LAKE BUTLER WATER BUDGET MODELING – UPDATED TO INCLUDE REFERENCE TIMEFRAME ANALYSIS

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Prepared for:

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Document Review

The technical contents of the Lake Butler Water Budget Modeling – Updated to Include Reference Timeframe Analysis - Technical Report – Final 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
CMP	corrugated metal pipe
DEM	digital elevation model
ECT	Environmental Consulting & Technology, Inc.
EPA	U.S. Environmental Protection Agency
ET	Evapotranspiration
FAS	Floridan Aquifer System
FDOT	Florida Department of Transportation
ft	Foot
HSG	hydrologic soil group
ICPR	Interconnected Pond Routing
in	Inch
LiDAR	Light Detection and Ranging
FH	minimum frequent high
FL	minimum frequent low
MFLs	minimum flows and levels
NAVD88	North American Vertical Datum of 1988
NEXRAD	Next-Generation Radar
NFSEG	North Florida Southeast Georgia Groundwater Model
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

1.0 Executive Summary

In support of the establishment of Minimum Flows and Levels (MFLs) at Lake Butler, a water budget model is desired by the Suwannee River Water Management District (SRWMD or District) to assess hydrologic changes in the Lake system. An existing hydrologic and hydraulic (H&H) model using the Interconnected Pond Routing (ICPR) model Version 3.1 was previously developed by Stantec in 2013 and was primarily used for simulation of design storm events. However, the existing H&H model in ICPR is not considered an appropriate tool to be used in development of a water budget model, as it is incapable 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 complexity of the Lake hydrologic system, especially as it relates to the upper Floridan aquifer system (FAS), requires a predictive computer model to adequately examine the effects of hydrologic changes.

The District authorized Environmental Consulting & Technology, Inc. (ECT) to undertake the water budget modeling project under several individual work orders between 2015 and 2017. The overall modeling project encompassed two major phases – Phases A & B. Phase A included data collection and review and model selection. Phase B included model development, calibration, long-term simulation, an update with new data, and response to peer review comments.

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 water budget model completed in Phase B 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 Lake Butler MFLs.

The Lake Butler Water Budget Modeling Phase B 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 Lake Butler MFLs.

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

<u>Model Development</u>

The Storm Water Management Model (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 Butler.

By utilizing the previous ICPR model data, including subcatchments, junctions, storages, channels, pipes, weirs, etc., a water budget model in SWMM was developed under this task.

The Light Detection and Ranging (LiDAR) topographic data in the digital elevation model (DEM) format was provided by the District and used to develop some of the model parameters. The model was geo-referenced to the projected coordinate system "NAD_1983_HARN_StatePlane_Florida_North_FIPS_0903_Feet", as specified in the project scope of work.

Model Calibration

The SWMM water budget model was calibrated by comparing the model simulated lake stage against the known gage data. Multiple model parameters were adjusted within reasonable ranges to achieve the best overall fit of the model estimate with the observed data.

The lake stage gage data from 2005 through 2014 were 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.

Long-term Model Simulation and Assessment of Current and Predicted Pumping Scenarios

Once the District accepted the calibration of the water budget model, the model was used to perform a long-term simulation for 32 years from 1983 through 2014. It was assumed the existing land use stayed the same throughout the entire simulation span.

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 Lake.

The 32-year model period includes two significant droughts. The lake stage data during that period do not adequately represent the longer lake stage data record. To include a more representative record, a 50-year "hybrid" lake stage data set was used that combined the 32-year simulated lake stages for the current pumping scenario with the historical lake stage data prior to 1983.

Based on the event-based MFLs method developed by St. Johns River Water Management District (SJRWMD), frequency analysis of the hybrid lake stage data set was conducted to determine whether the Lake MFLs recommended by the District are being met. The current pumping scenario refers to a hypothetical case where the long-term model simulation assumes land use at 2006 conditions and groundwater withdrawals under the current pumping scenario. Results of the frequency analysis are presented in a separate status assessment memo.

The Lake Butler water budget model as well as the historical gage data were used to determine the limit of the upper FAS potentiometric elevation at which the recommended MFLs will no longer be achieved. 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 was tripped (i.e., exceeded). The simulation results were carried over to the entire hybrid data set using a transfer function. Based on the frequency analysis results, the recommended MFLs would be met with a freeboard or maximum potentiometric elevation decline of 40 and 13.6 ft in the upper FAS beyond the no-pumping scenario, for the minimum frequent high (FH) and frequent low (FL) levels, respectively. The FL level is the constraining MFL since it allows the smaller upper FAS drawdown.

2.0   Watershed Description

2.1   General Description

Lake Butler (the Lake) is located in east central Union County, Florida. The Lake has an area of approximately 460 acres at a water elevation of 130 ft NAVD88 and has an approximate perimeter of 16,400 feet along its low and swampy shorelines. The Lake Butler watershed, including Lake Butler and its contributing drainage areas, has a total area of approximately 2,840 acres (Figure 2-1).

An outfall canal, located on the south lakeshore, is the major conveyance way. The canal and a series of culverts under roadways convey flows through the City of Lake Butler urban area and agricultural lands to the south, prior to discharging to Richard Creek at a point approximately three river miles southeast of the Lake.

2.2   Climate

The climate in Union County can be characterized by long, warm summers and relatively mild winters. In summer, the temperature is fairly uniform, in the upper 80's and lower 90's 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 Union 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 accompanied by tropical depressions. These rains can be heavy and of long duration. 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 Butler watershed can be characterized as a mildly sloping and poorly drained plain in general, 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 2011 LiDAR topographic survey data provided by U.S. Geographical Survey (USGS) (NGC, 2011).

Lake Butler and most of its contributing areas have an average land surface elevation of 135 ft NAVD88 or lower. The watershed on the west of the Lake is characterized by higher land elevations, with an average land surface elevation of 140 ft NAVD88 or higher. The highest land surface elevation of approximately 159 ft NAVD88 is observed southwest of State Road (S.R.) 100. Isolated high land elevations of 155 ft NAVD88 or greater are observed in the areas along the north and east watershed boundaries.

2.4   Soils

According to the Natural Resource Conservation Service (NRCS), there is a total of 26 different types of soils that occur within the project study area that are mapped in the Soil Survey of Union County (USDA, 1991). 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 Butler watershed is classified as 25.7% for Sand, 53.4% Loamy Sand, 5.8% for Sandy Loam, and the remaining 15.2% for water. A majority of the watershed is classified as Loamy Sand, most of which is located to the north, east, and west of the Lake (Table 2-1 and Figure 2-3).

Table 2-1. Statistical summary of soil texture classes in Lake Butler watershed.

Soil Texture Class	Area (acre)	Percentage
Sand	729.1	25.7%
Loamy Sand	1,515.2	53.4%
Sandy Loam	164.8	5.8%
Water	430.5	15.2%
Total	2,839.6	100%

Source: NRCS, 2015.

2.5   Land Use/Land Cover

The 2006 land use coverage provided by SRWMD is based on the Florida Land Use and Cover Classification System (Figure 2-4; FLUCCS, Florida Department of Transportation [FDOT], 1999).

The Lake Butler watershed is generally rural with limited developed land (residential, transportation, etc.), most of which is located along the south lakeshore. The top three land uses in the watershed are upland forests (43.4%), wetlands (21.3%), and waters (14.9%) (Table 2-2).

Table 2-2. Statistical summary of 2006 land use in Lake Butler watershed.

FLUCCS	Description	Area (acre)	Percentage
1000	Urban & Built-up	281.4	9.9%
2000	Agriculture	288.9	10.2%
3000	Rangeland	4.4	0.2%
4000	Upland Forests	1,231.7	43.4%
5000	Waters	421.9	14.9%
6000	Wetlands	605.0	21.3%
8000	Transportation, Communication & Utilization	6.3	0.2%
	Total	2,839.6	100%

Source: SRWMD, 2015.

2.6   Major Conveyance System

Lake Butler receives surface flows from a watershed covering approximately 2,840 acres, or 4.4 square miles, by means of flows emerging from the extensive forested wetlands that fringe the Lake, by direct precipitation, and by stormwater runoff from surrounding developed lands. Inflow to the west side of the Lake is contributed by six defined inflows:

1. A 24" corrugated metal pipe (CMP) under NE 113th Trail, 0.74 miles northwest of the lakeshore (Stantec, 2013);
2. A 3'x8' concrete box culvert on County Road (C.R.) 231, 0.33 miles north of S.R. 100 (Stantec, 2013);
3. An un-surveyed culvert on C.R. 231, 0.12 miles north of the 3'x8' box culverts mentioned above;
4. An un-surveyed culvert on C.R. 231, 0.14 miles south of Nubby Luke Road;
5. An un-surveyed culvert on C.R. 231, 0.03 miles north of Nubby Luke Road (Stantec, 2013); and
6. A 3'x10.5' concrete box culvert on S.R. 100 (Stantec, 2013).

On the east side of the Lake, an un-surveyed culvert on C.R. 238, approximately 0.15 mile south of NE 111th Way, conveys flows to wetlands adjacent to the lakeshore (Stantec, 2013) (Figure 2-5).

Lake Butler discharges by means of the outfall canal located on the south lakeshore. The canal conveys flows southward under a succession of streets and through agricultural lands, ultimately discharging to Richard Creek at a point approximately three river miles southeast of the Lake (Stantec, 2013).

On the way to Richard Creek, flows from Lake Butler pass through culverts of varying types, dimensions and ages that are located under the following streets, which include in order from north to south: NE 3rd St., NE 2nd St., NE 1st St., S.R. 100, SE 2nd St., SE 4th St., S.R. 121, SE 5th Ave, and Palatka-Lake Butler State Trail. The culverts under NE 3rd St. and NE 2nd St. were surveyed by Stantec (Figure 2-5).

Upon evaluation of the ground survey data, the LiDAR-based DEM and a field survey by the District in November 2015, the highest point of the outfall canal appears to be located in the ditch segment between NE 3rd St. and NE 2nd St.

3.0 Water Budget Model Development

3.1 Model Selection

To support the establishment of MFLs in Lake Butler, a water budget model was required to be developed and calibrated in order to assess the Lake's hydrologic changes over a long-term duration and under various 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, 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 candidate models include SWMM, MIKE SHE/MIKE 11, MODHIM, and other integrated models.

Note that ICPR Version 3.1 was previously utilized to develop a H&H model at the Lake for simulation of design storm events (Stantec, 2013). However, this model was not considered a candidate model for this study, as it is incapable of running long-term simulations of a full hydrologic cycle. However, some information from the ICPR model was used as input to the proposed water budget model.

Upon an initial discussion with the District staff and further evaluation of the candidate models' capability and data availability, EPA SWMM Version 5.1 was selected for this water budget modeling project. Much of the information presented herein was 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 on the basis of 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; and
- 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 very 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 determination of the subbasin boundaries within the model domain was made on the basis of 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).

3.2.2 Surface Runoff

The Nonlinear Reservoir Runoff method is used by SWMM, as illustrated in the graph below. 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.
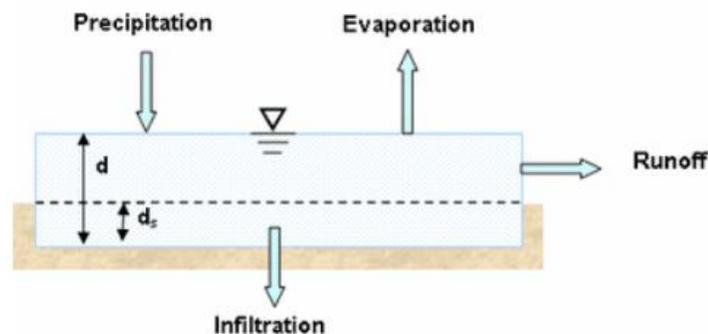
Source: EPA SWMM Help File (V5.1.015)

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 Butler 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.

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 during Phase A of the overall water budget modeling project, including:

- Hourly daily Next-Generation Radar (NEXRAD) rainfall data by SRWMD (10/1/2007 through 12/31/2014);
- Daily NEXRAD rainfall data by SRWMD (2/1/2001 through 12/31/2014);
- Sub-hourly NEXRAD rainfall data by National Oceanic and Atmospheric Administration (NOAA) (4/6/1995 to 10/1/2007);
- Daily rainfall data (Daymet) by Oak Ridge National Laboratory (ORNL) (1/1/1980 to 12/31/2014) (Thornton *et al.*, 2012); and
- 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.

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
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

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)
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
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
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).

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 12/31/2014); and
- 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), and
    - USC00083321 – Gainesville 3 WSW FL US (10/6/1953 to 12/31/1988).

Single or combination 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 Butler watershed.

Using an area-weighted method, a monthly ET pattern can be developed for each aquifer in the Lake Butler watershed. Lake Butler was excluded from the estimation of the monthly ET pattern for Aquifer AB0100, since the Lake itself was treated as a storage unit in SWMM and the direct evaporation from the Lake was calculated 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

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.

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

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

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

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 & Aquifers

Aquifers are sub-surface groundwater areas used to model the vertical movement of water infiltrating from the subcatchments that lie above them. They also permit the infiltration of groundwater into the drainage system, or exfiltration of surface water from the drainage system, depending on the hydraulic gradient that exists. Aquifers are only required in the 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 the graph below. 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 lower groundwater loss rate were developed based on the 2016 North Florida Southeast Georgia (NFSEG) Groundwater Flow Model data developed by SJRWMD (Durden *et al.*, 2013; SJRWMD, 2016).
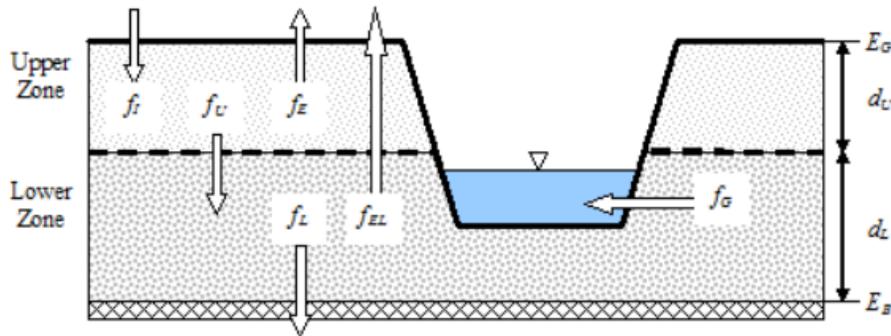
Source: EPA SWMM Help File (V5.1.015)

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; and
- 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.

3.3.1 Channels/Ditches

In SWMM, a channel/ditch is modeled as open geometry conduit with regular or irregular cross section. The data for the irregular channel geometry was derived mostly from the survey data and

the LiDAR-based DEM data. The upstream and downstream elevations were mostly taken from the LiDAR-based DEM when land survey data were not available.

Natural channel reaches were evaluated for out of bank conveyance capability based on LiDAR-based DEM data, aerial photographs, and field evaluations. Channel roughness (Manning's coefficients) values were derived from the SWMM User's Manual and other literature.

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 field surveyed by Stantec in 2012 for the culverts on the major conveyance system (Figure 2-5). For the un-surveyed culverts as identified on Figure 2-5, 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 accounts toward the total head loss, as do the 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 by the survey data and aerial photos. In addition, if a conduit experienced instability during a simulation, an equivalent conduit (elongated) would be automatically used 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 lower groundwater loss rate, an "outlet" link was used to calculate the lower groundwater loss rates at the surficial aquifer beneath the Lake. 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 Lake 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 and 2.0 were assigned to the paved and unpaved roads, respectively.

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 stormwater models (e.g., EPA SWMM, HEC-RAS, and ICPR), at subbasin scales in urban and rural areas including Florida. Also note that there has been a trend to use weir coefficients much lower than published values for broad crested weirs. The weir invert elevations were estimated from the LiDAR-based DEM data. A weir coefficient of 1.0 was assigned to all the overland flow weirs.

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 by primarily using the LiDAR-based DEM data.

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

3.3.6 Initial Conditions

The node initial elevations in the Lake and its adjacent wetland areas need to be set to match stage data measured at the Lake. A lake station (USGS 02321300 at Lake Butler, FL) currently operated by the District was used to establish the initial stage at the Lake. The initial stage values in other minor storage areas, junction nodes, and groundwater tables in aquifers were adjusted accordingly, to avoid unreasonable initial flows.

3.3.7 Boundary Conditions

In SWMM, outfalls are terminal nodes of the drainage system used to define the most downstream boundary under dynamic wave flow routing. The outfall for surface water was defined in the outfall canal, located just upstream of NE 1st St. As no observed stage data is available at this location, the outfall stage was determined by the minimum of critical flow depth and normal flow depth in the connecting canal/conduit.

To simulate time-variant lower groundwater loss of the surficial aquifer directly beneath the Lake, a second outfall was added to represent the groundwater level in the upper FAS. A long-term USGS groundwater well station (USGS ID: 300101082245201/SRWMD ID: S051933001), located approximately 4.2 miles west of Lake Butler, offers daily average groundwater level data measured in the upper FAS. The data gaps in the groundwater database were filled by using a correlation analysis with an adjacent USGS well station (USGS ID: 295055082130801 / SRWMD ID: S072132001, near Lake Hampton) or 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 the 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, adding dummy pipes, 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 junctions. These represent the flow and conveyance related elements of the model.

3.4   Preliminary Model Development and Simulation

The Lake Butler water budget model was first developed based on the 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 Butler 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 & 2-2B) and the major conveyance system map (Figure 2-5), the Lake Butler watershed was subdivided into a total of 21 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 Table 3-4.

Based on the similarity of the topographic and subsurface characters, the subbasin features were further grouped to create a total of six aquifers (Figure 3-2). In addition, a fictional Aquifer ABLAKE was created by duplicating the parameters of Aquifer AB0100, except for Lower GW Loss Rate that was assumed zero in Aquifer ABLAKE. Lower groundwater loss from this fictional aquifer or Lake Butler was simulated via an outlet link in the SWMM model, see Section 3.3.3. Hydrologic parameters for each aquifer are summarized in Table 3-5.

3.4.2 Hydraulic Model Parameterization

There is a total of 24 nodes in the conveyance system, including 12 "storage nodes" representing wetlands, lakes, and ponds, 10 "junction nodes", and two "outfall nodes" representing the model boundaries in the outfall canal and the upper FAS (Figure 3-3).

There is a total of 33 reaches, including 11 open channels, 10 pipes or culverts, 11 weirs representing the road overtopping or the sheet flow between subbasins, and one outlet representing lower groundwater loss at the Lake.

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 the major sub-watershed area (tributary). For the Lake Butler watershed, there is only one sub-watershed area. The remaining four-character fields are reserved for numbering of the subbasins within the major sub-watershed (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 3-2).

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 "NB0100" would be used at the loading node of subbasin "B0100" and its downstream connecting reach would have the name "RB0100XX." 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 "NB0090" while the next reach will be named "RB0090XX" 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, "RB0070P2" would be used for naming the second culvert that discharge node "NB0070" (Figures 3-3 and 3-4).

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 (Figure 3-4). A randomly picked period, from 1/1/2013 through 12/31/2014 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 or Lake Butler (Figure 3-5). As observed in this comparison plot, the preliminary model appears to capture the hydrologic response to rainfall and ET during the two-year simulation period.

In summary, the preliminary water budget model of Lake Butler 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.

The model developed for the existing conditions was calibrated in the subsequent task, by adjusting various model parameters to have a good overall fit with the observed lake stage data collected in the past two decades.

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
B0050	2.91	315	2.52	30	25	0.05	0.15	0.012	0.1	2.3	3.3037	0.360
B0060	20.35	1500	2.20	24.36	25	0.05	0.172	0.012	0.16	2.4	2.8657	0.355
B0100	435.89	16410	0.11	99.84	98.54	0.006	0.014	0.032	0.117	2.5	1.2821	0.345
B0110	23.50	2200	1.51	77.29	64.44	0.089	0.261	0.318	0.421	2.3	2.0609	0.354
B0120	49.83	4000	1.96	50.3	48.83	0.071	0.226	0.186	0.316	2.9	1.7957	0.340
B0130	19.18	1600	1.59	31.25	27.29	0.051	0.176	0.023	0.143	2.9	1.4460	0.338
B0140	14.92	650	1.40	44.11	41.67	0.067	0.226	0.141	0.314	2.1	3.8100	0.368
B0150	50.93	2200	1.36	38.8	25	0.05	0.172	0.012	0.159	2.0	4.3848	0.373
B0160	82.39	3600	1.16	24.16	25.21	0.055	0.161	0.014	0.13	2.1	3.6177	0.367
B0200	547.61	12000	0.96	39.7	44.63	0.069	0.262	0.134	0.379	2.5	2.0297	0.351
B0210	171.39	5500	1.33	17.05	29.37	0.052	0.237	0.027	0.302	2.5	1.2127	0.345
B0220	331.87	8500	0.92	12.31	31.24	0.055	0.27	0.047	0.398	2.4	1.4155	0.349
B0230	22.00	1600	0.80	6.76	25	0.05	0.222	0.012	0.222	2.1	3.5240	0.366
B0240	17.12	1300	1.31	16.79	33.11	0.045	0.223	0.012	0.324	2.1	3.3432	0.365
B0250	10.80	1200	1.71	5.75	25	0.05	0.205	0.012	0.199	2.0	4.3011	0.372
B0260	19.45	2100	1.04	19.8	35.1	0.06	0.29	0.09	0.48	2.2	2.5797	0.358
B0300	156.98	6800	1.32	23.65	37.07	0.062	0.288	0.106	0.476	2.3	2.0370	0.354
B0400	594.02	8500	1.22	32.81	41.73	0.067	0.271	0.135	0.409	2.5	2.0382	0.349
B0500	65.03	3000	1.21	24.81	37.69	0.062	0.283	0.108	0.465	2.1	3.5634	0.366
B0510	129.66	3500	1.71	16.71	33.49	0.058	0.271	0.075	0.398	2.2	2.5481	0.358
B0520	73.83	1600	1.67	2.17	25	0.05	0.248	0.012	0.333	2.0	4.1473	0.371

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)	Lower GW Loss Rate (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AB0100	0.4110	0.0550	0.1409	12.584	5.4340	15	0.3	10.85	0.000015	102.34	129	0.15
AB0200	0.4067	0.0577	0.1515	10.992	5.6196	15	0.3	11.07	0.000051	103.4	132	0.15
AB0210	0.4021	0.0597	0.1590	10.444	5.7050	15	0.5	12.89	0.000097	110.04	142	0.15
AB0300	0.4050	0.0575	0.1501	10.803	5.5261	15	0.5	14.17	0.000038	104.35	137	0.15
AB0400	0.4070	0.0586	0.1558	11.620	5.7535	15	0.4	12.96	0.000037	105.23	134	0.15
AB0510	0.4100	0.0544	0.1374	14.151	5.3053	15	0.4	13.85	0.000028	106.86	139	0.15
ABLAKE	0.4110	0.0550	0.1409	12.584	5.4340	15	0.3	10.85	0*	102.34	129	0.15

* Lower groundwater loss in Aquifer ABLAKE was simulated via an outlet link in the SWMM model, see Section 3.3.3.

4.0   Water Budget Model Calibration

4.1   Model Calibration Period

The Lake Butler water budget preliminary model was calibrated with data in a 10-year simulation span from 1/1/2005 through 12/31/2014. This simulation span includes a variety of hydrologic conditions, including one high water (2014) and two low water periods (2006-2008 and 2011-2012), from the long-term historical stage records collected at the Lake. 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 2006 land use/land cover data and other best available data sources is suitable for model calibration in 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 tested by calibration against known gage data.

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 Lake.

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 size of these ranges was set 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 different 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 in the model domain.

4.3.1.2   Evapotranspiration

Daily PET data has been developed by USGS for a period from 6/1/1995 through 12/31/2014, on a basis of 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 Butler 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 Lake Butler 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 2014 (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 47.61 inches lies within 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.

Table 4-1. Summary table of average monthly PET data for Lake Butler watershed (1996–2014).

Month	PET Value (inch/month)
January	1.39
February	1.97
March	3.54
April	4.98
May	6.30
June	6.12
July	6.48
August	5.95
September	4.56
October	3.27
November	1.84
December	1.20
Total	**47.61**

Sources: USGS, 2015.

4.3.1.3   Upper FAS Potentiometric Surface Levels

A long-term USGS groundwater well station (USGS ID: 300101082245201 / SRWMD ID: S051933001) is located approximately 4.2 miles west of the Lake (Figure 4-3). This well station provides potentiometric surface levels in the upper FAS at a variety of frequencies. To obtain a daily well hydrograph, the data gaps in the groundwater level data were filled by using a correlation analysis with an adjacent USGS well station (USGS ID: 295055082130801 / SRWMD ID: S072132001, near Lake Hampton), or by using a linear interpolation method. A 2-foot shift factor was estimated by approximating the groundwater level difference between the well station near Lake Butler and the lake itself, based on the May 2005 potentiometric contour map (Figure 4-3). Upon adding the 2-foot factor to the daily well levels at the well station, the new shifted daily well level data would be more representative of the groundwater conditions beneath the Lake. This "measured" groundwater dataset was used in the water budget model (Figure 4-4).

4.3.1.4   Lake Stages

USGS 02321300 at Lake Butler, FL is a long-term stage gage located at a concrete dock on the south lakeshore (Figure 4-5). This gage provides the long-term historical lake stage values in a variety of frequencies from 1957 to current (Figure 4-6A) and has been operated by the District since 2012. The lake stage records were used to establish the initial stage value at the Lake in the model as well as to compare with the simulated stage values for model calibration.

Since the majority of the stage values were provided on a monthly basis, the raw stage records in the simulation span (2005 through 2014) were resampled to have a maximum of 12 stage values per year (Figure 4-6B). The data resampling was to eliminate the bias due to the different frequencies in the raw data within the model simulation span. The resampled lake stage data was used to compare with the corresponding simulated stage values in the model calibration.

4.3.2   Adjustment of Hydrologic Model Parameters

Various hydrologic model parameters were adjusted during the model calibration process, including impervious percentage, lower groundwater loss rate, 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   Impervious Percentages

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 that dominate the 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 drought period in the Lake Butler watershed (Figure 4-6B).

Therefore, impervious percentage values for wetland areas were reduced to 50%, to account for low rainfall periods, as highlighted in Table 4-2. The impervious percentage value for each subbasin was recalculated and updated in the SWMM model as well (Table 4-3). The revised impervious

percentage and other hydrologic parameters for the subbasins (Table 4-3) were held constant in the model calibration.

