APPENDIX B — HYDROLOGICAL ANALYSES

INTRODUCTION

In addition to extensive work conducted to understand the ecological structure and function, and the most sensitive environmental values of priority waterbodies, assessing the status of minimum flows and levels (MFLs) requires substantial hydrological analysis. Performing the hydrological analysis also involves several steps, 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.
4. Estimating available water (freeboard or deficit).

Figure B-1 shows the flowchart for the hydrological analysis. This document describes the first three steps and associated results. Appendix D includes the description of the last step and associated results.

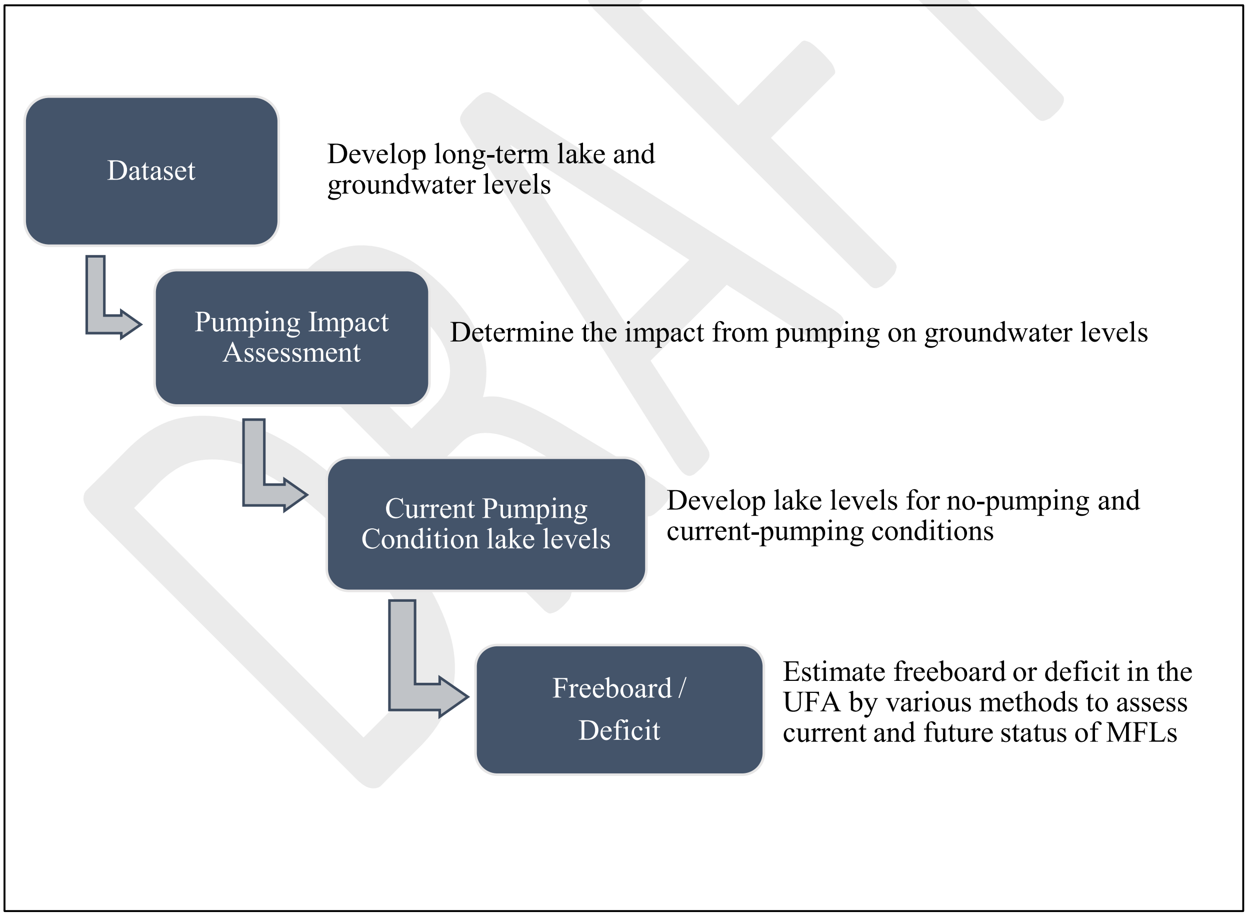

Figure B-1: Flowchart for hydrological analysis process.

BACKGROUND

Johns Lake is located in northwest Orange County, Florida, just south of Lake Apopka, with a small portion in Lake County, to the west (Figure B-2). The lake receives major inflows from Black Lake, connected to several upstream lakes and wetland slough systems (Figure B-2). The lakes draining to Johns Lake are generally located in the southeast of the lake's watershed. The Johns Lake system drains an approximately 26.9 square miles watershed. The lake has a water control structure regulating its outflow through ditches and culverts to Lake Apopka to the north (Figure B-2).

An Interconnected Channel and Pond Routing version 4 (ICPR4) model (Streamline Technologies, 2018) was developed for hydrologic and hydraulic processes, surface water – groundwater interaction, and water budget components modeling of Johns Lake. While the developed model covered the period from 1995 to 2018, the model was calibrated for the period from 2005 to 2018 and validated for the period from 1995 to 2004 using the observed water levels of Johns Lake recorded at station 03840562 by the St. Johns River Water Management District (SJRWMD), see Figure B-2. Subsequently, the calibrated and validated model was extended to the period 1948 to 2020 to estimate long-term lake levels. Applied Technology and Management (ATM) reviewed the model in 2022. Leta et al. (2022) updated the model to address the comments provided by ATM (2022). The updated model was then used to develop long-term Johns Lake level datasets representing no-pumping (NP) and current-pumping (CP) groundwater conditions for MFLs status assessments. The East-Central Florida Transient Expanded version 2 groundwater model (ECFTX v2.0; Gordu et al., 2022) was used to develop the relationships between groundwater pumping and Upper Floridan aquifer (UFA) drawdown, including generating NP and CP groundwater datasets.

Minimum levels determinations for lakes require long-term water levels and understanding the influence of both climate and pumping on water level exceedances and event frequencies. Due to the presence of short- and long-term climatic cycles and variabilities (e.g., El Nino Southern and Atlantic Multidecadal Oscillations), the frequencies of lake levels could be significantly different in wet periods such as in the 1960s than those in dry periods such as in the 2000s. Thus, it is important to determine and assess MFLs using long-term lake levels so that the effect of short- and long-term climatic variations on lake levels can be captured.

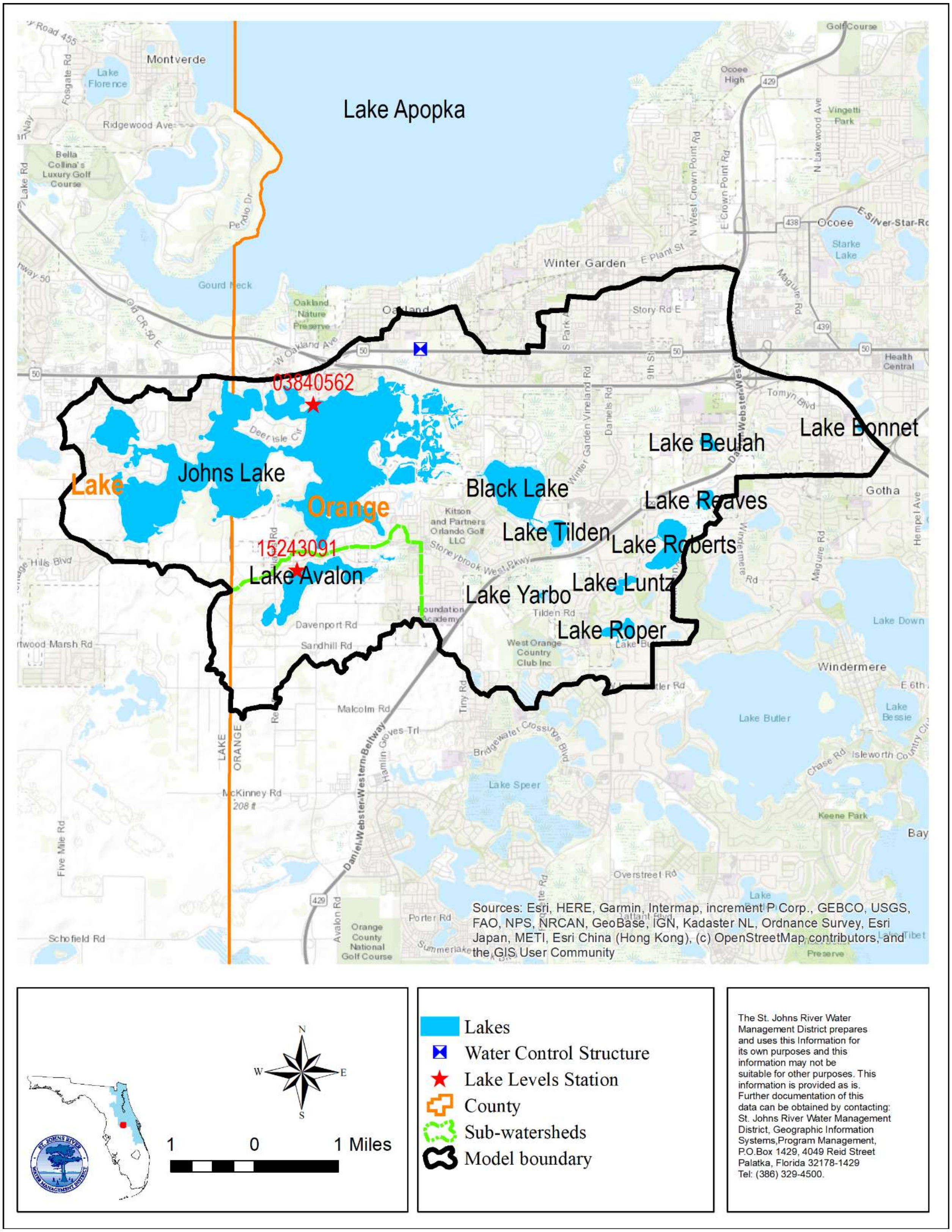

Figure B-2: Johns Lake and its watershed boundary.

