.3.1.3. Note that the period of record for the USGS Melrose station and the SJRWMD Lake Brooklyn Wells limited the long-term simulation period to 55.7 years (4/25/1960-12/31/2015).

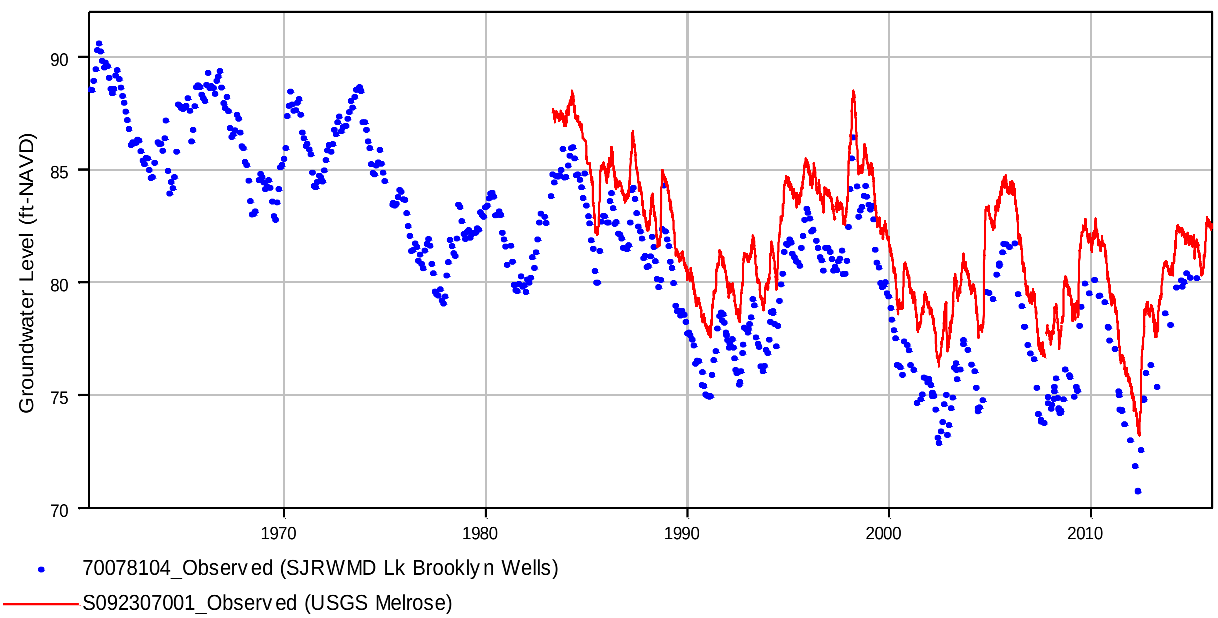


Figure 5-4A. Observed Groundwater Levels at SJRWMD Lake Brooklyn Wells and USGS Melrose Station (1960-2015).

A linear regression analysis was performed by using the observed data collected at the SJRWMD Lake Brooklyn Wells and USGS Melrose station. A total of 71 groundwater level data pairs between 4/28/1983 and 12/28/1989 were used in the regression analysis. The R^2 value is 0.98 for the resultant linear regression curve (Figure 5-4B). The daily groundwater level values from 4/25/1960 to 4/27/1983 were then estimated at the USGS Melrose station, by 1) estimating the groundwater level data at the USGS Melrose station at irregular intervals with the observed data at the Lake Brooklyn Wells and the resultant linear regression curve and 2) generating the daily groundwater level data with a linear interpolation method. Finally, the calculated daily groundwater level data set was combined with the observed groundwater level data to develop a longer groundwater level data set at the USGS Melrose station. The estimated groundwater level data set significantly extended the simulation period of the water budget model by over two decades.

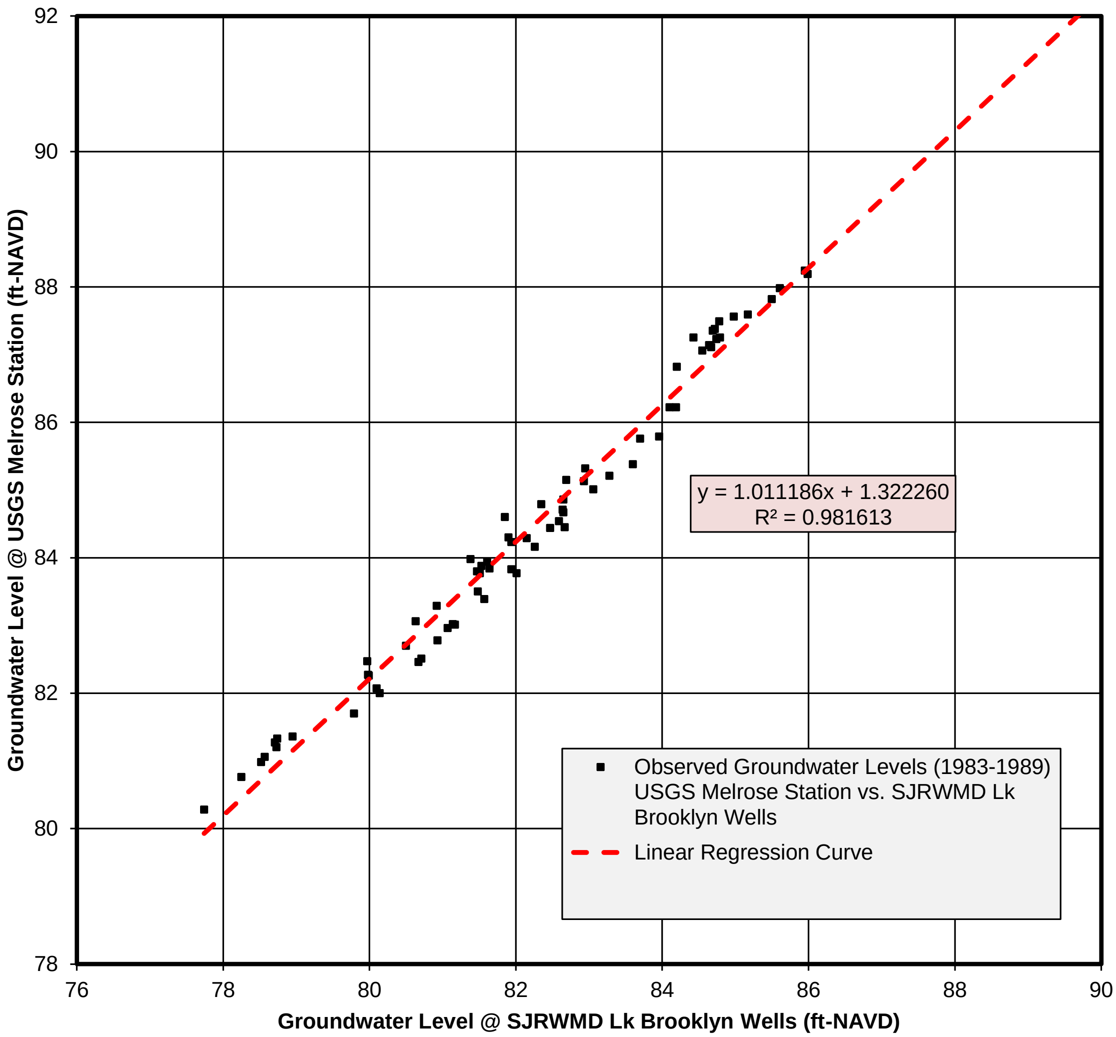


Figure 5-4B. Correlation Analysis of Groundwater Levels - SJRWMD Lake Brooklyn Wells vs. USGS Melrose Station (1983-1989).

The estimated shift factors, as listed in Table 4-2, were applied to the estimated groundwater level data set at the USGS Melrose station. The observed and filled well hydrographs, as well as the shifted well hydrographs, are illustrated on Figure 5-5. The shifted groundwater well hydrographs were used to represent the groundwater conditions beneath the major lakes and sinkholes and these data sets are referred to as the measured data sets.

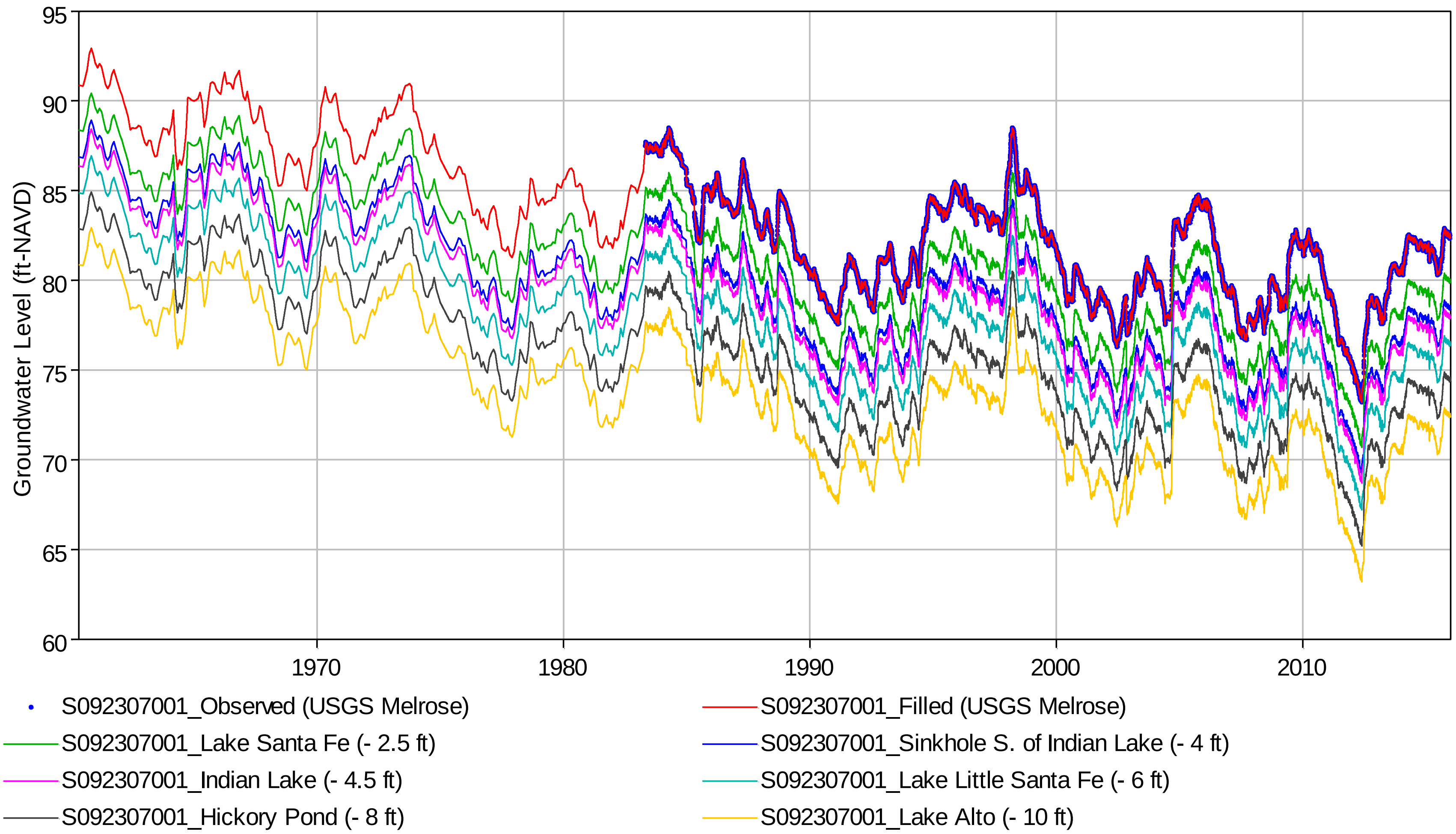


Figure 5-5. Observed/Filled/Shifted Groundwater Level Hydrographs at USGS Melrose Station (1960-2015).

5.2.4 Reference Timeframe Analysis

Evaluating the historic influence of water use on flows and levels in regional rivers, springs, lakes, and estuaries is a component of the MFL process in the District. Groundwater is the source of most potable water used in the northeastern Florida and southeastern Georgia (SJRWMD & SRWMD, 2017). To evaluate the historic influence of groundwater withdrawals, estimates of groundwater use over time were prepared by the District for the area encompassed by the NFSEG model domain.

A technical memorandum *Development of a Reference Timeframe Flow (RTF) Regime for the Minimum Flows and Minimum Water Levels (MFLs) Re-Evaluation of the Lower Santa Fe and Ichetucknee Rivers and Priority Springs* was developed by the District in 2019 and published as Appendix D of a recent MFL report *Minimum Flows and Minimum Water Levels Re-Evaluation for the Lower Santa Fe and Ichetucknee Rivers and Priority Springs* (HSW, 2021). This memo outlines the process used to develop reference timeframe flow and/or groundwater-head (head) time-series (e.g., no-pumping condition) at groundwater monitoring locations, springs and/or stream gage locations using observed and modeled data and an estimated time series of historic groundwater withdrawals. The model used in this analysis is the North Florida Southeast Georgia Groundwater Model, (NFSEG 1.1) (Durden *et al.* 2019). For the reference timeframe analysis, a reference timeframe head (level), or flow time-series (RTF) is defined as an estimate of the historic time-series that would have been observed in the absence of any groundwater withdrawals (HSW, 2021).

The RTF adjustment factors for groundwater levels were estimated by the District for the USGS Melrose station, Lake Alto, and Lake Santa Fe for a period of 1948 through 2015, as illustrated in Figure 5-6.

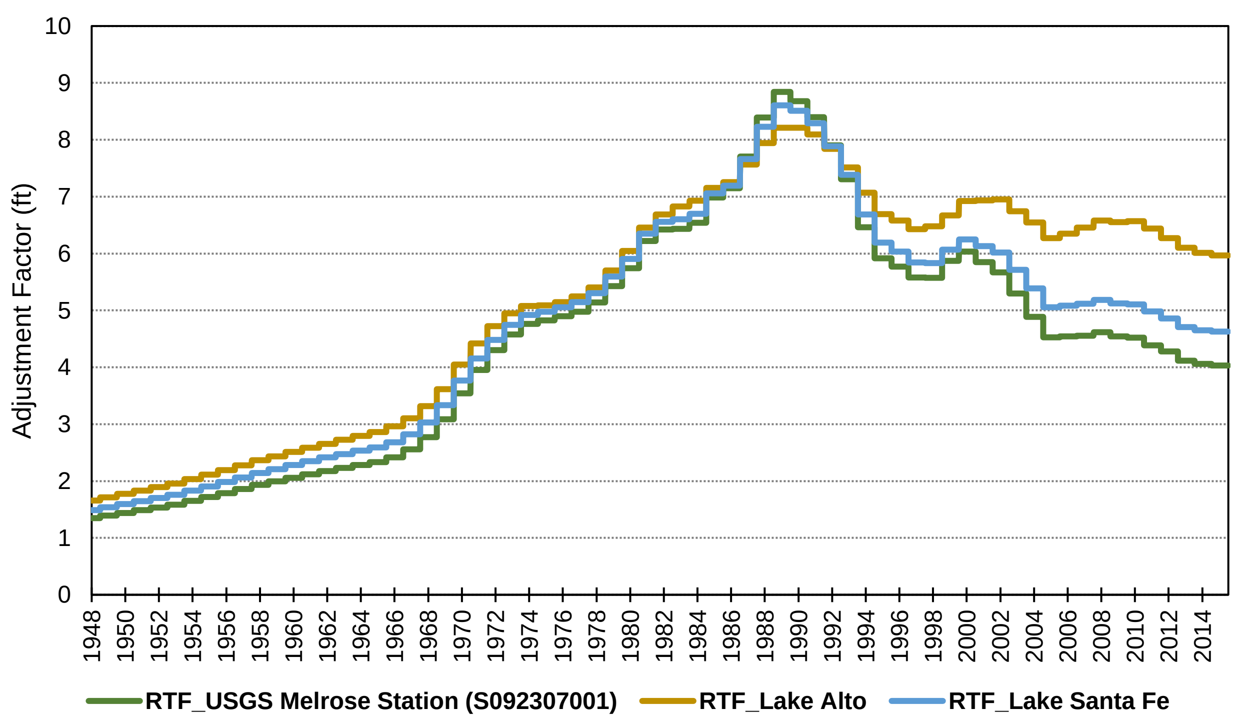


Figure 5-6. RTF Adjustment Factors at USGS Melrose Station, Lake Alto, and Lake Santa Fe (1948-2015).