Table 4-2. 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	65	25	0.012	0.1	0.05	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

Table 4-2. 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
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).

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

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
B0050	2.91	315	2.52	30.00	25	0.05	0.15	0.012	0.1	2.3	3.3037	0.360
B0060	20.35	1500	2.20	24.36	25	0.05	0.172	0.012	0.16	2.4	2.8657	0.355
B0100	435.89	16410	0.11	97.10	98.54	0.006	0.014	0.032	0.117	2.5	1.2821	0.345
B0110	23.50	2200	1.51	39.44	64.44	0.089	0.261	0.318	0.421	2.3	2.0609	0.354
B0120	49.83	4000	1.96	28.80	48.83	0.071	0.226	0.186	0.316	2.9	1.7957	0.340
B0130	19.18	1600	1.59	29.86	27.29	0.051	0.176	0.023	0.143	2.9	1.4460	0.338
B0140	14.92	650	1.40	28.11	41.67	0.067	0.226	0.141	0.314	2.1	3.8100	0.368
B0150	50.93	2200	1.36	38.80	25	0.05	0.172	0.012	0.159	2.0	4.3848	0.373
B0160	82.39	3600	1.16	23.96	25.21	0.055	0.161	0.014	0.13	2.1	3.6177	0.367
B0200	547.61	12000	0.96	21.18	44.63	0.069	0.262	0.134	0.379	2.5	2.0297	0.351
B0210	171.39	5500	1.33	15.52	29.37	0.052	0.237	0.027	0.302	2.5	1.2127	0.345
B0220	331.87	8500	0.92	6.84	31.24	0.055	0.27	0.047	0.398	2.4	1.4155	0.349
B0230	22.00	1600	0.80	6.76	25	0.05	0.222	0.012	0.222	2.1	3.5240	0.366
B0240	17.12	1300	1.31	16.79	33.11	0.045	0.223	0.012	0.324	2.1	3.3432	0.365
B0250	10.80	1200	1.71	5.75	25	0.05	0.205	0.012	0.199	2.0	4.3011	0.372
B0260	19.45	2100	1.04	10.10	35.1	0.06	0.29	0.09	0.48	2.2	2.5797	0.358
B0300	156.98	6800	1.32	12.07	37.07	0.062	0.288	0.106	0.476	2.3	2.0370	0.354
B0400	594.02	8500	1.22	16.75	41.73	0.067	0.271	0.135	0.409	2.5	2.0382	0.349
B0500	65.03	3000	1.21	12.95	37.69	0.062	0.283	0.108	0.465	2.1	3.5634	0.366
B0510	129.66	3500	1.71	8.55	33.49	0.058	0.271	0.075	0.398	2.2	2.5481	0.358
B0520	73.83	1600	1.67	2.17	25	0.05	0.248	0.012	0.333	2.0	4.1473	0.371

4.3.2.2   Groundwater & 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 4-4).

Fraction of total evaporation available for the upper unsaturated zone was adjusted based on evaluation of the land use/land cover features in the watershed as well as the initial model run results (Table 4-4). This parameter was kept constant for the subsequent model calibration runs.

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 4-5).

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 4-6).

The lower groundwater loss rates in aquifers control 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 lower groundwater loss rate values are highlighted in Table 4-4.

Also note that the lower groundwater loss in Aquifer ABLAKE was modeled as an "outlet" link in the SWMM model, as discussed in Section 4.3.3.2 below. Using a constant lower groundwater loss rate for other aquifers seems reasonable, based on the simulated flows at Outlet RB0100T, which vary from 0.97 to 1.09 cfs with an average value of 1.03 cfs (Figure 4-7).

Table 4-4. 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)	Lower GW Loss Rate (in/hr)	Bottom Elev. (ft NAVD88)	Water Table Elev. (ft NAVD88)	Unsat. Zone Moisture
AB0100	0.4110	0.0550	0.1409	12.584	5.4340	15	1.0	10.85	0.00075	102.34	129.8	0.15
AB0200	0.4067	0.0577	0.1515	10.992	5.6196	15	1.0	11.07	0.00255	103.40	130.0	0.15
AB0210	0.4021	0.0597	0.1590	10.444	5.7050	15	1.0	12.89	0.00243	110.04	138.0	0.15
AB0300	0.4050	0.0575	0.1501	10.803	5.5261	15	1.0	14.17	0.0019	104.35	129.8	0.15
AB0400	0.4070	0.0586	0.1558	11.620	5.7535	15	1.0	12.96	0.00185	105.23	129.8	0.15
AB0510	0.4100	0.0544	0.1374	14.151	5.3053	15	1.0	13.85	0.0014	106.86	132.0	0.15
ABLAKE	0.4110	0.0550	0.1409	12.584	5.4340	15	1.0	10.85	0*	102.34	129.8	0.15

* Lower groundwater loss in Aquifer ABLAKE was simulated via an outlet link in the SWMM model, see Section 3.3.3.

Table 4-5. 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

Sources: Peace River integrated modeling (HGL, 2008); Myakka River Watershed Initiative (Interflow, 2008).

Table 4-6. 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)
B0050	AB0100	NB0050	136.34	0.02	0.7	0.02	0.7	0	125	129.5
B0060	AB0100	NB0060	138.52	0.02	0.7	0.02	0.7	0	125	129.5
B0100	ABLAKE	NB0100	131.50	0.02	0.7	0.02	0.7	0	125	129.5
B0110	AB0100	NB0100	133.97	0.02	0.7	0.02	0.7	0	125	129.5
B0120	AB0100	NB0100	131.68	0.02	0.7	0.02	0.7	0	125	129.5
B0130	AB0100	NB0100	131.70	0.02	0.7	0.02	0.7	0	125	129.5
B0140	AB0100	NB0100	134.17	0.02	0.7	0.02	0.7	0	125	129.5
B0150	AB0100	NB0100	136.58	0.02	0.7	0.02	0.7	0	125	129.5
B0160	AB0100	NB0100	139.37	0.02	0.7	0.02	0.7	0	125	129.5
B0200	AB0200	NB0200	134.85	0.02	0.7	0.02	0.7	0	125	129.5
B0210	AB0210	NB0210	144.20	0.02	0.7	0.02	0.7	0	125	138.0
B0220	AB0210	NB0220	145.52	0.02	0.7	0.02	0.7	0	125	138.0
B0230	AB0200	NB0230	141.55	0.02	0.7	0.02	0.7	0	125	135.0
B0240	AB0200	NB0240	141.95	0.02	0.7	0.02	0.7	0	125	135.0
B0250	AB0200	NB0250	141.98	0.02	0.7	0.02	0.7	0	125	135.0
B0260	AB0200	NB0260	137.35	0.02	0.7	0.02	0.7	0	125	133.0
B0300	AB0300	NB0100	139.86	0.02	0.7	0.02	0.7	0	125	129.5
B0400	AB0400	NB0400	137.14	0.02	0.7	0.02	0.7	0	125	129.5
B0500	AB0100	NB0100	133.48	0.02	0.7	0.02	0.7	0	125	130.0
B0510	AB0510	NB0510	141.75	0.02	0.7	0.02	0.9	0	125	132.0
B0520	AB0510	NB0510	142.03	0.02	0.7	0.02	0.9	0	125	132.0

4.3.3 Adjustment of Hydraulic Model Parameters

Various hydraulic model parameters were also adjusted during model calibration, including channel invert elevations, outlet rating curves, storage 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

Based on the ground survey data, LiDAR-based DEM data, and field survey data conducted by the District in November 2015, the highest point of the outfall canal appears to be in the ditch segment between NE 3rd St. and NE 2nd St., which was modeled as Channel RB0060C in the SWMM model.

The upstream invert of Channel RB0060C was adjusted based on the observed lake stage values (Figure 4-6B) during periods of high lake levels in 2005 and 2012 through 2014 when the lake levels exceeded the control elevation in the outfall ditch. The final upstream invert of RB0060C was set at 128.75 ft NAVD88 for simulation time prior to 1/1/2012 and after 8/1/2014 when the outfall ditch was in good maintenance condition and was increased to 130.0 ft NAVD88 from 1/1/2012 to 8/1/2014 when the outfall ditch was possibly silted or not well-maintained after two prolonged drought periods from 2006 to 2008 and 2011. Using time-varied upstream invert elevations of Channel RB0060C improved the model calibration results significantly, particularly during periods of high lake levels.

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

4.3.3.2   Outlet Functional Rating Curves

To simulate the time-variant lower groundwater loss rate, an "outlet" link (RB0100T) was used to calculate the lower groundwater loss rates from the Lake 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 the Lake and groundwater table elevations in the upper FAS was used in this project (Equation C).

$$Q = A * \Delta H^B \tag{C}$$

where, Q = flow (cfs)
   A = coefficient A (ft2/s)
   B = coefficient B (set at 1.0, per Darcy's equation)
   ΔH = head difference (ft)

The initial coefficient A of 0.0001 ft2/s used in the function was first estimated using Darcy's equation with the vertical hydraulic conductivity value of Intermediate Aquifer System/Intermediate Confining Unit in the 2016 NFSEG groundwater flow model (Durden *et al.*, 2013; SJRWMD, 2016). Seismic profiling of numerous northeast Florida lakes shows a variety of collapse structures providing preferred paths toward the aquifer (Kindinger *et al.*, 2000). Based on the initial model calibration run results, the initial coefficient A does not 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 runs during model calibration. The final coefficient A was set at 0.014 ft2/s, by applying a factor of 140 to the initial value.

4.3.3.3   Storage Curves

The storage curves or depth-area relationships were modified at two large wetland areas (Nodes NB0200 and NB0400 in the model) (Figure 3-3), where the LiDAR-based DEM topographic data does not provide a reliable estimate of the true ground elevations due to heavy vegetation cover and/or standing water. The storage curves at these two wetlands or nodes were manually adjusted based on the wetland limits and average water depths estimated from the LiDAR-based DEM topographic data, aerial imagery, land use/land cover map, as well as soil map. The original and revised storage curves were held constant for the remaining trial and error runs in model calibration.

4.3.3.4   Initial Conditions

The node initial elevations in the Lake and its adjacent wetland areas were adjusted to match stage data measured at USGS 02321300 at Lake Butler, FL (Figure 4-5). The node initial elevation in the Lake was set at 129.78 ft NAVD88 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 4-4 and 4-6) were adjusted accordingly to avoid unreasonable initial flows.

4.4   Model Calibration Results

4.4.1 Model Simulation and Calibration

The Lake Butler water budget model was calibrated with data from 2005 through 2014, 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;
- Storage curves;
- The ratio of direct lake evaporation to PET;
- The coefficients used for ET calculation in the upper and lower zones of aquifers;
- The coefficients used for computing of lateral groundwater flow;
- Initial conditions at nodes (lakes, wetlands, and channels) and water tables in aquifers; and
- Shift factor used to adjust potentiometric surface levels.

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

- Channel invert elevations (control elevation of the Lake);
- Outlet functional rating curves for flow exchange between the Lake and upper FAS; and
- Lower groundwater loss rates between the surficial aquifers and upper FAS.

4.4.2 Model Calibration Results

The simulated and observed lake stage hydrographs are graphically presented on Figure 4-8. The final calibration model simulated stage values replicate the trends of the historical data for Lake Butler.

A scatter plot comparing individual simulated lake stages with corresponding observed values is provided on Figure 4-9 to assist in the model assessment. The statistical analysis results are summarized in this plot as well. The RMSE of the residuals was 0.39, which is less than the 0.5-foot primary goal. 80.8% of the residuals were within ±0.5 foot of the observed values meeting the second goal of 67%. 98.3% 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 abovementioned criteria over a wide range of stages, is also being met.

4.4.3 Water Budget Results

The water budgets of the Lake Butler 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 has, on average, precipitation of 49.7 in/yr, evaporation (from land surface and conveyance system) and ET of 31.7 in/yr, deep percolation of 14.4 in/yr, outflow to the downstream canal of 3.3 in/yr, and storage change in aquifers and conveyance system of 0.3 in/yr in the 10-year simulation period from 2005 through 2014 (Table 4-7).

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 of the upper FAS of 14.4 in/yr may consist of three possible components that were not distinguished in the model, including 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).

4.4.4   Summary of Model Calibration

Based on the model calibration results presented on Figures 4-8 and 4-9 for a 10-year simulation span, the Lake Butler 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 Butler water budget model will provide a useful tool for comparing water management alternatives in the context of MFLs.

Table 4-7. Summary table of water budget results in Lake Butler watershed (2005-2014).

Runoff Quantity

Items	Total Volume (acre-ft)	Total Depth (in)	Average Depth (in/yr)
Precipitation	117,723.8	497.5	49.75
Evaporation	8,561.5	36.2	3.62
Infiltration	86,518.7	365.6	36.56
Surface Runoff	22,648.3	95.7	9.57
Final Storage	0.0	0.0	0.0

Groundwater

Items	Total Volume (acre-ft)	Total Depth (in)	Average Depth (in/yr)
Initial Storage	33,144.9	140.1	14.01
Infiltration	86,518.7	365.6	36.56
Upper Zone ET	44,452.0	187.8	18.79
Lower Zone ET	2,608.3	11.0	1.10
Deep Percolation	26,621.8	112.5	11.24
Groundwater Flow	12,350.3	52.2	5.23
Final Storage	33,631.3	142.1	14.21
Storage Change	486.5	2.1	0.21

Flow Routing

Items	Volume (acre-ft)	Volume (10^6 Gal)	Average Depth (in/yr)
Initial Storage	2,877.8	937.8	1.22
Surface Runoff	22,648.0	7,380.2	9.57
Groundwater Inflow	12,350.3	4,024.5	5.22
External Outflow*	15,173.2	4,944.4	6.41
Evaporation	19,654.3	6,404.6	8.31
Final Storage	3,052.1	994.6	1.29
Storage Change	174.3	56.8	0.07
* External Outflow includes:			
To Downstream Ditch	8,210.8	2,675.5	3.47
To Upper Floridan Aquifer	6,961.9	2,268.5	2.94

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 as well as the historical lake stage data prior to 1983 to determine if MFLs are being met.

The calibrated Lake Butler water budget model was used to run long-term simulations for a total of 32 years from 1/1/1983 through 12/31/2014, which is limited by the available groundwater well data records since 7/2/1982. 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 Lake, which was described in Section 4.3.1.3.

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 32-year model period includes the two lowest lake stage periods since lake stage data collection began in 1957 (Figure 4-6A). Both periods occur between 2000 and 2010 and coincide with decreased rainfall at those times (Figure 5-1). The lake stages have since rebounded to pre-drought levels. The lake stage data during the 32-year model period do not adequately represent the longer lake stage data history.

To include a more representative record, a 50-year "hybrid" data set was developed by combining the 32-year simulated lake stages for the current pumping scenario with the historical gage data prior to 1983 (7/2/1957-9/28/1967 and 11/12/1974-12/31/1982). It was assumed that the 50-year hybrid lake stage data set for the current pumping scenario is a statistically realistic representation of the hydrology, absent significant anthropogenic or climatological changes, over the next 50 years.

In the subsequent sections, the current pumping scenario for Lake Butler assessed in the context of MFLs refers to a hypothetical case where the hybrid lake stage data set assumes land use at 2006 conditions and groundwater withdrawals under the current pumping scenario. The main reasons for selecting the 2006 land use are: 1) the 2006 land use data was utilized in development of the water budget model; and 2) there have been no significant land use changes in the Lake Butler watershed since 2006.

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 (2005-2014)	NEXRAD (1/1/2005 - 12/31/2014)	USGS PET (1/1/2005-12/31/2014)	SRWMD S051933001 Shifted by 2 ft (1/1/2005 – 12/31/2014)
Long-term Simulations (1983-2014)	Oak Ridge National Laboratory (ORNL) Daymet (1/1/1983 - 6/30/2002) NEXRAD (7/1/2002 - 12/31/2014)	NOAA Pan Evaporation at Gainesville stations (1/1/1983 – 5/31/1995) USGS PET (6/1/1995-12/31/2014)	SRWMD S051933001 Shifted by 2 ft (1/1/1983 – 12/31/2014)

Source: ORNL, 2015; NOAA, 2015; USGS, 2015; SRWMD, 2016.

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).

The Daymet rainfall data from 1/1/1983 to 6/30/2002 and the NEXRAD rainfall data from 7/1/2002 to 12/31/2014 (Table 5-1), were assembled to be used in the long-term model simulations, through a series of runs by testing the simulated stage levels against the known gage data.

The rainfall data collected at various NOAA and SRWMD weather stations were not selected, mostly due to their long distance to the Lake Butler watershed and/or lengthy data gaps.

5.2.2 Evapotranspiration

The daily PET data developed by USGS in individual 2 km x 2 km pixels (Figure 4-1) has a period of record from 6/1/1995 to 12/31/2014.

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 by USGS. Upon review of the pan evaporation data at these three stations, the two stations at Gainesville, FL (USC00083321 and USC00083322) were selected to estimate the PET value prior to 6/1/1995. Based on a regression analysis between the USGS PET and NOAA pan evaporation data at these two NOAA stations, a coefficient of 0.77 was estimated and the regression then used to convert pan evaporation data to PET.

In summary, the daily PET data required for the long-term model simulation with a span of 32 years (Table 5-1 and Figure 5-3) were developed by combining the USGS PET data as well as the PET values estimated from the NOAA pan evaporation data.

5.2.3 Upper FAS Potentiometric Surface Levels

The data record collected at the USGS well station (USGS ID: 295055082130801 / SRWMD ID: S051933001, data record starting from 7/2/1982) was used to estimate the groundwater conditions beneath the Lake (Table 5-1), by applying the method discussed in Section 4.3.1.3. The 2-foot shift factor, as discussed in Section 4.3.1.2, was applied to the daily well records at this well station. Note that the period of record for this well limited the long-term simulation period to 32 years (1983–2014).

The observed and filled well hydrographs, as well as the shifted well hydrograph (+ 2-ft), are illustrated on Figure 5-4. The shifted groundwater well hydrograph was used to represent the groundwater conditions beneath the Lake in the long-term model simulation and this data set is referred to as the "measured" data set.

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 both the USGS well station (USGS 295055082130801 / SRWMD ID: S051933001) and Lake Butler for a period of 1948 through 2015, as illustrated on Figure 5-5.

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. A drawdown of 6.6 feet was estimated for the current pumping scenario beneath the Lake. The drawdown value was subtracted from the no-pumping data set to create a consistent (i.e., stationary pumping through time) "current pumping" data set. The measured, no-pumping, and current pumping data sets at Lake Butler for a period of 1982 through 2015 are illustrated on Figure 5-6.

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 32 years from 1983 through 2014, by implementing the time series data collected and composited 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 Lake itself through an "outlet" link in the model. The groundwater level data sets developed for the "measured" and current pumping scenarios (Figure 5-6) were implemented in the long-term model simulations to estimate the groundwater loss from the Lake itself for each of these two scenarios.

In the SWMM model, a constant lower groundwater loss rate 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 Lake where collapse structures might provide preferred paths toward the upper FAS. The calibrated lower groundwater loss rates values listed in Table 4-4 were used for the long-term model simulation of the measured scenario. The lower groundwater loss rate values for the current pumping scenarios were estimated based on the following equation (Equation D). The lower groundwater loss rate values used in the model simulations of the measured and current pumping scenarios are summarized in Table 5-2. The remainder of the model parameters were not changed.

$$A' = A * \frac{\Delta H + B}{\Delta H} \tag{D}$$

where, A' = proposed lower groundwater loss rate (in/hr), i.e., the current pumping scenario
A = base lower groundwater loss rate (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 in the Lake and groundwater table elevations in the upper FAS, which is 73.8 ft for the base conditions

Table 5-2. Summary of lower groundwater loss rate values (in/hr) for the measured and current pumping scenarios

Aquifer	Base/Measured Scenario	Current Pumping Scenario (B = 0.17 ft)
AB0100	0.00075	0.000748
AB0200	0.00255	0.002544
AB0210	0.00243	0.002424
AB0300	0.0019	0.001896
AB0400	0.00185	0.001846
AB0510	0.0014	0.001397

The simulated lake stage hydrograph for the measured and current pumping scenarios as well as the corresponding gage records are graphically presented on Figure 5-7A. The simulated stage

hydrographs for the measured and current pumping scenarios generally replicate the trends of the historical data in the 32-year period.

A scatter plot comparing simulated lake stages for the measured and current pumping scenarios is provided on Figure 5-7B. The statistical analysis results are summarized in this plot as well. The average residual was 0.0053 foot, i.e., the difference between these two scenarios is insignificant in terms of the simulated lake stages.(Figure 5-7A).

The simulated lake stages for the current pumping scenario will be involved in the subsequent analysis, i.e., assessment of the current pumping scenario in the context of MFLs.

5.4 "Hybrid" Data Method

As pointed out in Section 5.1, the 32-year model period includes two severe drought periods. The period of record from 1957 through 2014 shows the stage exceeded 75% of the time is 128.78 ft NAVD88 (Figure 5-9), meaning that stages below that level are the lowest quartile of the data. Stages exceeding that level in the 32-year model period account for 66.9% of the period from 1983 through 2014. This does not adequately represent the longer period of record at Lake Butler. Since the model simulation is necessary for use in testing hypothetical allowable upper FAS drawdowns, ideally the model would be extended back to capture the full period of record. However, the groundwater well data needed for the model only extends back until 7/2/1982 and the ORNL Daymet rainfall data only extends back until 1/1/1980. Using alternative data, such as relationships with other wells and rainfall stations, to drive the model would introduce greater error into the modeling analysis. To incorporate the modeled data for further analysis, and yet include the measured data to extend the period of record further back, a hybrid lake stage data set was used by combining the long-term model results and the historical lake stage data prior to 1983. Because the simulated stage hydrograph of the 32-year model run approximates the stage hydrograph for that period (Figure 5-7A), the analysis for the MFLs will include the measured data (7/2/1957-9/28/1967 and 11/12/1974-12/31/1982) and the simulated data (1/1/1983 – 12/31/2014). Figure 5-8 shows the hybrid stage hydrograph, while Figure 5-9 shows the hybrid lake stage duration curve, both for the current pumping scenario. Figure 5-8 shows that there was a multi-year gap in the measured stage data between 1967 and 1974. Those years were excluded from the subsequent analysis. Shorter gaps in data were filled in by using a linear interpolation method.

The use of the hybrid lake stage data set also allows for analysis over a greater portion of the Atlantic Multidecadal Oscillation than the long-term model simulation alone (Enfield *et al.*, 2001).

5.5 Recommended MFLs

MFLs, including a minimum frequent high (FH) level and a minimum frequent low (FL) level, have been recommended by the District for Lake Butler (Table 5-2). The event-based MFLs method (SJRWMD, 2006; Neubauer *et al.*, 2008) was utilized to determine the minimum lake levels for Lake Butler. MFLs determination is based on the evaluation of topography, vegetation, soils, and hydrologic indicator data collected from plant communities associated with the water body (ECT, 2021). The MFLs levels relate to hydroperiod categories and definitions adapted from water regime modifiers developed by Cowardin *et al.*, (1979).

Table 5-3. Summary of minimum recommended lake levels for Lake Butler.

Designated Level	Elevation Benchmarks	Elevation (ft NAVD88)	Defining event of hydrologic criteria
Minimum Frequent High (FH)	Mean elevation of seasonally-flooded basin swamp	129.55	30-day inundation/ 2-year return interval
Minimum Frequent Low (FL)	Mean elevation of landward extent of the deep marsh	127.30	120-day exposure/ 5-year return interval

Source: ECT, 2021.

The recommended FH level for the Lake is 129.55 ft NAVD88. Based on the SJRWMD guidance (Table 5-2), 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).

The recommended FL level for the Lake is 127.30 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).

5.6   Assessment of Current Pumping Scenario

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 5-8 illustrates the recommended lake MFLs superimposed on the hybrid lake stage hydrograph, and the stage of a lake can remain above or below each of the MFLs for extended periods.

Figure 5-9 illustrates the recommended lake MFLs superimposed on the stage-duration curve of the hybrid lake stage data set. In this context, the FH and FL levels anchor the hydrology of the Lake.

Since the historical lake stage data prior to 1983 is corresponding to the observed groundwater levels, a transfer function is needed to adjust the historical lake stage data set prior to being used for assessment of the current pumping scenario. For the FH level, the maximum elevations remaining wet for 30 days for each year were used (Figure 5-10); and for the FL level, the minimum elevations remaining dry for 120 days for each year were used (Figure 5-11). The modeled results for the measured scenario were plotted on the x-axis and the modeled results for the current pumping scenario were plotted on the y-axis. A regression relationship was developed and then used as a transfer function to adjust the observed lake stage data prior to 1983. The transfer functions for the FH and FL levels are presented on Figures 5-10 and 5-11.

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.

6.0 Assessment of Hypothetical Water Resource Development

6.1 Introduction

The Lake Butler water budget model as well as the historical lake stage data prior to 1983 were 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 Butler.

A series of runs of the 32-year long-term model simulations were performed with different aquifer declines. The simulation results were carried over to the entire hybrid data set using a transfer function. The updated hybrid 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 hybrid lake stage data set for each scenario:

1. the 50-year (1957-1967 and 1974-2014) hybrid lake stage data set is a statistically realistic representation of the hydrology, absent significant anthropogenic or climatological changes, over the next 50 years; and
2. any potential water resource developments under consideration would essentially continue indefinitely.

6.2 Assessment of Hypothetical Allowable Floridan Aquifer Drawdowns

Based on the frequency analysis results presented in the status assessment memo for Lake Butler, the recommended MFLs for the Lake would be met under the current pumping scenario. Therefore, further drawdowns in the upper FAS might be allowable at the 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 Lake itself through an "outlet" link 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 (Figure 5-6). Based on the methodology described in Section 5.3 (Equation D), the lower groundwater loss rate values 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, the historical data adjusted, and the resulting hybrid data set was assessed with respect to each minimum level.

To adjust the historical lake stage data used for the current pumping scenario (Section 5.6), a transfer function needed to be created for different upper FAS drawdowns. For the FH level, the maximum elevations remaining wet for 30 days for each year were used (Figure 6-1); and for the FL level, the minimum elevations remaining dry for 120 days for each year were used (Figure 6-2). The modeled results for the current pumping scenario were plotted on the x-axis and the modeled results with the proposed upper FAS drawdown were plotted on the y-axis. A regression relationship was developed and then used as a transfer function to adjust the observed data prior to 1983 for different upper FAS drawdown scenarios. The transfer functions are presented on Figures 6-1 and 6-2, based on an upper FAS drawdown of 40 and 13.6 ft for the FH and FL levels, respectively, beyond the no-pumping scenario.

