HYDROLOGIC MODELING FOR MINIMUM FLOWS AND LEVELS SUPPORT – JOHNS LAKE

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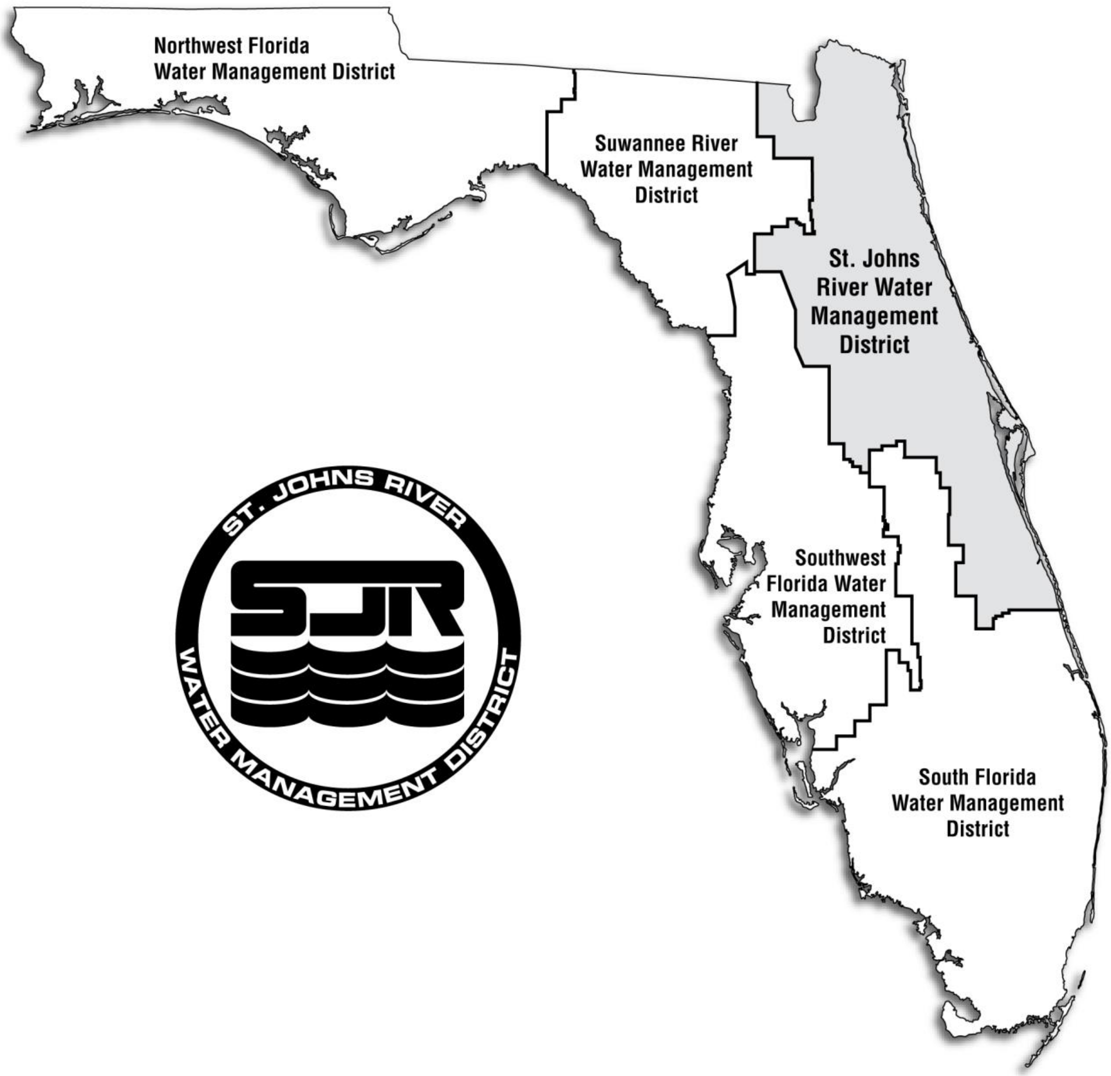
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EXECUTIVE SUMMARY

The St. Johns River Water Management District (SJRWMD) has been establishing Minimum Flows and Levels (MFLs) for Johns Lake. The program designates the minimum hydrologic conditions that must be maintained for the lake to avoid significant harm to water resources and ecosystem services, resulting from permitted water withdrawals. Johns' Lake MFLs are scheduled for adoption in 2023. In support of the MFLs program, SJRWMD used an Interconnected Channel and Pond Routing version 4 (ICPR4) model (Streamline Technologies, 2018) for hydrologic/hydraulic processes, surface water – groundwater interaction, and water budget components modeling of Johns Lake.

Using the available hydro-meteorological and geospatial data, SJRWMD set up the ICPR4 model for the period from 1995 to 2018, manually calibrated and validated the model for the period 2005 to 2018 and 1995 to 2004, respectively. The calibrated and validated model subsequently extended to the period 1948 to 2018 for long-term simulations. SJRWMD then contracted with the Streamline Technologies (SLT) to review the calibrated, validated, and extended model of SJRWMD and improve the simulated results. SLT reviewed and made some modifications to the SJRWMD model that included splitting one groundwater region into four regions, changing the representation of surficial aquifer saturated hydraulic conductivity and fillable porosity and initial lake/groundwater conditions, incorporating additional retention ponds, and refining model resolutions. SJRWMD finally made some further updates to the SLT model, such as modifying the representation of initial groundwater and lake conditions, further adjusting surficial aquifer thickness, adding more crop zones, and replacing the old bathymetry with new bathymetry data for Johns Lake. This project eventually used the updated version of the SLT model, which was later peer reviewed by Applied Technology and Management (ATM) and further updated to address the peer review comments of ATM.

ICPR4 reasonably simulated the observed water levels temporal variations and magnitudes of Johns Lake for both the calibration and validation periods. SJRWMD achieved better model performance statistical values and ratings during the validation period, highlighting the capability of the model in simulating water levels outside the calibration period. More importantly, the model adequately replicated the observed low to medium levels of Johns, which are crucial for MFLs modeling and assessment processes. However, larger discrepancy between the long-term observed and simulated water levels is noticed before 1993, a period when significant urbanization had not occurred or considered as a pre-development period. The decrease in model performance during this period could also be due to additional uncertainties attributed by lack of long-term observed groundwater and rainfall data within the watershed. SJRWMD also found that leakance, vertical and horizontal saturated hydraulic conductivities of the surficial aquifer system are the most important/sensitive parameters for the ICPR4 model of Johns Lake. Overall, the ICPR4 model showed reasonable simulations of hydrologic and surface water – groundwater interaction processes of the lake. Therefore, it is concluded that the model can be used for MFLs modeling and scenarios analysis.

This model summary report summarizes work completed in three tasks that include existing data review and model development (Appendix - 1), model calibration, validation, and long-term simulation (Appendix - 2), and sensitivity analysis (Appendix - 3), including updating the model to address the comments of ATM. The appendices containing the three technical memoranda provide details regarding each task.

Existing Data Review

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 G - 1). The lake receives inflow from Black Lake, which is in turn connected to several upstream lakes and wetland slough systems (Figure G - 1). The lakes that drain to Johns Lake are generally located in the southeast of the lake's watershed. Johns' Lake system drains a roughly 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 G - 1).

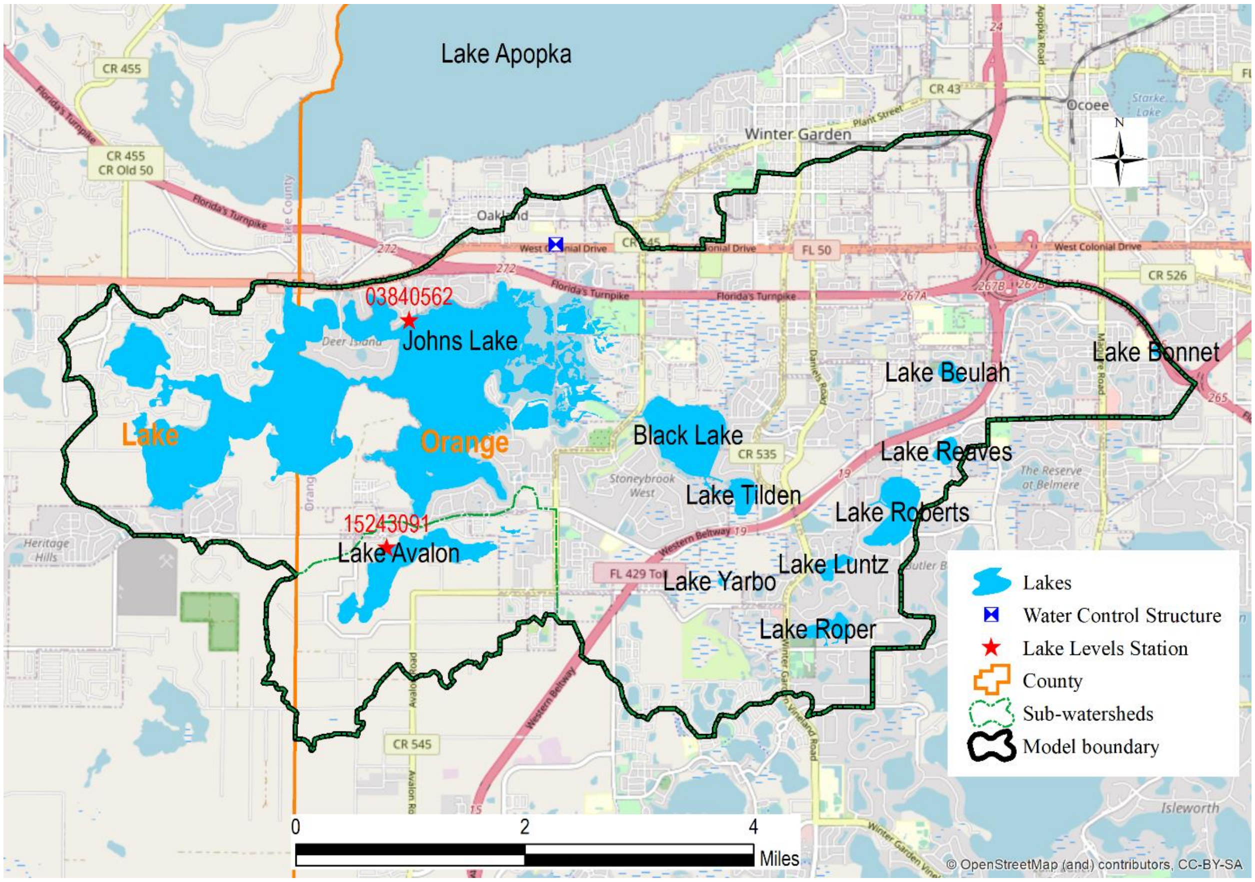

Figure G - 1. Johns Lake watershed in Lake and Orange Counties.

Hydro-meteorological Data

We obtained the hydro-meteorological data from different sources and processed it as documented in Appendix - 1. Figure G - 2 presents locations of the hydro-meteorological stations and NEXRAD pixels. ICPR4 specifically utilized a composite hourly rainfall data from the Isle_Win station (1948 – 1994) and NEXRAD (1995 – 2018), both extracted from the SJRWMD's hydrological databases. The composite annual rainfall values are shown in Figure G - 3. The figure indicates that the lowest rainfall amount was recorded in 2000.

ICPR4 used gridded daily reference evapotranspiration (RET) retrieved from the SJRWMD and USGS's hydrological databases (1985 – 2018). The gridded RET data shares the same pixel's identification with the NEXRAD data (Figure G - 2). Due to lack of RET data within the watershed before 1/1/1985, we derived daily RET values from daily estimated PET data (1948 – 1984) based on the Hargreaves's method (Hargreaves and Samani, 1985) at the National Oceanic and Atmospheric Administration (NOAA) Clermont station. We first calculated monthly correction factors as the ratio of the available RET and PET values at Clermont station for the overlapping period of record (POR), i.e., 1/1/1985 to 12/31/2017. The factors then applied to estimate RET values at Clermont for the period from 1/1/1948 to 12/31/1984. Similarly, we derived monthly correction factors 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 1/1/1985 to 12/31/2017 (see Appendix - 1 for details). Using these factors, we moved the estimated RET data at Clermont station to each pixel of the NEXRAD for the period 1/1/1948 to 12/31/1984. We also validated the estimated RET using the USGS RET data of 1/1/1985 to 12/31/2017 and achieved a monthly coefficient of determination $R^2 >$ 0.9, indicating the reasonable estimation of the RET values from the Hargreaves' PET values. The annual RET values are shown in Figure G - 3. Unlike the annual rainfall value, the lowest annual RET was reported in 2001 (Figure G - 3).

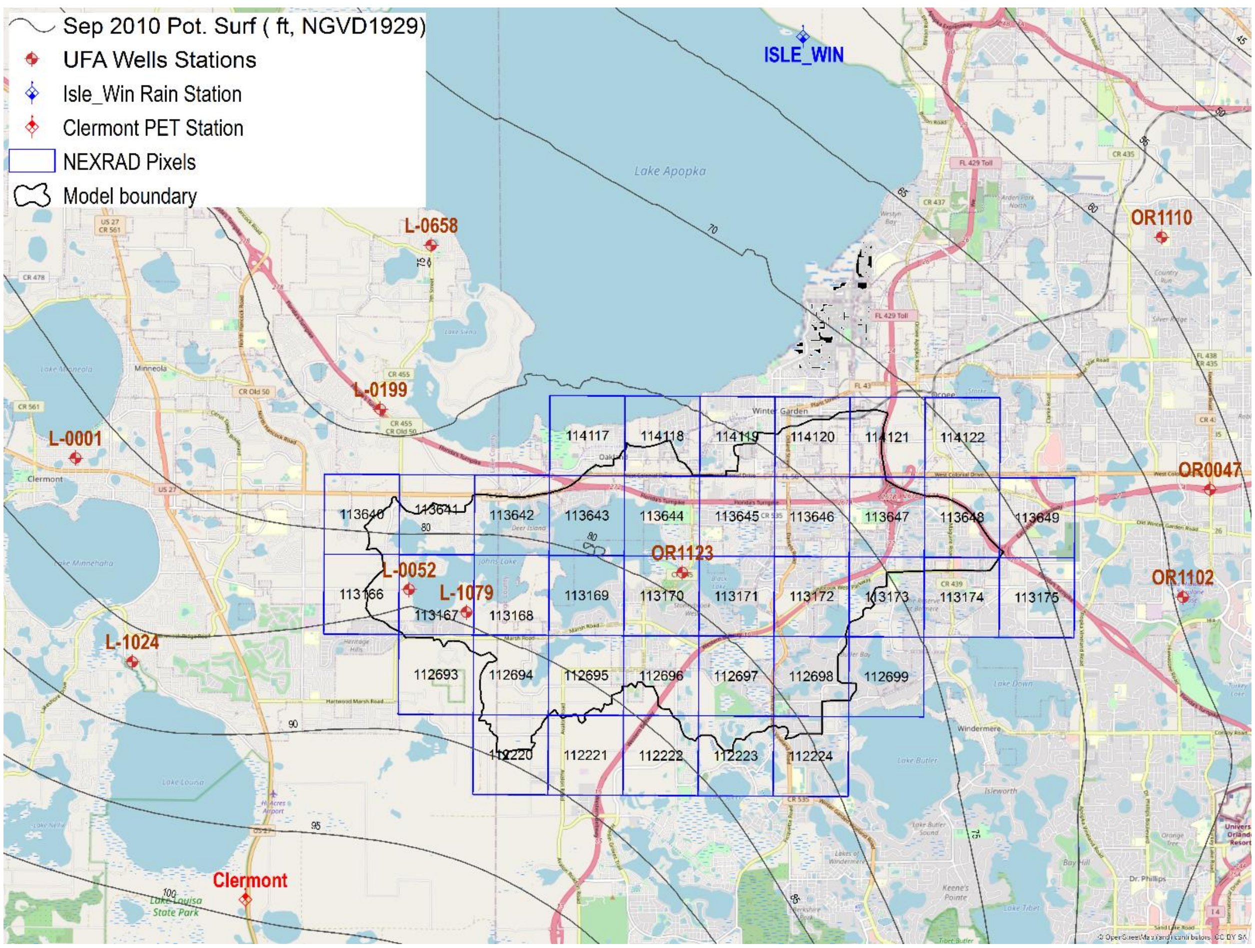

Figure G - 2. NEXRAD pixels identifications and hydro-meteorological stations of Johns Lake.

ICPR4 also used recorded and gap-filled daily groundwater (GW) levels at OR1123, which is located around the center of the watershed (Figure G - 2), along with calculated raster potentiometric offset values with respect to OR1123 location (see Appendix - 1). We used the offset values to spatially vary the recorded groundwater levels at OR1123 and represent the Upper Floridan Aquifer (UFA) stages as boundary conditions. OR1123 has recorded water levels since 10/21/2010, but long-term data back to 1/1/1948 was needed. We used Line of Organic Correlation (LOC) method (Helsel & Hirsch, 2002) to fill the gap at OR1123 with observed data at L0052 (since 6/29/1993) and OR0047 (before 6/29/1993) stations as detailed in Appendix - 1. Extended daily groundwater levels at OR1123 are shown in Figure G - 4. The figure also presents recorded levels of Johns Lake at station 03840562 (Figure G - 1) as retrieved from the SJRWMD's hydrological databases.

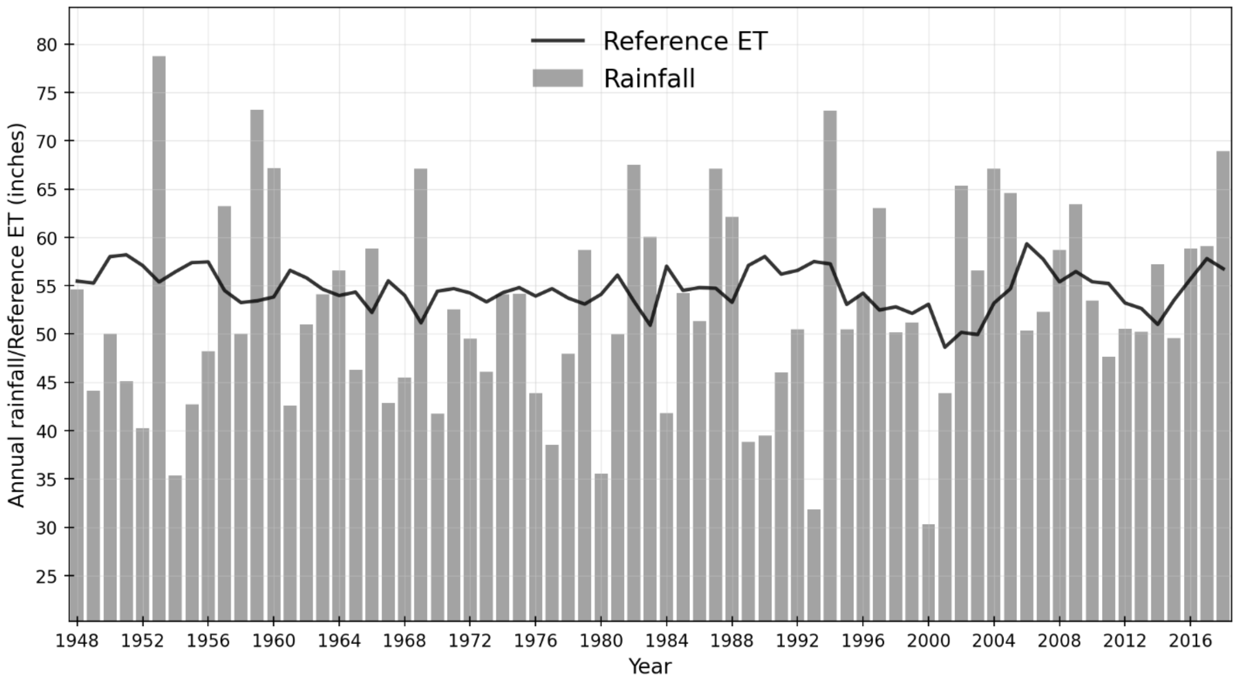

Figure G - 3. Annual rainfall and reference evapotranspiration of Johns' Lake watershed.

Annual average offset values, derived from May and September potentiometric maps of 1978 to 2017, superimposed with observed water level time series at OR1123 to account for potentiometric levels spatial variability and to move up and down the locally observed water levels at OR1123. 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 and September potentiometric maps that were produced from sparsely scattered well data. The approach 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 available) is possible, that would also significantly increase the memory usage of the model and computational demand, especially for the long-term MFLs simulation and scenario runs. For example, based on our experience with the ICPR4 model of Clermont Chain of Lakes developed by Jones and Edmunds Associates (JEA) (2020), using the spatially interpolated May and September potentiometric maps, and superimposing with weekly offset values, doubled the computation demands and memory usage of the model. On the other hand, the simple approach used in the ICPR4 model of Johns Lake produced better results and significantly reduced the computation time and memory usage of the model. Therefore, the groundwater boundary representation approach implemented in the ICPR4 model of Johns Lake is robust and reasonably saves computation time.

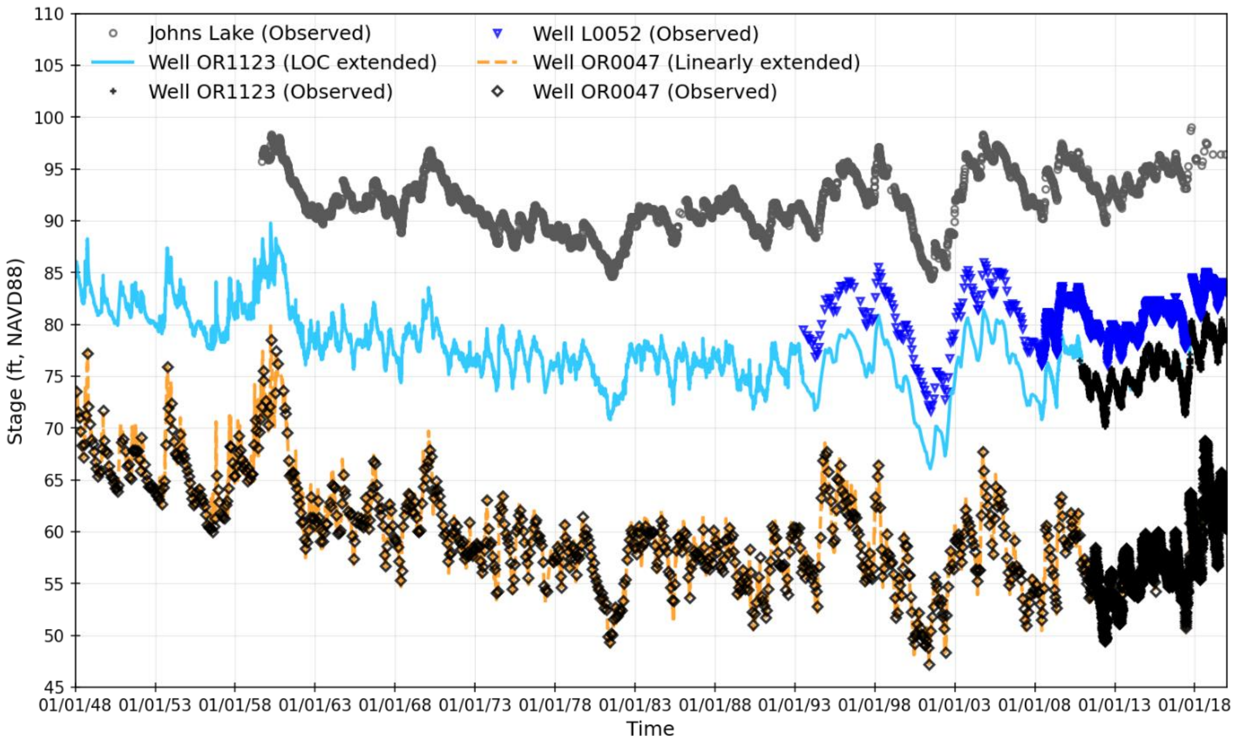

Figure G - 4. Observed and extended groundwater levels at OR1123 (LOC = Line of Organic Correlation).

Geographic Information System (GIS) Data

ICPR4 utilized various geospatial data, such as Digital Elevation Model (DEM), Land Use/Land Cover (LULC), and Soil maps. We burned Johns and Avalon's Lakes bathymetry data into the topography DEM data available in the SJRWMD's GIS databases. Figure G - 5 presents the final DEM with bathymetry used in the ICPR4 model.

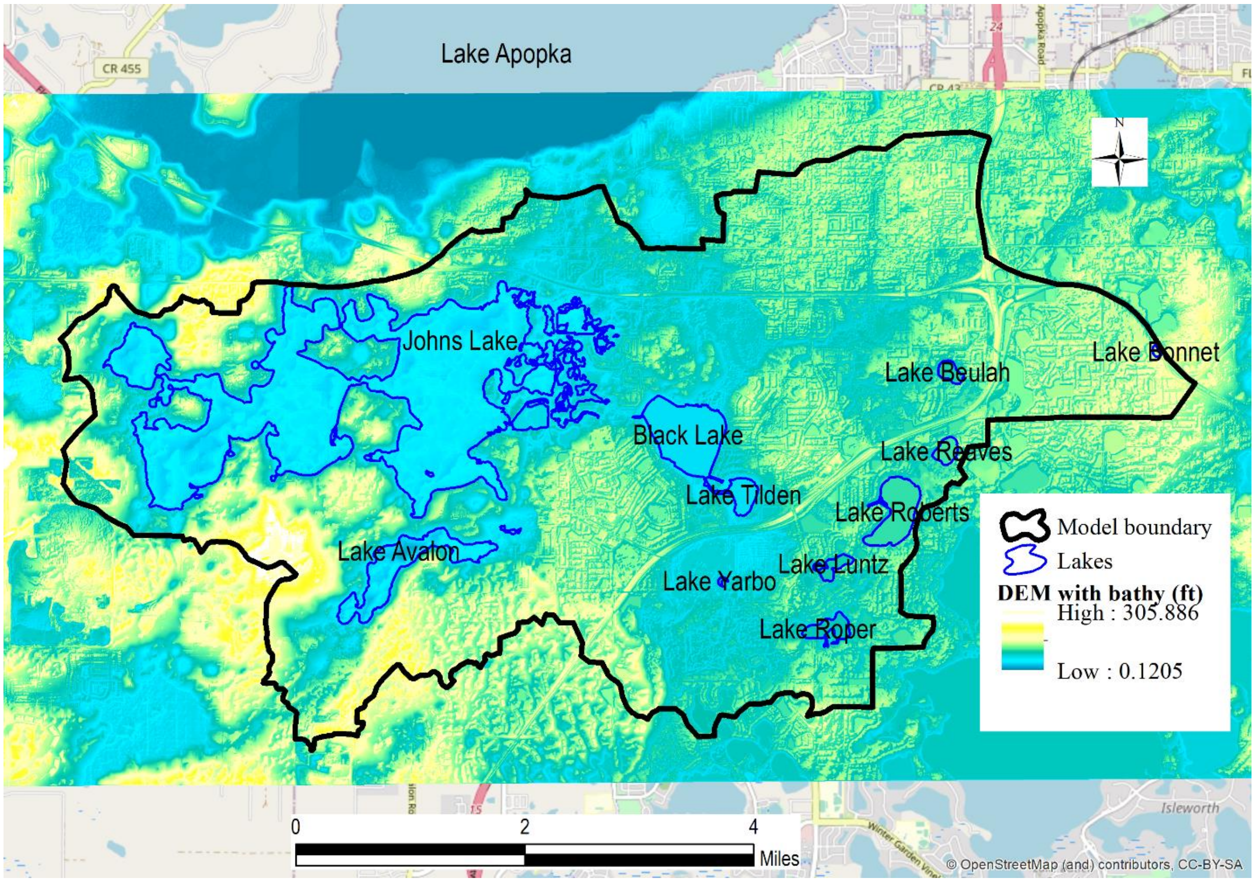

Figure G - 5. DEM burned with bathymetry data as obtained from Hydroperiod Tool of Johns Lake. Values reported in NAVD88.

ICPR4 used the 2014 LULC map as modified by Collective Water Resources (CWR) (2019) based on the aerial imagery of 2017 for the Storm Water Management Model (SWMM) (Rossman, 2015) modeling application to Johns and Avalon Lakes. However, the modified LULC is limited to the area within the watershed boundaries of Johns and Avalon Lakes. As ICPR4 requires a large buffer zone around the boundary edges, we extended the CWR (2019)'s LULC map by using the SJRWMD's LULC map of 2014. The extended LULC data is shown in Figure G - 6.

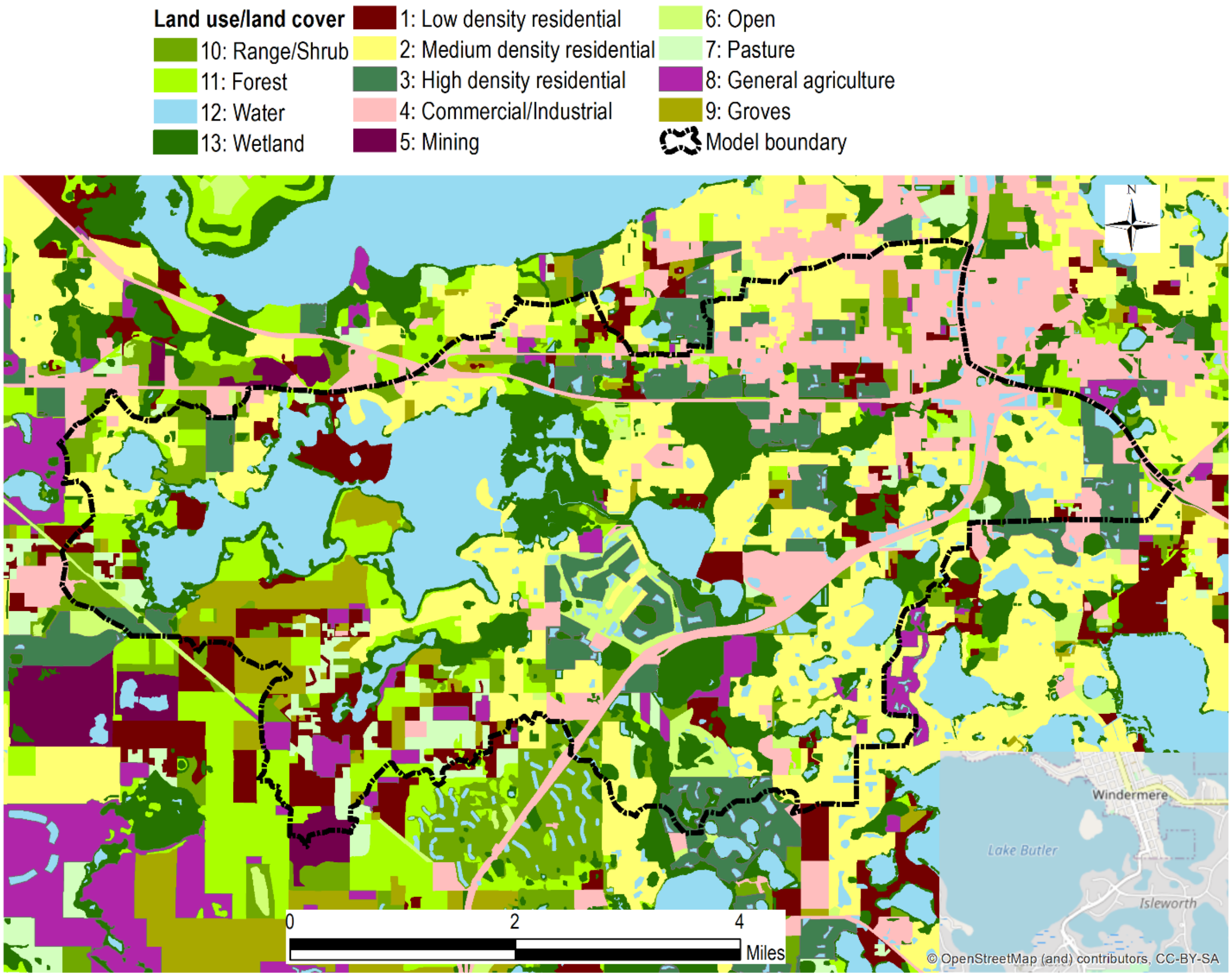

Figure G - 6. Extended Land Use/Land Cover (LULC) 2014. Number in the legend represents SJRWMD's LULC code.

We obtained soil maps for Lake and Orange Counties from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) databases (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr12/tr/?cid=nrcs142p2_010596). We then processed, analyzed, and derived required properties for ICPR4 at Map Unit Key (MUK) scale. While the approach used to process and generate MUK data and properties are detailed in Appendix - 1, Figure G - 7 shows the soil hydrologic groups of the study area.

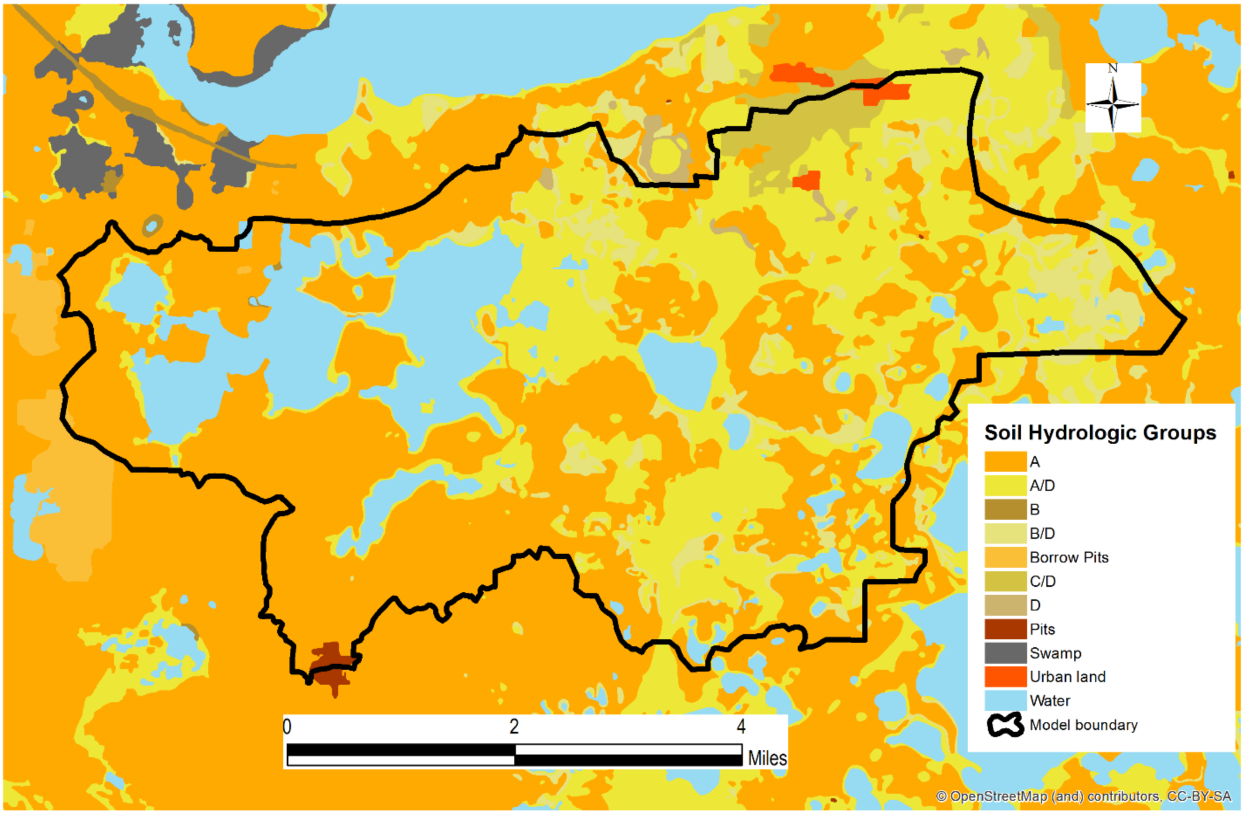

Figure G - 7. Soil hydrologic groups of the study area.

Water Control Structures Data

For Johns Lake watershed, CWR (2019) collected existing water control structures and corresponding data from previous studies (Miller Sellen Connor & Walsh, 2003; Robison, 2008) and the Florida Department of Environmental Protection (FDEP). Then, they combined the data with the Environmental Resources Permit's data provided by SJRWMD in 2018, including their field survey data of October 2018. CWR (2019) reviewed, analyzed, and used this composite data for the Storm Water Management Model (SWMM) modeling application to Johns and Avalon Lakes. CWR (2019) well documented the different sources of the data and described in detail, specifically in their tasks A and B reports of Johns and Avalon Lakes. We exported the structural data used in the SWMM model and the corresponding properties that in turn used for the ICPR4 model of Johns Lake. However, after model peer review report by ATM (2022), we also received ICPR4 model of Johns Lake system developed by CDM Smith (2021) for flood modeling purpose.

Table G – 1 compares the water structural data extracted from both the SWMM model of CWR (2019) and ICPR4 model of CDM Smith (2021), including the data used by SJRWMD. The data reported in Table G – 1 limited to the existing water control structures from Black Lake to Johns Lake outfall until the West Orange Trail. As summarized in Table G – 1, some differences can be noticed between the structural data obtained from the SWMM model of CWR (2019) and ICPR4 model of CDM Smith (2021). Assuming the data from the CDM Smith (2021) model is up to date, we updated the peer reviewed ICPR4 model by ATM (2022) and replaced with the data extracted from the ICPR4 model of CDM Smith (2021).

Table G – 1. Comparison of water control structures from Black Lake to West Orange Trail.

Source	Name	Upstream invert (ft, NAVD88)	Downstream invert (ft, NAVD88)	Depth (ft)	Width (ft)	Geometry	Remark
CWR (2019)	Dual box culverts at Avalon Drive	89.10	89.00	5	9	Rectangular	
	Box-culvert at Florida's Turnpike	88.36	88.26	10	10	Rectangular	
	Dual RCP Pipe at south of SR50	91.75	91.89	6	6	Circular	
	Dual box culverts under SR50	84.78	84.75	11	8	Rectangular	
	CMP Pipe with slide gate at north of SR50	93.33	93.23	6	6	Circular	
	CMP Pipe at north of SR50	94.50	94.40	3.5	3.5	Arch	
	Culvert 1 at East Oakland Avenue	92.18	92.65	3.5	3.5	Horizontal Ellipse	
	Culvert 2 at East Oakland Avenue	92.93	93.05	3	3	Circular	
	Dual pipe at West Orange Trail	90.14	89.63	4	4	Circular	
SJRWMD (2021)	Dual box culverts at Avalon Drive	89.10	89.00	5	9	Rectangular	
	Box-culvert at Florida's Turnpike	NA	NA	10	10	Rectangular	Not modeled[a]
	Dual RCP Pipe at south of SR50	91.75	91.89	6	6	Circular	
	Dual box culverts under SR50	NA	NA	11	8	Rectangular	Not modeled[a]
	CMP Pipe with slide gate at north of SR50	93.33	93.23	6	6	Circular	
	CMP Pipe at north of SR50	94.50	94.40	3.5	3.5	Arch	
	Culvert 1 at East Oakland Avenue	92.18	92.65	3.5	3.5	Horizontal Ellipse	
	Culvert 2 at East Oakland Avenue	92.93	93.05	3	3	Circular	
	Dual pipe at West Orange Trail	90.14	89.63	4	4	Circular	
CDM Smith (2021)	Dual box culverts at Avalon Drive	89.15/89.2*	89.73/89.7*	5	9	Rectangular	Slightly different elevation used
	Box-culvert at Florida's Turnpike	88.30	88.47	10	11	Rectangular	
	Dual RCP Pipe at south of SR50	91.75/91.79*	92.07/92.1*	5	5	Circular	Slightly different elevation used
	Dual box culverts under SR50	85.04/85.05*	85.18/85.2*	10.9167/10.833*	9	Rectangular	Slightly different elevation/diameter used
	CMP Pipe with slide gate at north of SR50	93.41	93.55	5.75/5.5833*	5.75/5.5833*	Circular	Slightly different diameter used
	CMP Pipe at north of SR50	94.71	95.00	3.3333	3.3333	Horizontal Ellipse	
	Culvert 1 at East Oakland Avenue	92.54	92.24	4.75	4.75	Horizontal Ellipse	
	Culvert 2 at East Oakland Avenue	NA	NA	NA	NA	NA	Not modeled[a]
	Dual pipe at West Orange Trail	89.89/90.08	89.32/90.16*	4	4	Circular	Slightly different elevation used

*Upstream/downstream values correspondingly used for the upstream and downstream part of the structures. [a]**Not modeled** means the large box culverts were eliminated from modeling since they experience insignificant losses due to other constrictions in the system and to speed up the computation time.