REVIEW OF AVAILABLE DATA

Rainfall and Reference Evapotranspiration

SJRWMD staff obtained hourly rainfall and daily reference evapotranspiration (RET) from different sources. Figure B-3: presents locations of the hydro-meteorological stations and Next Generation Weather Radar (NEXRAD) pixels, including their identification numbers (IDs). Hourly NEXRAD rainfall data was available for the period from 1995 to the present from the SJRWMD hydrologic databases. In addition, gauged hourly rainfall data was available at Isle_Win station of SJRWMD for the period from 1948 to the present. SJRWMD staff compiled the hourly rainfall data from Isle_Win station (1948-1994) with the NEXRAD data (1995-2020) to create a composite rainfall data for the period from 1948 to 2020 and use in the ICPR4 model of Johns Lake. The composite annual rainfall values of the period from 1948 to 2020 are shown in Figure B-4:, which indicates the highest and lowest rainfall amount recorded in 1953 and 2000, respectively.

Gridded daily RET data, which shares the same pixel IDs with NEXRAD rainfall data, was available for the period from 1985 to 2020 from the SJRWMD's hydrologic databases. However, the RET data consistently showed missing values for the first 5 months of 1995 (1/1/1995-5/31/1995) whereas the data on the United States Geological Survey (USGS)'s website showed more complete values for that period (https://www.usgs.gov/centers/car-fl-water/science/reference-and-potential-evapotranspiration?qt-science_center_objects=0#qt-science_center_objects). Consequently, SJRWMD staff directly downloaded the RET data from the USGS's website, extracted to the pixels shown in Figure B-3:, and merged with the SJRWMD's RET to create a more complete daily RET dataset for the period from 1985 to 2020. Missing values of the merged data were filled with the average values of the pixels with records. The remaining missing values were filled with the daily average values within a month. Due to lack of RET data before 1985, daily RET values were estimated from the daily estimated potential evapotranspiration (PET) data (1948 – 1984), which is based on the Hargreaves's method (Hargreaves and Samani, 1985). The PET data was available at the Clermont station of the National Oceanic and Atmospheric Administration (NOAA) (Figure B-3:). First, monthly correction factors, which are the ratio of the available pixel RET and station PET values at Clermont station, were calculated for the overlapping period of record (POR), i.e., 1/1/1985 to 12/31/2017. Then, these factors were used to estimate RET values from the PET values of Clermont for the period from 1/1/1948 to 12/31/1984. Similarly, monthly correction factors were derived as the ratio of RET data at each pixel inside the watershed to the Clermont's pixel USGS RET data for the overlapping POR, which covered the period from 1/1/1985 to 12/31/2017. The factors were then used to move the estimated RET data at Clermont station to each pixel of the NEXRAD for the period from 1/1/1948 to 12/31/1984. The estimated RET values showed a monthly coefficient of determination, $R^2 > 0.9$ when validated against the USGS RET data of 1/1/1985 to 12/31/2017, indicating the reasonable estimation of the RET values from the Hargreaves' PET values. Leta et al. (2022) detailed the procedures for the RET data extension techniques. Completed RET data is shown in Figure B-4: that indicates the lowest RET recorded in 2001 and the highest value in 2006.

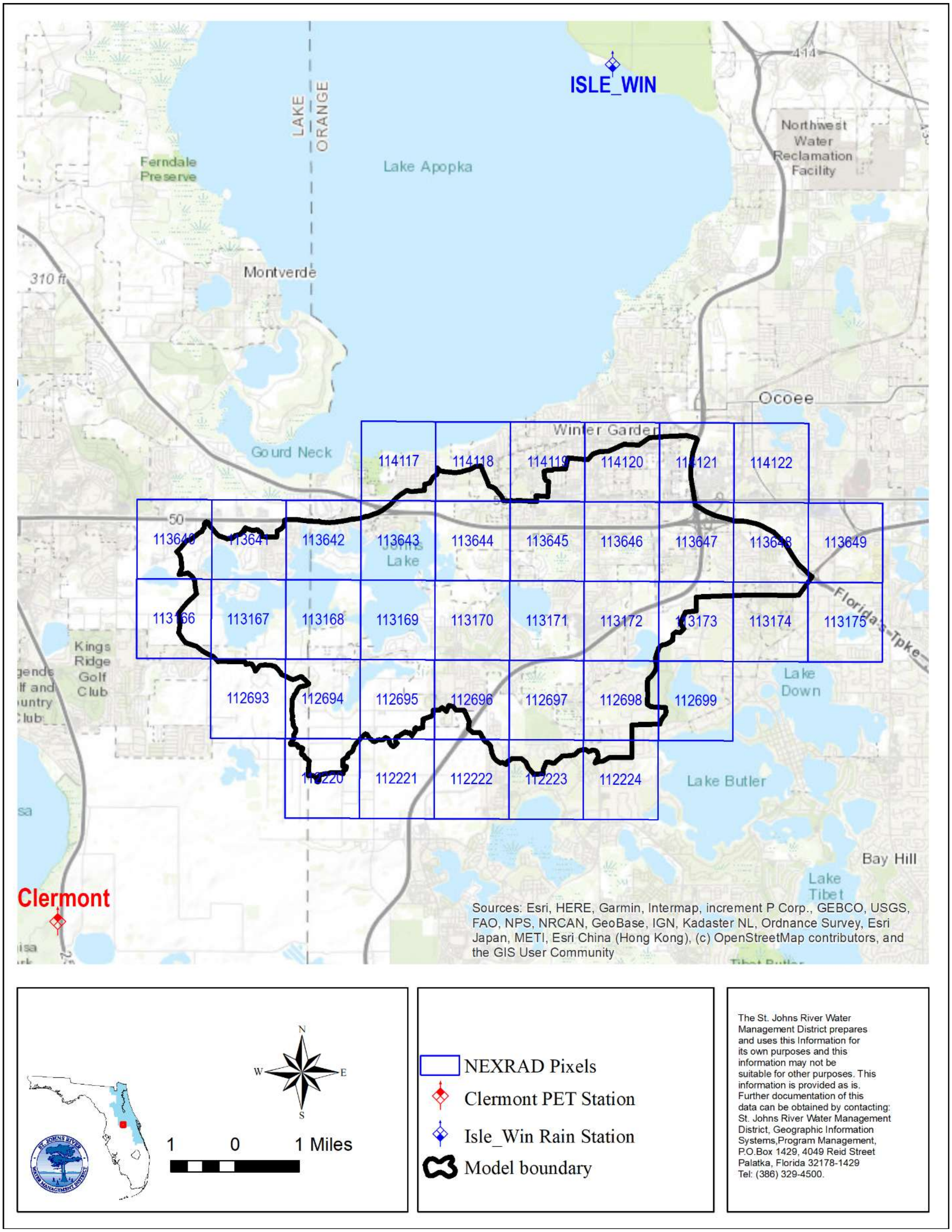

Figure B-3: NEXRAD pixel identifications and hydro-meteorological stations of Johns Lake.

