APPENDIX B — HYDROLOGICAL ANALYSES

INTRODUCTION

In addition to extensive work conducted to understand the ecological structure and function, and most sensitive environmental values of priority waterbodies, assessing the status of minimum flows and levels (MFLs) requires substantial hydrological analysis. Several steps were involved in performing the hydrologic analysis, including:

1. Review of available data for compiling long-term datasets;
2. Historical groundwater pumping impact assessment;
3. Development of lake level datasets representing no-pumping and current-pumping conditions; and
4. Estimating available water (freeboard or deficit).

Figure 1 shows the flowchart for the hydrologic analysis. This document describes the first three steps and associated results. Appendix C includes the description of the last step.

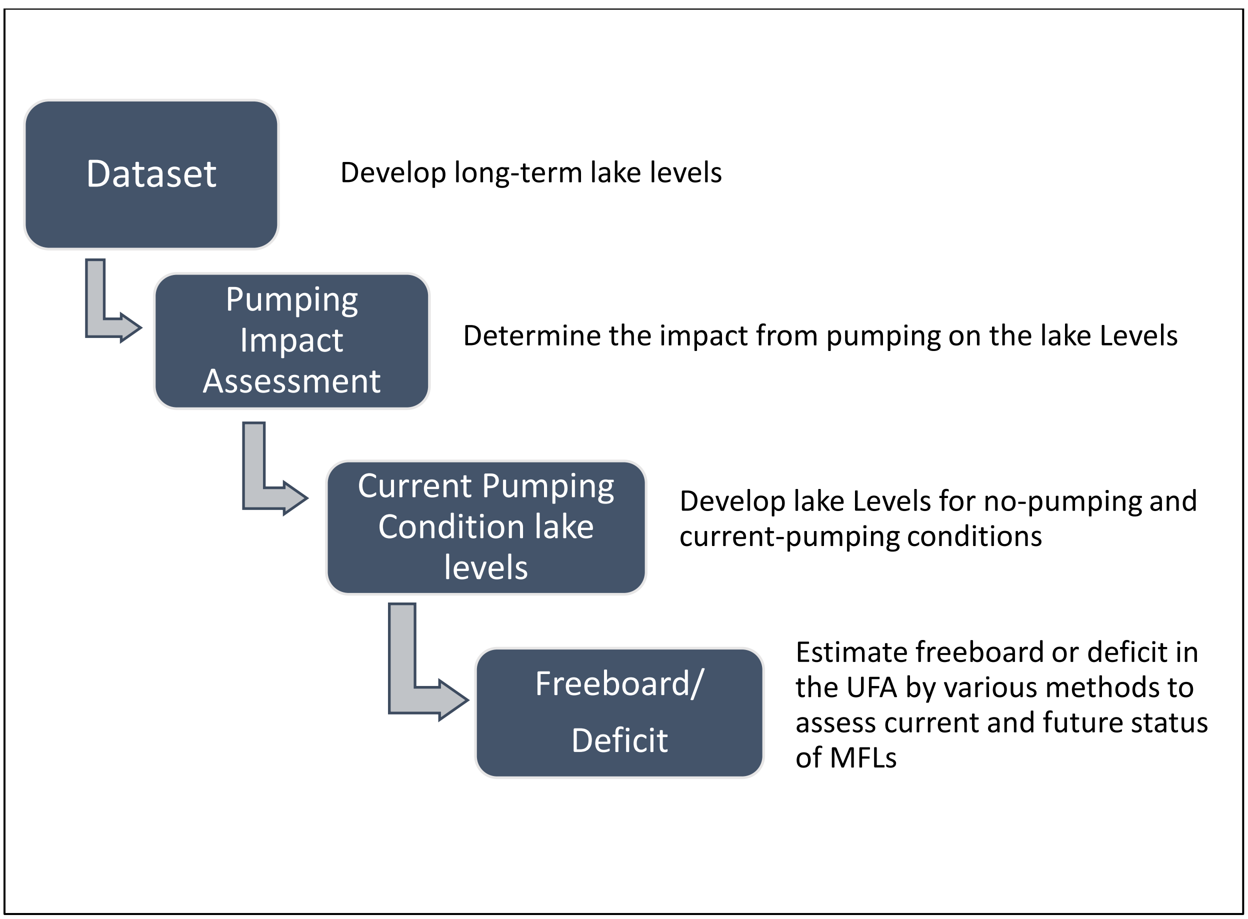
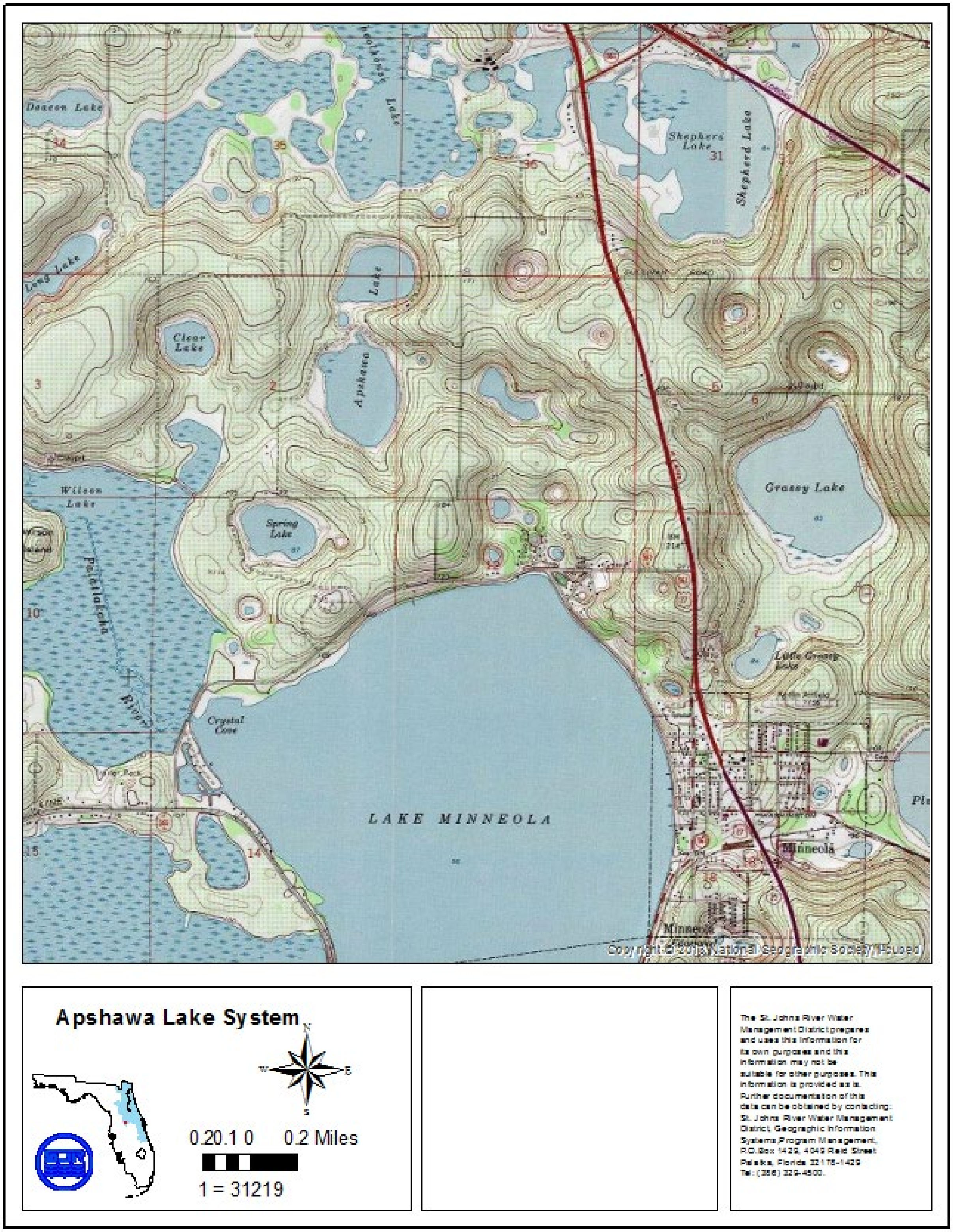


Figure 1. Flowchart for hydrologic analysis process.

Background

Apshawa Lake is in Lake County, Florida, about three miles north of the City of Clermont (Figure 2). It is located within a St. Johns River Water Management District (SJRWMD) priority water resource caution area (SJRWMD 2010). Lake Apshawa is located in the physiographic region known as the Groveland Karst subdistrict of the Central Lakes District. (Brooks 1982). Apshawa Lake is a system of two isolated lakes, Apshawa Lake South and Apshawa Lake North.

In 1941, historic Apshawa Lake consisted of about 158 acres of open water and floodplain wetlands. A ditch connected two main waterbodies. In about 1953, water levels were very low and fill road with a culvert was constructed across the Apshawa Lake system. By 1966, the waterbodies were isolated from each other. However, in times of extremely high water, these the two lakes become one lake.



Author:, Source:C:\Users\lakarams\AppData\Local\Temp\...TMP, Time:11/10/2020 9:15:07 AM

Figure 2. Apshawa Lake system.

APSHAWA LAKE LONG-TERM SIMULATION

The SJRWMD contracted with Dynamic Solutions, LLC (DSLLC) to develop a Hydrological Simulation Program FORTRAN (HSPF) model of Apshawa Lakes South and North. This model was completed in January 2019 (DSLLC 2019). The model was calibrated for a period from January 1, 2006 to December 31, 2016. It also was verified for a period from January 1, 1995 to December 31, 2005. The model is based on the 2009 land cover.

The HSPF model provided a framework to assess minimum flows and levels (MFLs) of Apshawa Lakes South and North. Developing MFLs at the SJRWMD requires analysis of long-term simulation results. Using the calibrated Apshawa Lake HSPF model, SJRWMD has developed a long-term simulation model for a period from January 27, 1959 to December 31, 2018. This section describes the updates of the Apshawa Lakes HSPF model for long-term simulations.

REVIEW OF AVAILABLE DATA

Apshawa Lakes Water Level Data

The SJRWMD has water level monitoring at both Apshwa Lake South (station ID: 02930258) and Apshwa Lake North (station ID: 15850288). Figure 6 shows the location of both stations. Station 02930258 on Apshawa Lake South has a period of record from 4/6/1953 to present. The period of record of station 15850288 on Apshawa Lake North is from 7/10/2001 to 6/1/2017. Table 1 presents the two stations.

Table 1. SJRWMD stations at Apshawa Lake.

Station Number	Station Name	Latitude	Longitude	Date Start	Date End
02930258	Apshawa Lake at Minneola (WL)	28.600	-81.773	4/6/1953	present
15850288	Apshawa Lake North at Minneola (WL)	28.609	-81.772	7/10/2001	6/1/2017

Long-term rainfall data

Like in the original HSPF model, the long-term rainfall recorded at Isle_Win was used in the long-term simulation. Isle_Win rainfall data are composed of data from different rainfall stations (DSLLC 2019). The rainfall data at Isle_Win are available from January 1, 1916 to December 31, 2018. The annual rainfall at Isle_Win ranges from 22.28 inches in year 2000 to 78.77 inches in year 1953, with an average annual precipitation of 50.39 inches. Table 2 presents a summary of annual rainfall at Isle_Win. The annual rainfall at Isle_Win is shown in Figure 3.

Table 2. Summary of annual rainfall (in) at Isle_Win for a period of record from 1916 to 2018.

Statistical Parameter	Rainfall (in)
Mean	50.39
Standard Error	0.95
Median	49.96
Standard Deviation	9.60
Minimum	22.28
Maximum	78.77

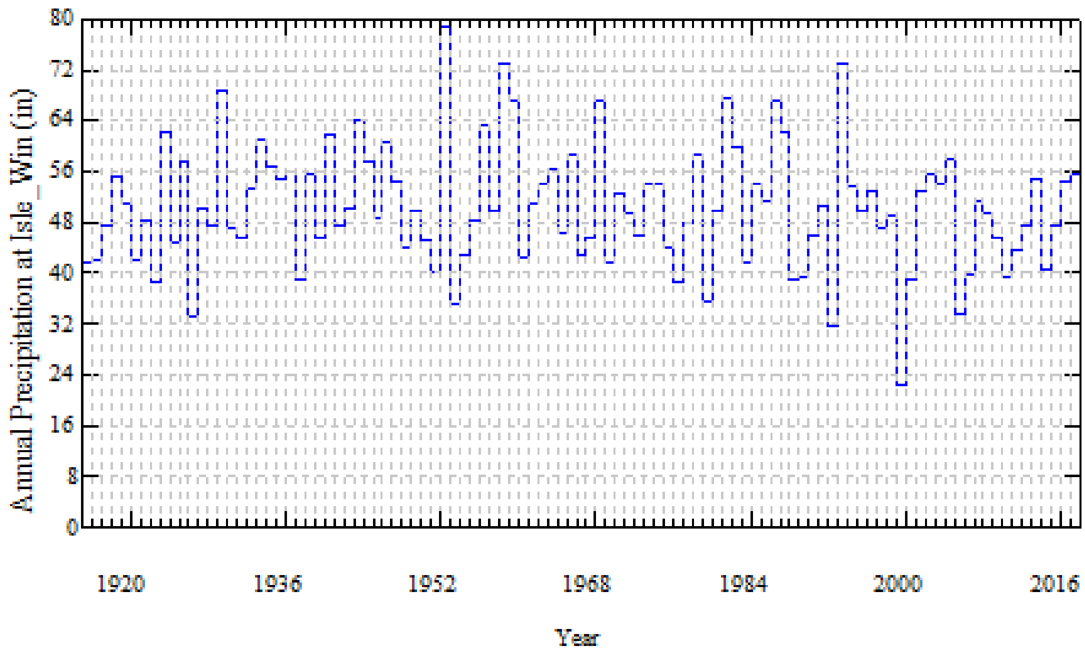


Figure 3. Annual rainfall at Isle Win station.