Based on the model results, the recommended FH and FL levels would be met with a maximum drawdown of 40 and 13.6 ft beyond the no-pumping scenario, respectively (Figures 6-3 and 6-4). 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 40 and 13.6 ft, the recommended FH and FL levels would no longer be met respectively.

The freeboard values or maximum allowable upper FAS drawdowns for the recommended FH and FL levels for Lake Butler are presented in Table 6-1. The FL level is the constraining MFL since it allows the smaller upper FAS drawdown.

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

Designated Level	Upper FAS Freeboard (ft)
Minimum Frequent High (FH)	40.0
Minimum Frequent Low (FL)	13.6

Long-term lake stage hydrographs and stage duration curves for each scenario can be used to evaluate the time extent and magnitude of the hydrologic changes involved at the Lake with the maximum drawdown of 40 ft for FH level (Figures 6-5 and 6-6) and 13.6 ft for FL level (Figures 6-7 and 6-8), beyond the no-pumping scenario. It appears that when the Lake is in high level conditions, the upper FAS drawdown has less impact to the lake stages as 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 Lake Butler and the aquifer underneath have no chance to recover to their normal water levels after prolonged drought conditions, such as the 2000-2002 and 2006-2008 drought periods.

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 Butler located in east central Union County, Florida.

The best available data sources, including the existing ICPR model, 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 Butler water budget model was calibrated using a 10-year lake gage data record from 2005 through 2014. 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 Butler water budget model was employed in a long-term simulation for a 32-year period from 1983 through 2014. 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 32-year simulated lake stages for the current pumping scenario were combined with the historical lake stage data prior to 1983 to develop a 50-year hybrid lake stage data set to assess the Lake under the current pumping scenario.

The 50-year hybrid data set was also utilized in assessment of hypothetical allowable upper FAS drawdowns in the context of MFLs. The proposed Lake MFLs recommended by the District, including FH level of 129.55 ft NAVD88 and FL level of 127.30 ft NAVD88, would be met with a maximum drawdown of 40 and 13.6 ft beyond the no-pumping scenario, respectively. The recommended FH and FL levels would no longer be met with upper FAS drawdowns greater than 40 and 13.6 ft, respectively. The FL level is the constraining MFL with a smaller 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 Lake, as follows:

1. In the SWMM model, a constant lower groundwater loss rate 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 Butler watershed, except for the area immediately beneath the Lake where collapse structures might provide preferred paths toward the upper FAS. An "outlet" link was employed in the SWMM model with a functional rating curve developed to calculate the time-variant discharge from the Lake to the upper FAS.

2. Topographic surveys at the outfall canal and major drainage structures and limited bathymetry survey at the Lake were provided by the District. However, the topographic and bathymetric survey data is not sufficient to determine the location and elevation of the highest point of the outfall canal or control point of the Lake. It was assumed that the LiDAR-based DEM data could be used to assist in locating the control point in the outfall canal, and the invert elevation at the control point could be further determined during model calibration.

3. The 10-year calibration period of 2005 through 2014 covers a wide range of hydrologic conditions. It was assumed that the calibrated model will provide a realistic simulation over a much longer period of record (i.e., 32 years).

4. Various data sources with different techniques and levels of accuracy (e.g., NEXRAD vs. ORNL Daymet daily rainfall data and NOAA pan evaporation vs. USGS PET data), were utilized in developing the long-term model.

5. It was assumed that the 50-year (1957-1967 and 1974-2014) hybrid lake stage data set is a statistically realistic representation of the hydrology, absent significant anthropogenic or climatological changes, over the next 50 years.

6. It was also assumed that any hypothetical water resource developments under consideration would essentially continue indefinitely in assessing allowable upper FAS drawdowns in context of MFLs.

The limitation 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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Agricultural Sciences, Agricultural Experiment Stations, and Soil Science Department; and the Florida Department of Agriculture and Consumer Services.

Figures

Legend
— Major Roads
— Canal/Stream
☐ Lake Butler Watershed

Lake Butler

238

121

231

100

City of Lake Butler

Outfall Canal

Richard Creek

238

121

231

100

N

0   3,000
Feet
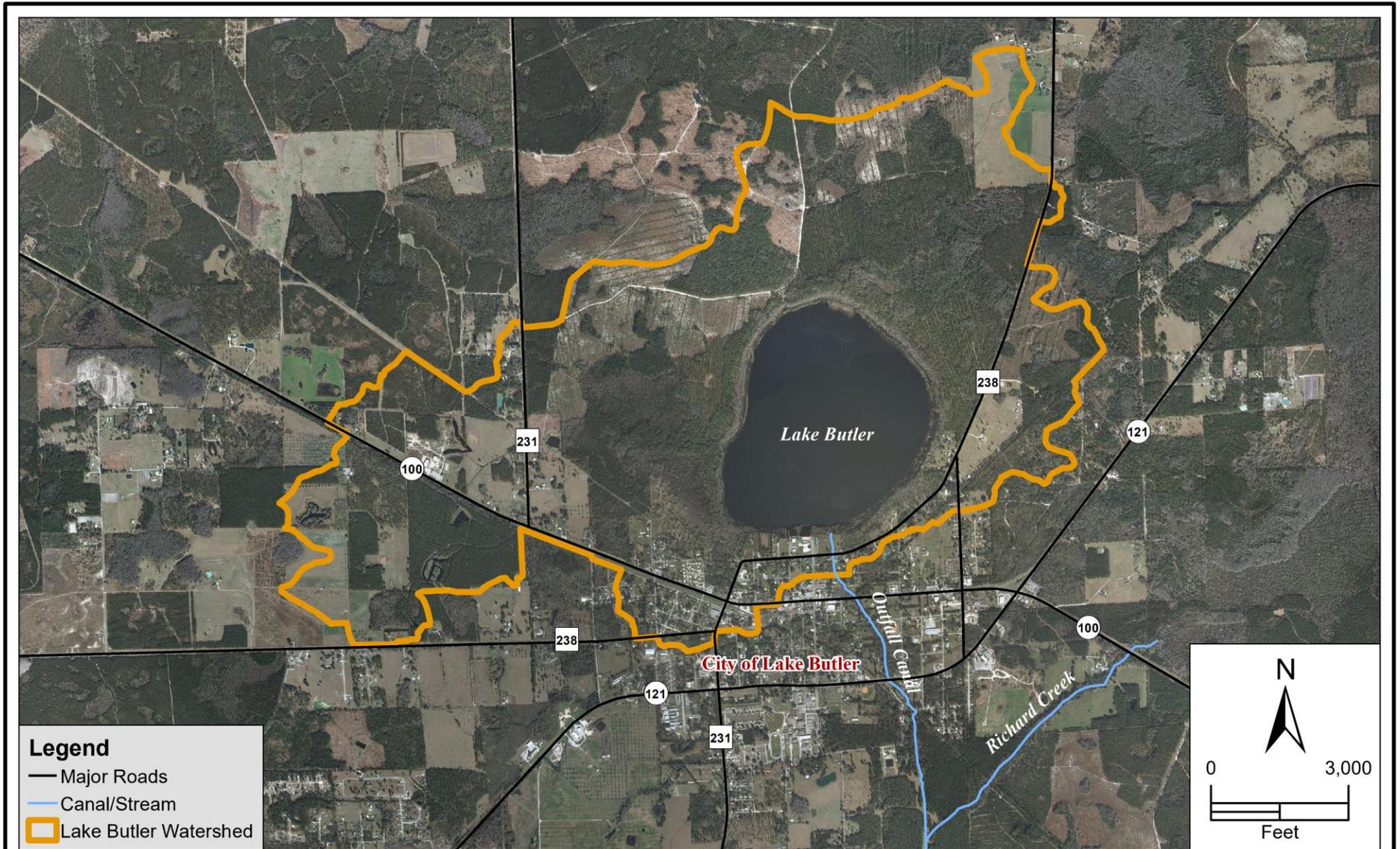
Figure 2-1
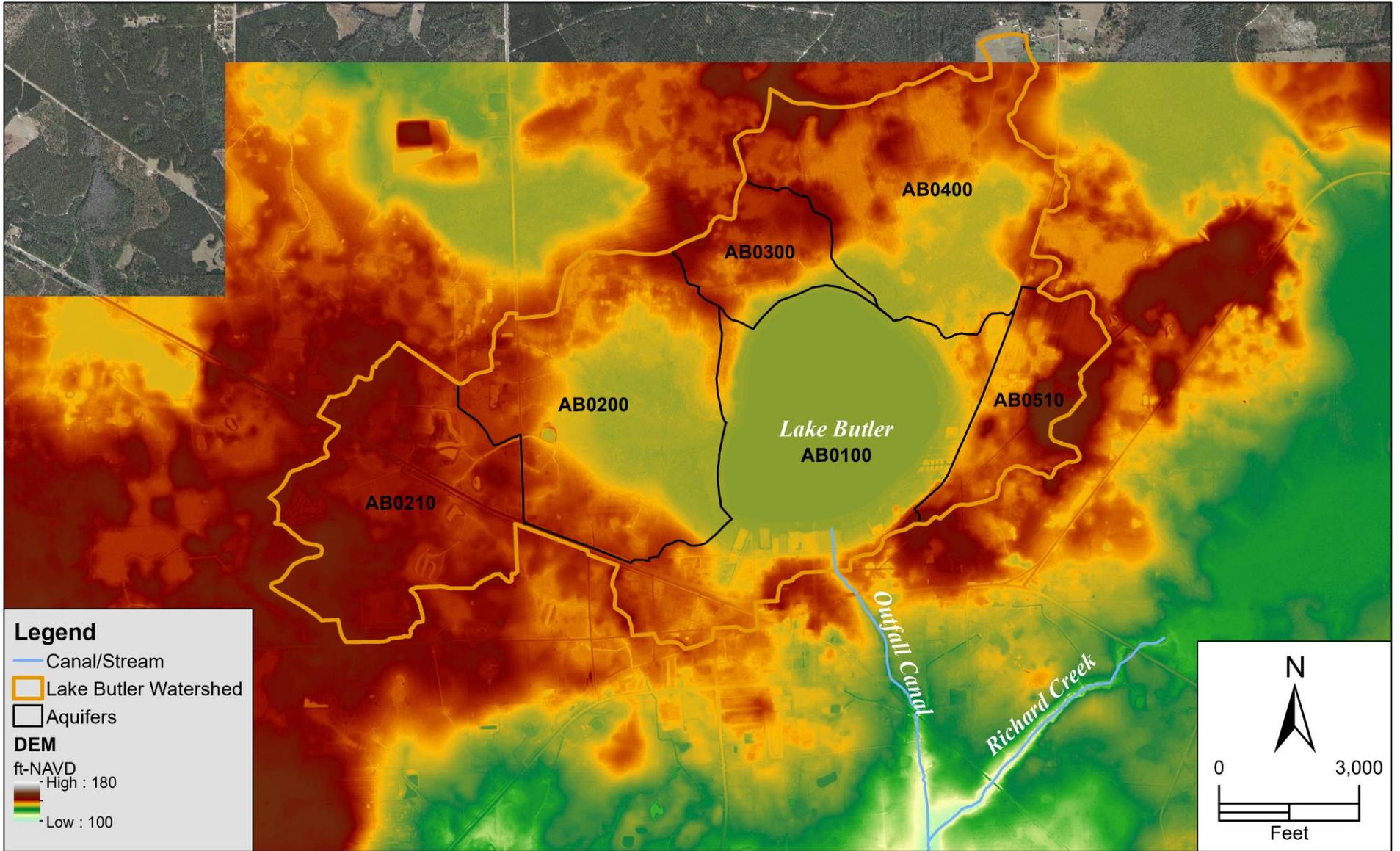Lake Butler Watershed Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
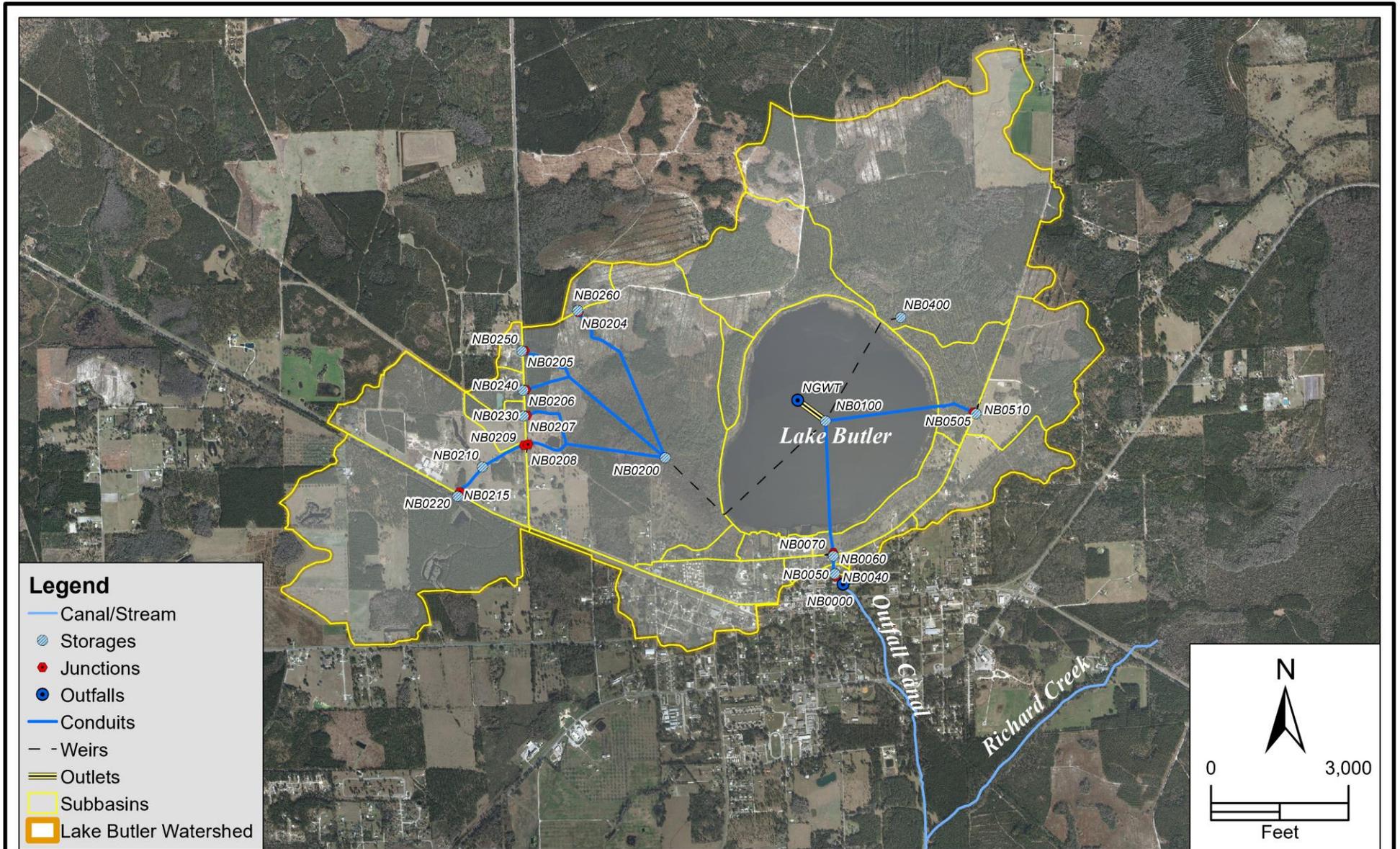
Sources: FDOT, 2011; FDOT, 2013; USGS, 2011; ECT, 2015.

ECT Environmental Consulting & Technology, Inc

Legend

— Major Roads
— Canal/Stream
▭ Lake Butler Watershed

DEM
ft-NAVD
High : 180
Low : 100

Lake Butler

Outfall Canal

Richard Creek

N

0   3,000
Feet
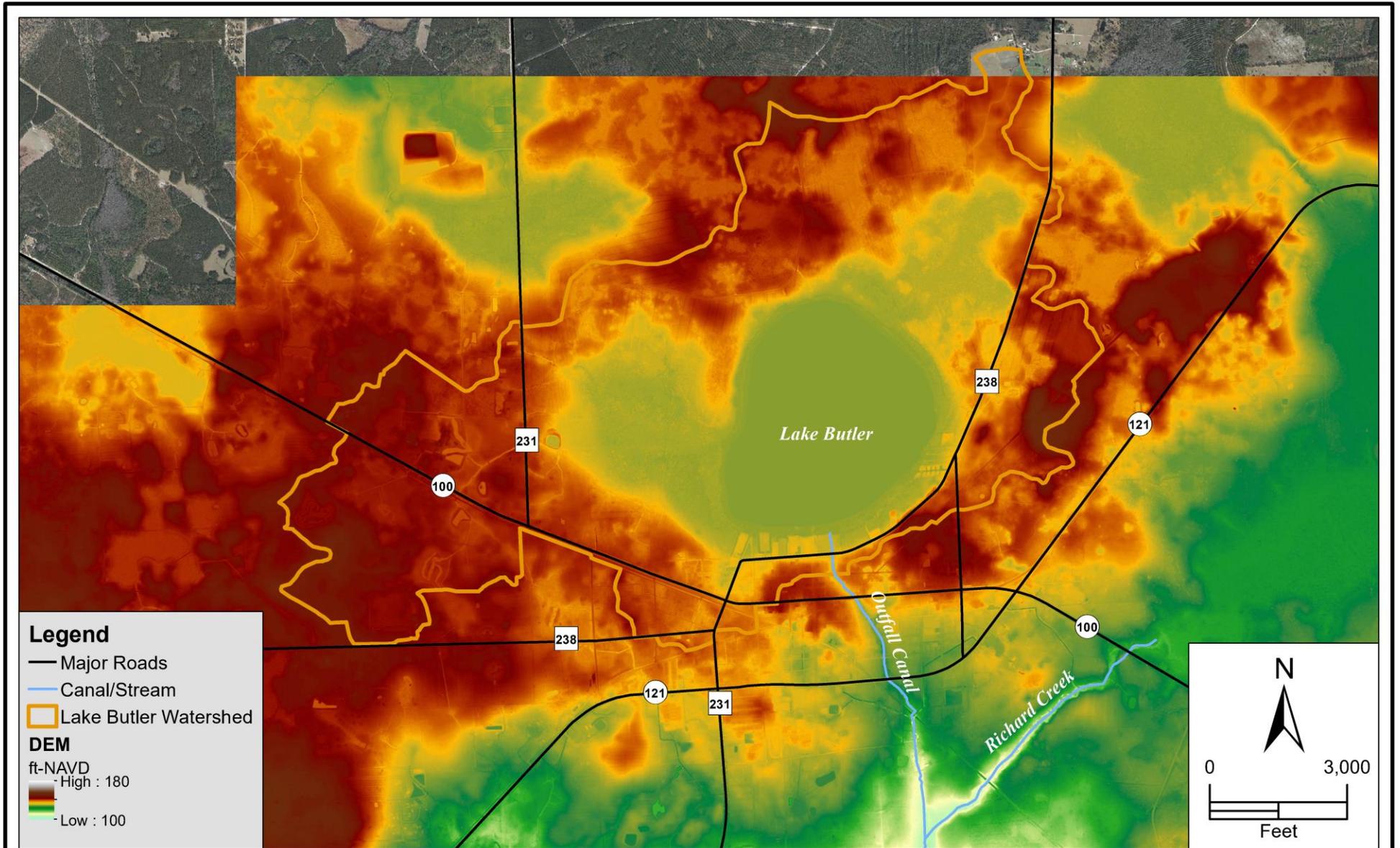
Figure 2-2A
Topographic DEM Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

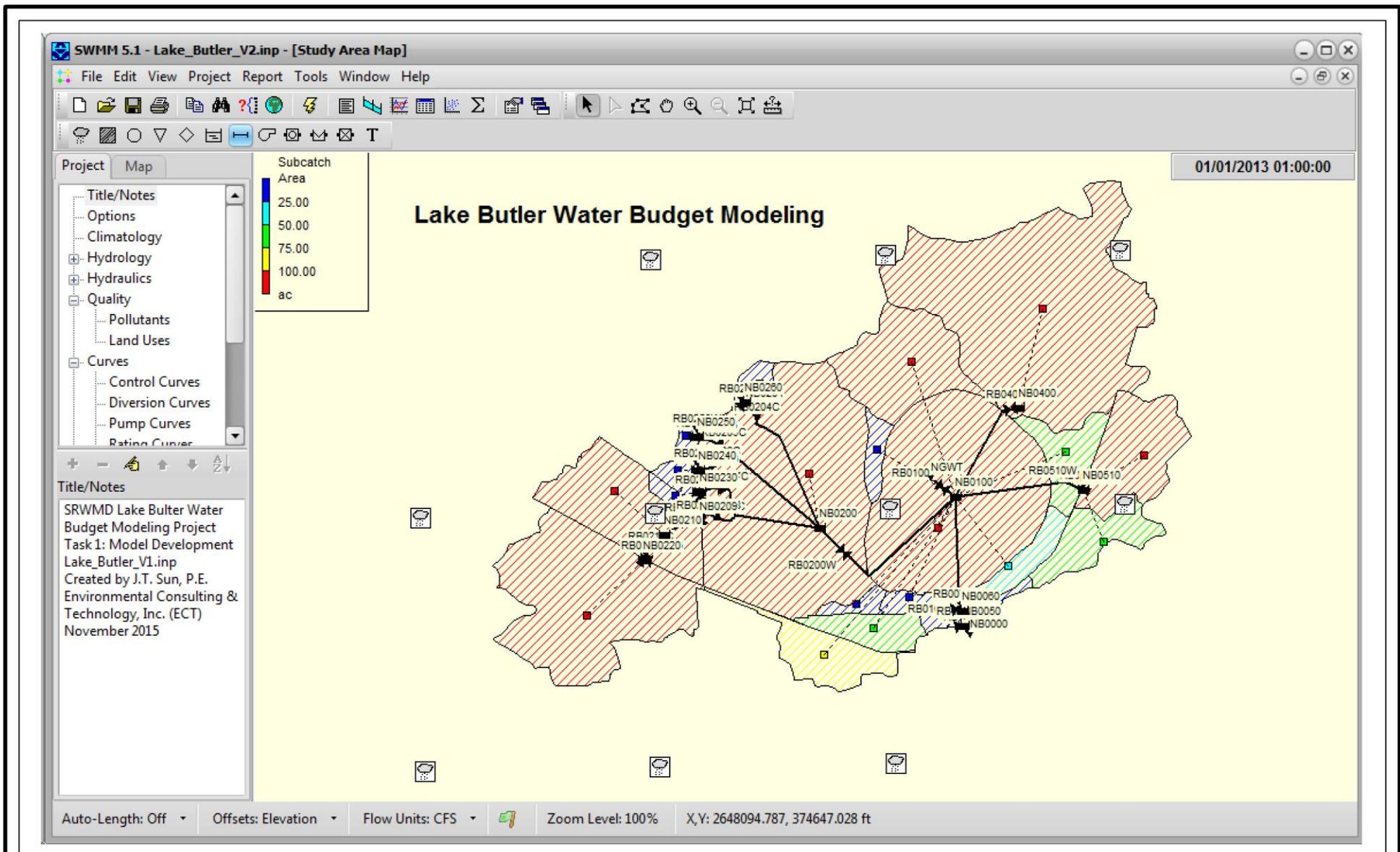Sources: FDOT, 2011; FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

ECT Environmental Consulting & Technology, Inc

Legend
— Major Roads
— Canal/Stream
☐ Lake Butler Watershed

Topo Contours
ft-NAVD
— 157 - 158
— 155 - 156
— 153 - 154
— 151 - 152
— 149 - 150
— 147 - 148
— 145 - 146
— 143 - 144
— 141 - 142
— 139 - 140
— 137 - 138
— 135 - 136
— 133 - 134
— 131 - 132
— 129 - 130
— 127 - 128
— 125 - 126
— 123 - 124
— 121 - 122
— 119 - 120
— 117 - 118
— 115 - 116
— 113 - 114
— 111 - 112
— 109 - 110
— 107 - 108
— 104 - 106