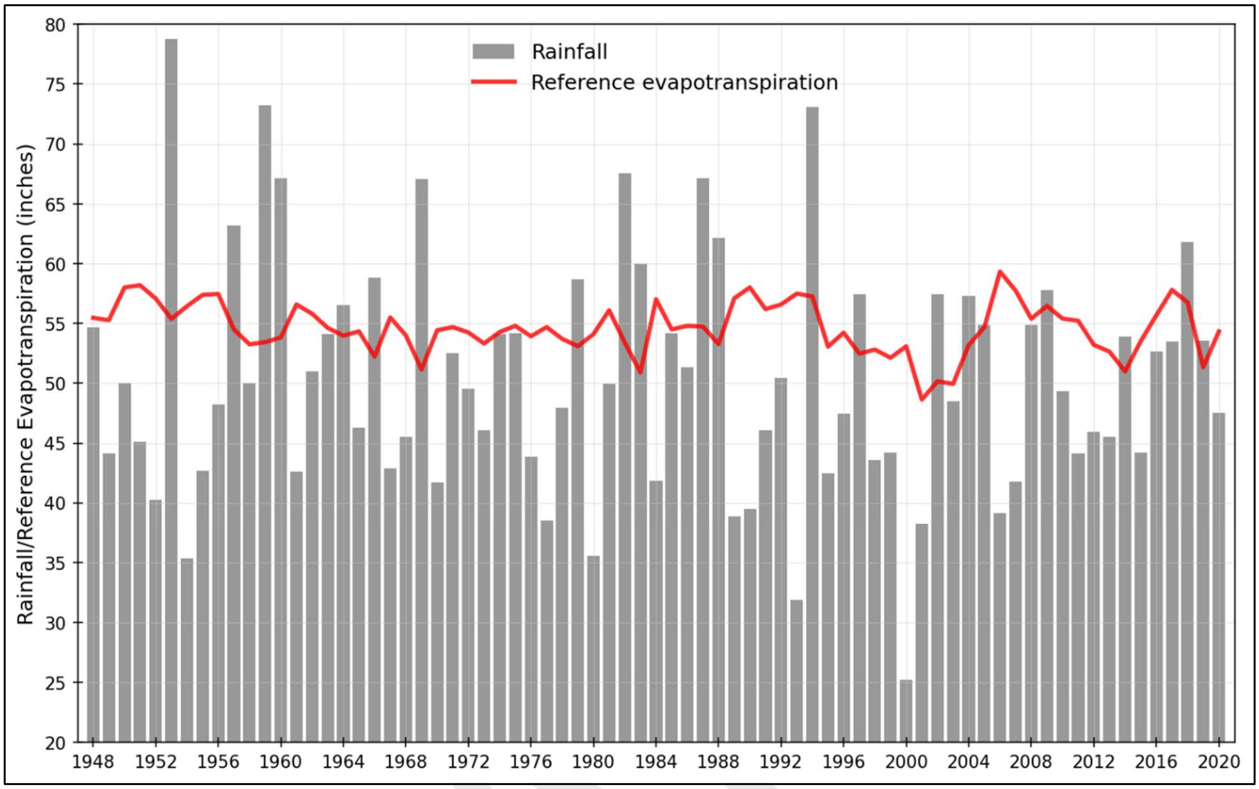

Figure B-4: Composite annual rainfall and Reference Evapotranspiration of Johns Lake.

Groundwater Levels

ICPR4 requires groundwater level data to simulate seepage rates beneath the lakes and elsewhere. SJRWMD staff reviewed several UFA monitoring wells during the analysis (Figure B-5:Table B-1: lists the three selected wells with their periods of record. Although well OR1123 is located close to the middle of the watershed (see Figure B-3:that station did not have a long POR (only since 10/21/2010). Consequently, the ICPR4 model used the data recorded at station OR1123 combined with data from L0052 (since 6/29/1993) and OR0047 (before 6/29/1993) stations to represent the long-term UFA boundary condition.

Table B-1: Summary of groundwater wells within and around the watershed and the data period of record.

Station Name	Station #	Available period
Ft. McCoy Tower (L0052)	70231656	6/29/1993–present
Johns Lake E Well (OR1123)	31792877	10/21/2010–present
Orlo Vista (OR0047)	09272094	9/30/1930–present

The Line of Organic Correlation (LOC) method (Helsel & Hirsch, 2002) was applied to fill the gaps at OR1123 using the observed data at L0052 and OR0047 stations. Leta et al. (2022) provides details on the groundwater data extension methods based on the available UFA data from the above three wells. Extended daily groundwater levels at OR1123 are shown in Figure B-6: along with observed data at L0052 and OR0047 stations. The figure also presents recorded water levels of Johns Lake at station 03840562 (Figure B-2as retrieved from the SJRWMD's hydrological databases.

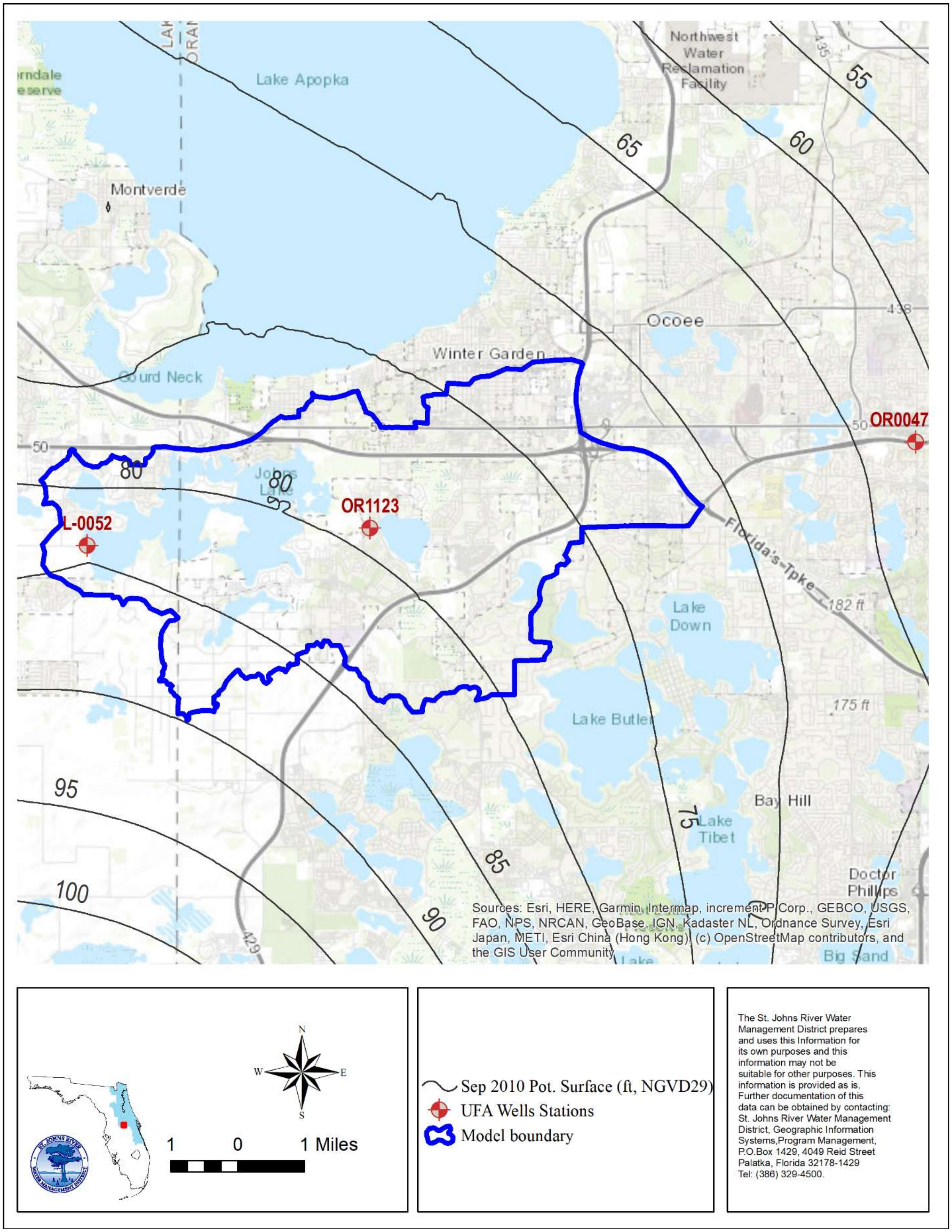

Figure B-5: Groundwater monitoring stations along with the representative September 2010 potentiometric surface contours.