Long-term potential evapotranspiration data

The long-term simulation model uses the potential evapotranspiration (PET) data at the Clermont 9s NOAA station, the same station used in the calibration model (DSLLC 2019). The Clermont PET is available from January 1, 1948 to December 31, 2018. The annual PET at Clermont ranges from 55.23 inches in year 1983 to 65.46 inches in year 2000, with an average annual precipitation of 59.49 inches. Table 3 presents a summary of annual of PET at Clermont. The annual PET is shown in Figure 4.

Table 3. Summary of annual PET (in) at Clermont from 1948 to 2018.

Statistical Parameter	PET (in)
Mean	59.49
Standard Error	0.22
Median	59.27
Standard Deviation	1.90
Minimum	55.23
Maximum	65.46

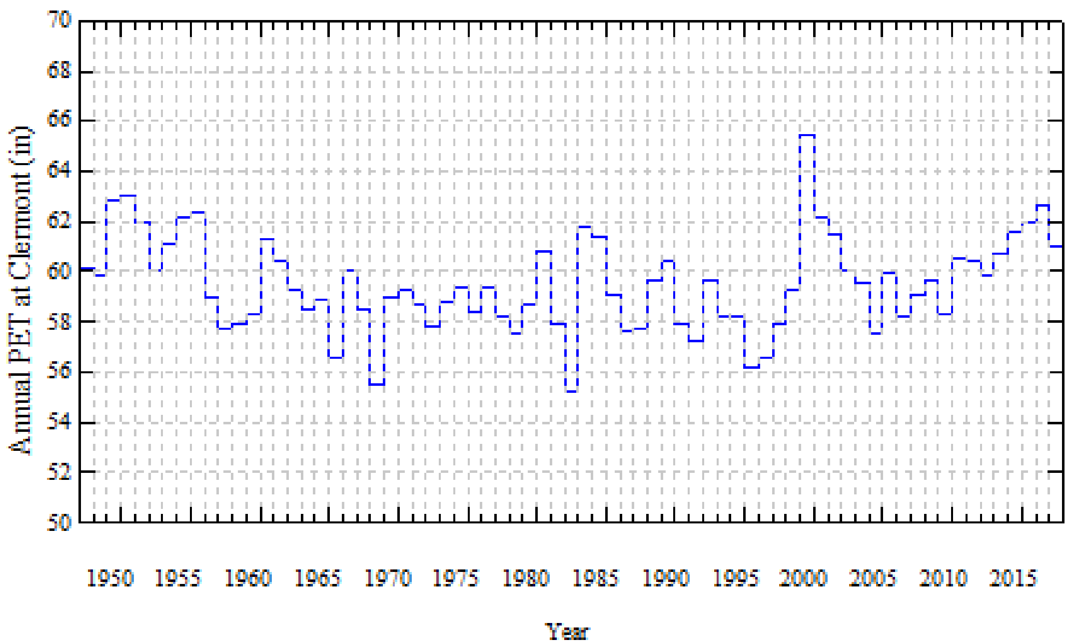


Figure 4. Annual PET at Clermont station.

Long-term UFA groundwater levels

UFA groundwater monitor wells near Apshawa Lake include L-0001, L-0062 and L-0054. L-0001 well is the closest one and was used in the original model. L-0062 and L-0054 wells were used to extend or fill in the missing values of L-0001 (DSLLC 2009). Table 4 presents the UFA groundwater wells and their period of record. The extended long-term L-0001 UFA groundwater levels are from January 27, 1959 to December 31, 2018. Figure 5 shows the extended L-0001 well levels. Figures 6 and 7 show the locations of lakes and UFA wells stations, respectively.

Table 4. UFA Groundwater stations near Apshawa Lake.

STATION NUMBER	STATION_NAME	LATITUDE	LONGITUDE	Data Start	Data End
11111435	L-0001 Clermont Deep Replacement (WL) FA	28.554	-81.765	5/17/1982	present
09252090	L-0062 Mascotte Deep (WL) FA	28.535	-81.913	1/27/1959	present
09680944	L-0054 College St at Leesburg (WL) FA	28.812	-81.892	9/12/1973	present

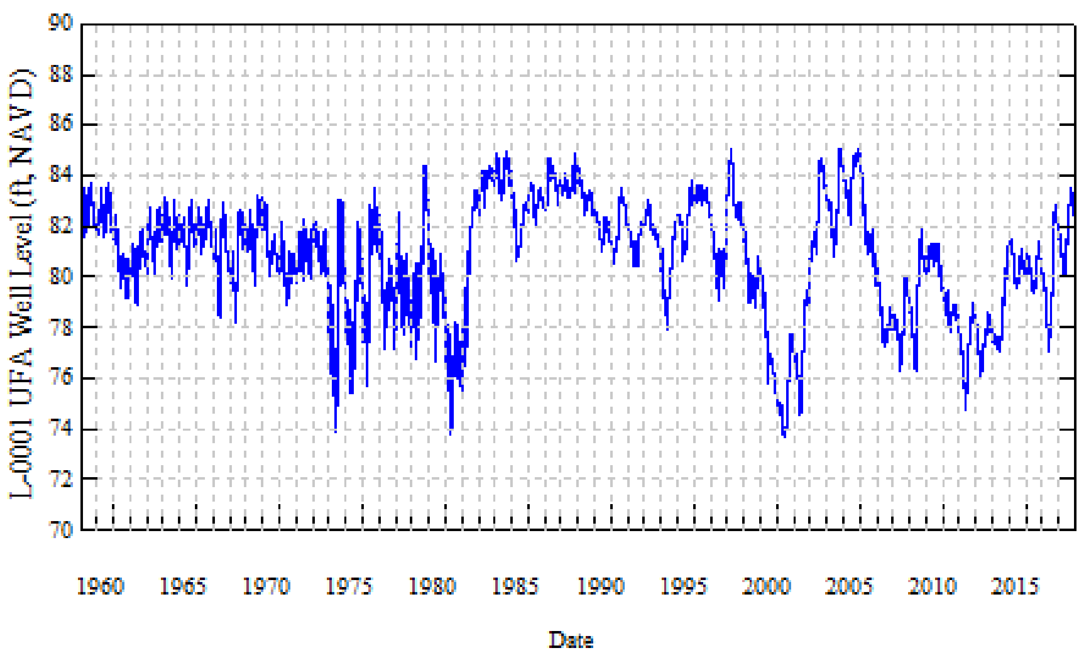
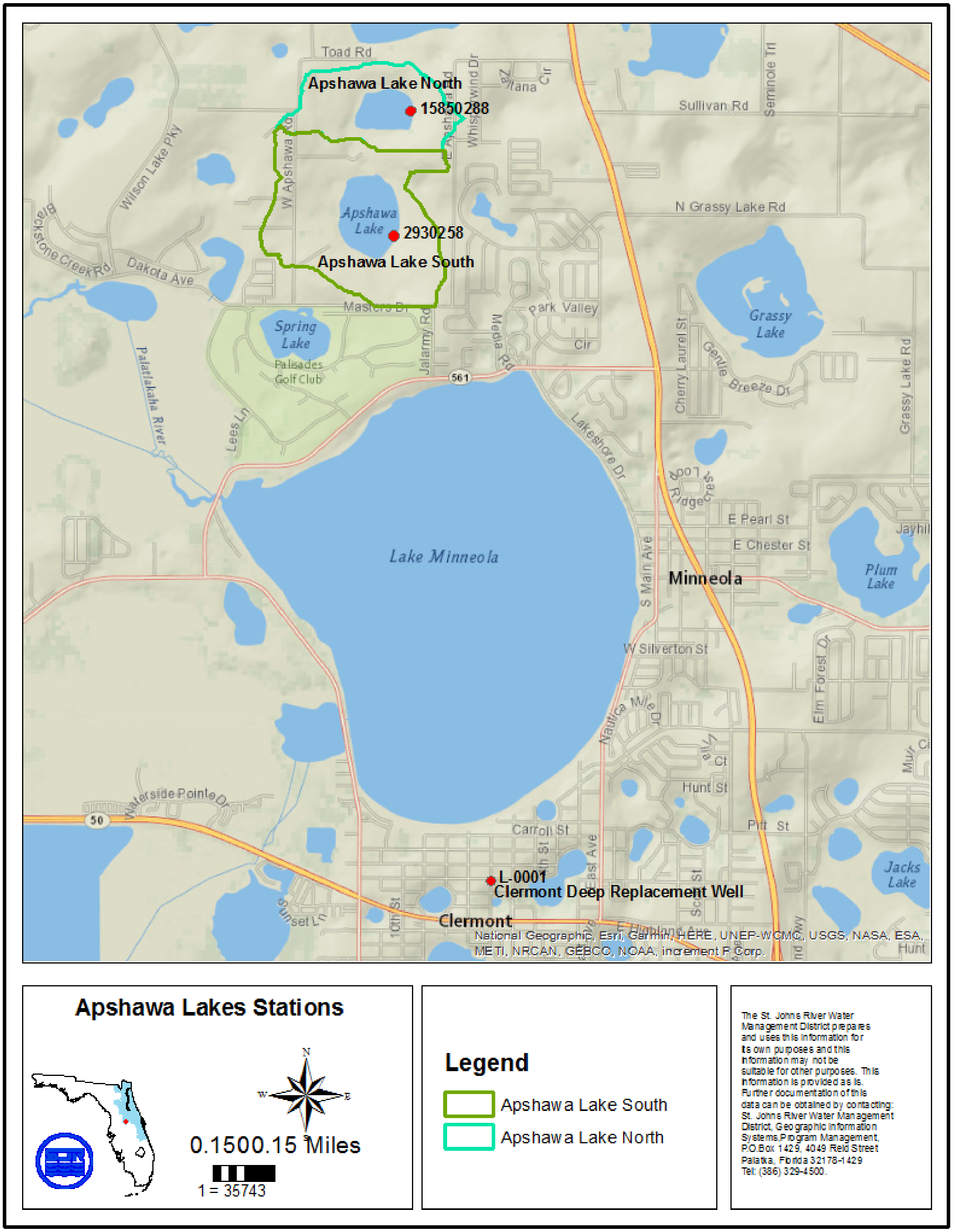
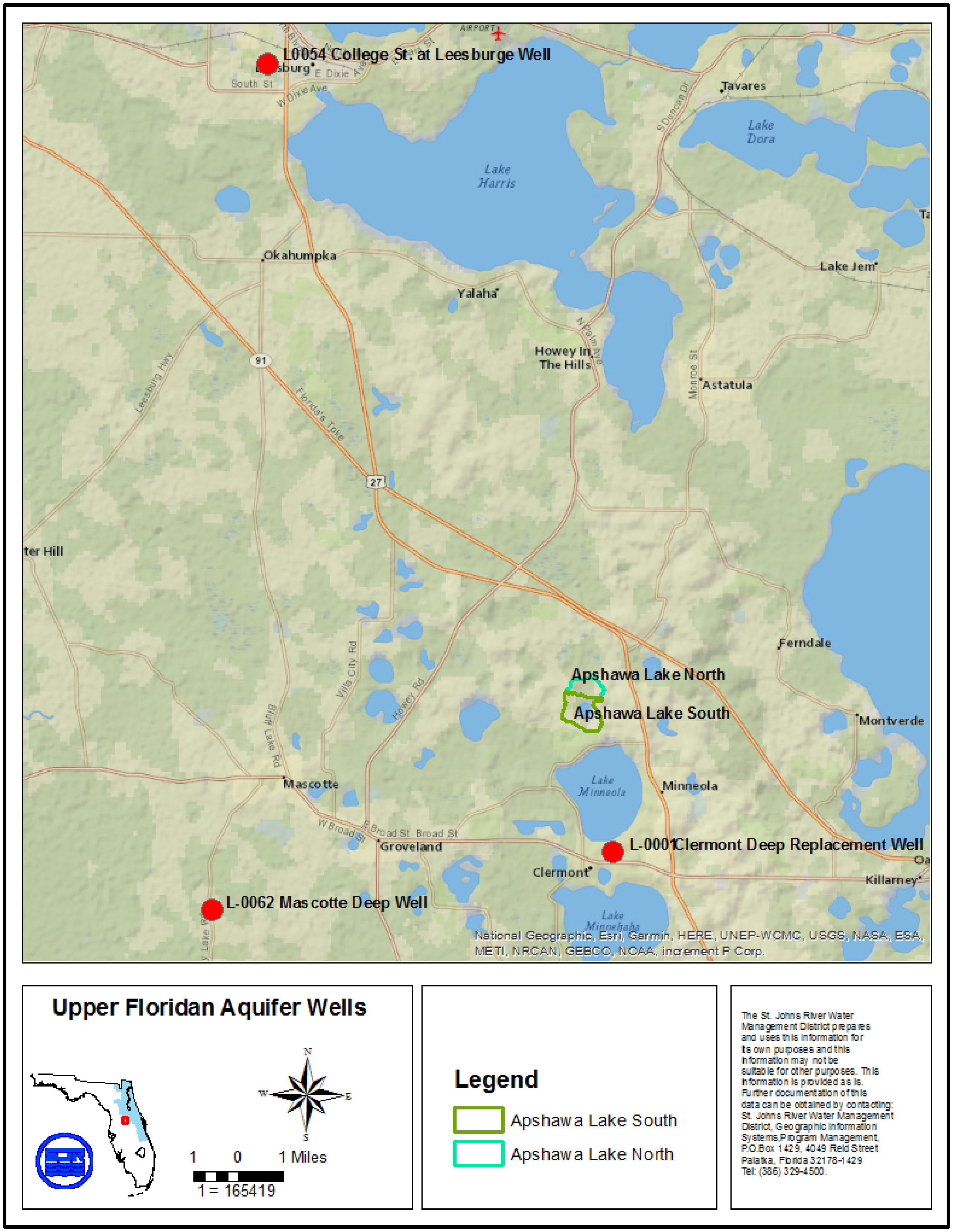


Figure 5. Extended long-term UFA groundwater levels at well L-0001.