In this report, the term RTF data set is referred to as the no-pumping groundwater levels, which was created by adding the RTF adjustment factors to the measured groundwater level data set. Additionally, the District conducted a separate model simulation in the NFSEG model for current pumping groundwater levels that represents a 2015 average water use for the District and a 2011-2015 average water use for the SJRWMD portions of the model domain. Upper FAS drawdown values of 5.87 and 4.89 feet were estimated for the current pumping scenario beneath Lake Alto and Lake Santa Fe, respectively. The drawdown values were subtracted from the no-pumping data sets to create a consistent (i.e., stationary pumping through time) current pumping data set for each lake. Note that the Upper FAS drawdown value of 4.89 feet estimated at Lake Santa Fe was applied to all other major lakes and sinkholes, except for Lake Alto. The measured, no-pumping, and current pumping groundwater level data sets at the USGS Melrose station, the major lakes, and sinkholes for a period of 1960 through 2015 are illustrated in Figures 5-7A through 5-7G. As shown in these figures, the current pumping groundwater levels in the 1980s and 90s are higher than the measured data set, due to higher RTF adjustment factors than the upper FAS drawdowns estimated at Lake Alto and Lake Santa Fe for the current pumping scenario (Figure 5-6), i.e., more pumping during 1980s and 90s than the current pumping scenario.

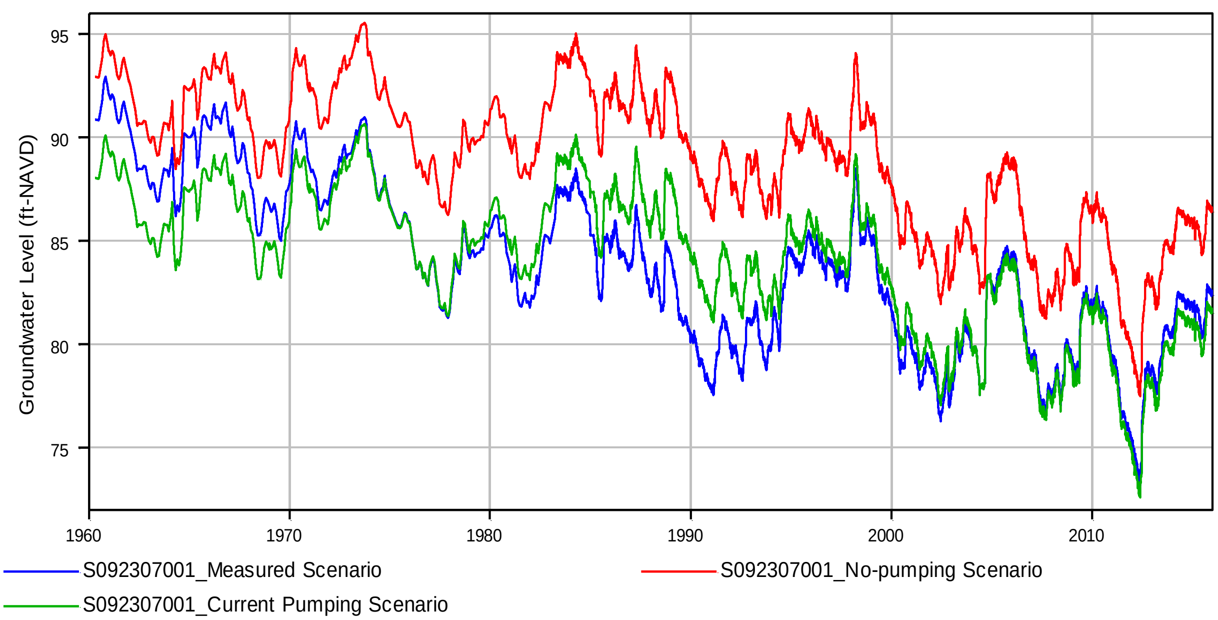


Figure 5-7A. Groundwater Level Hydrographs at USGS Melrose Station - Measured, No-pumping & Current Pumping Scenarios (1960-2015).

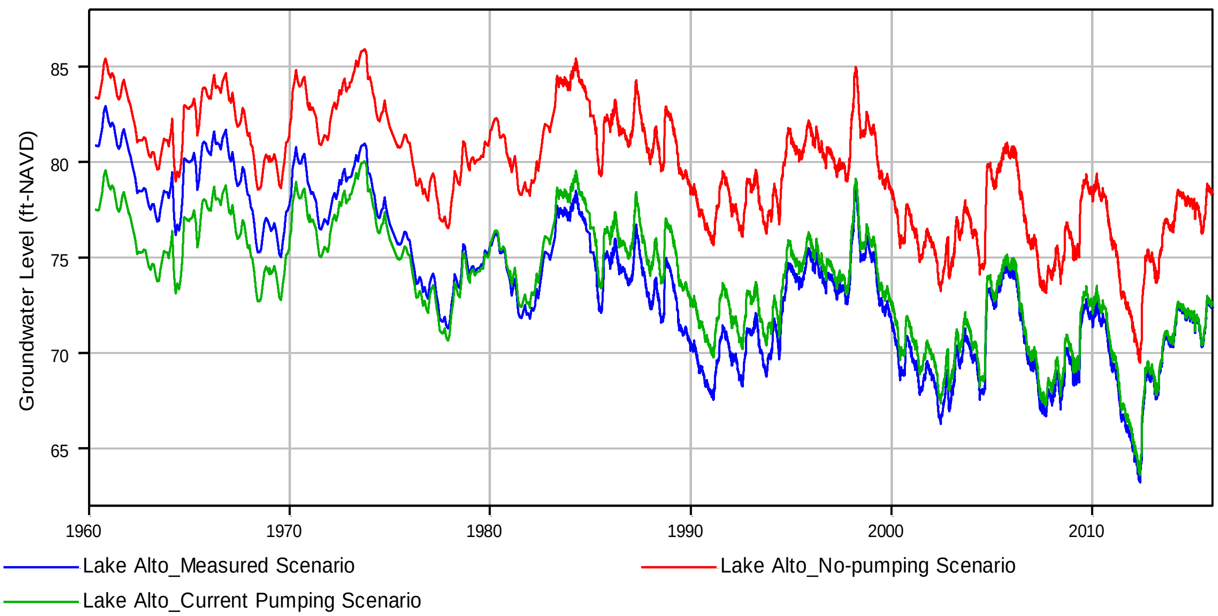


Figure 5-7B. Groundwater Level Hydrographs at Lake Alto - Measured, No-pumping & Current Pumping Scenarios (1960-2015).

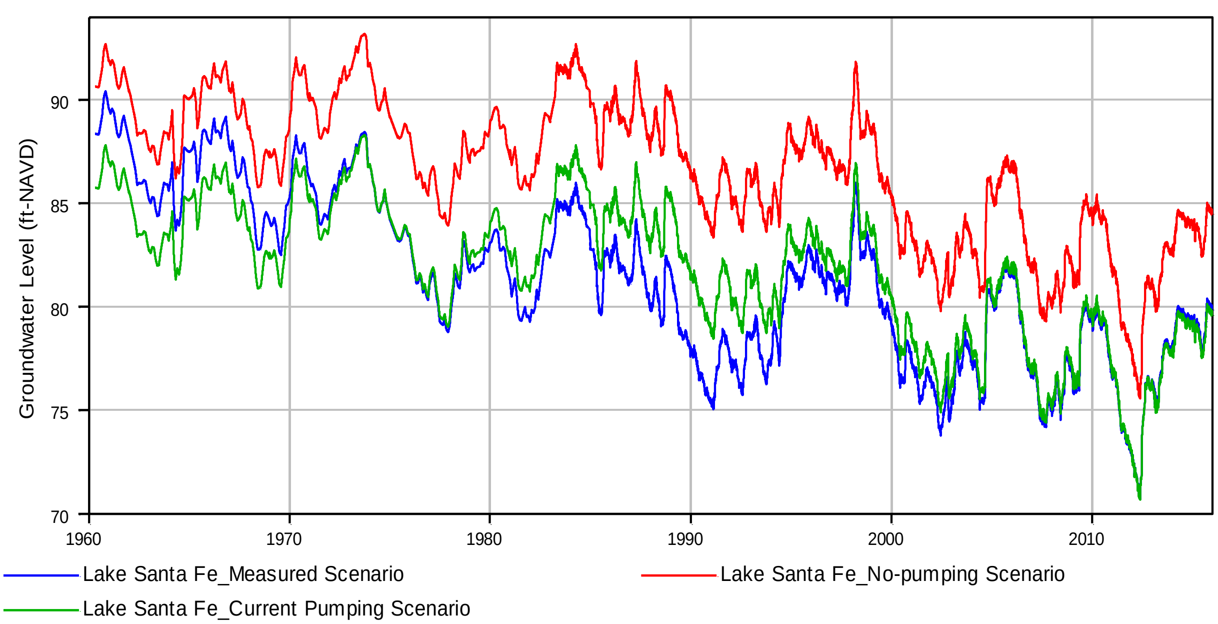


Figure 5-7C. Groundwater Level Hydrographs at Lake Santa Fe - Measured, No-pumping & Current Pumping Scenarios (1960-2015).

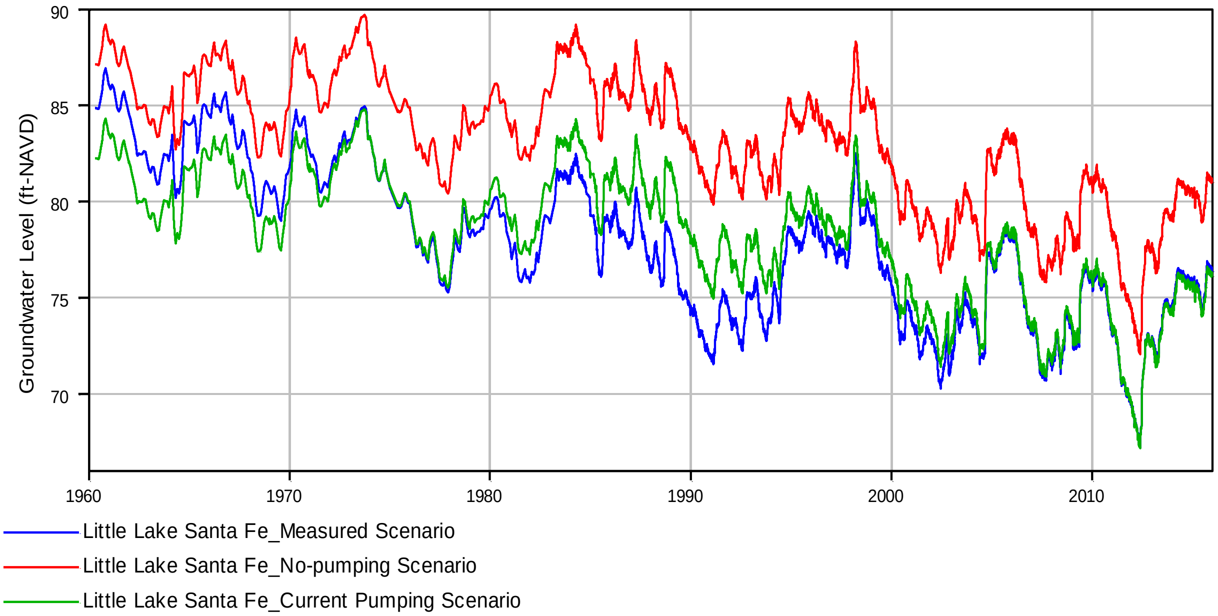


Figure 5-7D. Groundwater Level Hydrographs at Little Lake Santa Fe - Measured, No-pumping & Current Pumping Scenarios (1960-2015).

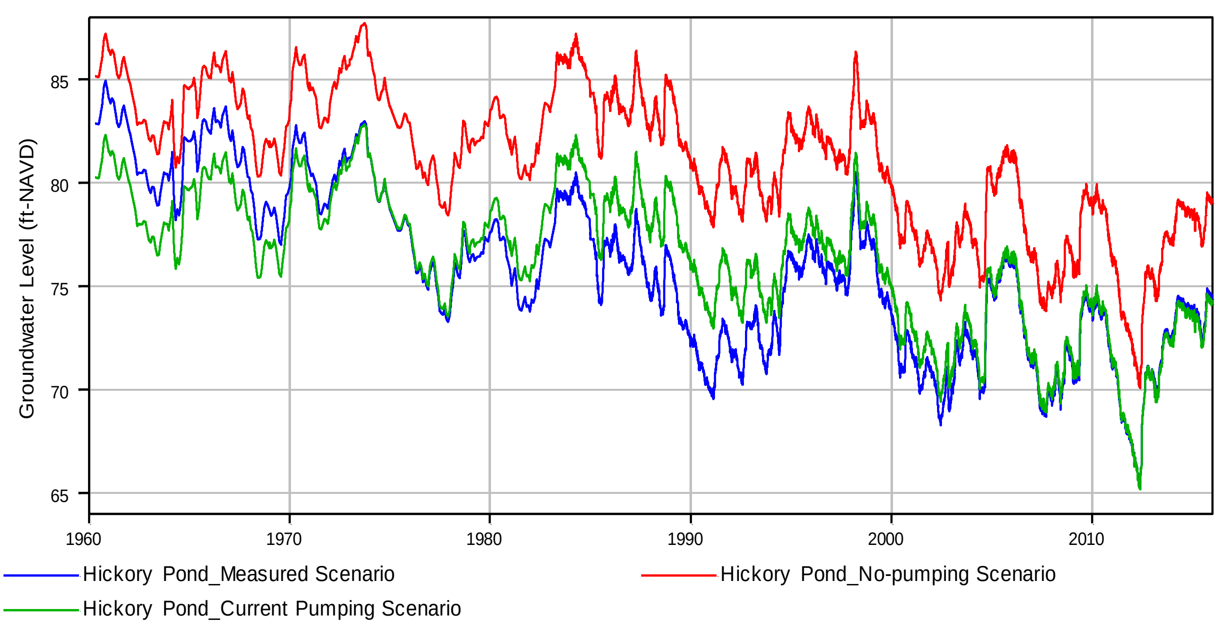


Figure 5-7E. Groundwater Level Hydrographs at Hickory Pond - Measured, No-pumping & Current Pumping Scenarios (1960-2015).