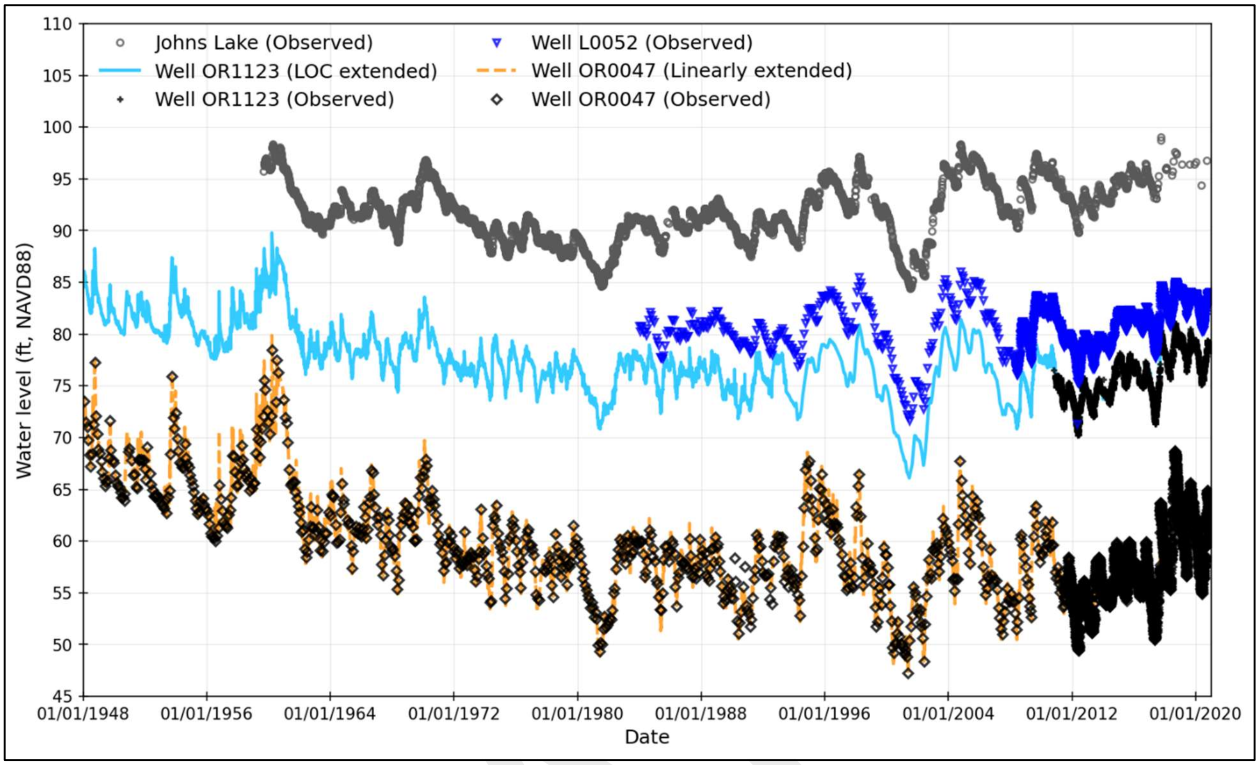

Figure B-6: Observed and extended groundwater levels along with observed water levels of Johns Lake (LOC = Line of Organic Correlation).

Annual average offset values, derived from the spatially interpolated May and September potentiometric maps from 1978 to 2017, were superimposed with observed water levels at OR1123 to account for potentiometric levels spatial variability and to move up and down the locally observed water levels at OR1123. Figure B-7: presents annual average offset values used in the ICPR4 model of Johns Lake along with the representative September 2010 potentiometric contours. Although the method did not consider temporal offset values due to limited data, such approach gives more weight to the observed well data over the spatially interpolated May/September potentiometric maps that were produced from sparsely scattered well data. The approach is also expected to reduce uncertainty that could be introduced from the spatially interpolated potentiometric maps. Moreover, while using the temporally varied spatial maps (if monthly maps were available) is possible, that would also significantly increase the memory usage and computational demand of the model, especially during the long-term MFLs simulation and scenario runs.

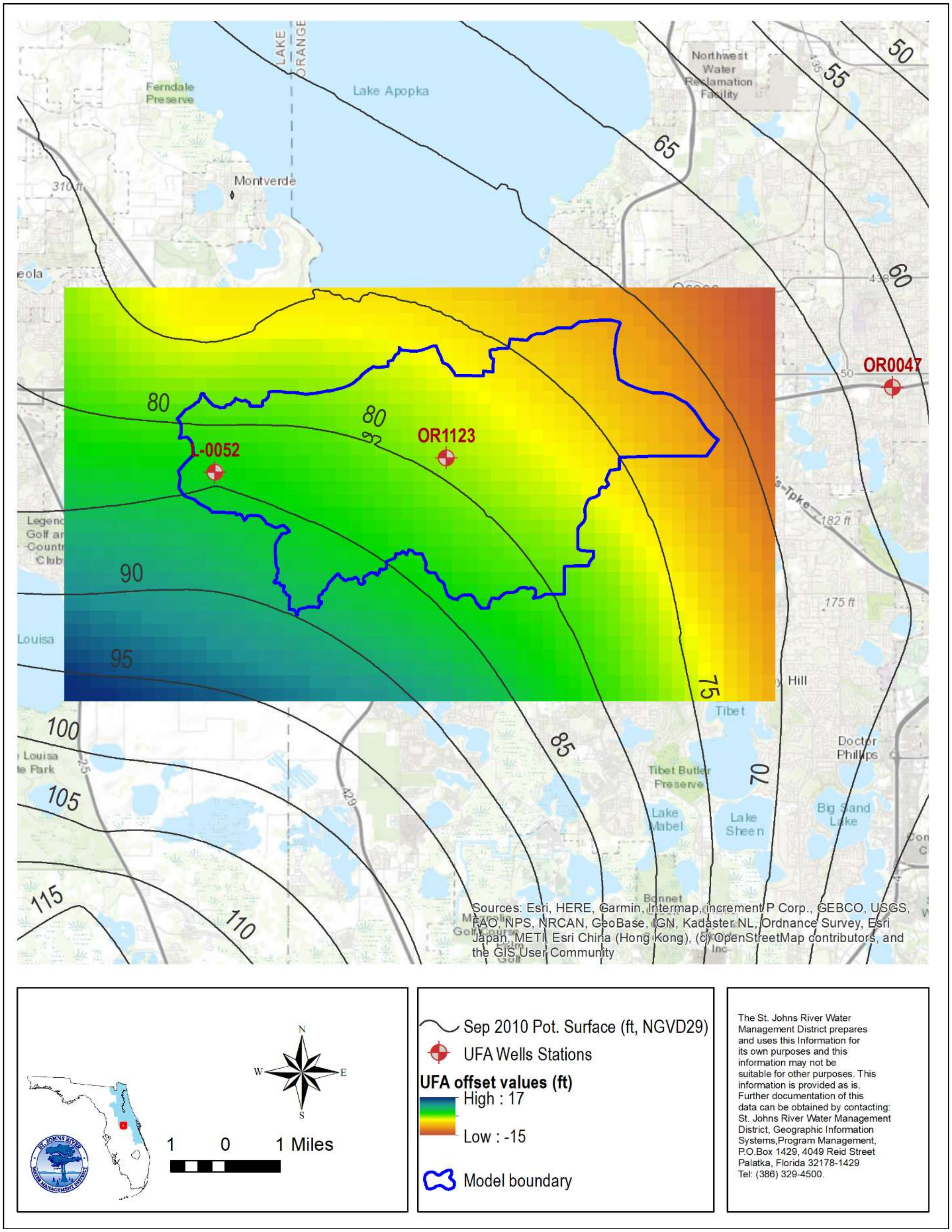

Figure B-7: Annual average offset values with respect to OR1123 as derived from May and September potentiometric levels from 1978 to 2017.

Lake Levels

Observed water levels of Johns Lake were retrieved from the SJRWMD's hydrologic databases. The lake had irregularly recorded data as shown in Figure B-6:Table B-2: summarizes the recorded water level values of Johns Lake. The data was used to calibrate and validate the ICPR4 model.

Table B-2: Summary of Johns Lake water levels data. Values are in ft, NAVD88.

Lakes	Station ID	Available Period	Min	Max	Median	Mean	Standard Deviation
Johns	3840562	9/7/1959 to present	84.42	99.00	91.45	91.62	2.71

LONG-TERM LAKE LEVEL SIMULATIONS

MFLs analysis requires long-term lake levels to capture the effect of short- and long-term climatic variations on lake levels. Therefore, long-term lake levels simulation is needed for MFLs determinations and assessments, including generating long-term lake levels under no-pumping (NP) and current-pumping (CP) groundwater conditions. The ICPR4 model of Johns Lake used long-term historical, NP, and CP groundwater conditions (described below) as boundary conditions to estimate the corresponding long-term lake levels.

Historical Long-term Lake Levels

Long-term historical lake levels were simulated by using long-term observed rainfall, RET, and groundwater levels data as boundary condition (previously described). Figure B-8: compares the long-term simulated historical water levels of Johns Lake and long-term observed data at station 03840562 (Figure B-2The daily long-term simulated water levels adequately represented the temporal evolutions and variations of the long-term observed levels of Johns Lake (Figure B-8: However, Figure B-8: indicates that the model noticeably overestimated the pre-development observed water levels, especially for the period from 1962 to 1992. This could be due to additional uncertainties attributed to the lack of long-term observed groundwater and rainfall data within the watershed, including significant land use/land cover (LULC) developments of the watershed, especially since 2000. However, given that the model used recent LULC and reasonably matched the observed lake levels of the post-development period, the simulated values are deemed to be a good representation of potential future lake levels. As such, the model simulation is deemed appropriate for MFLs determinations and status assessments.