Author:, Source: U:\Water Supply Planning\ResEvalMdlg\MFLs\03_MFL_Systems\ApshawaSouth\3_HydroAnalysis\3_Modeling\3_Data\Apshawa.mxd, Time:5/26/2021 2:11:56 PM

Figure 6. Location of water level stations in Apshawa Lakes and well L-0001.



Author:, Source: U:\Water Supply Planning\ResEvalMdlg\MFLs\03_MFL_Systems\ApshawaSouth\3_HydroAnalysis\3_Modeling\3_Data\Apshawa.mxd, Time:5/26/2021 3:54:08 PM

Figure 7. UFA groundwater wells locations.

Apshawa Lake HSPF Model Update

In addition to extending the input time series of rainfall, PET, and UFA groundwater levels, the HSPF model was updated to address the peer review's comments of the original model. A major comment of the peer review concerned the interaction between UFA and the lakes.

Apshawa Lakes and UFA Groundwater Interaction

In the HSPF model, the interaction between the lakes and UFA was computed in the Special Action block of HSPF using Darcy's equation:

$$\mathrm{Q} = k\frac{\Delta \mathrm{h}}{\mathrm{L}}A \qquad \text{Equation (1)}$$

Where:

Q : seepage flow

k : hydraulic conductivity

Δh : head difference between lake and UFA

L : length of the material through which water seeps from the lake to the UFA

A : cross-section area of material through which water seeps from the lake to the UFA

In the original model, A and L are assumed constant. Then, equation 1 is rewritten as:

$$Q = \mathrm{K}\Delta h \qquad \text{Equation (2)}$$

Where:

K = kA/L is a constant calibration parameter and referred to as hydraulic conductance.

In the updated model, only L is a constant and lamped with k. Equation 1 is rewritten as:

$$\mathrm{Q} = K\Delta \mathrm{h}A \qquad \text{Equation (3)}$$

Where:

K = k/L is a calibration parameter and referred to as leakance. Furthermore, the K value in the updated model varies depending of the level and area of the lake.

Updated Apshawa Lake Model Calibration and Verification

All parameters in the original HSPF model were kept the same except the leakance K values. The K values were varied based on two lake levels for both Apshawa South and Apshawa North lakes. The final calibrated K values of Apshawa South Lake are 0.0015 and 0.0018 for lake level above and below 84 ft, NAVD, respectively. The resulted K values of Apshawa North are 0.0028 and 0.0030 for lake level above and below 84 ft, NAVD.

The calibration period (1/1/2005 – 12/31/2016) and verification period (1/1/1994 – 12/31/2005) were kept like the original model. The results of both calibration and verification are very similar to the original model. Tables 5 and 6 display water balance summary of land segments for calibration and verification, respectively. Figures 8 and 9 are the simulation results of the calibration for Apshawa Lake South and Apshawa Lake North, respectively. Figures 10 and 11 show the verification results of Apshawa Lake South and Apshawa Lake North, respectively.

During the historic drought 2000-2002 in the verification period, simulated stages at Apshawa Lake South were much lower than observed values. The gage on Apshawa Lake South is located at the end of a canal off the lake. Robinson (2015) stated the canal has an invert elevation of 79.4 ft NAVD 88. During the drought of 2000 to 2002, the lake stage dropped below the invert elevation and readings stayed around 79.4 ft NAVD88. Tables 7 and 8 present summaries of annual lake water budget for Apshawa Lake South and Apshawa Lake North, respectively.

Table 5. Calibration water balance summary of land segments, inch.

Land Segment	Precipitation (SUPY)	Potential ET (PET)	Total Actual ET (TAET)	Total Outflow (PERO)	Surface Outflow (SURO)	Inactive GW Inflow (IGWI)	Active GW Inflow (AGWI)
Low Density Residential-A	45.97	59.82	33.23	7.68	0.51	5.15	8.05
Pasture-A	45.97	59.82	33.57	7.31	0.20	5.18	8.10
Agriculture-A	45.97	59.82	33.25	7.45	0.11	5.37	8.40
Groves-A	45.97	59.82	33.25	7.45	0.10	5.37	8.40
Range/Shrub-A	45.97	59.82	35.04	6.44	0.21	4.60	7.19
Forest-A	45.97	59.82	35.44	6.12	0.03	4.57	7.16
Composite	45.97	59.82	40.11	2.13	0.54	3.94	6.16
Low Density Residential-A/D	45.97	59.82	34.19	7.19	0.92	4.69	7.33
Pasture-A/D	45.97	59.82	34.44	6.83	0.40	4.80	7.51
Agriculture-A/D	45.97	59.82	34.11	6.95	0.22	5.01	7.84
Groves-A/D	45.97	59.82	34.11	6.95	0.21	5.02	7.85
Range/Shrub-A/D	45.97	59.82	35.79	6.03	0.42	4.26	6.66
Pasture-C	45.97	59.82	38.07	5.37	2.11	2.68	4.19
Groves-C	45.97	59.82	38.54	4.93	1.71	2.67	4.17

Table 6. Verification water balance summary of land segments, inch

Land Segment	Precipitation (SUPY)	Potential ET (PET)	Total Actual ET (TAET)	Total Outflow (PERO)	Surface Outflow (SURO)	Inactive GW Inflow (IGWI)	Active GW Inflow (AGWI)
Low Density Residential-A	50.63	59.38	34.08	10.16	0.77	6.35	9.93
Pasture-A	50.63	59.38	34.45	9.60	0.24	6.53	10.22
Agriculture-A	50.63	59.38	34.17	9.67	0.12	6.75	10.55
Groves-A	50.63	59.38	34.17	9.66	0.11	6.75	10.56
Range/Shrub-A	50.63	59.38	35.79	8.81	0.26	6.00	9.38
Forest-A	50.63	59.38	36.12	8.44	0.03	6.06	9.48
Composite	50.63	59.38	40.99	4.44	0.90	5.25	8.21
Low Density Residential-A/D	50.63	59.38	34.94	9.85	1.63	5.81	9.09
Pasture-A/D	50.63	59.38	35.30	9.18	0.61	6.11	9.56
Agriculture-A/D	50.63	59.38	35.08	9.17	0.31	6.35	9.93
Groves-A/D	50.63	59.38	35.08	9.16	0.29	6.35	9.93
Range/Shrub-A/D	50.63	59.38	36.52	8.47	0.66	5.60	8.77
Pasture-C	50.63	59.38	38.65	8.53	3.95	3.44	5.38
Groves-C	50.63	59.38	39.20	7.94	3.33	3.47	5.43

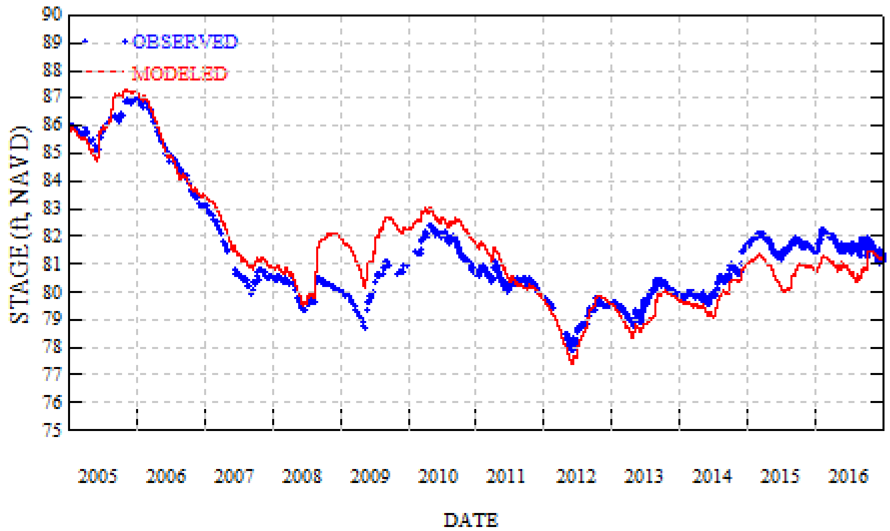


Figure 8. Observed and simulated stages at Apshawa Lake South for model calibration.

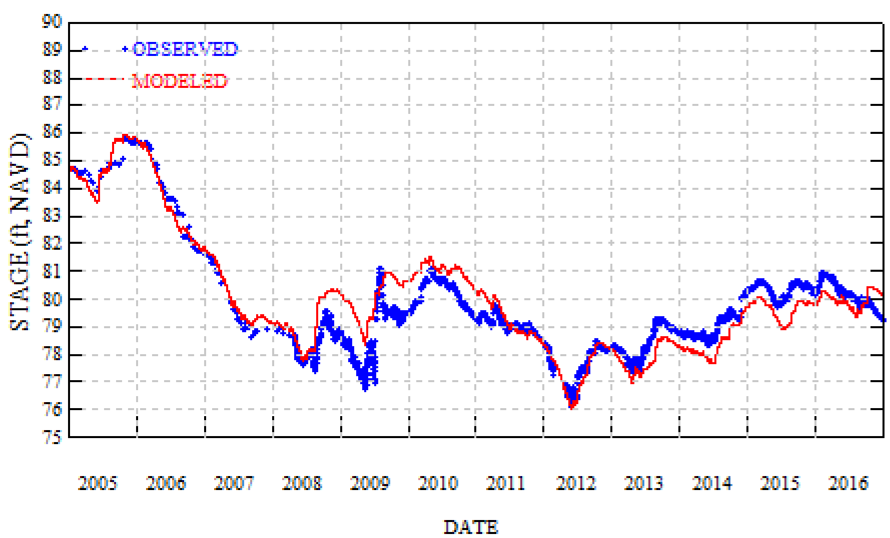


Figure 9. Observed and simulated stages at Apshawa Lake North for model calibration.

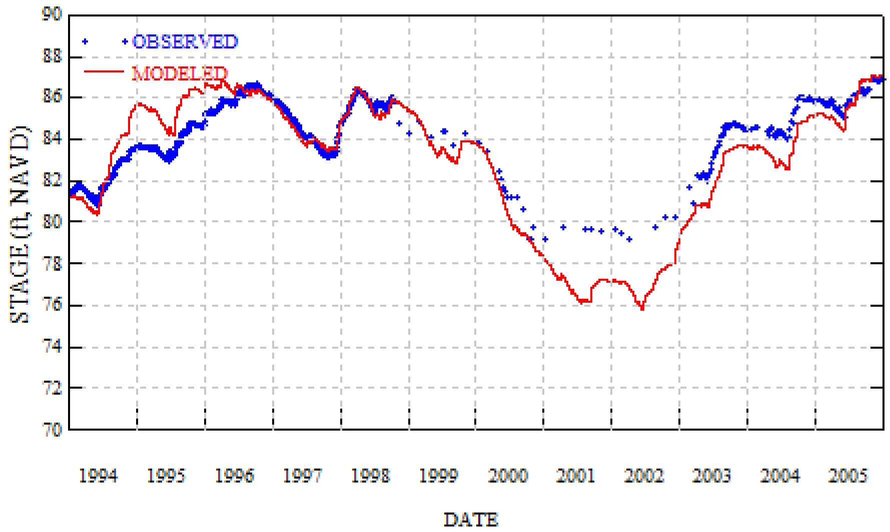


Figure 10. Observed and simulated Stages at Apshawa South for model verification.