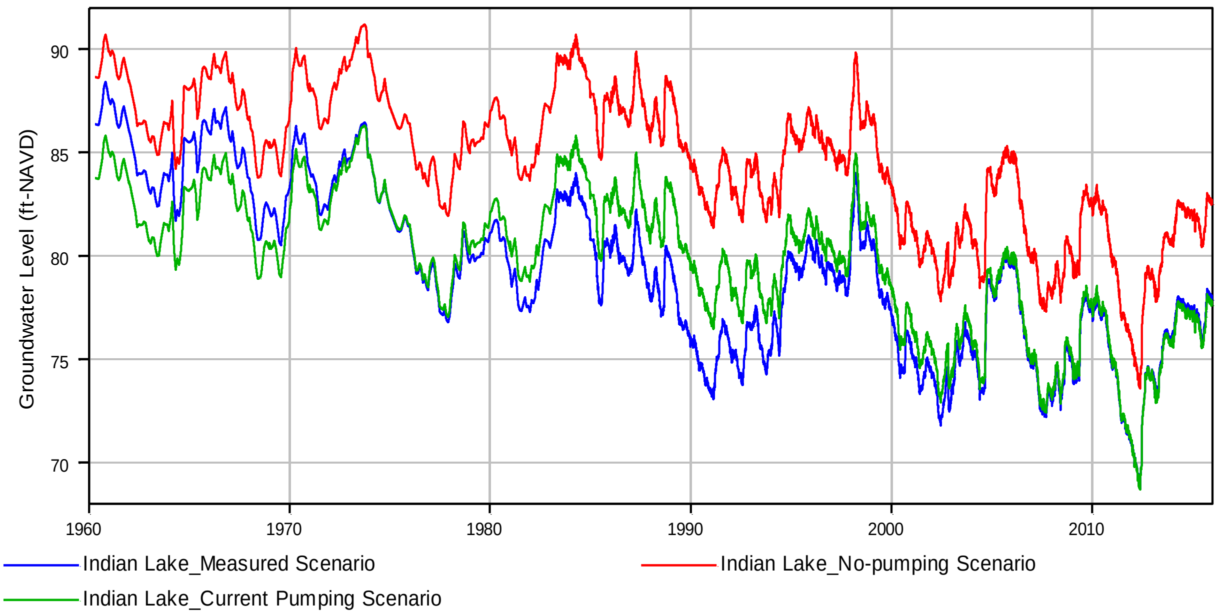


Figure 5-7F. Groundwater Level Hydrographs at Indian Lake - Measured, No-pumping & Current Pumping Scenarios (1960-2015).

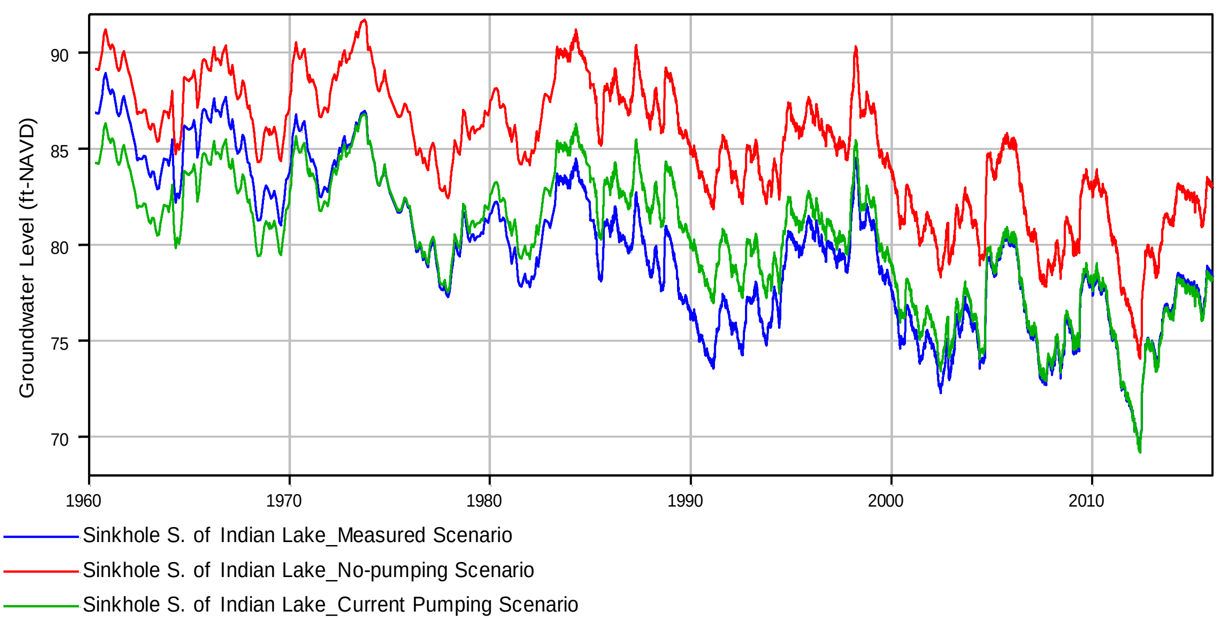


Figure 5-7G. Groundwater Level Hydrographs at Sinkhole South of Indian Lake - Measured, No-pumping & Current Pumping Scenarios (1960-2015).

5.2.5 2016 Land Use/Land Cover

As described in Sections 3 and 4, the 2004/2006 land use data was used in the model development and calibration. However, to be consistent with the current pumping conditions to be assessed in this project, the 2016 state-wide land use map assembled by the Florida Department of Environmental Protection (FDEP) from all WMD's land use databases was downloaded and utilized in model parameterization for the subsequent long-term modeling simulations (Figure 5-8).

Comparison results of the 2004/2006 and 2016 land use data in the lake watershed are summarized in Table 5-2. As shown in this table, the most significant land use change occurred for the wetlands and barren lands (FLUCCS 6000 and 7000), mostly due to reclassification of the burned areas in the Santa Fe Swamp from barren lands in 2004/2006 to wetlands in 2016. The second largest change occurred at rangeland (FLUCCS 3000), with an approximately 691-acre increase, which is approximately 1.8% of the total watershed area. One of the major acreage increases in rangeland was found at the northeast corner of the lake watershed where the reclaimed land (FLUCCS 1650) was reclassified as rangeland (Figures 2-4 and 5-8).

Table 5-2. Comparison of 2004/2006 and 2016 land use data in Lake Alto and Lake Santa Fe watershed.

FLUCCS	Description	2004/2006 Area (acre)	2016 Area (acre)	Difference (acre)	2016 % of 2004/2006
1000	Urban & Built-up	3,138.0	2,942.9	-195.07	93.78%
2000	Agriculture	3,025.7	2,860.7	-165.06	94.54%
3000	Rangeland	783.2	1,474.2	690.92	188.21%
4000	Upland Forests	11,668.8	11,466.1	-202.73	98.26%
5000	Waters	5,849.2	6,017.4	168.19	102.88%
6000	Wetlands	9,651.9	12,210.6	2,558.62	126.51%
7000	Barren Lands	3,029.4	81.4	-2,948.02	2.69%
8000	Transportation, Communication & Utilization	337.5	430.6	93.14	127.60%
	Total	**37,483.8**	**37,483.8**	**0.00**	**100.0%**

Source: SRWMD, 2006; SJRWMD, 2004; FDEP, 2022.

Based on the 2016 land use data, the lookup table of hydrologic parameters for surface runoff calculation (Table 4-3), and the approach described in Section 4.3.2.1 for model calibration, the hydrologic parameters for each subbasin were recalculated, as listed in Table 5-3, and utilized in the long-term model simulations.

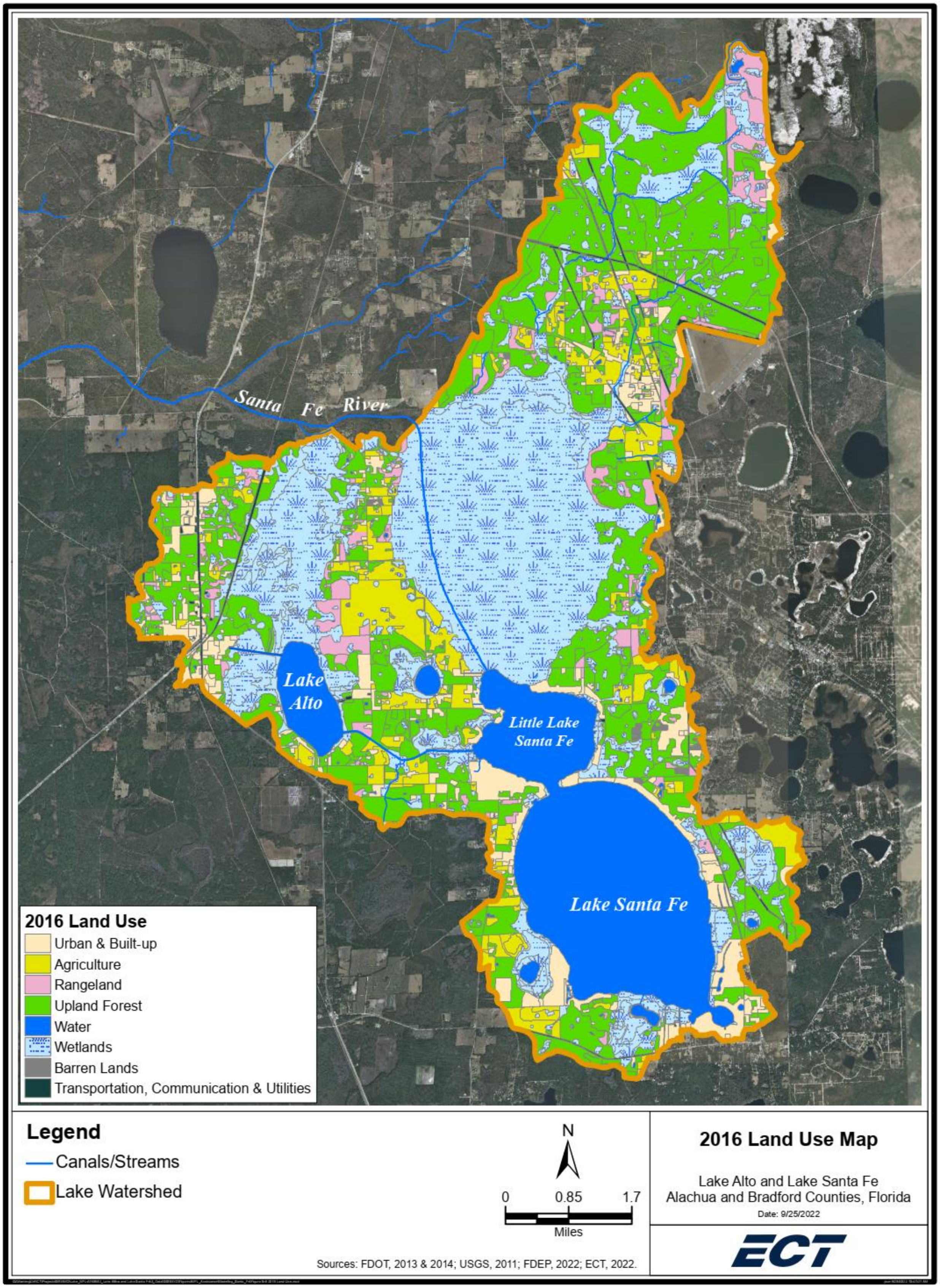


Figure 5-8. 2016 Land Use Map.

Table 5-3. Summary table of revised hydrologic parameters in subbasins –2016 land use.

Subbasin Name	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.
A0100	34.32	58.91	0.083	0.262	0.197	0.351
A0110	22.05	43.91	0.068	0.226	0.101	0.283
A0120	11.86	34.43	0.059	0.240	0.055	0.333
A0200	31.80	56.07	0.081	0.253	0.251	0.400
A0210	2.07	25.61	0.052	0.233	0.017	0.286
A0220	4.05	28.27	0.051	0.268	0.026	0.415
A0300	40.16	64.90	0.090	0.251	0.318	0.383
A0310	9.11	33.76	0.059	0.215	0.080	0.234
A0320	8.38	32.40	0.057	0.230	0.062	0.319
A0330	2.02	25.77	0.051	0.230	0.018	0.273
A0400	44.89	69.89	0.094	0.254	0.354	0.405
A0405	5.69	30.69	0.050	0.270	0.012	0.441
A0410	8.03	33.03	0.055	0.259	0.052	0.354
A0412	8.02	32.89	0.058	0.282	0.073	0.456
A0414	7.66	31.80	0.057	0.257	0.063	0.367
A0420	6.47	31.47	0.050	0.242	0.012	0.294
A0422	3.73	28.73	0.054	0.230	0.041	0.237
A0430	8.44	33.44	0.055	0.285	0.050	0.462
A0500	46.08	71.08	0.095	0.251	0.359	0.400
A0505	7.38	32.26	0.055	0.265	0.048	0.413
A0510	8.42	33.42	0.058	0.281	0.077	0.455
A0512	8.42	33.42	0.058	0.278	0.077	0.440
A0514	13.37	38.37	0.063	0.267	0.116	0.422
A0516	41.82	29.58	0.058	0.220	0.048	0.291
A0518	16.13	31.71	0.054	0.264	0.047	0.398
A0520	41.01	36.17	0.061	0.196	0.041	0.231
A0522	19.66	31.99	0.058	0.214	0.055	0.315
A0530	8.72	32.38	0.055	0.253	0.052	0.385
A0540	24.88	27.49	0.053	0.219	0.012	0.322
A0542	25.44	25.62	0.050	0.226	0.012	0.293
A0544	4.68	28.87	0.054	0.294	0.041	0.486

Table 5-3. Summary table of revised hydrologic parameters in subbasins –2016 land use (cont.).