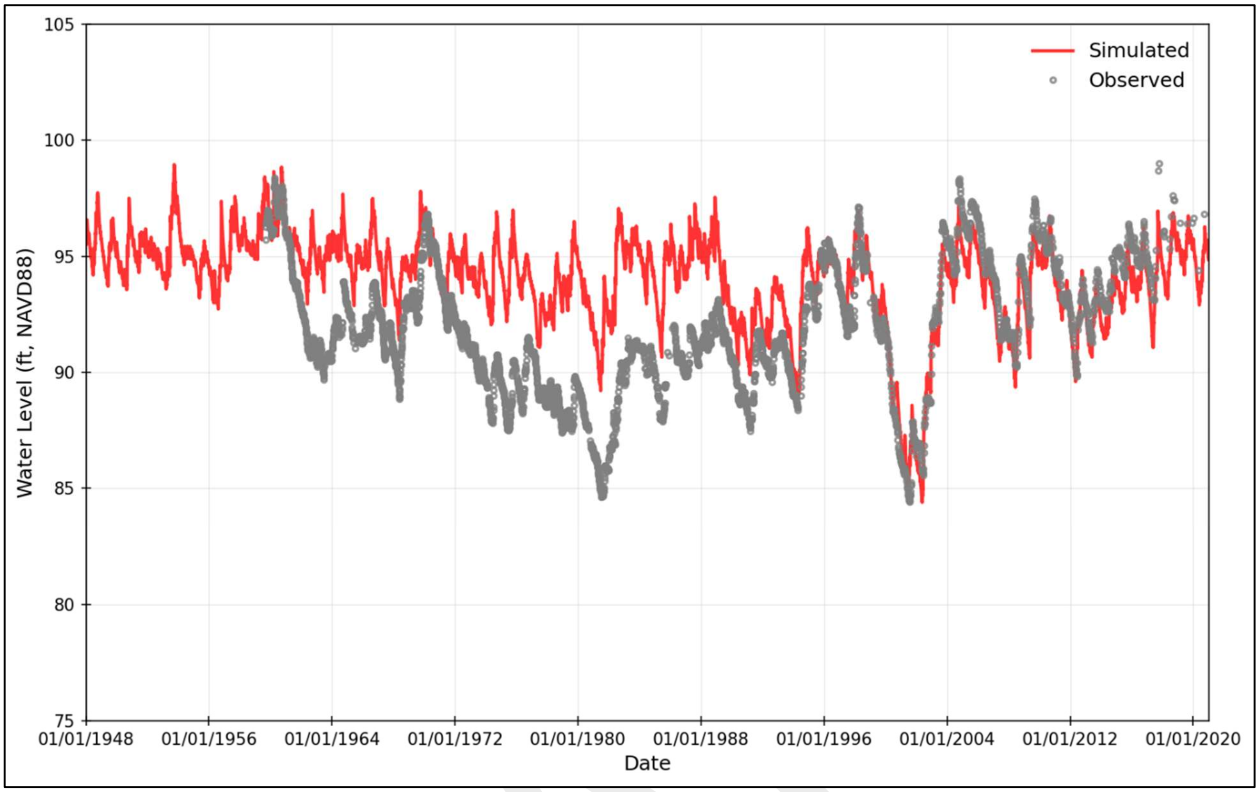

Figure B-8: Comparison of long-term observed and simulated water levels of Johns Lake.

GROUNDWATER PUMPING IMPACT ASSESSMENT

The current and future status of minimum water levels developed for Johns Lake need to be assessed. The objective of the current status assessment is to determine whether the lake minimum levels are being achieved under the current pumping condition. Because of our limited understanding of possible future climatic conditions and difficulties in predicting future lake levels using global climate models, historical lake levels were considered to be the best available data and adjustments to these data due to groundwater pumping impact are deemed to be the best data with which to assess the current status of recommended minimum levels.

The adjustment of historical lake levels requires considering the effect of current groundwater pumping on lake levels not only for the recent years but also for the entire period of record (from 1948 to 2020). Two sets of adjusted lake levels were developed: NP and CP conditions lake levels. The NP condition lake levels constitute a reference hydrologic condition in which lake was not under the influence of any groundwater pumping for the period from 1948 to 2020. The CP condition lake levels represent a reference hydrologic condition in which lake was under the influence of current groundwater pumping constantly for the period from 1948 to 2020. The current groundwater pumping was defined as the average groundwater pumping obtained from the past five years (2016 to 2020) data. The past five years average value was used to calculate the CP condition so that it is more representative of the most recent average groundwater demand condition. Figure B-9: shows the overall steps for developing lake levels for both NP and CP groundwater conditions.

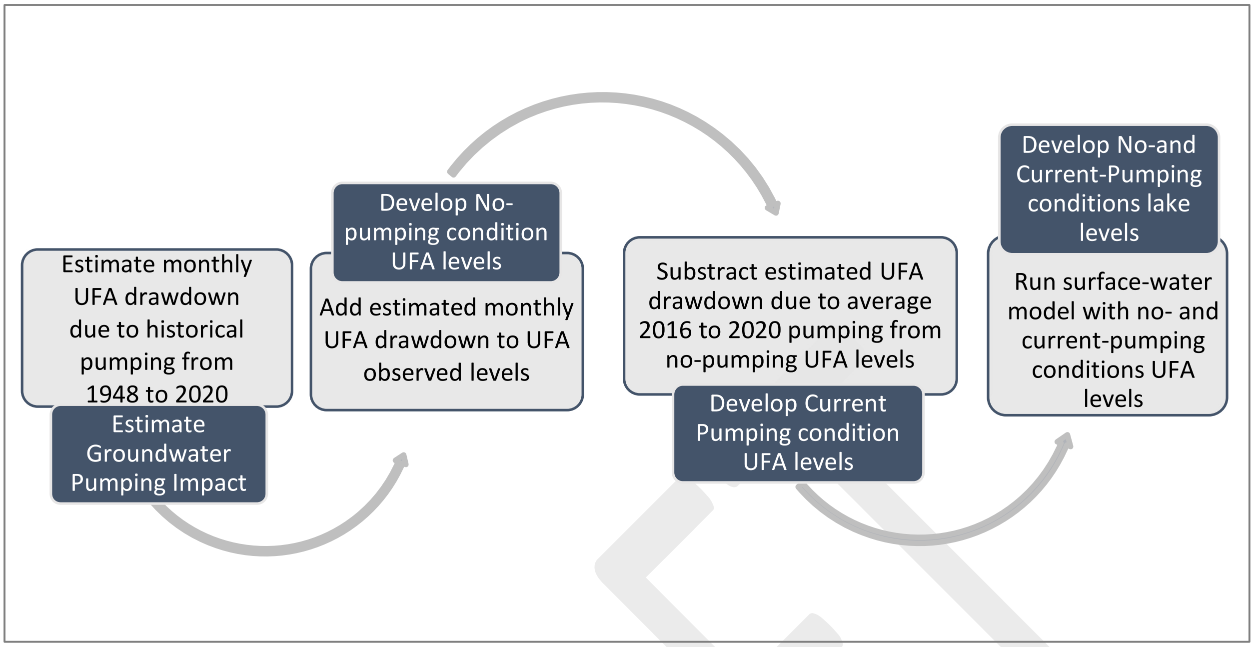

Figure B-9: Steps for developing no-pumping and current-pumping condition lake levels

As shown in Figure B-9:the ICPR4 model requires the NP and CP conditions UFA levels data to simulate the respective NP and CP conditions lake levels. As previously discussed, the ICPR4 model used the historically observed and gap filled UFA levels data from OR1123 well along with spatially varied average offset values to simulate the exchange of flows between the UFA and Johns Lake. This data needs to be replaced with NP UFA levels data to simulate the NP lake levels and CP UFA levels data to simulate CP lake levels.

The first step in developing the CP condition groundwater levels is to develop the NP condition groundwater level dataset. This dataset was developed by adding an estimate of the impact due to historical groundwater pumping (i.e., the UFA drawdown due to pumping) to the observed record at OR1123. Then, the CP condition groundwater level dataset was developed by subtracting an estimate of impact due to the current pumping (average groundwater pumping from 2016 to 2020) from the NP groundwater levels. The ICPR4 model later used these NP and CP conditions groundwater levels as boundary conditions and simulated the corresponding NP and CP conditions water levels of Johns Lake.

Groundwater Modeling

The Central Florida Water Initiative – Hydrologic Analysis Team [CFWI-HAT], which was a collective effort between the St. Johns River, South Florida, and Southwest Florida water management districts and stakeholders, (2020) originally developed the groundwater ECFTX model to primarily support water supply planning and management strategies of the region. The original ECFTX model was developed by CFWI-HAT (2020) and later recalibrated by Gordu et al. (2022) and is referred to as the ECFTX version 2 (ECFTX v2.0) model. The recalibrated ECFTX v2.0 model aimed to improve simulations of groundwater levels and flows especially in the Wekiva River groundwater contributing basin and Seminole County.

The model used a steady state condition of 2003, followed by monthly transient stress periods covering the period from 2004 to 2014. The boundaries of the ECFTX v2.0 model domain and the CFWI planning areas are shown in Figure B-10:Details about the ECFTX v2.0 model can be found in Gordu et al. (2022).

An estimate of drawdowns resulting from regional groundwater pumping for the period from 1948 to 2020 on a monthly time step is needed for the NP and CP simulations. Because the ECFTX v2.0 model did not cover this period, a methodology was developed to estimate the impact of regional pumping on groundwater levels for every month of the period from 1948 to 2020. The methodology includes developing a relationship between groundwater pumping and the UFA drawdown beneath the lake using the ECFTX v2.0 model. To develop the relationship, the following model simulations were performed so that a wide range of pumping conditions can be included in the regression analysis:

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

The ECFTX v2.0 model used these various pumping simulations to estimate the UFA drawdown beneath Johns Lake when compared to the pumps-off scenario. As an example, the impact for the calibration period pumping condition was calculated by subtracting the simulated calibrated UFA levels from the simulated pumps off UFA levels beneath Johns Lake for each transient stress period.