Lake Butler

Outfall Canal

Richard Creek

N

0 — 3,000
Feet
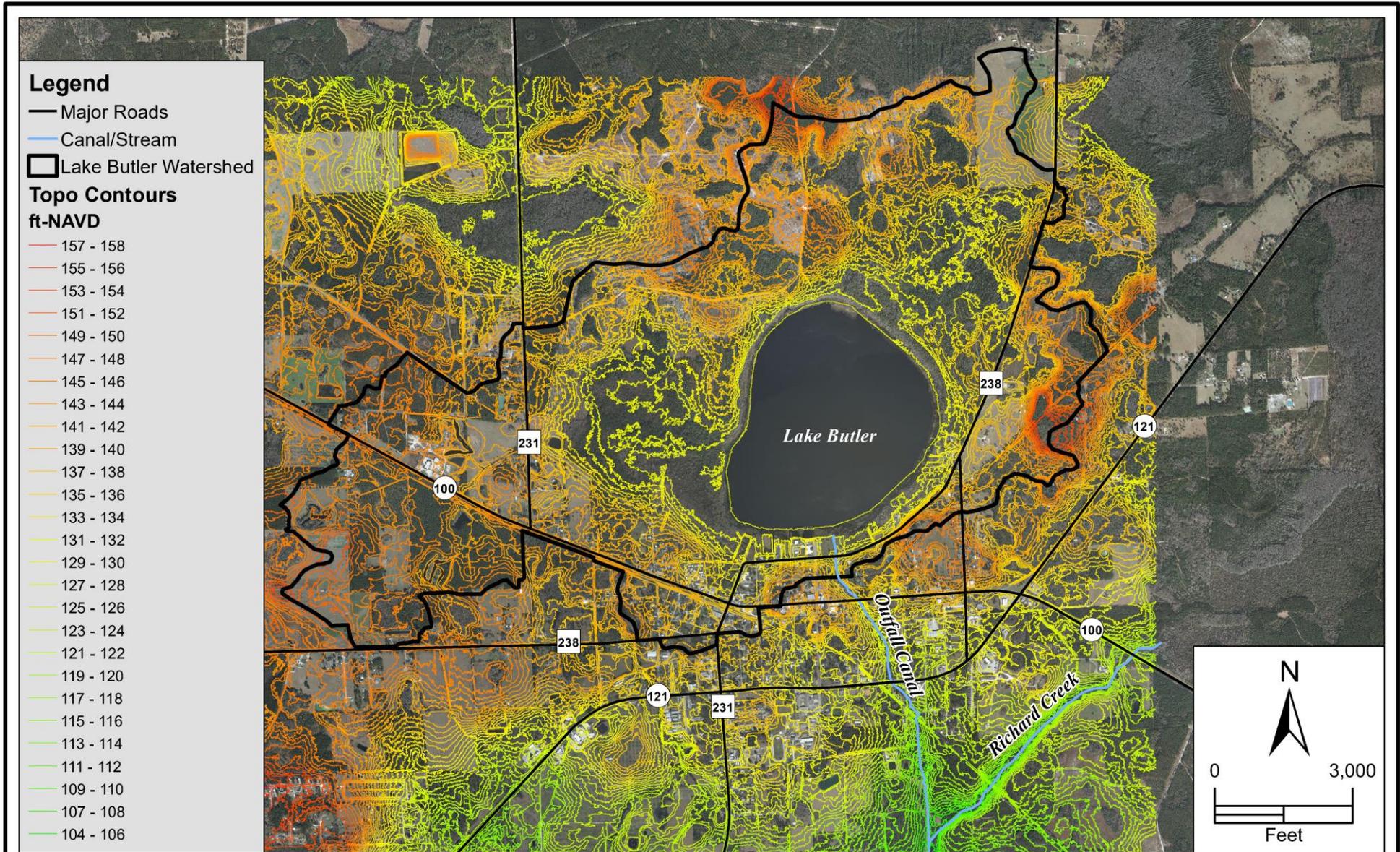
Figure 2-2B
Topographic Contours Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
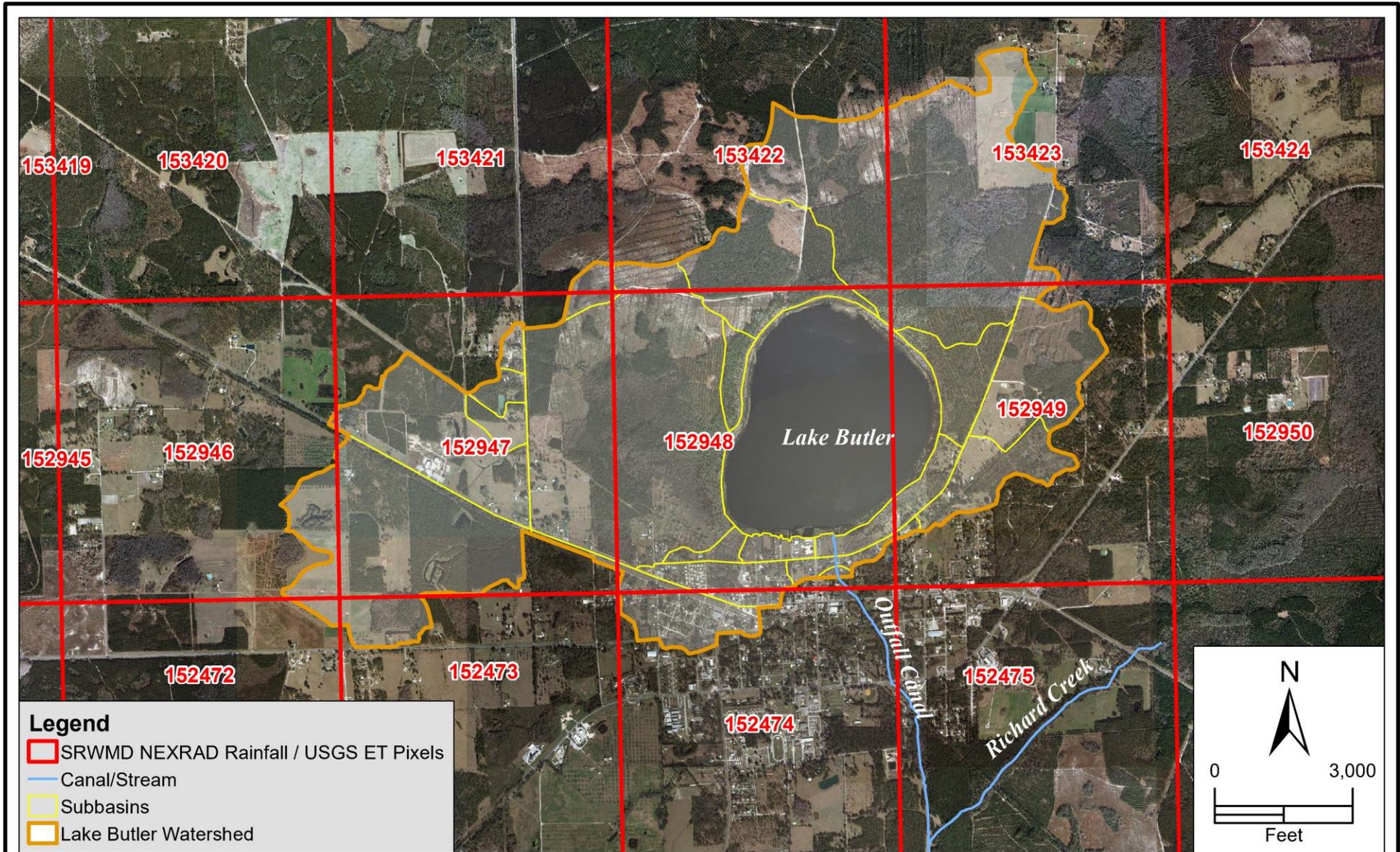Suwannee River Water Management District

Sources: FDOT, 2011; FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

ECT Environmental Consulting & Technology, Inc

Legend
— Canal/Stream
☐ Lake Butler Watershed

Soil Texture Class
■ Loamy Sand
■ Sand
■ Sandy Loam
■ Water

Lake Butler

Outfall Canal

Richard Creek

N

0 — 3,000
Feet
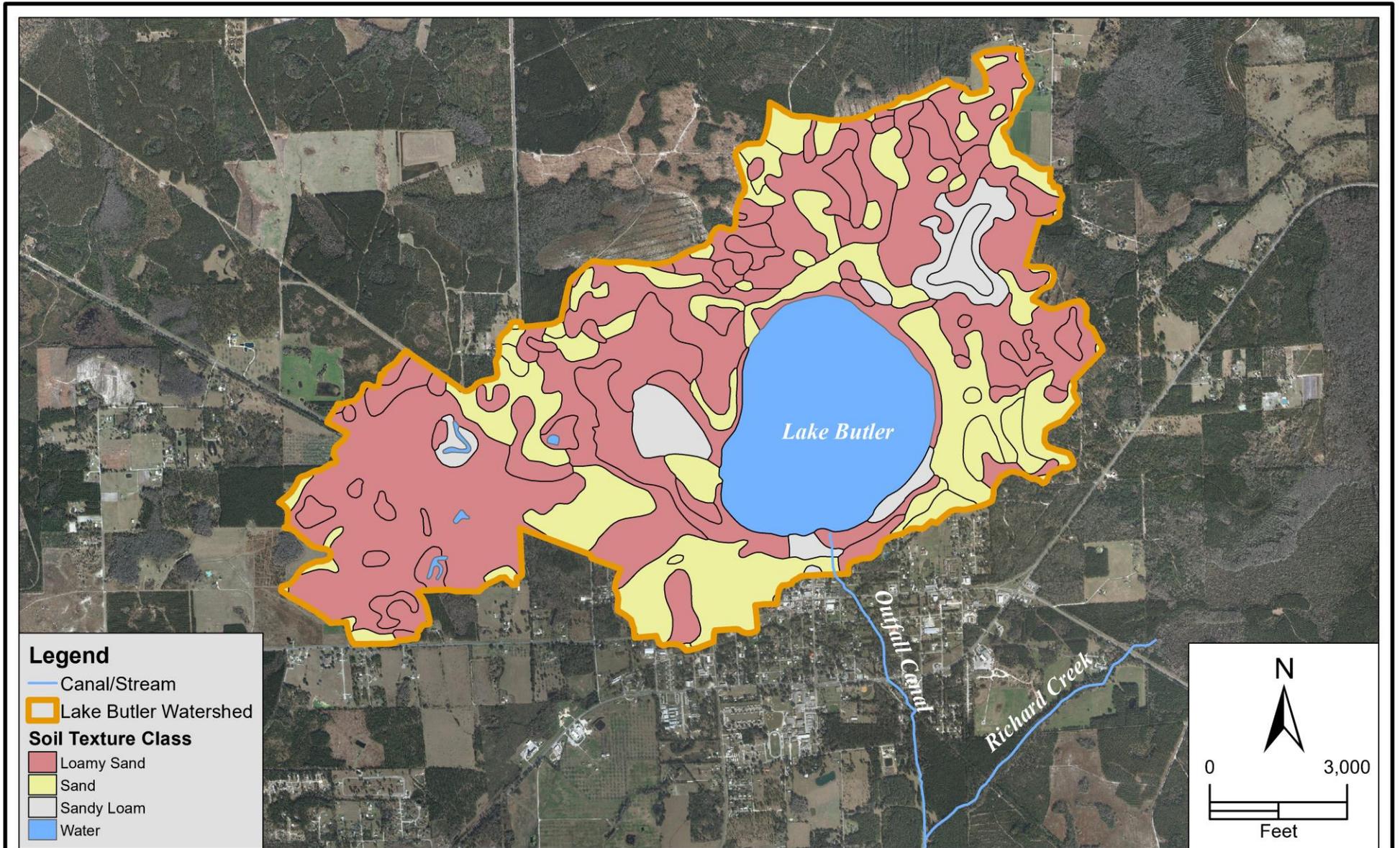
Figure 2-3
Soil Texture Classes Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

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Legend

— Canal/Stream
▢ Lake Butler Watershed

2006 Land Use
- Urban & Built-up
- Agriculture
- Rangeland
- Upland Forest
- Water
- Wetlands
- Transportation, Communication & Utilities

Lake Butler

Outfall Canal

Richard Creek

N

0   3,000
Feet
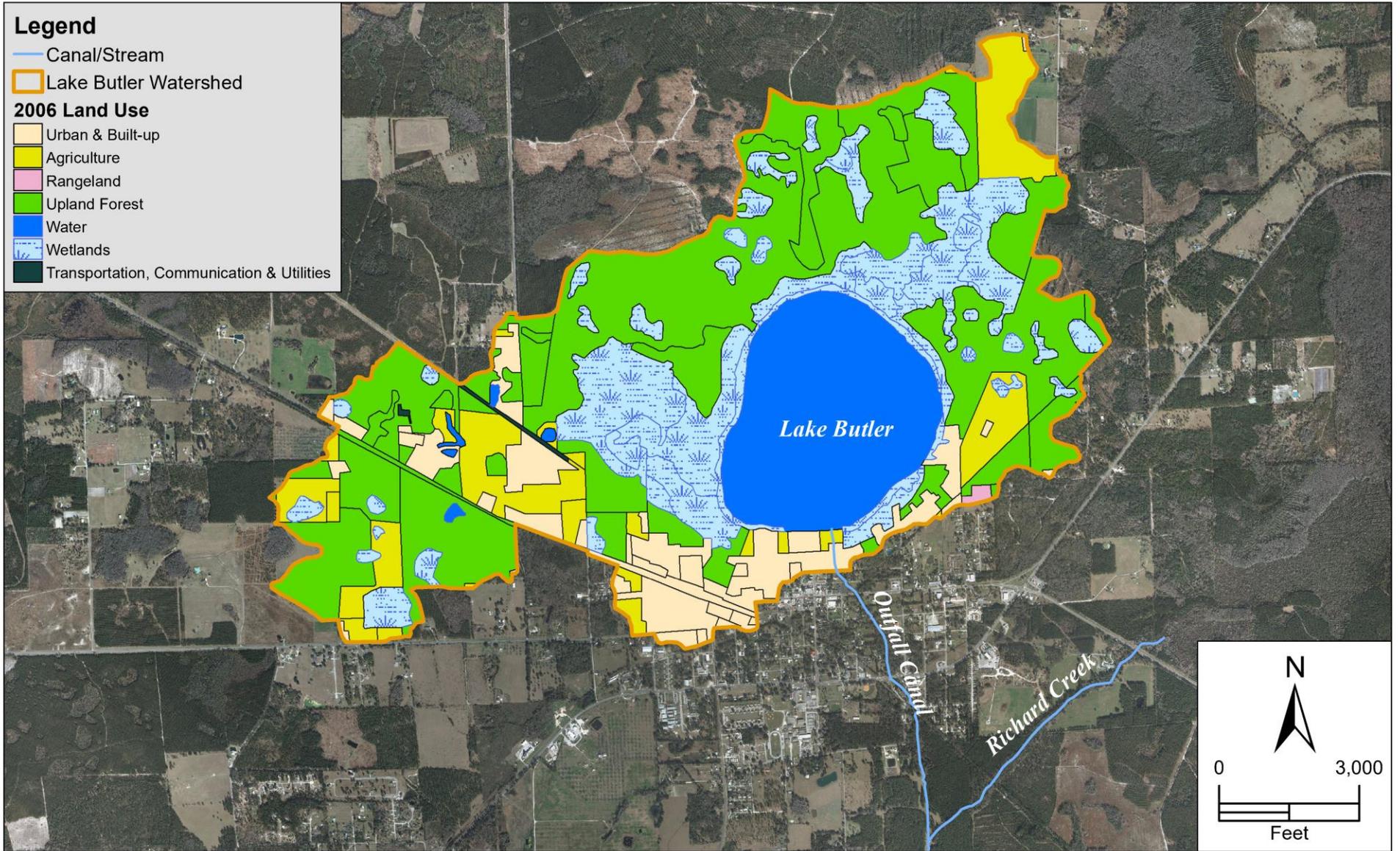
Figure 2-4
2006 Land Use Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

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Labels on map:
- 24" CMP
- 231
- Un-surveyed Culverts
- 3'x8' Box Culvert
- 100
- 3'x10.5' Box Culvert
- 238
- Un-surveyed Culvert
- 121
- Lake Butler
- (2) 36" RCPs
- 238
- 121
- 231
- 2.6'x5' Box Culvert
- Outfall Canal
- Richard Creek
- 100

Legend
- Major Roads
- Canal/Stream
- Lake Butler Watershed

N

0 — 3,000
Feet

Figure 2-5
Major Conveyance System Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: FDOT, 2011; FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

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Legend

— Canal/Stream
▭ Lake Butler Watershed
▭ Subbasins

DEM
ft-NAVD
High : 180
Low : 100

N

0 ────── 3,000
Feet
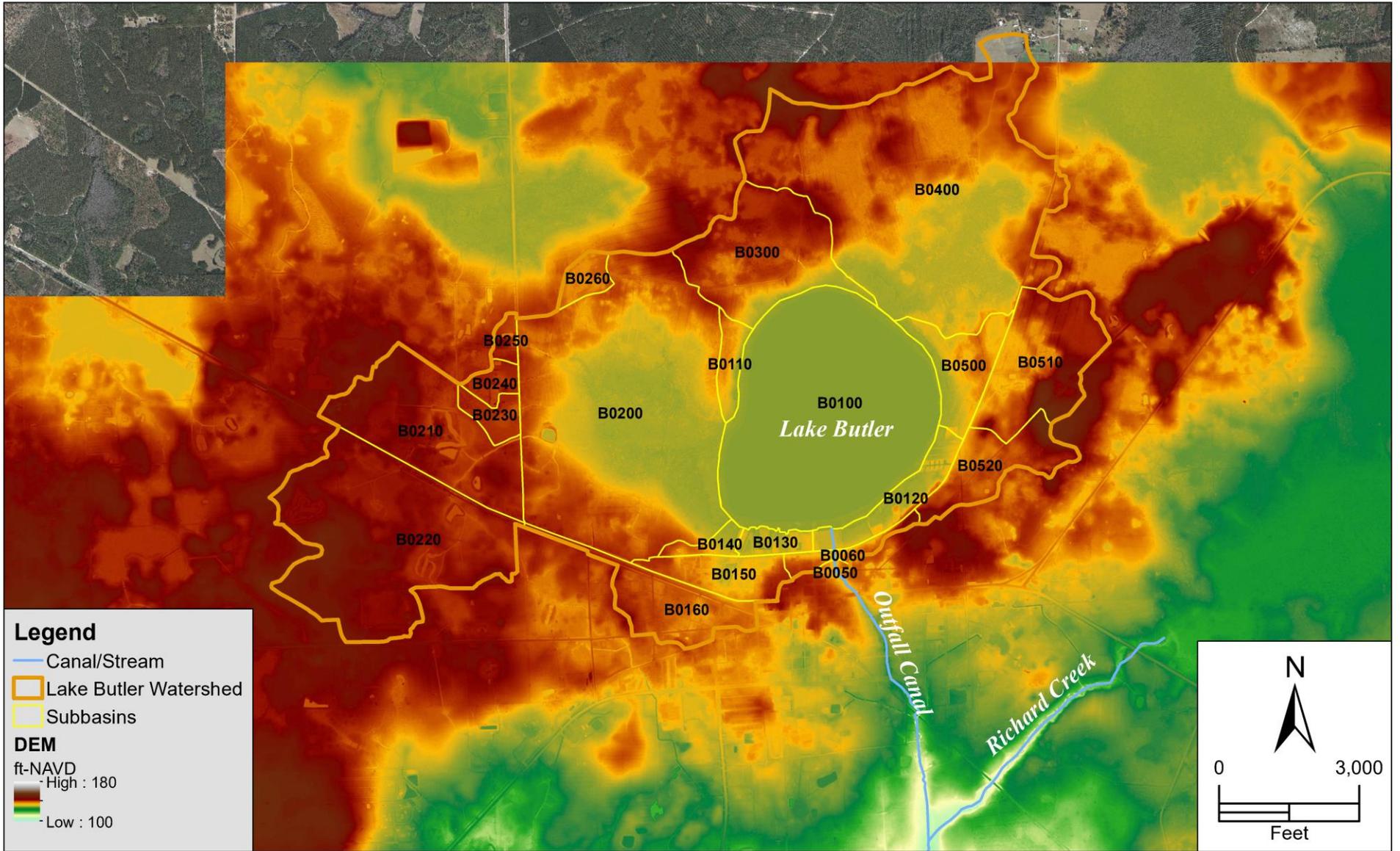
Figure 3-1
Subbasin Delineation Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

ECT Environmental Consulting & Technology, Inc

Legend
— Canal/Stream
▭ Lake Butler Watershed
▭ Aquifers
DEM
ft-NAVD
High : 180
Low : 100

AB0400

AB0300

AB0200

AB0510

Lake Butler
AB0100

AB0210

Outfall Canal

Richard Creek

N

0   3,000
Feet

Figure 3-2
Aquifers Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

ECT Environmental Consulting & Technology, Inc

Sources: FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

Figure 3-3
Model Schematic Map
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
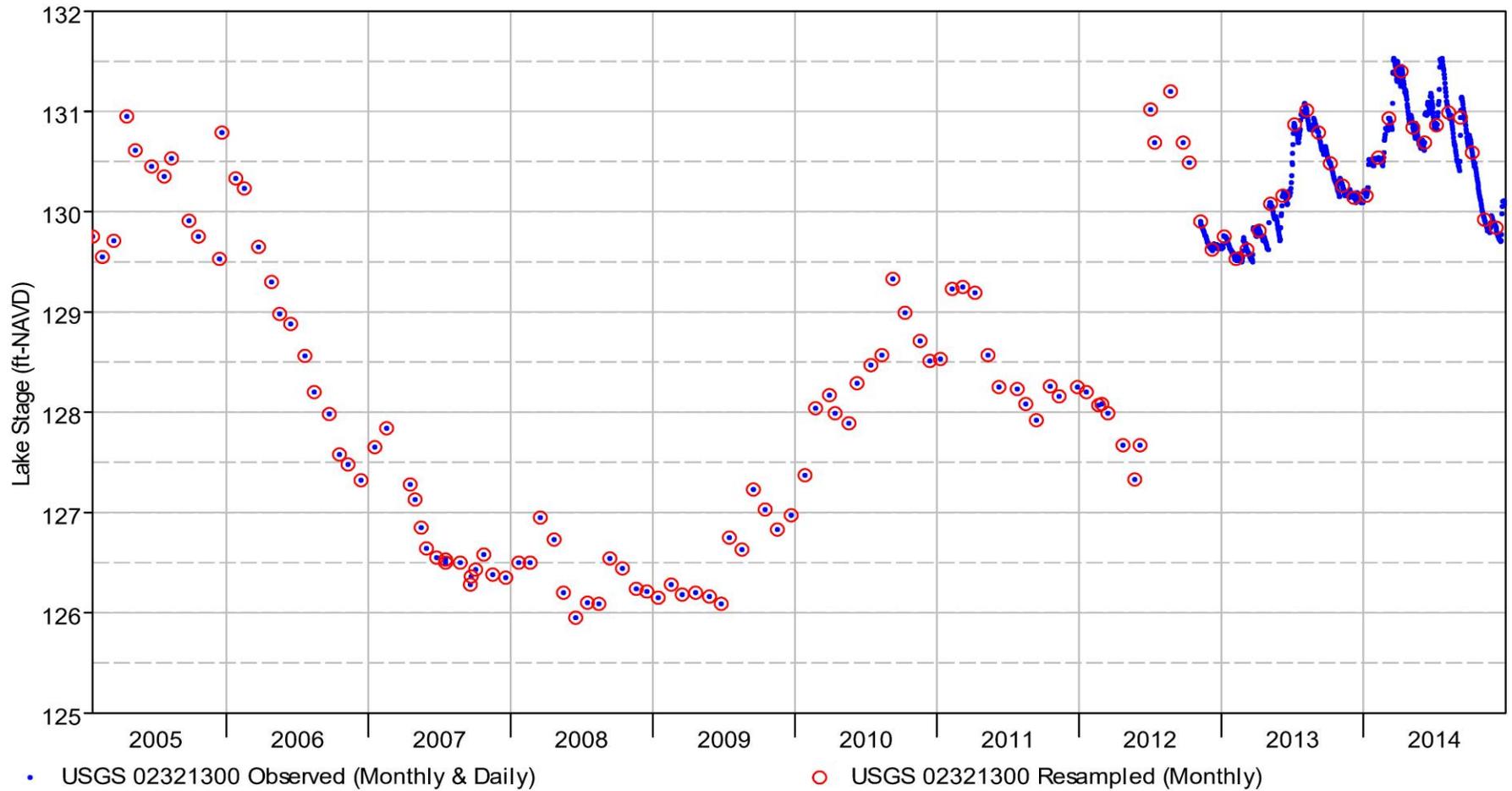Suwannee River Water Management District

Sources: FDOT, 2013; USGS, 2011; SRWMD, 2015; ECT, 2015.

Legend
— Canal/Stream
◉ Storages
● Junctions
◉ Outfalls
— Conduits
– – Weirs
═ Outlets
▢ Subbasins
▢ Lake Butler Watershed

ECT
Environmental
Consulting &
Technology, Inc

Figure 3-4
Subbasins and Model Schematic in SWMM's Main Window
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
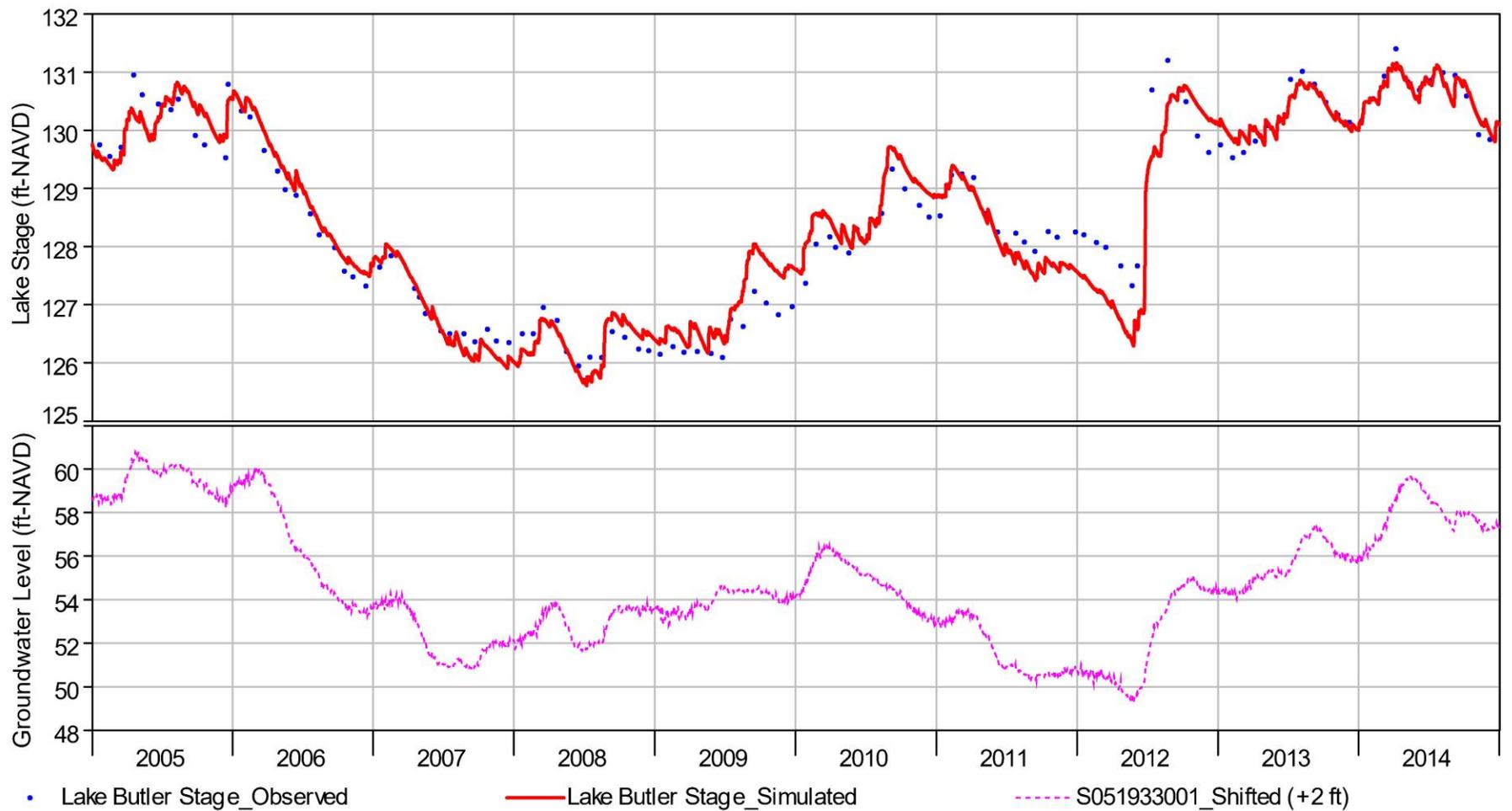Suwannee River Water Management District
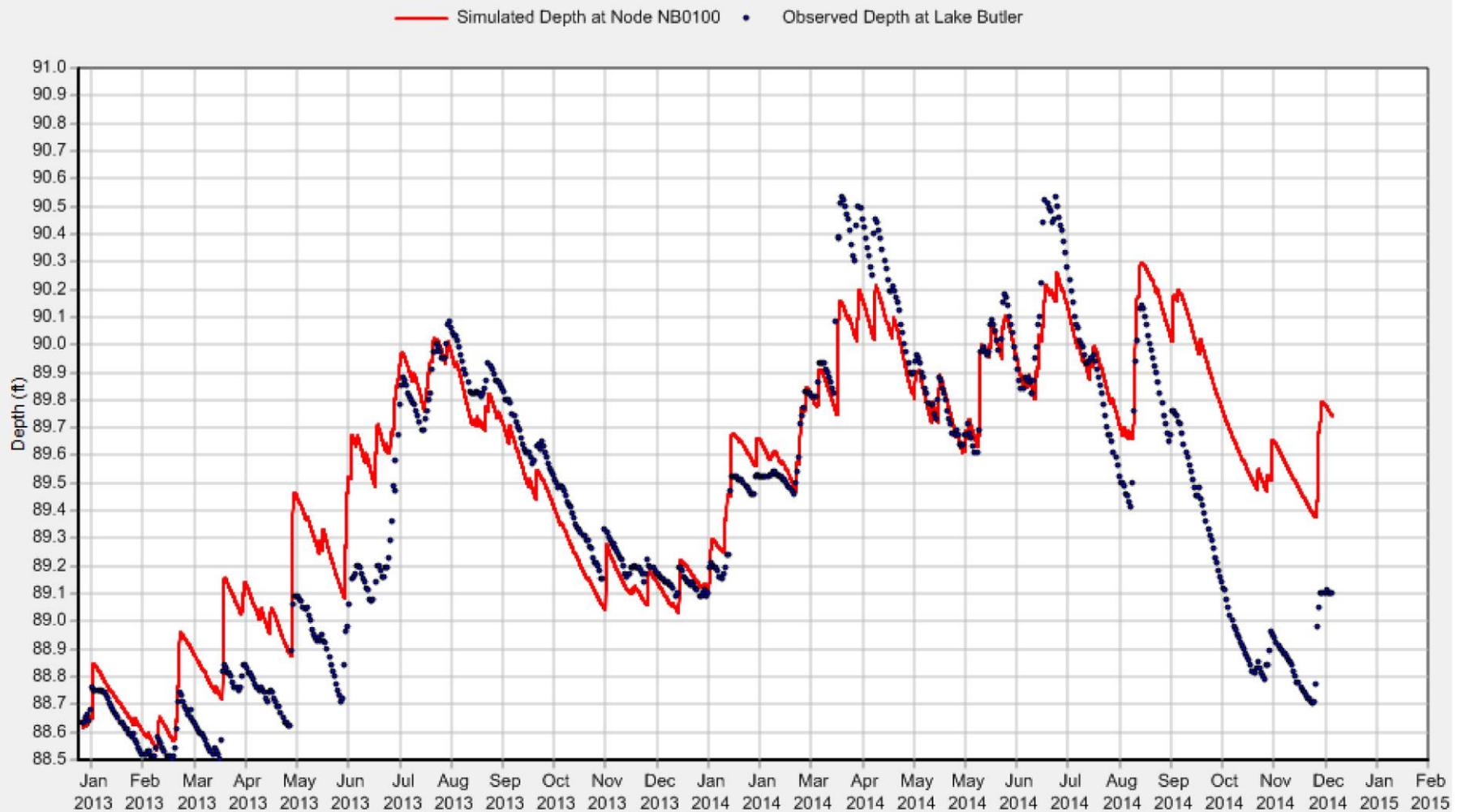
Sources: ECT, 2015.