Subbasin Name	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.
A0550	19.89	37.28	0.057	0.239	0.068	0.357
A0560	17.89	29.47	0.050	0.242	0.013	0.377
A0570	31.89	27.51	0.051	0.214	0.012	0.298
A0580	12.29	32.29	0.057	0.267	0.069	0.434
A0582	8.57	26.97	0.052	0.245	0.027	0.354
A0584	4.26	27.42	0.051	0.278	0.024	0.451
A0586	9.97	27.78	0.052	0.240	0.028	0.364
A0588	8.72	31.77	0.057	0.267	0.065	0.416
A0590	10.86	34.39	0.056	0.266	0.059	0.428
A0592	21.89	33.66	0.051	0.242	0.012	0.357
A0600	41.00	66.00	0.091	0.256	0.330	0.398
A0610	12.90	37.90	0.063	0.228	0.112	0.222
A0620	6.73	31.73	0.057	0.219	0.064	0.194
A0630	15.82	40.82	0.066	0.284	0.135	0.468
A0640	0.00	25.00	0.050	0.249	0.012	0.394
B0100	94.62	96.91	0.009	0.023	0.041	0.128
B0110	4.65	27.31	0.052	0.270	0.029	0.421
B0112	1.19	25.44	0.051	0.284	0.012	0.456
B0120	7.84	30.89	0.052	0.265	0.039	0.406
B0130	12.83	37.83	0.063	0.255	0.112	0.261
B0140	53.47	67.93	0.039	0.159	0.087	0.299
B0150	10.58	32.74	0.058	0.267	0.072	0.439
B0160	5.33	26.53	0.052	0.221	0.024	0.385
B0200	23.96	41.90	0.067	0.211	0.142	0.322
B0300	28.40	49.46	0.074	0.271	0.201	0.438
B0400	34.05	55.21	0.079	0.245	0.231	0.377
B0410	15.21	32.27	0.057	0.239	0.068	0.377
C0100	47.90	72.87	0.098	0.249	0.242	0.252
C0110	4.01	28.86	0.053	0.214	0.035	0.202
C0120	2.46	27.19	0.052	0.270	0.025	0.408
C0200	37.57	62.32	0.086	0.259	0.205	0.327

Table 5-3. Summary table of revised hydrologic parameters in subbasins –2016 land use (cont.).

Subbasin Name	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.
C0201	4.06	26.55	0.051	0.232	0.020	0.311
C0202	12.22	31.91	0.057	0.257	0.066	0.376
C0203	0.28	25.03	0.050	0.251	0.012	0.358
C0204	8.99	33.88	0.059	0.285	0.064	0.453
C0210	10.56	34.65	0.059	0.281	0.059	0.426
C0212	7.07	29.72	0.054	0.256	0.040	0.363
C0220	9.13	32.64	0.056	0.285	0.039	0.447
C0230	10.51	31.71	0.055	0.282	0.040	0.444
C0240	7.53	31.26	0.056	0.290	0.039	0.458
C0244	14.52	34.72	0.058	0.249	0.060	0.348
C0250	14.49	39.23	0.064	0.282	0.078	0.413
C0254	4.78	29.78	0.055	0.295	0.034	0.475
C0260	25.28	50.28	0.075	0.269	0.138	0.360
C0270	23.80	45.81	0.056	0.221	0.077	0.167
C0280	19.00	43.16	0.068	0.273	0.098	0.389
C0282	22.10	34.50	0.059	0.245	0.056	0.342
C0300	43.66	67.87	0.093	0.247	0.250	0.289
C0301	4.63	25.71	0.050	0.252	0.012	0.398
C0303	0.00	25.00	0.050	0.294	0.012	0.484
C0304	2.60	25.93	0.051	0.271	0.019	0.413
C0306	13.46	25.00	0.050	0.213	0.012	0.267
C0308	21.02	40.85	0.065	0.227	0.115	0.289
C0310	18.14	32.17	0.057	0.175	0.051	0.208
C0311	11.02	27.39	0.051	0.197	0.025	0.177
C0314	6.33	27.61	0.055	0.220	0.029	0.292
C0316	7.26	27.75	0.053	0.254	0.029	0.300
C0320	7.87	28.90	0.051	0.225	0.024	0.267
C0322	14.17	25.56	0.050	0.253	0.014	0.355
C0330	8.56	28.51	0.052	0.233	0.021	0.315
C0340	9.02	31.22	0.055	0.257	0.045	0.361
C0342	22.26	46.36	0.071	0.243	0.160	0.317

Table 5-3. Summary table of revised hydrologic parameters in subbasins –2016 land use (cont.).

Subbasin Name	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.
C0344	13.32	38.31	0.063	0.264	0.098	0.403
C0350	7.99	30.96	0.054	0.283	0.035	0.446
C0360	5.41	30.36	0.055	0.294	0.038	0.473
C0370	5.51	30.51	0.056	0.294	0.042	0.475
C0400	42.82	67.82	0.093	0.254	0.210	0.272
C0410	19.75	42.75	0.065	0.254	0.089	0.347
C0420	3.02	28.02	0.053	0.269	0.026	0.410
C0430	6.08	31.08	0.056	0.286	0.040	0.432
C0500	48.65	73.61	0.099	0.249	0.235	0.239
C0505	2.74	26.05	0.049	0.219	0.012	0.213
C0507	4.41	27.70	0.053	0.293	0.030	0.484
C0508	14.33	39.33	0.064	0.286	0.089	0.437
C0510	16.61	40.90	0.065	0.260	0.086	0.354
C0520	23.58	44.42	0.055	0.243	0.065	0.354
C0522	13.24	38.17	0.063	0.272	0.071	0.380
C0530	7.48	32.48	0.057	0.272	0.058	0.416
C0540	4.68	29.68	0.055	0.212	0.045	0.196
C0550	27.47	48.38	0.058	0.222	0.108	0.354
C0552	12.04	36.87	0.062	0.228	0.104	0.272
D0040	6.60	30.47	0.055	0.256	0.052	0.389
D0045	14.82	38.22	0.063	0.271	0.115	0.431
D0050	18.55	41.76	0.066	0.271	0.120	0.419
D0055	5.79	27.24	0.052	0.287	0.028	0.467
D0100	94.99	96.27	0.006	0.020	0.023	0.121
D0110	38.65	58.78	0.084	0.220	0.171	0.248
D0120	19.19	42.24	0.065	0.264	0.114	0.414
D0130	15.76	28.06	0.053	0.281	0.036	0.466
D0140	4.11	25.00	0.052	0.256	0.012	0.404
D0150	9.77	29.30	0.053	0.216	0.028	0.348
D0160	25.09	31.03	0.056	0.175	0.059	0.206
D0170	18.35	39.09	0.064	0.248	0.097	0.375

Table 5-3. Summary table of revised hydrologic parameters in subbasins –2016 land use (cont.).

Subbasin Name	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.
D0180	14.05	25.47	0.050	0.299	0.016	0.498
D0200	9.65	33.83	0.058	0.262	0.075	0.399
E0100	95.57	96.63	0.005	0.016	0.021	0.120
E0110	20.05	30.30	0.048	0.274	0.018	0.455
E0120	35.76	59.84	0.084	0.264	0.186	0.335
E0130	13.91	26.04	0.050	0.255	0.016	0.410
E0140	48.30	72.74	0.098	0.245	0.308	0.317
E0150	7.88	27.53	0.053	0.247	0.030	0.397
E0160	6.67	30.99	0.055	0.244	0.052	0.316
E0162	3.35	28.35	0.053	0.286	0.038	0.466
E0170	12.96	31.96	0.054	0.237	0.046	0.300
E0172	10.41	35.41	0.060	0.290	0.093	0.479
E0180	46.25	50.86	0.068	0.204	0.137	0.272
E0190	17.73	25.00	0.050	0.292	0.012	0.478
E0200	21.57	33.55	0.047	0.154	0.016	0.249
E0210	15.90	40.90	0.064	0.280	0.118	0.454
E0220	19.87	42.59	0.068	0.257	0.125	0.345
E0230	23.40	45.88	0.058	0.256	0.096	0.414
E0300	18.58	38.16	0.061	0.273	0.097	0.432
E0400	17.34	41.92	0.067	0.279	0.129	0.442
E0410	17.15	48.86	0.071	0.268	0.136	0.431
E0420	13.45	36.56	0.062	0.288	0.102	0.477
E0422	8.84	32.17	0.057	0.285	0.068	0.465
E0425	4.22	28.73	0.054	0.296	0.029	0.480
E0430	14.57	33.70	0.057	0.260	0.030	0.389
E0440	10.16	25.05	0.050	0.282	0.012	0.449
E0450	15.22	37.23	0.055	0.237	0.065	0.304
E0452	10.38	35.38	0.060	0.279	0.084	0.430
E0460	1.76	32.57	0.055	0.253	0.012	0.354
E0462	13.65	34.34	0.045	0.223	0.019	0.326
E0500	25.58	46.96	0.070	0.246	0.113	0.351

Table 5-3. Summary table of revised hydrologic parameters in subbasins –2016 land use (cont.).

Subbasin Name	% of Imperv. Area	% of Zero Storage Imperv.	Storage on Imperv. Area Depth (in)	Storage on Perv. Area Depth (in)	Manning n Imperv.	Manning n Perv.
E0600	27.49	50.58	0.067	0.251	0.147	0.386
E0700	24.33	27.07	0.049	0.246	0.012	0.366

5.3 Long-term Model Simulations

The calibrated water budget model described in Section 4.0 was used to perform long-term simulations for a total of 55.7 years from 4/25/1960 through 12/31/2015, by implementing the time series data and 2016 land use data described in Section 5.2 above, for the measured and current pumping scenarios.

Based on the model methodology described in Section 3.3.3, the upper FAS potentiometric surface levels were used in estimating the groundwater loss from the major lakes and sinkholes through various “outlet” links in the model. The groundwater level data sets developed for the measured and current pumping scenarios (Figures 5-7A through 5-7G) were implemented in the long-term model simulations to estimate the groundwater loss from the major lakes and sinkholes for each of these two scenarios.

In the SWMM model, a constant groundwater loss rate to deep aquifer for the Aquifers in the model (Section 3.2.6) is used to estimate groundwater loss to the upper FAS. The assumption is made that influence on water budget model results by the upper FAS potentiometric surface level fluctuation is considered insignificant in the watershed, except for the area immediately beneath the major lakes and sinkholes where collapse structures might provide preferred paths toward the upper FAS. The calibrated groundwater loss rates to deep aquifer, as listed in Table 4-5, were used for the long-term model simulation of the measured scenario. The groundwater loss rates to deep aquifer for the current pumping scenarios were estimated based on the following equation (Equation D). The remainder of the model parameters were not changed.

$$A' = A * \frac{\Delta H + B}{\Delta H} \qquad \text{(D)}$$

where, A' = proposed groundwater loss rate to deep aquifer (in/hr), i.e., the current pumping scenario

A = base groundwater loss rate to deep aquifer (in/hr), i.e., the measured scenario

B = upper FAS drawdown (ft), difference between the current pumping and measured scenarios

ΔH = head difference (ft), between the water elevations at Lake Santa Fe and groundwater table elevations in the upper FAS, which is 61 ft for the measured scenarios

The simulated lake stage hydrographs for the measured and current pumping scenarios as well as the corresponding groundwater level records are graphically presented on Figures 5-9A and 5-9B for Lake Alto and Lake Santa Fe, respectively.

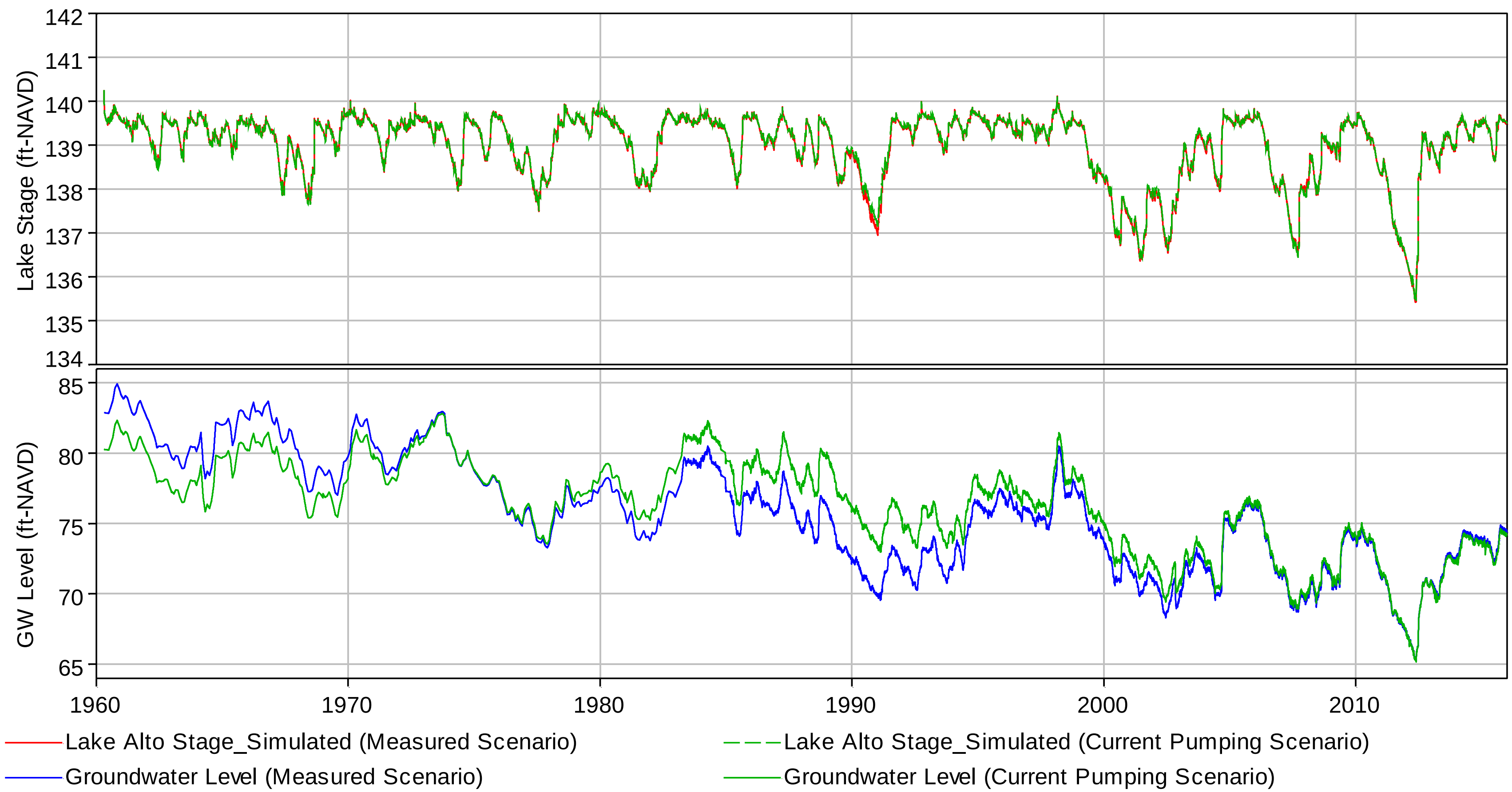


Figure 5-9A. Simulated Lake Stage Hydrographs at Lake Alto - Measured and Current Pumping Scenarios (1960-2015).