Other Data

Additional data that we analyzed, processed, and used for the ICPR4 model includes (see Appendix - 1 for details):

- **Imperviousness fraction** – obtained from the values reported by CWR (2019) for the SWMM model of Johns and Avalon Lakes.
- **Crop coefficient (kc) and root depth** – kc values obtained from the values used in Hydrological Simulation Program – Fortran (HSPF) and other ICPR models at the SJRWMD. These datasets were used to create monthly composite values for the thirteen LULC shown in Figure G - 6. Regarding root depth, we considered GW evapotranspiration extinction depth proposed by Shah et al. (2007). We zoned the thirteen LULC into five classes (forest, grassland, bare-land, wetland, and water) and then assigned extinction depth based on the values documented in Shah et al. (2007) and study area’s soil types (see Attachment A – 3 of Appendix - 1).
- **Fillable porosity (fp)** – derived as the soil moisture content values at saturation point minus the values at field capacity based on SSURGO data, which is based on previous study (Streamline Technologies, 2018).
- **Horizontal saturated hydraulic conductivity (kh)** – assumed to be twice the vertical saturated hydraulic conductivity values obtained from SSURGO data.
- **Time of concentration (Tc)** – calculated using the watershed lag method documented in the NRCS National Engineering Handbook (part 630.1502) (NRCS, 1986) for each mapped basin of ICPR4.

MODEL DEVELOPMENT

Based on the previously discussed geospatial, hydro-meteorological, and other data, including the data used in the SWMM model of Johns and Avalon Lakes (CWR, 2019), we set up the ICPR4 model for the period 1995 to 2018. ICPR4 used all the sub-basins delineated by CWR (2019) for the SWMM model as mapped basins (see Figures B – 14 and B – 15 of Appendix - 1). The model also used stage/area and stage/time nodes, links, overland flow weirs, orifice, and other hydraulic structures implemented in the SWMM model. ICPR4 replicated all the nodes represented in the SWMM model of CWR (2019) except for outfall nodes used to connect them with the UFA system and the corresponding junction nodes. Furthermore, we retrieved node information and data such as stage-area curves from the SWMM model. However, since the DEM used by the ICPR4 model was mosaiced with bathymetry data for Johns and Avalon Lakes, we directly extracted the stage-area curves of the two lakes from the DEM. We referenced all elevations and water levels data to the North American Vertical Datum 1988 (NAVD88).

Open and closed conduit links in the SWMM model were represented as open channel and pipe links, respectively, in the ICPR4 model (Figure G - 8). Conduits combined with orifice links in the SWMM model were modeled as drop structures in the ICPR4 model. SWMM used trapezoidal surface overflow weirs to connect modeled nodes, should flows occur outside the primary conveyance features, such as due to bank overtopping. We implemented these weirs as irregular overland flow in ICPR4 model that typically occurs along the ridges between mapped basins or along the roadways (Figure G - 8) and generated their cross-sections from the DEM map. To speed up the run time, SLT

(2021) reviewed the model set up by SJRWMD and refined some of the implemented hydraulic structures (see Task C report of SLT (2021) for details).

For water bodies and wetland areas where surface water – groundwater interaction is expected to be significant, we used a 2D overland flow region by implementing the pond control volumes (PCVs) feature of ICPR4 and generating the corresponding 2D mesh for those portions (see Figure G - 8). SLT (2021) added more PCV elements to the model set up by SJRWMD, including splitting a single groundwater flow region into four regions and increasing mesh resolutions. The Model Development section of Appendix - 1 provides details on the original model set up by SJRWMD, while the SLT (2021) Task C report provides details on their modifications to the SJRWMD model.

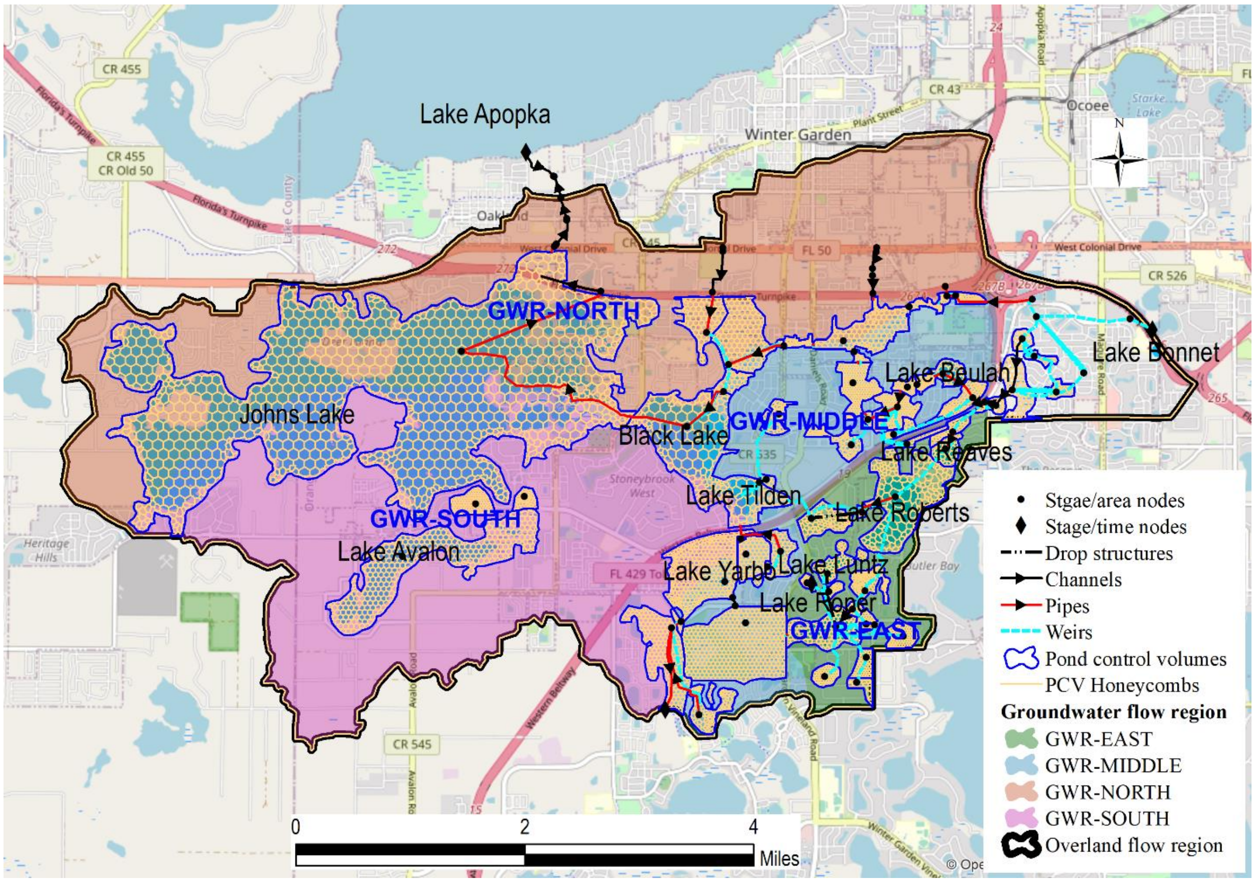

Figure G - 8. Model schematic, overland flow region, pond control honeycombs, and four groundwater flow regions (GWR).

Model Updates

We used the non-continuous daily observed water levels at station 03840562 for Johns Lake (see Figure G - 1) and performed model calibration and validation procedures. To match simulated levels with observed levels, we manually calibrated the ICPR4 model for the period 2005 to 2018 and validated it for the period 1995 to 2004. Consequently, we extended the calibrated and validated to the period from 1948 to 2018 and ran the long-term simulation as detailed in Appendix - 2. SLT (2021) reviewed the calibration and validation results and made some adjustments to the original calibrated and validated ICPR4 model by the SJRWMD. Specifically, SLT (2021) modified the representation of the initial groundwater and lake conditions with the simultaneous use of a 2-year warm up period, added a few mapped-basins, converted spatially varied horizontal saturated hydraulic conductivities and fillable porosity values of the surficial aquifer system to constant values, and doubled the original calibrated leakance values of Johns Lake, while reducing them by 90% for the wetland portion of the PCV bordering the lake. We made further adjustments to the SLT model that included putting back the leakance value to the original calibrated value for the wetland part of Johns Lake, increasing surficial aquifer system thickness, modifying the representation of initial groundwater and lake conditions, avoiding the use of a 2-year warm up period, and updating the old bathymetry of Johns Lake with a new bathymetry data set that was recently produced by the SJRWMD for a Hydroperiod Tool database of Johns Lake. The calibrated, validated, and long-term results, including the calibrated parameters and their optimized values are detailed in Appendix - 2. However, after model peer-review by ATM (2022), we further updated the model to address the review comments and re-ran the model for the period from 1948 to 2018. Major modifications to the model include:

- **Updating the water control structural data and properties** – as previously discussed, ATM (2022) recommended using the water control data from the CDM Smith (2021) model of Johns Lake. Based on the data extracted from the CDM Smith (2021) model, we updated and replaced the water control structures data used from the CWR (2019) model that applied to the existing structures from Black Lake to Johns Lake outfall until the West Orange Trail (Figure G - 8).
- **Using hot start** – ATM (2022) identified model numerical instabilities for a few nodes and links at the beginning of the simulation. We addressed this issue by running the model for the period 2003 to 2018 and selecting a date and corresponding simulated results, which are close to the average observed water levels of the system. We used the selected simulated values as a hot start for the model. This resolved the initial conditions issue throughout the system as detailed in the resolution document.
- **Aligning and extending some weirs' cross-sections** – ATM (2022) commented weir cross section alignments and enclosures issues for some links. We extensively reviewed all the weirs implemented in the model and made some alignments and extensions to ensure weir enclosure as needed.
- **Updating some channels cross-section –** after model peer review comments of ATM (2022), we revised all the channels that previously used one cross-section. Depending on the length of the channels and topographic variations, we used different cross-sections for the upstream and downstream part of some channels.
- **Increasing the leakance value for Lake Beulah** – ATM (2022) noticed ICPR4 consistently overestimated the observed water levels of Lake Beulah. Although this lake is far upstream of Johns Lake (Figure G - 1), it makes contribution to the link that delivers major inflows to the Black Lake. Thus, by increasing the leakance value of the lake, we further improved the simulated water levels of Lake Beulah and better matched with the observed water levels.

SIMULATED WATER LEVELS

Figure G - 9 compares the simulated water levels of Johns Lake with observed water levels for the period from 1948 to 2018. The figure also compares long-term simulated water levels before and after updating the ICPR4 model. Table G - 2 summarizes the goodness-of-fit metrics for both the old and updated model results. Although long-term historical runs using current conditions should not be expected to match observed data under very different historical conditions, Table G - 2 presents the goodness-of-fit statistical values as additional information. As reported in Figure G - 9 and Table G - 2, updating the old model based on the peer review comments of ATM (2022) had minor impact on simulated water levels of Johns Lake and on the goodness-of-fit statistical values. Therefore, re-calibrating and re-validating the updated model are not necessary.

Table G - 2. Goodness-of-fit statistics for daily water levels simulation.

Statistics	**Symbol**	**Old model**		**Updated model**	
		Calibration/validation (1995-2018)	**Long-term (1948-2018)**	**Calibration/validation (1995-2018)**	**Long-term (1948-2018)**
Nash-Sutcliffe Efficiency	NSE	0.92	-0.25	0.92	-0.39
Root mean squared error	RMSE	0.96	3.04	0.92	3.19
Mean error	ME	-0.23	2.14	-0.18	2.30
Absolute mean error	AME	0.79	2.47	0.76	2.60
Percent bias	PBIAS	-0.25	2.33	-0.50	2.52
Pearson correlation coefficient	R	0.95	0.61	0.95	0.59
Percent of observation bracketed within ± 1 foot	±1ft (%)	67.91	25.89	69.31	25.66

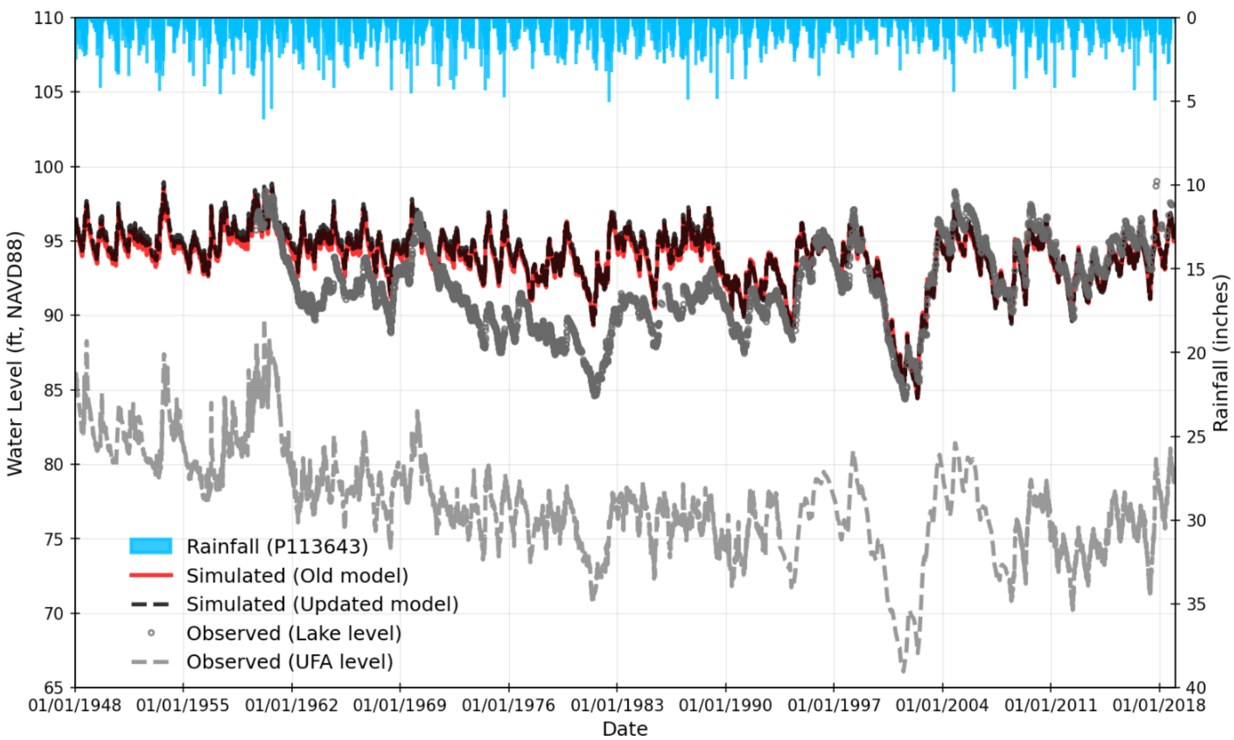

Figure G - 9. Observed and simulated long-term water levels of Johns Lake.

ICPR4 reasonably simulated and tracked the temporal patterns and magnitudes of observed levels of Johns Lake for both the calibration (2005-2018) and validation (1995-2004) periods. This is also confirmed with good statistical values as reported in Table G - 2. More importantly, low to medium observed levels of Johns are better reproduced by the model during the calibration and validation periods (Figure G - 9), which are crucial for MFLs assessment.

The daily long-term simulated water levels adequately represented the temporal evolutions and variations of the long-term observed water levels of Johns Lake (Figure G - 9). However, the figure clearly indicates that the model noticeably overestimated the pre-development observed levels, especially for the period 1962 to 1992 that resulted in poor model performance for long-term simulation (Table G - 2). Although the specific reasons are unclear, we found that the large discrepancy during this period could be related to:

- The extended groundwater (GW) levels based on observed data from outside the watershed
- Significant land use/land cover (LULC) developments in the watershed
- Lack of long-term observed rainfall data within the watershed as the model used a composite gauged data from outside the watershed for the period 1948 to 1994

The observed levels of Johns Lake, well OR1123 and well OR0047 that are shown in Figure G - 4 showed significantly different correlation values over the POR. For example, although the correlation between observed levels at OR1123 and OR0047 is strong (R^2 = 0.88), the correlation between Johns Lake and OR0047 is very weak (R^2 = 0.14) for the entire POR (Figure G - 4). However, if the dataset is split into before and since 1993, the correlation values drastically increased for both datasets ($R^2 \geq$ 0.60), indicating the relationship between the lake and GW levels might have changed over time. OR0047, which is located outside the watershed (Figure G - 2), is used to fill missing values at OR1123 before 1993. Although OR0047 and Johns showed strong correlation if split into two datasets, the estimated GW levels at OR1123 based on observed levels of Johns Lake and well OR0047 showed about 6 ft difference, on average, during the pre-development period (before 1993). Since the LOC regression between OR0047 and OR1123 was developed based on the overlapping POR at OR1123 (since 10/21/2010), it is likely that additional bias was introduced into the extended GW levels at OR1123 for the pre-development period. Furthermore, SJRWMD noticed substantial LULC change based on the historical LULC maps of 1973, 1990, 1995, and 2014. The analysis indicated that more than 30% of the pre-development agricultural land converted to developed areas between 1970 and 2014. Since the model used LULC from 2014, this could also likely contribute additional uncertainties to the simulated levels of Johns.

In general, considering the pre-development LULC (converting developed areas to agriculture land – assuming the pre-development agriculture as Grove) and adjusting the pre-development estimated groundwater levels at OR1123 (reducing the estimated levels by 6 ft) appeared to improve the match between observed and simulated levels of Johns Lake for the pre-development period. However, this could be at the cost of systematically underestimating the post-development observed lake levels (see Figures C – 21 and C – 22 of Appendix - 2). We thus believed that the large discrepancy between observed and simulated levels of the pre-development period could be due to additional uncertainties arose from lack of long-term observed groundwater and rainfall data in the watershed, including noticeable LULC change. Therefore, the simulated levels of pre-development period should be used with caution. For example, given the long-term POR of Johns Lake, the MFLs analysis may use the observed levels adjusted with the differences derived from simulated historical and scenario levels instead of directly using the simulated lake levels.

SENSITIVITY ANALYSIS

We performed model sensitivity analysis (SA) using a one-factor-at-a-time (OAT) method, which is commonly called the "local" method (Saltelli et al., 2004; Campolongo et al., 2010). The method varies one model input parameter value at a time while other model input parameter values are kept constant. By changing one parameter value at a time, we evaluated the influence/importance of certain parameters of the ICPR4 model on the simulated levels of Johns. We compared and evaluated the sensitivity of five selected parameters (Table G - 3) with respect to the calibration results. SA utilized the model calibration period of the extended model (2005 – 2018). We perturbed the calibrated values of the five selected parameters as summarized in Table G - 3. The table also provides simulated and relative changes in minimum, mean, and maximum simulated water levels of Johns Lake. Appendix - 3 provides details on the SA results.

Table G - 3. Impact on minimum, maximum, and mean simulated levels. Bold refers to ≥ |±1%| change.

Parameter	Calibrated value	Calibration			Sensitivity			Percent change		
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Ia	Decreased by 10%	89.6	97.0	93.6	89.7	97.0	93.6	0.08	0.01	0.04
	Decreased by 20%				89.7	97.1	93.6	0.09	0.07	0.05
	Increased by 10%				89.6	97.0	93.6	-0.03	-0.01	-0.04
	Increased by 20%				89.5	97.0	93.6	-0.08	-0.03	-0.04
kc	Decreased by 10%	89.6	97.0	93.6	90.1	97.3	93.9	0.63	0.31	0.35
	Decreased by 20%				90.7	97.6	94.2	**1.28**	0.57	0.70
	Increased by 10%				89.0	96.8	93.2	-0.68	-0.22	-0.37
	Increased by 20%				88.5	96.8	92.8	**-1.25**	-0.22	-0.82
kv	Divided by 2	89.6	97.0	93.6	86.8	96.8	92.1	**-3.10**	-0.22	**-1.62**
	Divided by 3				85.7	96.8	91.3	**-4.32**	-0.22	**-2.50**
	Multiplied by 2				90.8	97.3	94.1	**1.36**	0.34	0.50
	Multiplied by 3				90.8	97.1	93.8	**1.41**	0.12	0.22
kh	Divided by 2	89.6	97.0	93.6	91.0	97.6	94.3	**1.54**	0.59	0.76
	Divided by 3				91.3	97.7	94.5	**1.95**	0.76	0.96
	Multiplied by 2				87.8	96.8	92.7	**-1.98**	-0.22	-0.95
	Multiplied by 3				86.8	96.8	92.1	**-3.10**	-0.22	**-1.64**
k	Divided by 2	89.6	97.0	93.6	93.8	98.5	95.7	**4.70**	**1.54**	**2.20**
	Divided by 3				94.5	98.8	96.0	**5.47**	**1.88**	**2.60**
	Multiplied by 2				83.6	96.8	88.2	**-6.70**	-0.22	**-5.80**
	Multiplied by 3				82.7	96.8	86.6	**-7.70**	-0.22	**-7.46**

We found that increasing or decreasing the calibrated initial rainfall abstraction (Ia) values by 10 or 20% barely changes the simulated lake levels (Table G - 3 and Figure G - 10), and similarly for crop coefficient (kc) values (Table G - 3 and Figure G - 11). On the other hand, both saturated vertical (kv) and horizontal (kh) hydraulic conductivities of the surficial aquifer system (SAS) relatively showed moderate impact on simulated levels of Johns (Table G - 3, Figure G - 12, and Figure G - 13). Leakance (k) values, which control the flux to or from the lake, is the most sensitive/important parameter for Johns Lake (Table G - 3 and Figure G - 14).

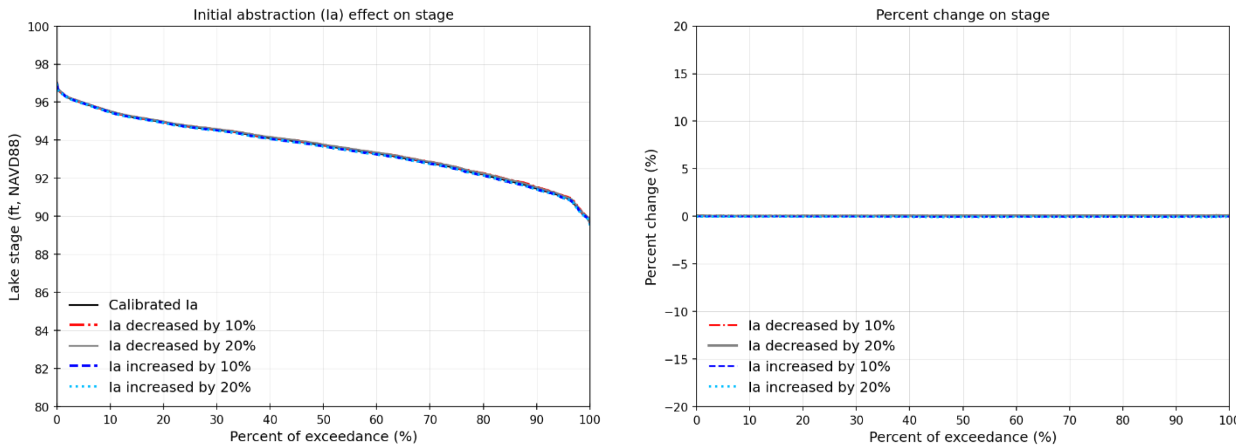

Figure G - 10. Impact of initial rainfall abstraction on simulated stages of Johns Lake

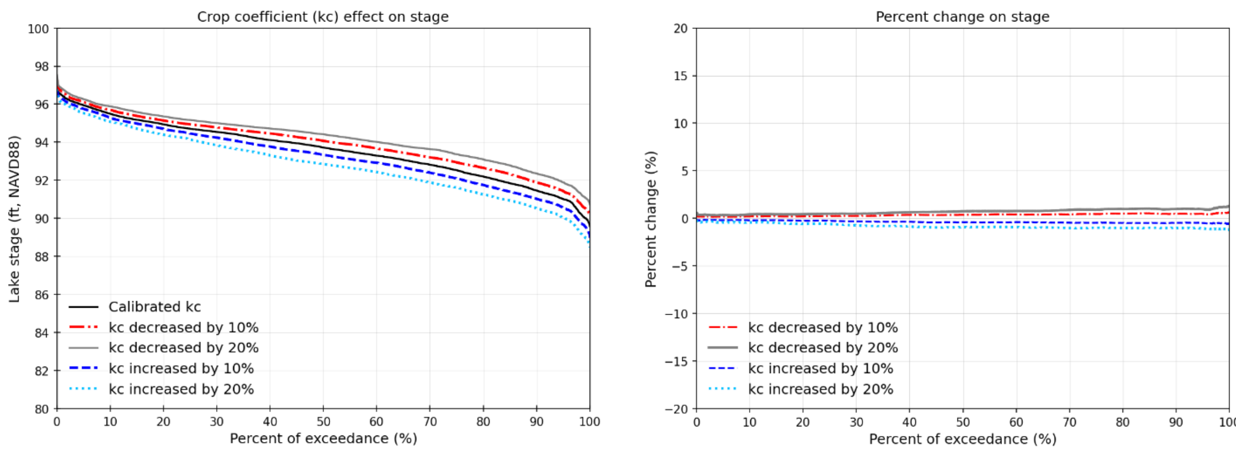

Figure G - 11. Impact of crop coefficient on simulated stages of Johns Lake

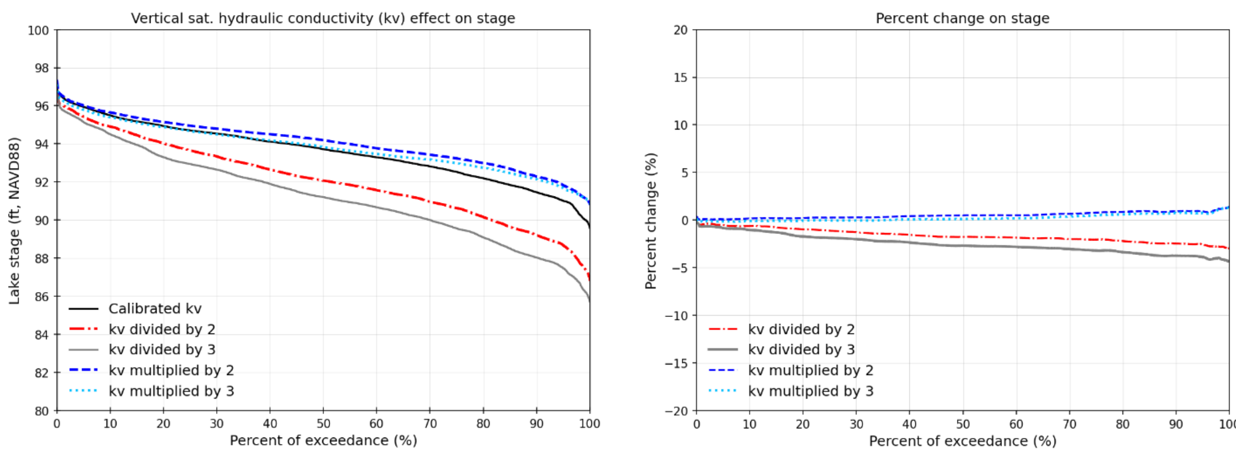

Figure G - 12. Impact of vertical saturated hydraulic conductivity on simulated levels of Johns Lake.

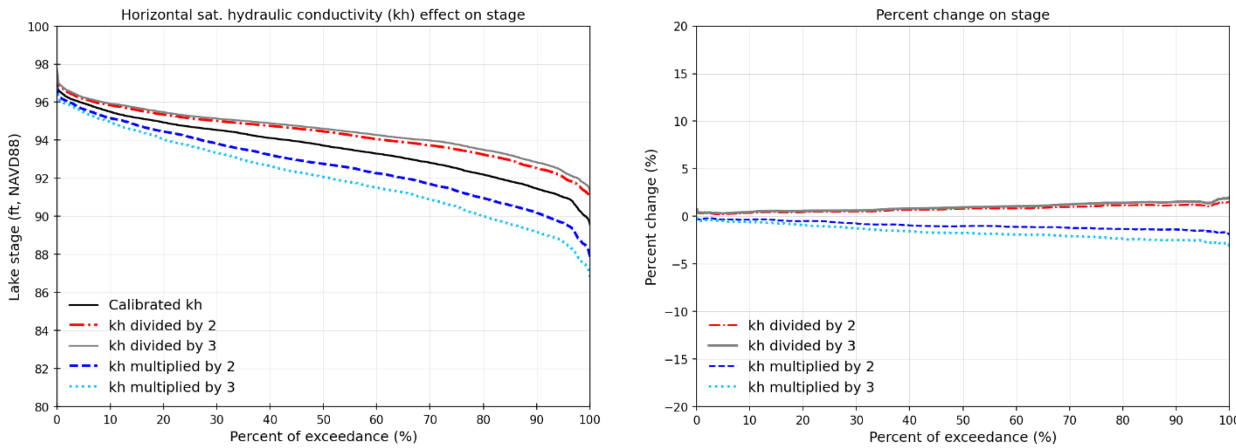

Figure G - 13. Impact of horizontal saturated hydraulic conductivity on simulated levels of Johns Lake

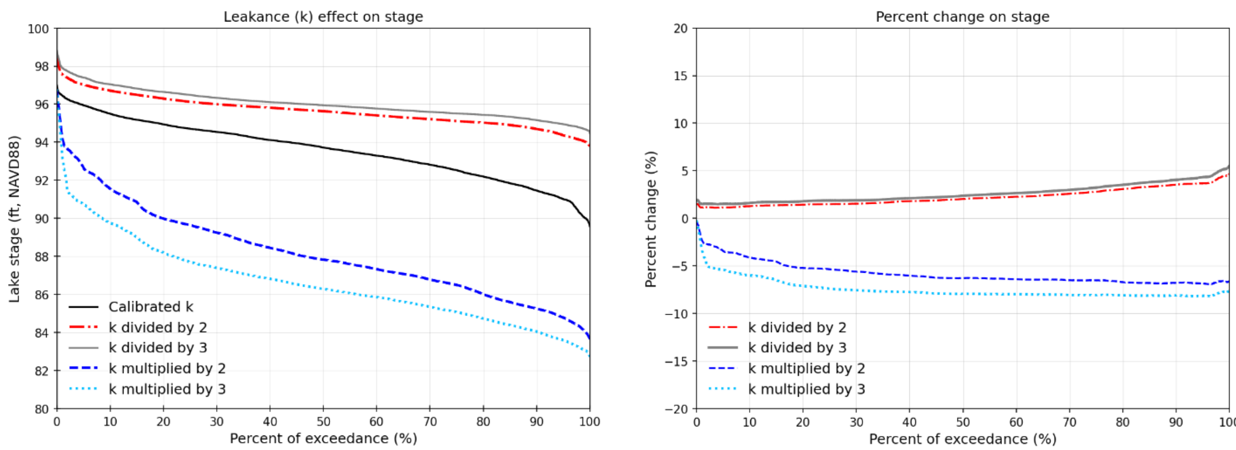

Figure G - 14. Impact of leakance value on simulated levels of Johns Lake

It is expected that leakage can move the simulated lake level hydrographs downward when kv is increased and vice versa. Increasing the calibrated kv values of Johns' watershed also appears to increase the leakage of the system, but we noticed that the increased amount is relatively small compared to the amount of link inflows and seepage rates into the lake from the upstream areas (see Appendix - 3 for details). Consequently, the simulated levels of Johns Lake are shifted upward although kv is multiplied by a factor of 2 or 3 (Figure G - 12). This could be due to an increase in hydraulic gradient between the lake and SAS along with an increase in sub-surface inflows as we also noticed the simulated levels are higher than the calibrated levels of the lake. Overall, k, kv, and kh are identified as the most important parameters for Johns Lake hydrologic system modeling.

Due to lack of accurate data for the existing Johns Lake outfall water control structures and new water control developments particularly in the downstream part of the lake, we performed additional sensitivity analysis (SA) of Johns Lake to the water control operation and invert elevation value. This SA specifically focused on water control structure located just downstream of the West Colonial Drive (WCD) (Figure G - 1), particularly weir link invert elevation that represents a paved channel between WCD and water control structure. SA results indicated that Johns Lake did not show sensitivity to the water control opening operation. For example, changing the assumed weir opening position from two-third to full of the pipe dimension did not have any effects on the simulated water levels of Johns Lake (Figure G - 15). However, the lake somehow showed sensitive to the weir link representing a paved channel between the WCD and water control structure as lowering the weir invert elevation by 0.5 feet would generally cause an overall decrease (up to -0.12 ft) in daily simulated water levels of Johns Lake (Figure G - 15).

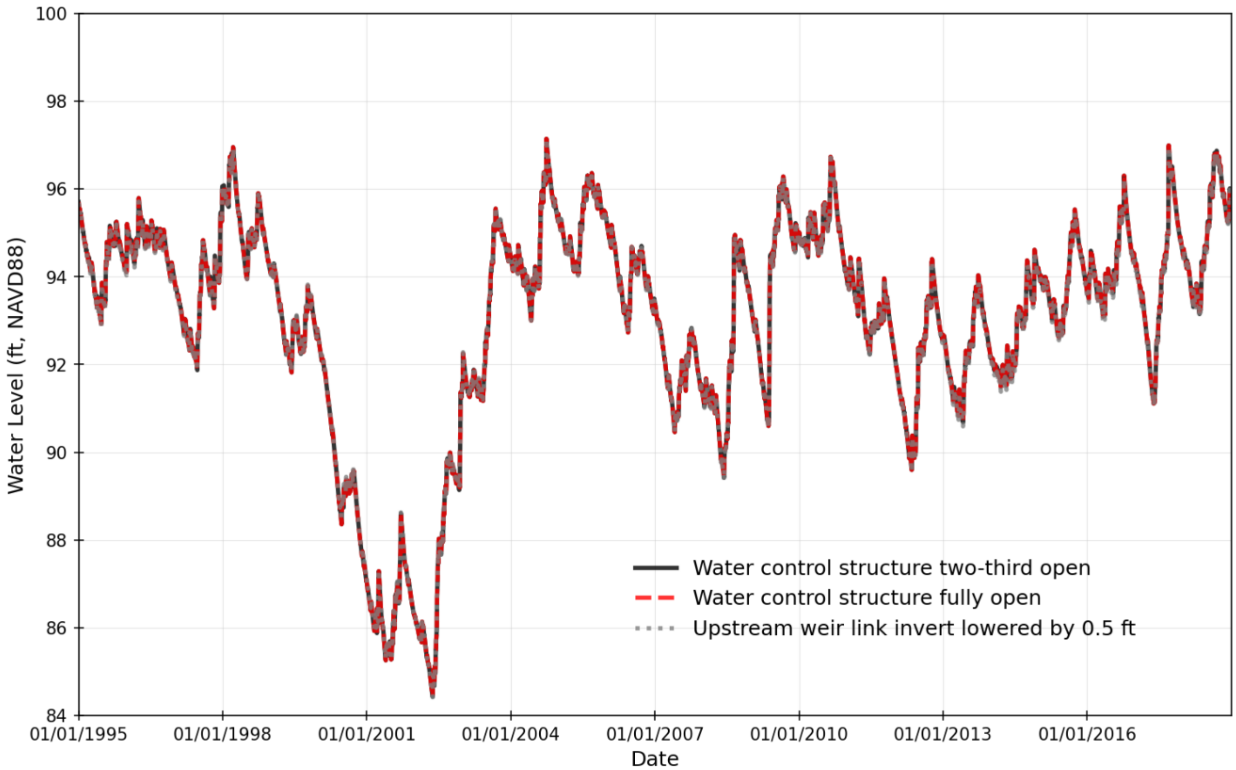

Figure G - 15. Effect of water control structure and weir link invert elevation on simulated water levels of Johns Lake.

Overall, the model was not sensitive to the water control structure located downstream of WCD. Therefore, it is expected that the new water control structures, which are far from the downstream of the WCD structure, would have minimal impact on simulated water levels of Johns Lake. Consequently, further updating the model with those recently constructed downstream water control structures is not necessary.

SUMMARY AND CONCLUSIONS

In support of hydrologic and MFLs modeling of Johns Lake, we collected, reviewed, and analyzed available hydro-meteorological and geo-spatial data of Johns and Avalon watersheds. In addition, all the data utilized in the previously set up, calibrated, and validated SWMM model of the watersheds (CWR, 2019), including water control structures and their corresponding properties, were re-processed, converted to the ICPR4 model’s format, and used as inputs to the ICPR4 model. Based on the available hydro-meteorological and GIS data, we set up the model for the period 1995 to 2018, calibrated the model for the period 2005 to 2018, and validated it for the period 1995 to 2004. We subsequently extended the calibrated and validated model to the period from 1948 to 2018 for long-term simulations. We also ran a parameter sensitivity analysis for the calibration period of the extended model and determined the most sensitive parameters for the model.

The ICPR4 model reasonably represented the observed daily water levels, and temporal variations and magnitudes of Johns Lake for both the calibration and validation periods. Most of the daily statistical values met the targeted values during the calibration period except for the percent of observations bracketed within ± 1ft and Nash-Sutcliffe Efficiency (NSE). We achieved better statistical values and improved model performance rates during the validation period, indicating the applicability of the ICPR4 model outside the calibration period. However, the performance of the model is lowered for the long-term simulation particularly during the pre-development period, which could be due to lack of long-term observed groundwater and rainfall data within a watershed, including noticeable changes in land use/land cover conditions of the watershed. We also identified that the leakance and vertical and horizontal saturated hydraulic conductivities of the surficial aquifers are the most influential/sensitive parameters for hydrologic processes modeling of Johns Lake. Overall, the ICPR4 model showed reasonable simulations of surface water – groundwater interaction processes and levels of Johns Lake, indicating the model can be used for MFLs modeling and scenarios analysis.

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APPENDIX - 1

EXISTING DATA REVIEW AND MODEL DEVELOPMENT

TECHNICAL MEMORANDUM

DATE: July 6, 2020
SUBJECT: ICPR4 Model Development for Johns Lake – Task B

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. The St. Johns Water Management District (SJRWMD)’s MFLs Program, mandated by state water policy, is a District-wide effort to establish MFLs for priority lakes, streams and rivers, wetlands, springs, and groundwater aquifers. MFLs designate the minimum hydrologic conditions that must be maintained in these water resources to prevent significant harm resulting from permitted water withdrawals.

Johns Lake is a priority lake listed in the District’s 2019 MFLs priority list and is scheduled for completion in 2021. The lake’s watershed is primarily located in northwest Orange County, Florida, just south of Lake Apopka, with a small portion in Lake County, in the west (Figure B - 1). The watershed is approximately 26.9 square miles. The lake receives inflow from Black Lake that is in turn connected to several upstream lakes and wetland slough systems (see Figure B - 1). The lakes that drain to Johns Lake are generally located to the southeast of the lake’s watershed. Johns Lake has a control structure regulating outflow through ditches and culverts to Lake Apopka to the north. Adjacent to Johns Lake is Lake Avalon, which is located in a closed basin system (Figure B - 1).

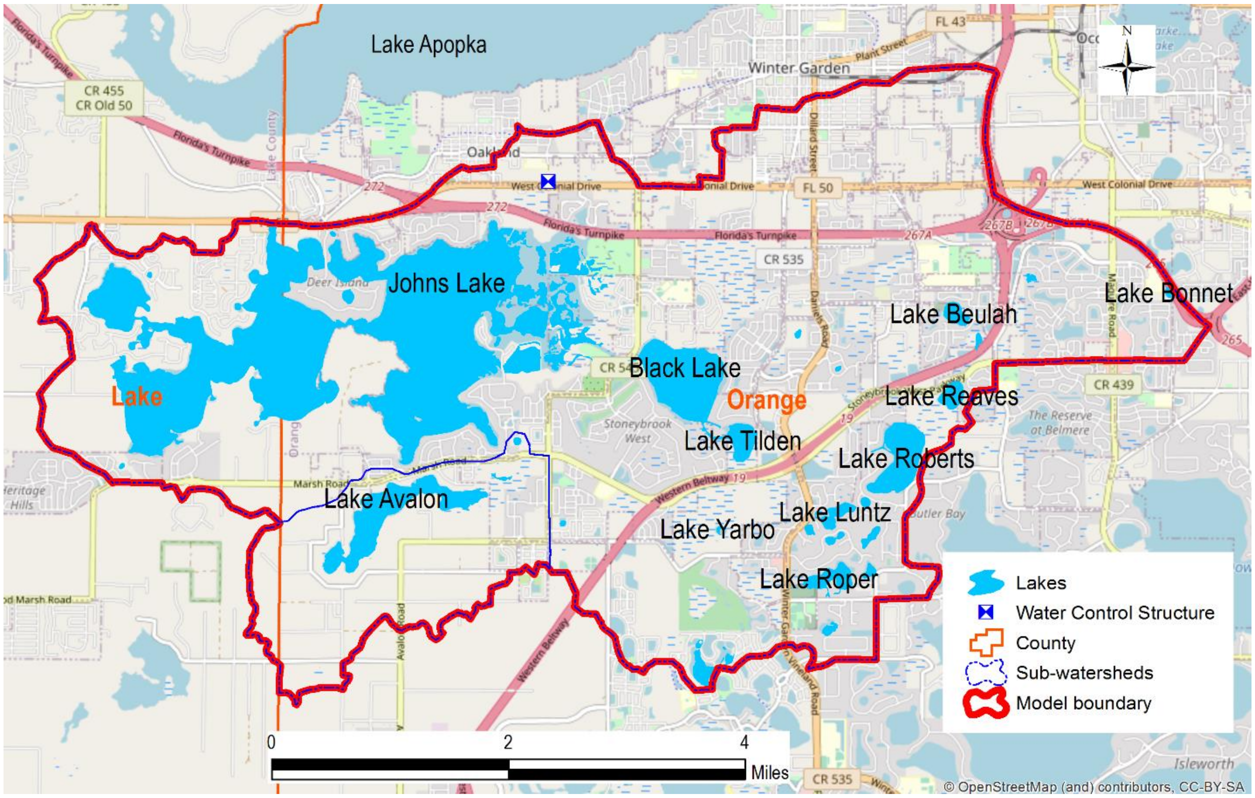

Figure B - 1. The Johns and Avalon Lakes and their watershed boundaries

The purpose of establishing minimum lake levels for Johns Lake is to protect the lake from significant harm due to excessive groundwater or surface water withdrawals. Because minimum levels are usually based on hydrologic events with associated durations and return periods, MFLs assessment requires frequency analysis of lake levels. Due to the presence of short- and long-term climatic cycles (e.g. El Nino Southern and Atlantic Multidecadal Oscillations), the frequencies of lake levels could be significantly different in wet periods such as in 1960s than those in dry periods such as in 2000s. Thus, it is important to perform frequency analysis using long-term lake levels so that the effect of short- and long-term climatic variations on lake levels can be captured. Although observed long-term lake levels data can be used for such analyses, such data are usually discontinuous and sometimes sparse. Thus, long-term lake levels need to be simulated by using hydrologic models. This is also important for a better understanding of the Lake's water budget.