Figure 3-5
Node Depth Hydrographs Comparison at Lake Butler (2013-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: ECT, 2015.

153419 153420 153421 153422 153423 153424

152945 152946 152947 152948 *Lake Butler* 152949 152950

152472 152473 152475 *Richard Creek*

Outfall Canal

152474

N

0 — 3,000
Feet

Legend
SRWMD NEXRAD Rainfall / USGS ET Pixels
Canal/Stream
Subbasins
Lake Butler Watershed

Figure 4-1
SRWMD NEXRAD Rainfall / USGS ET Pixels
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
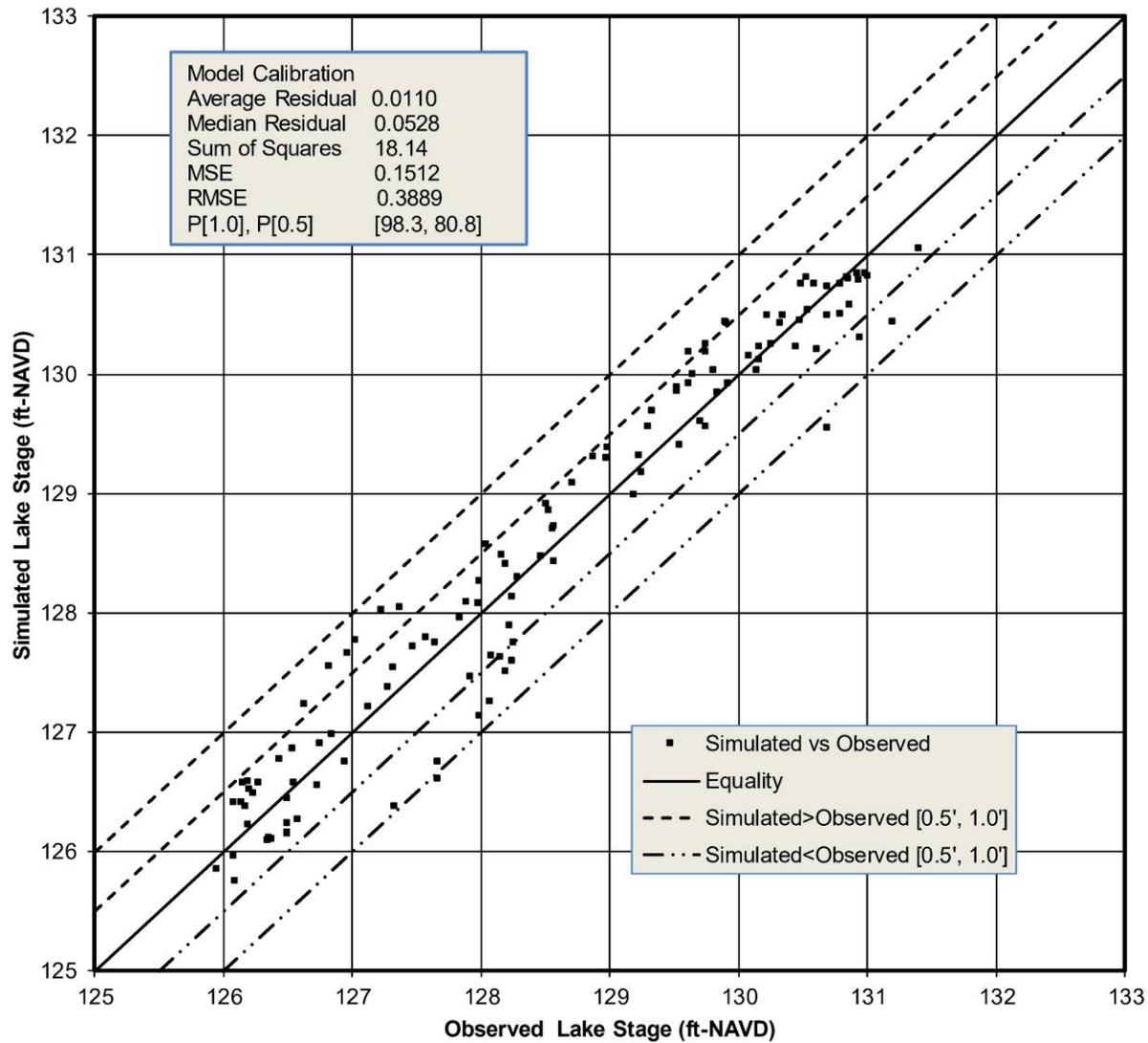
Sources: FDOT, 2013; USGS, 2015; SRWMD, 2015; ECT, 2015.

ECT Environmental
Consulting &
Technology, Inc
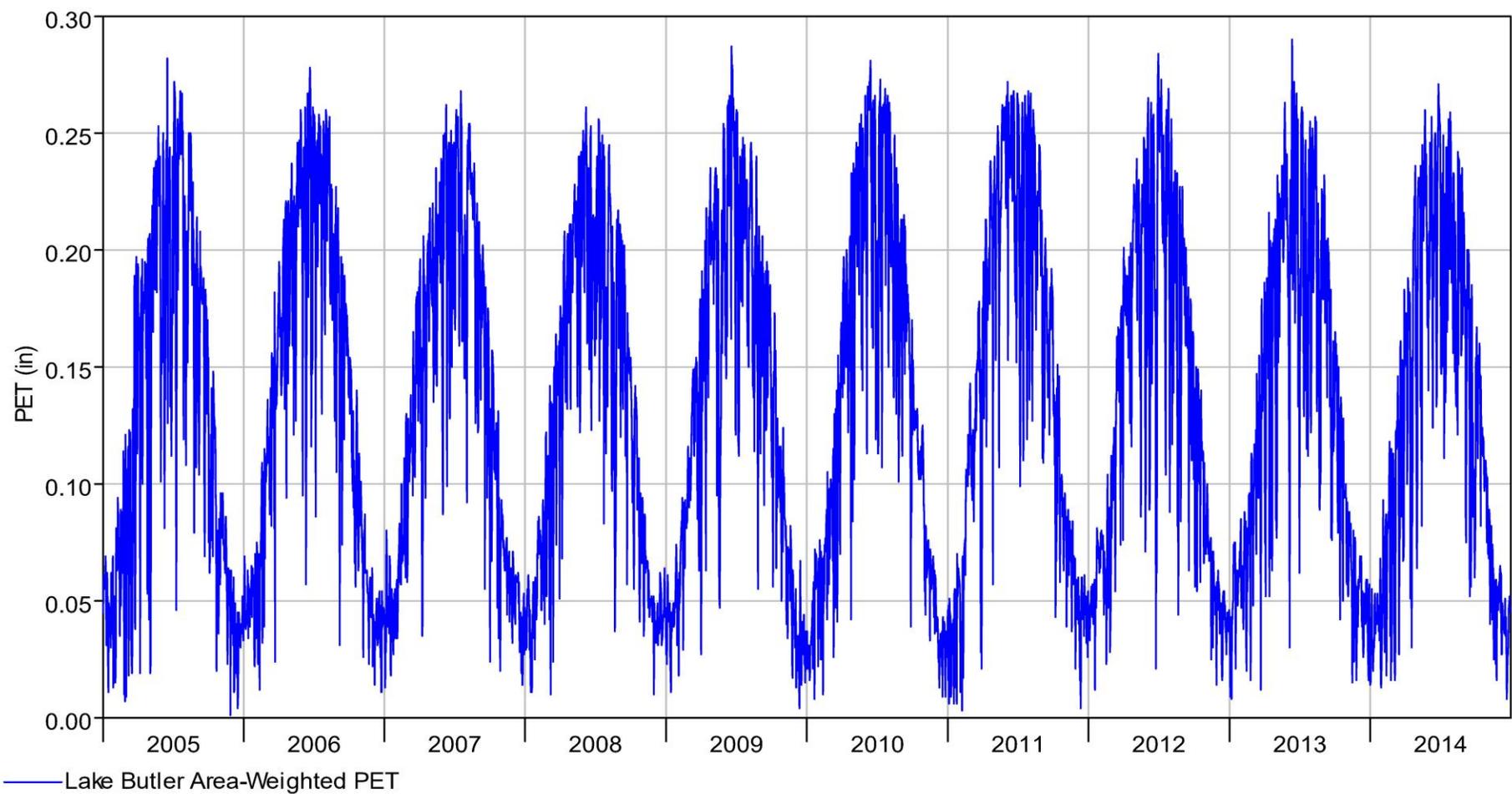
Figure 4-2
Area-Weighted Daily Potential Evapotranspiration (2005-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
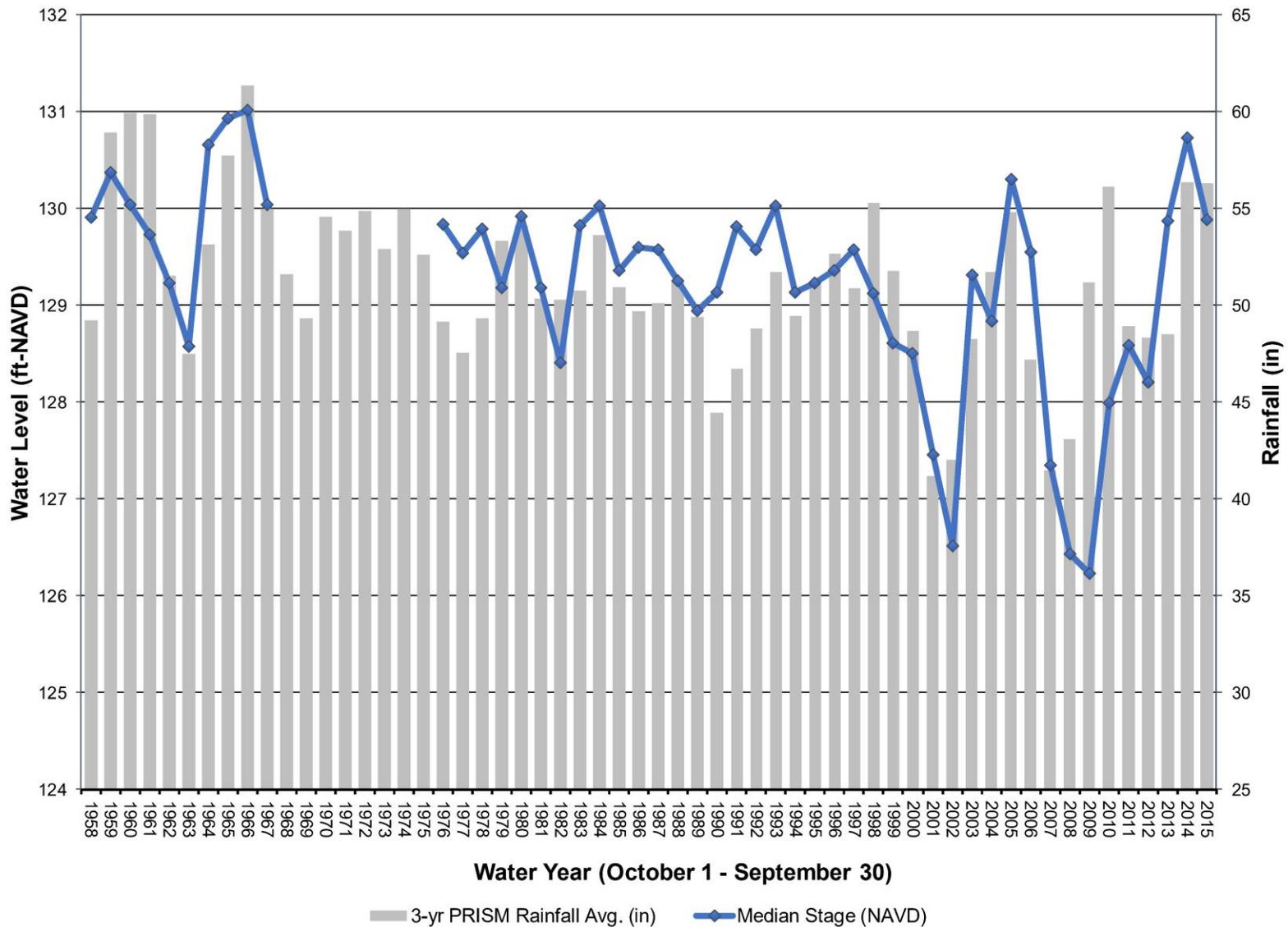Suwannee River Water Management District

Sources: USGS, 2015; ECT, 2015.

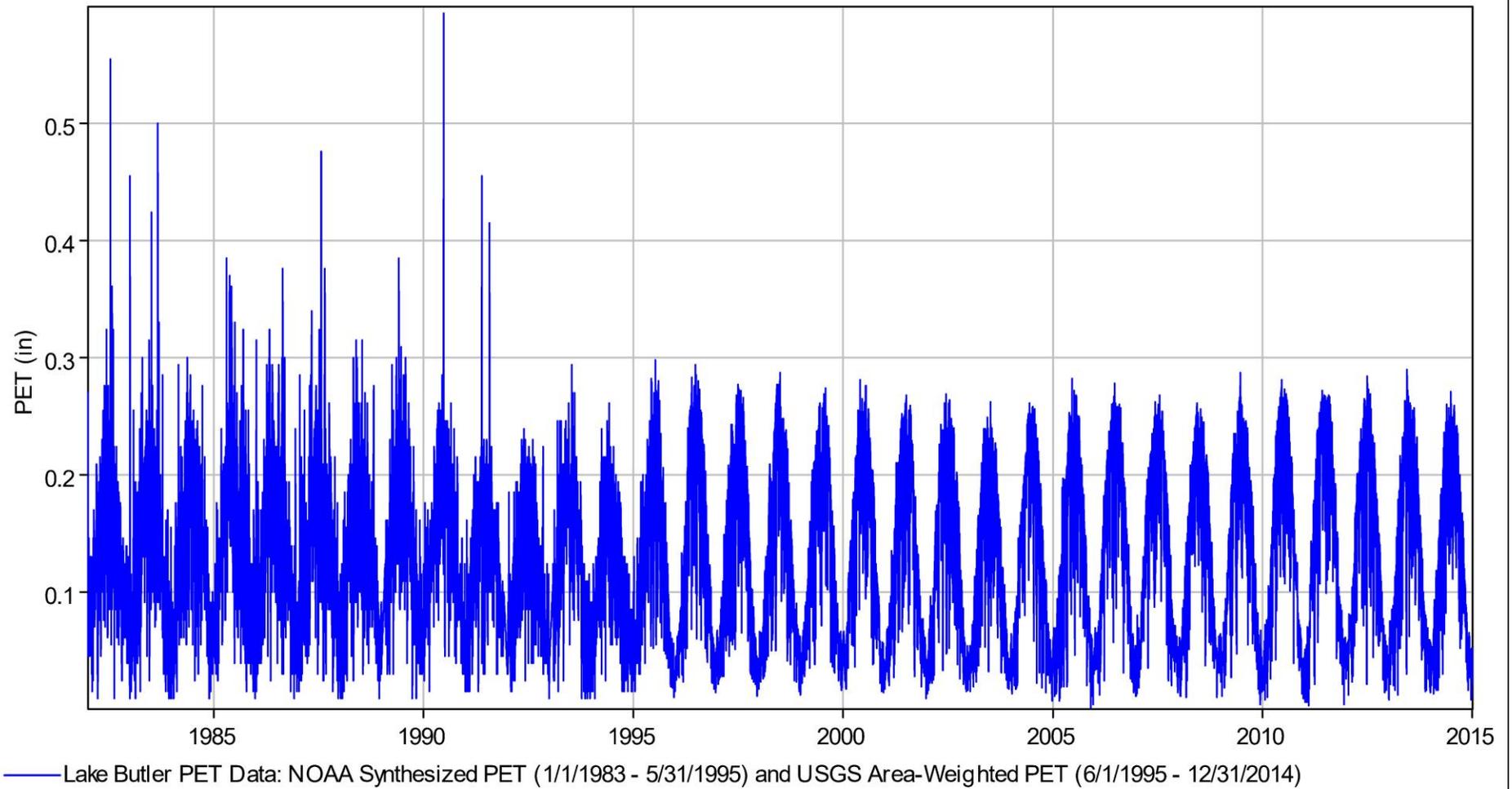ECT Environmental Consulting & Technology, Inc

UNION

Lake Butler

USGS ID 3001010082245201
SRWMD ID: S051933001

50

BRADFORD

NOAA: USC00088529
Starke, FL

70

40

ALACHUA

USGS ID 295055082130801
SRWMD ID: S072132001

Lake Hampton

Legend

▲ NOAA Rainfall Stations
● USGS/SRWMD Well Stations
— Potentiometric Contours (May 2005)
▭ Lake Butler Watershed
▭ County Boundary

60

80

N

0 ——— 3
Miles
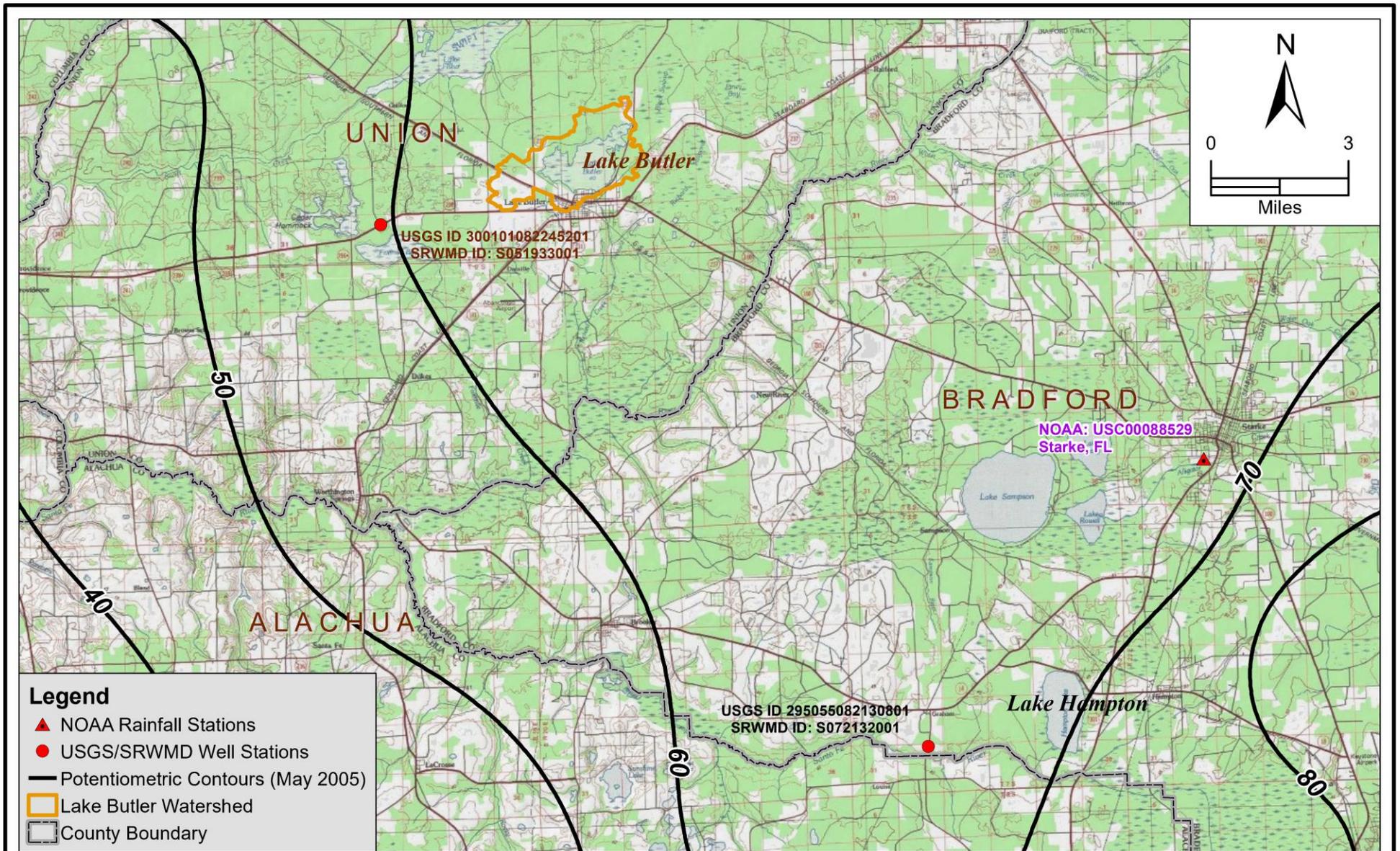
Figure 4-3
USGS Groundwater Well Stations and Potentiometric Contours in May 2005
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