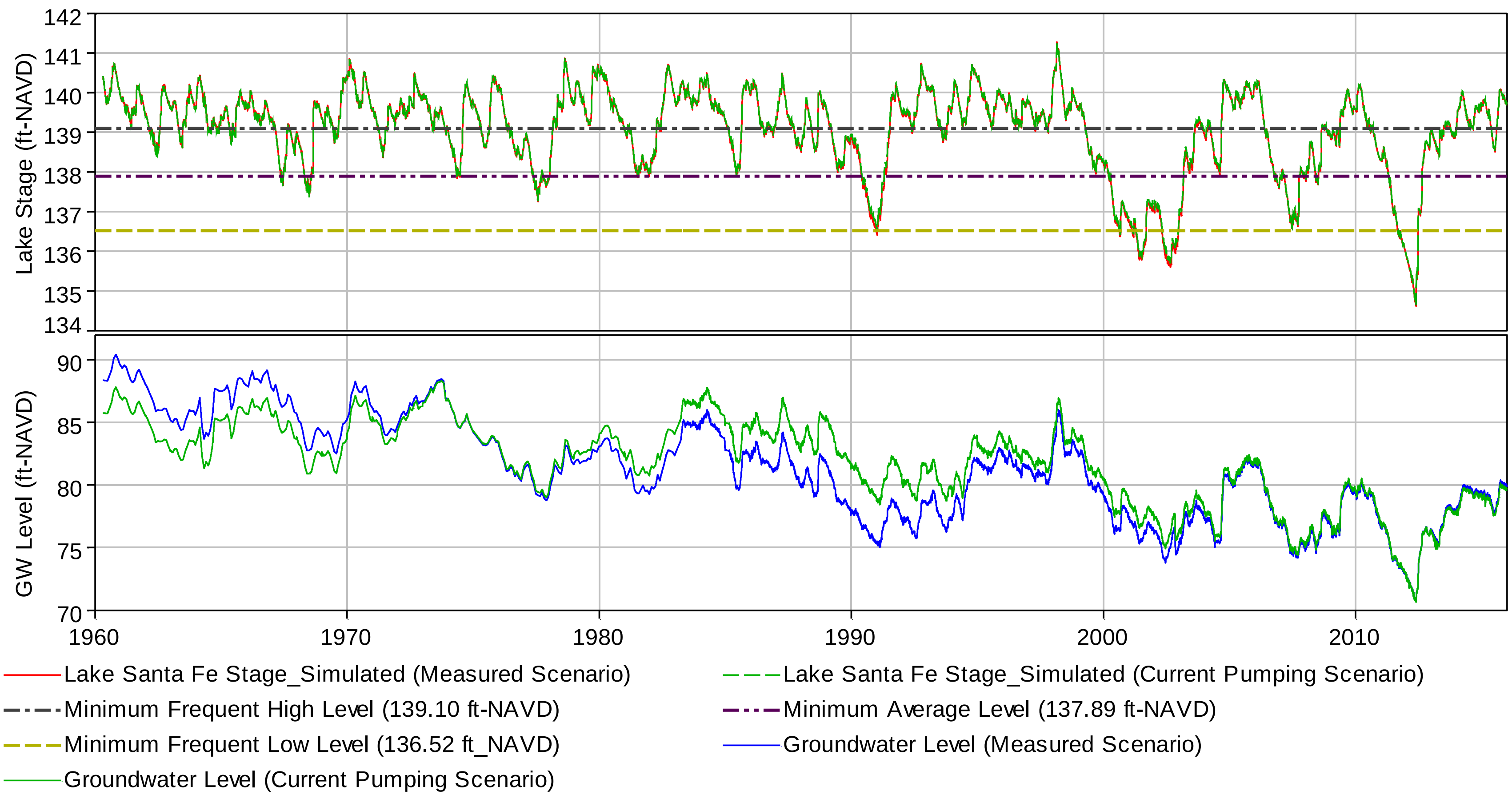


Figure 5-9B. Simulated Lake Stage Hydrographs at Lake Santa Fe - Measured and Current Pumping Scenarios (1960-2015).

Scatter plots comparing simulated lake stages for the measured and current pumping scenarios are provided on Figures 5-10A and 5-10B for Lake Alto and Lake Santa Fe, respectively. The statistical analysis results are summarized in these scatter plots as well. The average residuals were less than 0.02 foot for both Lake Alto and Lake Santa Fe, i.e., the difference between these two scenarios is insignificant in terms of the simulated lake stages (Figures 5-9A and 5-9B).

The simulated lake stages for the current pumping scenario for Lake Santa Fe will be involved in the subsequent assessment of the current pumping scenario in the context of MFLs.

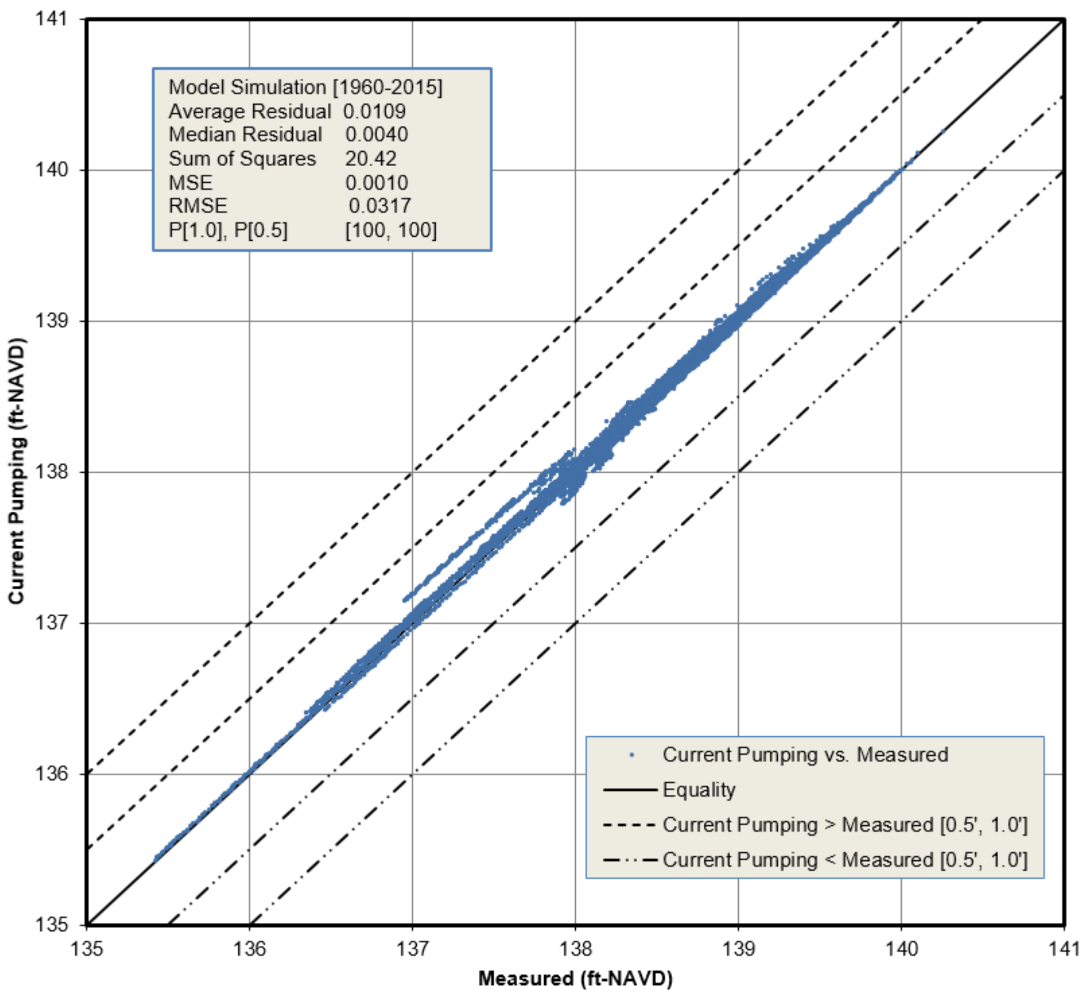


Figure 5-10A. Scatter Plot Comparing Simulated Lake Stages at Lake Alto - Current Pumping vs. Measured Scenarios (1960-2015).

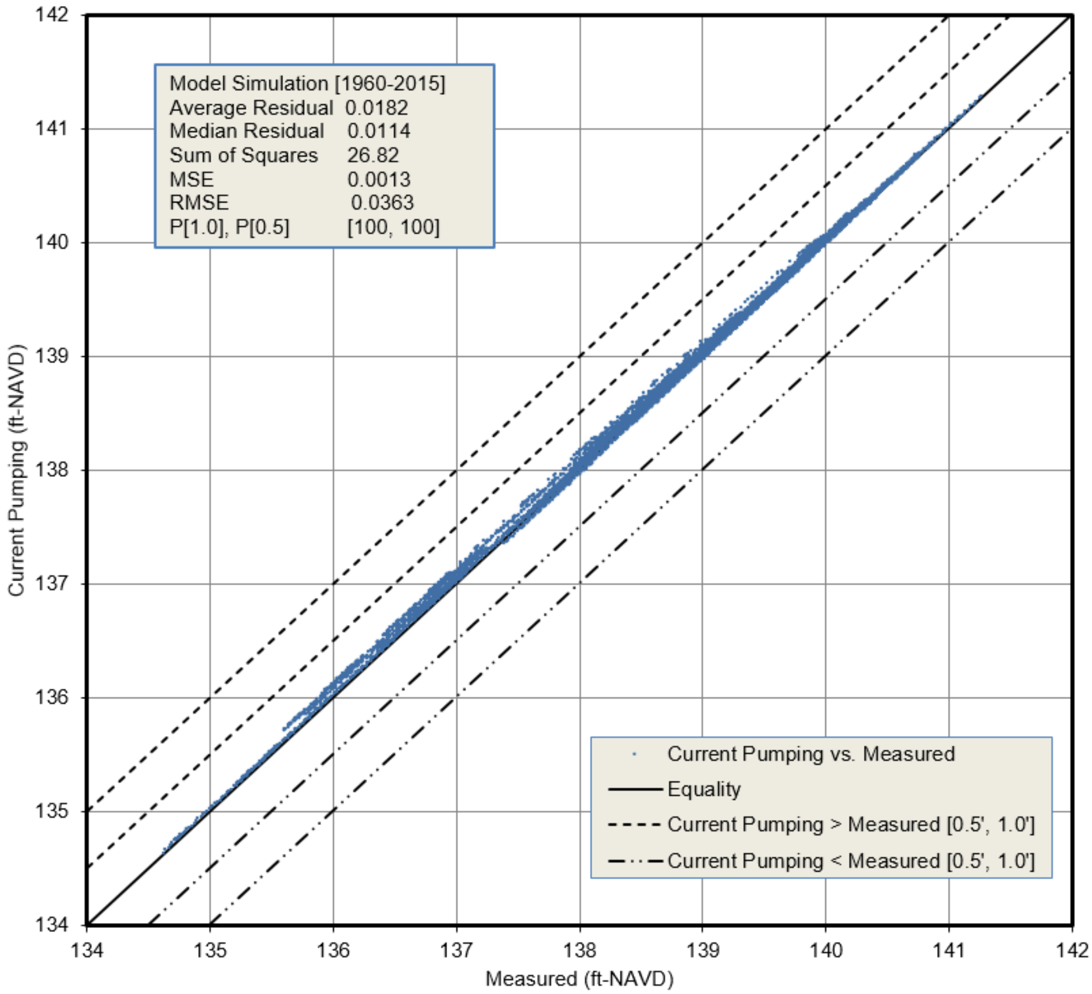


Figure 5-10B. Scatter Plot Comparing Simulated Lake Stages at Lake Santa Fe - Current Pumping vs. Measured Scenarios (1960-2015).

5.4 Recommended MFLs for Lake Santa Fe

MFLs, including a minimum frequent high (FH) level, a minimum average (MA) level, and a minimum frequent low (FL) level, have been recommended by the District for Lake Santa Fe (Table 5-4). The event-based MFLs method (SJRWMD, 2006; Neubauer *et al*., 2008) was utilized to determine the minimum lake levels for Lake Santa Fe. MFL determination is based on the evaluation of topography, vegetation, soils, and hydrologic indicator data collected from plant communities associated with the water body (ECT, 2022). The MFLs relate to hydroperiod categories and definitions adapted from water regime modifiers developed by Cowardin *et al*. (1979).

The recommended FH level for Lake Santa Fe is 139.10 ft NAVD88. Based on the SJRWMD guidance, this elevation should remain continuously wet for at least 30 days and occur at least once every 2 years on average (at least 50% of the years) (Table 5-4).

The recommended MA level for Lake Santa Fe is 137.89 ft NAVD88. Based on the SJRWMD guidance, this elevation should remain continuously dry for at most 180 days and no more often than once every 1.7 years on average (at most 59% of the years).

The recommended FL level for Lake Santa Fe is 136.52 ft NAVD88. Based on the SJRWMD guidance, this elevation should remain continuously dry for at most 120 days and no more often than once every 5 years on average (at most 20% of the years).

Table 5-4. Summary of minimum recommended lake levels for Lake Santa Fe.

Designated Level	Elevation Benchmarks	Elevation (ft NAVD88)	Defining event of hydrologic criteria
Minimum Frequent High (FH)	Maximum of mean surface elevations of seasonally flooded cypress wetlands	139.10	30-day inundation/ 2-yr return interval
Minimum Average (MA)	Mean elevation of thick organic soils sampled in cypress and hardwood swamp minus 0.3 foot	137.89	180-day exposure/ 1.7-yr return interval
Minimum Frequent Low (FL)	Mean elevation of thick organic soils sampled in cypress and hardwood swamp minus 20 inches	136.52	120-day exposure/ 5-yr return interval

Source: ECT, 2022.

5.6 Assessment of Current Pumping Scenario for Lake Santa Fe

To obtain a better understanding of the relationship between MFLs and the hydrology of a lake, MFLs can be examined in three different ways: 1) in the context of the long-term hydrograph of a lake; 2) in the context of the stage-duration curve of a lake; and 3) in the context of the frequency of events pertinent to each minimum level (Robison, 2014).

Figure 5-11 illustrates the recommended lake MFLs superimposed on the model-simulated lake stage hydrograph for Lake Santa Fe. The stage of a lake can remain above or below each of the MFLs for extended periods.

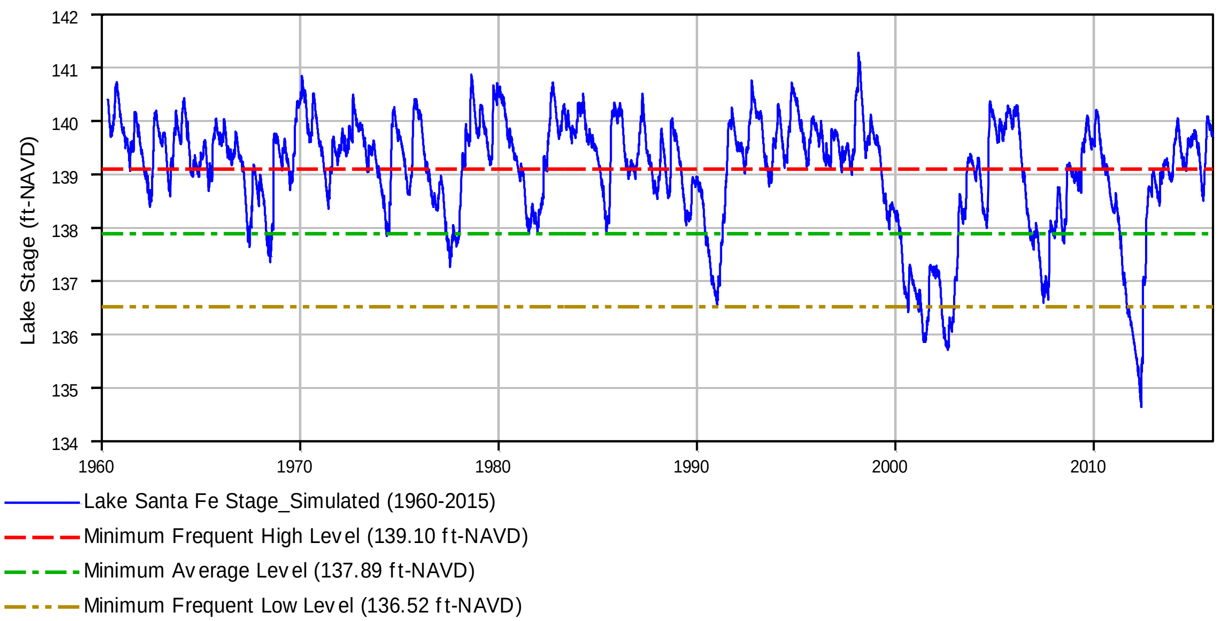


Figure 5-11. Simulated Lake Stage Hydrograph at Lake Santa Fe - Current Pumping Scenario (1960-2015).