A Storm Water Management Model (SWMM) (Rossman, 2015) application was previously developed by Collective Water Resources (CWR) (CWR, 2019) to simulate the water levels of the Johns and Avalon Lakes. The model simulation covered the period from 1995 to 2016 with verification and calibration periods of 1995 to 2004 and 2005 to 2016, respectively. Because SWMM uses a simplified approach for simulating surface water – groundwater (SW-GW) interaction, areas that experience strong SW-GW interaction might not be adequately represented by the model. For further evaluation of the SWMM model developed by CWR (2019), the District has developed an Interconnected Channel and Pond Routing version 4 (ICPR4) model (Streamline Technologies, 2018) that spatially varies the representation of SW-GW interaction. This will provide the District an opportunity to compare the ICPR4 model results with the previously developed SWMM model results. Further, such studies help to evaluate the suitability of SWMM for modeling MFLs water bodies in the future. It should be noted that while Lake Avalon is not listed in the MFLs priority list, the lake is included in the ICPR4 model for comparison purposes with the SWMM model results.

This technical memorandum focuses on ICPR4 data processing and preparation and model set up for the period from 1995 to 2018. The developed model will be subsequently calibrated and validated for the periods from 2005 to 2018 and from 1995 to 2004, respectively.

INPUT DATA

The ICPR4 model utilized all the data previously collected, reviewed, and processed for the SWMM model (CWR, 2019). However, all the data were re-processed, converted, and formatted to the ICPR4 model requirements, including burning the bathymetry data of the Johns and Avalon Lakes with the LiDAR Digital Elevation Model (DEM) data.

GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

Digital Elevation Model (DEM)

The DEM data (5 ft resolution for Lake County & 10 ft resolution for Orange County) and bathymetry data (Johns and Avalon Lakes only) as utilized in the SWMM model (CWR, 2019) were used for this project. CWR (2019) processed the DEM and bathymetry data separately and externally combined them into stage-area curves for use in SWMM. In addition, CWR (2019) converted point elevations and contour lines bathymetry to raster maps (Figure B - 2). However, both the DEM and bathymetry data showed cell alignment issues, including difference in raster resolutions (see Figure B - 2).

As ICPR4 needs a combined DEM and bathymetry raster map, first, we mosaiced the two counties DEM data into one map with a resampling size of 10 ft using ArcGIS tools. Then, raster bathymetry that was derived from the original point elevation surveys data for Lake Avalon and bathymetry contour lines data for Johns Lake was burned into the mosaiced DEM data. We used a topo to raster tool of ArcGIS to convert the bathymetry elevation points/contours to a raster. We addressed the cells alignment issue by snapping with the mosaiced DEM during the conversion of contour lines and point elevation surveys to raster. In addition, we superimposed the bathymetry data with the District's 1-foot contour map.

Furthermore, we limited the spatial extent of topo to raster interpolation by using the lakes' boundaries as additional interpolation inputs. This interpolation approach addressed cell alignment issue, including those flat surface areas generated by CWR (see Figure B - 2). Finally, before we burned the bathymetry raster into the DEM, we compared the bathymetry elevation values with the DEM values for the overlapping area around the edges of the lakes. If the bathymetry values were higher than the DEM values, the bathymetry values were replaced with the DEM values. Figure B - 3 presents the final DEM with bathymetry used in ICPR4. Due to lack of bathymetry data for the rest of the lakes in the watershed, the DEM data was used.

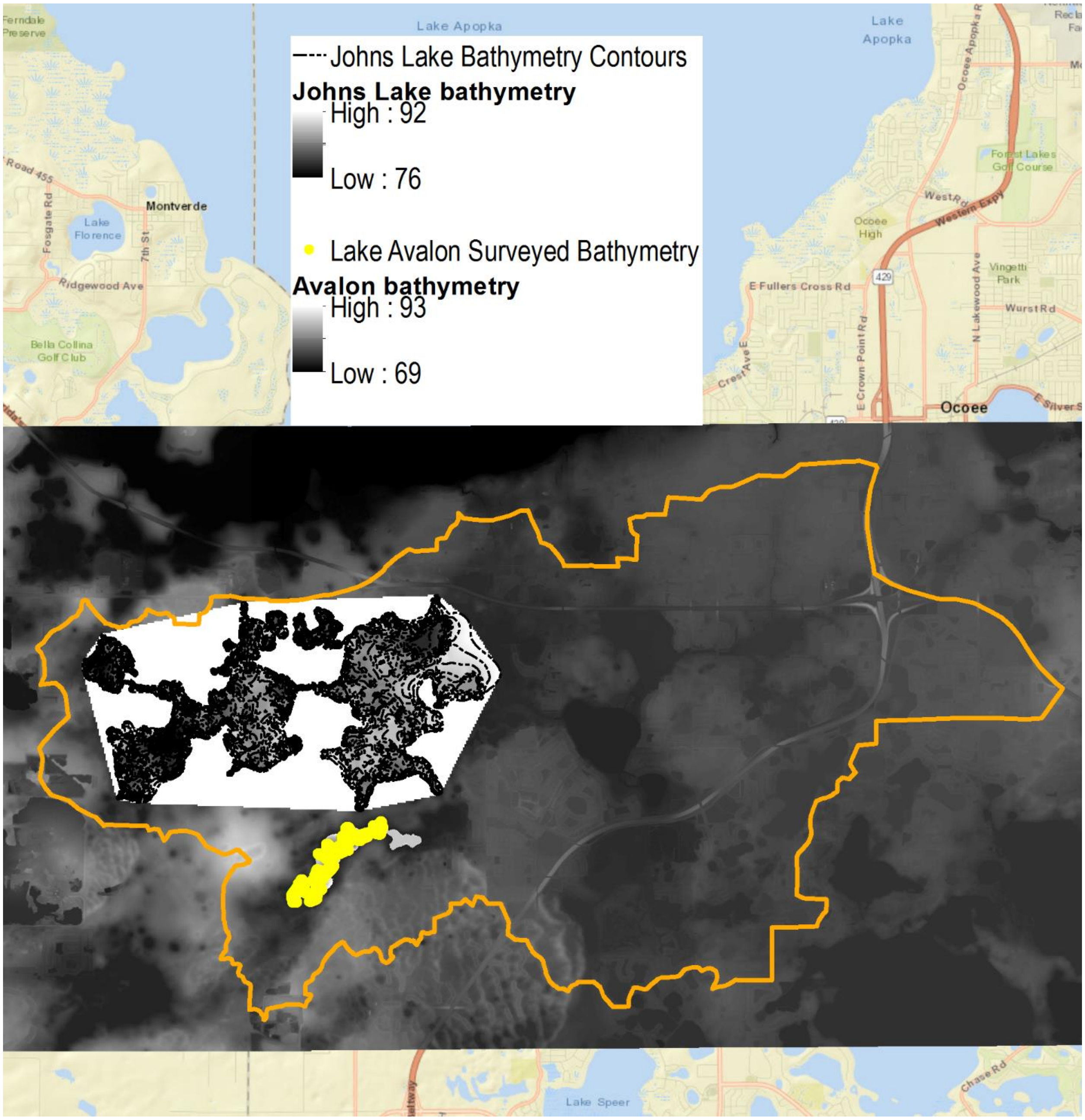

Figure B - 2. DEM and bathymetry data (NAVD88) as obtained from Collective Water Resources (CWR, 2019).

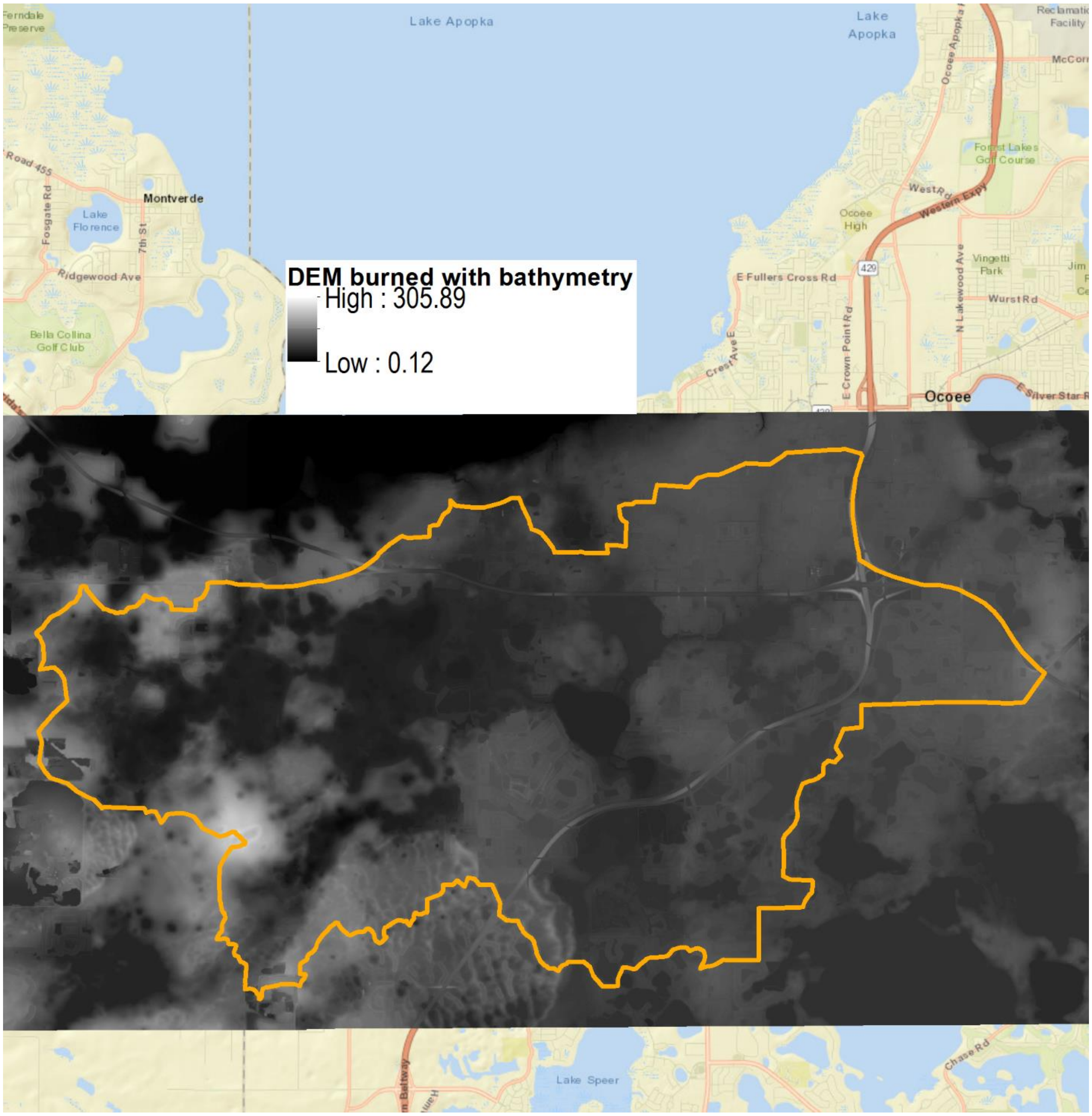

Figure B - 3. DEM burned with bathymetry data (NAVD88) processed for ICPR4 model input.

Land Use/Land Cover (LULC)

LULC 2014 data modified by CWR (2019) for the SWMM model was used in this project. However, the spatial extent of data was just limited to the model boundary. ICPR4 requires data outside the boundary edges (a large buffer zone around the boundary region) to avoid problems occurred during mesh generation. Therefore, we extended CWR's LULC data using the District's LULC 2014 data. The extended data is shown in Figure B - 4.

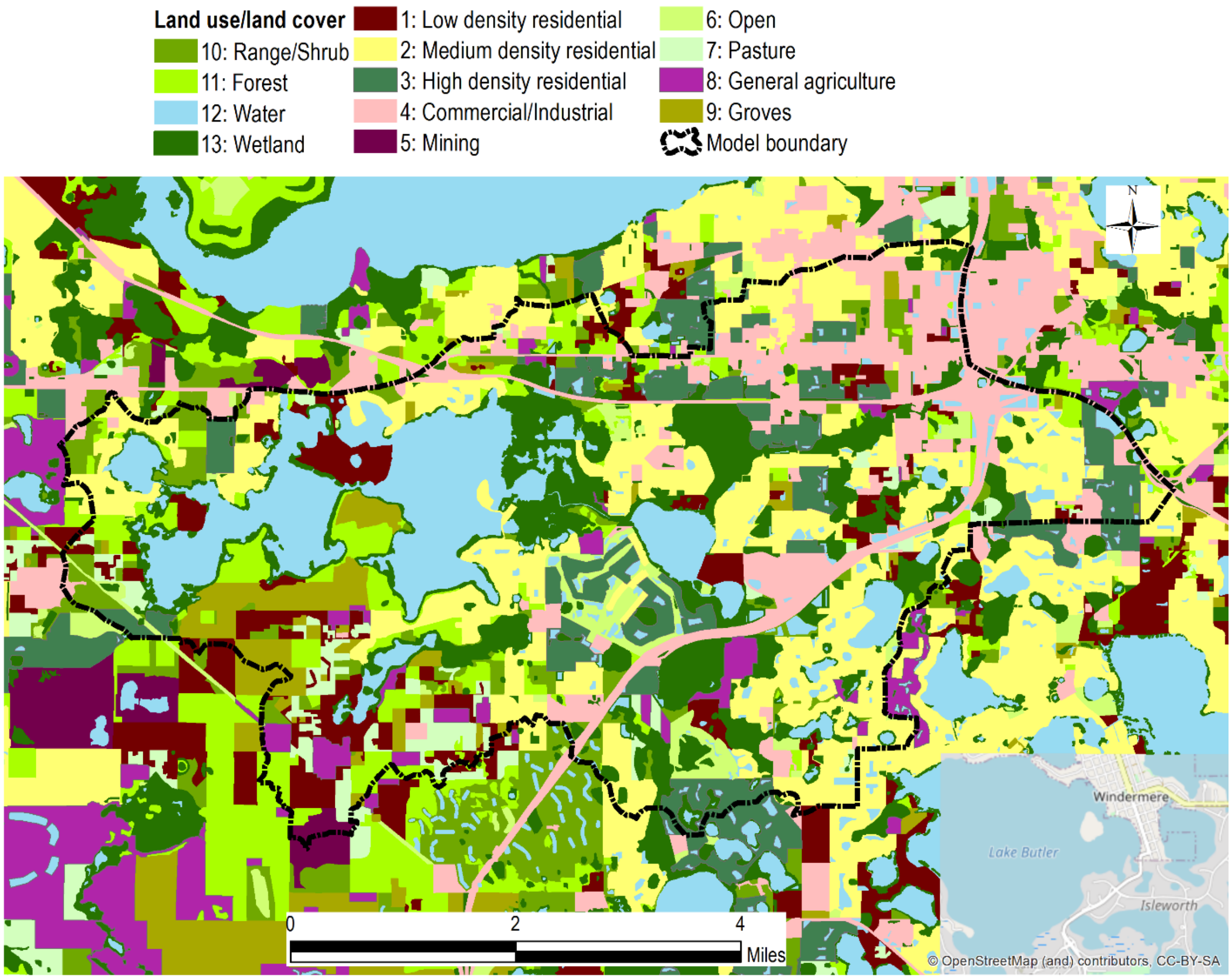

Figure B - 4. Extended Land Use/Land Cover 2014. Numbers in legend represent District's land use/cover code

Soils

Soil maps and corresponding properties for both Lake and Orange Counties were obtained from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) databases (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr12/tr/?cid=nrcs142p2_010596, accessed October 2019). The soil maps identify each soil type with a unique Map Unit Key (MUK). The MUK numbers are presented in Attachment A - 1 while their hydrologic soil groups are shown in Figure B - 5. Each MUK is linked with several soil properties tables stored in Microsoft access databases. Within one MUK, there are several component keys (CK) and component horizon keys (CHK) as shown in Table B - 1. Example of soil database properties is shown in Table B - 1 for Orange County.

We analyzed the percent of CK and the corresponding CHK properties within each MUK to derive the vertical layers properties of the study site. The vertical layer properties for each MUK were estimated based on the dominant CK and the corresponding CHK properties. For example, for MUK 323154, CK 18140201 (bold) along with the corresponding CHK's properties were selected and processed for ICPR4 as this CK covered 90% of the MUK area. A similar approach was followed for the rest of MUKs. Representative soil properties were used for further analyses.

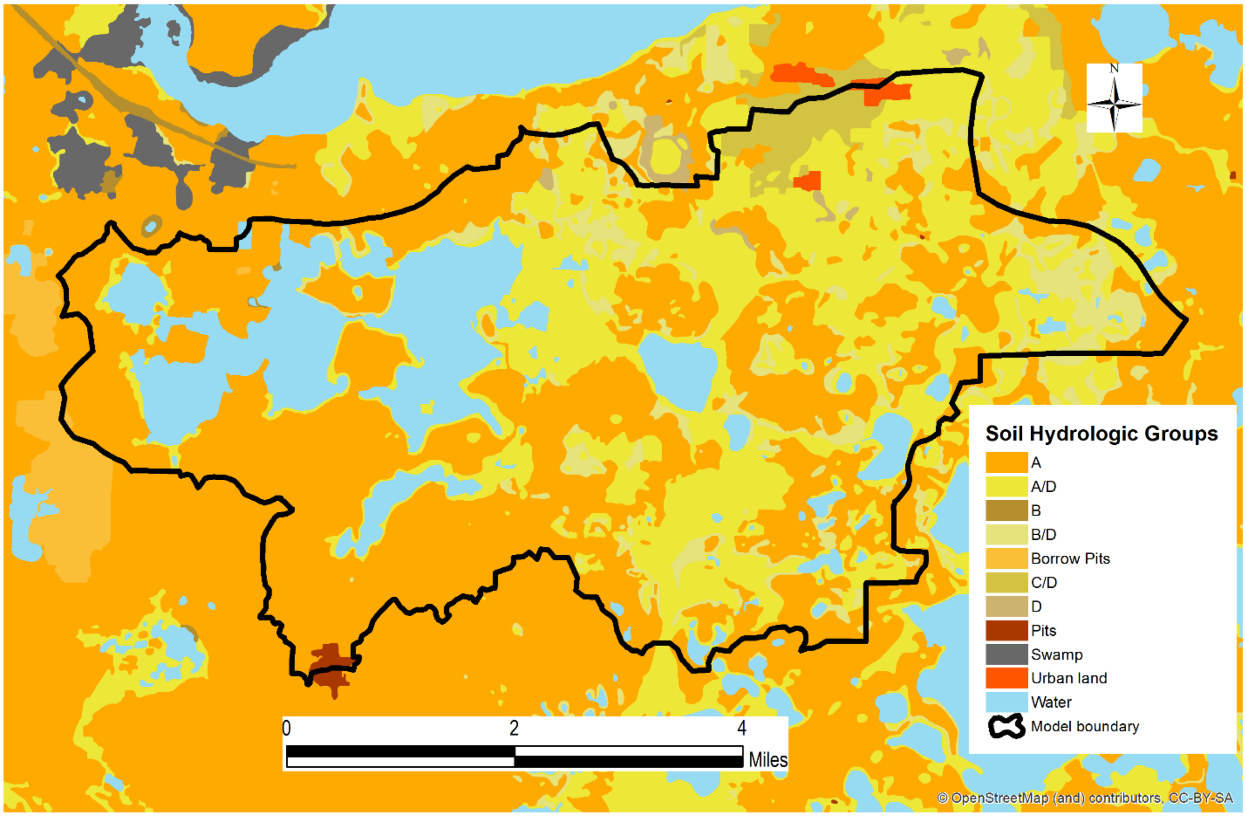

Figure B - 5. Soil hydrologic groups for the Lake and Orange Counties.

Table B - 1. Example of soil database properties for the Orange County. OM is organic matter

Soil Texture	MUK	CK	CHK	Layer Order	Layer Thickness (ft)	Percent Component	Percent Sand	Percent Clay	Percent OM	Bulk density (g/cm^3)	Partical density (g/cm^3)
Fine sand	**323154**	**18140201**	**53079818**	**0**	**0.427**	**90**	**97.500**	**1.500**	**1.000**	**1.55**	**2.610**
Fine sand - Sand	**323154**	**18140201**	**53079816**	**1**	**5.741**	**90**	**97.500**	**1.500**	**0.250**	**1.6**	**2.640**
Fine sand - Sand	**323154**	**18140201**	**53079817**	**2**	**0.492**	**90**	**94.500**	**4.200**	**0.100**	**1.66**	**2.646**
Sand	323154	18140202	53079819	0	0.328	4	96.500	2.000	1.250	1.45	2.601
Sand - Fine sand	323154	18140202	53079820	1	6.332	4	96.500	2.000	0.250	1.55	2.640
Sand	323154	18140203	53079821	0	0.755	3	93.600	5.000	1.250	1.47	2.601
Sand	323154	18140203	53079822	1	4.068	3	93.600	5.000	0.250	1.47	2.640
Loamy sand - Loamy fine sand	323154	18140203	53079823	2	0.492	3	84.700	11.000	0.100	1.6	2.646
Sandy loam - Fine sandy loam - Sandy clay loam	323154	18140203	53079824	3	2.100	3	61.400	20.000	0.100	1.65	2.646
Fine sand	323154	18140204	53079825	0	0.656	3	97.000	2.000	1.250	1.4	2.601
Fine sand - Sand	323154	18140204	53079826	1	6.004	3	97.800	1.600	0.250	1.45	2.640
Sand	323121	18140205	53079827	0	6.660	100	94.000	3.000	0.750	1.52	2.620
Muck	323123	18140206	53079829	0	2.329	2			70.000	0.25	1.285
Fine sandy loam - Sandy clay loam	323123	18140206	53079828	1	4.331	2	64.200	21.500	0.500	1.6	2.630
Fine sand	323123	18140207	53079832	0	1.181	74	92.200	6.500	3.500	1.52	2.516
Fine sand - Sand	323123	18140207	53079833	1	1.148	74	95.000	4.000	0.250	1.52	2.640
Sandy loam - Fine sandy loam - Sandy clay loam	323123	18140207	53079830	2	2.100	74	59.600	22.500	0.250	1.6	2.640
Sand - Loamy fine sand	323123	18140207	53079831	3	2.231	74	81.300	9.500	0.500	1.52	2.630
Fine sandy loam	323123	18140208	53079835	0	0.984	24	70.100	13.500	4.500	1.62	2.481
Sandy clay loam - Fine sandy loam	323123	18140208	53079836	1	3.675	24	55.100	27.500	1.250	1.48	2.601
Loamy fine sand - Fine sand	323123	18140208	53079834	2	2.001	24	94.000	5.000	0.500	1.52	2.630

Soil bulk density of each CHK was assumed to be equivalent to the oven dry mass values reported in the soil databases. The standard soil particle density of 2.65 g cm^{-3} was adjusted based on the percent organic matter (OM) of the soil and using the method documented in Maidment (1998). During the calculation, the iron content of the soil was assumed to be negligible. Based on both bulk and particle densities, the total porosity of the soils was estimated using empirical equations (Maidment, 1998). Then the saturated soil moisture content was assumed to be equivalent to the effective porosity, which was assumed to be 93% of the total porosity (Maidment, 1998).

Other parameters, such as pore size index, bubble pressure, and residual moisture content were estimated based on the percent of sand and clay, and porosity as described in Maidment (1998). However, for soils that had % OM greater than 50, the percent of sand and clay were missing especially for the top layer. For those soils, we completed missing values based on the percent OM of the top layer, and % of sand and clay of the next bottom layer. Percent of sand and clay from the next layer were used to proportion the remaining percentage (100 - %OM) to % of sand and clay for the top layer. The processed and completed soil data of the study area is reported in Attachment A - 1 and Attachment A - 2. These datasets were utilized for the Vertical Layers and Green-Ampt infiltration methods of the ICPR4 model, respectively.

Intermediate Confining Unit (IUC) and Leakance Data

In order to model the leakage rates beneath the lakes and elsewhere, ICPR4 requires (i) Intermediate confining unit (ICU) top elevation along with leakance values or (ii) top and bottom ICU elevation along with hydraulic conductivity of the ICU. Both datasets should be provided with the Upper Floridian Aquifer (UFA) potentiometric levels, which are used as a bottom boundary condition. In this project, the first option was selected. This provided easy comparison with the leakance values used in the SWMM model of CWR (2019). The top ICU elevation data used in the East-Central Florida Transient (ECFTX) groundwater model (Central Florida Water Initiative (CFWI), 2020) of the District (Figure B - 6) was used as a starting point in the ICPR4 model.

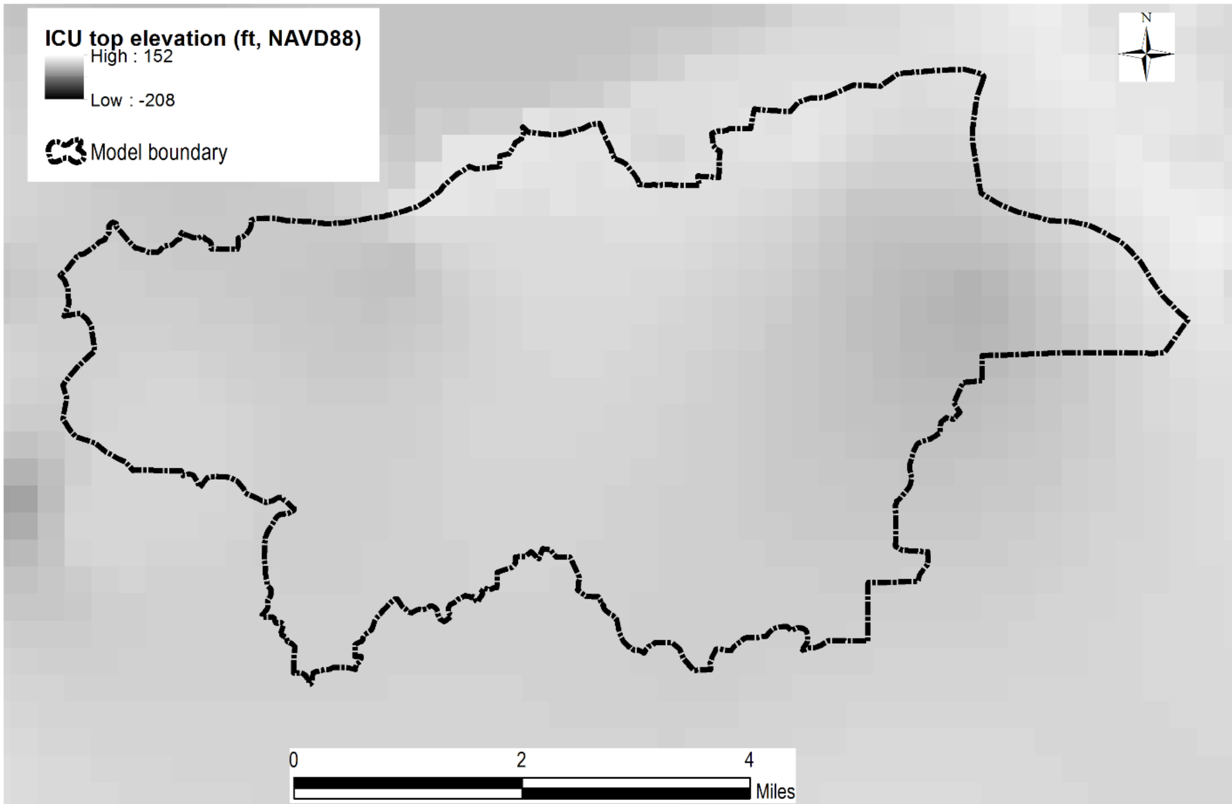

Figure B - 6. Intermediate Confining Unit (ICU) top elevation obtained from the ECFTX model

Similarly, the leakance values used in the ECFTX model of CFWI (2020) (Figure B - 7) were used as a starting point for the ICPR4 model. The gridded ECFTX leakance mean values were zoned to the lakes and wetlands/depressions polygons and the remaining part using the zonal statistics tool of ArcGIS. A single zone is used outside the lakes' and wetlands/depressions' boundaries. Depending on the model performance, the leakance values will be adjusted during the calibration step. Within the modeled area, the highest leakance value was noticed beneath Avalon Lake (Figure B - 7). This is also consistent with the previous study (CWR, 2019). Such information will be utilized during the calibration and validation processes.

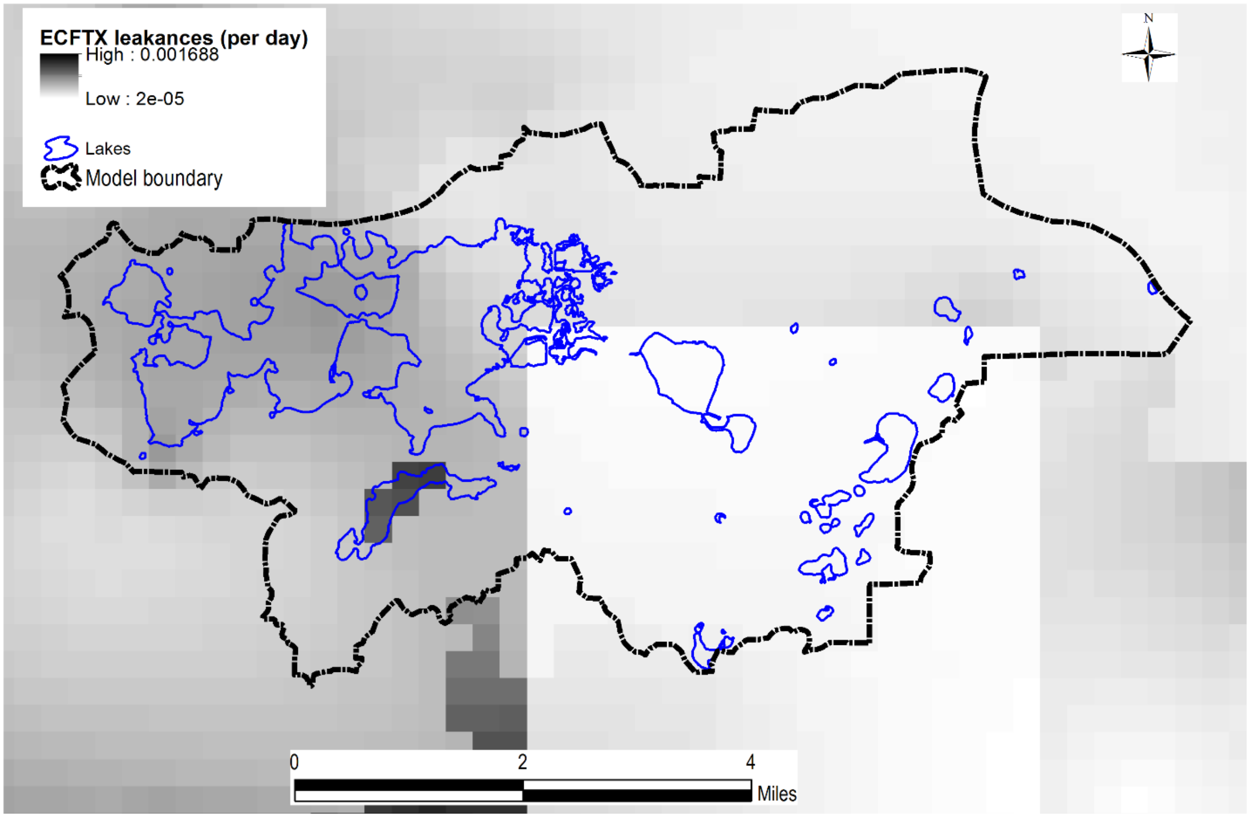

Figure B - 7. ECFTX model leakance values used as a starting point for the ICPR4 model set-up

Initial Water Table (IWT)

Although a single IWT value for the entire model domain can be assumed in ICPR4, the IWT is assumed to be 3 ft below the ground elevations everywhere. Depending on the model performance, the IWT values can be adjusted as needed.

HYDRO-METEOROLOGICAL DATA

Rainfall and Reference Evapotranspiration (ETo)

Complete hourly NEXRAD rainfall data was available for the period from 1995 to 2018 from SJRWMD's hydrometeorological databases. 38 rainfall pixels within and around the model boundary were selected (Figure B - 8). The corresponding rain values were downloaded for the period from 1995 to 2018 and processed to the ICPR4 model input format.

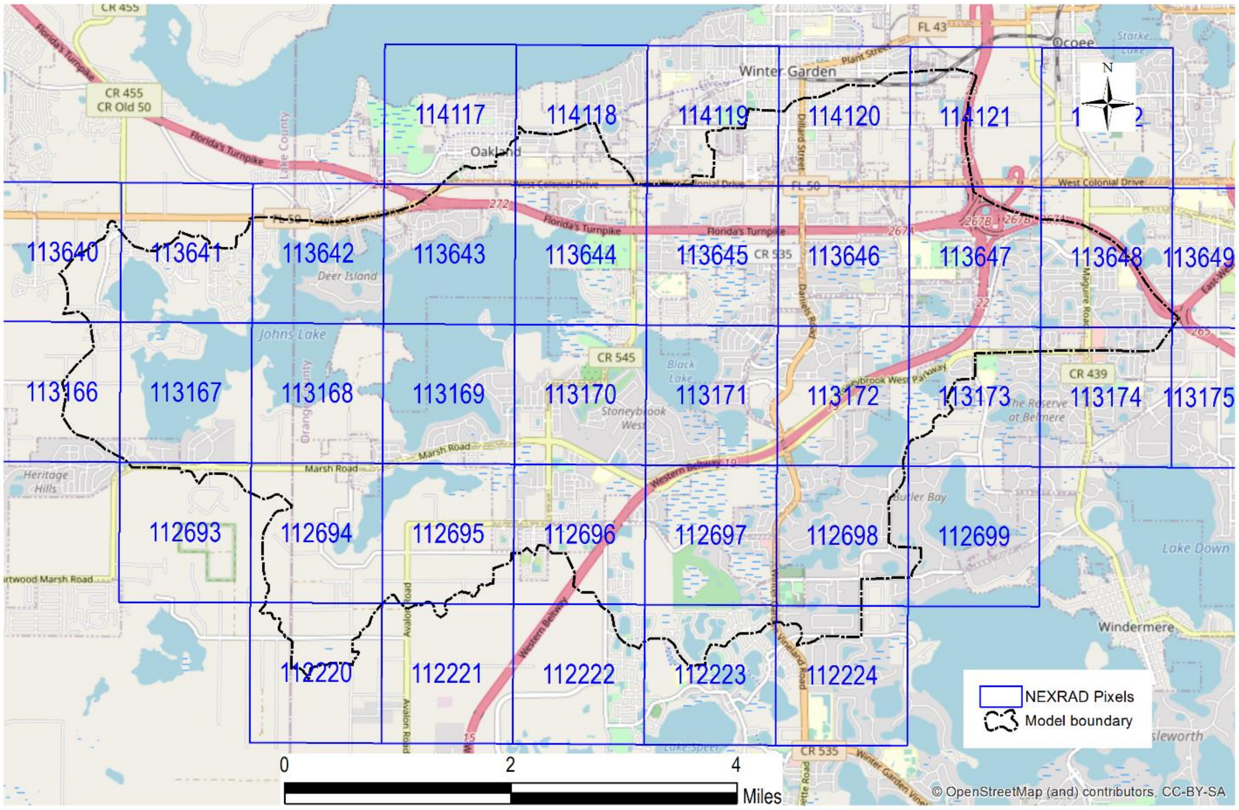

Figure B - 8. Selected NEXRAD pixels for rainfall and reference evapotranspiration. Numbers represent the pixels identification.

Figure B - 9 summarizes the annual rainfall values for some pixels inside or around Johns Lake. The selected pixels show minor annual rainfall spatial variability. The lowest rainfall was recorded in 2000.

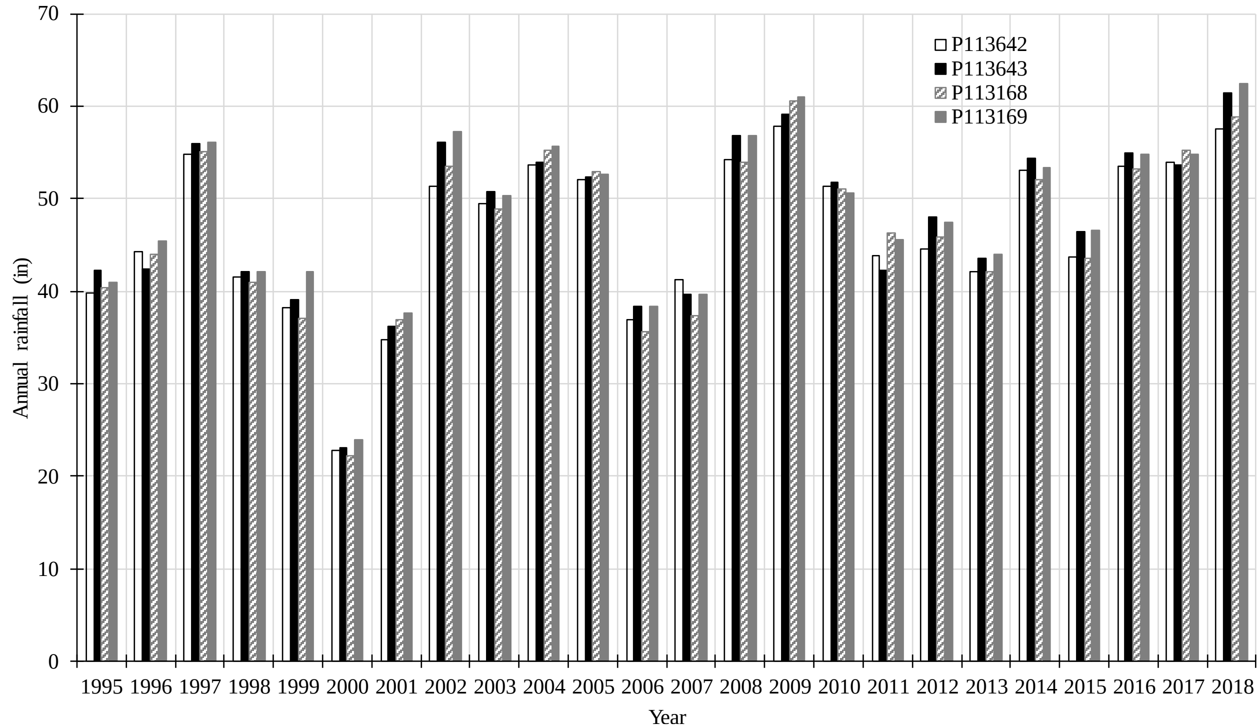

Figure B - 9. Annual rainfall values for pixels around the Johns Lake

For the same pixels of rainfall data, daily reference evapotranspiration (ETo) data of the period from 1/1/1985 to 12/31/2018 were available from the SJRWMD databases. However, after review of the District's database, we found that ETo values were consistently missing for the first 5 months of 1995 (1/1/1995 – 5/31/1995) whereas the data on the USGS's website showed a 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, we directly downloaded the ETo data from the USGS's website, extracted for the same pixels, and merged with the District's ETo data for the period from 1985 to 2018. Missing values for the merged data were filled with the average values of the pixels with records. Still missing values were filled with the daily average values within a month. Completed annual ETo values are presented in Figure B - 10. The lowest ETo values were recorded in 2001.