ECT Environmental Consulting & Technology, Inc

Sources: NGS, 2013; USGS, 2015; SRWMD, 2015; ECT, 2015.
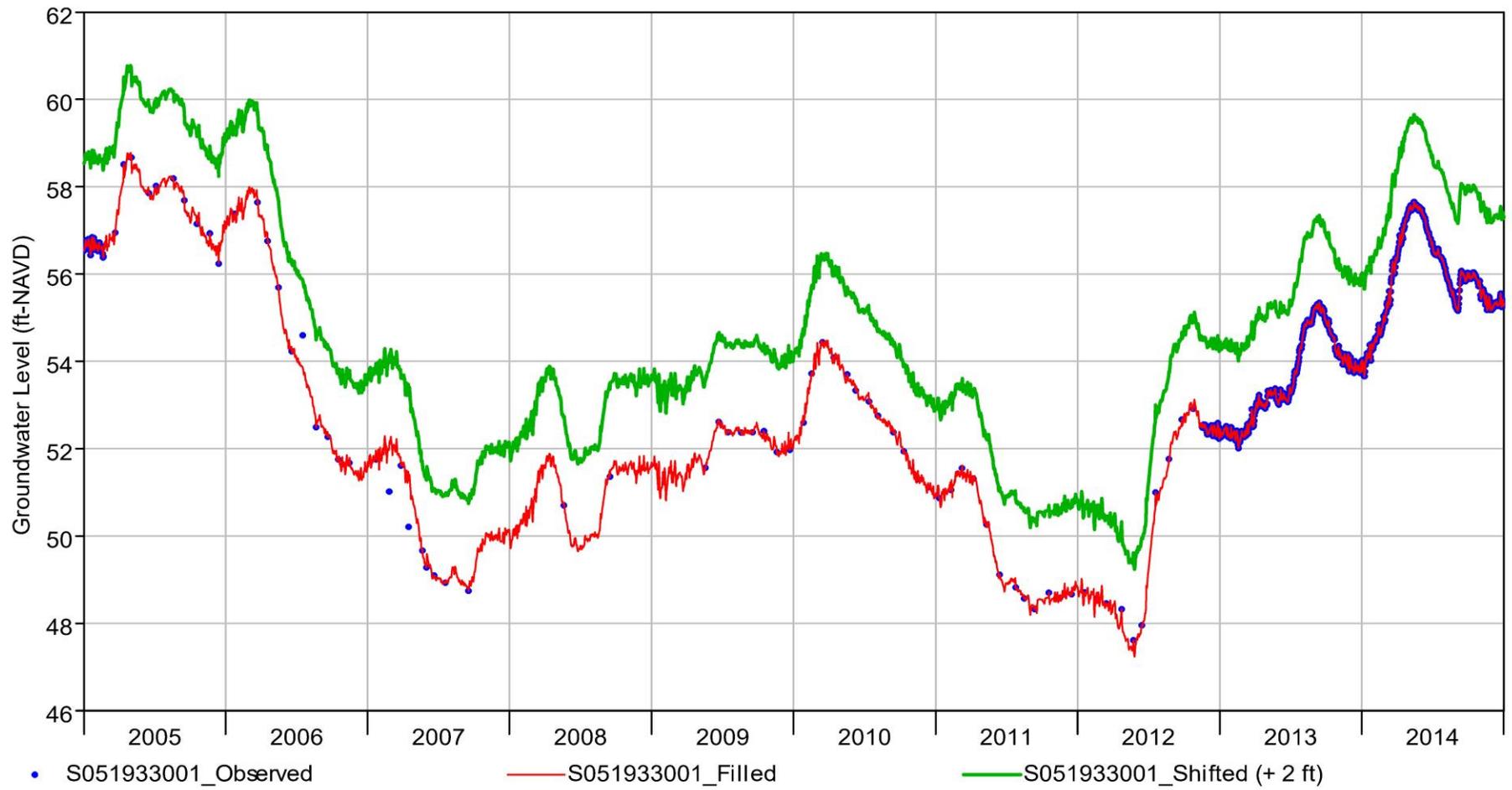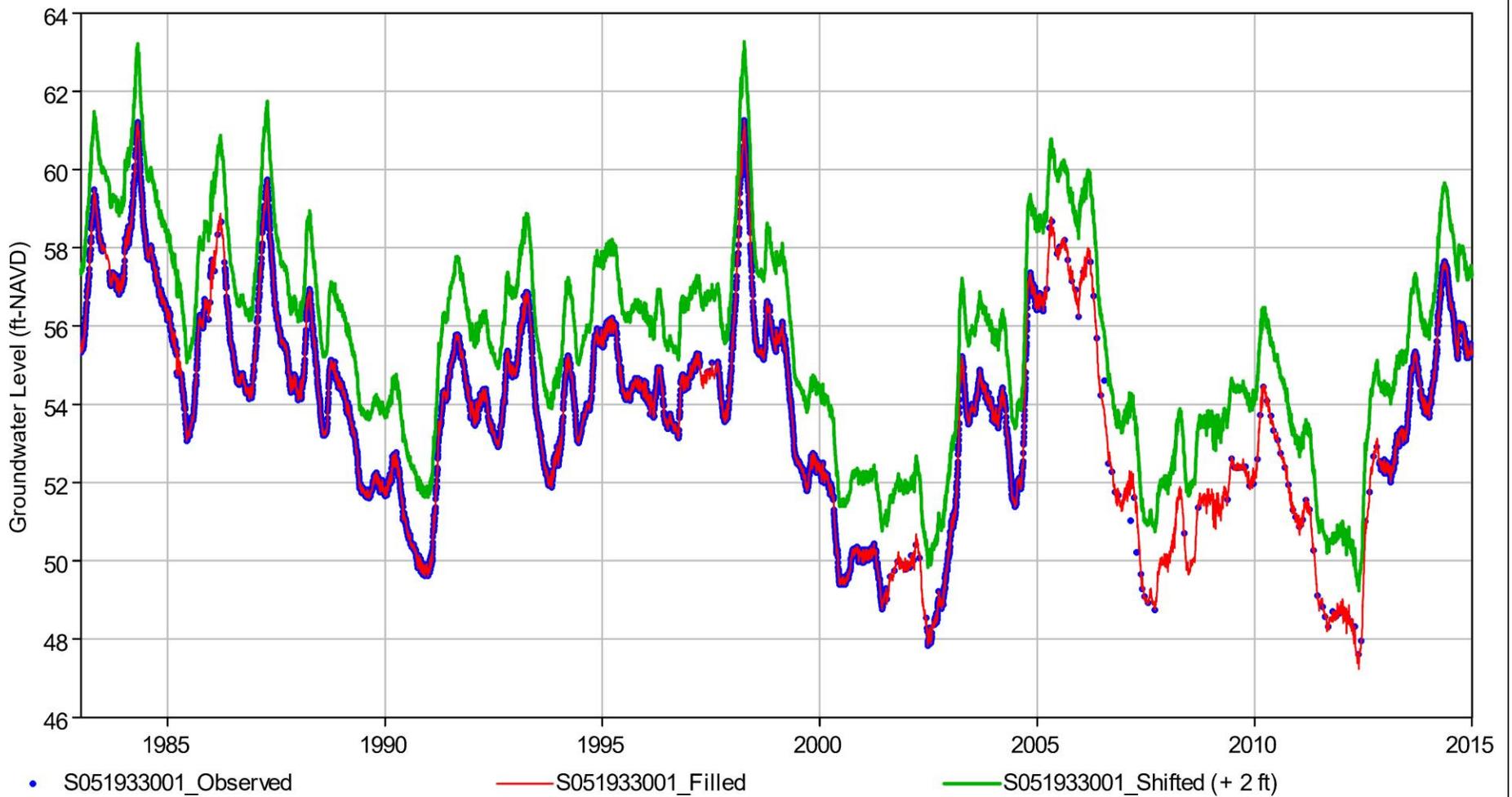
Figure 4-4
Groundwater Levels at USGS Well Station (SRWMD ID S051933001)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Legend
- ● USGS/SRWMD Lake Stations
- — Canal/Stream
- ▭ Lake Butler Watershed

Lake Butler

USGS 02321300

Outfall Canal

Richard Creek

N

0   3,000
Feet

Figure 4-5
USGS/SRWMD Lake Stations
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

ECT Environmental Consulting & Technology, Inc

Sources: FDOT, 2013; USGS, 2015; SRWMD, 2015; ECT, 2015.
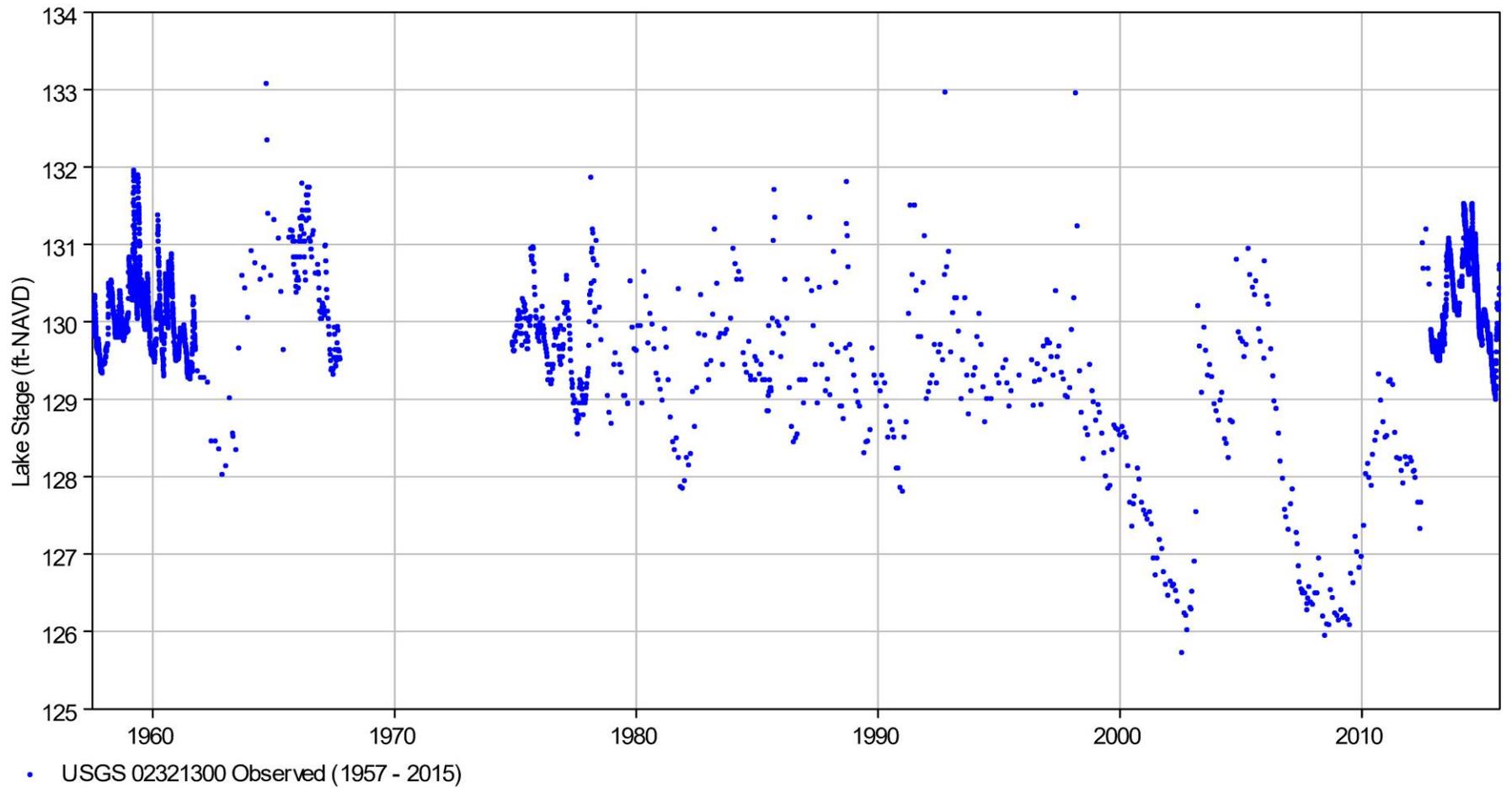
Figure 4-6A
Observed Lake Stage Hydrograph (1957-2015)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
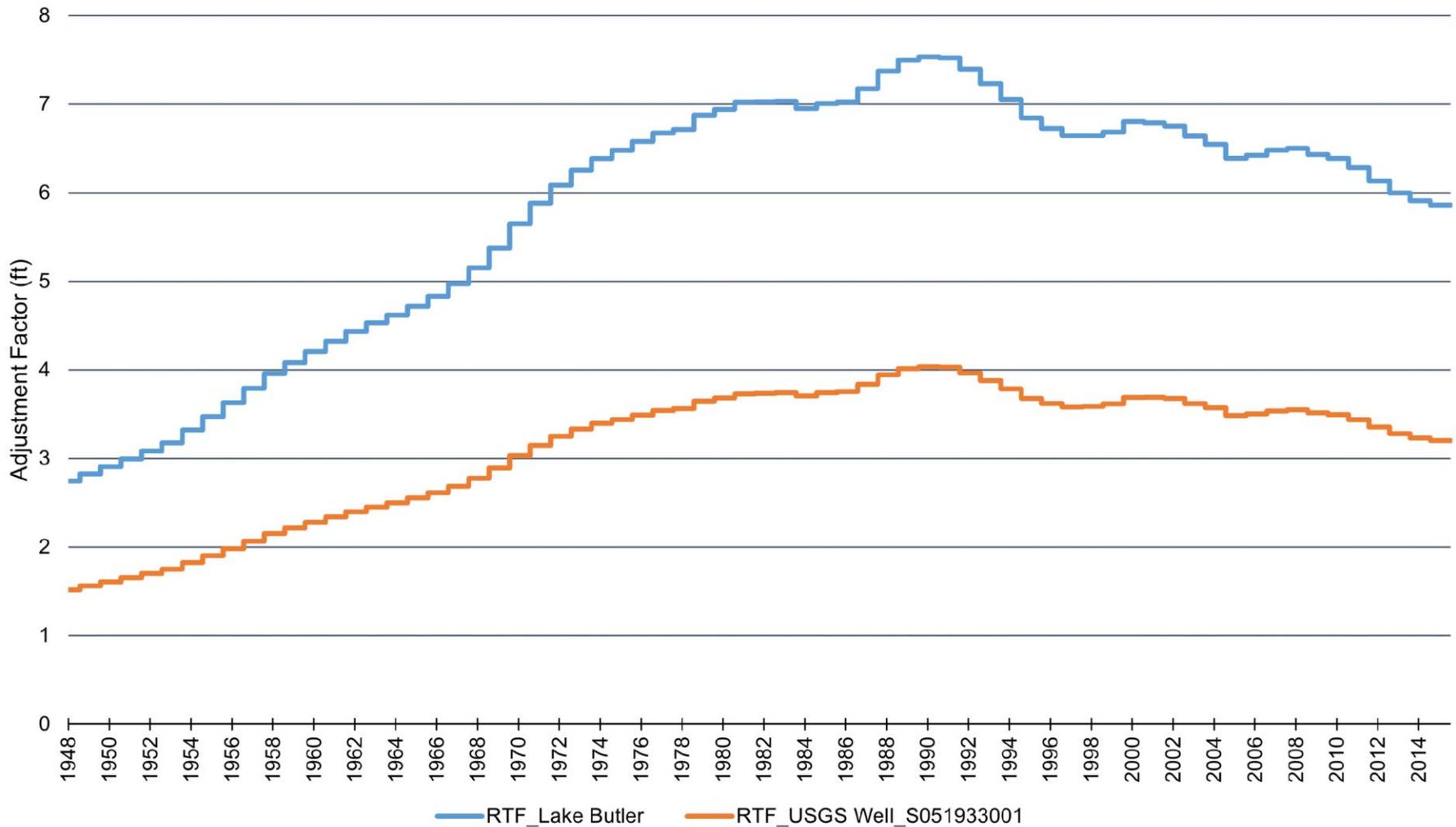Suwannee River Water Management District

Sources: SRWMD, 2015; ECT, 2015.

Figure 4-6B
Observed and Resampled Lake Stage Hydrographs (2005-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
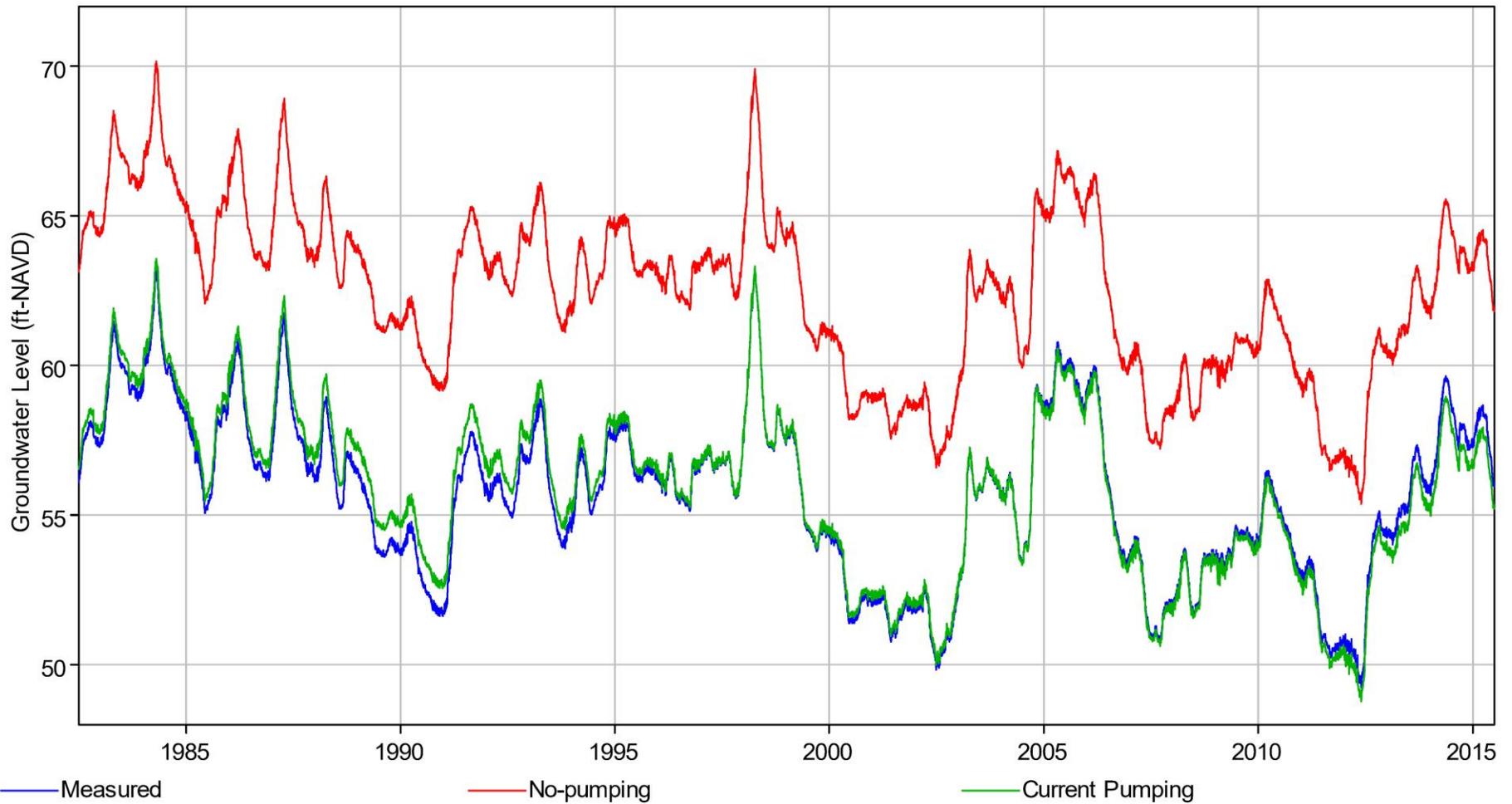
Sources: SRWMD, 2015; ECT, 2015.

Figure 4-7
Simulated Flow Hydrograph at Outlet RB0100T (2005-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: ECT, 2017.

Figure 4-8
Observed and Simulated Lake Stage Hydrographs Comparison (2005-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: USGS, 2015; SRWMD, 2015; ECT, 2017.

Model Calibration
Average Residual 0.0110
Median Residual 0.0528
Sum of Squares 18.14
MSE 0.1512
RMSE 0.3889
P[1.0], P[0.5] [98.3, 80.8]

- Simulated vs Observed
— Equality
-- Simulated>Observed [0.5', 1.0']
-·- Simulated<Observed [0.5', 1.0']

Simulated Lake Stage (ft-NAVD)

Observed Lake Stage (ft-NAVD)

Figure 4-9
Scatter Plot Comparing Simulated and Observed Stages (2005-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: SRWMD, 2015; ECT, 2017.

ECT Environmental Consulting & Technology, Inc

Figure 5-1
Annual Median Lake Stage Data vs. PRISM Rainfall Data (3-Yr Average) (WY 1958-2015)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: PRISM, 2017; SRWMD, 2017; ECT, 2017.

Legend
- ORNL Daymet Rainfall Pixels
- Canal/Stream
- Subbasins
- Lake Butler Watershed
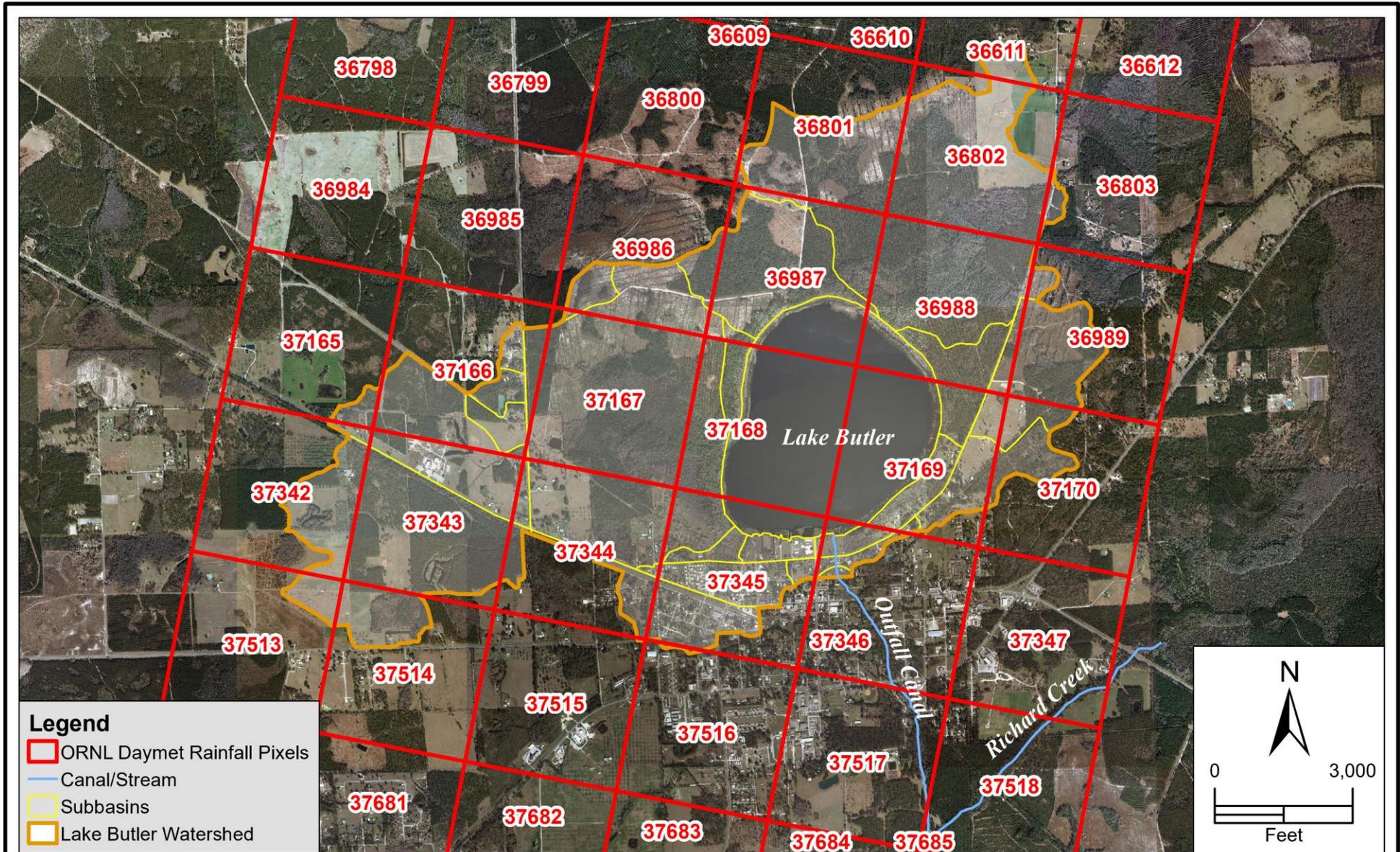
Figure 5-2
ORNL Daymet Rainfall Pixels
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: FDOT, 2013; ORNL, 2015; USGS, 2015; ECT, 2015.

ECT Environmental Consulting & Technology, Inc

Lake Butler PET Data: NOAA Synthesized PET (1/1/1983 - 5/31/1995) and USGS Area-Weighted PET (6/1/1995 - 12/31/2014)

Figure 5-3
NOAA & USGS Potential Evapotranspiration Data (1983-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

ECT Environmental Consulting & Technology, Inc

Sources: USGS, 2015; NOAA, 2015; ECT, 2015.

Figure 5-4
Groundwater Levels at USGS Well Station [SRWMD ID S051933001] (1983-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
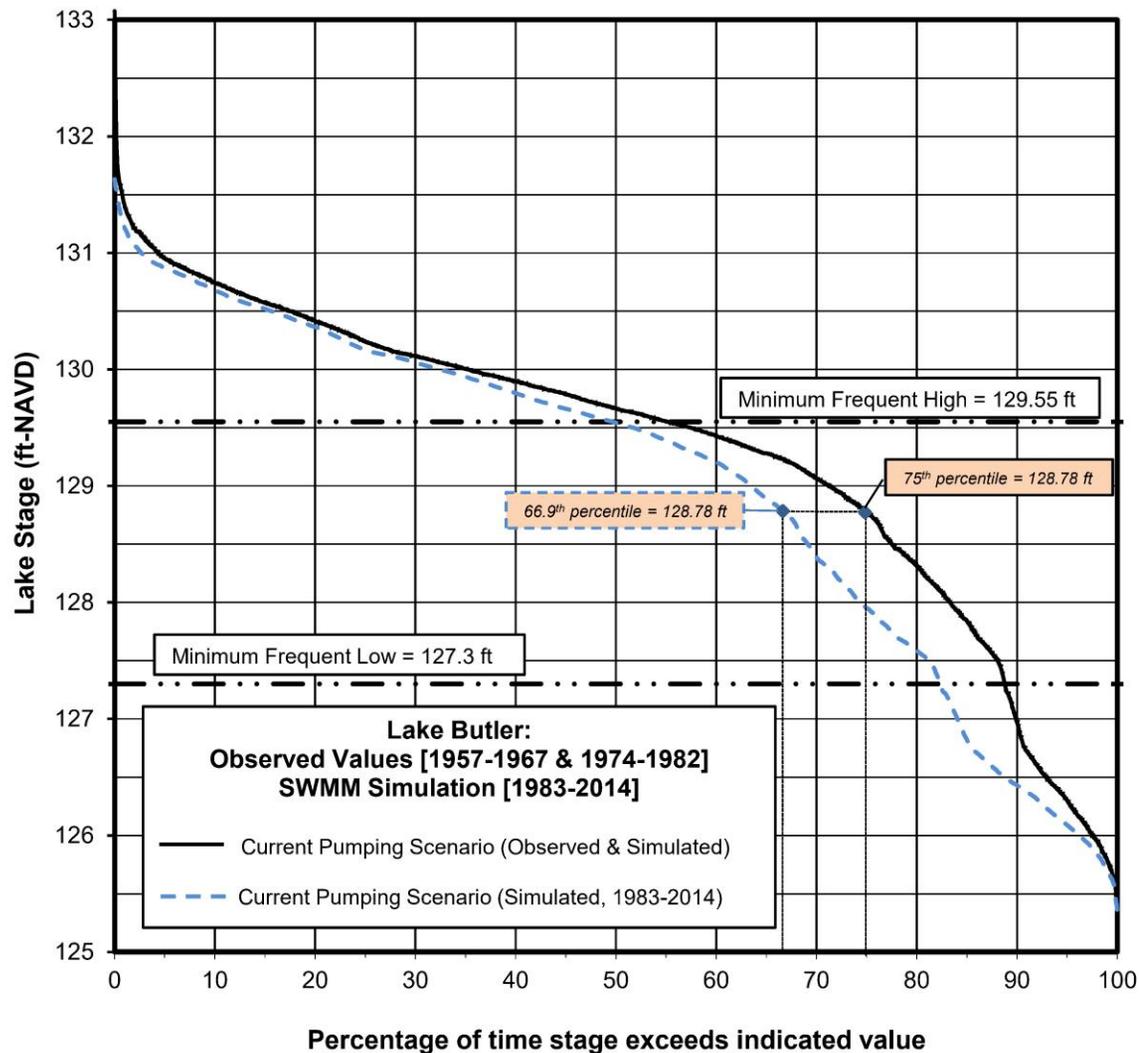Suwannee River Water Management District

Sources: USGS, 2015; ECT, 2017.