Figure 5-12 illustrates the recommended lake MFLs superimposed on the stage-duration curve of the model-simulated lake stage data set for Lake Santa Fe. In this context, the FH, MA, and FL levels anchor the hydrology of Lake Santa Fe.

Based on the event-based MFLs method (Robison, 2014), the ultimate determination of whether MFLs are being met is made through a frequency analysis. Results of the frequency analysis for the current pumping scenario are presented in a separate status assessment memo for Lake Santa Fe.

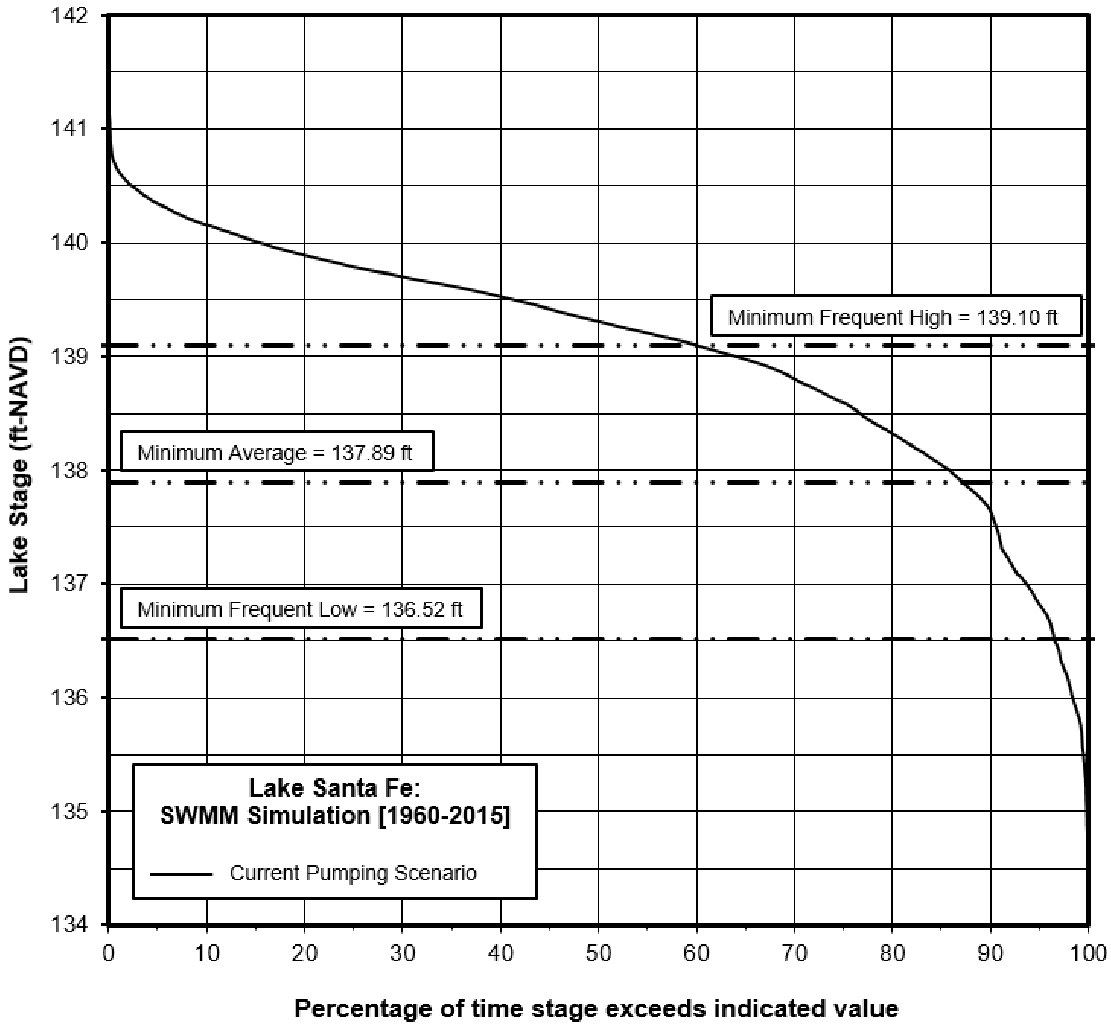


Figure 5-12. Stage Duration Curve - Model Simulation at Lake Santa Fe - Current Pumping Scenario (1960-2015).

6.0 Assessment of Hypothetical Water Resource Development for Lake Santa Fe

6.1 Introduction

The Lake Alto and Lake Santa Fe water budget model was used to assess the hydrologic effects of upper FAS drawdowns in the context of MFLs. This section documents the determination of freeboard or maximum allowable upper FAS declines beyond the no-pumping scenario for Lake Santa Fe.

A series of runs of the 55.7-year long-term model simulations were performed with different aquifer declines. The updated lake stage data set was developed and used to assess each aquifer decline scenario for each minimum level until it is no longer being met.

The following two assumptions were applied in developing the model-simulated lake stage data set for each scenario:

1. The 55.7-year (4/25/1960 through 12/31/2015) rainfall, ET, and groundwater data sets are reasonable representation of the long-term climate in the watershed, absent significant anthropogenic or climatological changes.
2. To assess future water resource developments, a constant upper FAS drawdown value beyond the no-pumping scenario was assumed throughout the entire model simulation period.

6.2 Assessment of Hypothetical Allowable Floridan Aquifer Drawdowns

Based on the initial frequency analysis results, the recommended MFLs for Lake Santa Fe would be met under the current pumping scenario. Therefore, further drawdowns in the upper FAS might be allowable at this lake. As the most probable water resource development in this area would be manifested in drawdowns in the upper FAS by groundwater withdrawals, as opposed to direct surface water withdrawals, this analysis will include only upper FAS drawdowns.

Based on the model methodology described in Section 3.3.3, the upper FAS potentiometric surface levels were used in modeling the groundwater loss from the major lakes and sinkholes through various “outlet” links in the model. The upper FAS drawdowns were simulated by subtracting a set amount from the groundwater level data set for the no-pumping scenario (Figures 5-7A through 5-7G). Based on the methodology described in Section 5.3 (Equation D), the groundwater loss rates to deep aquifer for the Aquifers in the model were adjusted for different upper FAS drawdowns. The remainder of the model parameters were not changed.

To determine the freeboard or maximum allowable amount of upper FAS drawdown in the area beyond the no- pumping scenario, a series of runs were performed. Drawdowns were gradually increased, the long-term models re-run, and the resulting model-simulated lake stage data set was assessed with respect to each minimum level to be no longer met.

Based on the model results, the recommended FH, MA, and FL levels at Lake Santa Fe would be met with maximum drawdowns of 28.0, 29.7, and 22.0 ft beyond the no-pumping scenario, respectively (Figures 6-1A through 6-1C). Based on the event-based MFLs procedures, the minimum level is being met if any pertinent event lies within the shaded box shown in the figures. With upper FAS drawdowns greater than 28.0, 29.7, and 22.0 ft, the recommended FH, MA, and FL levels at Lake Santa Fe, respectively, would no longer be met.

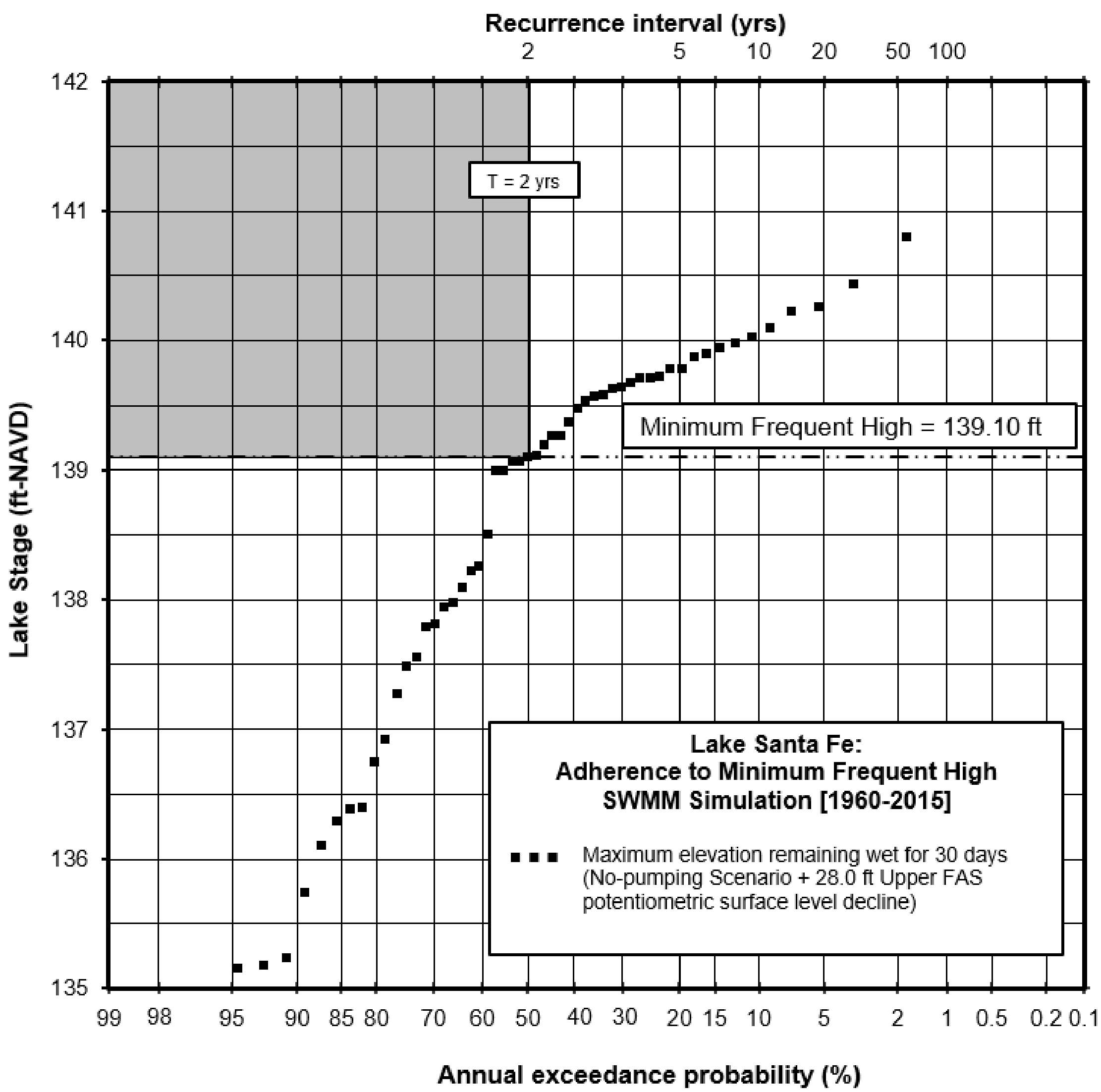


Figure 6-1A. Minimum Frequent High Level and SWMM Simulation (1960-2015) at Lake Santa Fe - No-pumping + 28.0 ft Upper FAS Potentiometric Surface Level Decline.

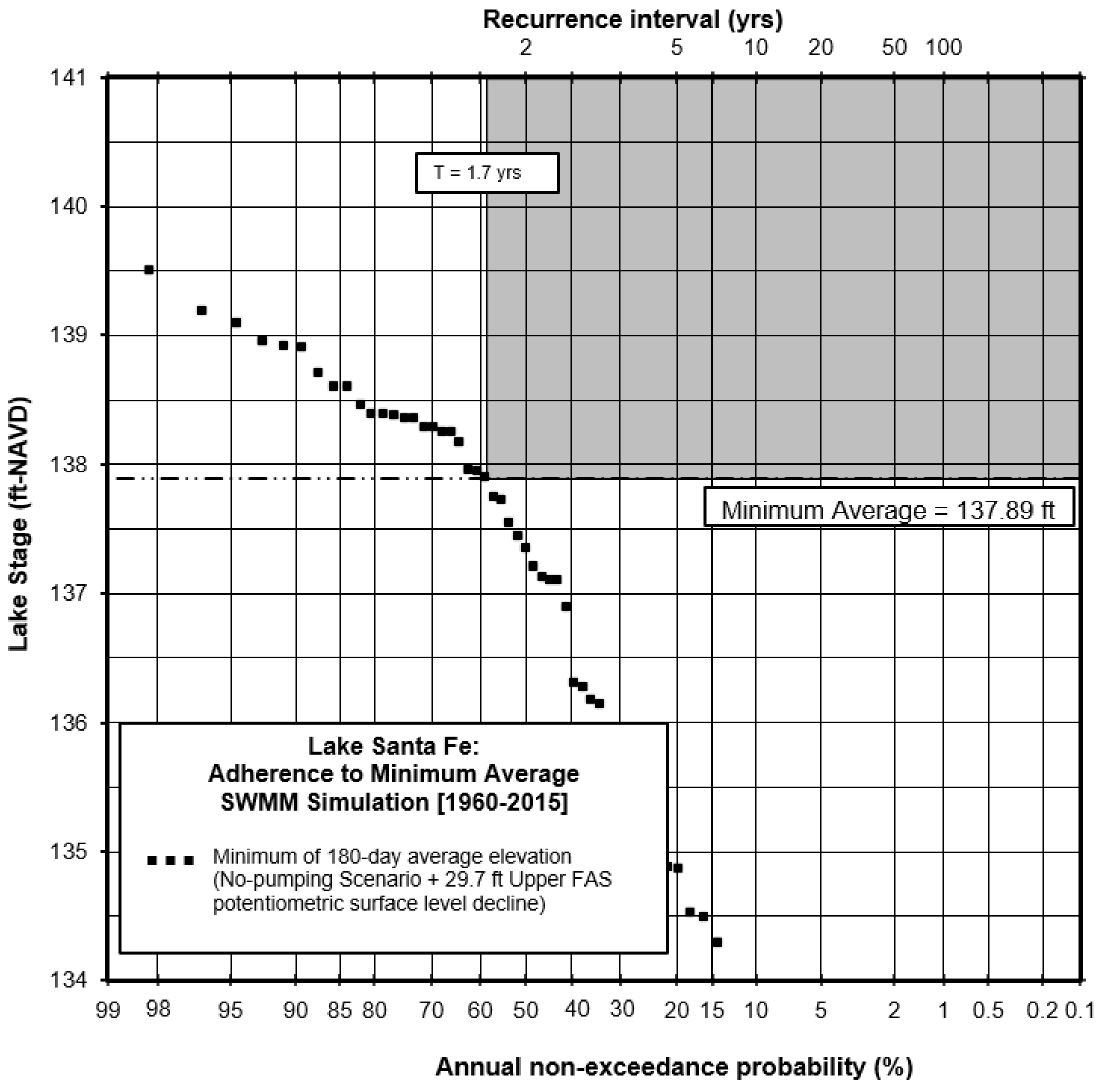


Figure 6-1B. Minimum Average Level and SWMM Simulation (1960-2015) at Lake Santa Fe - No-pumping + 29.7 ft Upper FAS Potentiometric Surface Level Decline.