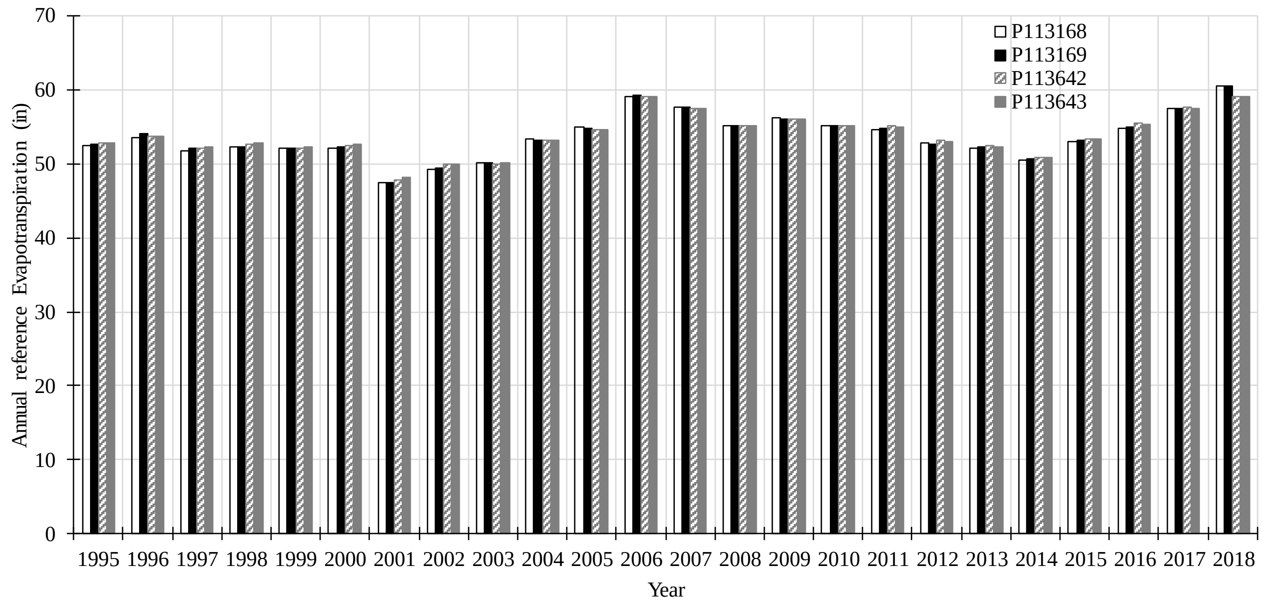

Figure B - 10. Annual reference evapotranspiration for selected pixels inside/around Johns Lake

Upper Floridan Aquifer (UFA) Potentiometric Levels

UFA levels are needed to simulate leakage rates beneath the lakes and elsewhere in the Johns Lake and Avalon Lake watersheds. May and September Potentiometric (POT) surface maps were available for the period from 1978 to 2017 from the SJRWD and Florida Department of Environmental Protection (DEP). 2018 POT data was not available at the time of this project work. POT surface maps were retrieved from the following sources:

- Raster maps with different resolutions for the period from 1978 to 2010 except 2009 from SJRWMD.
- Image maps for the years 2009, 2011, and 2012 from SJRWMD.
- Raster maps of 500 meters resolution for the period from 2013 to 2017 (https://geodata.dep.state.fl.us/datasets/upper-floridan-aquifer-potentiometric-surface).

All the POT surface maps were reported in NGVD29 vertical datum. We converted all the POT maps to NAVD88 using the SJRWMD's vertical datum offset values. After converting the vertical datum, we generated a uniform 820 feet resolution POT surface maps for the period from 1978 to 2017. Then, for each grid cell of the ECFTX model (CFWI, 2020), we estimated the annual average values of POT levels within the cell using zonal statistics tool of ArcGIS. POT average surface offset values were considered to represent the spatial variability of UFA levels. The representative September 2010 POT surface shows that the UFA groundwater flow is generally from south to north (Figure B - 11), indicating noticeable spatial heterogeneity within the watershed. This spatial variability was considered in ICPR4 by using offset values with respect to well data location.

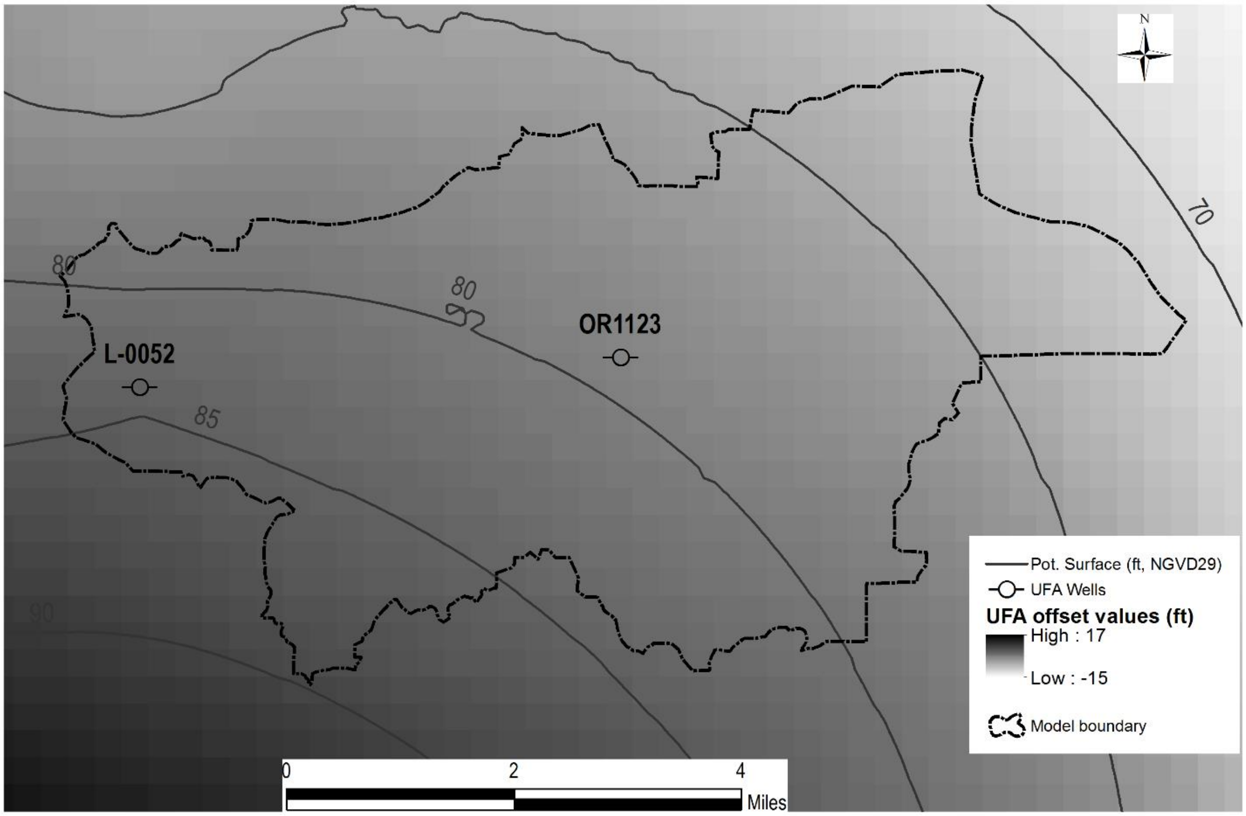

Figure B - 11. Location of UFA wells, Potentiometric levels of September 2010 (NGVD29), and UFA offset values with respect to OR1123.

A number of daily UFA wells data within and around the watershed were collected, reviewed, and analyzed during the previous CWR study (CWR, 2019). Two UFA wells: L-0052 and OR1123 were selected and gap filled by CWR (2019) for the period from 1960 to 2016. These data were subsequently extended to the period from 1960 to 2018 for the ICPR4 model. The two wells data consistently show similar patterns but water levels at L0052 are higher by about 5 ft, on average (Figure B - 12). Because OR1123 is approximately located in the center of the model domain as well as close to the Johns Lake (Figure B - 11), it was selected to be used along with UFA POT surface maps. The POT annual average surface offset values were estimated with respect to the grid cell where OR1123 is located (Figure B - 11). The ICPR4 model used the POT surface offset values reported in Figure B - 11 along with the daily observed UFA levels at OR1123 (Figure B - 12).

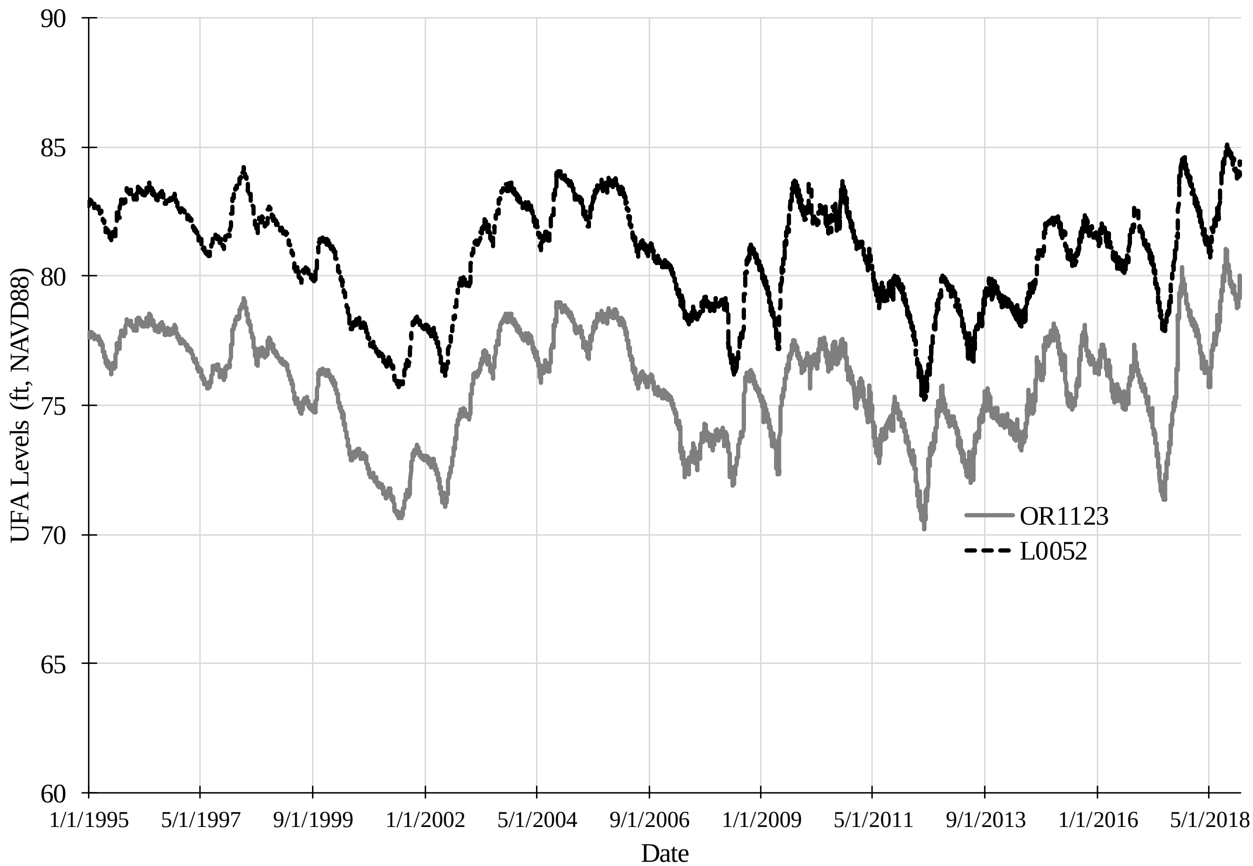

Figure B - 12. The daily observed and gap filled UFA levels at wells OR1123 and L0052 (CWR, 2019).

Lake Levels

The water level data for Johns and Avalon lakes within the watershed was retrieved from the SJRWMD's hydrologic databases and the SWMM model of CWR (2019). The lakes had irregularly recorded data as summarized in Table B - 2.

Table B - 2. Summary of 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	91.43	91.58	2.69
Avalon	15243091	12/31/1960 to present	79.03	96.18	87.07	87.12	2.05

The Johns and Avalon Lakes have historical water levels that show similar pattern with each other but Johns' water levels are consistently higher by approximately 7 ft, on average (Figure B - 13). Water level data of the two lakes will be used for the model calibration and validation purposes.

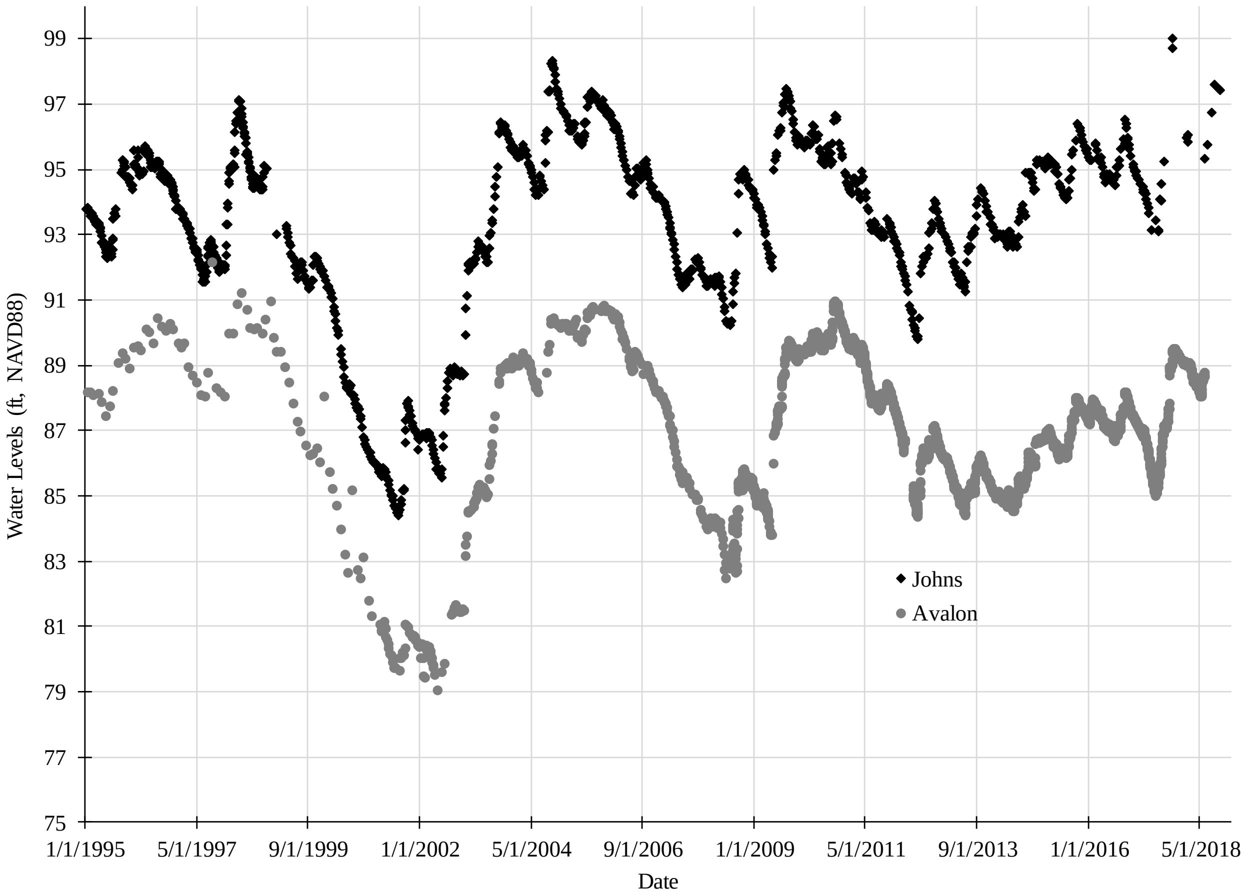

Figure B - 13. Observed water levels of Johns and Avalon Lakes

OTHER DATA

Imperviousness Fractions

Imperviousness fractions of the different LULC (see Figure B - 4) were used in the ICPR4 model for surface runoff simulations. The values as obtained from CWR (2019) are reported in Table B - 3. CWR used 100% for water and wetlands but this seems not appropriate for long-term simulation, especially for the wetland areas that may dry out during the dry season. Consequently, we set those values to zero in ICPR4.

Table B - 3. Imperviousness fractions used in the SWMM model. DCIA: Directly Connected Impervious Area.

Land use/land cover*	Impervious (%)	DCIA (%)
1:Low density residential	15	6
2:Medium density residential	49	21
3:High density residential	66	44
4:Commercial/Industrial	78	78
5:Mining	1	0
6:Open	9	2
7:Pasture	2	0
8:General agriculture	1	0
9:Groves	3	0
10:Range/Shrub	0	0
11:Forest	0	0
12:Water	100	100
13:Wetland	100	100

* numbers in first columns represent District's 13 land use/land cover codes

Crop Coefficient and Root Depth

Crop coefficient (kc) and root depth data are needed for the ICPR4 model to estimate actual evapotranspiration from reference evapotranspiration (ETo). The kc values were collected from different sources that include the values used in the Hydrologic System Fortran Program (HSPF) models and the St. Johns Marshall Conservation Area (SJMCA) and Putnam county ICPR models at the District. The kc values are summarized in Table B - 4.

Table B - 4. Crop coefficient values for different land use/land cover (LULC)

Month	Residential*	Mining	Open	Pasture	General agriculture	Forest/Groves	Water	Wetland
1	0.65	1.00	0.65	0.47	0.75	0.90	1.09	0.70
2	0.70	1.00	0.70	0.51	0.80	0.90	1.09	0.71
3	0.75	1.00	0.75	0.59	1.00	0.90	1.09	0.78
4	0.90	1.00	0.90	0.61	1.00	0.90	1.09	0.94
5	0.90	1.00	0.90	0.54	1.00	0.95	1.09	1.04
6	0.95	1.00	0.95	0.85	0.75	1.00	1.09	1.09
7	0.95	1.00	0.95	0.92	0.75	1.00	1.09	1.04
8	0.95	1.00	0.95	0.91	0.75	1.00	1.09	1.10
9	0.90	1.00	0.90	0.81	0.80	1.00	1.09	1.04
10	0.80	1.00	0.80	0.73	1.00	1.00	1.09	0.89
11	0.70	1.00	0.70	0.62	1.00	1.00	1.09	0.76
12	0.65	1.00	0.65	0.50	1.00	1.00	1.09	0.74

* Low/medium/high density residential and Range/Shrub lands used the same crop coefficient

The root depth values were extended to the groundwater evapotranspiration (GWET) extinction depth based on the LULC and soil types as proposed by Shah et al. (2007), which reported GWET extinction depths for grassland, bare-land, and forest. In order to use these values, we simplified the 13 LULC reported in Table B - 3 into four categories (grassland, bare-land, forest, water, and wetland). Table B - 5 shows the four reclassified LULC along with the original LULC.

Table B - 5. The four re-classified LULC for groundwater extinction depth estimation.

LULC 2014	New class
1:Commercial/Industrial	Grassland
2:Forest	Forest
3:General agriculture	Grassland
4:Groves	Forest
5:High density residential	Grassland
6:Low density residential	Grassland
7:Medium density residential	Grassland
8:Mining	Bare-land
9:Open	Grassland
10:Pasture	Grassland
11:Range/Shrub	Grassland
12:Water	Water
13:Wetland	Wetland

Using ArcGIS tools, we intersected the four reclassified LULC with the surficial soil textural classes obtained from the NRCS SSURGO databases. Then, we assigned the extinction depth values reported in Shah et al. (2007) to the intersected layers. Attachment A - 3 summarizes the extinction depth for the different LULC-soil texture combinations of the study area. Wetland extinction depth was assumed to be hydric grassland whereby the values were assigned based on the values used in the North Florida Southeast Georgia (NFSEG) groundwater model at the District (Durden et al., 2019). While we assigned bare-land's extinction depth for water with other soil-texture combination, we assumed a very shallow depth of 0.5 ft for water-water area.

Fillable Porosity

This parameter is needed for Surficial Aquifer System (SAS) groundwater modeling. The soil moisture content values at saturation point minus the values at field capacity were assumed as fillable porosity based on a previous study (Streamline Technologies, 2018). This parameter will be calibrated if needed.

Horizontal Hydraulic Conductivity

Based on ICPR4 technical reference (Streamline Technologies, 2018), the horizontal hydraulic conductive of the SAS assumed to be twice the vertical hydraulic conductivity values obtained from SSURGO data. This parameter will be adjusted during the calibration process if needed.

Time of Concentration

Time of Concentration (Tc) was used with ICPR4 to generate runoff hydrographs using the NRCS TR-55 Unit Hydrograph methodology (NRCS, 1986). The Tc is defined as the time for runoff to travel from the hydraulically most representatively distant point of the watershed to a point of interest within the watershed (NRCS, 1986). We calculated representative Tc values for the sub-basins (mapped basins in ICPR4) using the watershed lag method documented in NRCS National Engineering Handbook of hydrology (part 630.1502) (NRCS, 1986). Travel times for these flows were based on the extraction of average terrain slope, flow length, basin's area, and maximum potential retention using GIS-based tools. The unit hydrograph peak rate factor for all mapped basins was set to 284. The calculated Tc and associated mapped basins properties of ICPR4 are reported in Attachment A - 4.

MODEL DEVELOPMENT

Based on the previously discussed input data, we set-up the ICPR4 model for Johns and Avalon watersheds, and ran the model for the period from 1995 to 2018. The model set-up is detailed as follows.

MAPPED BASINS DELINEATION

58 sub-basins as delineated by CWR (2019) for the SWMM model were used as mapped basins in the ICPR4 model (Figure B - 14). The mapped basin's area ranges from 15 to 6,526 acres. While a single mapped basin was used for the Lake Avalon, the remaining mapped basins represent the drainage areas of Johns Lake and its tributaries. For easy comparison of the results from the two models, we used the same names for the ICPR4 model elements as those used in the SWMM model.

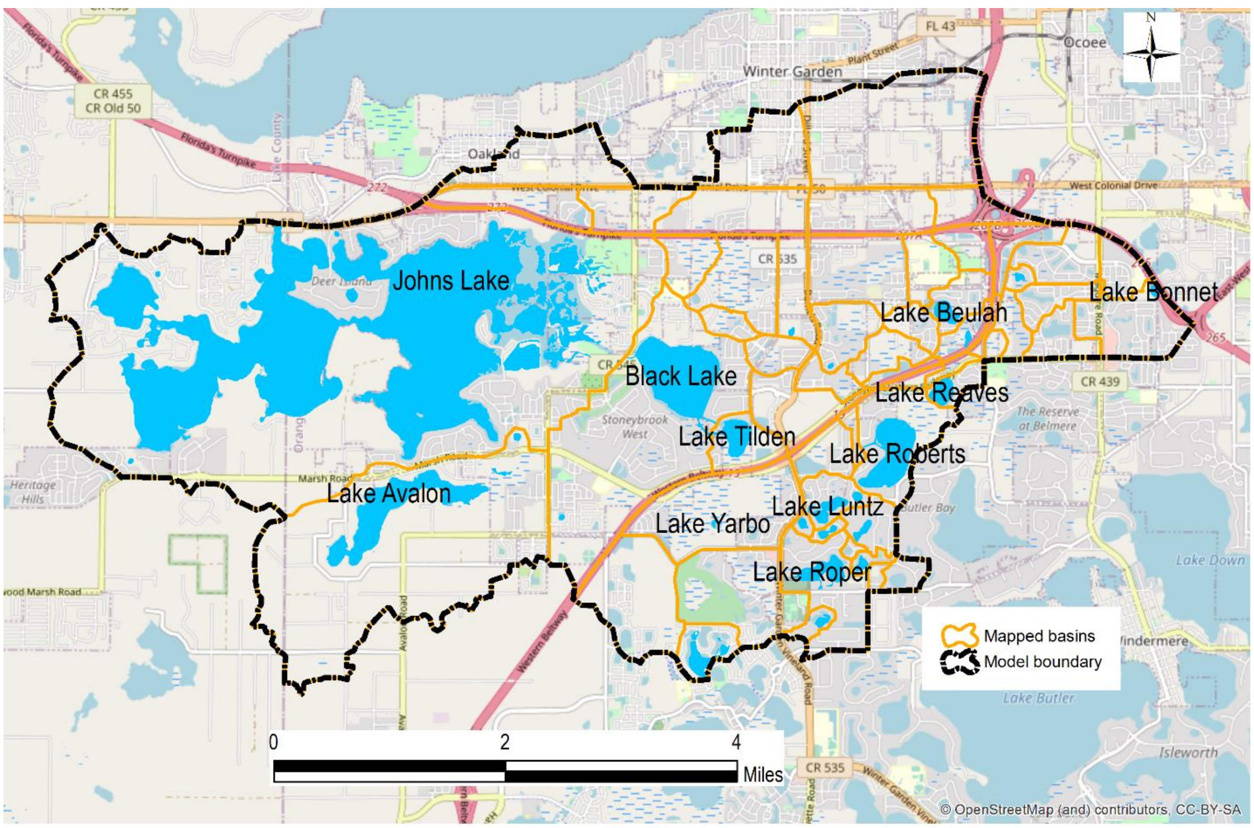

Figure B - 14. ICPR4 mapped basins obtained from SWMM model

RAINFALL EXCESS ESTIMATIONS

In order to estimate rainfall excess (surface runoff) from the mapped basins, we used the Green-Ampt infiltration methods available in the ICPR4 model. The Green-Ampt infiltration methods have been used to estimate infiltration and rainfall excess for numerous hydrological models in Florida and have been shown to be more accurate than the NRCS Curve Number method in areas with deep and sandy soils (Jones Edmunds Associate, 2020).

ICPR4 provides two Green-Ampt methodologies for estimating rainfall excess. One method is a single-layer method, and the other is a multi-layer method called Vertical Layers. Based on a previous study (Jones Edmunds Associate, 2020), we used Green-Ampt infiltration method for lakes and wetland/depression areas while the Vertical Layers method was used for the remaining areas. The parameters were estimated based on soil property values from the NRCS SSURGO database (see Attachment A - 1 and Attachment A - 2).

NODES

The nodes that were considered in the Johns and Avalon ICPR4 model are:

- Stage/Area nodes – to represent lakes' storage-area relationship
- Stage/Time nodes – to represent outlets, observation nodes, and boundaries

All the nodes used in the SWMM model were replicated in the ICPR4 model, except nodes that were used as outfalls to connect with the UFA system and the corresponding junction nodes. The nodes information was determined based on the data used in the SWMM model. However, for the Johns Lake (node N-Johns_000) and Lake Avalon (node N-Avalon_000), we directly extracted the storage-area curves from the DEM with bathymetry data in ICPR4. We typically used a 0.25-foot interval to generate stage-area relationship. We assumed a minimum area of 4000 square feet to 1-D storage nodes. Figure B - 15 shows the ICPR4 model schematics of the Johns and Avalon Lakes watersheds.

LINKS

Conduit links in the SWMM model were converted into open channel and pipe links in the ICPR4 model (Figure B - 15). While closed conduits were considered as pipe links, open conduits were represented as open channels in ICPR4. All the conduits' data of SWMM were retrieved and used in ICPR4.

DROP STRUCTURES

Hydraulic structures considered as conduit and orifice links in the SWMM model were implemented as drop structures in the ICPR4 model (Figure B - 15). Drop structures contain weirs and orifice discharge coefficients data attached to a particular pipe link (represented as closed conduit in SWMM). The weirs, orifice, and pipe data were derived from the data used in the SWMM model.

OVERLAND FLOW WEIRS

Trapezoidal surface overflow weirs were used in the SWMM model to connect modeled nodes if flow should occur outside of the primary conveyance features (e.g., bank overtopping). These weirs were implemented as irregular overland flow in ICPR4 (Figure B - 15) and were typically based on the ridges between mapped basins or along the roadways. We determined the weirs' cross-sections and other data based on the DEM. The weirs were included to allow accurate simulation of hydrologic conditions during extreme storm events.

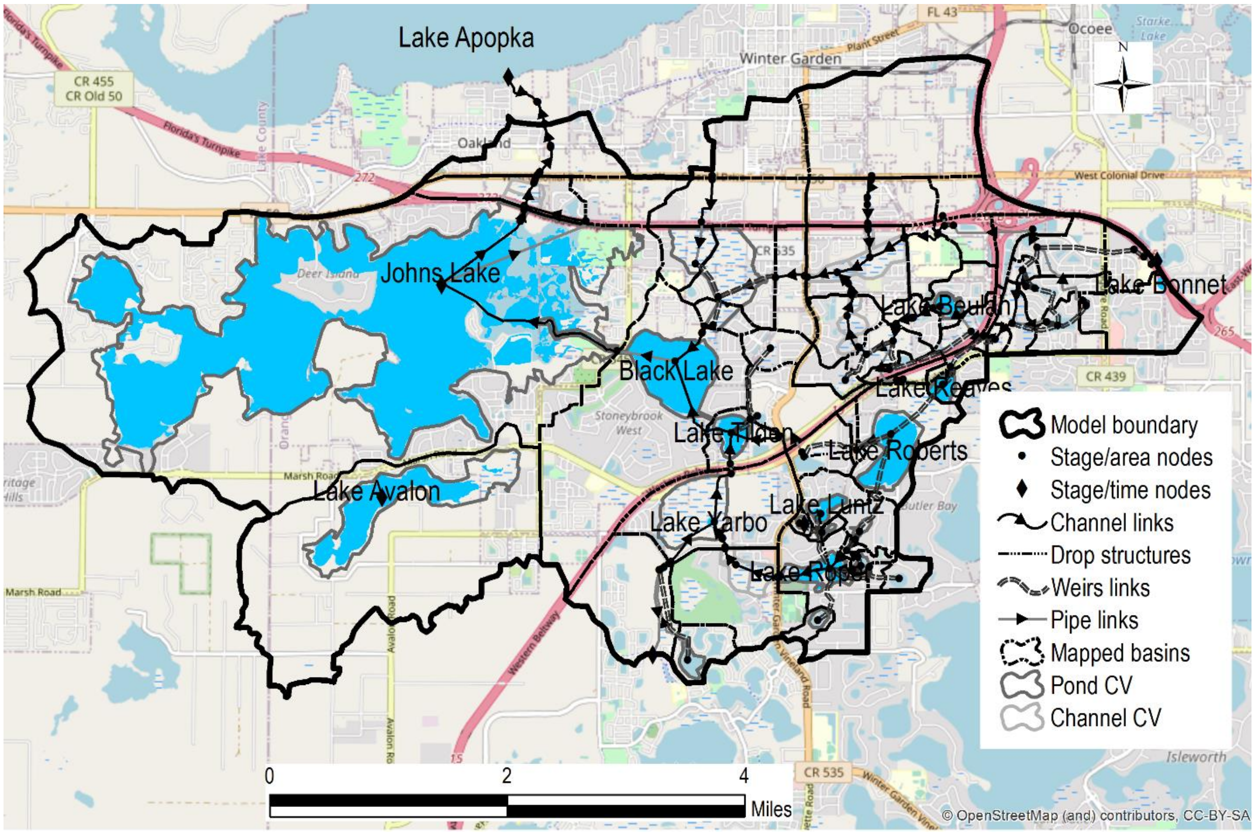

Figure B - 15. Johns and Avalon Lakes model schematics

TWO DIMENSIONAL (2D) OVERLAND FLOW

While we used 1D mapped basins with one overland flow region for overland flow modeling, a 2D overland flow was considered for some areas where surface and groundwater interaction was expected to be strong. These included lakes and wetlands/depression areas. If such areas had a minimum area of 4 acres, we implemented them as pond control volume (PCV) features. In addition, channels that are located along the wetland/depression areas with a minimum area of 4 acres were implemented as channel control volume (CCV) features. Both PCVs and CCVs interact similarly with groundwater, but a PCV is considered as "Level Pool" whereas a CCV assumes a sloping water surface (Streamline Technologies, 2018). We determined the boundaries of PCVs based on a simplified contour lines as derived from the DEM/bathymetry of the study area. The locations of PCVs and CCVs are shown in Figure B - 15. The following PCV and CCV parameters and features were used in the ICPR4 model:

- Polygons that represent the boundary of the modeled lakes, wetlands, and channels. These polygons used during mesh and honeycomb generation. For the study area model, the overland flow mesh and honeycomb were limited to within the PCV or CCV boundaries.
- Breakpoints – Points that represent user-specified vertices location for mesh and honeycomb generation (Figure B - 16). A mesh spacing of approximately 100 to 500 feet was used depending on the PCV/CCV size and shape.

2D GROUNDWATER FLOW

In order to model the interaction between surface water and groundwater below the Lakes watersheds, ICPR4 uses physically based SAS parameters, such as fillable porosity, horizontal hydraulic conductivity, and top elevation of confining unit (see previous sections for the data detail). The following 2D groundwater flow features and parameters were used for the ICPR4 model of Johns and Avalon:

- Groundwater Region – A polygon that represents the boundary of the groundwater region. One groundwater flow region was assumed for the study site (CWR, 2019).
- Breakpoints – for the PCV or CCV areas, detail break points were added to represent user-specified vertices for mesh and honeycomb generation. A mesh spacing of approximately 200 to 1000 feet was used.

Figure B - 16 presents the breakpoints used for both the pond control or channel control volumes and groundwater flow region.

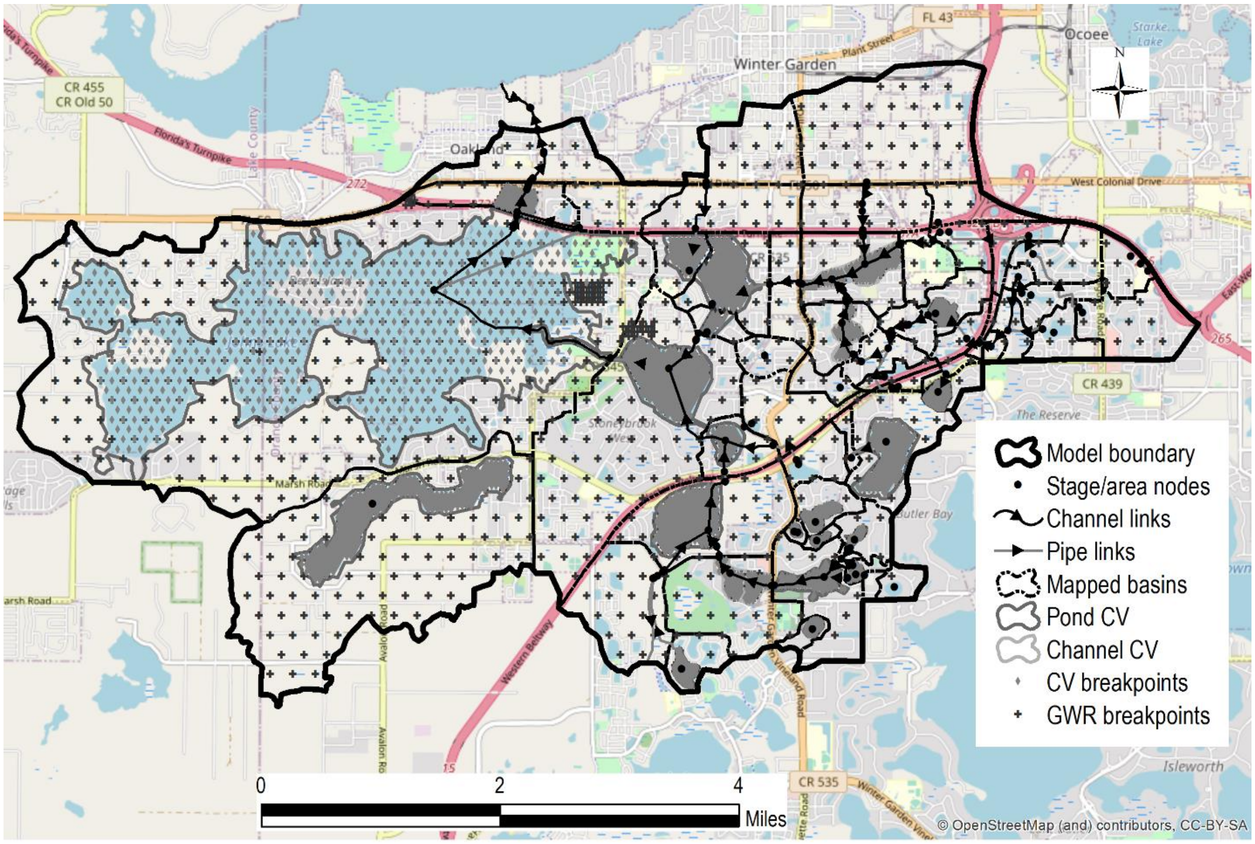

Figure B - 16. Breakpoints used for pond control or channel control volumes and groundwater flow region.

SUMMARY

For hydrologic modeling and MFLs evaluation of Johns Lake, available hydro-meteorological and geo-spatial data of Johns and Avalon watersheds were collected, reviewed, and analyzed. In addition, all the data utilized in the previously developed, calibrated, and verified SWMM model of the watersheds (CWR, 2019), including water control structures and their properties, were re-processed and converted to the ICPR4 model's format and used as inputs to the model. Based on the available data, we set up the model for the period from 1/1/1995 to 12/31/2018. The developed model will be subsequently used for model calibration and verification processes.