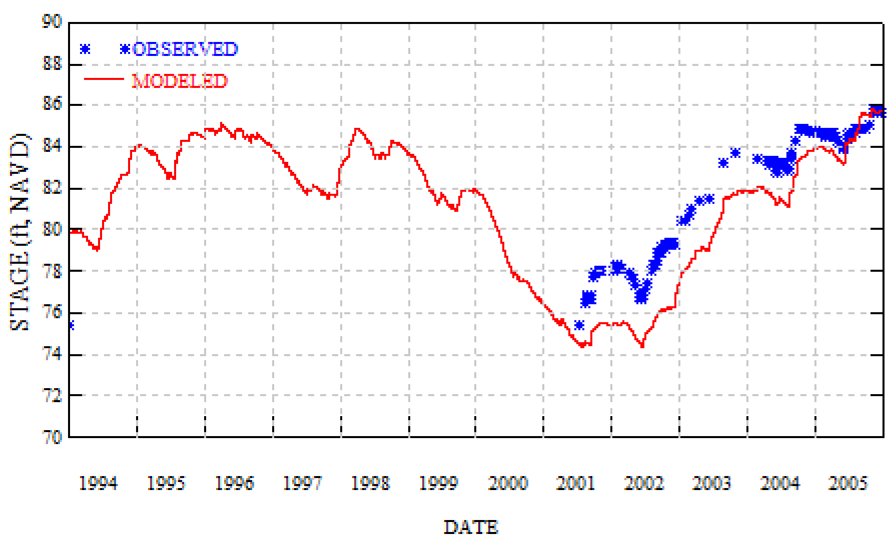


Figure 11. Observed and simulated stages at Apshawa North for model verification.

Table 7. Estimated annual water budget of Apshawa Lake South, acre-ft.

Year	ΔVolume	Inflows		Outflows			
		Rainfall	Runoff	ET	Vertical Seepage	Lateral Seepage	Embankment Flows
1995	46.98	338.09	269.48	370.54	189.98	0.073	0.000
1996	-34.66	342.66	200.61	386.88	190.97	0.075	0.000
1997	-76.24	302.83	145.39	329.62	194.76	0.080	0.000
1998	46.76	304.24	269.46	378.09	148.78	0.069	0.000
1999	-112.10	271.59	163.14	333.82	212.93	0.080	0.000
2000	-313.31	95.73	47.99	299.30	157.65	0.081	0.000
2001	-48.31	122.59	95.38	199.08	67.12	0.074	0.000
2002	102.85	174.45	148.78	198.57	21.74	0.066	0.000
2003	252.28	271.70	288.52	296.34	11.52	0.077	0.000
2004	109.82	297.19	220.42	328.88	78.84	0.062	0.000
2005	103.57	385.28	251.94	384.64	148.78	0.054	0.176
2006	-284.39	202.56	72.97	373.77	186.03	0.066	0.053
2007	-156.80	191.38	103.56	284.08	167.59	0.073	0.000
2008	60.98	231.81	229.53	269.75	130.53	0.073	0.000
2009	17.27	238.26	199.51	290.19	130.24	0.073	0.000
2010	-31.27	234.22	149.60	299.43	115.60	0.063	0.000
2011	-108.47	181.59	98.13	278.07	110.06	0.060	0.000
2012	-9.03	163.13	145.75	233.35	84.50	0.059	0.000
2013	6.22	190.41	145.40	242.10	87.43	0.058	0.000
2014	72.15	232.21	172.79	257.95	74.84	0.058	0.000
2015	-12.68	184.16	128.66	282.17	43.28	0.047	0.000
2016	17.95	220.25	149.54	288.92	62.88	0.042	0.000
Average	-15.93	235.29	168.03	300.25	118.91	0.07	0.01

Table 8. Estimated annual budget of Apshawa Lake North, acre-ft.

Year	ΔVolume	Inflows				Outflows	
		Rainfall	Runoff	Lateral Seepage	Embankment Flows	ET	Vertical Seepage
1995	18.09	179.54	144.78	0.073	0.000	195.98	110.32
1996	-20.07	174.59	107.2	0.075	0.000	197.07	104.87
1997	-41.35	166.38	76.41	0.080	0.000	179.89	104.33
1998	29.58	160.87	145.51	0.069	0.000	198.66	78.21
1999	-69.37	151.28	86.31	0.080	0.000	184.58	122.46
2000	-173.23	54.1	24.8	0.081	0.000	169.16	83.05
2001	-18.35	74.86	49.62	0.074	0.000	120.91	22.00
2002	81.66	106.69	77.93	0.066	0.000	122.25	-19.22
2003	196.81	154.28	153.46	0.077	0.000	167.79	-56.79
2004	84.35	169.5	116.25	0.062	0.000	186.86	14.60
2005	44.26	206.07	134.01	0.054	0.176	205.92	90.13
2006	-162.33	110.88	38.13	0.066	0.053	201.89	109.57
2007	-94.23	109.37	54.23	0.073	0.000	162.48	95.43
2008	35.92	132.74	121.08	0.073	0.000	154.42	63.55
2009	15.22	136.36	105.45	0.073	0.000	166.23	60.44
2010	-11.81	135.87	79.08	0.063	0.000	173.76	53.06
2011	-62.15	106.13	51.29	0.060	0.000	162.54	57.09
2012	-5.60	98.11	76.72	0.059	0.000	139.57	40.92
2013	2.98	113.24	75.99	0.058	0.000	143.66	42.65
2014	48.34	136.61	90.79	0.058	0.000	151.69	27.43
2015	6.88	110.08	67.18	0.047	0.000	168.31	2.12
2016	11.43	132.42	78.71	0.042	0.000	173.6	26.14
Average	-3.77	132.73	88.86	0.07	0.01	169.42	56.02

APSHAWA LAKE LONG-TERM SIMULATION

MFL analysis required long-term lake levels to capture the effect of short- and long-term climatic variations on lake levels. After the calibrated Dynamic Solutions HSPF model (Dynamic Solution, 2019) was updated, based on the peer review comments, the model simulation period was then extended from 1959 to 2018 with the previously described extended rainfall, potential evapotranspiration, and groundwater level data. The extended long-term L-0001 UFA groundwater levels were used to compute the exchange of flows between the UFA and Apshawa Lake in the model.

Historical Long-term Lake Levels

The long-term simulation model covers a period from 1/27/1959 to 12/31/2018. Figures 12 and 13 show comparisons of simulated and available observed long-term stages of Apshawa Lake South and Apshawa Lake North, respectively. Tables 9 and 10 present summary statistics of the long-term historical stage simulations for Apshawa Lake South and Apshawa Lake North, respectively. It should be noted that there are a lot of missing observed data; moreover, observed data of Apshawa Lake North starts from 7/10/2001.

Table 9. Apshawa Lake South stage (ft, NAVD) summary statistics for long-term historical simulation.

Statistical Parameter	Observed	Simulated
Mean	82.87	83.32
Standard Error	0.02	0.02
Median	82.97	83.46
Standard Deviation	2.01	2.66
Range	13.50	14.29
Minimum	77.91	75.86
Maximum	91.41	90.15
Count	10125.00	21889.00
Confidence Level(95.0%)	0.04	0.04

Table 10. Apshawa North stage (ft, NAVD) summary statistics for long-term historical simulation.

Statistical Parameter	Observed	Simulated
Mean	79.32	81.58
Standard Error	0.02	0.02
Median	79.26	81.69
Standard Deviation	1.37	2.50
Range	10.46	12.87
Minimum	75.37	74.35
Maximum	85.83	87.22
Count	3306.00	21889.00
Confidence Level(95.0%)	0.05	0.03

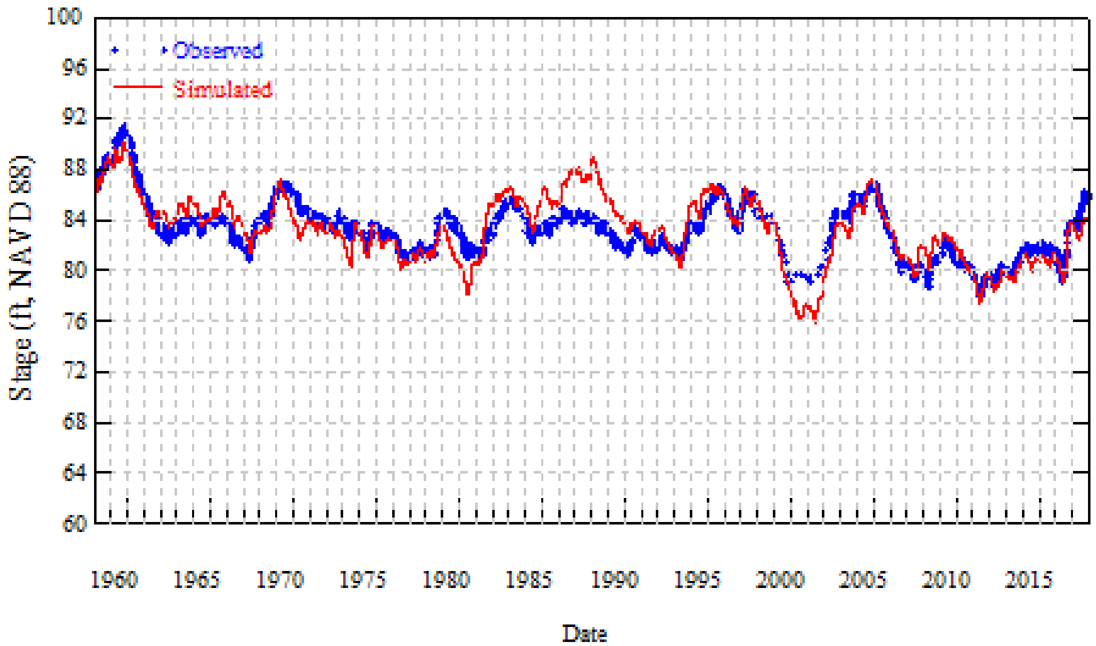


Figure 12. Comparisons of long-term simulation and observed stages at Apshawa South.

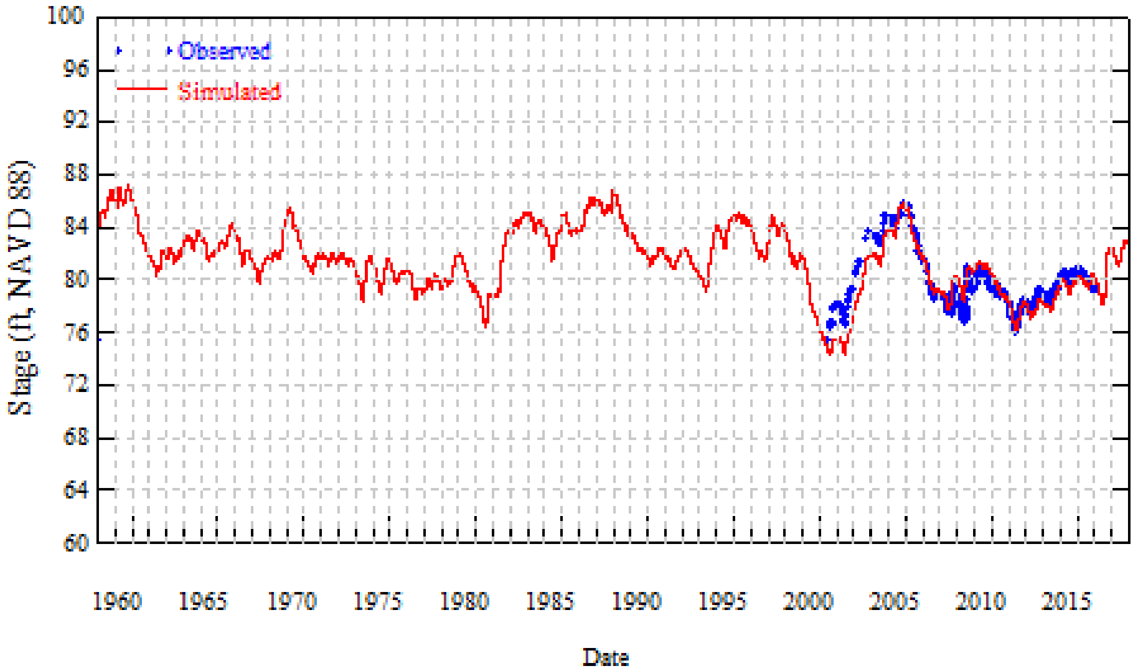


Figure 13. Comparisons of long-term simulation and available observed stages at Apshwa North.

DEVELOPMENT OF NO-PUMPING AND CURRENT PUMPING LAKE LEVELS

The objective of the MFLs status assessment is to determine whether the Apshawa Lake minimum levels are being achieved under the current pumping condition. Because of our limited understanding of possible future climatic conditions and significant uncertainties in predicting future lake levels using global climate model forecasts, historical lake levels are considered the best available data and are adjusted for groundwater pumping impact to assess the current status of minimum levels.