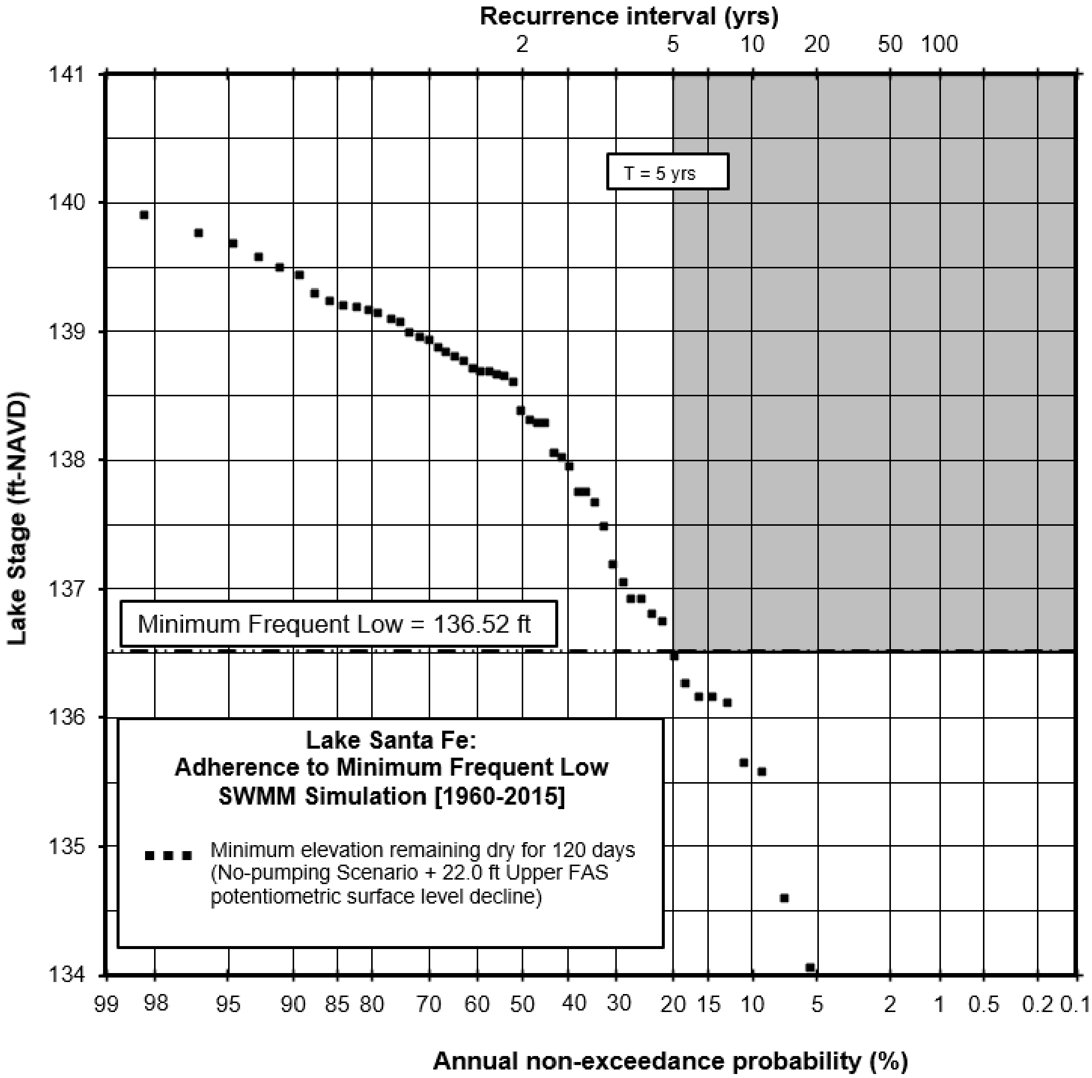


Figure 6-1C. Minimum Frequent Low Level and SWMM Simulation (1960-2015) at Lake Santa Fe - No-pumping + 22.0 ft Upper FAS Potentiometric Surface Level Decline.

The freeboard values or maximum allowable upper FAS drawdowns for the recommended FH, MA, and FL levels for Lake Santa Fe are presented in Table 6-1. The FL level is the constraining level for both Lake Santa Fe since it allows the smallest upper FAS drawdown.

Table 6-1. Summary of Upper FAS freeboard for the minimum recommended lake levels for Lake Santa Fe.

Designated Level	Upper FAS Freeboard (ft)
Minimum Frequent High (FH)	28.0
Minimum Average (MA)	29.7
Minimum Frequent Low (FL)	22.0

Long-term lake stage hydrographs and stage duration curves can be used to evaluate the time extent and magnitude of the hydrologic changes involved at Lake Santa Fe between the current pumping scenario and the maximum drawdowns of 28.0 ft for FH level (Figures 6-2A and 6-3A), 29.7 ft for MA level (Figures 6-2B and 6-3B), and 22.0 ft for FL level (Figures 6-2C and 6-3C) beyond the no-pumping scenario.

It appears that when the lakes are in high level conditions, the upper FAS drawdown has less impact on the lake stages compared to low stage conditions. This is particularly true for this lake system where rainfall is the only input to the hydrologic cycle and when both the lakes and the aquifer underneath have minimal chance to recover to their normal water levels after prolonged drought conditions, such as the 2000-2002 and 2006-2008 drought periods.

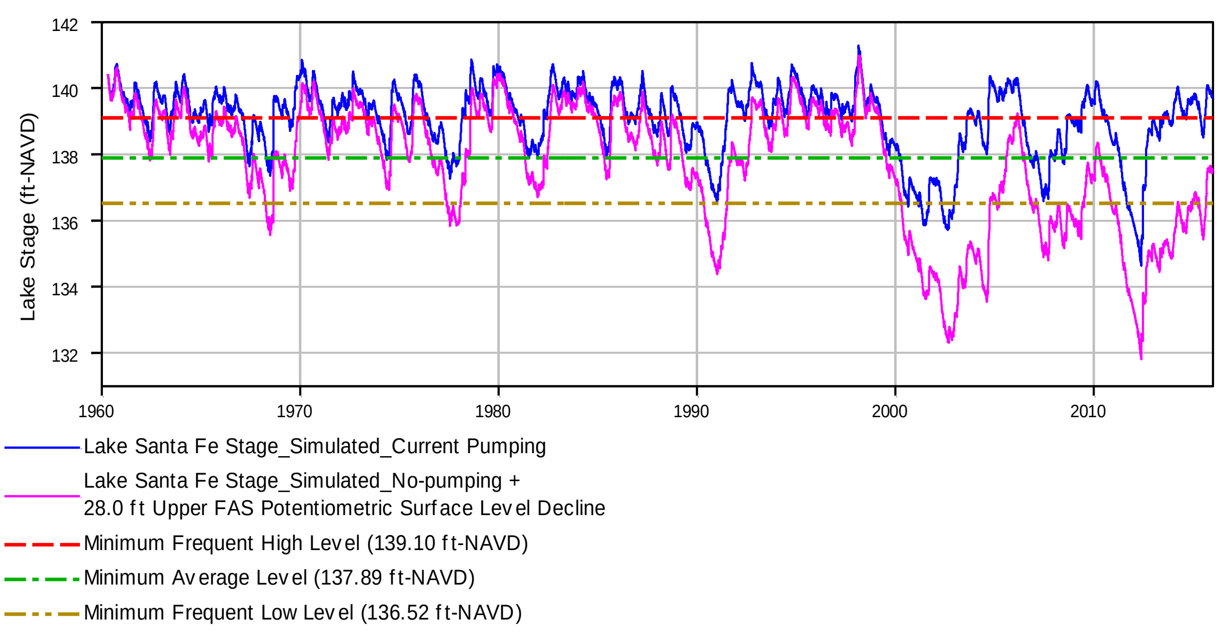


Figure 6-2A. Hydrographs Comparison - SWMM Simulation (1960-2015) at Lake Santa Fe - Current Pumping vs. No-pumping +28.0 ft Upper FAS Potentiometric Surface Level Decline.

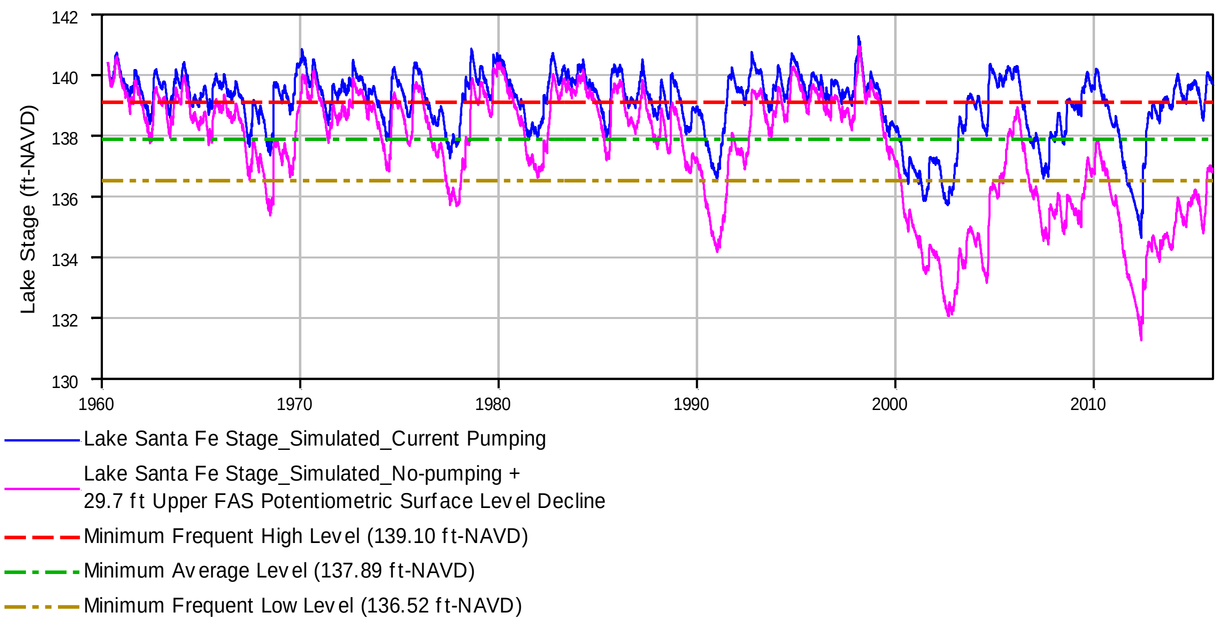


Figure 6-2B. Hydrographs Comparison - SWMM Simulation (1960-2015) at Lake Santa Fe - Current Pumping vs. No-pumping + 29.7 ft Upper FAS Potentiometric Surface Level Decline.

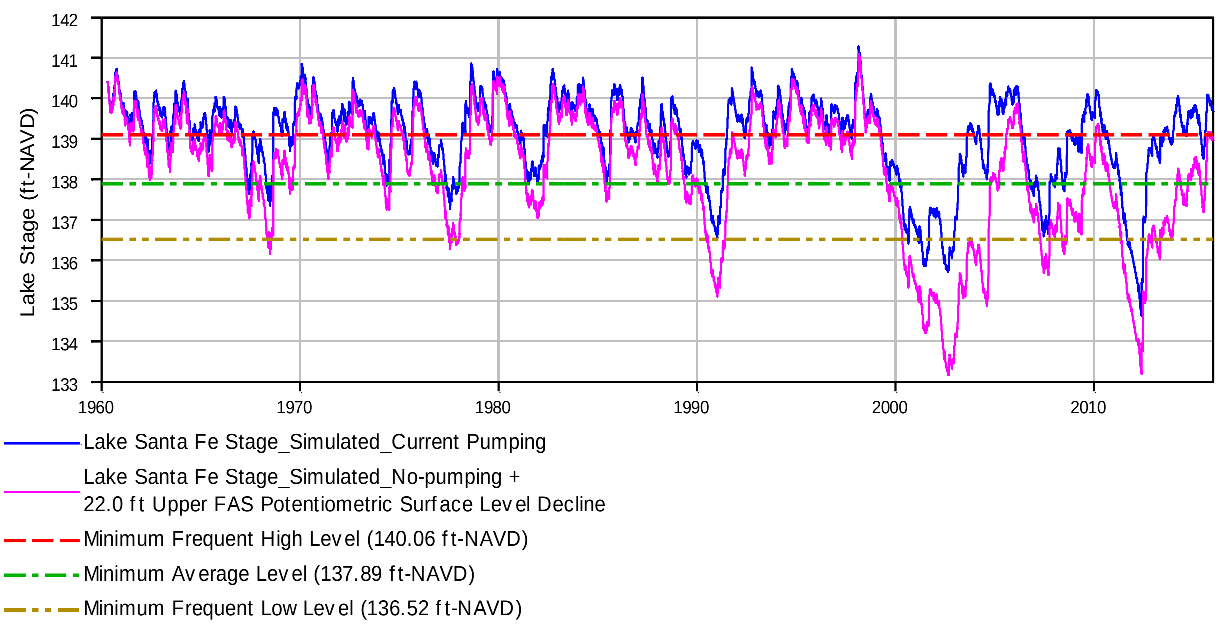


Figure 6-2C. Hydrographs Comparison - SWMM Simulation (1960-2015) at Lake Santa Fe - Current Pumping vs. No-pumping + 22.0 ft Upper FAS Potentiometric Surface Level Decline.