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ATTACHMENT A

Attachment A - 1: Soil parameters used by the ICPR4 model for Vertical Layer method. MC represents Moisture Content. Layer thicknesses are in feet

Soil Zone Zone	Layer Order	Kv Saturated	MC Saturated	MC Residual	MC Initial	MC Field	MC Wilting	Pore Size Index	Bubble Pressure	Layer Thickness
323121	0	70.016	0.390	0.030	0.091	0.091	0.033	0.492	2.458	6.660
323122	0	7.937	0.323	0.080	0.154	0.154	0.081	0.397	5.580	0.591
323122	1	0.255	0.401	0.104	0.225	0.225	0.122	0.258	5.640	3.576
323122	2	6.236	0.393	0.032	0.091	0.091	0.035	0.411	2.465	2.493
323123	0	26.079	0.368	0.020	0.066	0.066	0.022	0.460	2.103	1.181
323123	1	26.079	0.395	0.013	0.060	0.060	0.014	0.479	2.124	1.148
323123	2	0.255	0.366	0.096	0.225	0.225	0.122	0.295	5.920	2.100
323123	3	6.236	0.393	0.032	0.091	0.091	0.035	0.411	2.465	2.231
323124	0	26.079	0.344	0.020	0.066	0.066	0.022	0.496	2.487	0.591
323124	1	26.079	0.393	0.013	0.060	0.060	0.014	0.429	1.760	0.394
323124	2	0.255	0.384	0.111	0.354	0.354	0.202	0.159	10.337	2.526
323124	3	0.255	0.384	0.109	0.354	0.354	0.202	0.192	9.800	3.150
323125	0	26.005	0.358	0.047	0.121	0.121	0.053	0.529	2.730	0.328
323125	1	26.005	0.373	0.016	0.077	0.077	0.018	0.519	2.584	2.592
323125	2	8.002	0.310	0.091	0.224	0.224	0.134	0.343	6.346	0.656
323125	3	26.005	0.366	0.030	0.099	0.099	0.033	0.495	2.352	3.084
323126	0	26.005	0.358	0.047	0.121	0.121	0.053	0.529	2.730	0.328
323126	1	26.005	0.373	0.016	0.077	0.077	0.018	0.519	2.584	2.592
323126	2	8.002	0.310	0.091	0.224	0.224	0.134	0.343	6.346	0.656
323126	3	26.005	0.359	0.031	0.100	0.100	0.034	0.500	2.423	3.084
323127	0	26.005	0.358	0.047	0.121	0.121	0.053	0.529	2.730	0.328
323127	1	26.005	0.373	0.016	0.077	0.077	0.018	0.519	2.584	2.592
323127	2	8.002	0.310	0.091	0.224	0.224	0.134	0.343	6.346	0.656
323127	3	26.005	0.359	0.031	0.100	0.100	0.034	0.500	2.423	3.084
323128	0	26.079	0.344	0.059	0.175	0.175	0.123	0.496	2.484	1.083
323128	1	26.079	0.370	0.030	0.098	0.098	0.033	0.493	2.319	1.247
323128	2	0.255	0.318	0.096	0.242	0.242	0.158	0.291	9.028	4.331
323129	0	26.079	0.478	0.044	0.182	0.182	0.134	0.450	1.843	0.328
323129	1	26.079	0.370	0.046	0.119	0.119	0.051	0.493	2.317	0.919
323129	2	26.079	0.373	0.010	0.062	0.062	0.011	0.533	2.772	1.411
323129	3	0.255	0.278	0.096	0.252	0.252	0.174	0.253	15.769	1.017
323129	4	0.255	0.331	0.082	0.199	0.199	0.103	0.377	6.229	2.986
323130	0	26.079	0.532	0.094	0.479	0.479	0.120	0.293	2.320	1.509
323130	1	0.255	0.275	0.095	0.273	0.273	0.207	0.279	14.468	1.476

323130	2	0.255	0.361	0.082	0.206	0.206	0.111	0.368	4.314	1.608
323130	3	7.937	0.377	0.016	0.076	0.076	0.018	0.516	2.555	2.067
323131	0	26.079	0.652	0.025	0.426	0.426	0.151	0.351	9.421	0.427
323131	1	26.079	0.532	0.026	0.479	0.479	0.120	0.353	13.385	4.560
323131	2	26.079	0.532	0.026	0.479	0.479	0.120	0.353	13.385	0.427
323132	0	39.969	0.415	0.012	0.027	0.027	0.013	0.518	2.589	0.164
323132	1	39.969	0.413	0.007	0.020	0.020	0.008	0.519	2.598	6.496
323133	0	26.079	0.384	0.020	0.066	0.066	0.022	0.498	2.310	0.427
323133	1	26.079	0.393	0.013	0.060	0.060	0.014	0.493	2.248	2.493
323133	2	2.551	0.283	0.032	0.108	0.108	0.035	0.558	3.609	2.657
323133	3	26.079	0.393	0.032	0.091	0.091	0.035	0.493	2.248	1.083
323134	0	56.032	0.358	0.051	0.122	0.122	0.054	0.509	2.645	0.755
323134	1	56.032	0.327	0.030	0.099	0.099	0.033	0.527	3.025	5.906
323135	0	22.110	0.376	0.020	0.066	0.066	0.022	0.449	1.961	0.591
323135	1	22.110	0.393	0.013	0.060	0.060	0.014	0.441	1.832	1.837
323135	2	0.765	0.409	0.100	0.225	0.225	0.122	0.278	4.841	2.920
323135	3	0.255	0.366	0.100	0.225	0.225	0.122	0.272	6.748	1.312
323136	0	26.079	0.376	0.020	0.066	0.066	0.022	0.517	2.560	0.262
323136	1	26.079	0.395	0.013	0.060	0.060	0.014	0.506	2.426	1.247
323136	2	26.079	0.384	0.028	0.085	0.085	0.031	0.498	2.313	0.984
323136	3	26.079	0.395	0.013	0.060	0.060	0.014	0.493	2.240	1.017
323136	4	0.255	0.359	0.073	0.154	0.154	0.081	0.331	4.325	1.312
323136	5	26.079	0.396	0.032	0.091	0.091	0.035	0.458	3.638	1.837
323137	0	26.079	0.404	0.014	0.052	0.052	0.015	0.461	1.943	5.413
323137	1	26.079	0.410	0.014	0.052	0.052	0.015	0.458	1.910	5.413
323137	2	1.984	0.409	0.091	0.225	0.225	0.122	0.316	4.075	1.247
323138	0	26.079	0.742	0.016	0.668	0.668	0.450	0.515	5.858	2.100
323138	1	26.079	0.393	0.032	0.091	0.091	0.035	0.494	2.253	4.560
323139	0	26.079	0.354	0.051	0.135	0.135	0.068	0.518	2.588	0.328
323139	1	2.551	0.370	0.054	0.127	0.127	0.059	0.493	2.322	1.509
323139	2	26.079	0.373	0.014	0.070	0.070	0.015	0.526	2.639	4.823
323140	0	26.079	0.398	0.020	0.066	0.066	0.022	0.477	2.102	0.262
323140	1	2.551	0.376	0.036	0.100	0.100	0.040	0.469	2.124	1.083
323140	2	26.079	0.384	0.032	0.091	0.091	0.035	0.505	2.391	5.315
323141	0	26.079	0.391	0.014	0.052	0.052	0.015	0.474	2.057	1.575
323141	1	26.079	0.402	0.010	0.040	0.040	0.011	0.469	1.987	5.085
323142	0	26.079	0.391	0.014	0.052	0.052	0.015	0.474	2.057	1.837
323142	1	26.079	0.402	0.010	0.040	0.040	0.011	0.469	1.987	4.823
323143	0	26.079	0.356	0.051	0.151	0.151	0.088	0.516	2.561	0.427
323143	1	26.079	0.373	0.016	0.077	0.077	0.018	0.519	2.584	0.755
323143	2	26.079	0.372	0.043	0.116	0.116	0.048	0.491	2.298	1.804

323143	3	26.079	0.373	0.023	0.088	0.088	0.026	0.505	2.398	3.675
323144	0	26.079	0.361	0.041	0.120	0.120	0.051	0.547	2.900	0.098
323144	1	26.079	0.366	0.007	0.052	0.052	0.008	0.546	2.903	0.328
323144	2	26.079	0.357	0.015	0.074	0.074	0.017	0.542	2.849	2.559
323144	3	7.994	0.327	0.091	0.225	0.225	0.136	0.341	5.456	1.509
323144	4	7.937	0.363	0.036	0.106	0.106	0.040	0.483	2.271	2.165
323145	0	26.079	0.429	0.027	0.101	0.101	0.030	0.470	1.988	0.328
323145	1	26.079	0.372	0.007	0.035	0.035	0.008	0.485	2.202	2.592
323145	2	0.255	0.409	0.092	0.225	0.225	0.122	0.312	4.124	1.247
323145	3	7.937	0.364	0.050	0.101	0.101	0.055	0.377	4.171	2.493
323146	0	26.079	0.362	0.046	0.121	0.121	0.053	0.526	2.693	0.427
323146	1	26.079	0.373	0.014	0.070	0.070	0.015	0.526	2.639	1.083
323146	2	26.079	0.349	0.037	0.109	0.109	0.041	0.493	2.427	1.312
323146	3	2.551	0.310	0.084	0.208	0.208	0.114	0.383	6.400	1.017
323146	4	26.079	0.357	0.026	0.079	0.079	0.029	0.487	2.333	2.822
323148	0	70.036	0.435	0.029	0.104	0.104	0.032	0.499	2.567	0.328
323148	1	70.036	0.395	0.006	0.034	0.034	0.007	0.518	2.730	3.576
323148	2	6.599	0.382	0.036	0.177	0.177	0.040	0.491	2.561	0.919
323148	3	6.599	0.342	0.051	0.144	0.144	0.079	0.524	2.968	0.591
323148	4	26.005	0.387	0.015	0.074	0.074	0.017	0.526	2.902	1.247
323149	0	39.969	0.437	0.018	0.052	0.052	0.020	0.502	2.439	0.427
323149	1	39.969	0.402	0.008	0.030	0.030	0.009	0.517	2.576	3.084
323149	2	7.937	0.350	0.024	0.100	0.100	0.027	0.550	3.002	0.984
323149	3	26.079	0.387	0.008	0.050	0.050	0.009	0.524	2.663	2.165
323150	0	26.005	0.366	0.034	0.105	0.105	0.038	0.538	2.839	0.328
323150	1	26.005	0.382	0.008	0.055	0.055	0.009	0.528	2.705	6.332
323151	0	26.079	0.424	0.020	0.066	0.066	0.022	0.486	2.171	0.984
323151	1	26.079	0.395	0.013	0.060	0.060	0.014	0.506	2.426	1.017
323151	2	2.268	0.384	0.032	0.108	0.108	0.035	0.485	2.203	1.673
323151	3	26.079	0.395	0.027	0.091	0.091	0.030	0.500	2.318	2.986
323152	0	70.016	0.349	0.043	0.113	0.113	0.045	0.548	3.110	0.328
323152	1	70.016	0.389	0.006	0.051	0.051	0.007	0.525	2.657	6.332
323153	0	39.969	0.406	0.014	0.052	0.052	0.015	0.522	2.629	0.164
323153	1	39.969	0.403	0.010	0.040	0.040	0.011	0.524	2.647	6.496
323154	0	39.969	0.378	0.009	0.040	0.040	0.010	0.523	2.638	0.427
323154	1	39.969	0.366	0.005	0.020	0.020	0.005	0.531	2.738	5.741
323154	2	26.079	0.347	0.005	0.022	0.022	0.006	0.505	2.574	0.492
323155	0	26.079	0.412	0.046	0.371	0.371	0.215	0.482	2.258	2.001
323155	1	26.079	0.467	0.041	0.421	0.421	0.177	0.463	2.117	0.656
323155	2	26.079	0.344	0.051	0.120	0.120	0.052	0.524	2.835	0.262
323155	3	26.079	0.359	0.030	0.098	0.098	0.033	0.513	2.663	0.755

323155	4	26.079	0.366	0.023	0.087	0.087	0.025	0.508	2.581	2.986
323156	0	26.079	0.763	0.030	0.687	0.687	0.450	0.472	4.532	2.822
323156	1	26.079	0.376	0.032	0.091	0.091	0.035	0.443	1.942	3.839
323157	0	26.079	0.796	0.009	0.716	0.716	0.450	0.360	4.874	0.919
323157	1	26.079	0.388	0.020	0.066	0.066	0.022	0.482	2.166	0.328
323157	2	26.079	0.395	0.032	0.091	0.091	0.035	0.479	2.124	5.413
323158	0	26.005	0.332	0.059	0.144	0.144	0.078	0.512	2.705	0.984
323158	1	26.005	0.354	0.046	0.119	0.119	0.051	0.496	2.418	0.525
323158	2	26.005	0.338	0.032	0.100	0.100	0.036	0.508	2.617	1.247
323158	3	26.005	0.338	0.032	0.100	0.100	0.036	0.508	2.617	3.904
323159	0	26.005	0.313	0.060	0.182	0.182	0.134	0.515	3.748	0.328
323159	1	26.005	0.352	0.048	0.117	0.117	0.049	0.525	2.865	1.083
323159	2	6.600	0.326	0.065	0.170	0.170	0.115	0.482	3.057	0.853
323159	3	26.005	0.357	0.023	0.087	0.087	0.025	0.512	2.592	4.396
323161	0	26.079	0.362	0.041	0.113	0.113	0.046	0.524	2.617	0.427
323161	1	26.079	0.389	0.012	0.066	0.066	0.013	0.512	2.594	6.234
323162	0	26.079	0.369	0.030	0.097	0.097	0.033	0.522	2.627	0.492
323162	1	26.079	0.384	0.016	0.074	0.074	0.018	0.512	2.499	6.168
323164	0	26.079	0.532	0.026	0.479	0.479	0.120	0.353	13.385	1.247
323164	1	26.079	0.532	0.026	0.479	0.479	0.120	0.353	13.385	2.428
323164	2	26.079	0.532	0.026	0.479	0.479	0.120	0.353	13.385	2.986
323165	0	26.079	0.397	0.011	0.041	0.041	0.012	0.512	2.470	0.328
323165	1	26.079	0.395	0.006	0.025	0.025	0.007	0.514	2.486	4.757
323165	2	26.079	0.413	0.011	0.044	0.044	0.012	0.451	1.862	1.575
323167	0	26.005	0.366	0.035	0.106	0.106	0.039	0.537	2.783	0.328
323167	1	26.005	0.362	0.014	0.073	0.073	0.016	0.549	2.948	1.017
323167	2	26.005	0.354	0.052	0.146	0.146	0.081	0.515	2.544	0.984
323167	3	26.005	0.369	0.024	0.090	0.090	0.027	0.522	2.625	0.328
323167	4	8.002	0.335	0.090	0.230	0.230	0.142	0.340	5.106	1.345
323167	5	26.005	0.342	0.073	0.174	0.174	0.077	0.430	3.245	2.657
323168	0	26.079	0.376	0.020	0.066	0.066	0.022	0.503	2.373	0.328
323168	1	26.079	0.393	0.013	0.060	0.060	0.014	0.501	2.331	1.017
323168	2	2.551	0.293	0.032	0.108	0.108	0.035	0.515	3.309	0.755
323168	3	0.255	0.364	0.093	0.225	0.225	0.122	0.309	5.786	1.411
323168	4	26.079	0.395	0.032	0.091	0.091	0.035	0.437	2.578	3.150
323169	0	26.079	0.376	0.020	0.066	0.066	0.022	0.455	2.028	0.689
323169	1	26.079	0.395	0.013	0.060	0.060	0.014	0.459	1.976	1.640
323169	2	0.060	0.409	0.108	0.225	0.225	0.122	0.243	5.046	2.657
323169	3	0.060	0.385	0.111	0.354	0.354	0.202	0.138	10.198	1.673
323170	0	26.005	0.376	0.020	0.083	0.083	0.022	0.525	2.616	0.427
323170	1	26.005	0.373	0.010	0.062	0.062	0.011	0.533	2.772	4.495

323170	2	2.599	0.358	0.045	0.125	0.125	0.057	0.537	2.787	1.739
323171	0	26.079	0.380	0.020	0.066	0.066	0.022	0.500	2.341	0.492
323171	1	26.079	0.393	0.013	0.060	0.060	0.014	0.494	2.253	4.856
323171	2	2.551	0.304	0.032	0.108	0.108	0.035	0.561	3.335	1.312
323172	0	26.079	0.397	0.011	0.041	0.041	0.012	0.512	2.470	0.492
323172	1	26.079	0.395	0.006	0.025	0.025	0.007	0.514	2.486	5.249
323172	2	26.079	0.413	0.011	0.044	0.044	0.012	0.451	1.862	0.919
323173	0	26.079	0.397	0.011	0.041	0.041	0.012	0.512	2.470	0.328
323173	1	26.079	0.395	0.006	0.025	0.025	0.007	0.514	2.486	5.249
323173	2	26.079	0.413	0.011	0.044	0.044	0.012	0.451	1.862	1.083
323174	0	26.079	0.397	0.011	0.041	0.041	0.012	0.512	2.470	0.427
323174	1	26.079	0.395	0.006	0.025	0.025	0.007	0.514	2.486	3.904
323174	2	26.079	0.413	0.011	0.044	0.044	0.012	0.451	1.862	2.329
323175	0	26.079	0.769	0.015	0.692	0.692	0.450	0.500	6.255	0.492
323175	1	26.079	0.376	0.020	0.066	0.066	0.022	0.496	2.293	0.853
323175	2	6.520	0.407	0.100	0.225	0.225	0.122	0.281	4.688	1.739
323175	3	6.520	0.366	0.092	0.225	0.225	0.122	0.319	5.516	3.576
1542264	0	70.016	0.397	0.011	0.041	0.041	0.012	0.512	2.470	0.262
1542264	1	70.016	0.395	0.006	0.025	0.025	0.007	0.512	2.558	5.315
1542264	2	25.937	0.412	0.011	0.044	0.044	0.012	0.451	1.890	1.083
1542266	0	70.016	0.390	0.020	0.066	0.066	0.022	0.501	2.410	0.328
1542266	1	70.016	0.395	0.013	0.060	0.060	0.014	0.499	2.382	2.100
1542266	2	7.937	0.297	0.032	0.108	0.108	0.035	0.519	3.322	0.984
1542266	3	26.079	0.395	0.032	0.091	0.091	0.035	0.492	2.304	3.576
1542268	0	26.079	0.365	0.061	0.183	0.183	0.086	0.453	2.992	0.427
1542268	1	26.079	0.345	0.050	0.150	0.150	0.056	0.465	3.338	0.656
1542268	2	0.255	0.310	0.090	0.279	0.279	0.253	0.081	25.368	4.659
1542268	3	0.255	0.356	0.103	0.322	0.322	0.249	0.108	15.648	0.919
1542269	0	26.079	0.376	0.020	0.066	0.066	0.022	0.517	2.560	0.262
1542269	1	26.079	0.395	0.013	0.060	0.060	0.014	0.506	2.426	1.837
1542269	2	6.520	0.366	0.094	0.225	0.225	0.122	0.304	5.783	2.559
1542269	3	0.255	0.384	0.096	0.354	0.354	0.202	0.112	48.635	0.328
1542270	0	2.551	0.314	0.068	0.154	0.154	0.081	0.444	6.946	0.492
1542270	1	0.255	0.366	0.106	0.225	0.225	0.122	0.226	7.322	2.001
1542270	2	0.060	0.384	0.094	0.354	0.354	0.202	0.107	51.215	2.657
1542272	0	0.061	0.332	0.013	0.060	0.060	0.014	0.211	8.785	1.247
1542272	1	0.061	0.419	0.112	0.350	0.350	0.200	0.108	11.344	3.248
1542272	2	0.061	0.384	0.107	0.354	0.354	0.202	0.102	12.020	0.492
1542274	0	26.079	0.376	0.020	0.066	0.066	0.022	0.502	2.443	0.328
1542274	1	26.079	0.393	0.013	0.060	0.060	0.014	0.493	2.318	2.854
1542274	2	2.551	0.279	0.032	0.108	0.108	0.035	0.562	3.854	1.476

1542274	3	26.079	0.395	0.032	0.091	0.091	0.035	0.492	2.304	1.017
1542276	0	70.016	0.408	0.014	0.052	0.052	0.015	0.498	2.386	0.427
1542276	1	70.016	0.402	0.010	0.040	0.040	0.011	0.502	2.423	6.234
1542278	0	26.079	0.406	0.014	0.052	0.052	0.015	0.473	2.083	0.427
1542278	1	26.079	0.412	0.011	0.044	0.044	0.012	0.470	2.051	2.231
1542278	2	6.520	0.366	0.092	0.225	0.225	0.122	0.319	5.516	3.609
1542280	0	7.937	0.340	0.020	0.066	0.066	0.022	0.499	2.539	0.820
1542280	1	2.551	0.359	0.073	0.154	0.154	0.081	0.368	4.357	2.526
1542280	2	2.551	0.395	0.032	0.091	0.091	0.035	0.405	2.401	0.656
1542280	3	2.551	0.395	0.032	0.091	0.091	0.035	0.437	2.610	0.984
1542282	0	26.079	0.438	0.035	0.106	0.106	0.039	0.484	2.371	0.492
1542282	1	26.079	0.385	0.019	0.081	0.081	0.021	0.507	2.749	1.181
1542282	2	6.520	0.357	0.054	0.145	0.145	0.080	0.499	2.643	1.312
1542282	3	26.079	0.391	0.010	0.060	0.060	0.011	0.517	2.893	3.675
1542286	0	7.937	0.726	0.014	0.653	0.653	0.450	0.370	9.254	0.755
1542286	1	25.937	0.726	0.014	0.653	0.653	0.450	0.370	9.254	1.345
1542286	2	6.520	0.340	0.073	0.154	0.154	0.081	0.323	5.457	0.492
1542286	3	0.061	0.382	0.108	0.354	0.354	0.202	0.108	11.092	1.903
1542288	0	26.079	0.358	0.051	0.134	0.134	0.067	0.515	2.548	1.673
1542288	1	26.079	0.356	0.031	0.099	0.099	0.034	0.502	2.461	4.987
1542290	0	70.016	0.447	0.020	0.048	0.048	0.022	0.497	2.451	0.328
1542290	1	70.016	0.422	0.008	0.025	0.025	0.009	0.506	2.518	1.673
1542290	2	70.016	0.396	0.005	0.029	0.029	0.005	0.512	2.550	2.657
1542290	3	70.016	0.399	0.005	0.024	0.024	0.006	0.510	2.529	2.001
1542292	0	26.079	0.348	0.048	0.164	0.164	0.106	0.528	3.003	1.509
1542292	1	26.079	0.354	0.026	0.094	0.094	0.029	0.515	2.861	5.151
1542294	0	26.079	0.413	0.042	0.188	0.188	0.047	0.457	1.924	1.509
1542294	1	26.079	0.377	0.017	0.051	0.051	0.019	0.475	2.174	5.151
1542295	0	59.528	0.341	0.024	0.090	0.090	0.027	0.541	3.037	0.328
1542295	1	59.528	0.352	0.010	0.062	0.062	0.011	0.548	2.979	4.331
1542295	2	7.937	0.357	0.051	0.140	0.140	0.074	0.515	2.582	0.492
1542295	3	26.079	0.342	0.014	0.070	0.070	0.015	0.549	3.061	1.509
1542296	0	26.079	0.457	0.040	0.105	0.105	0.052	0.475	2.087	0.427
1542296	1	26.079	0.377	0.010	0.027	0.027	0.011	0.509	2.515	6.234
1542297	0	59.528	0.357	0.011	0.063	0.063	0.012	0.551	3.087	0.328
1542297	1	59.528	0.345	0.005	0.045	0.045	0.006	0.565	3.292	6.332
1542298	0	26.079	0.348	0.020	0.066	0.066	0.022	0.493	2.436	1.509
1542298	1	26.079	0.393	0.032	0.091	0.091	0.035	0.466	2.051	5.151
1542299	0	56.126	0.334	0.033	0.103	0.103	0.037	0.544	3.367	0.591
1542299	1	56.126	0.325	0.013	0.066	0.066	0.014	0.563	3.375	6.070
1542300	0	70.016	0.410	0.014	0.052	0.052	0.015	0.520	2.611	0.262

1542300	1	70.016	0.410	0.014	0.052	0.052	0.015	0.520	2.611	1.575
1542300	2	70.016	0.410	0.014	0.052	0.052	0.015	0.520	2.641	4.823
1542301	0	26.079	0.406	0.014	0.052	0.052	0.015	0.473	2.083	0.427
1542301	1	26.079	0.412	0.011	0.044	0.044	0.012	0.470	2.051	0.820
1542301	2	0.765	0.366	0.103	0.225	0.225	0.122	0.249	7.493	5.413
1542302	0	26.079	0.376	0.020	0.066	0.066	0.022	0.502	2.443	0.427
1542302	1	26.079	0.393	0.013	0.060	0.060	0.014	0.500	2.396	1.083
1542302	2	2.551	0.293	0.032	0.108	0.108	0.035	0.515	3.399	0.820
1542302	3	2.551	0.364	0.093	0.225	0.225	0.122	0.309	5.786	3.346
1542303	0	22.110	0.376	0.020	0.066	0.066	0.022	0.530	2.791	0.492
1542303	1	26.079	0.393	0.013	0.060	0.060	0.014	0.520	2.665	1.345
1542303	2	2.551	0.288	0.032	0.108	0.108	0.035	0.544	3.559	1.083
1542303	3	7.937	0.393	0.013	0.060	0.060	0.014	0.520	2.665	0.262
1542303	4	2.551	0.366	0.096	0.225	0.225	0.122	0.295	5.940	3.478
1603127	0	26.079	0.361	0.034	0.105	0.105	0.038	0.531	3.073	0.656
1603127	1	26.079	0.342	0.015	0.075	0.075	0.017	0.542	3.145	4.101
1603127	2	2.551	0.342	0.108	0.265	0.265	0.195	0.227	3.850	1.903
1603129	0	26.079	0.462	0.018	0.070	0.070	0.020	0.466	2.044	0.492
1603129	1	26.079	0.395	0.015	0.053	0.053	0.017	0.492	2.304	3.248
1603129	2	2.551	0.359	0.068	0.140	0.140	0.076	0.285	6.550	2.920
1603130	0	26.079	0.417	0.014	0.047	0.047	0.015	0.456	1.877	0.984
1603130	1	26.079	0.384	0.063	0.174	0.174	0.080	0.445	1.897	5.676
1603131	0	26.079	0.417	0.014	0.047	0.047	0.015	0.456	1.877	0.984
1603131	1	26.079	0.384	0.063	0.174	0.174	0.080	0.445	1.897	5.676
1603132	0	26.079	0.360	0.023	0.090	0.090	0.026	0.534	2.847	0.492
1603132	1	26.079	0.349	0.014	0.070	0.070	0.015	0.543	2.973	4.101
1603132	2	2.551	0.352	0.101	0.251	0.251	0.177	0.255	8.489	2.067
1603133	0	26.079	0.396	0.014	0.052	0.052	0.015	0.512	2.551	0.492
1603133	1	26.079	0.402	0.011	0.039	0.039	0.012	0.509	2.515	4.101
1603133	2	2.551	0.366	0.086	0.148	0.148	0.095	0.259	7.498	2.067
1603135	0	39.969	0.350	0.035	0.106	0.106	0.039	0.528	2.721	0.492
1603135	1	39.969	0.352	0.011	0.063	0.063	0.012	0.547	2.979	4.757
1603135	2	26.079	0.311	0.014	0.071	0.071	0.016	0.573	3.400	1.411
1603136	0	70.016	0.358	0.027	0.095	0.095	0.030	0.537	2.785	0.427
1603136	1	70.016	0.352	0.014	0.070	0.070	0.015	0.540	2.932	5.151
1603136	2	25.937	0.306	0.042	0.115	0.115	0.047	0.518	3.119	1.083
1603138	0	26.079	0.742	0.006	0.668	0.668	0.450	0.359	5.916	5.249
1603138	1	26.079	0.356	0.032	0.091	0.091	0.035	0.545	2.985	1.411
1603140	0	26.079	0.344	0.020	0.066	0.066	0.022	0.496	2.487	0.492
1603140	1	26.079	0.395	0.013	0.060	0.060	0.014	0.428	1.745	0.427
1603140	2	0.255	0.384	0.107	0.354	0.354	0.202	0.102	12.020	3.740

1603140	3	0.255	0.384	0.107	0.354	0.354	0.202	0.102	12.020	0.853
1603144	0	2.608	0.366	0.093	0.225	0.225	0.122	0.309	5.879	6.660
1603146	0	0.061	0.332	0.013	0.060	0.060	0.014	0.094	20.054	1.247
1603146	1	0.061	0.419	0.112	0.350	0.350	0.200	0.108	11.344	3.248
1603146	2	0.061	0.384	0.107	0.354	0.354	0.202	0.102	12.020	0.492
1603148	0	70.016	0.408	0.014	0.052	0.052	0.015	0.498	2.386	0.591
1603148	1	70.016	0.402	0.010	0.040	0.040	0.011	0.502	2.423	6.070
1603150	0	70.016	0.408	0.014	0.052	0.052	0.015	0.498	2.386	0.328
1603150	1	70.016	0.402	0.010	0.040	0.040	0.011	0.502	2.423	6.332
1603152	0	26.079	0.406	0.014	0.052	0.052	0.015	0.473	2.083	0.427
1603152	1	26.079	0.412	0.011	0.044	0.044	0.012	0.470	2.051	1.837
1603152	2	6.520	0.366	0.092	0.225	0.225	0.122	0.319	5.516	4.003
1603154	0	7.937	0.749	0.007	0.674	0.674	0.450	0.358	5.357	0.919
1603154	1	25.937	0.749	0.007	0.674	0.674	0.450	0.358	5.357	5.741
1603156	0	26.079	0.360	0.020	0.066	0.066	0.022	0.528	2.681	0.492
1603156	1	26.079	0.393	0.013	0.060	0.060	0.014	0.466	2.051	1.181
1603156	2	6.520	0.283	0.032	0.108	0.108	0.035	0.549	3.679	1.312
1603156	3	26.079	0.395	0.032	0.091	0.091	0.035	0.520	2.657	3.675
1603157	0	22.110	0.376	0.020	0.066	0.066	0.022	0.449	2.041	0.591
1603157	1	22.110	0.395	0.013	0.060	0.060	0.014	0.440	1.890	2.165
1603157	2	2.551	0.366	0.100	0.225	0.225	0.122	0.272	6.748	3.904
1603158	0	25.937	0.776	0.010	0.698	0.698	0.450	0.370	4.401	3.182
1603158	1	70.016	0.376	0.032	0.091	0.091	0.035	0.502	2.443	3.051
1603160	0	26.079	0.383	0.052	0.138	0.138	0.071	0.485	2.205	0.755
1603160	1	2.551	0.338	0.052	0.148	0.148	0.084	0.530	2.780	0.591
1603160	2	26.079	0.370	0.020	0.083	0.083	0.022	0.514	2.506	5.315
1603162	0	70.016	0.358	0.024	0.090	0.090	0.027	0.544	2.919	0.492
1603162	1	70.016	0.348	0.011	0.064	0.064	0.012	0.551	3.025	4.101
1603162	2	70.016	0.343	0.012	0.065	0.065	0.013	0.547	3.044	2.067
1603164	0	25.937	0.364	0.020	0.066	0.066	0.022	0.510	2.556	0.427
1603164	1	25.937	0.393	0.013	0.060	0.060	0.014	0.479	2.170	2.231
1603164	2	6.520	0.366	0.103	0.225	0.225	0.122	0.249	7.521	4.003
1603166	0	26.079	0.372	0.020	0.066	0.066	0.022	0.485	2.201	0.492
1603166	1	26.079	0.380	0.020	0.066	0.066	0.022	0.480	2.133	1.083
1603166	2	26.079	0.395	0.032	0.091	0.091	0.035	0.472	2.031	5.085
2513623	0	70.016	0.411	0.010	0.035	0.035	0.011	0.504	2.463	0.262
2513623	1	70.016	0.377	0.005	0.021	0.021	0.006	0.523	2.688	6.398
3102925	0	26.005	0.365	0.044	0.117	0.117	0.049	0.532	2.711	0.328
3102925	1	26.005	0.371	0.014	0.070	0.070	0.015	0.535	2.790	0.755
3102925	2	8.002	0.367	0.052	0.127	0.127	0.059	0.502	2.371	0.427
3102925	3	26.005	0.366	0.031	0.100	0.100	0.034	0.510	2.468	2.559

3102925	4	26.005	0.380	0.014	0.069	0.069	0.015	0.522	2.583	2.592
3102989	0	26.005	0.377	0.021	0.056	0.056	0.023	0.524	2.608	0.492
3102989	1	26.005	0.380	0.015	0.048	0.048	0.017	0.529	2.715	6.168
323147	0	26.079	0.397	0.011	0.041	0.041	0.012	0.512	2.470	0.328
323147	1	26.079	0.395	0.006	0.025	0.025	0.007	0.514	2.486	4.757
323147	2	26.079	0.413	0.011	0.044	0.044	0.012	0.451	1.862	1.575
1698337	0	70.016	0.358	0.027	0.095	0.095	0.030	0.537	2.785	0.427
1698337	1	70.016	0.352	0.014	0.070	0.070	0.015	0.540	2.932	5.151
1698337	2	25.937	0.306	0.042	0.115	0.115	0.047	0.518	3.119	1.083
323166	0	26.079	0.376	0.020	0.066	0.066	0.022	0.503	2.373	0.328
323166	1	26.079	0.393	0.013	0.060	0.060	0.014	0.501	2.331	1.017
323166	2	2.551	0.293	0.032	0.108	0.108	0.035	0.515	3.309	0.755
323166	3	0.255	0.364	0.093	0.225	0.225	0.122	0.309	5.786	1.411
323166	4	26.079	0.395	0.032	0.091	0.091	0.035	0.437	2.578	3.150
323176	0	26.079	0.456	0.024	0.024	0.188	0.047	0.512	1.370	6.590
1542304	0	26.079	0.456	0.024	0.188	0.188	0.047	0.512	1.370	6.590

Attachment A - 2: Soil parameters used by the ICPR4 model for Green-Ampt method. MC represents Moisture Content. Layer thicknesses are in feet.

Soil Zone	Kv Saturated	MC Saturated	MC Residual	MC Initial	MC Field	MC Wilting	Pore Size Index	Bubble Pressure	Layer Thickness
323121	70.016	0.390	0.030	0.091	0.091	0.033	0.492	2.458	6.660
323122	3.176	0.391	0.075	0.169	0.169	0.086	0.328	4.446	6.660
323123	11.291	0.380	0.047	0.123	0.123	0.057	0.395	3.431	6.660
323124	4.071	0.381	0.096	0.311	0.311	0.175	0.220	8.880	6.660
323125	24.231	0.363	0.031	0.104	0.104	0.038	0.491	2.855	6.660
323126	24.231	0.360	0.032	0.104	0.104	0.039	0.493	2.887	6.660
323127	24.231	0.360	0.032	0.104	0.104	0.039	0.493	2.887	6.660
323128	9.287	0.332	0.077	0.204	0.204	0.129	0.362	6.708	6.660
323129	10.559	0.345	0.062	0.166	0.166	0.089	0.411	6.198	6.660
323130	8.491	0.386	0.046	0.242	0.242	0.105	0.311	5.041	6.660
323131	26.079	0.542	0.025	0.475	0.475	0.122	0.351	9.421	5.413
323132	39.969	0.413	0.007	0.020	0.020	0.008	0.519	2.598	6.660
323133	16.691	0.349	0.024	0.085	0.085	0.026	0.519	2.795	6.660
323134	56.032	0.330	0.032	0.102	0.102	0.035	0.525	2.982	6.660
323135	8.446	0.393	0.069	0.165	0.165	0.083	0.337	4.131	6.660
323136	20.990	0.386	0.032	0.091	0.091	0.036	0.456	3.095	6.660
323137	23.591	0.407	0.021	0.070	0.070	0.026	0.445	2.149	12.073
323138	26.079	0.503	0.022	0.273	0.273	0.166	0.338	1.543	6.660
323139	20.747	0.372	0.024	0.086	0.086	0.028	0.518	2.565	6.660
323140	22.254	0.383	0.032	0.091	0.091	0.035	0.498	2.336	6.660
323141	26.079	0.399	0.011	0.043	0.043	0.012	0.470	2.003	6.660
323142	26.079	0.399	0.011	0.043	0.043	0.012	0.470	2.006	6.660
323143	26.079	0.372	0.030	0.098	0.098	0.035	0.503	2.402	6.660
323144	16.082	0.353	0.039	0.118	0.118	0.052	0.478	3.255	6.660
323145	14.453	0.379	0.040	0.099	0.099	0.048	0.411	3.289	6.660
323146	22.486	0.351	0.036	0.106	0.106	0.044	0.481	3.045	6.660
323148	47.419	0.389	0.017	0.074	0.074	0.021	0.515	2.752	6.660
323149	30.719	0.392	0.011	0.048	0.048	0.012	0.523	2.658	6.660
323150	26.005	0.381	0.009	0.057	0.057	0.010	0.528	2.712	6.660
323151	20.097	0.396	0.025	0.087	0.087	0.028	0.495	2.284	6.660
323152	70.016	0.387	0.008	0.054	0.054	0.009	0.526	2.680	6.660
323153	39.969	0.403	0.010	0.040	0.040	0.011	0.524	2.647	6.660
323154	38.942	0.366	0.005	0.021	0.021	0.005	0.528	2.719	6.660
323155	26.079	0.388	0.015	0.208	0.208	0.099	0.307	1.570	6.660
323156	26.079	0.540	0.018	0.343	0.343	0.211	0.255	1.119	6.660
323157	26.079	0.450	0.027	0.176	0.176	0.092	0.413	1.833	6.660
323158	26.005	0.339	0.037	0.108	0.108	0.043	0.507	2.614	6.660

323159	23.520	0.350	0.034	0.107	0.107	0.046	0.510	2.753	6.660
323161	26.079	0.387	0.014	0.069	0.069	0.015	0.513	2.595	6.660
323162	26.079	0.383	0.017	0.076	0.076	0.019	0.513	2.509	6.660
323164	26.079	0.532	0.026	0.479	0.479	0.120	0.353	13.385	6.660
323165	26.079	0.399	0.008	0.030	0.030	0.008	0.499	2.338	6.660
323167	22.369	0.348	0.060	0.158	0.158	0.077	0.452	3.419	6.660
323168	17.943	0.375	0.041	0.115	0.115	0.050	0.432	3.292	6.660
323169	9.160	0.396	0.076	0.200	0.200	0.105	0.292	5.272	6.660
323170	19.894	0.369	0.020	0.080	0.080	0.024	0.534	2.766	6.660
323171	21.443	0.374	0.017	0.070	0.070	0.019	0.507	2.473	6.660
323172	26.079	0.397	0.007	0.029	0.029	0.008	0.505	2.399	6.660
323173	26.079	0.398	0.007	0.029	0.029	0.008	0.503	2.384	6.660
323174	26.079	0.401	0.008	0.033	0.033	0.009	0.492	2.267	6.660
323175	10.470	0.408	0.078	0.239	0.239	0.133	0.308	4.480	6.660
3102925	24.852	0.372	0.024	0.087	0.087	0.027	0.518	2.555	6.660
3102989	26.005	0.380	0.016	0.049	0.049	0.017	0.528	2.707	6.660
1542264	62.850	0.398	0.007	0.029	0.029	0.008	0.502	2.446	6.660
1542266	38.788	0.381	0.025	0.083	0.083	0.028	0.498	2.476	6.988
1542268	4.453	0.323	0.086	0.266	0.266	0.222	0.147	20.424	6.660
1542269	14.343	0.378	0.060	0.164	0.164	0.082	0.377	7.196	4.987
1542270	0.374	0.370	0.096	0.285	0.285	0.159	0.185	29.931	5.151
1542272	0.061	0.394	0.087	0.278	0.278	0.154	0.133	10.771	4.987
1542274	19.959	0.362	0.021	0.078	0.078	0.024	0.511	2.722	5.676
1542276	70.016	0.402	0.010	0.041	0.041	0.011	0.502	2.421	6.660
1542278	14.814	0.385	0.058	0.149	0.149	0.076	0.383	4.049	6.266
1542280	3.437	0.368	0.051	0.119	0.119	0.056	0.408	3.456	4.987
1542282	22.225	0.387	0.022	0.084	0.084	0.028	0.510	2.780	6.660
1542286	9.834	0.538	0.054	0.472	0.472	0.305	0.081	5.293	4.495
1542288	26.079	0.356	0.036	0.108	0.108	0.042	0.505	2.483	6.660
1542290	70.016	0.406	0.006	0.027	0.027	0.007	0.509	2.531	6.660
1542292	26.079	0.352	0.031	0.110	0.110	0.046	0.518	2.894	6.660
1542294	26.079	0.385	0.023	0.082	0.082	0.025	0.471	2.118	6.660
1542295	48.136	0.350	0.014	0.071	0.071	0.017	0.546	2.971	6.660
1542296	26.079	0.382	0.012	0.032	0.032	0.014	0.507	2.487	6.660
1542297	59.528	0.346	0.006	0.046	0.046	0.006	0.564	3.282	6.660
1542298	26.079	0.382	0.029	0.085	0.085	0.032	0.472	2.139	6.660
1542299	56.126	0.326	0.014	0.069	0.069	0.016	0.561	3.374	6.660
1542300	70.016	0.410	0.014	0.052	0.052	0.015	0.520	2.633	6.660
1542301	5.504	0.375	0.086	0.192	0.192	0.102	0.291	6.477	6.660
1542302	8.807	0.360	0.064	0.165	0.165	0.081	0.390	4.543	5.676
1542303	8.961	0.361	0.060	0.154	0.154	0.074	0.407	4.530	6.660

1603127	19.357	0.344	0.044	0.132	0.132	0.070	0.451	3.339	6.660
1603129	15.764	0.384	0.039	0.092	0.092	0.043	0.399	4.146	6.660
1603130	26.079	0.389	0.056	0.155	0.155	0.070	0.447	1.894	6.660
1603131	26.079	0.389	0.056	0.155	0.155	0.070	0.447	1.894	6.660
1603132	18.777	0.351	0.041	0.128	0.128	0.066	0.453	4.675	6.660
1603133	18.777	0.390	0.034	0.074	0.074	0.038	0.431	4.064	6.660
1603135	37.026	0.343	0.013	0.068	0.068	0.015	0.551	3.049	6.660
1603136	62.850	0.345	0.019	0.079	0.079	0.021	0.536	2.953	6.660
1603138	26.079	0.661	0.007	0.546	0.546	0.362	0.115	0.632	6.660
1603140	4.559	0.381	0.092	0.306	0.306	0.171	0.162	10.374	5.512
1603144	2.608	0.366	0.093	0.225	0.225	0.122	0.309	5.879	6.660
1603146	0.061	0.394	0.087	0.278	0.278	0.154	0.104	13.588	4.987
1603148	70.016	0.402	0.010	0.041	0.041	0.011	0.501	2.420	6.660
1603150	70.016	0.402	0.010	0.041	0.041	0.011	0.502	2.421	6.660
1603152	13.586	0.383	0.063	0.160	0.160	0.082	0.373	4.266	6.266
1603154	23.454	0.749	0.007	0.674	0.674	0.450	0.358	5.357	6.660
1603156	22.225	0.370	0.027	0.087	0.087	0.030	0.517	2.753	6.660
1603157	10.645	0.376	0.064	0.157	0.157	0.078	0.342	4.751	6.660
1603158	47.512	0.580	0.015	0.401	0.401	0.247	0.246	1.196	6.234
1603160	23.993	0.369	0.026	0.095	0.095	0.033	0.512	2.496	6.660
1603162	70.016	0.347	0.012	0.066	0.066	0.013	0.550	3.023	6.660
1603164	14.267	0.375	0.067	0.160	0.160	0.079	0.343	5.411	6.660
1603166	26.079	0.391	0.029	0.085	0.085	0.032	0.475	2.060	6.660
2513623	70.016	0.378	0.006	0.022	0.022	0.006	0.522	2.679	6.660
323147	26.079	0.399	0.008	0.030	0.030	0.008	0.499	2.338	6.660
1698337	62.850	0.345	0.019	0.079	0.079	0.021	0.536	2.953	6.660
323176	26.079	0.456	0.024	0.188	0.188	0.047	0.512	1.370	1.181
1542304	26.079	0.456	0.024	0.188	0.188	0.047	0.512	1.370	1.181
323166	26.079	0.375	0.041	0.115	0.115	0.050	0.432	3.292	6.660

Attachment A - 3: Groundwater evapotranspiration extinction depth based on Shah et al. (2007)

LULC-Texture	Used Name	Extinction Depth (ft)	Remark
Bare-land-Fine sand	BLND_FS	1.64	Shah et al (2007)
Bare-land-Muck	BLND_MK	1.64	Shah et al (2007)
Bare-land-Sand	BLND_S	1.64	Shah et al (2007)
Bare-land-Sandy clay loam	BLND_SCL	6.56	Shah et al (2007)
Bare-land-Water	BLND_WTR	1.64	Shah et al (2007)
Forest-Fine sand	FRST_FS	8.20	Shah et al (2007)
Forest-Muck	FRST_MK	8.20	Shah et al (2007)
Forest-Sand	FRST_S	8.20	Shah et al (2007)
Forest-Sandy clay loam	FRST_SCL	13.12	Shah et al (2007)
Forest-Water	FRST_WTR	8.20	Shah et al (2007)
Grass-Fine sand	GRAS_FS	4.76	Shah et al (2007)
Grass-Fine sandy loam	GRAS_FSL	7.55	Shah et al (2007)
Grass-Muck	GRAS_MK	4.76	Shah et al (2007)
Grass-Sand	GRAS_S	4.76	Shah et al (2007)
Grass-Sandy clay loam	GRAS_SCL	9.84	Shah et al (2007)
Grass-Water	GRAS_WTR	4.76	Shah et al (2007)
Water-Fine sand	WATR_FS	1.64	Assumed bare-land
Water-Muck	WATR_MK	1.64	Assumed bare-land
Water-Sand	WATR_S	1.64	Assumed bare-land
Water-Sandy clay loam	WATR_SCL	1.64	Assumed bare-land
Water-Water	WATR_WTR	0.50	Assumed no grass
Wetland-Fine sand	WLND_FS	4.92	Assumed hydric grassland
Wetland-Muck	WLND_MK	4.92	Assumed hydric grassland
Wetland-Sand	WLND_S	4.92	Assumed hydric grassland
Wetland-Sandy clay loam	WLND_SCL	9.84	Assumed hydric grassland
Wetland-Water	WLND_WTR	4.92	Assumed hydric grassland