The adjustment of historical lake levels required considering the effect of current groundwater pumping from the Upper Floridan Aquifer (UFA) on lake levels not only for the recent years but also for the entire period-of record from 1959 to 2018. Two sets of adjusted lake levels were developed, no-pumping condition and current-pumping condition lake levels. The no-pumping condition lake levels constituted a reference hydrologic condition in which lakes were not under the influence of any groundwater pumping from 1959 to 2018. The current-pumping condition lake levels represented a reference hydrologic condition in which lakes were under the influence of current groundwater pumping constantly from 1959 to 2018. The long-term HSPF model was used to simulate no-pumping condition and current-pumping condition lake levels, which required no-pumping and current pumping condition UFA levels as boundary conditions. The impact from pumping on the UFA near the lakes must first be determined using information extracted from a groundwater flow model to generate the no-pumping and current pumping condition UFA levels. This process involved performing a pumping impact analysis using simulated groundwater levels in the UFA beneath the lake under different simulated pumping conditions. Using this information, a pumping-drawdown relationship was developed for Apshawa Lake system, which was used to estimate impact from historical groundwater pumping. The no-pumping condition groundwater level dataset was developed by adding an estimate of impact due to historical pumping (i.e., the UFA drawdown due to pumping) to the observed/extended groundwater levels. The current-pumping condition groundwater level dataset was developed by subtracting an estimate of impact due to current pumping (average groundwater pumping from 2014-2018) from the no-pumping groundwater levels. No-pumping and current-pumping condition groundwater levels were later input into the HSPF model to simulate no-pumping and current-pumping condition lake levels. The process is illustrated in Figure 14.

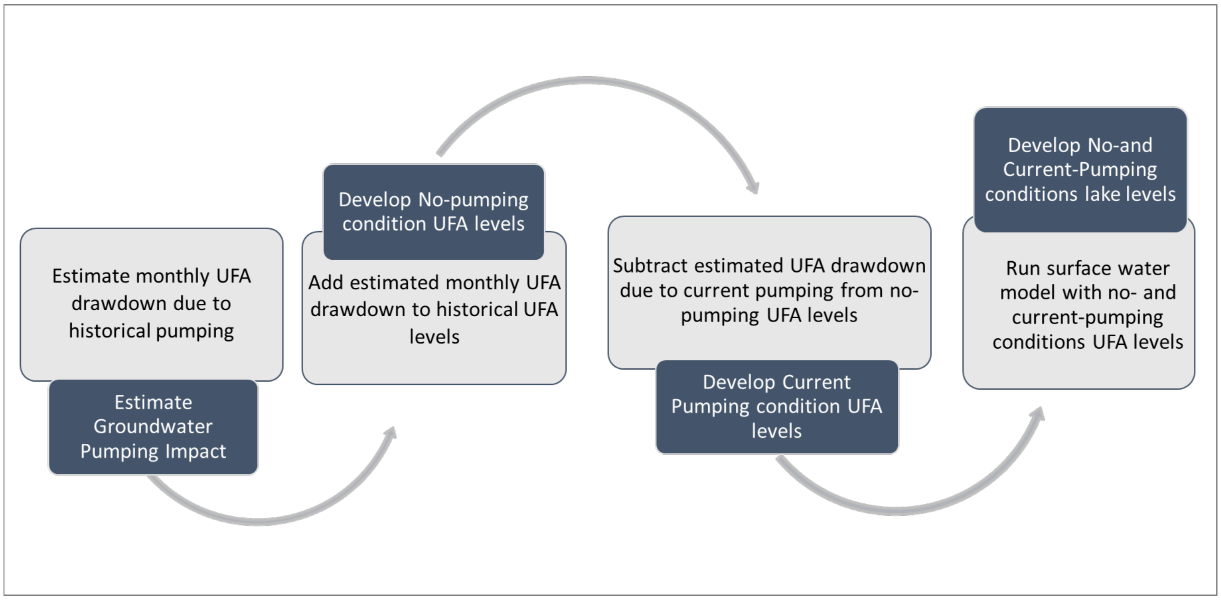


Figure 14. Flow chart illustrating the groundwater flow model pumping impact analysis and development of no pumping and current pumping conditions Upper Floridan Aquifer and lake levels for an MFL lake.

GROUNDWATER PUMPING IMPACT ASSESSMENT

The East-Central Florida Transient Expanded (ECFTX) groundwater flow model was developed by the Central Florida Water Initiative (CFWI) to support regional water supply planning and understand groundwater resource limitations for sustainable water supplies while protecting natural systems (CFWI HAT, 2020). The ECFTX model was recalibrated in 2022, referred to as ECFTX v2.0, to improve simulation of groundwater levels and flows within the Wekiva river basin (Gordu et al., 2022). ECFTX v2.0 was used for this pumping impact analysis. ECFTX v2.0 model consists of an initial stress period representing steady state conditions for the year 2003, followed by 132 monthly transient stress periods representing the years 2004 through 2014. The ECFTX v2.0 model domain and CFWI planning areas are shown in Figure 15.

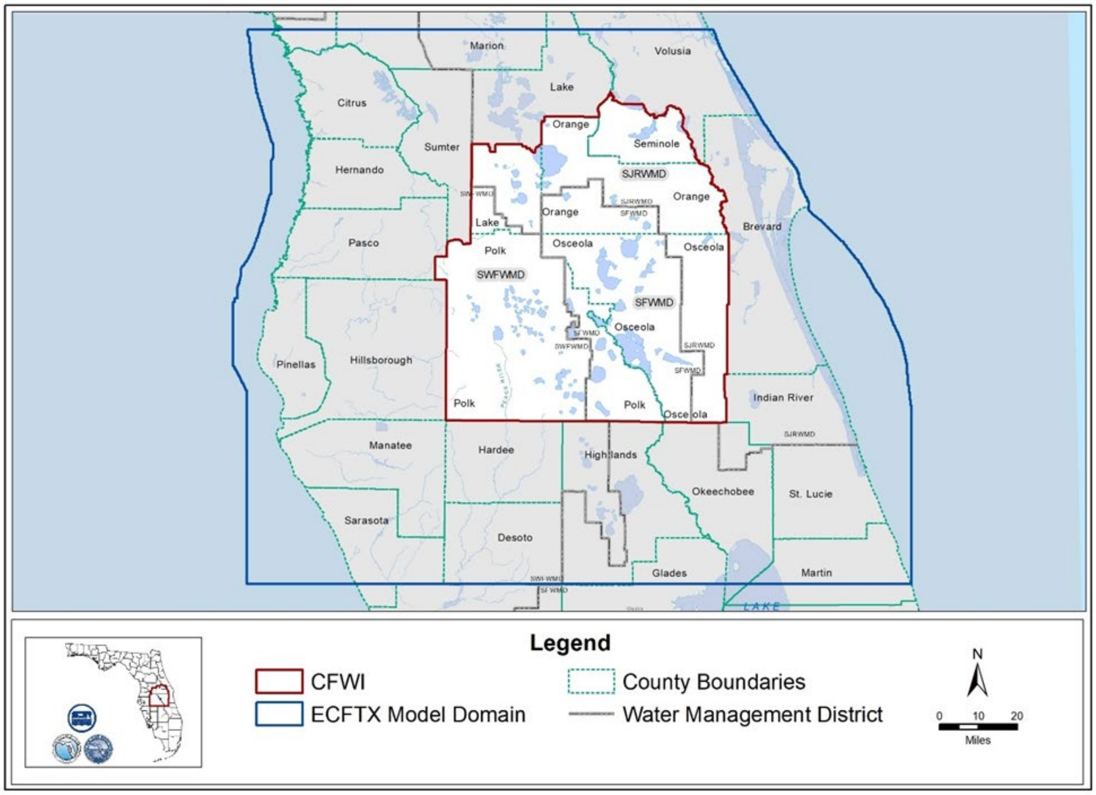


Figure 15. ECFTX v2.0 model domain boundary (blue) and CFWI planning area (red).

An estimate of daily Upper Floridan Aquifer (UFA) drawdown beneath Apshawa Lake resulting from regional pumping for the period of 1959 to 2018 was needed to develop the no-pumping condition UFA levels. Since the ECFTX model was not designed to simulate monthly conditions over this long-term period, a methodology was developed using available ECFTX model data to estimate the impact of regional pumping on groundwater levels outside of the model simulation period. This methodology included the development of a relationship between groundwater pumping and UFA drawdown beneath Apshawa Lake using the ECFTX v2.0 model. To develop this relationship, and capture a wide range of pumping conditions, the following model simulations were used:

- Pumping reduced by 50%
- Pumping reduced by 25%
- Calibration period condition
- Pumps off

For each simulation, the simulated UFA levels beneath Apshawa Lake were extracted from the ECFTX v2.0 model for each transient monthly stress period (2004 through 2014) by taking an average of the simulated UFA levels at model grid cells intersecting the lake boundary. For example, the impact for the calibration pumping condition was calculated by subtracting the simulated calibrated model UFA levels from the simulated pumps off UFA levels beneath Apshawa Lake for each transient stress period. This calculation was repeated for the 50% and 25% reduced pumping scenarios. This resulted in 132 simulated impact values for each pumping scenario, corresponding to each month in the transient simulation. Groundwater pumping information was also extracted from the ECFTX model for the calibration, 25% reduced pumping and 50% reduced pumping scenarios to develop pumping-drawdown relationship. Groundwater pumping within close proximity of the lake would have a direct impact on the groundwater levels beneath Apshawa Lake. To develop the relationship and estimate the pumping impact from 1959 to 2018, we tested three buffer zones within 10-, 20- and 30- mile radius of Apshawa Lake. Figure 16 shows the extents of the boundaries used in the groundwater pumping impact assessment at Apshawa Lake. It should be noted that groundwater pumping within a buffer area was considered as a proxy to develop the relationship and capture the variation of regional pumping over time. The impact of groundwater pumping on lake levels was assessed based on all groundwater pumping within the groundwater model domain.

For each scenario, the total pumping in model layers 3 through 11 (Upper UFA to LFA) was extracted from the buffer area shown in Figure 16 and summarized for each transient monthly stress period in the model. The modelled impact and pumping data for each scenario and transient stress period were combined into a single table, yielding a total of 396 pumping-impact paired data values to use to fit a relationship between impact and groundwater pumping. A simple linear regression was fit to the dataset where modelled impact (response variable) and groundwater pumping (predictor variable) data at Apshawa Lake. Figures 17 - 22 show the linear relationship between UFA impact and groundwater pumping within the 10-, 20- and 30-mile radius of Apshawa Lake. A strong linear relationship (R^2 = 0.91- 0.96) existed between UFA impact and groundwater pumping within the three buffers of the lake.

To evaluate the performance of pumping-drawdown relationships for determining the most appropriate buffer to use for the final analysis, the impact from the average 2014-2018 pumping was calculated by inputting the average 2014-2018 pumping rate to each linear regression equation shown in Figures 17 - 22 and compared with the average 2014-2018 model simulation drawdown in the UFA beneath the lake. Table 11 includes the average 2014 to 2018 pumping and estimated impact from pumping drawdown relationships developed for each buffer area. At Apshawa Lake North, the 30-mile simulated current pumping impact was calculated to be 1.44 feet and was the closest value to the ECFSSX v2.0 model impact of 1.44 feet. At Apshawa Lake South, the 30-mile simulated current pumping impact was calculated to be 1.44 feet and was the closest value to the ECFSSX v2.0 model impact of 1.42 feet.

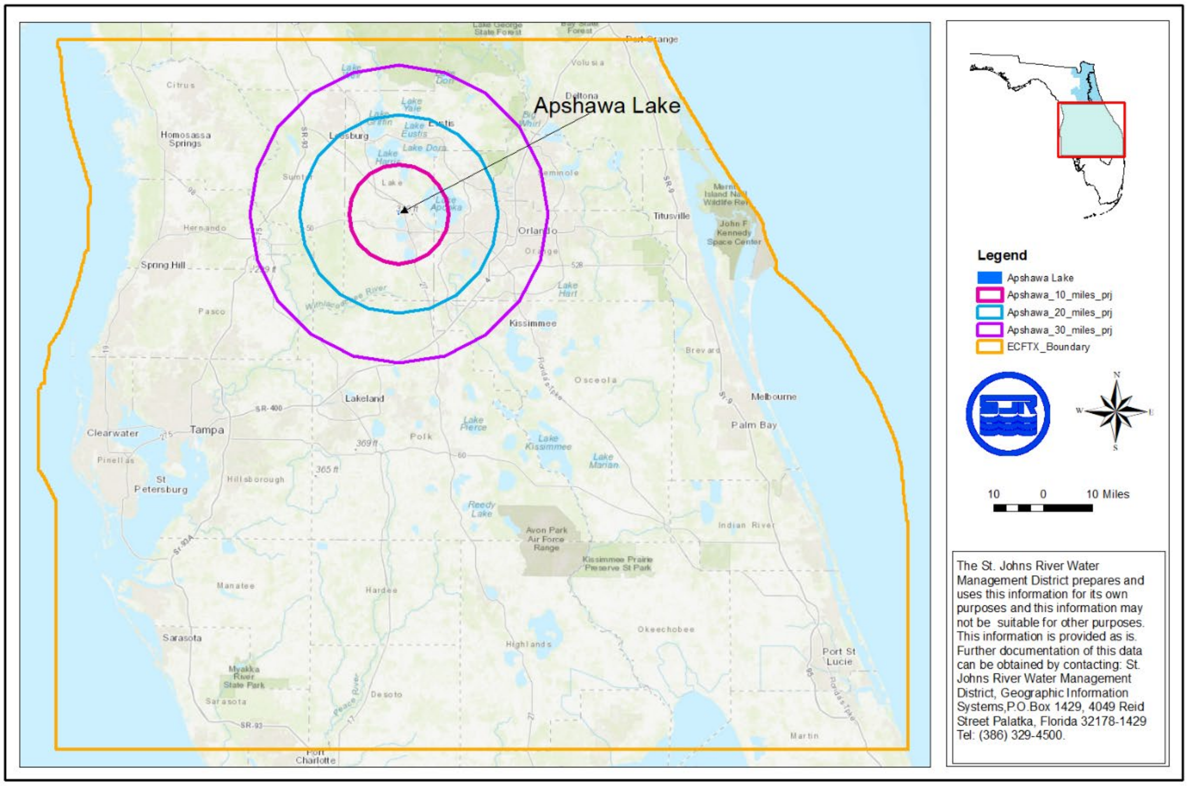


Figure 16. Apshawa Lake 10, 20, 30-mile buffer zone.