Figure B-11:shows the regression plot of groundwater pumping rate and drawdown for Johns Lake within the 15-mile buffer zone. The figure also shows the presence of a strong linear relationship between the UFA drawdown (impact) and groundwater pumping within the 15-mile buffer zone of Johns Lake.

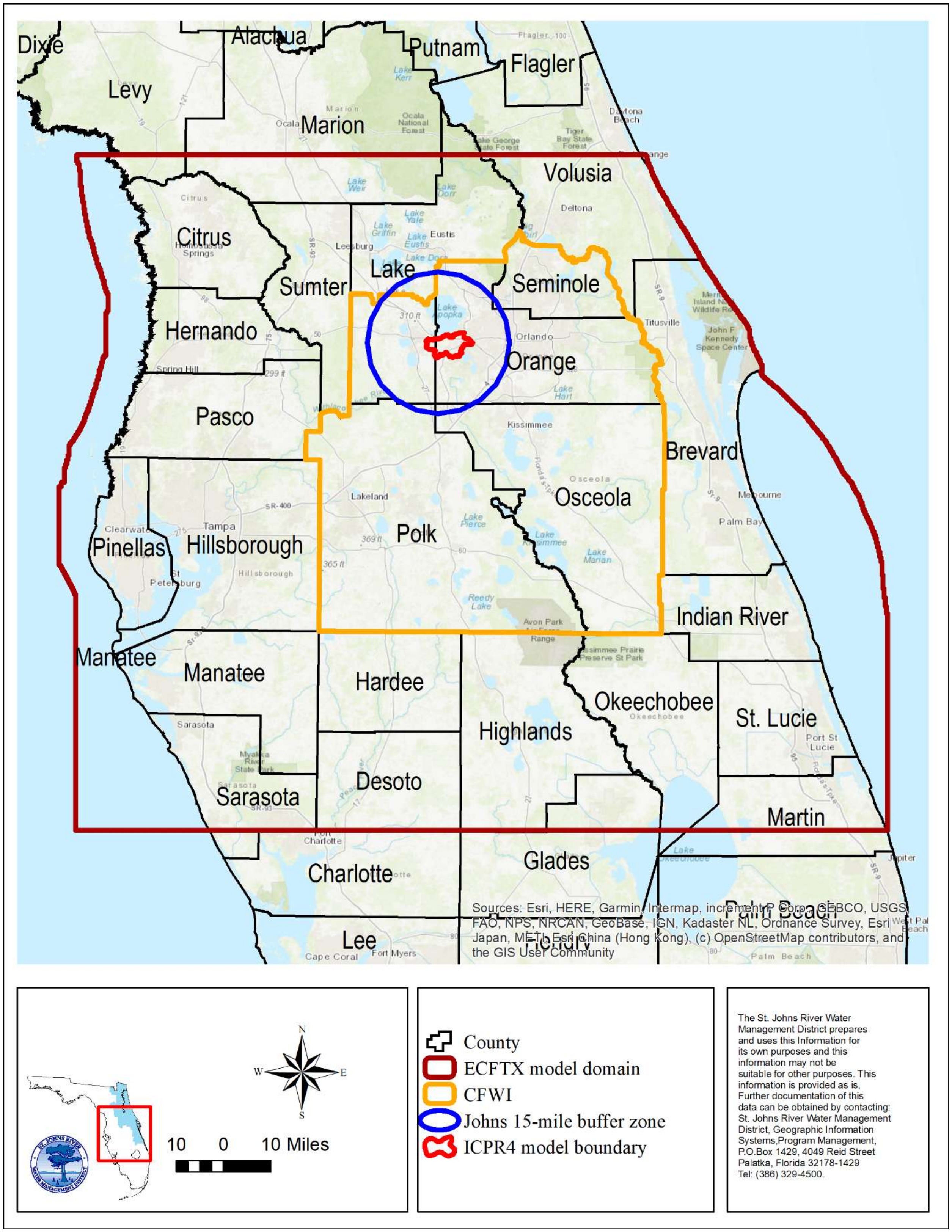

Figure B-10: The 15-mile buffer zone of Johns Lake and East Central Florida Extended Transient (ECFTX) model domain of the Central Florida Water Initiative (CFWI). The 15-mile zone was used to extract the groundwater drawdowns from ECFTX model version 2 and monthly water use data.

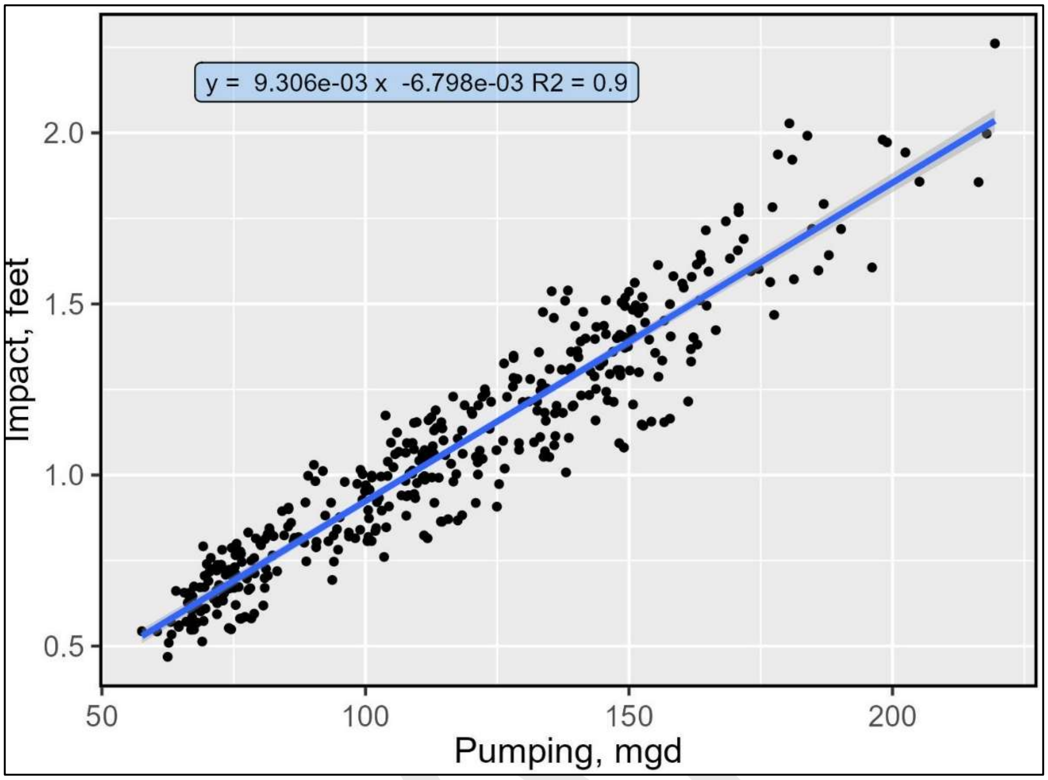

Figure B-11: Linear regression between UFA drawdown near Johns Lake and groundwater pumping within 15-mile buffer area. “mgd” represents a million gallons per day.

Groundwater Use

It was assumed that most of the impact on Johns Lake had been caused by groundwater pumping within a radius of 15-miles. Figure B-10: shows the extent of the 15-mile buffer zone. To estimate the impact on groundwater levels from pumping, monthly groundwater use data was compiled for the period from 1948 to 2020 within the 15-mile buffer zone of Johns Lake.

The groundwater pumping data was estimated for the period from 1948 to 2020 using the data available from different sources. The pumping data from 1995 to 2020 was available from the CFWI regional water supply plan . Data for the period from 2015 to 2020 was available from the SJRWMD historical water use database with actual monthly use and station-level details. The data for the period from 1965 to 1995 was based on the USGS’s 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 values 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 data of AWUS was used. To estimate annual groundwater use by county for the period before 1965, per capita groundwater use was estimated for each county. By multiplying the 1965 per capita water use by the historic county-level population from U.S. Census, the annual groundwater uses by county were calculated 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 1948 to 1994 to estimate the water use data within Johns Lake 15-mile buffer zone (Figure B-10:). To disaggregate the annual data to monthly groundwater use, SJRWMD staff applied the average monthly proportions by county, estimated from the monthly SJRWMD database for the period from 2004 to 2020, to the annual data. Figure B-12:shows the monthly water use data for the period from 1948 to 2020 within the 15-mile buffer area of Johns Lake.