Attachment A - 4. Mapped basin parameters used in ICPR4 model. Tc represents Time of concentration. Min refers to minutes

Mapped basin	Node	Tc (min)	Max Allowable Q	Time Shift	Unit Hydrograph	Peaking Factor	Remark
B_Black_1	N-Black_000	287	999	0	DELMARVA284	284	Black Lake
B_Avalon_1	N-Avalon_000	520	999	0	DELMARVA284	284	Lake Avalon
B_Johns_1	N-Johns_000	566	999	0	DELMARVA284	284	Johns Lake
B_Johns_OF_1	N-Johns_Out_040	196	999	0	DELMARVA284	284	Johns Lake outfall
B_Johns_OF_2	N-Johns_Out_170	117	999	0	DELMARVA284	284	Johns Lake outfall
B_Buynak_1	N-Buynak_000	123	999	0	DELMARVA284	284	Lake Buynak
B_Clarice_1	N-Clarice_000	85	999	0	DELMARVA284	284	Lake Clarice
B_Reaves_1	N-Reaves_000	91	999	0	DELMARVA284	284	Lake Reaves
B_Black_30	N-Black_1130	168	999	0	DELMARVA284	284	u/s Lake Reaves
B_MaryFrancis_1	N-Yarbo_135	193	999	0	DELMARVA284	284	Lake Mary Frances & wetlands system
B_Roberts_1	N-Roberts_000	162	999	0	DELMARVA284	284	Lake Roberts
B_Banana_Bay_1	N-Banana_000	42	999	0	DELMARVA284	284	Banana Bay - closed basin
B_Lu_1	N-Lu_000	61	999	0	DELMARVA284	284	Lake Lu
B_Roper_3	N-Roper_120	130	999	0	DELMARVA284	284	un-named lake u/s Lake Roper
B_Roper_1	N-Roper_000	244	999	0	DELMARVA284	284	Lake Roper
B_Roper_4	N-Roper_020	46	999	0	DELMARVA284	284	un-named lake u/s Lake Roper
B_Black_21	N-Black_710	40	999	0	DELMARVA284	284	u/s Lake Reaves
B_Luntz_1	N-Luntz_000	105	999	0	DELMARVA284	284	Lake Luntz
B_Tilden_3	N-Tilden_220	74	999	0	DELMARVA284	284	FDOT ponds u/s Lake Tilden
B_CawoodWest_1	N-CawoodWest_000	84	999	0	DELMARVA284	284	Cawood Ponds West
B_Yarbo_1	N-Yarbo_000	122	999	0	DELMARVA284	284	Lake Yarbo
B_Yarbo_2	N-Yarbo_050	151	999	0	DELMARVA284	284	wetlands system u/s Lake Yarbo
B_Black_23	N-Black_1100	37	999	0	DELMARVA284	284	u/s Lake Reaves, FDOT ponds
B_Black_25	N-Black_920	63	999	0	DELMARVA284	284	u/s Lake Reaves
B_Black_29	N-Black_1110	169	999	0	DELMARVA284	284	u/s Lake Reaves
B_Black_31	N-Black_Out_1230	103	999	0	DELMARVA284	284	u/s Lake Reaves
B_Black_27	N-Black_950	146	999	0	DELMARVA284	284	u/s Lake Reaves
B_Black_12	N-Black_360	247	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_5	N-Black_230	173	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_11	N-Black_320	146	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_4	N-Black_210	131	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_14	N-Black_600	123	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_10	N-Black_400	35	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_9	N-Black_160	58	999	0	DELMARVA284	284	FDOT ponds u/s of Black Lake
B_Beulah_1	N-Beulah_000	102	999	0	DELMARVA284	284	Lake Beulah
B_Black_7	N-Black_090	166	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_8	N-Black_120	94	999	0	DELMARVA284	284	wetland u/s of Black Lake
B_Black_13	N-Black_535	103	999	0	DELMARVA284	284	wetland u/s Black Lake

B_Black_15	N-Black_570	67	999	0	DELMARVA284	284	u/s of Black Lake
B_Black_20	N-Black_810	54	999	0	DELMARVA284	284	FDOT ponds u/s of Black Lake
B_Tilden_2	N-Tilden_120	94	999	0	DELMARVA284	284	u/s Lake Tilden
B_Black_18	N-Black_050	112	999	0	DELMARVA284	284	wetlands u/s of Black Lake
B_Johns_OF_3	N-Johns_Out_300	116	999	0	DELMARVA284	284	u/s Johns Lake
B_Black_6	N-Black_060	130	999	0	DELMARVA284	284	u/s of Black Lake
B_Tilden_1	N-Tilden_000	57	999	0	DELMARVA284	284	Lake Tilden
B_Roper_2	N-Roper_100	53	999	0	DELMARVA284	284	wetland system u/s Lake Roper
B_Black_3	N-Black_200	76	999	0	DELMARVA284	284	wetlands u/s of Black Lake
B_Black_24	N-Black_910	55	999	0	DELMARVA284	284	u/s Lake Reaves
B_Black_26	N-Black_930	51	999	0	DELMARVA284	284	u/s Lake Reaves
B_Tilden_4	N-Tilden_240	54	999	0	DELMARVA284	284	u/s Lake Tilden
B_Black_17	N-Black_640	107	999	0	DELMARVA284	284	u/s of Black Lake
B_Lu_2	N-Lu_020	78	999	0	DELMARVA284	284	Lake Lu
B_Black_2	N-Black_040	72	999	0	DELMARVA284	284	wetlands u/s of Black Lake
B_Black_28	N-Black_1010	149	999	0	DELMARVA284	284	u/s Lake Reaves
B_Tilden_5	N-Tilden_300	125	999	0	DELMARVA284	284	closed basin, surface overflow to south to tilden
B_Black_19	N-Black_800	33	999	0	DELMARVA284	284	FDOT ponds u/s of Black Lake
B_Reaves_2	N-Reaves_010	53	999	0	DELMARVA284	284	u/s Lake Reaves
B_Black_22	N-Black_900	25	999	0	DELMARVA284	284	u/s Lake Reaves, FDOT ponds

APPENDIX - 2

MODEL CALIBRATION, VALIDATION, AND LONG-TERM SIMULATION

TECHNICAL MEMORANDUM

DATE: August 31, 2021

SUBJECT: Johns & Avalon Lakes ICPR4 Model Calibration, Validation & Long-term simulation – Tasks C & D

INTRODUCTION

Johns Lake is a priority lake listed in the District's 2020 Minimum Flows and Levels (MFLs) priority list and is scheduled for completion in 2022. The lake's watershed is primarily located in northwest Orange County, Florida, just south of Lake Apopka, with a small portion in Lake County, in the west (Figure C - 1). The purpose of establishing minimum levels for Johns Lake is to protect the lake from significant harm due to excessive groundwater and/or surface water withdrawals. Because minimum levels are usually based on hydrologic events with associated durations and return periods, MFLs assessment requires frequency analysis of lake levels. Due to the presence of short- and long-term climatic cycles (e.g. El Nino Southern and Atlantic Multidecadal Oscillations), the frequencies of lake levels could be significantly different in the wet periods than those in the dry periods. Therefore, it is important to perform frequency analysis using long-term continuous lake levels so that the effect of short- and long-term climatic variations can be captured in the lake levels. Although observed long-term lake levels data can be used for such analyses, such data are usually discontinuous and sometimes sparse. Thus, long-term lake levels need to be simulated by using hydrologic and hydraulic models. This is also important for a better understanding of the Lake's water budget elements.

We developed an Interconnected Channel and Pond Routing version 4 (ICPR4) model (Streamline Technologies, 2018) for simulating the hydrologic and hydraulic processes, surface water – groundwater (SW-GW) interaction, and water budget elements of Johns Lake. We first developed the model for the period from 1995 to 2018 (see Task B report for details). Then, we calibrated, validated, and extended the model for the period from 1948 to 2018. We used the period 2005 to 2018 for calibration, 1995 to 2004 for validation, and 1948 to 2018 for long-term simulations. This model is hereafter called the original model. We subsequently contracted Streamline Technologies (SLT) to review and improve this model. SLT made some modifications to the original model that included splitting one groundwater region into four regions, changes to the representation of surficial aquifer saturated hydraulic conductivity, fillable porosity, and initial lake and groundwater conditions, incorporating additional retention ponds, and increasing model resolution (SLT, 2021). This model is hereafter referred as the SLT model, and its details can be found in SLT (2021) report. We finally made further updates to the SLT model. This includes modifying the representation of initial groundwater and lake conditions, further adjusting surficial aquifer thickness, adding more crop zones, and replacing old bathymetry with new bathymetry data for Johns Lake. This technical memorandum utilizes the final and updated version of the STL model and presents the corresponding results for the calibration, validation, and long-term periods.

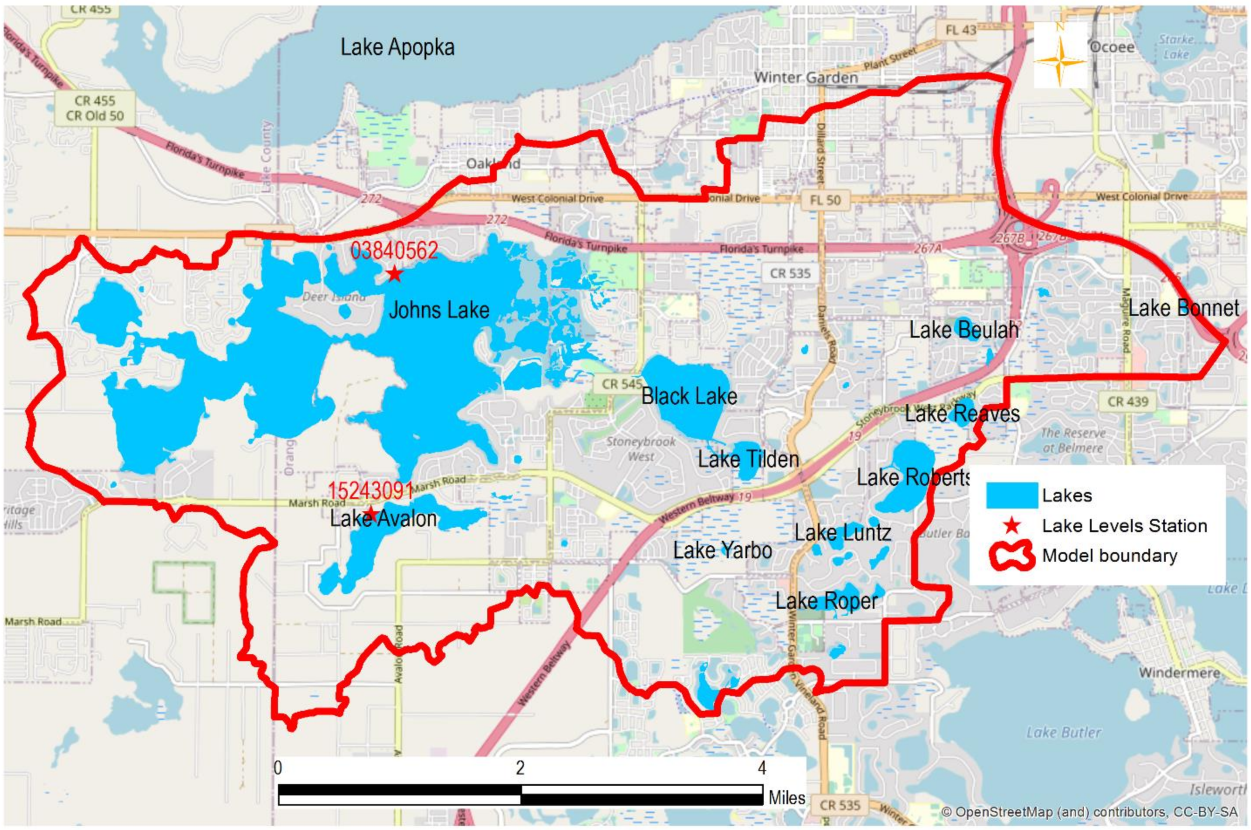

Figure C - 1. Johns Lake watershed along with locations of observed water levels for Johns and Avalon Lakes

HYDRO-METEOROLOGICAL DATA

While hydro-meteorological and geospatial data utilized for the calibration and validation periods are documented in Task B report, we extended the reference evapotranspiration (RET) and UFA groundwater stage time series for the long-term simulations. We extended the data back to 1/1/1948 based on the available data from nearby stations, as detailed in the next sections.

Rainfall

NEXRAD hourly data for the 38 pixels that are within and around the study area (see Figure C - 2) was available for the period from 1/1/1995 to present. We extended the pixels' hourly data back to 1/1/1948 based on a composite hourly data available at Isle_Win station (see Figure C - 2). Isle_Win is the closest station with complete long-term hourly rainfall values. We directly used the station's rainfall values for the period from 1/1/1948 to 12/31/1994 and combined with the NEXRAD values of 1/1/1995 to 12/31/2018. The long-term composite annual rainfall values are shown in Figure C - 3.

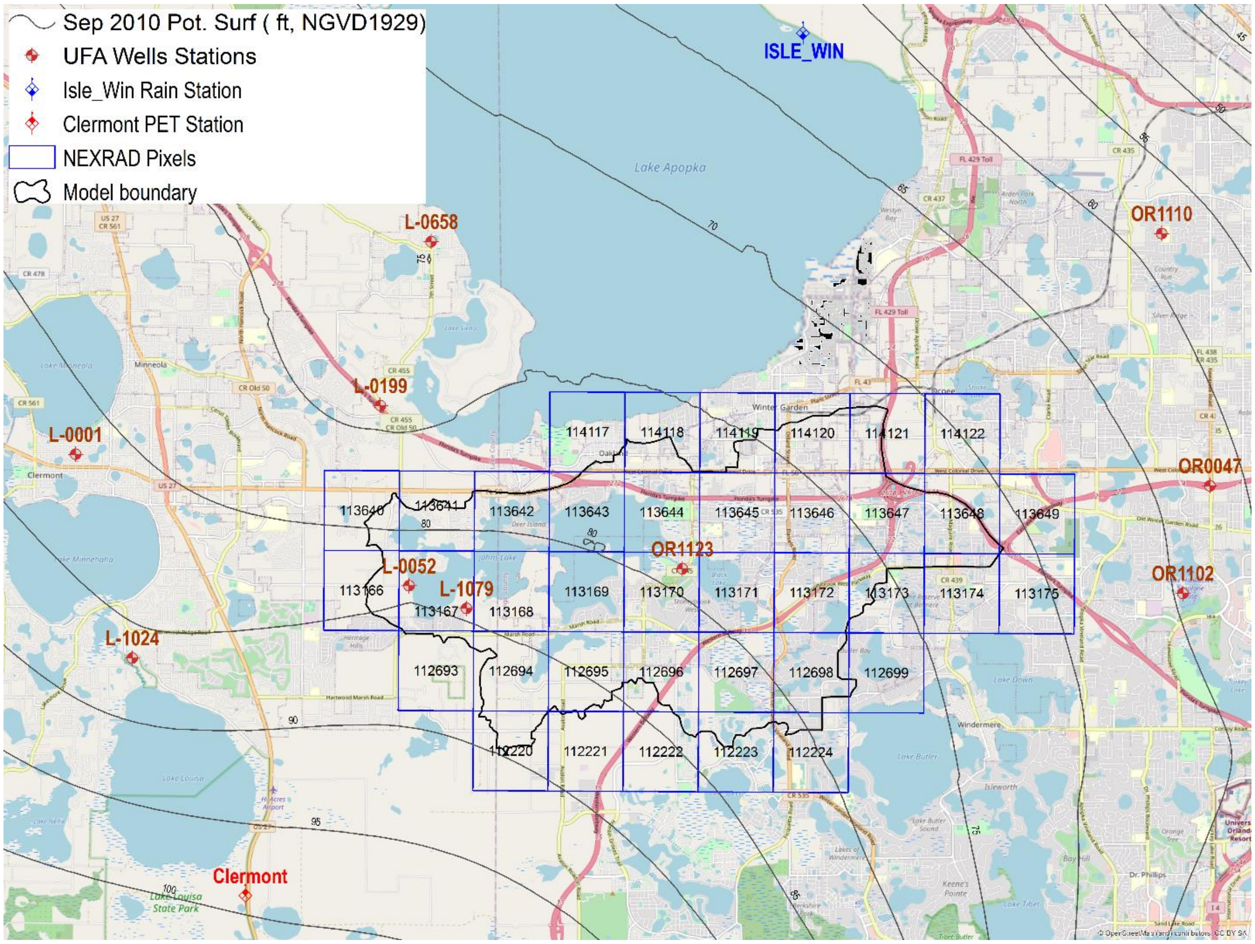

Figure C - 2. Locations of hydro-meteorological stations within and around the model boundary along with representative September 2010 potentiometric levels of Johns and Avalon Lakes

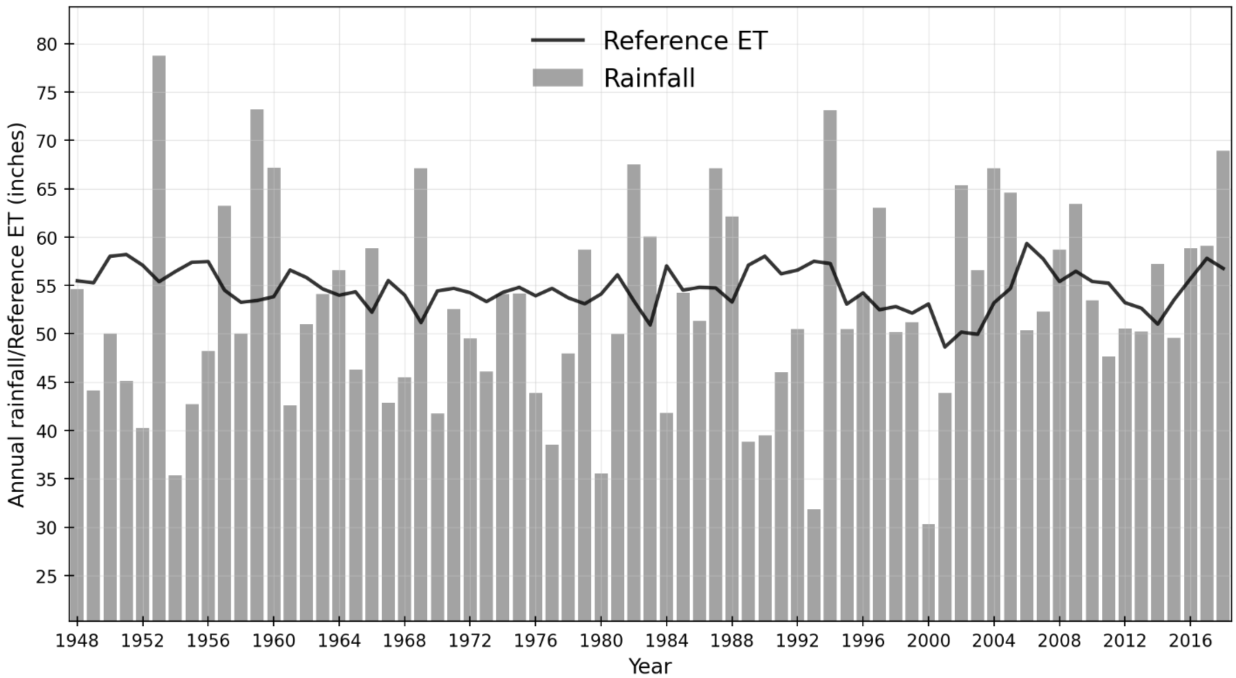

Figure C - 3. Average annual rainfall and reference evapotranspiration (1948 – 2018) of Johns and Avalon Watersheds

Reference Evapotranspiration (RET)

Daily RET data was available from the USGS and District's hydrological databases for the period from 1/1/1985 to present, as discussed in the Task B report of the project. We extended the USGS daily RET data back to cover the same period of rainfall data (1/1/1948 – 12/31/2018). Data extension utilized the daily Potential Evapotranspiration (PET) values estimated at the Clermont station (Figure C - 2) using the Hargreaves-Samani (1985) method. We used the calculated PET values for the period from 1/1/1948 – 12/31/1984 based on the following approaches:

1. Analyze the relationship between the USGS RET and Hargraves PET data for the overlapping POR (1/1/1985 –12/31/2017) at Clermont station. The Clermont station is located inside the USGS pixel identification 111268. Since some of the 2018 USGS PET data did not seem reasonable, we excluded both the 2018 RET and PET data from the analysis. As it should be expected, the RET and PET values show a strong correlation with a monthly coefficient of determination (R^2) of > 0.9 (Figure C - 4).

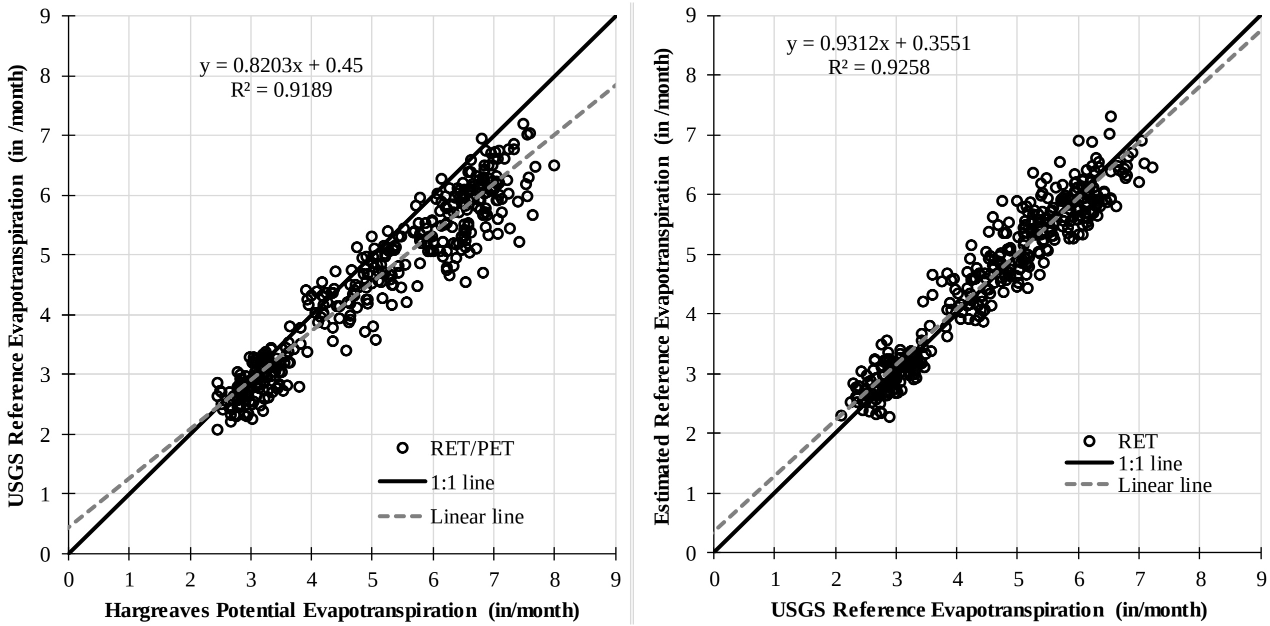

Figure C - 4. Comparison of monthly USGS reference evapotranspiration (RET) with potential evapotranspiration (PET) (left) and estimated RET (right) at Clermont station for the period 1/1/1985 to 12/31/2017.

2. Estimate RET values at pixel 111268 (1/1/1948 – 12/31/1984) from the Hargreaves PET. We used monthly average correction factors that we calculated as the ratio of the USGS RET to the Hargreaves PET for the period from 1/1/1985 to 12/31/2017.
3. Estimate a monthly correction factor to apply the estimated RET data at Clermont station to each of the NEXRAD pixels of Johns/Avalon watershed (see Figure C - 2). We calculated monthly average correction factors as the ratio of pixel’s RET to Clermont pixel’s (pixel ID: 111268) RET for the period from 1/1/1985 to 12/31/2017. Then, we applied the corresponding pixel’s correction factors to the estimated RET values at Clermont station and moved the daily estimated RET time series values to each pixel of the watershed for the period from 1/1/1948 to 12/31/1984.
4. Create composite RET data. We combined the pixels’ estimated RET data (1/1/1948 – 12/31/1984) with the USGS’s RET data (1/1/1985 – 12/31/2018) and created a composite RET data for the period from 1/1/1948 to 12/31/2018. For validation, we compared the estimated RET with USGS RET values for the overlapping POR (1/1/1985 – 12/31/2017). For this, we selected two pixels where Johns Lake is located (Figure C - 1). The estimated RET and USGS RET well matched for the two pixels (Figure C - 5). This is further reflected with a high R^2 of 0.93, indicating the reasonable estimate of RET from the Hargreaves’ PET data.

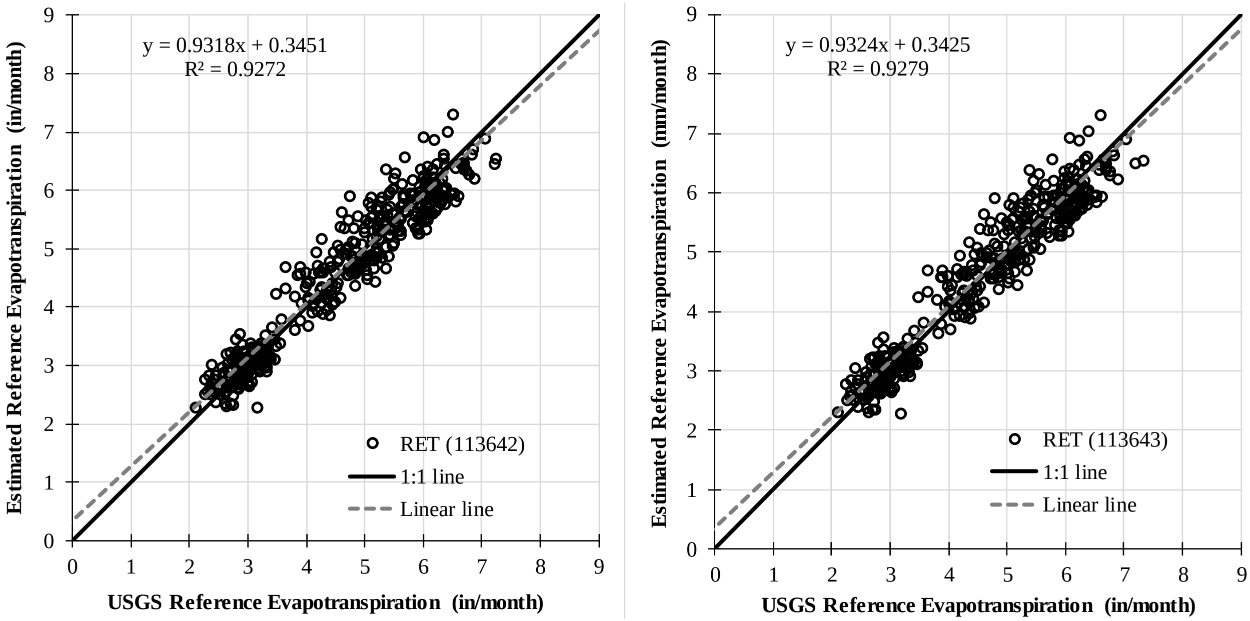

Figure C - 5. Comparison of the USGS and estimated RET values for pixels 113642 and 113643.

Groundwater Stages

Groundwater stage data was needed to simulate seepage rates beneath the lakes and elsewhere using the ICPR4 model. To extend and create complete groundwater stages for the period from 1/1/1960 to 12/31/2016, Collective Water Resources (CWR, 2019) reviewed and analyzed a number of UFA wells, which are within and around the study area. CWR (2019) used stages recorded at wells L-0062, L-0199, L-0658, and OR0047 to extend the well data at L-0052 and OR1123 that were used in the SWMM model. The latter two wells are located inside the study domain (Figure C - 2). CWR (2019) extended the two wells data based on a single average offset value. For ICPR4, we chose well data recorded at OR1123 as it is approximately located in the center of the study area (Figure C - 2). We used the OR1123's data along with groundwater offset values. We estimated the offset values based on May and September potentiometric surfaces to represent and spatially vary the UFA boundary condition in the ICPR4 model (see Task B report for details). However, the extended stages at OR1123 by CWR (2019) did not adequately follow the temporal variation of observed stages at Johns Lake and surrounding wells, as evidently seen in Figure C - 6, especially before 1993. In addition, Table C - 1 indicates a weak correlation between the extended OR1123 stages by CWR (2019) and observed stages of Johns when compared to the other wells. As a result, we decided to re-extend the observed stages at OR1123 based on other recorded stages that we obtained from wells L0052 and OR0047 (Figure C - 2).

Table C - 1. Pearson correlation coefficient values among lakes and wells data

	Johns Lake	Avalon Lake	OR0047	OR0047[a]	L0052	OR1123	OR1123[b]
Johns Lake	1.00	0.77	0.37	0.66	0.92	0.92	0.50
Avalon Lake		1.00	0.67	0.63	0.76	0.61	0.65
OR0047			1.00	1.00	0.86	0.94	0.80
OR0047[a]				1.00	0.85	0.94	0.60
L0052					1.00	0.96	0.93
OR1123						1.00	1.00
OR1123[b]							1.00

[a] linearly interpolated by SJRWMD; [b] gap filled and extended back to 1/1/1960 by Collective Water Resources (2019)

In general, observed water stages at L0052, OR0047, and OR1123 show similar temporal variations (Figure C - 7). In addition, observed stages at L0052 and OR0047 also show strong correlation with OR1123 (r > 0.9) as shown in Table C - 1. Although well L0052 is inside the watershed and closer to well OR1123 (about 4 miles), that station also had a relatively short POR (since 6/29/1993) compared to the OR0047 POR (since 9/30/1930). OR0047 station is approximately 8 miles from OR1123.

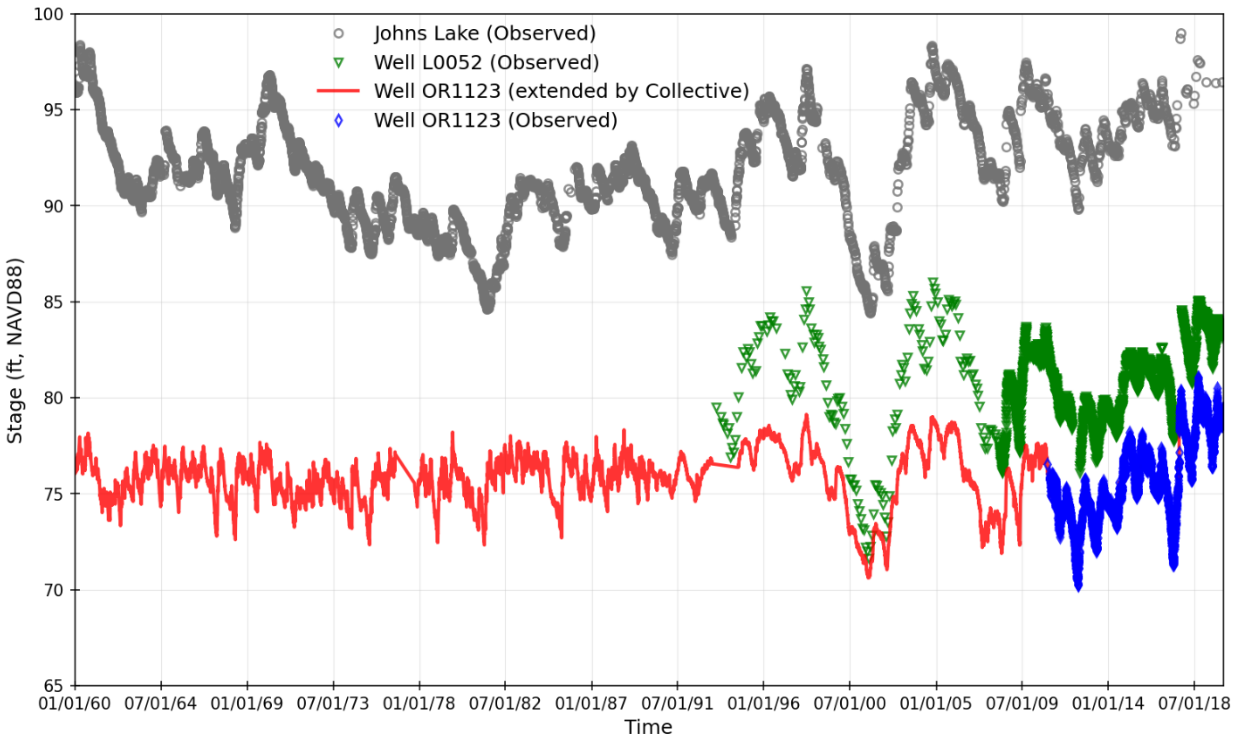

Figure C - 6. Observed daily lake and UFA stages along with extended groundwater levels by Collective Water Resources (2019).

Johns Lake also shows a strong correlation (r > 0.9) with observed groundwater stages at both L0052 (since 6/29/1993) and OR1123 (since 10/21/2010), but the correlation coefficient with the entire POR at OR0047 (since 9/7/1959) was lowered to 0.37 (Table C - 1). However, when we limited the correlation analysis to the POR at L0052 and OR1123, the r values significantly increased to 0.77 and 0.85, respectively. Table C - 1 also noticed similar correlation value between Johns and OR0047 for the rest of observed water stages (before 6/29/1993). Furthermore, we achieved r value of 0.85 if we used observed data since 2000 (roughly when noticeable land developments have begun in the watershed (SLT, 2021). Overall, results highlight a strong correlation between lakes and groundwater stages but that might have been changed over time.

Given the availability of long-term POR at station OR0047 and its strong correlation with wells L0052 and OR1123 (Table C - 1), we selected well OR0047 data along with observed stages at station L0052 to extend and produce a composite daily time series stages at station OR1123. We used the data from L0052 to fill missing values since 6/29/1993 and data at OR0047 to extend before 6/29/1993. To move both wells' observed stages to OR1123 station, we applied the Line of Organic Correlation (LOC) regression method (Helsel and Hirsch, 2002). Furthermore, we filled still missing values at OR1123 using a linear interpolation technique. The daily extended and observed water stages at OR1123 are shown in Figure C - 7. The monthly values along with May and September Potentiometric surfaces (since 1978) at OR1123 are presented in Figure C - 8. When compared to the extended stages by CWR (2019), the new extended stages at OR1123 indicate a better temporal variation and evolution with the Johns' observed stages (Figure C - 7). The new extended data also improved the match with the potentiometric surfaces at OR1123 location (Figure C - 8).

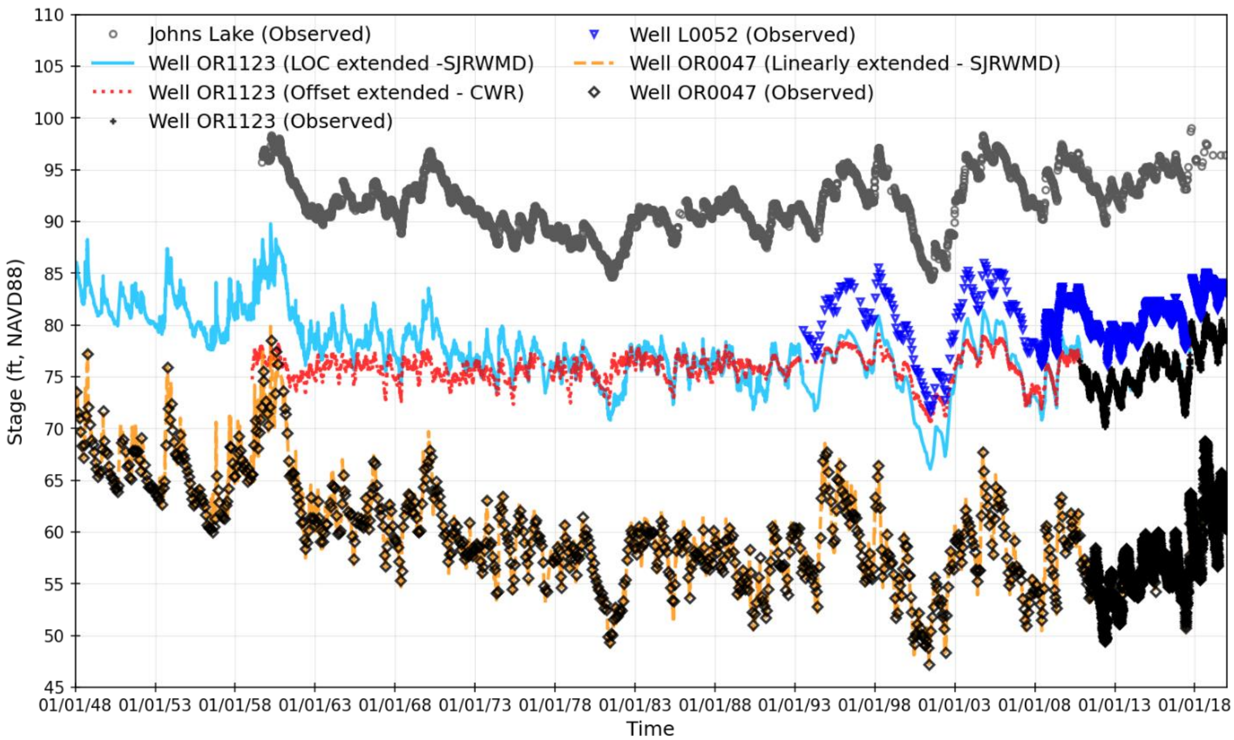

Figure C - 7. Observed and extended groundwater stages at well OR1123 (LOC = Line of Organic Correlation; CWR = Collective Water Resources).

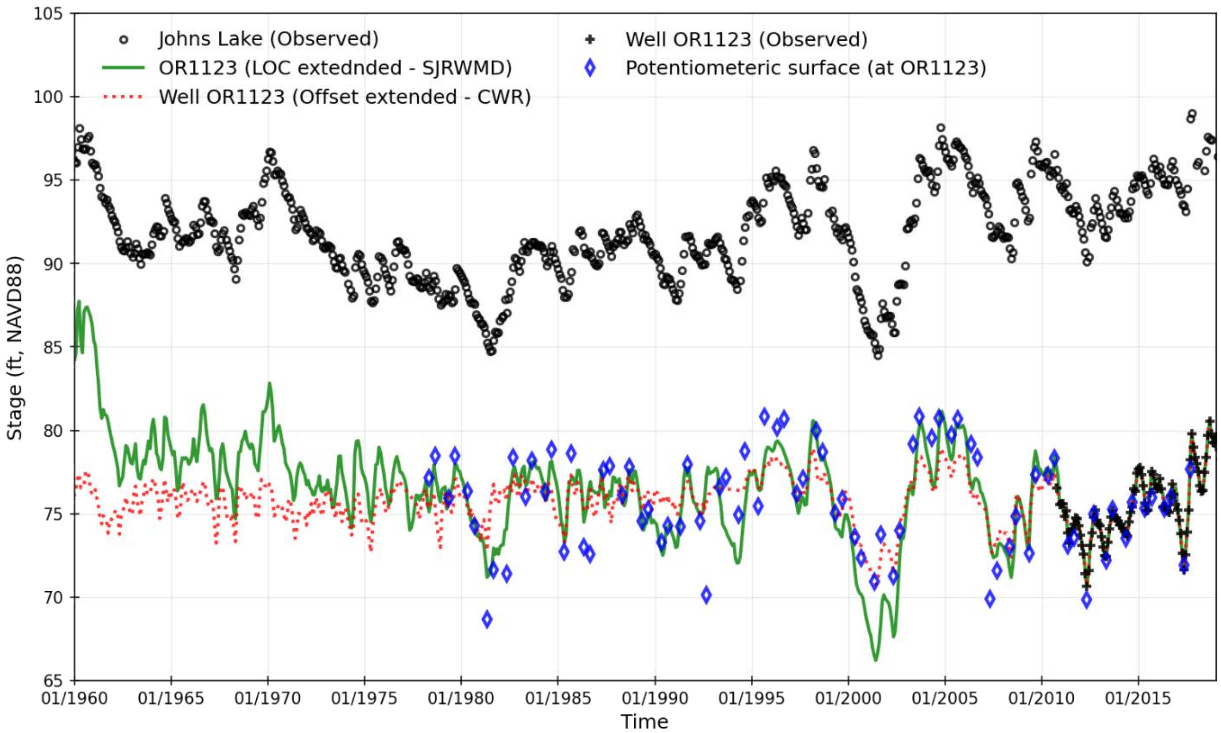

Figure C - 8. Monthly water stages of Johns &OR1123 along with May and September UFA potentiometric levels (1978 – 2017). Johns' monthly average stages calculated from non-continuous daily values that may not represent actual monthly values.