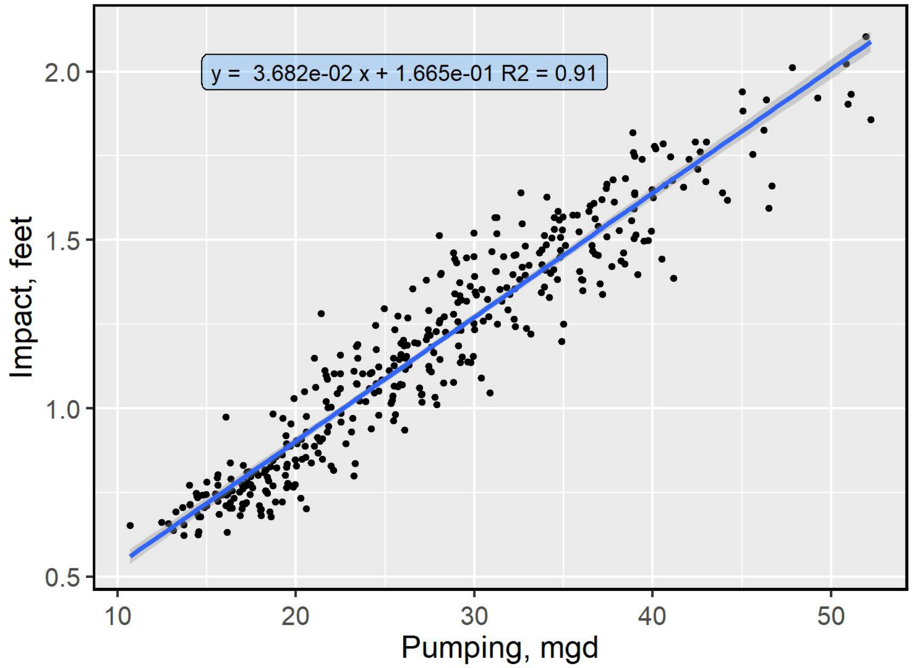


Figure 17. Linear regression between UFA drawdown near Apshawa Lake and groundwater pumping within Apshawa Lake North 10-mile buffer area.

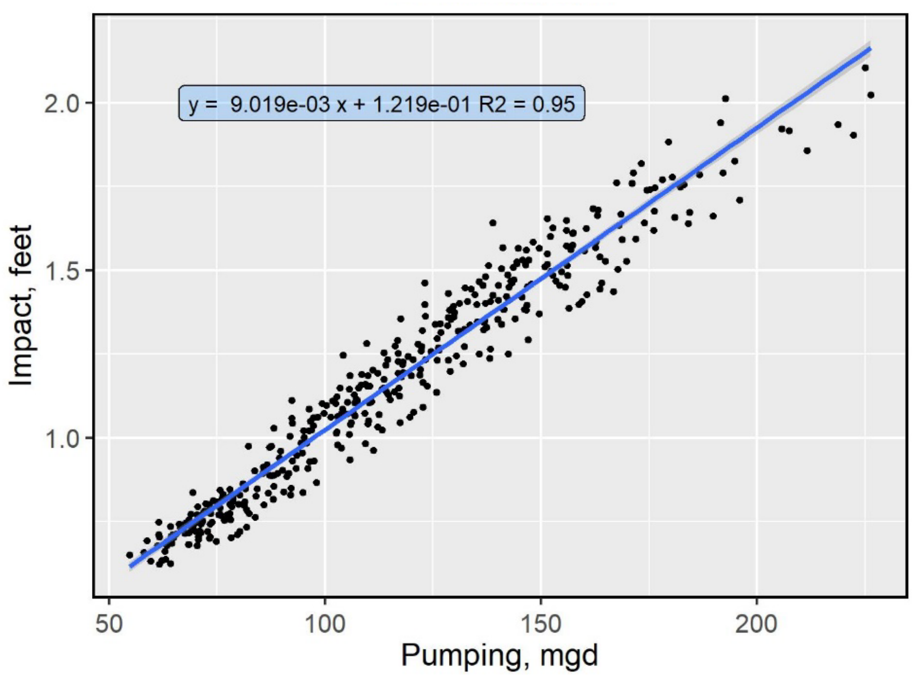


Figure 18. Linear Linear regression between UFA drawdown near Apshawa Lake and groundwater pumping within Apshawa Lake North 20-mile buffer area.

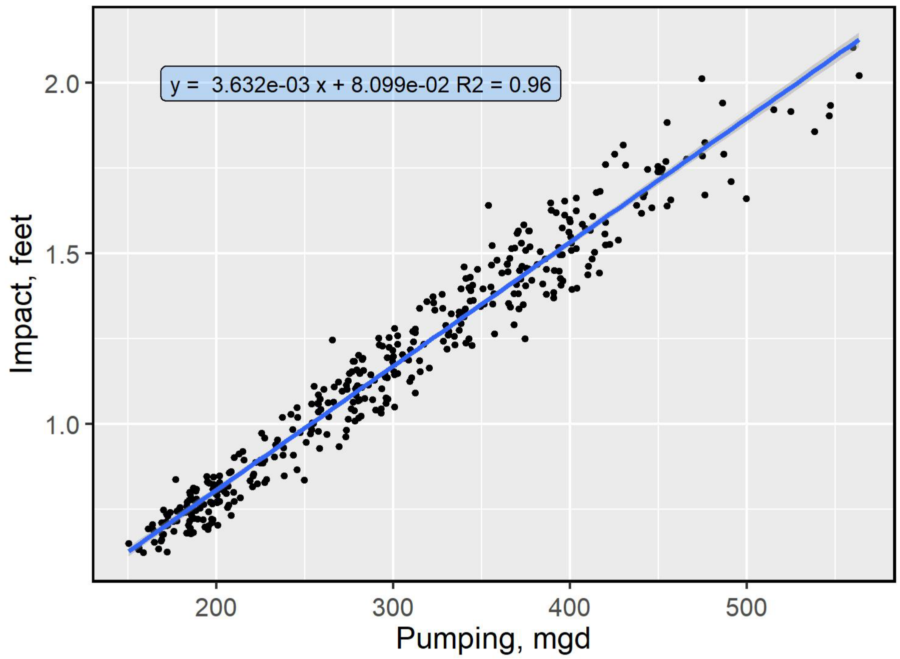


Figure 19. Linear regression between UFA drawdown near Apshawa Lake and groundwater pumping within Apshawa Lake North 30-mile buffer area.

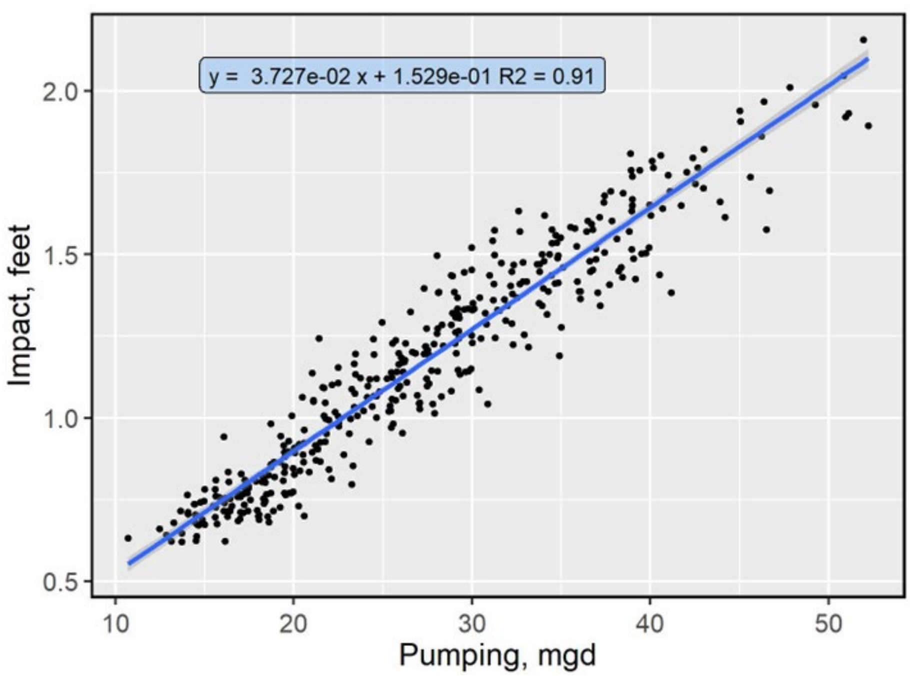


Figure 20. Linear regression between UFA drawdown near Apshawa Lake and groundwater pumping within Apshawa Lake South 10-mile buffer area.

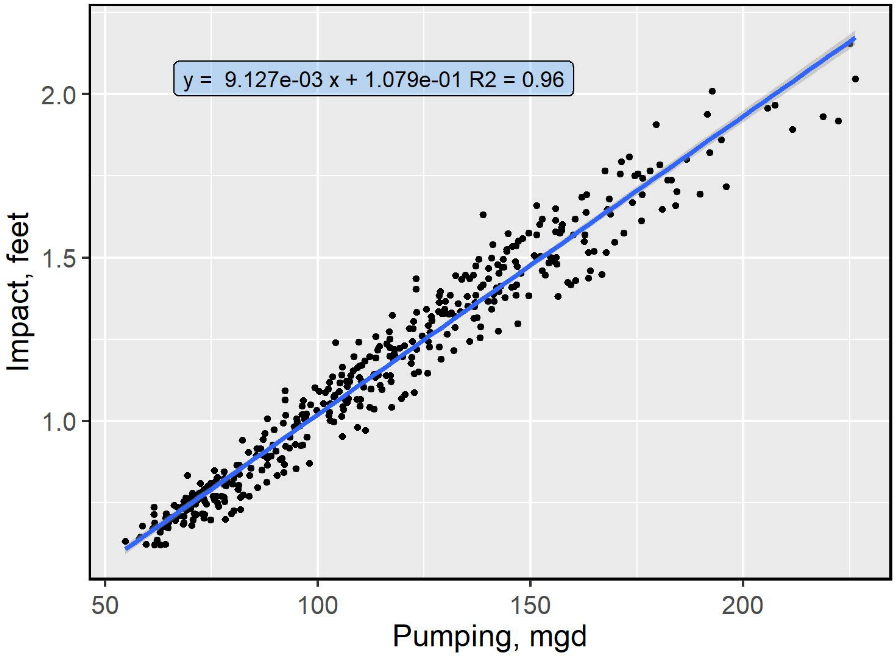


Figure 21. Linear regression between UFA drawdown near Apshawa Lake and groundwater pumping within Apshawa Lake South 20-mile buffer area.

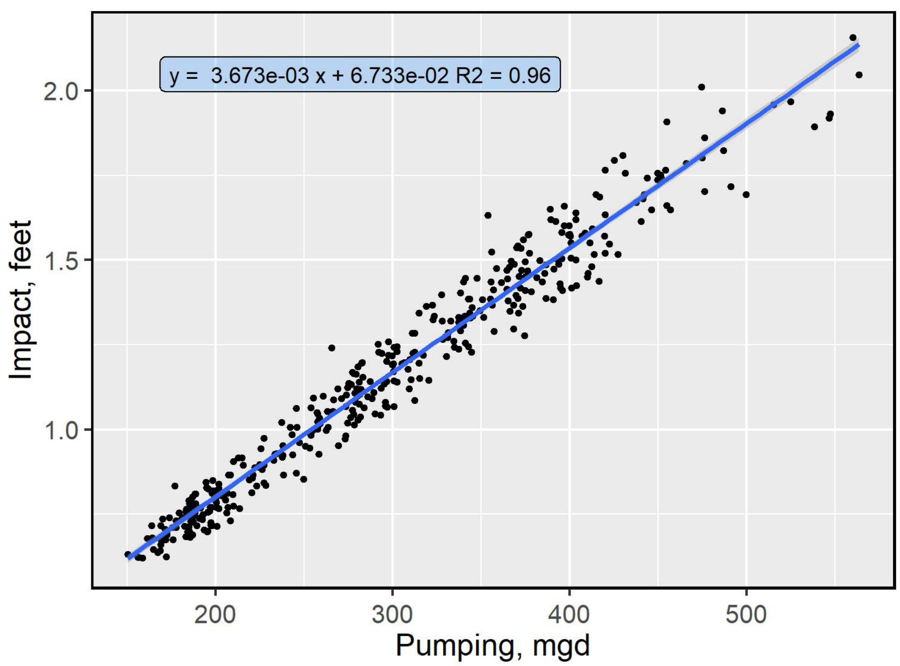


Figure 22. Linear regression between UFA drawdown near Apshawa Lake and groundwater pumping within Apshawa Lake South 30-mile buffer area.