Figure 5-5
RTF Adjustment Factors at USGS Well Station [SRWMD ID S051933001] and Lake Butler (1948-2015)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
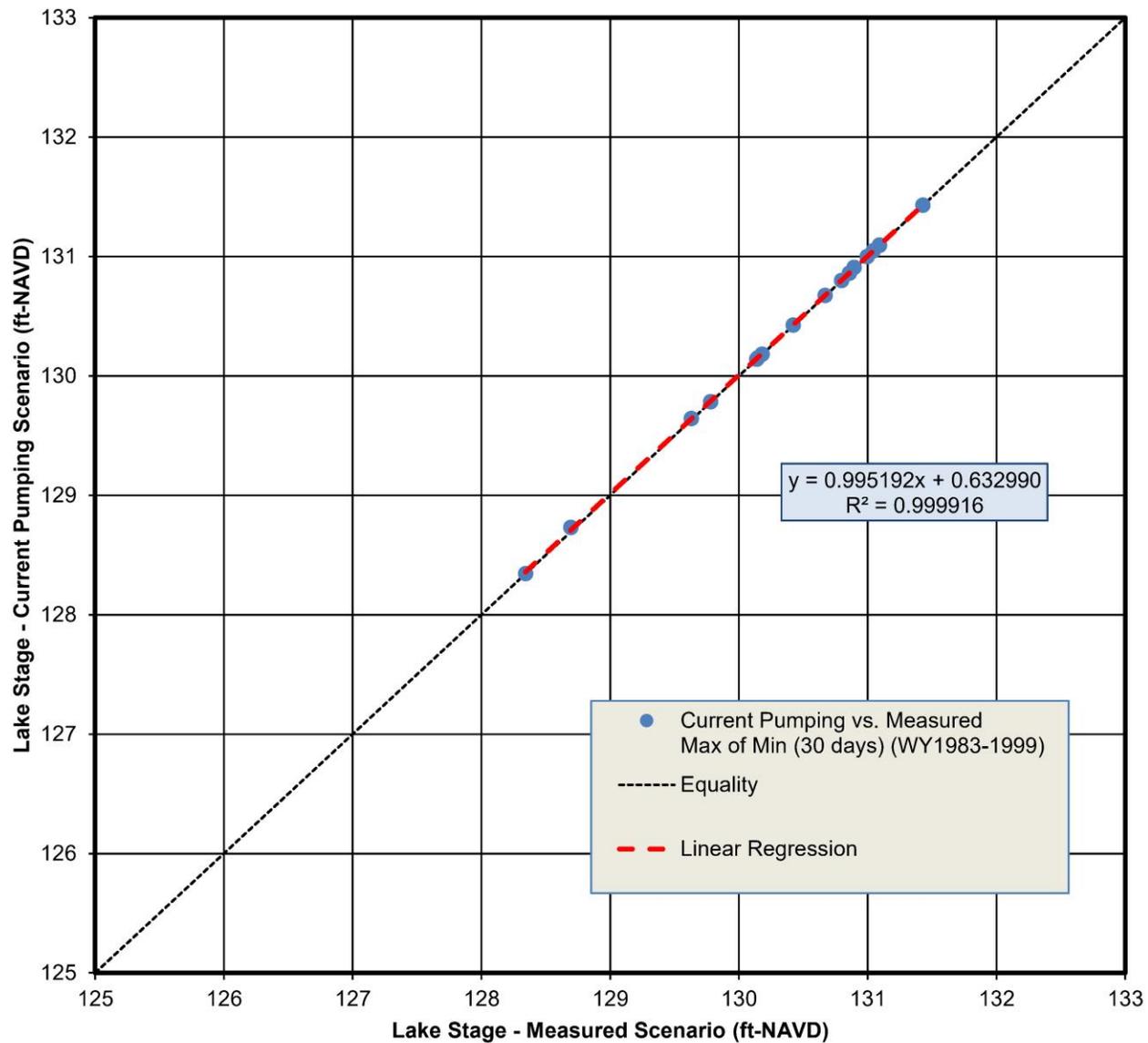Suwannee River Water Management District

Sources: SRWMD, 2020; ECT, 2021.

Figure 5-6
Groundwater Levels at Lake Butler - Measured, No-pumping & Current Pumping Scenarios (1982-2015)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: SRWMD, 2020; ECT, 2021.
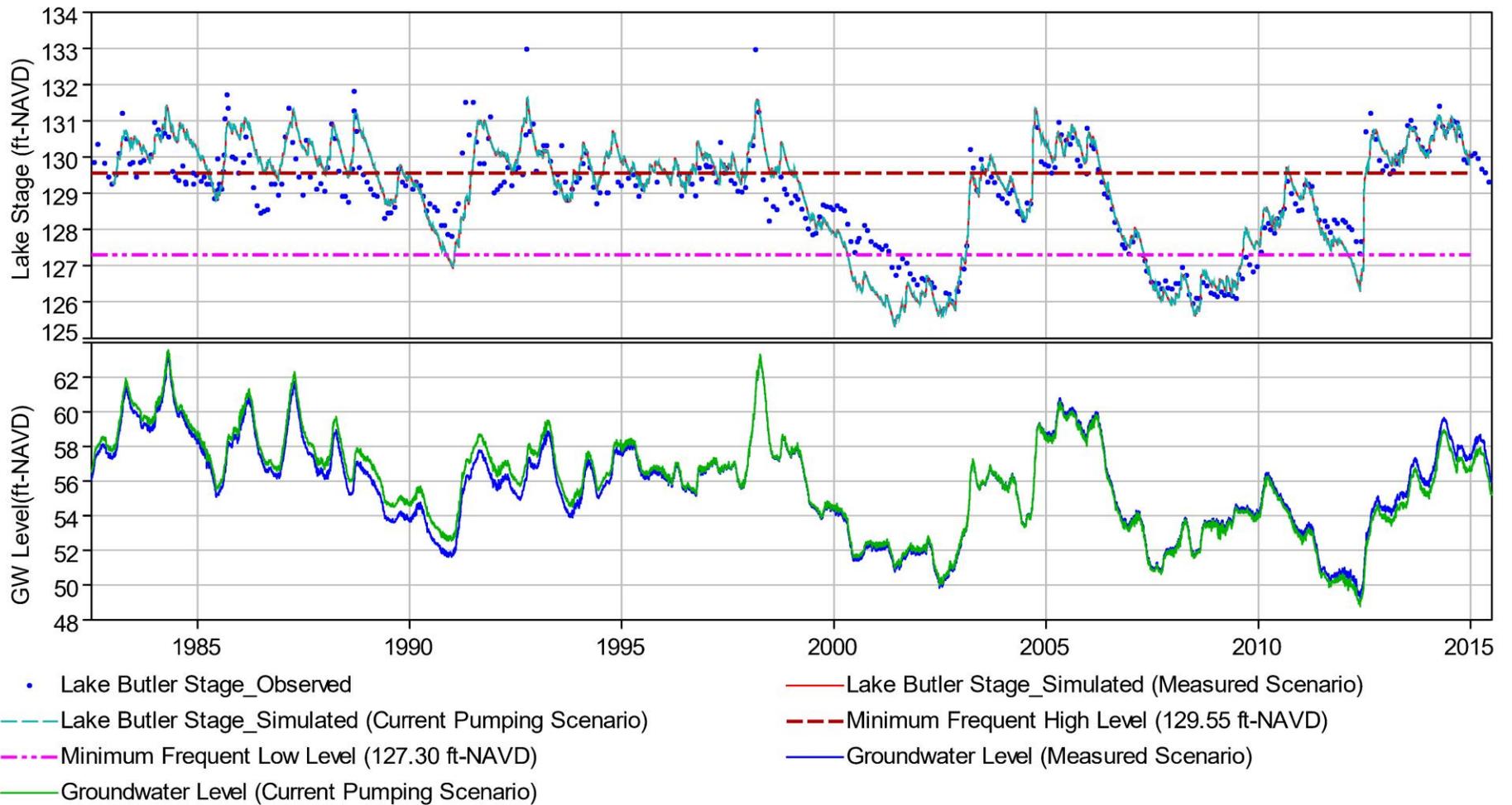
Figure 5-7A
Observed and Simulated Lake Stage Hydrographs Comparison - Measured and Current Pumping Scenarios (1983-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
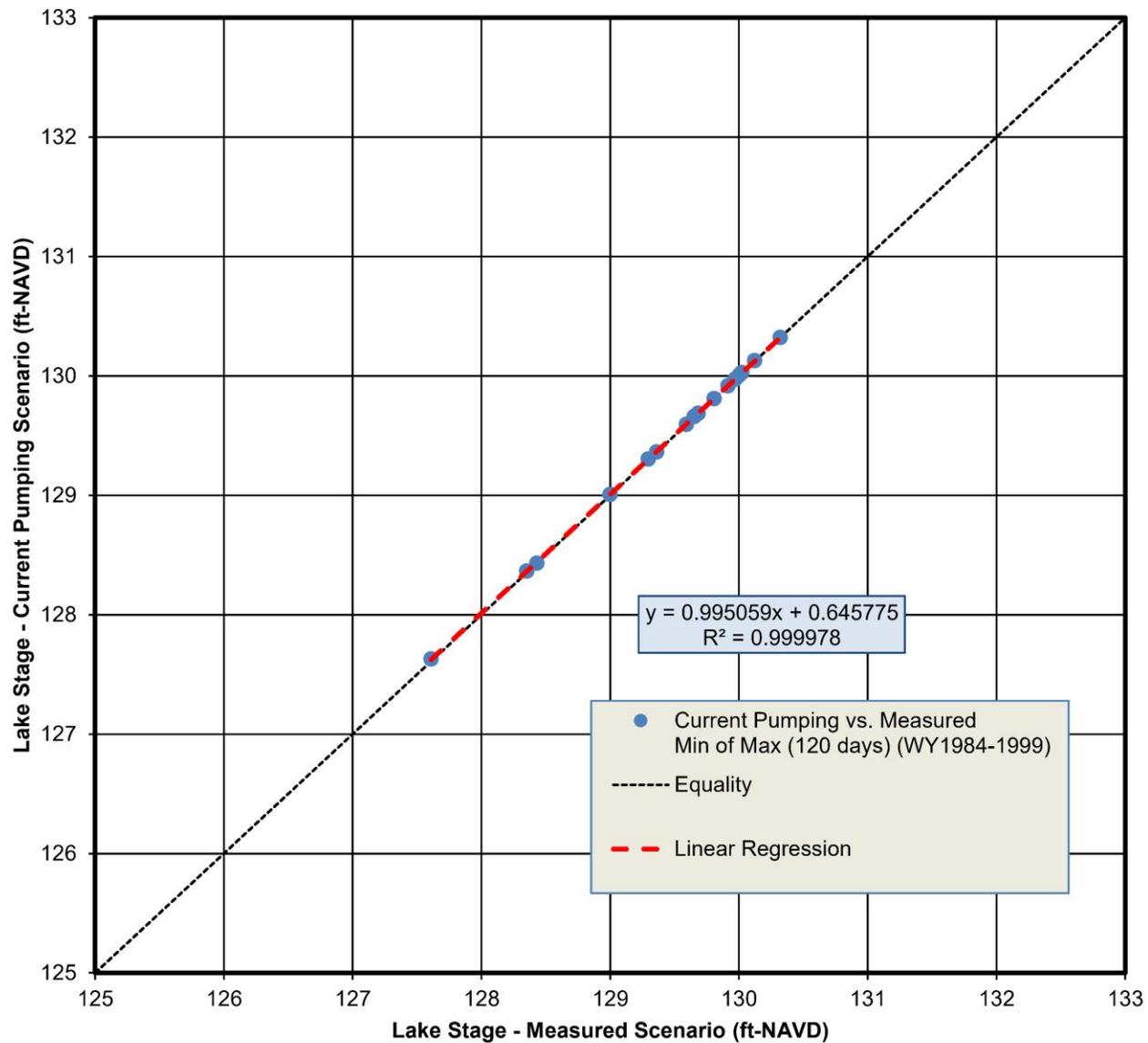Sources: USGS, 2015; SRWMD, 2016; ECT, 2021.
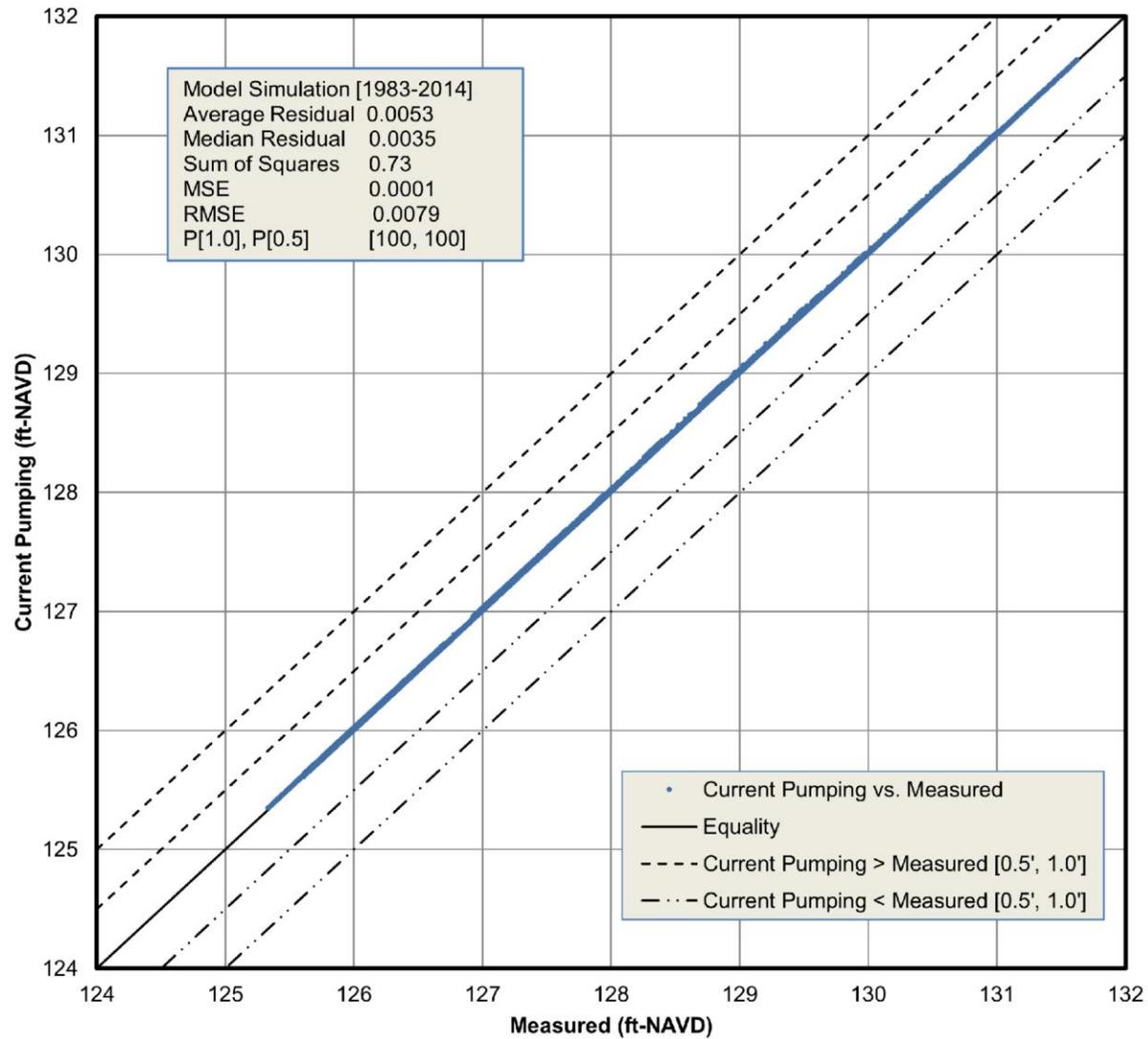
Figure 5-7B
Scatter Plot Comparing Simulated Lake Stages - Current Pumping vs. Measured Scenarios (1983-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
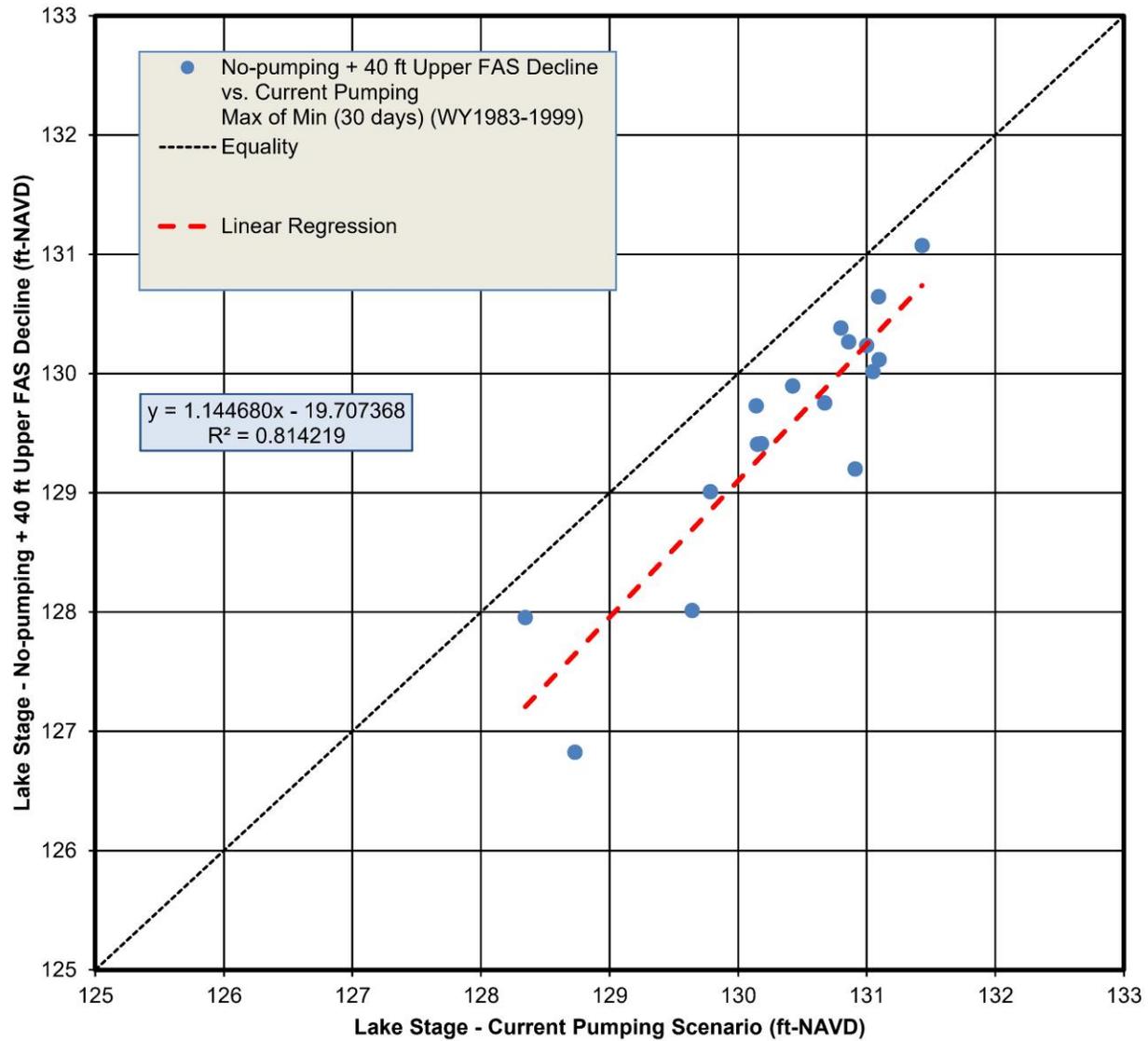Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.
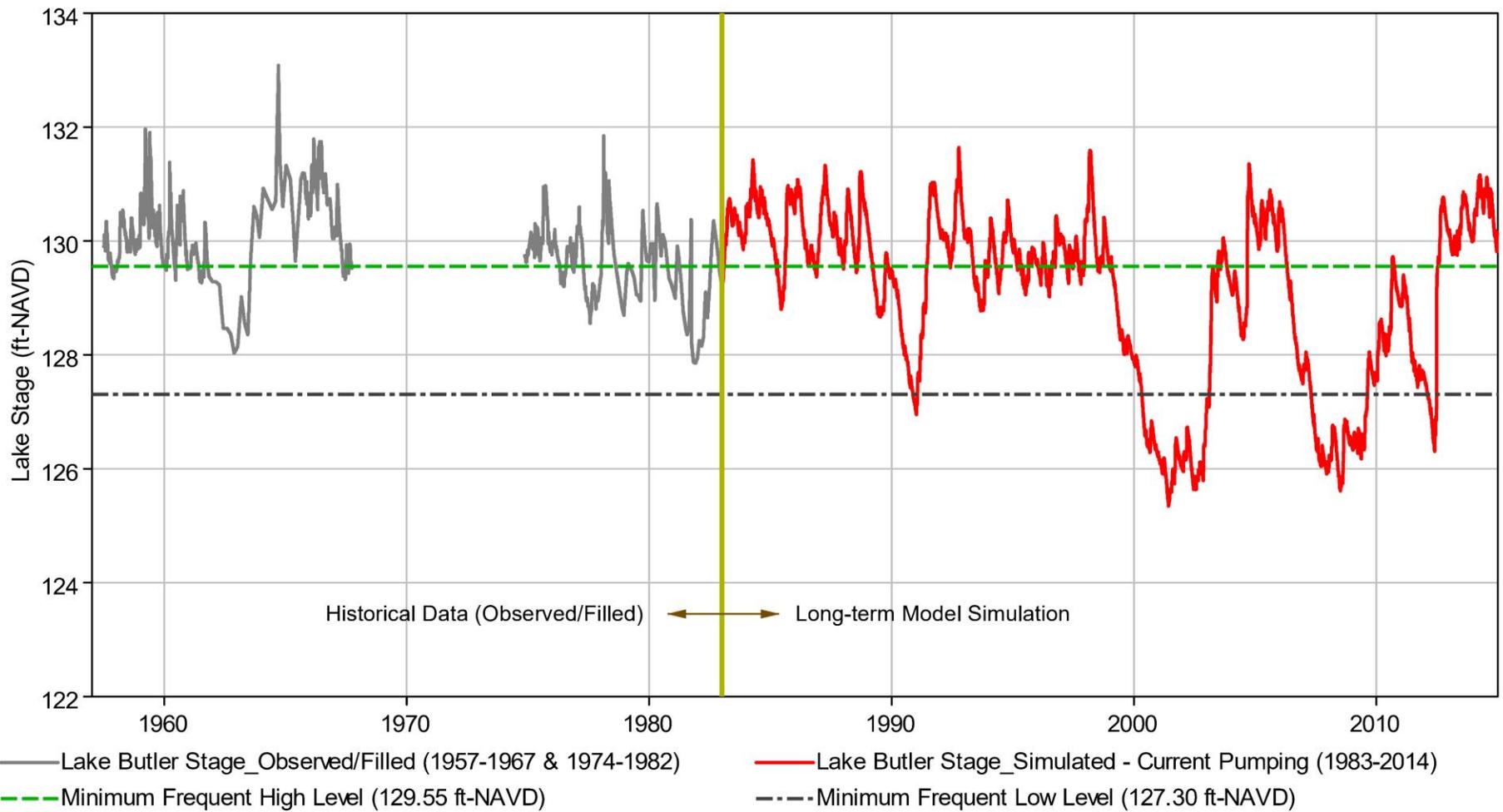
Figure 5-8
Hybrid Lake Stage Hydrographs - Current Pumping Scenario (1957-2014)
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 5-9
Stage Duration Curve - SWMM Simulation (1983-2014) and Hybrid Lake Stage Data Set (1957-2014) -
Current Pumping Scenario
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
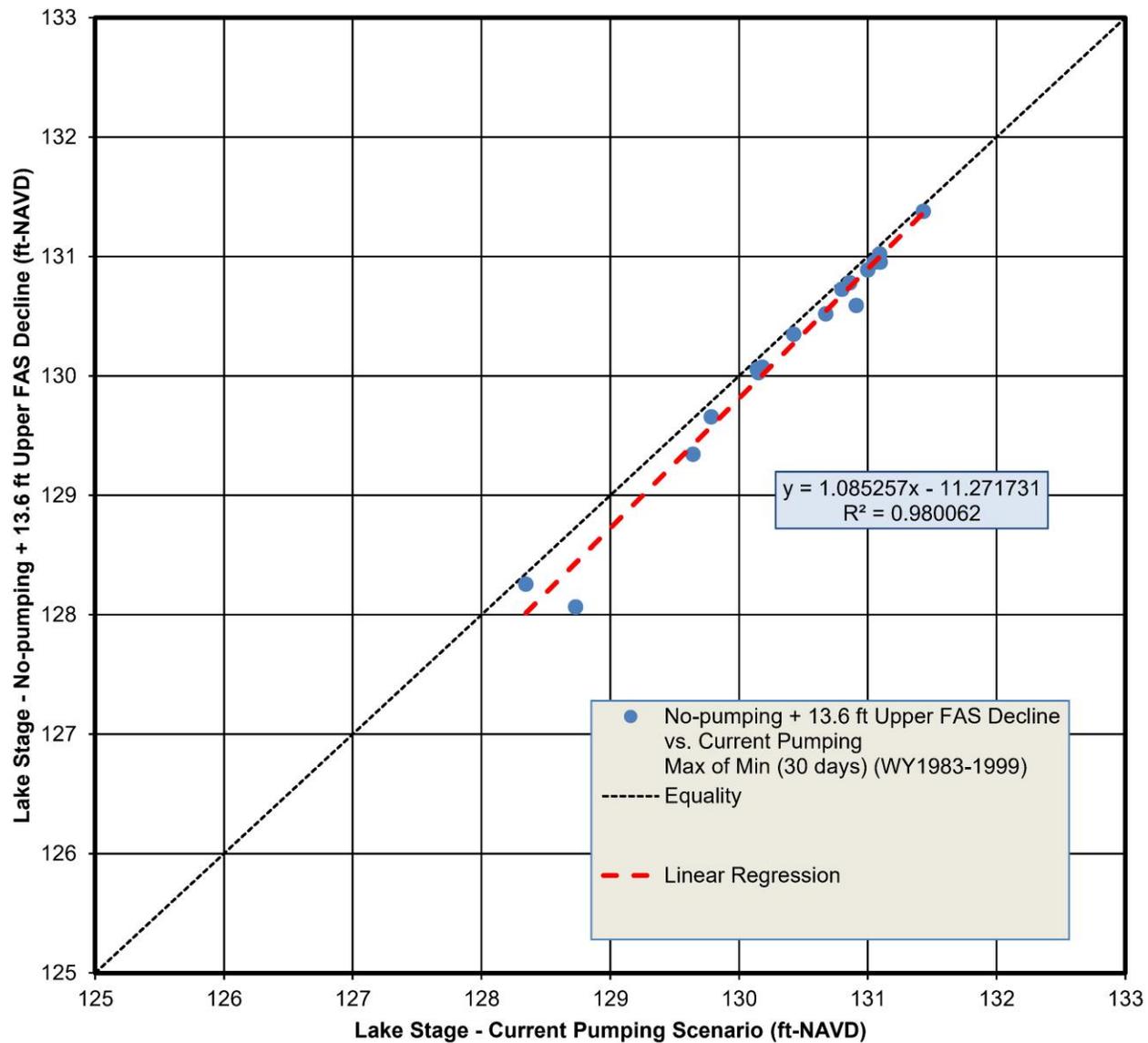Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