BATHYMETRY

In addition to extending hydro-meteorological and stages data, we also replaced the old bathymetry data of Johns Lake documented in Task B report with the recently collected high-resolution bathymetry data. The new bathymetry data was derived from a combination of LiDAR-derived contours, field survey of 2020 and 2021, and "heads up" digitized aerial photographs of 1984 and 2014 – all available in the SJRWMD's GIS databases. We converted all these datasets to point elevations and used interpolation techniques to produce a raster map for a habitat analysis using the Hydroperiod Tool. These datasets were only used to estimate the bathymetric portion of Johns Lake (≤ 96 ft – NAVD88). For higher elevations (> 96 ft), we still used the original DEM as reported in Figure B – 3 of the Task B report, but with the old bathymetric portion removed and the new bathymetry mosaiced in its place. We converted the mosaiced data to stage-area curves using the ICPR4's conversion tool. Figure C - 9 compares the old and new stage area curves of Johns Lake. The figure clearly indicates that the new bathymetry data generally produced larger areas for stages approximately ≤ 96 ft. As it was expected, the higher stages generate similar curves, since the stages were derived from the same DEM data as used in the original and SLT ICPR4 models.

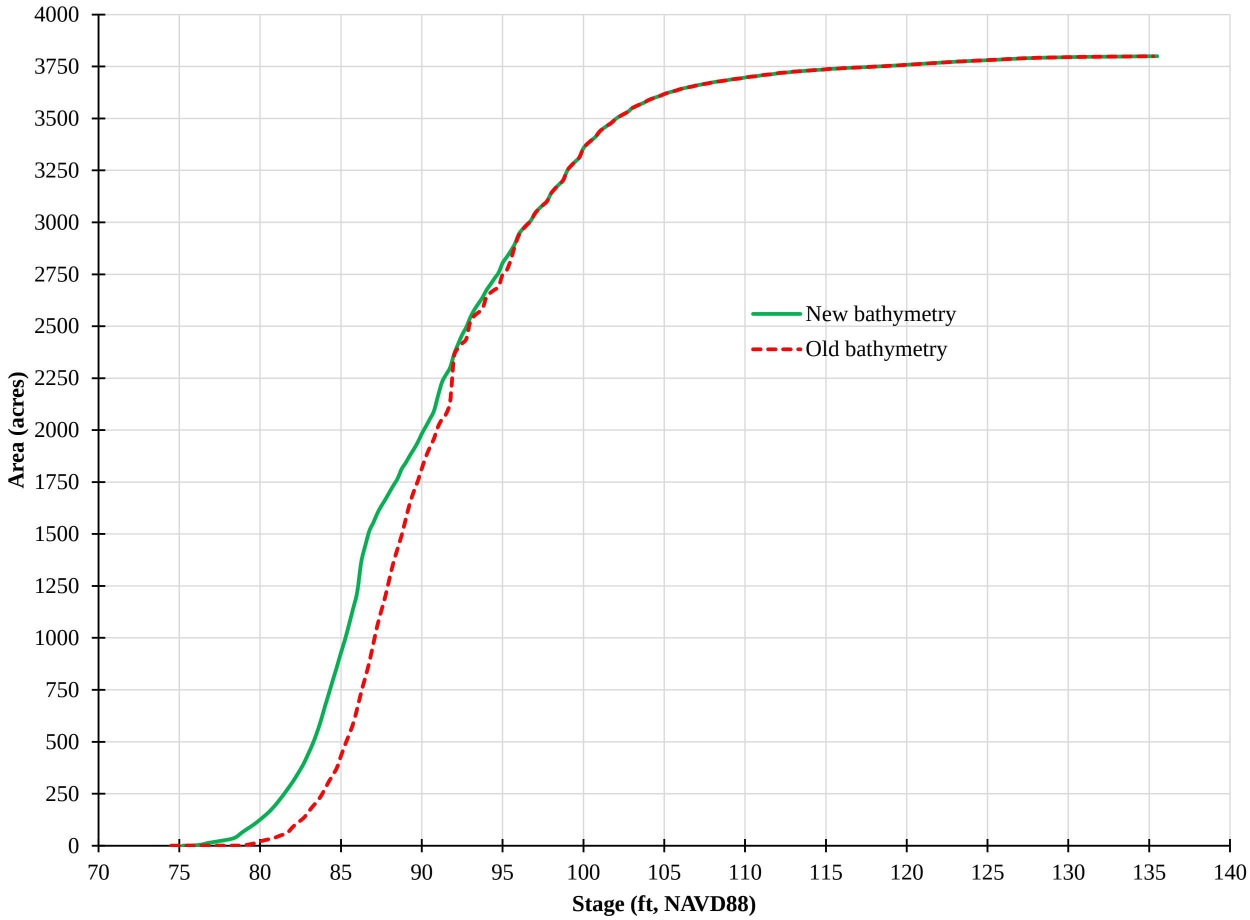

Figure C - 9. Old and new stage-area curves of Johns Lake.

CALIBRATION AND VALIDATION

We used the irregularly observed daily stages data at stations 03840562 for Johns Lake and 15243091 for Lake Avalon (Figure C - 1) for both model calibration and validation procedures. We also used observed daily stages at Lake Apopka (station # 19284372) for the period from 1/1/1948 to 12/31/2018 as downstream boundary condition in the north side of the study area (Figure C - 1). Nevertheless, the use of this boundary condition barely affects the simulated stages of Johns Lake. As this project focused on Johns Lake, we did not aim to calibrate the rest of the lakes located inside the watershed (Figure C - 1). However, we calibrated and validated observed stages of Lake Avalon only for the purpose of comparison with the Storm Water Management Model (SWMM) model's results. In addition, the rest lakes did not have bathymetric data combined with sporadically recorded stages that further limited calibration and validation processes. However, following the approach used by CWR (2019) for the SWMM model of Johns and Avalon Lakes, we also consistently checked if the simulated stages of those lakes reasonably follow the temporal variations of observed stages.

To match simulated stages with observed stages of Johns and Avalon Lakes, we manually calibrated the ICPR4 model for the period from 1/1/2005 to 12/31/2018. Then the model validation utilized observed stages for the period from 1/1/1995 to 12/31/2004. During model calibration and validation processes, we compared and evaluated the simulated lake stages with daily observed lake stages by consistently using both graphical and statistical evaluation methods. We also used multiple goodness-of-fit statistics with the following targeted values for monthly stages:

- Nash-Sutcliffe efficiency (NSE)
- Root Mean Squared Error (RMSE): RMSE ≤ 1 foot
- Mean Error (ME): ME ≤ |±1| foot
- Absolute Mean Error (AME): AME ≤ 1 foot
- Percent Bias (PBIAS): PBIAS ≤ |±10%| (calibration) and ≤ |±15%| (validation)
- Pearson correlation coefficient (r): r ≥ 0.8 (calibration) and r ≥ 0.7 (validation)
- Percent of observations bracketed within ±1 foot ≥ 85% (calibration) and ≥ 75% (validation)

Due to the sporadic nature of observations (sometimes two observed values per month), monthly average observed stages may lose their meaning. Consequently, we evaluated the ICPR4 model performance at a daily time scale. As model performance usually decreases with high temporal resolutions, the monthly targeted values could be relaxed for daily performance evaluation.

LONG-TERM SIMULATION

Using the extended rainfall, RET, and UFA stages, we extended the calibrated and validated ICPR4 model to the period from 1/1/1948 to 12/31/2018. We originally calibrated (2005-2018), validated (1995-2004), and extended (1948-2018) the ICPR4 model. Then, we provided the model to Streamline Technologies (SLT) for review and further improvements. Detail on the original model updates and methodologies and approaches used by the SLT are provided in STL (2021) report.

RESULTS AND DISCUSSION

Calibrated Parameters

During the calibration process, we adjusted the following model parameter values:

- ***Vertical saturated hydraulic conductivity (kv)*** – We reduced the original kv values reported in Attachment A – 1 of the Task B report by 75% for the first and second top layers of the vertical layer method of ICPR4 model.
- ***Leakance values*** – We spatially varied the leakance values and used the values from the ECFTX model (Central Florida Water Initiative (CFWI), 2020) as a starting point. While we kept the values of the ECFTX model for most of the leakance zones, we adjusted and calibrated the values beneath Johns, Black, and Avalon Lakes, including their corresponding sub-basins. The calibrated leakance values are reported in Attachment C - 1.
- ***Crop coefficient (kc)*** – To estimate the actual evapotranspiration values from reference evapotranspiration (RET) and crop coefficient, we calibrated the crop coefficient value for each land use/land cover (LULC) type. We reduced the original kc values documented in Table B – 4 of the Task B report by 50% for all LULC types except for forest, water, and wetland areas. Further, while we kept to a maximum kc of 1 for water and wetland areas, we reduced the original forest's kc values by 10% (January to May) to 20% (June to December). The calibrated kc values are reported in Table C - 2.

Table C - 2. Calibrated crop coefficient values.

Month	Bareland	Forest	Grass/residential	Water	Wetland
1	0.26	0.72	0.38	1.00	0.70
2	0.28	0.72	0.40	1.00	0.71
3	0.30	0.72	0.50	1.00	0.78
4	0.36	0.72	0.50	1.00	0.94
5	0.36	0.76	0.50	1.00	1.00
6	0.38	0.90	0.38	1.00	1.00
7	0.38	0.90	0.38	1.00	1.00
8	0.38	0.90	0.38	1.00	1.00
9	0.36	0.90	0.40	1.00	1.00
10	0.32	0.90	0.50	1.00	0.89
11	0.28	0.90	0.50	1.00	0.76
12	0.26	0.90	0.50	1.00	0.74

- ***Horizon saturated hydraulic conductivity for SAS (kh)*** – We initially assumed kh values to be twice the original kv values obtained from SSURGO data and spatially varied based on the soil map unit keys (MUK). SLT (2021) performed kh sensitivity assessment and eventually changed to a constant value of 40 feet per day for the entire model domain. As the SLT (2021)'s value found to be more reasonable, we used this value.
- ***Fillable porosity for SAS (p)*** – Similar to kh, we derived p from SSURGO's databases and spatially varied based on the MUK. SLT (2021) performed sensitivity analysis and reported a constant p value of 0.2 was seemed to be more reasonable and this value was used.

SLT Model Updates

We further modified and updated the SLT model. These include:

- **Surficial aquifer system (SAS) thickness** – The SAS thickness obtained from the ECFTX model seemed to be too shallow in some areas. These areas consequently experienced aquifer dry out during dry periods that caused negative aquifer thickness and instability for the ICPR4 model. To avoid such issues, SLT (2021) increased the ECFTX SAS thickness by 10 – 15 ft during calibration process, but only for the northern groundwater region. We also ran into similar issues for the other remaining groundwater regions when we further increased the leakance values, indicating the model was still not stable. Due to the coarse nature of the ECFTX model and detailed representation of the ICPR4 model, we consequently increased the ECFTX's SAS thickness values by 10 ft for the entire model domain. This change avoided aquifer dry out and negative aquifer thickness, which also seemed to be reasonable, as a minimum aquifer thickness of 15 ft is commonly used for groundwater systems modeling (e.g. see the Volusia groundwater model (Williams, 2006)).

- **Initial groundwater (GW) and lake conditions** – SLT (2021) first ran the model for the period 2003 to 2018 to equilibrate the initial conditions of lake and groundwater table of the SAS. Then, SLT (2021) identified the best dates and simulated stages that closely match with observed stages of Johns and Avalon Lakes to use as a hot start. In addition, SLT (2021) used different hot start dates and values for calibration, validation, and long-term simulations. Furthermore, SLT (2021) considered a 2-year warm up along with the hot start for both the calibration and validation periods (See SLT (2021) Task C report for details). However, such approaches significantly increased the computational time, especially when some modifications to the model inputs and a subsequent rebuild of the model were needed. It also increased the model size. Since such changes had a minimal effect on simulated lake stages of Johns (see Figure C - 10) where MFLs assessment/setting is expected to be implemented, we modified the

SLT's model set up and used only one representative simulated water table map as the initial water table (IWT). We created the IWT map from the SLT (2021)'s hot start simulation outputs. For Johns and Avalon Lakes, we set the initial water conditions to the observed stage values. The updated model also avoided the use of a 2-year warm up period. Such modifications significantly reduced the computational demand of ICPR4, especially for the long-term simulations.

- **Crop coefficient zone** – In order to define the groundwater ET extinction depth, we embedded low, medium, and high residential areas into grassland crop coefficient zone (see Table B – 5 & Attachment A – 3 of the Task B report) for both the original and SLT models. However, such approach doesn't provide flexible changes to parameter values (e.g. crop coefficient) if scenario analysis is needed. To facilitate such analyses, we differentiated residentials from grassland zone. It should be noticed that although we created additional zone, the residential areas still utilized grassland's properties.
- **Johns fringe leakance** – SLT (2021) reduced the calibrated leakance value of Johns' wetland or fringe area called "N-Johns_000" in the model by 90%. At the same time, SLT (2021) increased the originally calibrated leakance values beneath and higher stage areas of the lake by a factor of 2. As the adjusted wetland leakance value by SLT (2021) was even lower than the upland leakance value, it seemed not reasonable. Therefore, we put back the wetland's area leakance value to the originally calibrated value (see Attachment C - 1).
- **Johns new bathymetry** – The original and SLT models used an old bathymetry for Johns Lake. We updated the bathymetry of Johns Lake with the new bathymetry obtained from the recently produced John's Hydroperiod Tool databases.

Figure C - 10 compares simulated stages with and without updating the SLT model. It should be noticed that we made results comparison before updating Johns' bathymetry data. Overall, the updated version of SLT model noticeably improved representation of observed stages, especially for the validation period. In addition, the updated SLT model reduced the computational demand of ICPR4.

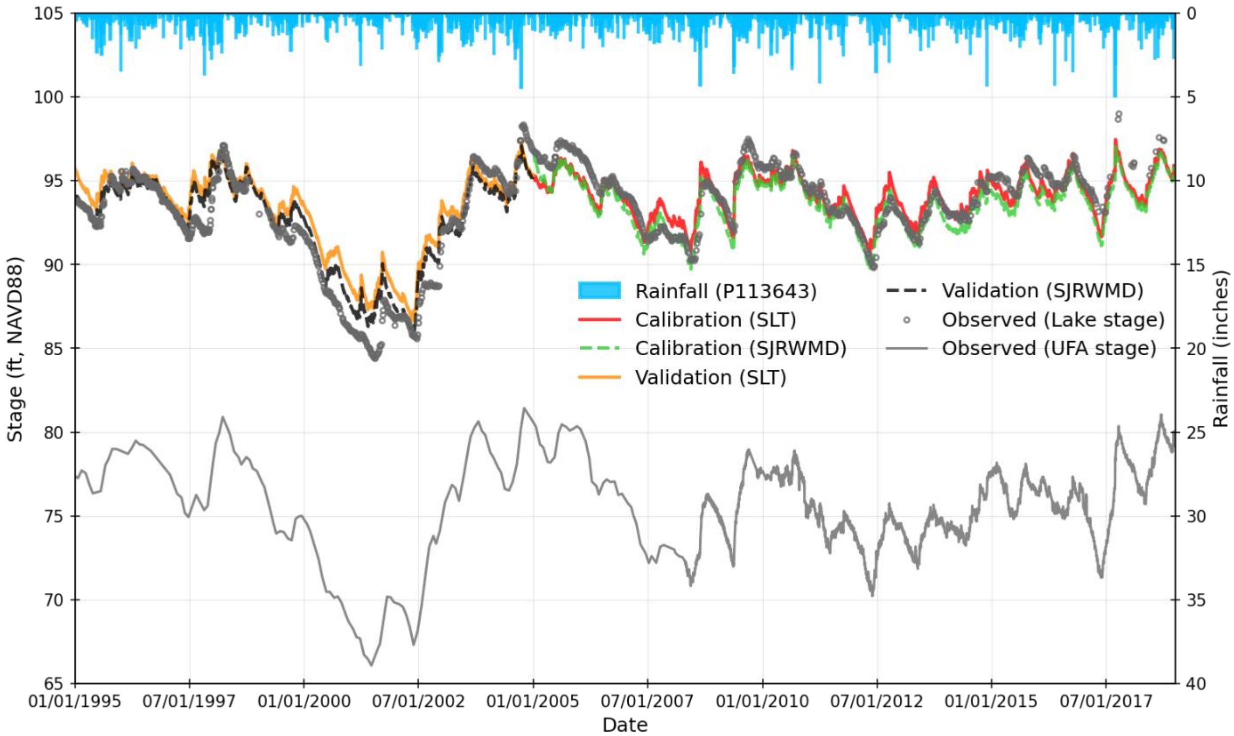

Figure C - 10. Johns daily simulated stages for the calibration and validation periods after updating the SLT model .

Calibration and Validation Simulated Stages

The observed and simulated stages of Johns are shown in Figure C - 11 for both the validation (1995 – 2004) and calibration (2005 – 2018) periods. ICPR4 generally reproduced the observed lake stages' temporal evolution and variation. However, the model could not reproduce observed stages for some events (e.g. 2005 – 2006 and 2017 – 2012), which is probably due to inaccurate rainfall data. Although the model used gridded NEXRAD data, the accuracy of this data cannot be verified due to lack of a gaged station in the watershed. For example, while the observed lake stages show a rising trend from late June 2005 to early November 2005, such trend is not consistently reflected in the recorded rainfall values (Figure C - 11). This probably reduced the performance of the model for the calibration period as all the statistical values are consistently increased during the validation period (Table C - 3). ICPR4 well represented the observed low stages of the calibration period (Figure C - 12). On the other hand, although we reduced the original saturated vertical hydraulic conductivity and impervious initial abstraction values by 50%, the model systematically underestimated the observed high stages of the calibration period (Figure C - 11 and Figure C - 12).

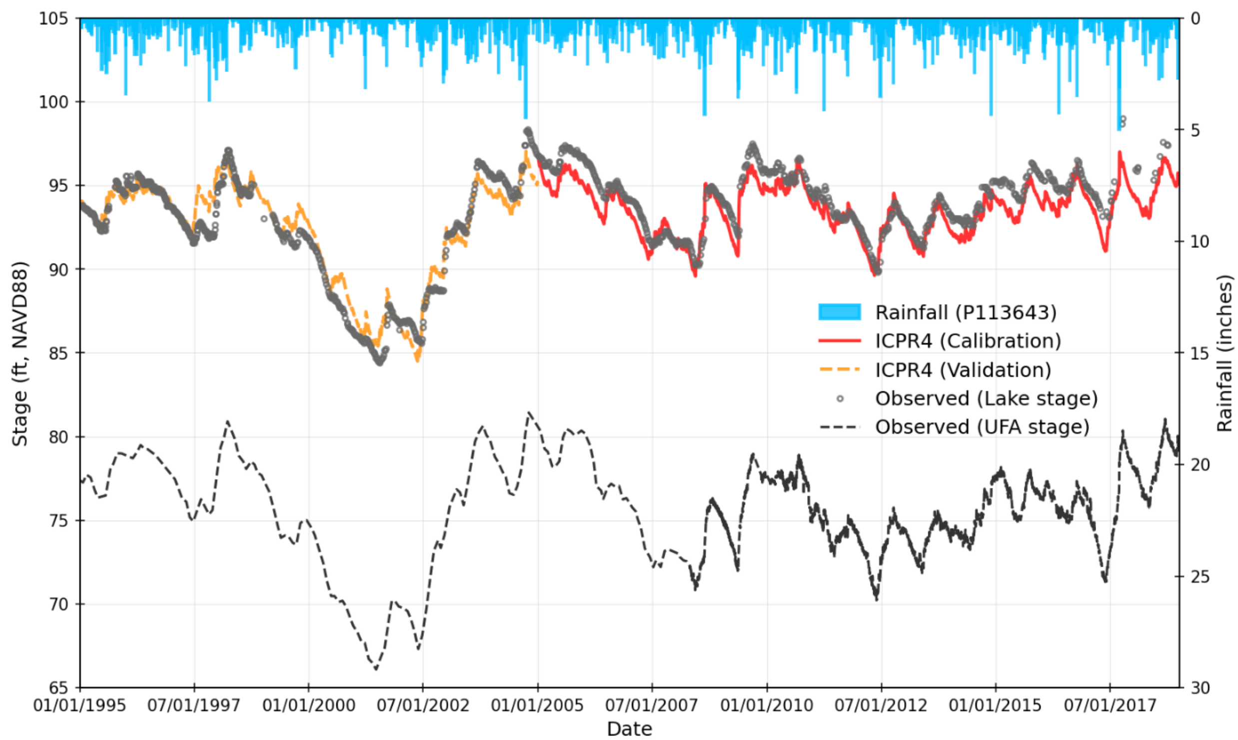

Figure C - 11. Observed and simulated lake levels of Johns Lake for the calibration and validation periods.

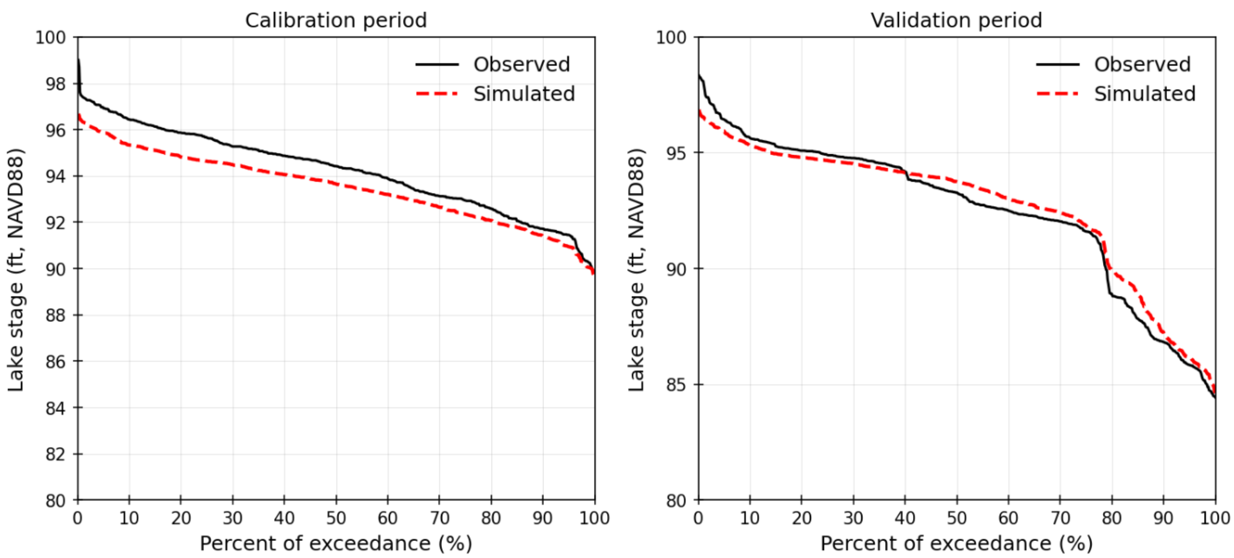

Figure C - 12. Observed and simulated water levels duration curves for calibration and validation periods of Johns Lake.

During the validation period, ICPR4 reasonably simulated and tracked the temporal patterns and magnitudes of observed stages of Johns Lake. This is also confirmed with good statistical values such as NSE and RMSE. More importantly, low to medium observed stages of Johns are better reproduced by the model during the validation period, indicating the capability of the model to simulate outside the calibration period (Figure C - 12). Overall, the model performance is reasonable, as most of the monthly statistically targeted values were achieved for both the calibration and validation periods (Table C - 3).

Table C - 3. Goodness-of-fit statistics for daily water stages simulation. Bold represents monthly targeted values not met.

Statistics	Johns		Avalon	
	Calibration	Validation	Calibration	Validation
NSE	**0.73**	0.92	**0.60**	0.91
RMSE	0.93	0.92	1.11	1.15
ME	-0.73	0.15	0.91	-0.31
AME	0.81	0.71	0.95	0.87
PBIAS	-0.78	0.17	1.04	-0.36
R	0.95	0.96	0.94	0.97
±1ft (%)[a]	**65.20**	**71.69**	**59.45**	**67.20**

NSE = Nash-Sutcliffe Efficiency; RMSE = Root Mean Squared Error; ME = Mean Error; AME = Absolute Mean Error; PBIAS = Percent Bias; r = Pearson correlation coefficient; [a]percent of observations bracketed within ± 1 ft

Figure C - 13 presents the simulated and observed daily stages for Lake Avalon. Unlike Johns Lake, the figure indicates that the model overestimated the observed high stages of Lake Avalon, especially after 2008. As opposed to this, the model adequately reproduced medium to high observed stages during the validation period with a tendency of underestimating extreme low observed stages (Figure C - 14).

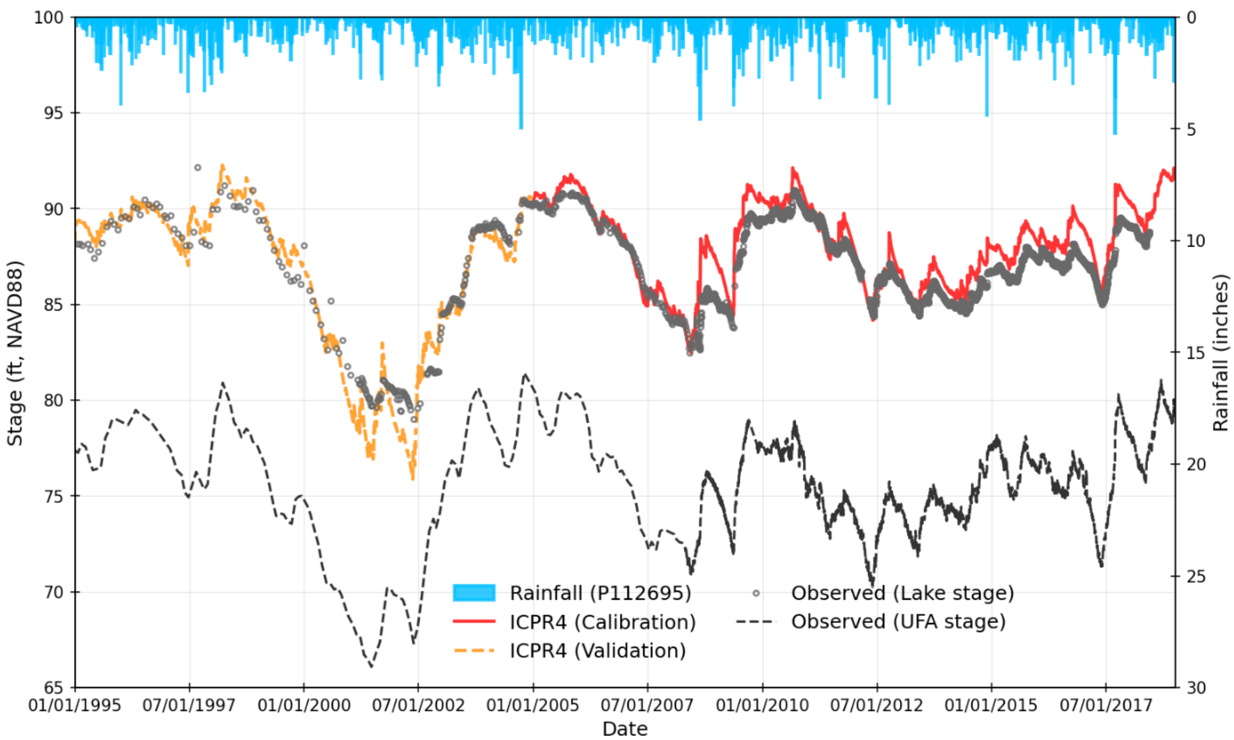

Figure C - 13. Observed and simulated water levels of Lake Avalon for validation and calibration periods.

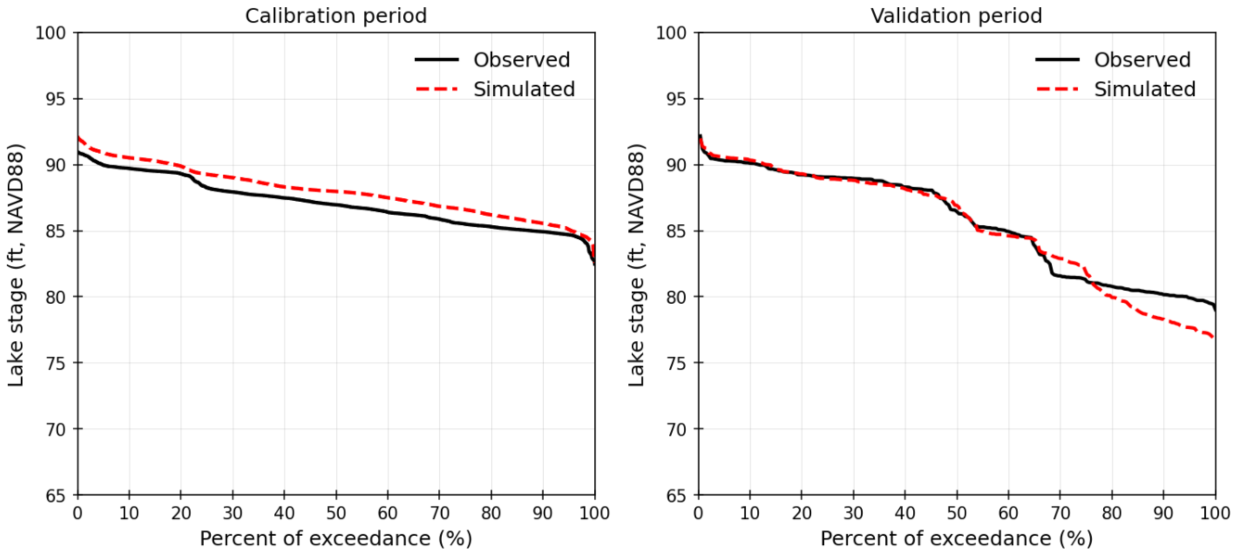

Figure C - 14. Observed and simulated stage duration curves of Lake Avalon for the calibration and validation periods.

Overall, as compared to Johns Lake, ICPR4 showed more sensitivity to rainfall amount for Lake Avalon. For example, the model generated more runoff especially after 2008 and thus overestimated observed high stages of the lake for a daily rainfall amount exceeding approximately 3 inches (Figure C - 14). This could be due to the small size nature of runoff contributing watershed and absence of detailed representation of stormwater management facilities (detention/retention ponds) that underestimated surface runoff residence and travel times to the lake.

ICPR4 and SWMM Results Comparison

We compared the ICPR4 and SWMM simulated water stages for both the SWMM calibration (2005 to 2016) and validation (1995 to 2004) periods. Although we calibrated ICPR4 model for the period from 2005 to 2018, we limited the statistical performance calculation and comparison to the SWMM model calibration period. Figure C - 15 and Figure C - 16 compare the simulated and observed stages for Johns Lake.

Figure C - 15 reveals that the observed stages temporal variations of Johns are better matched by the ICPR4 model as compared to the SWMM model. In addition, while the ICPR4 model outperformed the SWMM model in simulating observed low to medium stages of Johns, the SWMM model better reproduced observed high stages during the calibration period (Figure C - 15 and Figure C - 16). However, the ICPR4 model better simulated the observed stages of Johns than the SWMM model during the validation period, suggesting the suitability ICPR4 over SWMM for surface water – groundwater interaction modeling purposes and scenario analysis outside the calibration period.

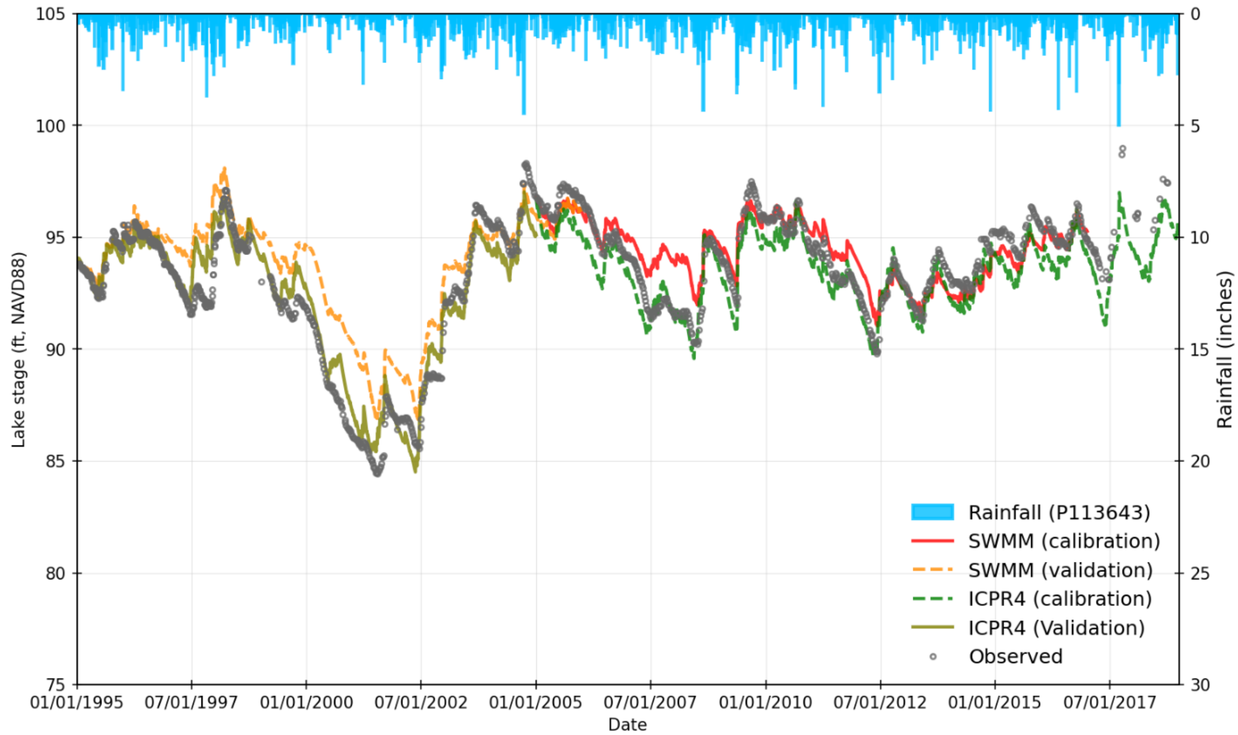

Figure C - 15. Daily observed and simulated stages comparison of Johns Lake for validation and calibration periods.

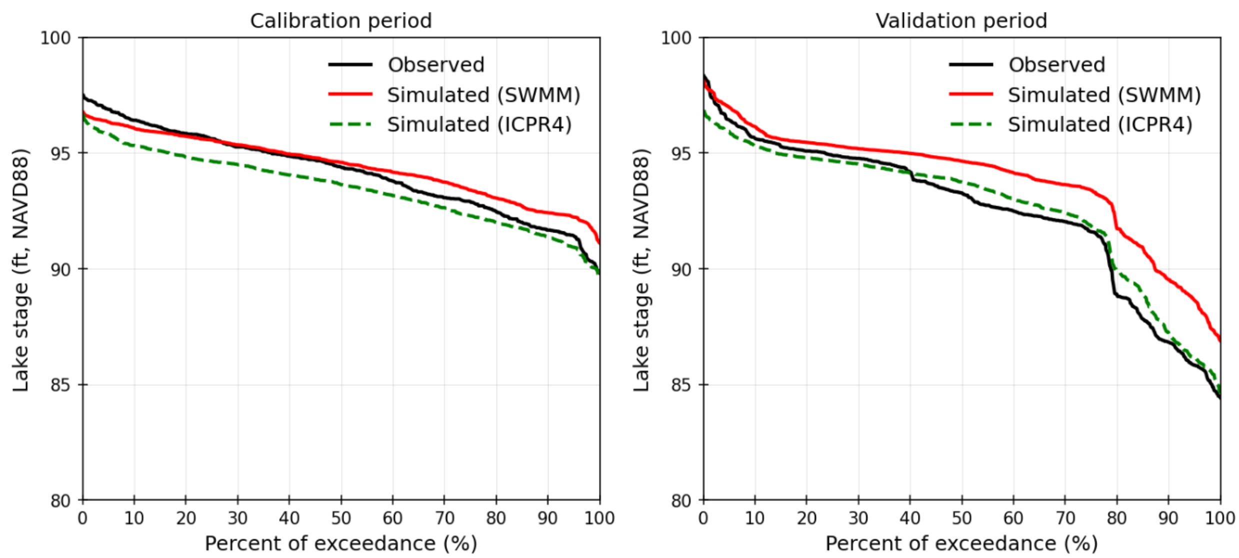

Figure C - 16. Observed and simulated stage duration curves of Johns Lake for validation and calibration periods.

For Lake Avalon, ICPR4 simulated stages better tracked the temporal evolution of observed stages, but the model showed a tendency of overestimating observed high stages of the calibration period (Figure C - 17). On the other hand, SWMM simulated stages showed a tendency of underestimating observed stages especially during the period 2012 to 2014 (Figure C - 17). While the observed medium to high stages of the calibration period better captured by the SWMM model (Figure C - 18), ICPR4 simulated stages closely matched observed stages of the validation period (Figure C - 17 and Figure C - 18)

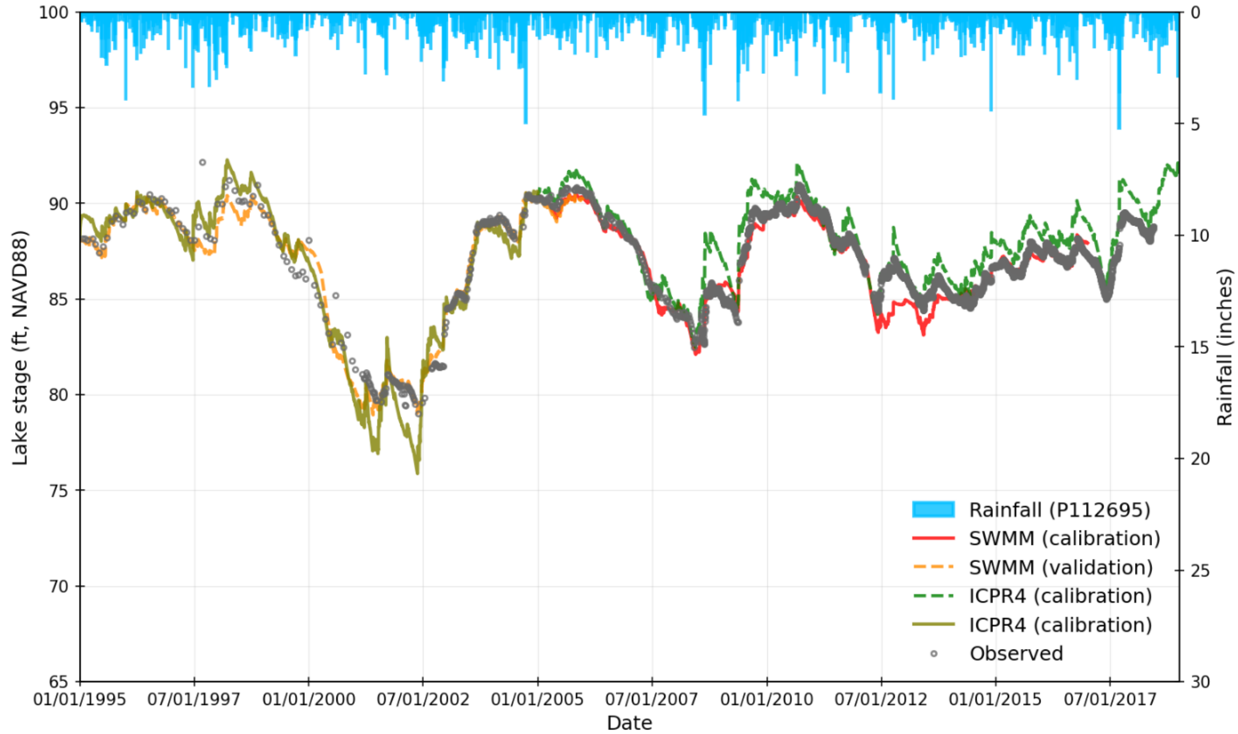

Figure C - 17. Comparison of SWMM and ICPR4 simulated lake levels with observed values of Lake Avalon for both validation (1995 – 2004) and calibration (2005 – 2018) periods,

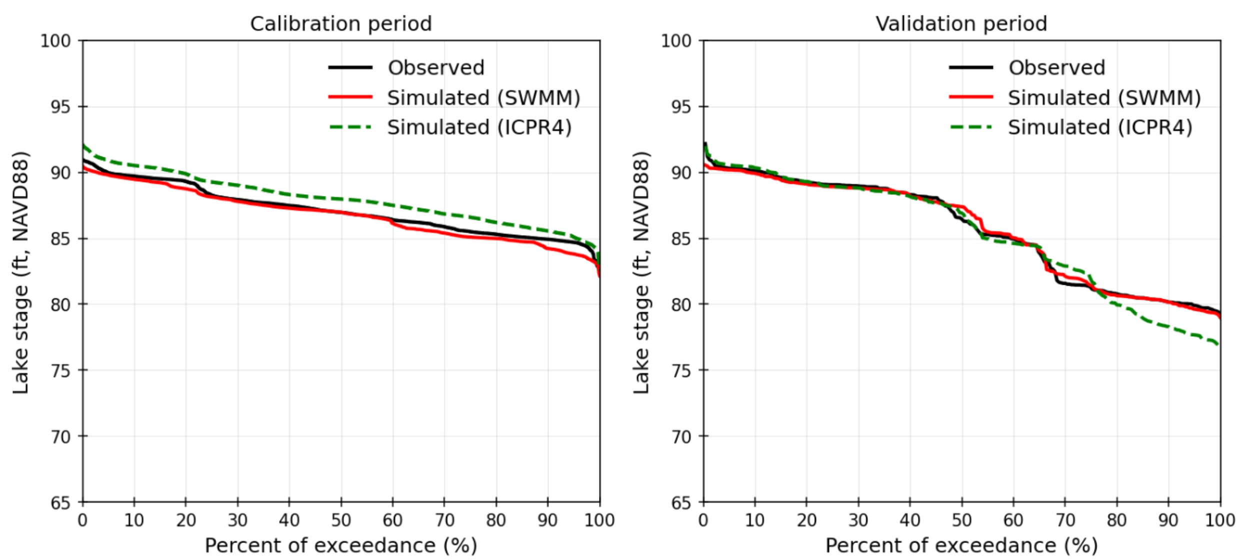

Figure C - 18. Observed and simulated water levels duration curve of Lake Avalon validation (1995 – 2004) and calibration (2005 – 2016) periods.