Table 11. Estimated impact from average 2014 to 2018 pumping in the model for the 10, 20, and 30-mile buffer areas compared with model simulated impact.

Lake	Buffer	AVG 2014-2018 Q (MGD)	Regression CP Impact (ft)	ECFSSX v2.0 CP Impact (ft)
Apshawa North	10-mile	33.05	1.38	1.44
Apshawa North	20-mile	138.53	1.37	1.44
Apshawa North	30-mile	373.53	1.44	1.44
Apshawa South	10-mile	33.05	1.38	1.42
Apshawa South	20-mile	138.53	1.37	1.42
Apshawa South	30-mile	373.53	1.44	1.42

GROUNDWATER USE

To estimate the impact on groundwater levels from historical pumping, monthly groundwater use data was compiled or estimated at all stations within a 30-mile radius of the Apshawa Lake centroid from 1930 to 2018. It should be noted that the groundwater pumping within the buffer zone was only used as a proxy to understand the variation of regional groundwater pumping from 1930 to 2018. The impact of groundwater pumping on lake levels was assessed based on all groundwater pumping within the groundwater model domain.

The groundwater pumping data was estimated from 1929 through 2018 using the data available from different sources. The pumping data from 1995 to 2014 was from the Central Florida Water Initiative (CFWI) regional water supply plan which was a collective effort between water management districts and stakeholders. Data for 2015 to 2018 was from the SJRWMD historical water use database with actual monthly use and station-level details. The data from 1965 to 1995 were based on the United States Geological Service (USGS) published county-level water use (available every five years starting in 1965) and the annual SJRWMD county-level Annual Water Use Survey (AWUS), starting in 1978. Using these two sources, the water use data was aggregated to the county for every five years and some years in between from 1965. Any missing years for each county were estimated using an exponential growth assumption to create a complete aggregate table. If the USGS and AWUS estimates do not match, the published AWUS data were used. To estimate annual groundwater use by county for the period before 1965, per capita groundwater use was estimated for each county. Multiplying the 1965 per capita water use by the historic county-level population from U.S. Census, the annual groundwater uses by county were estimated for the period before 1965. The U.S. Census data was reported in 10-year intervals. An exponential growth was assumed to estimate the annual population between 10-year intervals. The 1995 proportion of county water use captured in the buffer lake domain was multiplied to the county aggregate from 1929 to 1994 to estimate the water use within Apshawa Lake buffer zone (Figure 23). To disaggregate the annual data to monthly groundwater use, the average monthly proportions by county, estimated from the monthly SJRWMD database from 2004 to 2014, were applied to the annual data. Figure 10 shows the monthly estimated groundwater use in Apshawa Lake 30-miles buffer zone from 1929 to 2018.

The linear regression equation derived for 30-mile buffer shown in Figures 6 and 9 were used to calculate a monthly historical impact from long-term (1959 to 2018) estimated monthly pumping data within each the buffer area. The monthly estimated historical impact due to pumping was disaggregated to a daily time series extending from 1959 to 2018 using linear interpolation. The daily estimated historical impact from pumping at Apshawa Lake 30-mile buffer area for the period of 1959 to 2018 is shown in Figure 24.

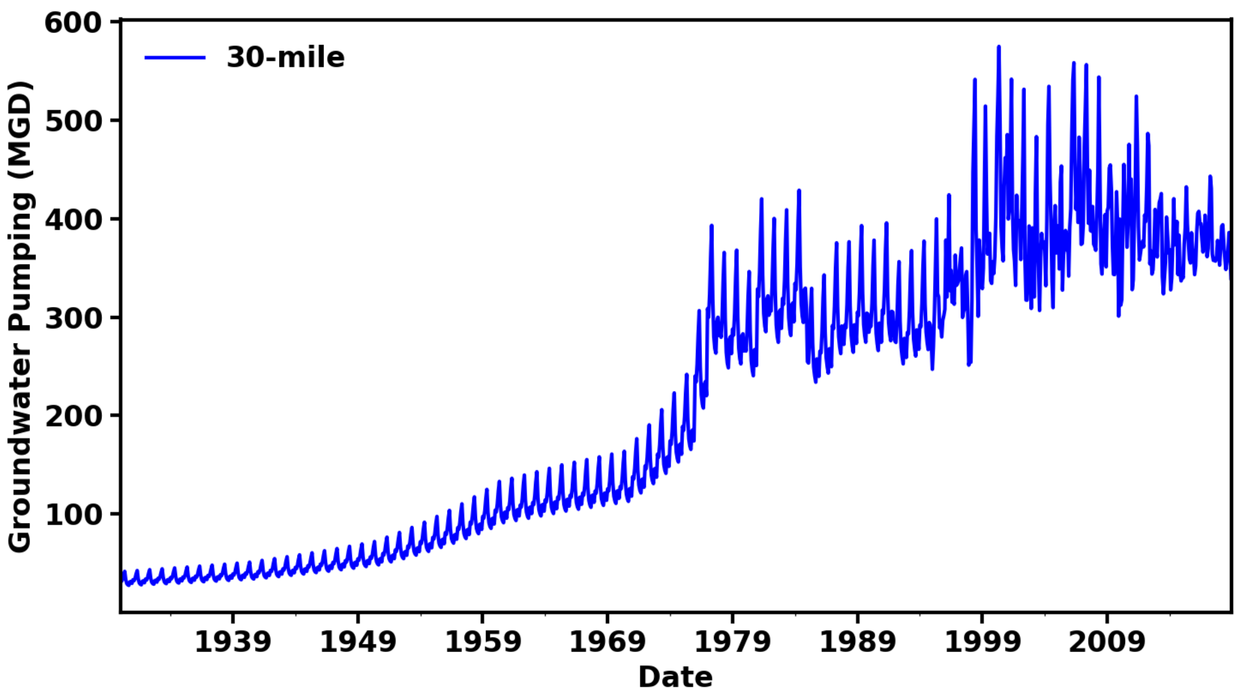


Figure 23. Estimated historical groundwater use in Apshawa Lake 30-mile buffer area.

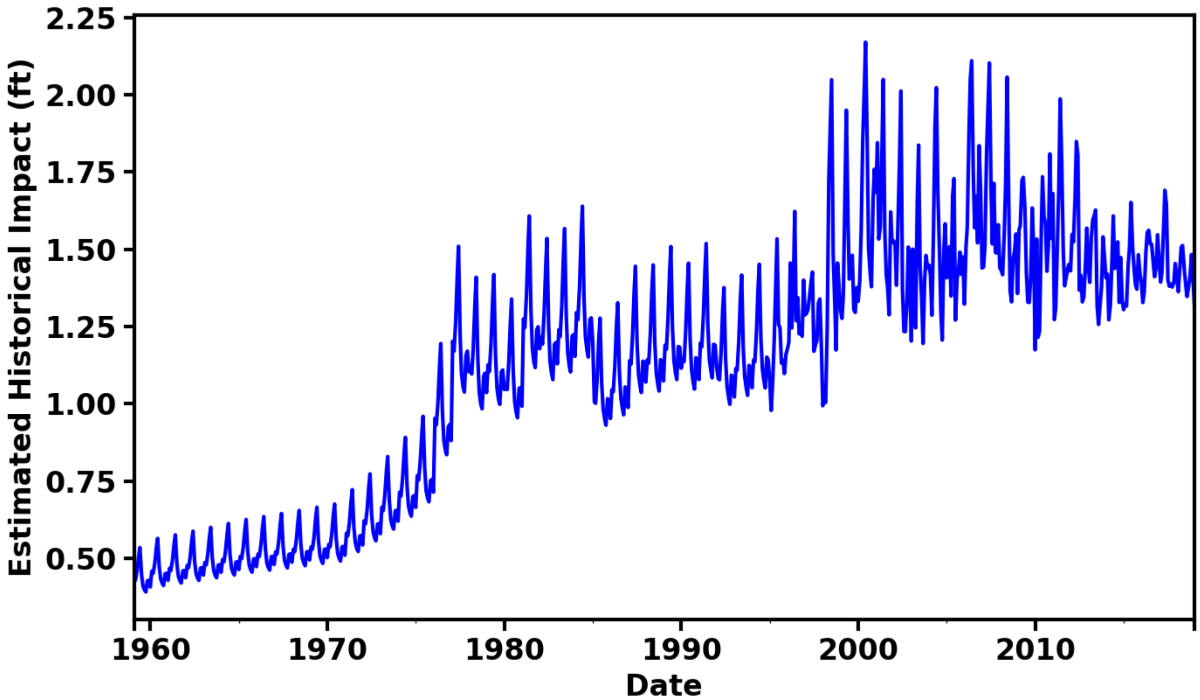


Figure 24. Daily estimated total historical impact from pumping on UFA levels near Apshawa Lake.

NO-PUMPING CONDITION GROUNDWATER LEVELS

The daily estimated impacts from pumping shown in Figure 24 were directly added to the daily historical, composed of observed and /estimated, groundwater levels near Apshawa Lake available from 1959 to 2018 to create the no-pumping condition groundwater level dataset for Apshawa Lake.

CURRENT-PUMPING CONDITION GROUNDWATER LEVELS

To generate the current pumping condition groundwater levels, the average 2003 to 2014 steady-state version of the ECFTX v2.0 model (referred to as ECFSSX v2.0) was used. The impact from average pumping from 2014 to 2018 was calculated by subtracting the steady-state simulated UFA level at Apshawa Lake under average 2014 to 2018 pumping rates and return flows in the model from the steady-state simulated groundwater levels with no pumping or return flows in the model. The simulated impact from current pumping at Apshawa Lake North and South is 1.44 feet.

The current pumping impact was then subtracted from the no pumping condition groundwater levels to generate the current pumping condition groundwater levels for the long-term period of 1959 to 2018. Figures 25 and 26 show the daily no-pumping and current-pumping condition groundwater levels for Apshawa Lake for the 30-mile buffer area, respectively.

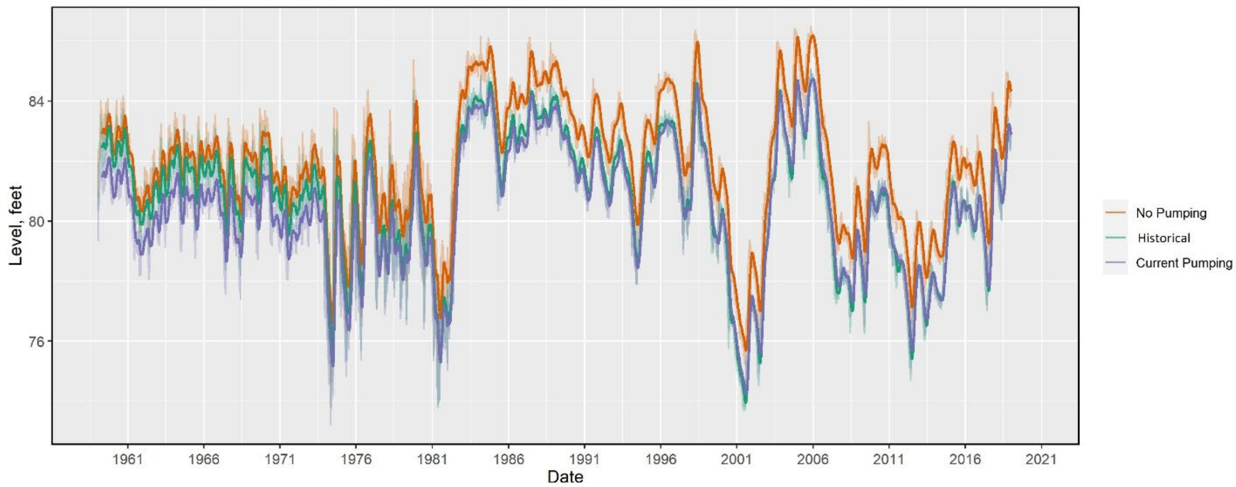


Figure 25. Historical, no-pumping, and current-pumping UFA levels near Apshawa Lake from groundwater use within 30-mile buffer of Apshawa Lake North.