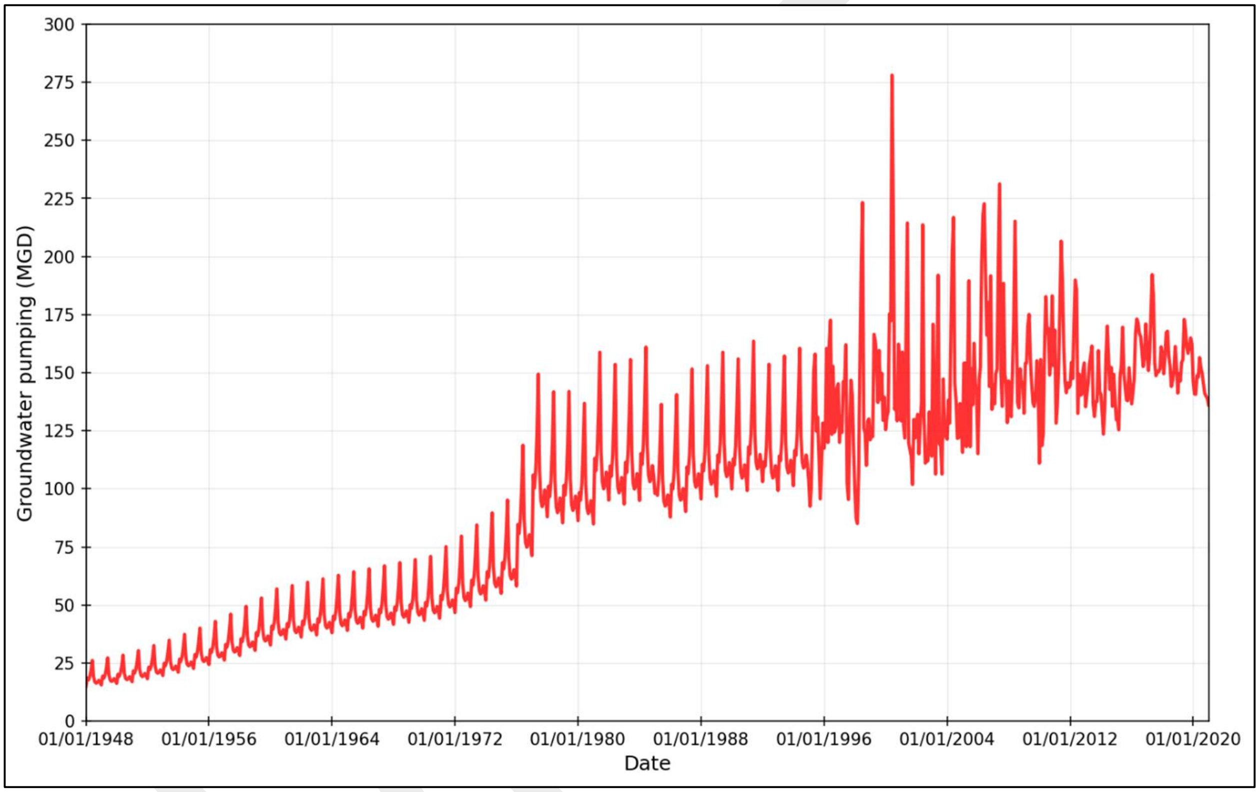

Figure B-12: Johns Lake estimated historical monthly groundwater use data within the 15-mile buffer zone.

As shown in Figure B-12:the monthly groundwater use data reached its highest value of approximately 278 mgd in 2000 but had significantly declined after that. The average monthly groundwater use over the past five years (2016 to 2020) is approximately 156 mgd.

Historical Impact on Groundwater Levels

A linear regression equation shown in Figure B-11:was used to calculate monthly historical impact values (drawdowns) due to groundwater pumping from the long-term groundwater use data (1948 to 2020) within the 15-mile buffer zone of Johns Lake (Figure B-12:. The monthly estimated historical impact values of 1948 to 2020 were later disaggregated to daily time series values using a linear interpolation technique. Figure B-13:presents the disaggregated daily time series impact values.

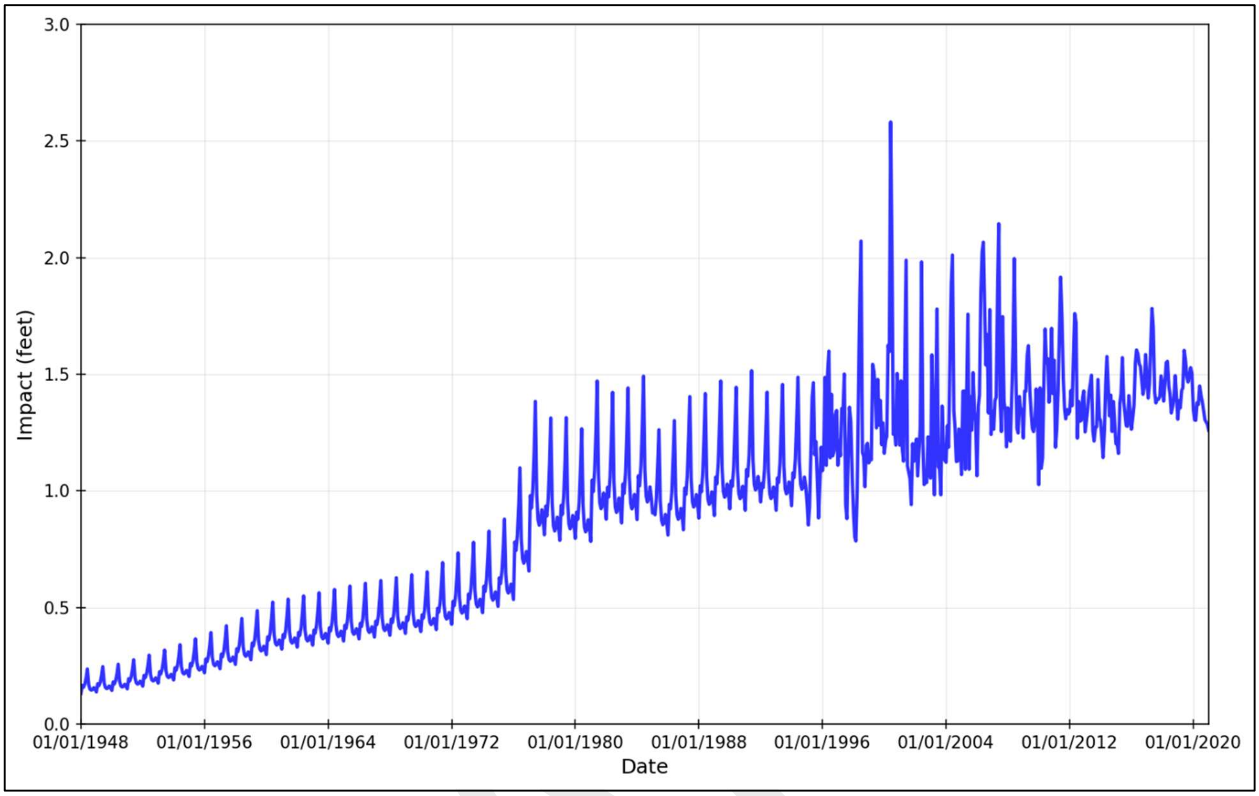

Figure B-13: Daily estimated historical impact from pumping of UFA levels within 15-mile of Johns Lake.

No-pumping Condition Groundwater Levels

The daily impact values (Figure B-13:were utilized to create NP condition groundwater level datasets of Johns Lake. The daily NP time series groundwater levels were generated by adding the daily impact values to the daily observed groundwater level data at OR1123.

Current-pumping Condition Groundwater Levels

To generate CP condition groundwater levels, the NP condition groundwater levels were subtracted by the average impact value of the past five years (from 2016 to 2020 as shown in Figure B-13:The average impact value for this period is approximately 1.44 ft. Figure B-14: shows the historical (existing), no-pumping, and current-pumping conditions groundwater levels for Johns Lake.