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Figure 5-10
Transfer Function for Minimum Frequent High Level - Current Pumping vs. Measured Scenarios
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

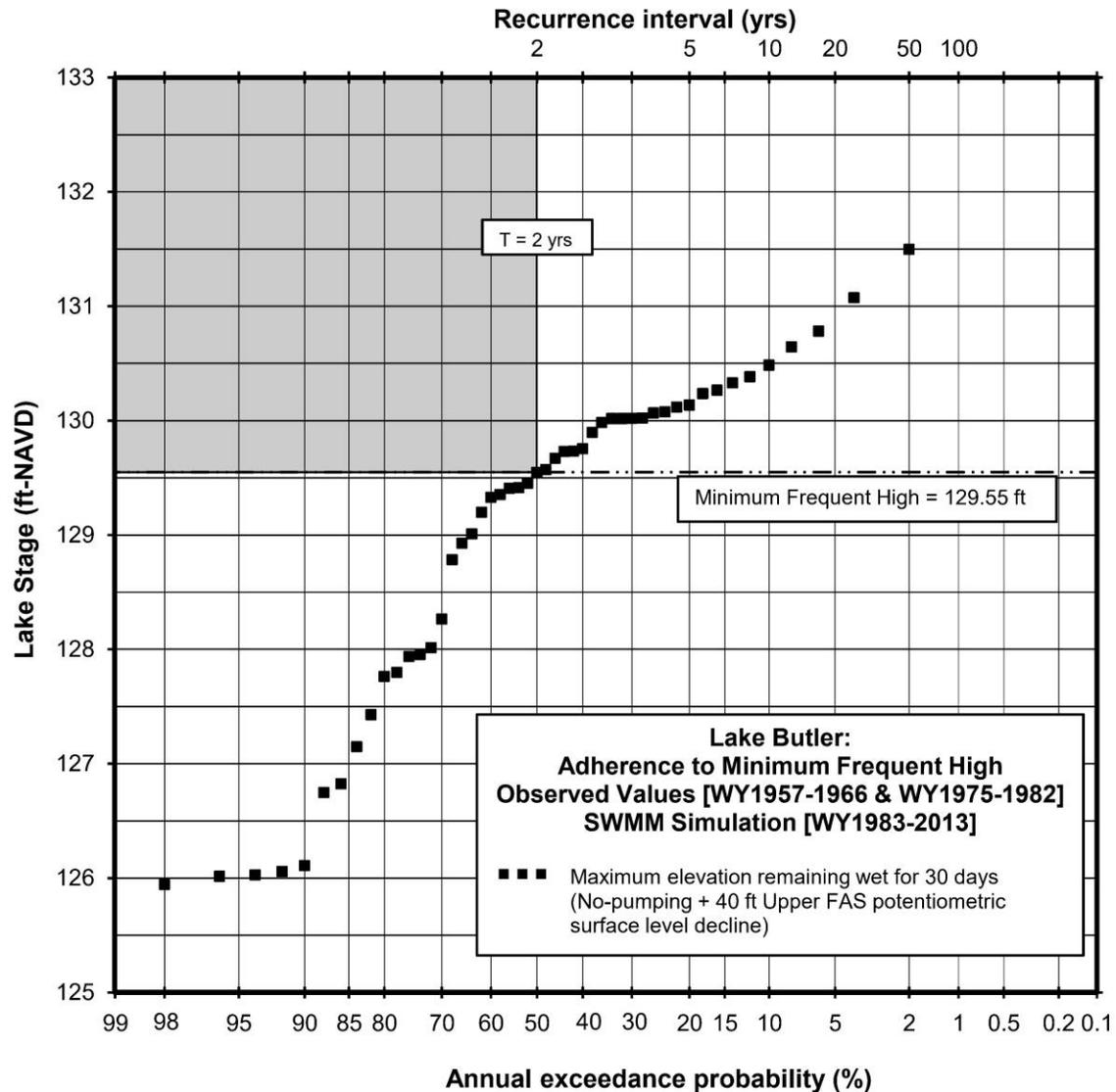Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 5-11
Transfer Function for Minimum Frequent Low Level - Current Pumping vs. Measured Scenarios
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District

Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 6-1
Transfer Function for Minimum Frequent High Level - Current Pumping vs. No-pumping + 40 ft
Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
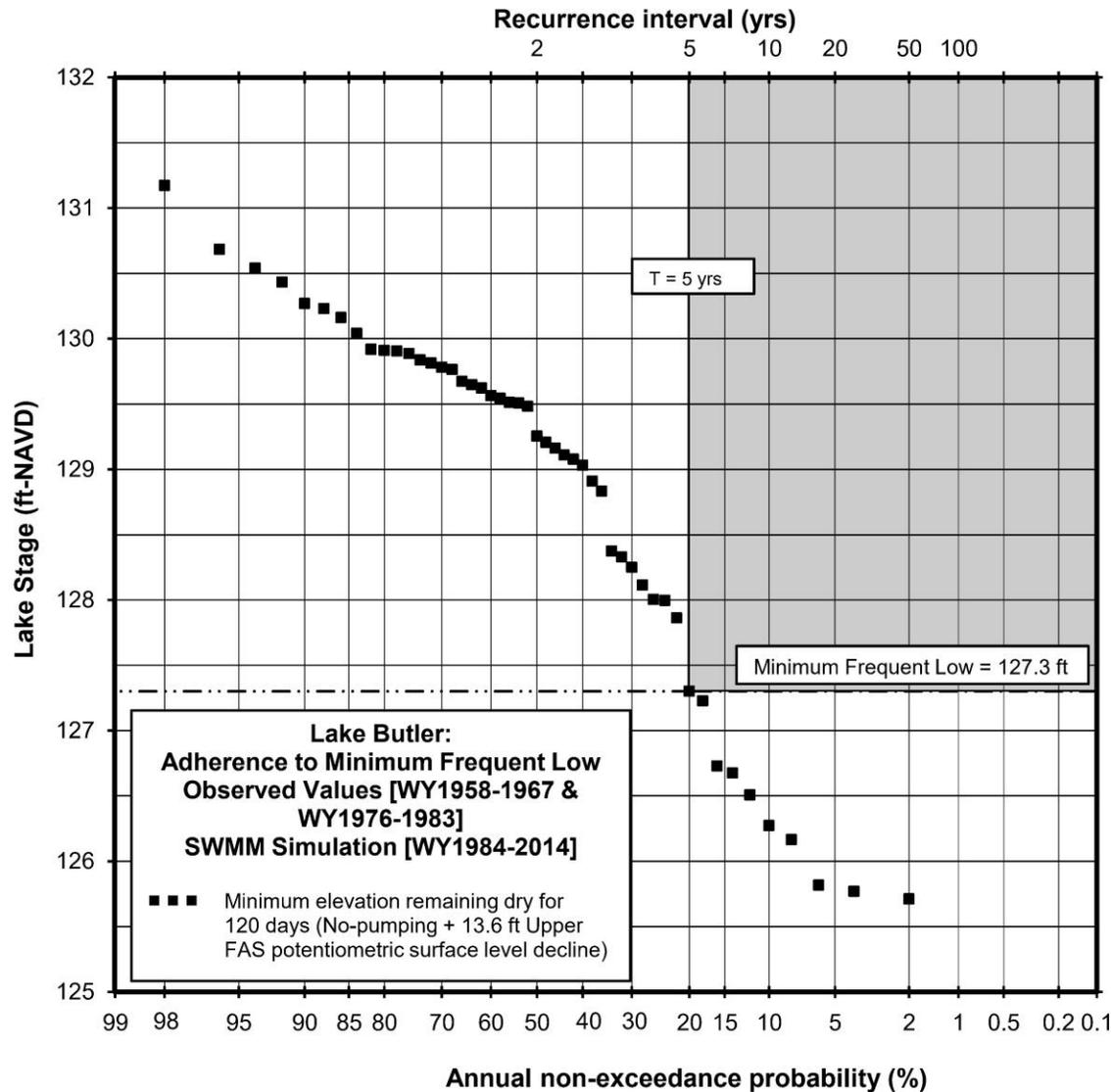Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 6-2
Transfer Function for Minimum Frequent Low Level - Current Pumping vs. No-pumping + 13.6 ft
Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 6-3
Minimum Frequent High Level and Hybrid Lake Stage Data Set (1957-2014) - No-pumping + 40 ft
Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
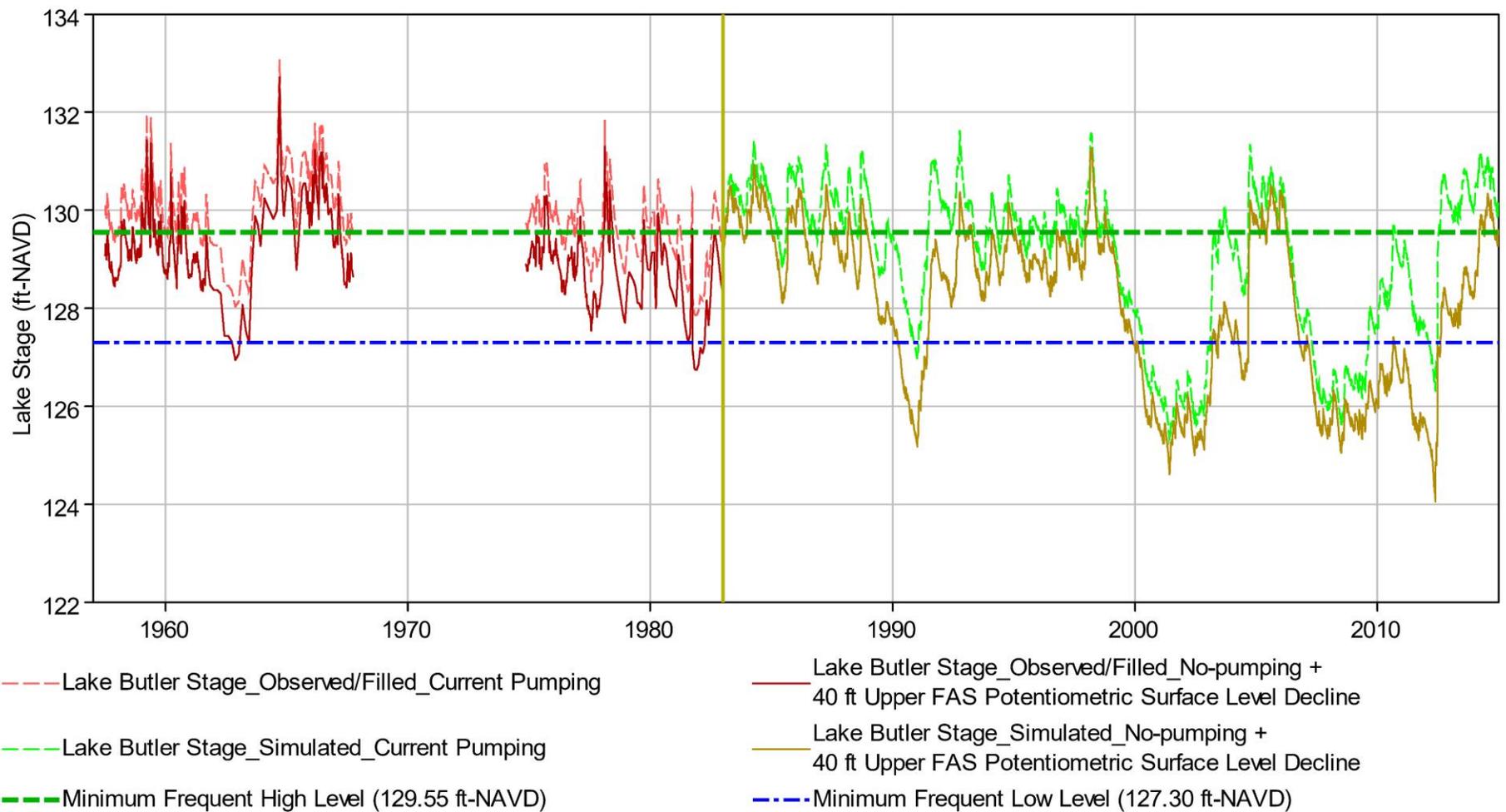Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 6-4
Minimum Frequent Low Level and Hybrid Lake Stage Data Set (1957-2014) - No-pumping + 13.6 ft
Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
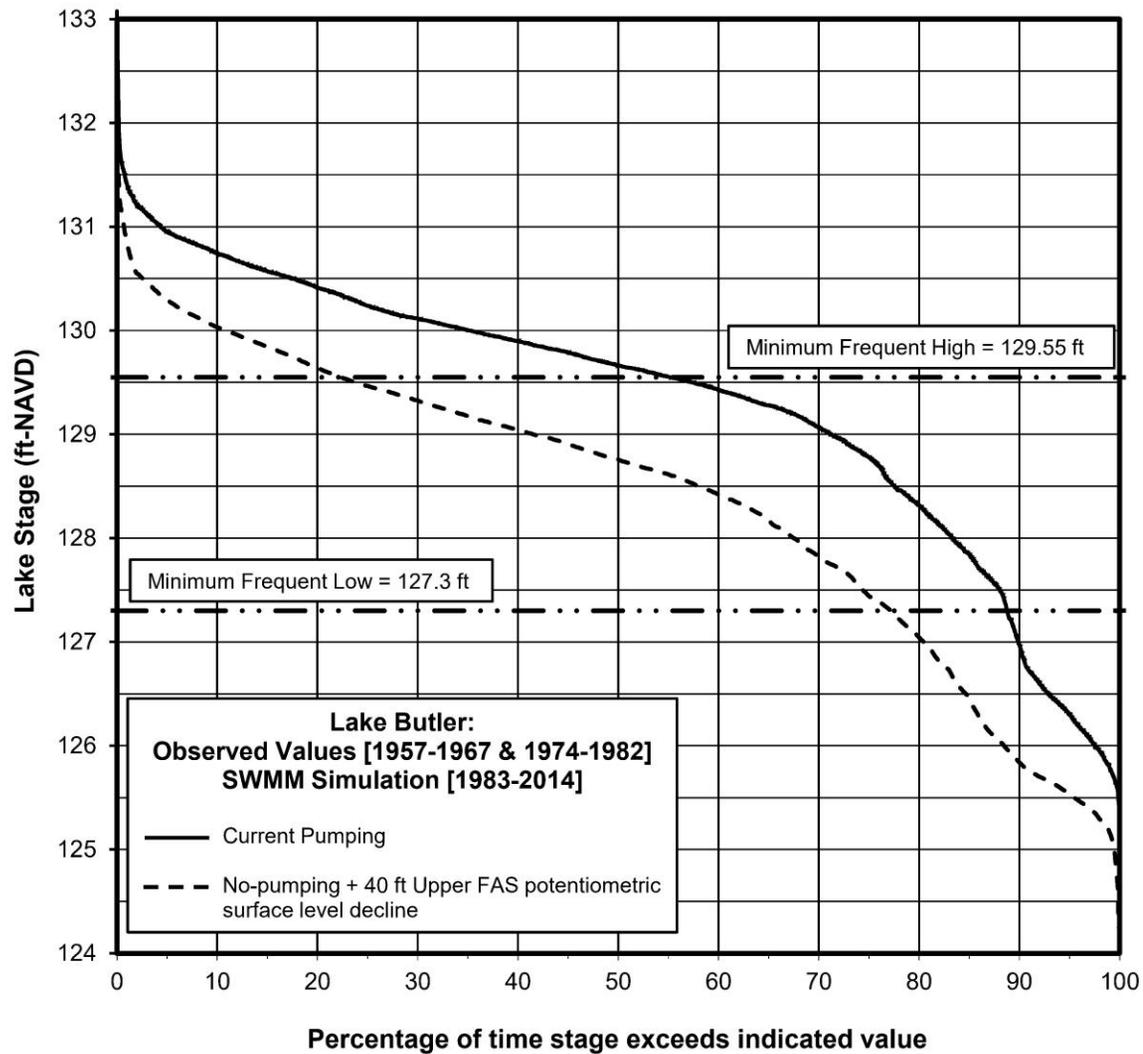Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 6-5
Hydrographs Comparison - Hybrid Lake Stage Data Set (1957-2014) - Current Pumping vs.
No-pumping + 40 ft Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 6-6
Stage Duration Curves - Hybrid Lake Stage Data Set (1957-2014) - Current Pumping vs.
No-pumping + 40 ft Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
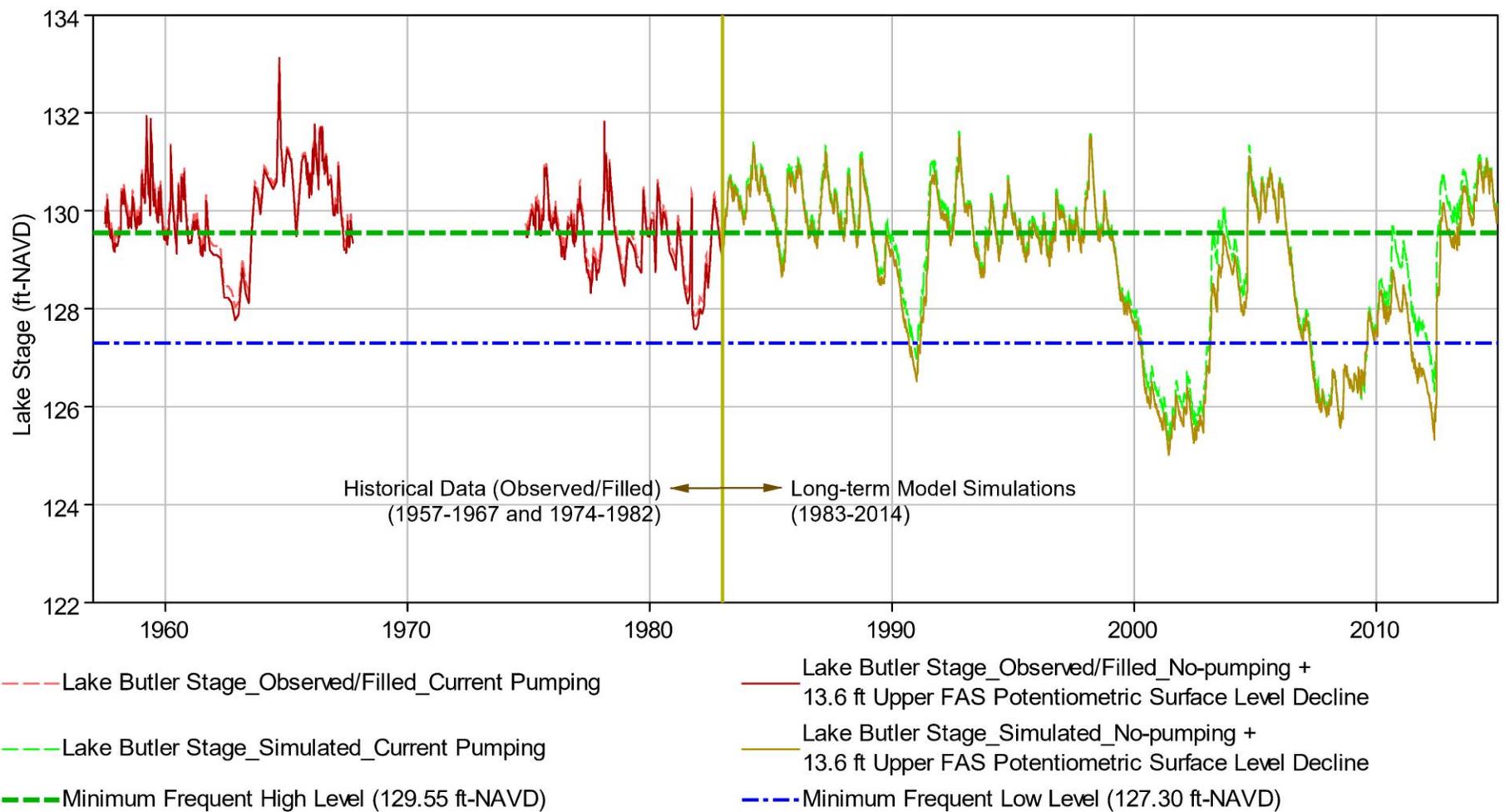Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

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Figure 6-7
Hydrographs Comparison - Hybrid Lake Stage Data Set (1957-2014) - Current Pumping vs.
No-pumping + 13.6 ft Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
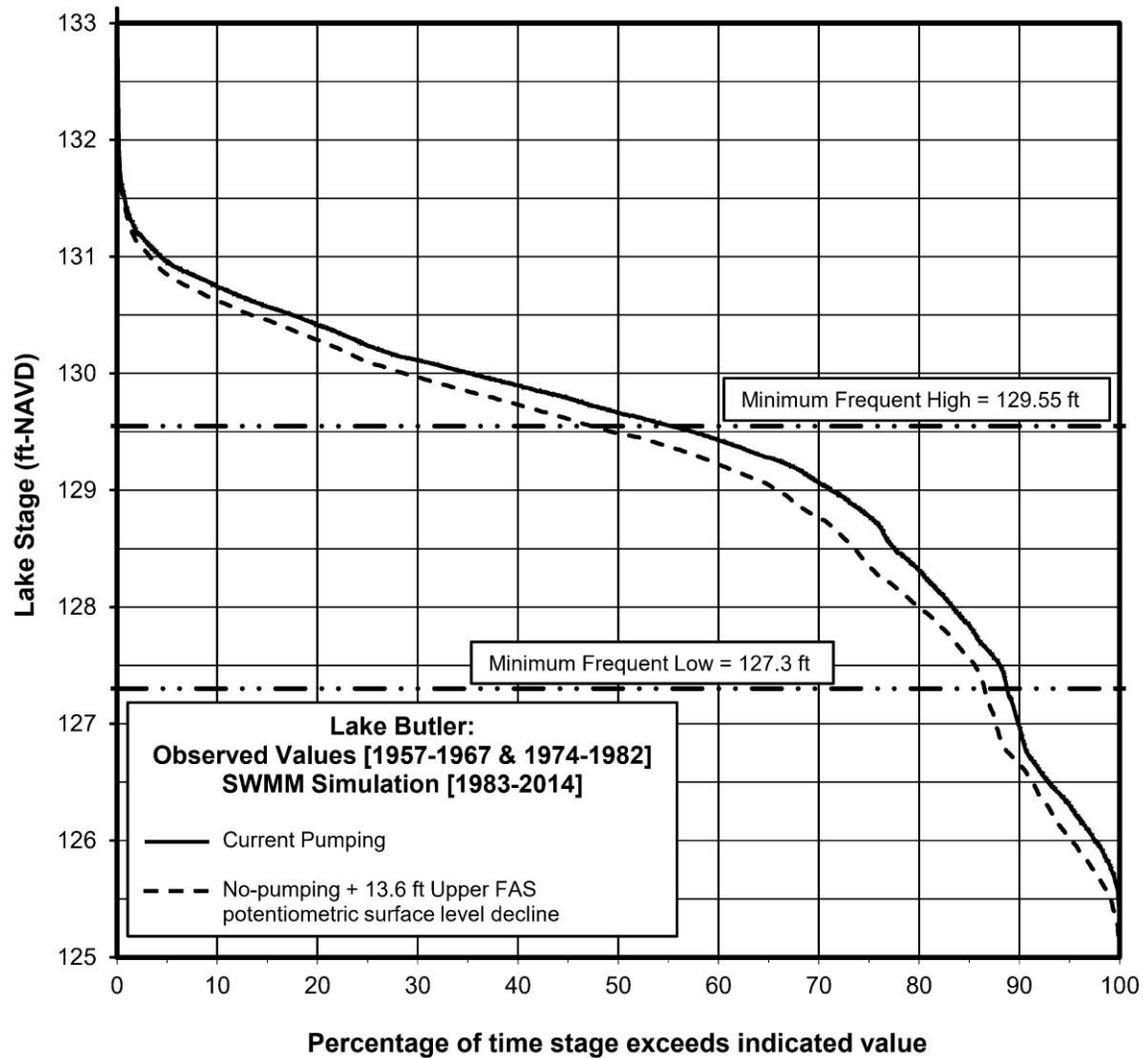Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Figure 6-8
Stage Duration Curves - Hybrid Lake Stage Data Set (1957-2014) - Current Pumping vs.
No-pumping + 13.6 ft Upper FAS Potentiometric Surface Level Decline
Lake Butler Water Budget Modeling - Updated to Include Reference Timeframe Analysis
Suwannee River Water Management District
Sources: USGS, 2015; SRWMD, 2020; ECT, 2021.

Appendix A -
SWMM Model Input and Output Data

(located on DVD)