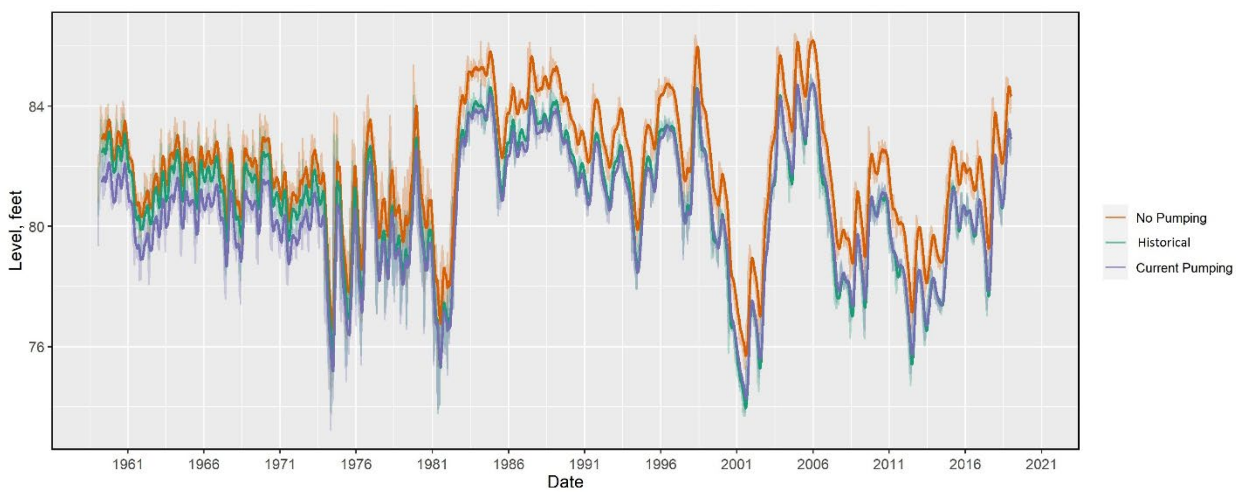


Figure 26. Historical, no-pumping, and current-pumping UFA levels near Apshawa Lake from groundwater use within 30-mile buffer of Apshawa Lake South.

LAKE LEVEL DATASETS FOR MFL ANALYSIS

The no-pumping and current-pumping Apshawa South and Apshawa North levels were simulated by inputting the no-pumping and current-pumping groundwater levels (Figures 25 and 26) to the long-term HSPF simulation model. However, because sufficient observed long-term lake levels were available for Apshawa South, the no-pumping and current-pumping Apshawa South levels were generated using long-term observed dataset instead of historical simulated lake levels as follows:

1. Calculate the difference between the simulated historical and the no-pumping lake levels (D1)
2. Add the difference (D1) to the historical observed lake levels to generate no-pumping lake levels (NP1)
3. Calculate the difference between the simulated no-pumping and the current-pumping lake levels (D2)
4. Subtract the difference (D2) from the no-pumping lake levels (NP1) to generate current-pumping lake levels.

Figures 27 and 28 show the no-pumping and current-pumping Apshawa South and Apshawa North levels, respectively. Tables 12 and 13 describe the statistics for the Apshawa South and Apshawa North datasets, respectively.

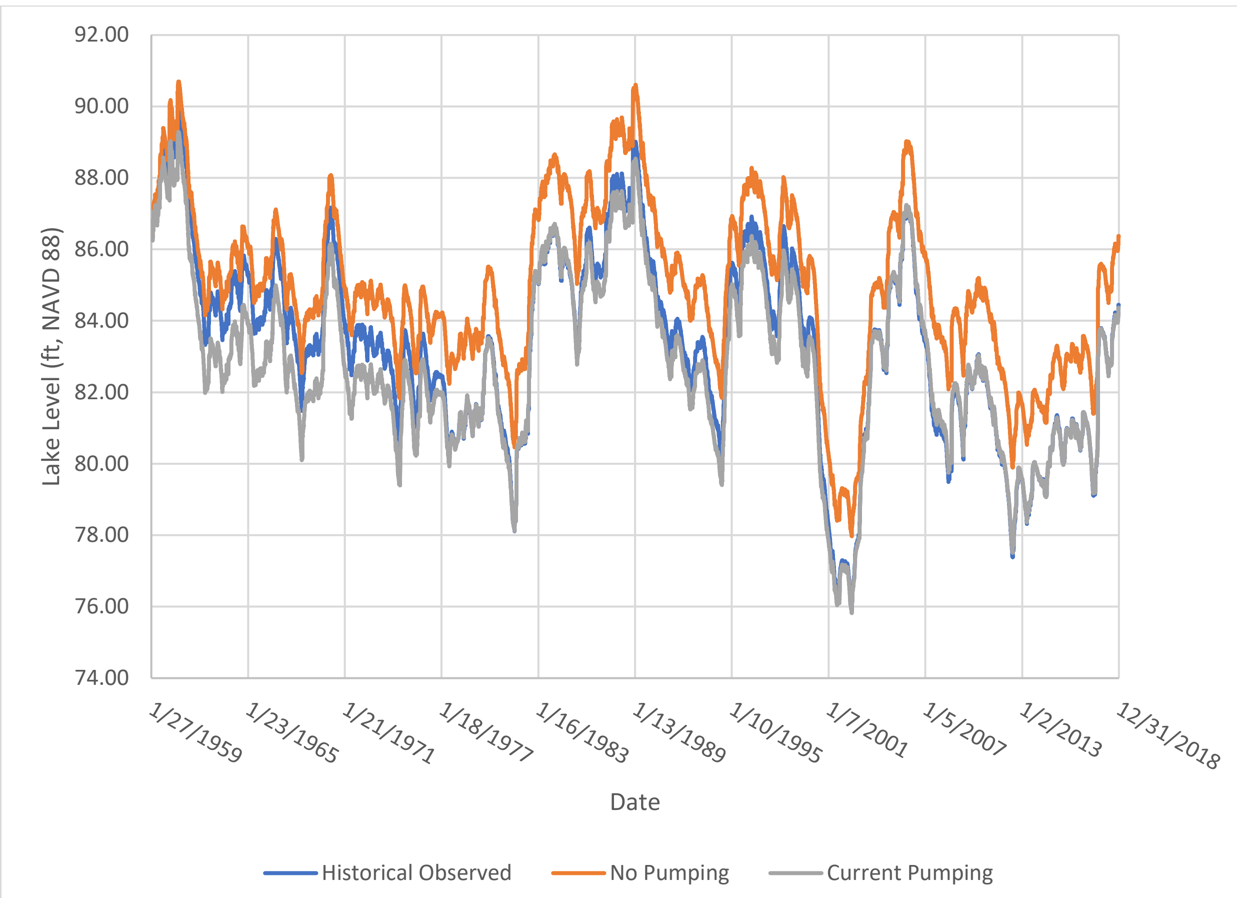


Figure 27. Simulated levels of historical observed, no-pumping, and current pumping at Apshawa Lake South.

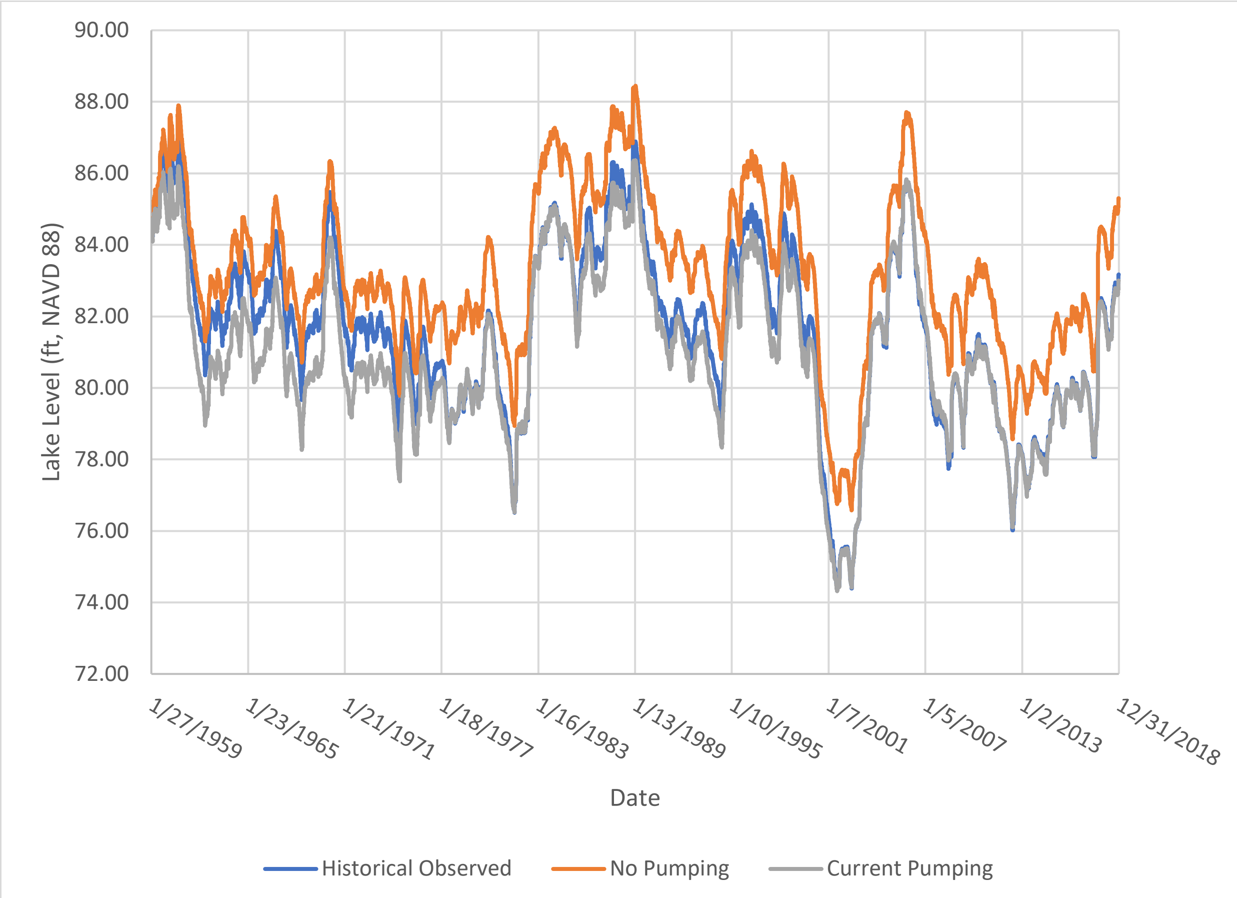


Figure 28. Simulated levels of historical observed, no-pumping, and current Pumping at Apshawa Lake North.

Table 12. Summary level (ft, NAVD 88) descriptive statistics of Apshawa Lake South.

Statistical Parameter	No Pumping	Historical Observed	Current Pumping
Mean	84.96	83.32	82.85
Median	84.91	83.46	82.67
Standard Deviation	2.38	2.66	2.52
Range	12.72	14.29	13.47
Minimum	77.97	75.86	75.82
Maximum	90.69	90.15	89.29

Table 13. Summary level (ft, NAVD 88) descriptive statistics of Apshawa Lake North.

Statistical Parameter	No Pumping	Historical Observed	Current Pumping
Mean	83.26	81.58	81.05
Median	83.08	81.69	80.79
Standard Deviation	2.27	2.50	2.36
Range	11.88	12.87	12.04
Minimum	76.57	74.35	74.32
Maximum	88.45	87.22	86.36

The current-pumping condition lake levels represented a reference hydrologic condition of the lakes in which the total regional groundwater pumping impacting the lakes was constant from 1959 to 2018 at a rate of averaged pumping from 2014 to 2018. Assuming climatic, rainfall, and other conditions present from 1959 to 2018 would repeat over the next 59 years, the current-pumping condition lake levels reflected the future condition of the lake levels if the average regional groundwater pumping does not change from 2014-2018 condition. Because of our limited understanding of possible future climatic conditions and significant uncertainties in global climate model predictions, using historical conditions to generate current-pumping condition lake levels was reasonable. Therefore, the no-pumping and current-pumping condition lake level datasets shown in Figures 27 and 28 were used to assess the MFLs at Apshawa Lake South and Apshawa Lake North, respectively.

REFERENCES

Brooks, H. K. 1982. Guide to the physiographic divisions of Florida. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences. University of Florida, Gainesville, Florida.

Dynamic Solutions. LLC. 2019. Apshawa Lake HSPF Model Development

CFWI HAT, 2020. Model Documentation Report East-Central Florida Transient Expanded (ECFTX) Model. Prepared by Central Florida Water Initiative (CFWI) Hydrologic Analysis Team (HAT). https://cfwiwater.com/pdfs/ECFTX_Model_Final_Report_Feb_2020.pdf

Gordu, F., Sisco, L., Basso, R., Zhang, H., Patterson, J., Kwiatkowski, P., Obeysekera, A., 2022. East-Central Florida Transient Expanded (ECFTX) V2.0 Model Report. Retrieved from https://cfwiwater.com/pdfs/ECFTX_2.0_Report_040522_final.pdf

Robison, C. P. 2015. Apshawa Lake Minimum Flows and Levels Hydrologic Methods Report.

St. Johns River Water Management District. 2010. Hydrologic Data Services. Palatka, Florida.