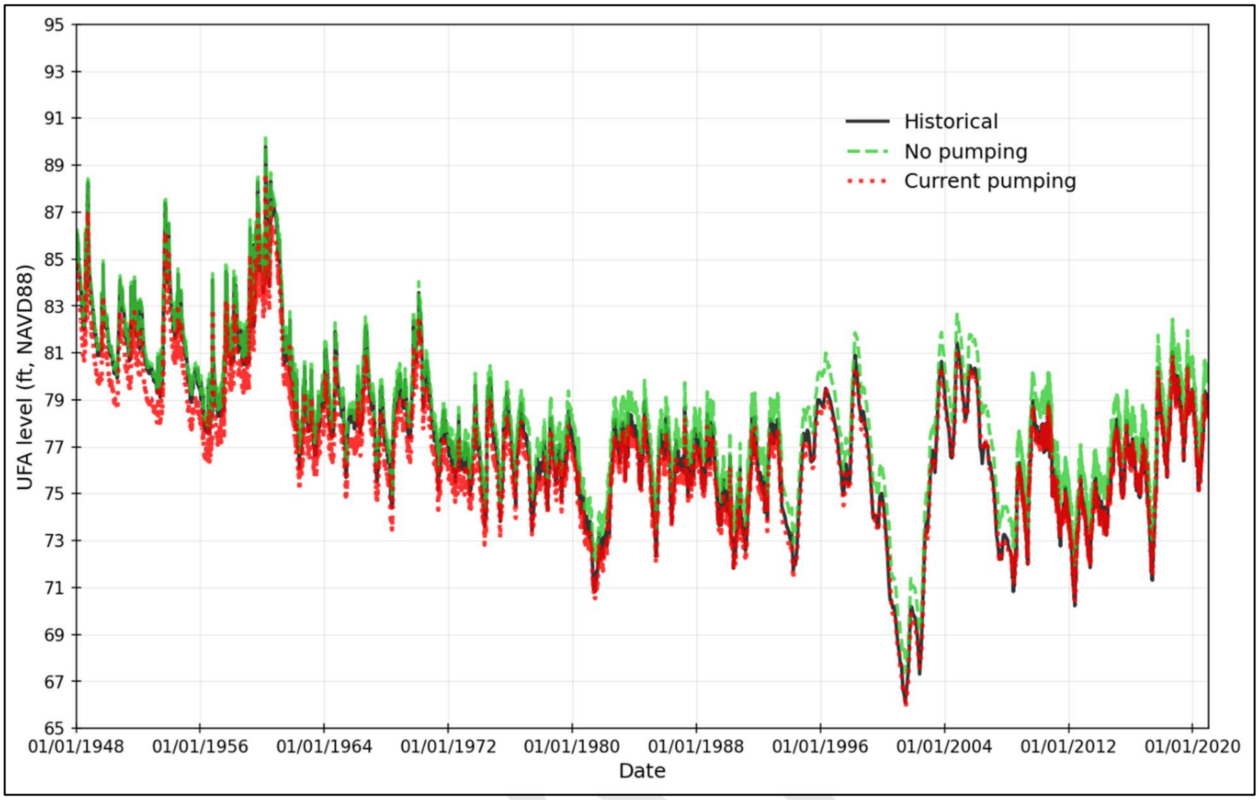

Figure B-14: Historical and estimated daily no-pumping and current-pumping UFA levels near Johns Lake.

Lake Level Datasets for MFLs Analysis

The long-term NP and CP lake levels were simulated by using the ICPR4 model of Johns Lake and the corresponding estimated NP and CP conditions groundwater level datasets (Figure B-14:) as UFA boundary conditions in the model. Figure B-15:shows the simulated historical, no-pumping, and current-pumping conditions water levels of Johns Lake. The figure indicates a more pronounced impact of NP and CP conditions groundwater levels on lake levels, especially during the extended dry periods. Table B-3: provides the descriptive statistics for the long-term historical, NP, and CP conditions lake levels.

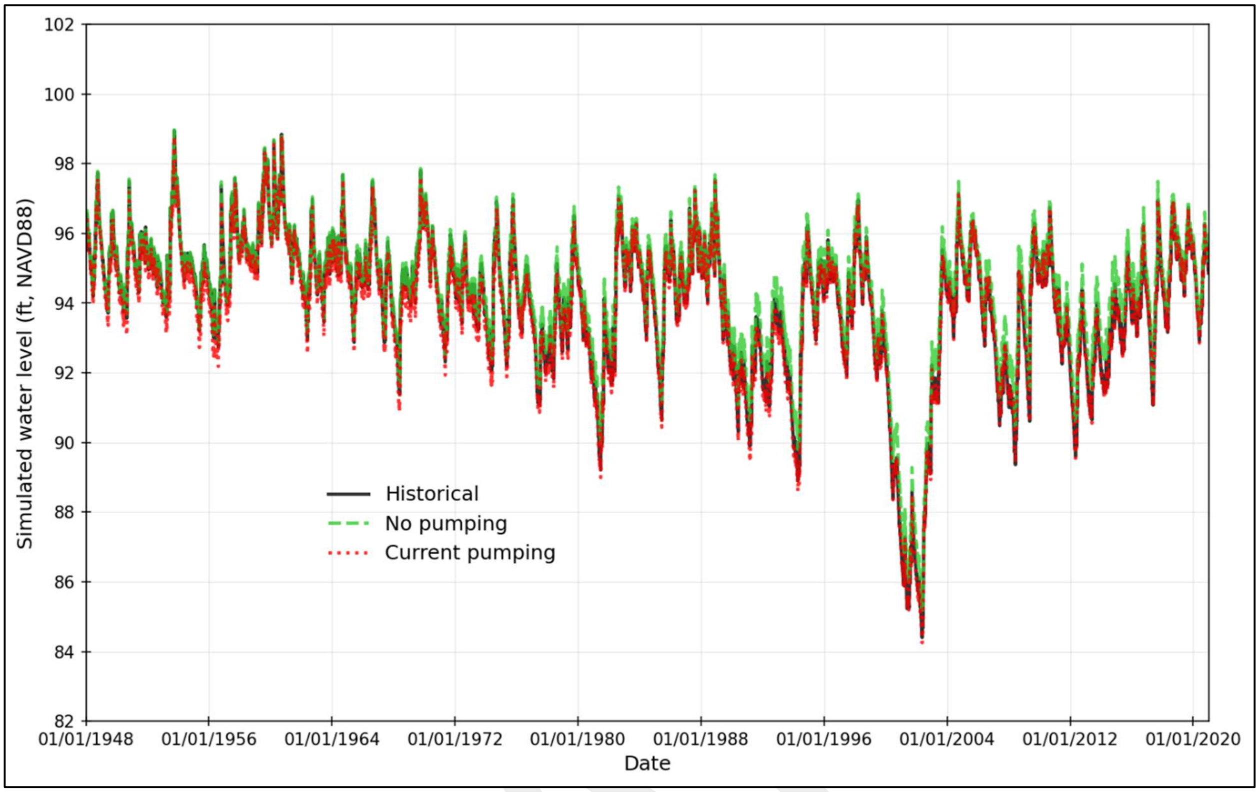

Figure B-15: The simulated historical, no-pumping, and current-pumping condition levels for Johns Lake.

Table B-3: Descriptive statistics of long-term historical, no – and current – pumping water levels of Johns in feet.

Statistics	Historical	No-pumping	Current-pumping
Mean	94.0	94.4	93.8
Standard deviation	2.1	1.9	2.1
Minimum	84.4	85.1	84.3
25% percentile	93.1	93.6	92.9
50% percentile	94.4	94.7	94.2
75% percentile	95.3	95.5	95.1
Maximum	99.0	99.0	98.8
Range	14.6	13.9	14.5

The CP condition lake levels represent a reference hydrologic condition of the lake in which the total regional groundwater pumping impacting the lake is constant from 1948 to 2020 at a rate of averaged pumping from 2016 to 2020. Assuming the present climatic, rainfall, and other conditions of the period from 1948 to 2020 are representative of the conditions over the next 73 years, the current-pumping condition lake levels would reflect the future condition of the lake levels if the average regional groundwater pumping does not change from the period 2016 to 2020 condition. Because of our limited understanding of possible future climatic conditions and uncertainties in global climate model predictions, using historical conditions to generate CP condition lake levels is reasonable.

SUMMARY AND CONCLUSIONS

For long-term lake level simulations and MFLs status assessments of Johns Lake, an Interconnected Channel and Pond Routing version 4 (ICPR4) model was developed that covered the period from 1995 to 2018. The model was calibrated for the period from 2005 to 2018 and validated for the period from 1995 to 2004. The calibrated and validated model was subsequently extended to the period from 1948 to 2020 for long-term simulation and MFLs scenario runs. The model extension included reviewing, compiling, and creating long-term historical datasets, such as hydro-meteorological and groundwater levels data, which were used as model inputs and boundary conditions. The model reasonably reproduced the hydrologic condition of Johns Lake.

For long-term pumping impacts assessment, groundwater levels for no-pumping (NP) and current-pumping (CP) conditions were estimated based on the estimated UFA drawdowns beneath the lake and observed groundwater levels. The East Central Florida Transient Expanded version 2 (ECFTX v2.0) groundwater model simulated the groundwater levels and UFA drawdowns beneath the lake under a wide range of pumping conditions. Because the ECFTX v2.0 model was designed to simulate monthly conditions for the period from 2004 to 2014, the model cannot simulate monthly UFA drawdowns due to pumping over the period from 1948 to 2020. Consequently, a linear relationship between simulated groundwater pumping and UFA drawdowns beneath the lake was developed for the period from 2004 to 2014. The developed linear relationship along with monthly water use data from the SJRWMD databases were used to estimate the monthly drawdowns that later disaggregated into daily impact values using linear interpolation technique. To create NP condition groundwater levels, the daily impact values were added to the daily observed groundwater levels of the period from 1948 to 2020. Then, daily CP condition groundwater levels were generated by subtracting the average drawdown (impact) values of the past five years (2016 to 2020) from the NP groundwater levels.

The long-term NP and CP conditions groundwater levels were fed into the ICPR4 model of Johns Lake as UFA boundary conditions and the corresponding long-term lake levels were simulated. The NP lake levels represent hydrologic conditions in which the lake was assumed to be not under the influence of groundwater pumping, whereas the CP lake levels represent hydrologic conditions in which the lake was assumed to be under the impact of current groundwater pumping condition since 1948. The long-term simulated NP and CP lake levels were used for MFLs determinations and status assessments.

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