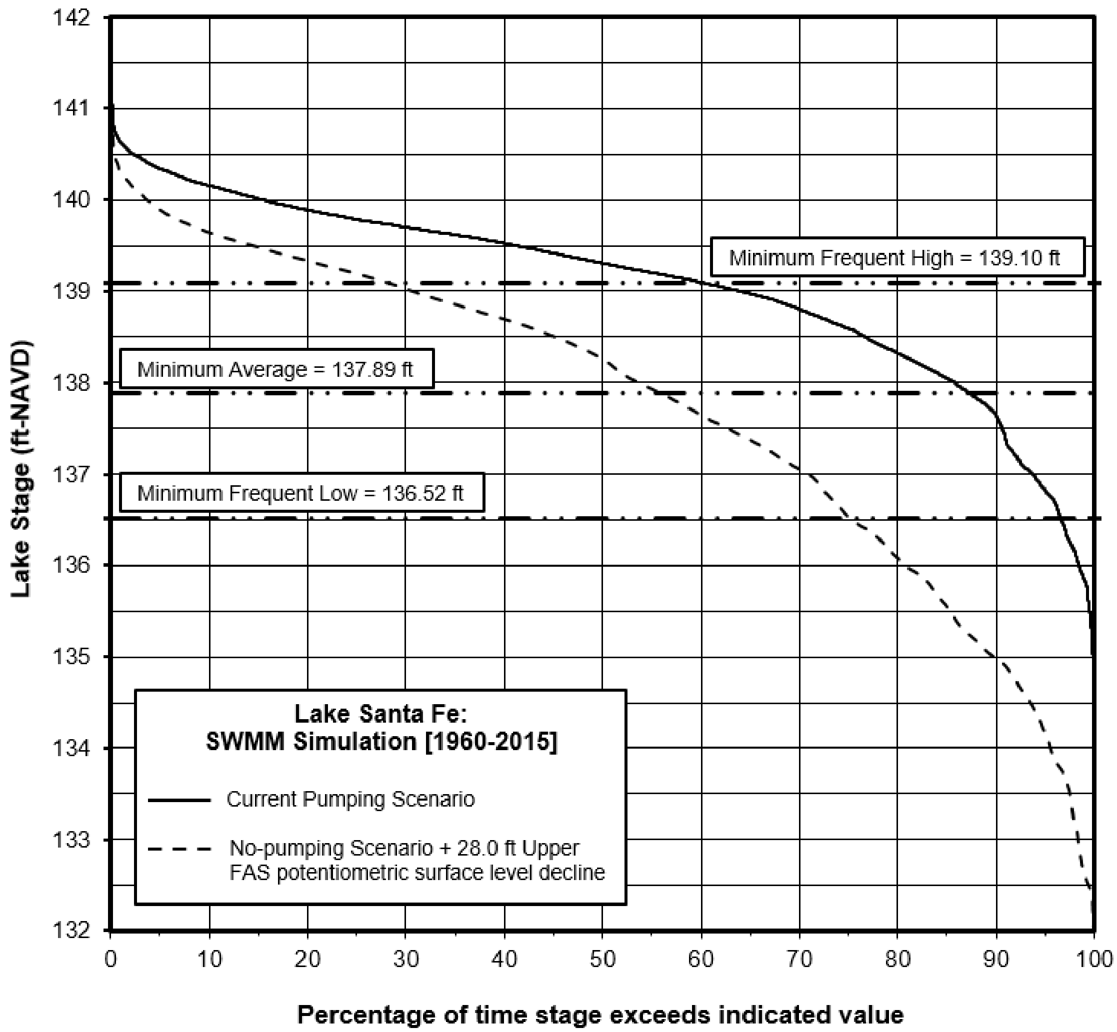


Figure 6-3A. Stage Duration Curves Comparison - SWMM Simulation (1960-2015) at Lake Santa Fe - Current Pumping vs. No-pumping + 28.0 ft Upper FAS Potentiometric Surface Level Decline.

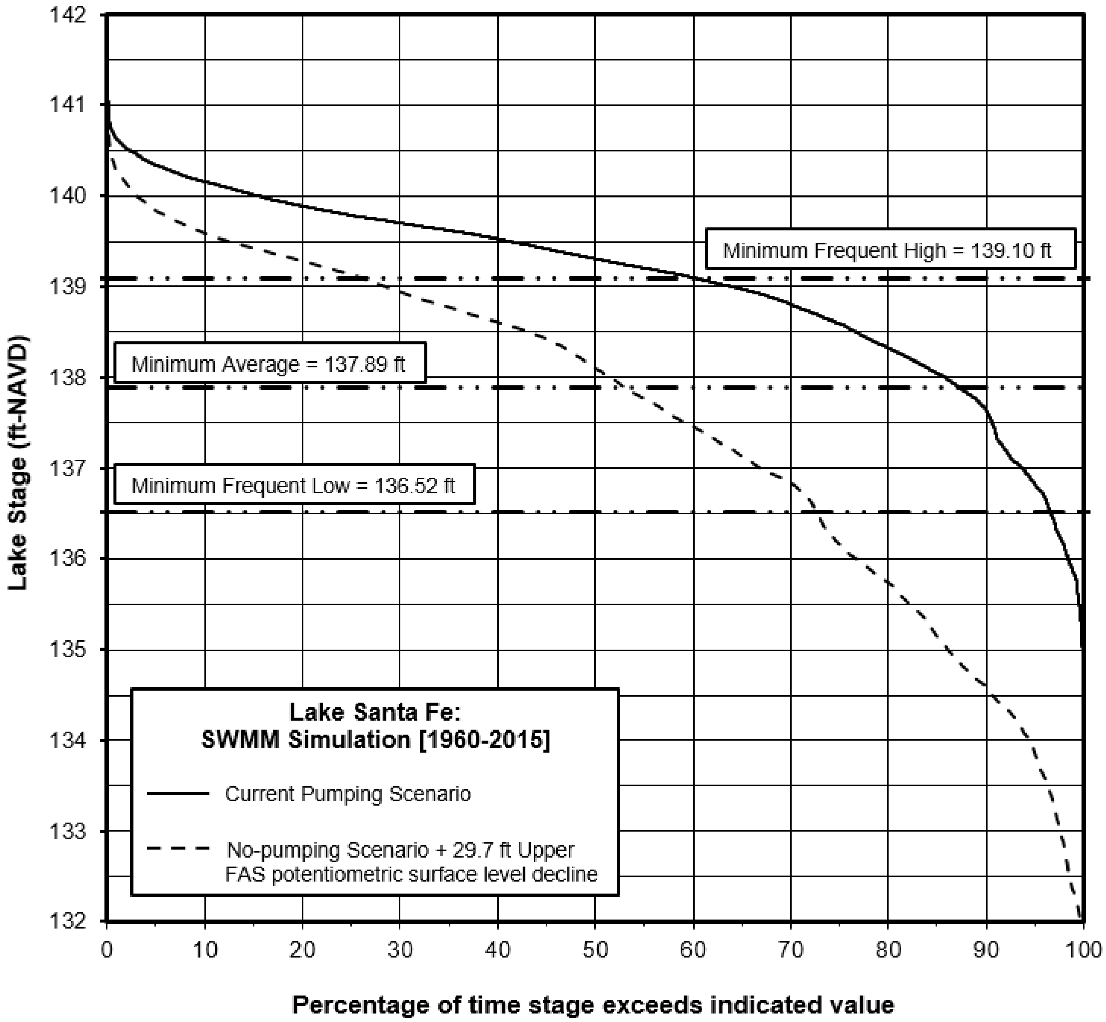


Figure 6-3B. Stage Duration Curves Comparison - SWMM Simulation (1960-2015) at Lake Santa Fe - Current Pumping vs. No-pumping + 29.7 ft Upper FAS Potentiometric Surface Level Decline.

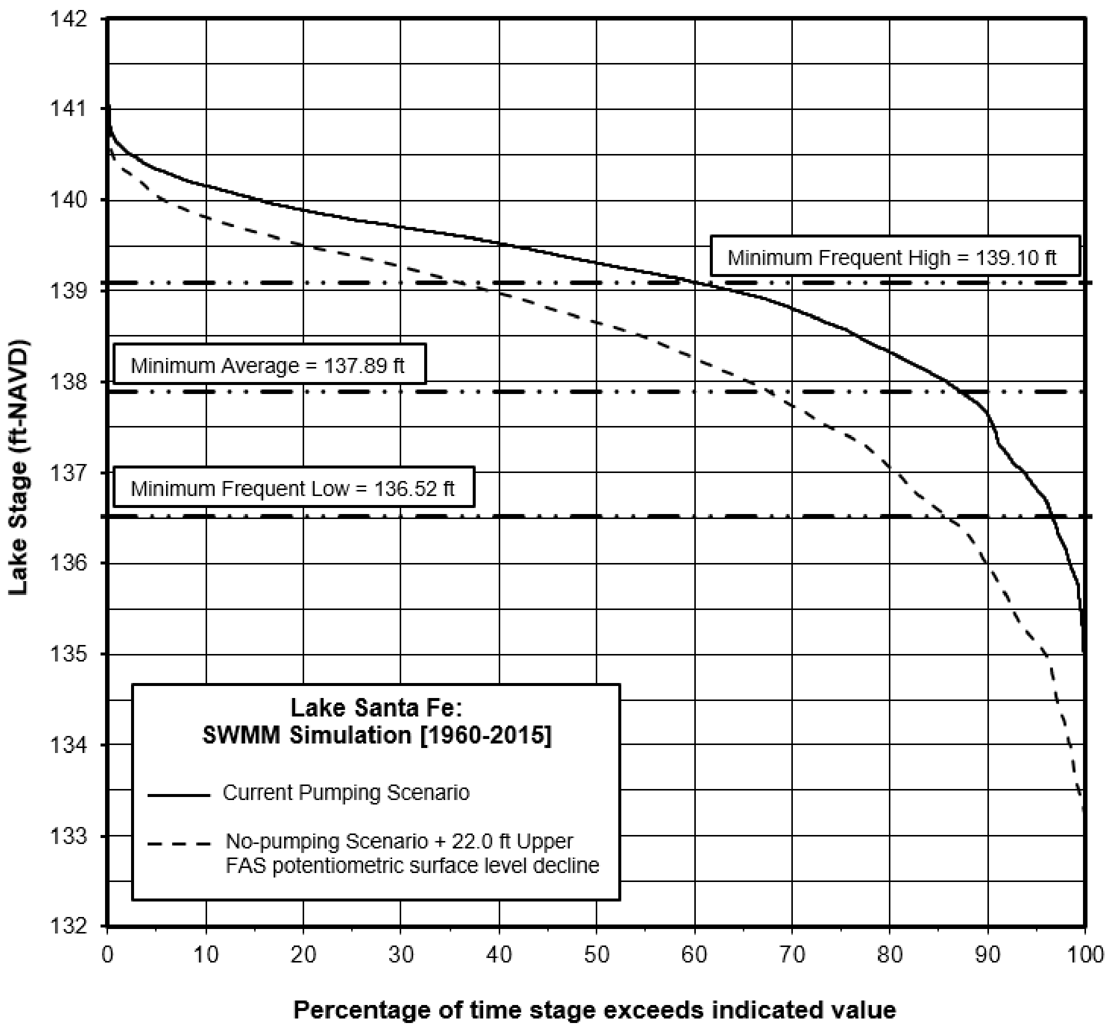


Figure 6-3C. Stage Duration Curves Comparison - SWMM Simulation (1960-2015) at Lake Santa Fe - Current Pumping vs. No-pumping + 22.0 ft Upper FAS Potentiometric Surface Level Decline.

7.0 Conclusions and Limitations

EPA SWMM Version 5.1 was selected in development of a water budget model, to assist in establishment of MFLs at Lake Alto and Lake Santa Fe located in northeastern Alachua County, Florida.

The best available data sources, including the topographic survey, USGS LiDAR-based DEM data, NFSEG groundwater flow model data, reference timeframe analysis results, and other pertinent data, have been reviewed and implemented in the model development.

The Lake Alto and Lake Santa Fe water budget model was well calibrated using a 10-year lake gage data record from 1/1/2006 through 12/31/2015. Model parameters were adjusted during the model calibration process to achieve the best overall fit of the model estimate with the observed data. The model calibration criteria or goals were met based on the statistical analysis results. The model calibration of the water budget model has been successfully executed.

The calibrated Lake Alto and Lake Santa Fe water budget model was employed in a long-term simulation for a 55.7-year period from 4/25/1960 through 12/31/2015. Based on the recent reference timeframe (RTF) analysis results provided by the District, the groundwater level data set for the no-pumping and current pumping scenarios were created and implemented in the long-term model simulations.

The 55.7-year model-simulated lake stages for the current pumping scenario were used to assess Lake Santa Fe under the current pumping scenario. The 55.7-year model-simulated lake stage data sets were also utilized in assessment of hypothetical allowable upper FAS drawdowns in the context of MFLs for Lake Santa Fe.

The recommended MFLs at Lake Santa Fe, including FH level of 139.10 ft NAVD88, MA level of 137.89 ft NAVD88, and FL level of 136.52 ft NAVD88, would be met with a maximum drawdown of 28.0, 29.7, and 22.0 ft beyond the no-pumping scenario, respectively. The recommended FH, MA, and FL levels would no longer be met with upper FAS drawdowns greater than 28.0, 29.7, and 22.0 ft, respectively. The FL level is the constraining level at Lake Santa Fe with the smallest freeboard.

Nevertheless, no model can possibly simulate all factors that could affect the hydrologic cycle. Prior to analyzing the final product of the model in context of MFLs, a judgment should be made as to the appropriateness of the model assumptions and/or limitations. Several principal modeling assumptions were made in developing the water budget model at the lakes, as follows:

1. In the SWMM model, a constant groundwater loss rate to deep aquifer is the only model parameter that is used to estimate groundwater loss to the upper FAS. The assumption is made that influence on water budget model results by the upper FAS potentiometric surface level fluctuation is considered insignificant in the lake watershed where it is confined, except for the area immediately beneath the major lakes and sinkholes where collapse structures might provide preferred paths toward the upper FAS. Various “outlet” links were employed in the SWMM model with a functional rating curve developed to calculate the time-variant discharge from the lakes/sinkholes to the upper FAS.
2. Topographic surveys at Santa Fe Canal and major drainage structures and bathymetry survey at Lake Alto were provided by the District. However, the topographic and bathymetric survey data may not be sufficient to determine the location and elevation of the highest point of the Santa Fe Canal and outflow control points of the lakes. It was assumed that the LiDAR-based

DEM data could be used to assist in locating the control points of the lakes, and the invert elevation at the control point could be further determined during model calibration.

3. The 10-year calibration period of 1/1/2006 through 12/31/2015 covers a wide range of hydrologic conditions. It was assumed that the calibrated model can provide a realistic simulation over a much longer period.
4. Various data sources with different techniques and levels of accuracy (e.g., NEXRAD vs. ORNL Daymet daily rainfall data and NOAA weather station data, NOAA pan evaporation vs. USGS PET data), were utilized in developing the long-term model.
5. It was assumed that the 55.7-year (4/25/1960 through 12/31/2015) rainfall, ET, and groundwater data sets are reasonable representation of the long-term climate in the watershed, absent significant anthropogenic or climatological changes, for Lake Alto and Lake Santa Fe.
6. To assess future water resource developments, a constant upper FAS drawdown value beyond the no-pumping scenario was assumed throughout the entire model simulation period.

The limitations in the water budget modeling efforts could be further improved with a more comprehensive integrated surface water and groundwater model and/or by recalibrating the model when additional data becomes available.

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Appendix A -
SWMM Model Input and Output Data

(located on DVD)