Overall, when compared to SWMM's results, ICPR4's results generally showed better agreement with observations, especially for Johns Lake (Figure C - 15, Figure C - 16, and Table C - 4).

Additionally, for both Johns and Avalon Lakes, the ICPR4 model better reproduced the observed low to medium stages as compared to the SWMM model (Figure C - 16 and Figure C - 18), which makes the ICPR4 model better suited for MFLs modeling and assessments.

Table C - 4. Daily goodness-of-fit statistics for ICPR4 and SWMM. Bold represents monthly targeted values not achieved.

Lake	Statistics	Model (Period)			
		ICPR4 (Calibration)	SWMM (Calibration)	ICPR4 (Validation)	SWMM (Validation)
Johns	NSE (-)	**0.75**	**0.69**	0.92	**0.68**
	RMSE (ft)	0.91	0.99	0.92	**1.86**
	ME (ft)	-0.71	0.25	0.15	**1.36**
	AME (ft)	0.79	0.77	0.71	**1.48**
	PBIAS (%)	-0.75	0.27	0.17	**1.47**
	R (-)	0.95	0.85	0.96	0.94
	±1ft (%)[a]	**66.39**	**75.50**	**71.69**	**45.03**
Avalon	NSE (-)	**0.67**	0.84	0.91	0.97
	RMSE (ft)	1.10	0.73	1.15	0.65
	ME (ft)	0.87	-0.32	-0.31	-0.01
	AME (ft)	0.92	0.50	0.87	0.41
	PBIAS (%)	1.00	-0.37	-0.36	-0.01
	R (-)	0.93	0.94	0.97	0.99
	±1ft (%)[a]	**61.79**	86.72	**67.20**	89.60

NSE = Nash-Sutcliffe efficiency; RMSE = Root Mean Squared Error; ME = Mean Error; AME = Absolute Mean Error; PBIAS = Percent Bias; r = Pearson correlation coefficient; [a]percent of observations bracketed within ± 1 ft

Long-term Simulated Stages

We used the calibrated and validated ICPR4 model along with extended rainfall, RET, and UFA stages to simulate the long-term stages of Johns Lake (1948 – 2018). While ICPR4 adequately represented the temporal evolutions and variations of the long-term observed stages, the model noticeably overestimated observed stages of the period 1962 to 1992 (Figure C - 19). Specific reasons for the mismatch between observed and simulated stages of this period are not clear, but it could be due to additional uncertainties introduced from:

1. **Extended GW stages –** To extend missing stages at well OR1123, we used the LOC method along with observed groundwater stages at well L0052 (for the period 6/29/1993 to 12/31/2018) and at well OR0047 (for the period before 6/29/1993). Station OR0047 is about 8 miles away from station OR1123. Although the relationship between observed stages at OR1123 and OR0047 is strong for the POR (R^2 = 0.88), the correlation between Johns Lake and OR0047 observed stages is very weak (R^2 = 0.14) for the entire POR. However, the correlation values significantly increased when we split the POR datasets into prior to and since the start of the POR at well L0052, which is 1993 (Figure C - 20). In addition, while the slopes before and after 1993 are similar, the intercept value for the dataset since 1993 is shifted down by about 6 ft (Figure C - 20). Additional analysis between observed stages at OR0047 and Johns Lake also indicated that the OR1123's extended stages from OR0047 are consistently higher than the values estimated from observed stages of Johns Lake (Attachment C - 2). In addition, the estimated OR1123 stages from OR0047 and Johns' stages showed an average difference of approximately 6 ft before 1993 (see Attachment C - 3). Since we developed the LOC regression based on observed data at OR1123 (since 10/21/2010) and the overlapping POR at OR0047, it is likely that additional bias was introduced into the extended data before 1993. For example, when we reduced the extended data before 1993 by a constant value of 6 ft and fed it into the model, the previously overestimated stages show improvements (Figure C - 21).

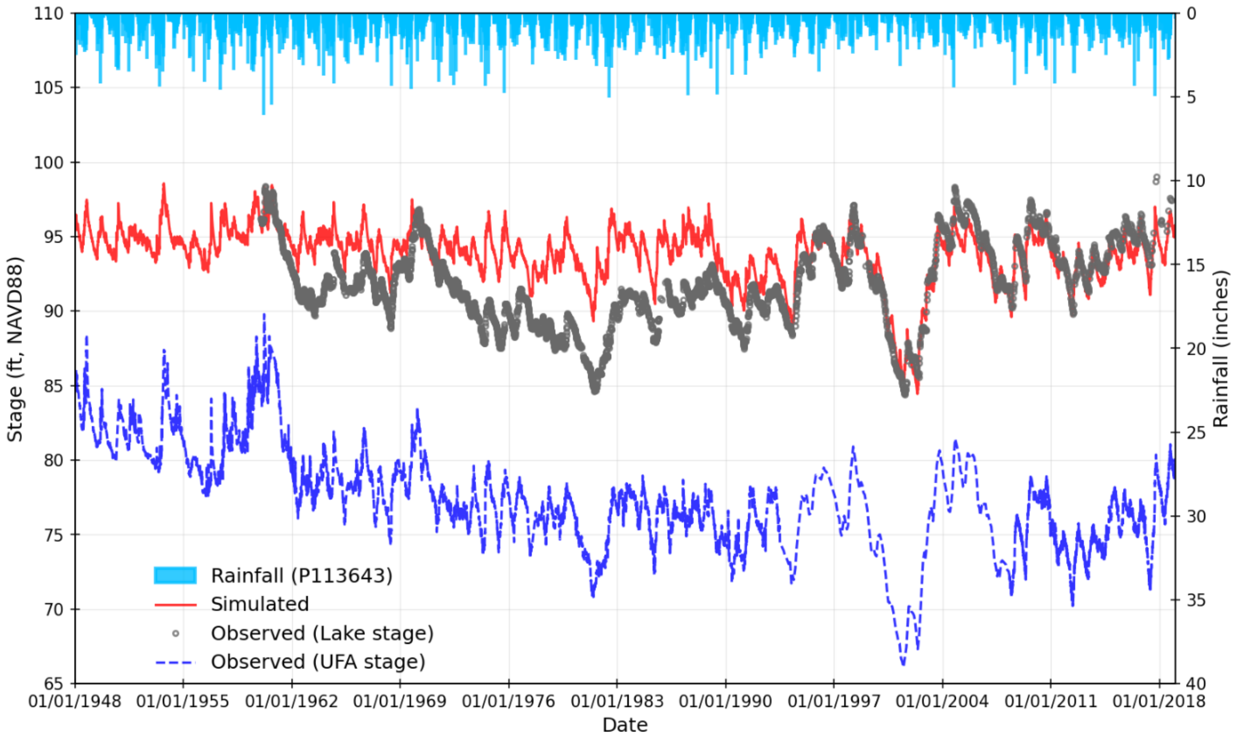

Figure C - 19. Daily long-term observed and simulated stages for Johns Lake.

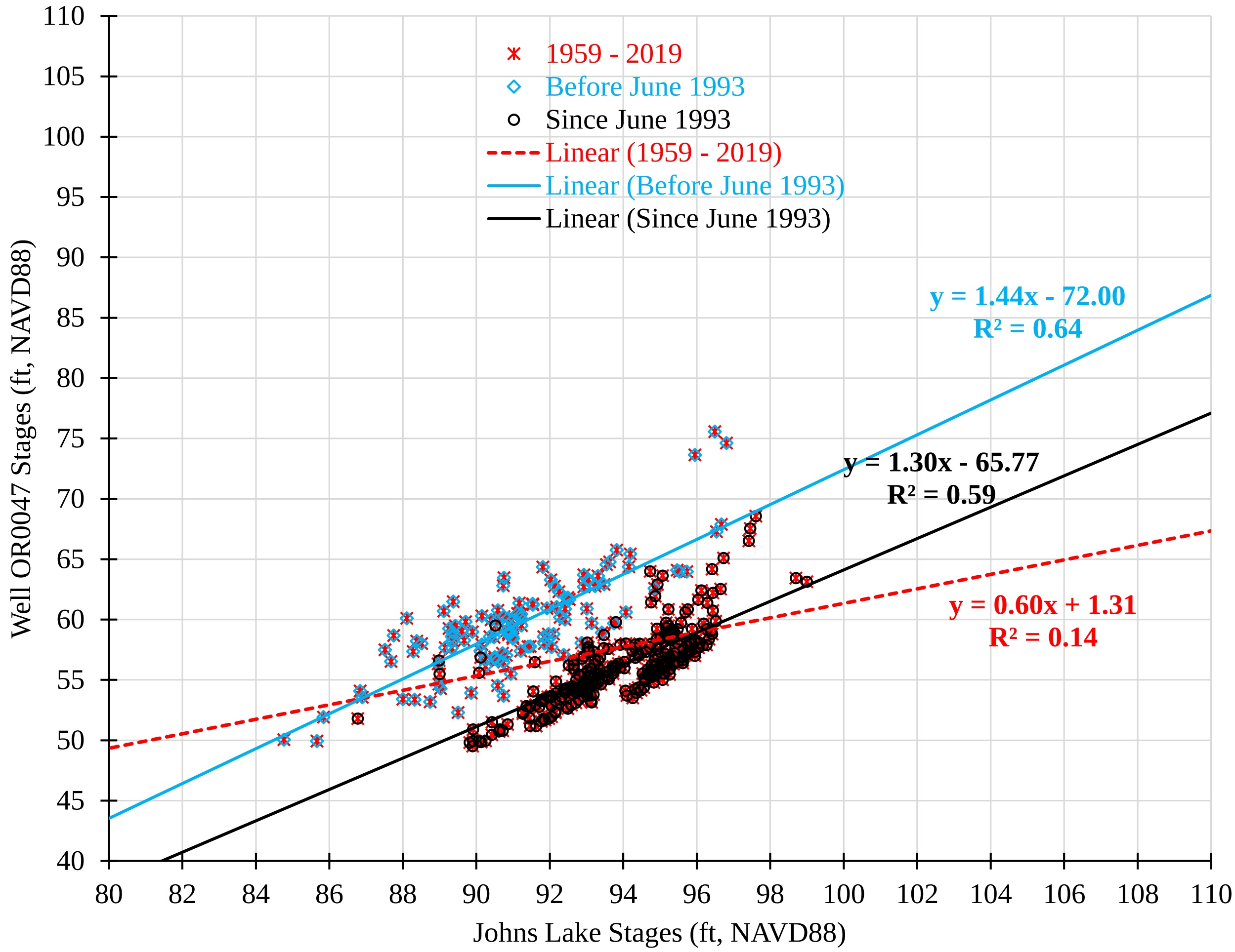

Figure C - 20. Scatter plots of observed stages at Johns Lake and well OR0047 (used for extending data at well OR1123).

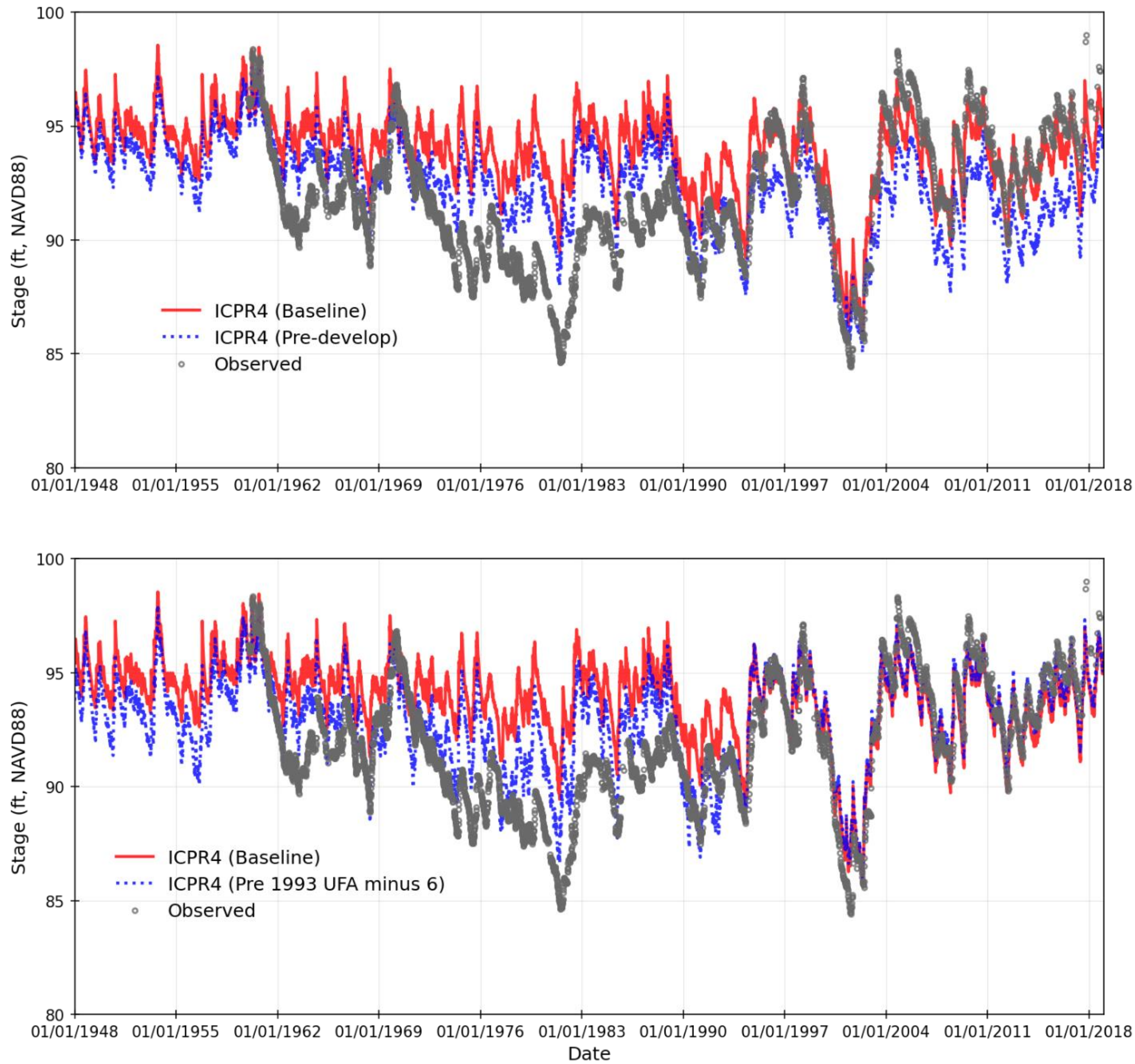

Figure C - 21. Impact of land use/land cover change, increased leakance, and UFA values (top) and combined (bottom) on simulated stages of Johns Lake.

2. **Land use/land cover change –** Another factor that potentially affected the simulated stages of Johns Lake before 1993 could be related to land use development of the watershed. The watershed has experienced significant urbanization since 2002 (SLT, 2021). In addition, historical LULC maps of 1973, 1990, 1995, and 2014 showed noticeable LULC changes between 1973 and 2014, as reported in Attachment C - 4. For example, we found that more than 30% of the watershed's cropland has been converted to developed areas (low, medium, and high residential and commercial/industrial areas) during the period from 1973 to 2014 (Attachment C - 5). To reflect this change and assess its implication on simulated stages of Johns Lake, we changed the current condition imperviousness fractions, crop coefficient (kc), and initial rainfall abstraction values of low, medium, and high residential and industrial/commercial areas to the corresponding cropland properties. Assuming the cropland in the 1970s represented Groves land use, which is

also proposed by SLT (2021), we set the current condition imperviousness, kc, and initial rainfall abstraction values of residential and commercial/industrial areas to the values used for Groves. This conversion reduced the overestimated simulated stages before 1993, but consistently lowered the simulated stages during the post-development period (Figure C - 21). Linked to LULC change, sediment and nutrients loadings to the lake might have increased and caused streambed compaction during the post-development period. This could have altered the leakance value of the lake between the pre- and post-development conditions. Since we assumed constant leakance value, which we derived based on the post-development conditions, it is possible that the pre-development leakance value would be higher than the calibrated leakance value. Therefore, we further increased the calibrated leakance value of Johns Lake by 50%, a value proposed by SLT (2021), and evaluated its effects on simulated stages of Johns. We found that the effect of increased leakance values on pre-development simulated stages is relatively low as compared to the effects of LULC change and adjusted groundwater stages (Figure C - 21 and Figure C - 22). Figure C - 22 also compares the long-term simulated stages of Johns under current (baseline), and pre-development LULC and adjusted groundwater stages combined with increased leakance values.

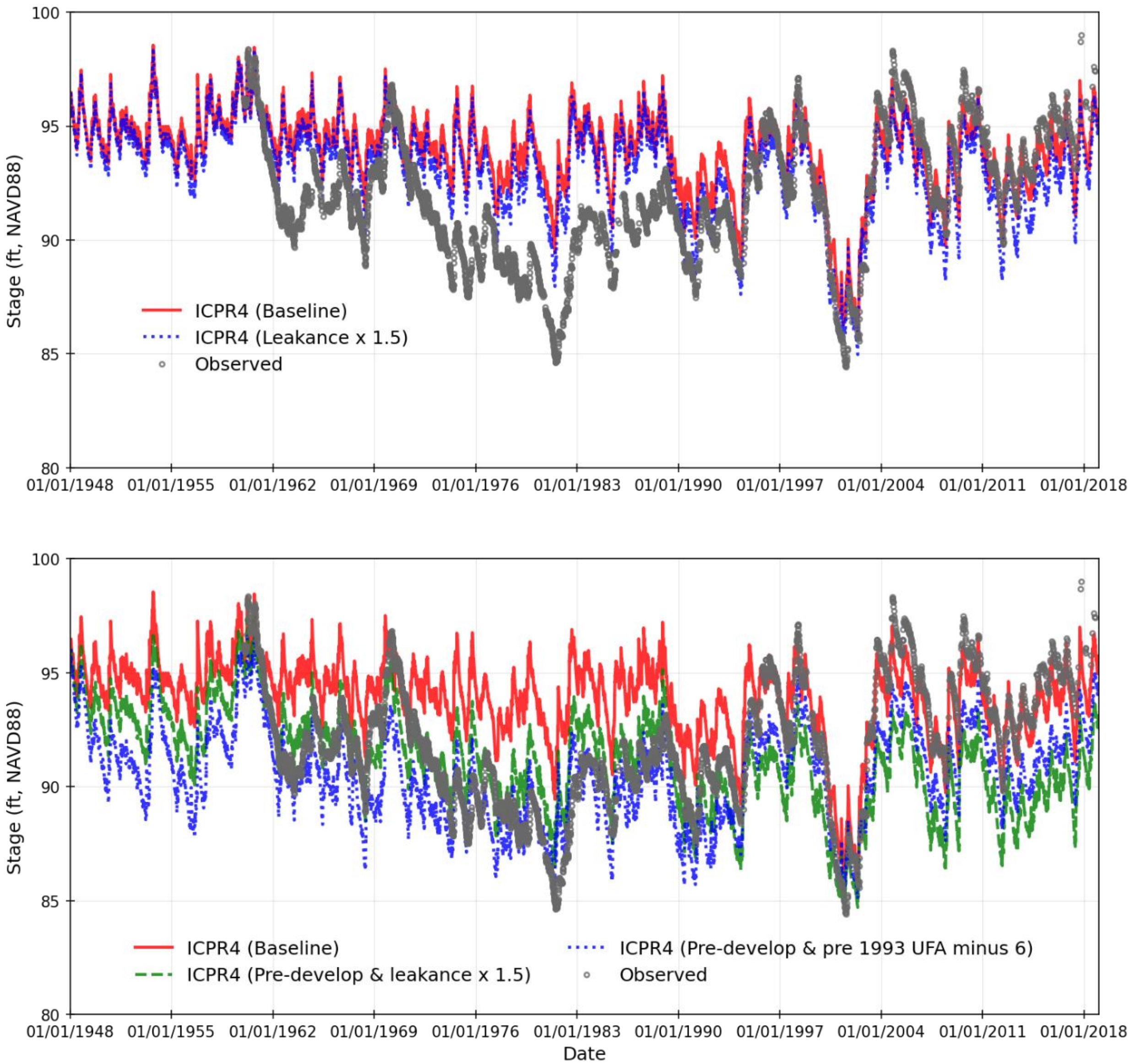

Figure C - 22. Impact of increased calibrated leakance and combined land use/land cover change, Upper Floridan Aquifer and leakance values (bottom) on simulated stages of Johns Lake.

3. **Rainfall data** – Uncertainty of the rainfall data should also not be ruled out, as we directly used one composite rain gauge data (before 1995) that was obtained from outside the watershed. As rainfall variation is commonly observed over a short distance, the direct use of composite rainfall values from ISLE_WIN station, which is located outside the watershed, probably introduced additional uncertainty to the long-term simulated stages of Johns Lake.

Overall, considering the pre-development LULC and groundwater conditions of Johns Lake watershed would improve the long-term simulated stages of the pre-development period (Figure C - 21). However, this could be at the cost of consistently underestimating the observed stages of the post-development conditions (Figure C - 21). Therefore, it is believed that the large discrepancy between the observed and simulated stages for the pre-development period of Johns Lake could be due to significant LULC change, absence of long-term observed groundwater, and rainfall data in the watershed.

Water Balance

As MFLs modeling and assessment processes focus on Johns Lake, here we present and discuss the simulated water balance components only for Johns Lake. However, Attachment C - 6 presents water balance components for the entire model domain. To estimate the lake's water balance components, we used the equations documented in Table 13 and terminologies illustrated in Figure 18 of the Task B report of SLT (2021) for Pond Control Volume (PCV) system. Table C - 5 summarizes the lake water budget elements for the calibration, validation, and long-term periods. The table indicates that leakage to the UFA system generally dominates the outflow components of the lake, followed by evaporation. Direct rainfall accounts for approximately 23% of the total inflow, whereas the direct runoff from Johns' Lake mapped-basin is only about 5% of the total inflow (Table C - 5). Higher surface outflows are simulated during the calibration and long-term periods, which could be due to the wetter conditions and higher direct rainfall amount as compared to the validation period (Table C - 5).

Table C - 5. Annual average water balance elements of Johns Lake for calibration, validation, and long-term periods.

Components	**Calibration (2005-2018)**		**Validation (1995-2004)**		**Long-term (1948-2018)**	
Surface water	**Flux (in/yr)**	**% total inflow**	**Flux (in/yr)**	**% total inflow**	**Flux (in/yr)**	**% total inflow**
Total inflows	**219**		**196**		**221**	
Direct rainfall	50	22.8	44	22.5	50	22.6
Link inflow	125	57.2	117	59.6	124	56.2
Surface seepage inflow	33	15.0	26	13.5	35	15.9
Watershed runoff	11	5.1	9	4.4	11	5.2
Total outflows	**221**	**100.9**	**196**	**99.8**	**222**	**100.5**
ET	45	20.5	40	20.3	44	20.0
Initial abstraction	2	0.7	2	0.9	1	0.7
Infiltration	53	24.2	46	23.4	54	24.6
Link outflow	10	4.7	7	3.7	21	9.3
Surface seepage outflow	111	50.8	101	51.5	101	45.9
Surface Storage Change	**-2**	**-0.9**	**0**	**0.2**	**-1**	**-0.5**
Sub-surface water						
Total inflows	**164**		**147**		**156**	
Infiltration	53	32.2	46	31.3	54	34.9
Seepage inflow	111	67.8	101	68.7	101	65.1
Total outflows	**157**	95.4	**141**	96.0	**148**	95.1
Seepage outflow	33	20.0	26	18.0	35	22.6
Leakage	124	75.4	115	78.1	113	72.5
Sub-surface Storage Change	**8**	**4.6**	**6**	**4.0**	**8**	**4.9**

In general, the change in surface water storage is less than 1% for the calibration, validation, and long-term periods (Table C - 5), indicating the reasonable simulation of John's water budget components by ICPR4. Compared to the surface water storage change, the change in sub-surface water storage is larger. The latter is likely due to the intrinsic inclusion of net sub-surface lateral inflow to the sub-surface water storage entering around the perimeter of John's PCV. As ICPR4 algorithm internally calculates this flux, it cannot be separated from the sub-surface water balance components (SLT, 2021). Since we normalized the simulated water balance components to the PCV's area, which is smaller than the actual groundwater contributing area, the lateral seepage per unit area is most likely overestimated and thus caused the large sub-surface water storage change (SLT, 2012).

SUMMARY AND CONCLUSIONS

Based on the available hydro-meteorological and geospatial data for the Johns and Avalon Lakes watersheds, we developed the ICPR4 model for the period from 1995 to 2018. Then, we split the model development period into calibration (2005 to 2018), and validation (1995 to 2004) periods for hydrological and hydraulic systems modeling and understanding. We manually calibrated some parameters of the model, such as saturated vertical and horizontal hydraulic conductivities, leakance values, crop coefficient, and initial abstraction values until we achieve a reasonable match between observed and simulated daily lake stages. We evaluated the model performance by consistently using graphical method and multiple statistical evaluation metrics. We subsequently extended the calibrated and validated model to the period from 1/1/1948 to 12/31/2018 for long-term hydrological and MFLs modeling.

ICPR4 reasonably simulated the observed daily water stages temporal variations and magnitudes of Johns Lake for both the calibration and validation periods. Most of the daily statistical values met the monthly targeted values during the calibration period except for the percent of observations bracketed within ± 1ft and NSE. We achieved better statistical values and improved model performance rate during the validation period, indicating the applicability of the ICPR4 model outside the calibration period. The ICPR4 model also outperformed the SWMM model in simulating low to medium stages of Johns lake especially during the validation period, which makes the ICPR4 model better suited for MFLs modeling. Overall, the ICPR4 model showed reasonable simulations of surface water – groundwater interaction processes of Johns Lake. Thus, the model can be used for MFLs modeling and scenarios analysis, which is the next task of this project.

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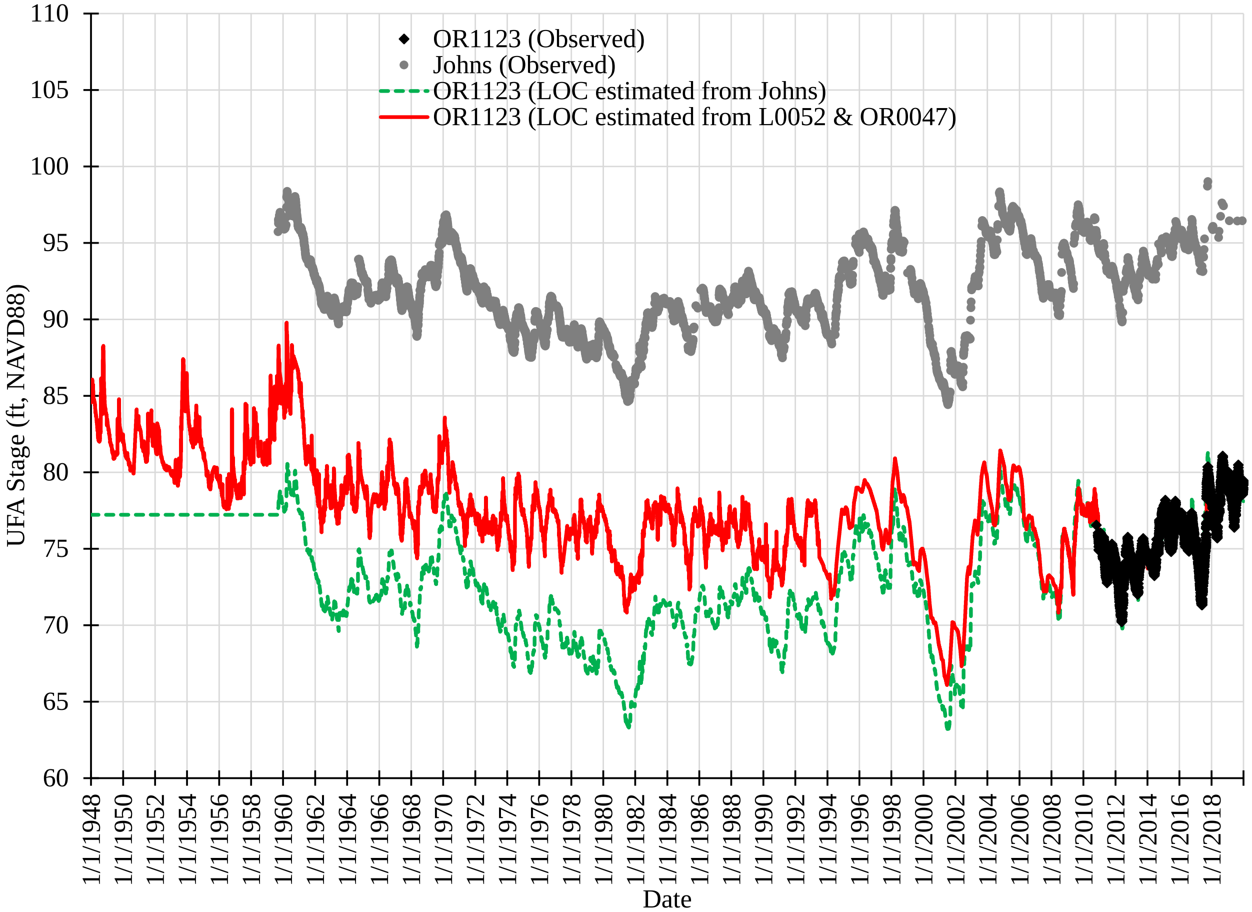
ATTACHMENT

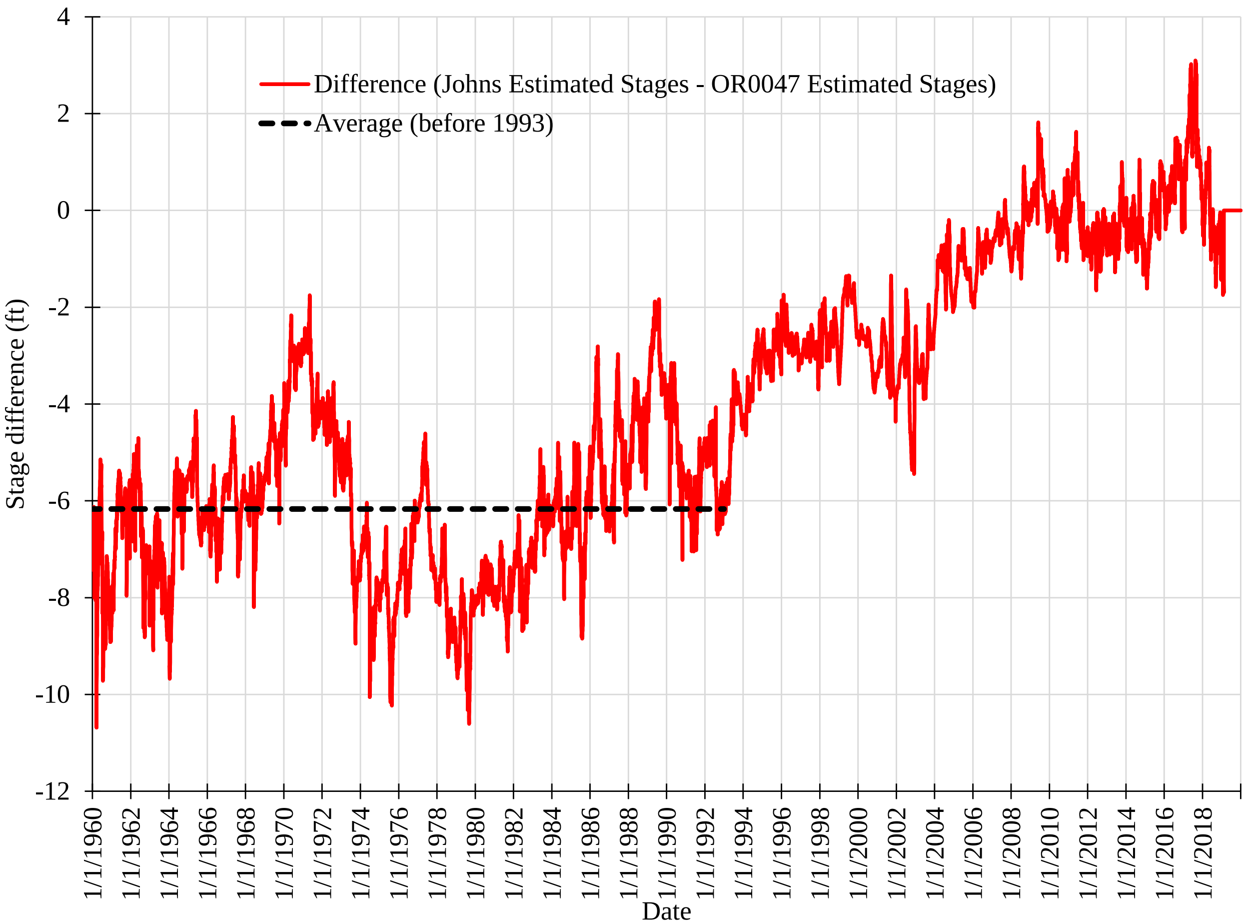
Attachment C - 1. East Central Florida Transient Expanded (ECFTX) model and ICPR4 model leakance values.

Lake/area	Name in the model	ECFTX Leakance	Calibrated Leakance
Avalon beneath – east	N-Avalon_000_3	0.000972	0.003403
Avalon beneath – west	N-Avalon_000_2	0.000647	0.002264
Avalon fringe zone	N-Avalon_000	0.000484	0.000968
Avalon sub-basin	B_Avalon_1	0.000324	0.000324
Banana	N-Banana_000	0.000061	0.000061
Beulah	N-Beulah_000	0.000236	0.000236
Black	N-Black_000	0.000038	0.000113
Black fringe zone	N-Black_090	0.000160	0.000160
Black sub-basin	B_Black_1	0.000059	0.000059
Black wetlands/depressions	N-Black_040	0.000147	0.000147
Black wetlands/depressions	N-Black_050	0.000147	0.000147
Black wetlands/depressions	N-Black_200	0.000140	0.000140
Black wetlands/depressions	N-Yarbo_135	0.000070	0.000070
Black wetlands/depressions	N-Black_100	0.000155	0.000155
Black wetlands/depressions	N-Black_535	0.000105	0.000105
Black wetlands/depressions	N-Black_080	0.000159	0.000159
Black wetlands/depressions	N-Black_300	0.000130	0.000130
CawoodWest	N-CawoodWest_000	0.000115	0.000115
Clarice	N-Clarice_000	0.000072	0.000072
Elsewhere - inside boundary	NoCV_inside	0.000104	0.000104
Elsewhere - outside boundary	NoCV_outside	0.000257	0.000257
Johns beneath – east	N-Johns_000_3	0.000357	0.002710
Johns beneath - west	N-Johns_000_2	0.000500	0.003797
Johns channel/wetlands	N-Johns_Out_190	0.000162	0.000162
Johns channels/wetlands	N-Johns_010	0.000060	0.000060
Johns channels/wetlands	N-Johns_Out_180	0.000162	0.000162
Johns fringe zone	N-Johns_000	0.000306	0.000306
Johns subbasin	B_Johns_1	0.000361	0.000361
Lun	N-Lu_000	0.000063	0.000063
Luntz	N-Luntz_000	0.000058	0.000058
Reaves	N-Reaves_000	0.000052	0.000052
Roberts	N-Roberts_000	0.000054	0.000054
Roper	N-Roper_000	0.000066	0.000066
Roper wetlands/depressions	N-Roper_020	0.000061	0.000061
Roper wetlands/depressions	N-Roper_120	0.000061	0.000061
Tilden	N-Tilden_000	0.000047	0.000047
Yarbo	N-Yarbo_000	0.000060	0.000060
Yarbo wetlands/depressions	N-Yarbo_130	0.000068	0.000068
Yarbo wetlands/depressions	N-Yarbo_140	0.000070	0.000070

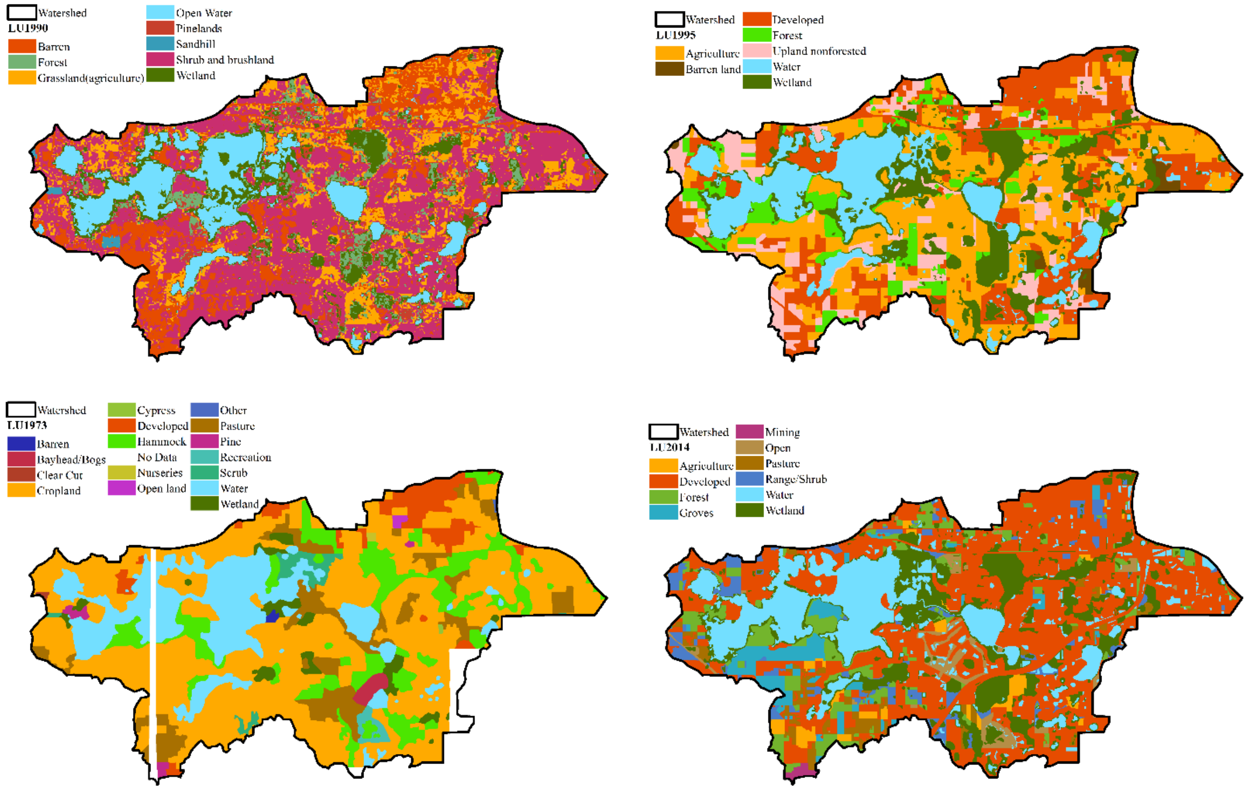
Attachment C - 2. Extended groundwater stages at well OR1123 based on observed stages at wells L0052, OR0047, and Johns Lake. While observed data at well L0052 used for the period since 6/29/1993, observed data at OR0047 used before that.



Attachment C - 3. Estimated stages differences based on observed stages at OR0047 and Johns Lake.



Attachment C - 4. Land use/land cover maps of 1973, 1990, 1995, and 2014 for Johns Lake watershed.



Attachment C - 5. Land use/land cover change between 1973 & 2014. Bold cropland to developed between 1973 & 2014.

Rank	LULC Change (From 1973 to 1990 to 1995 to 2014)	Area (km^2)	% Area
1	**Cropland_2_Shrub and brushland_2_Agriculture_2_Developed**	**6.13**	**7.91**
2	Water_2_Open Water_2_Water_2_Water	5.77	**7.44**
3	**Cropland_2_Shrub and brushland_2_Developed_2_Developed**	**3.25**	**4.19**
4	**Cropland_2_Barren_2_Developed_2_Developed**	**1.95**	**2.51**
5	**Cropland_2_Shrub and brushland_2_Upland nonforested_2_Developed**	**1.85**	**2.39**
6	**Cropland_2_Grassland(agriculture)_2_Developed_2_Developed**	**1.66**	**2.14**
7	**Developed_2_Barren_2_Developed_2_Developed**	**1.56**	**2.01**
8	**Cropland_2_Barren_2_Agriculture_2_Developed**	**1.45**	**1.87**
9	Cropland_2_Barren_2_Agriculture_2_Groves	1.09	**1.40**
10	Hammock_2_Wetland_2_Wetland_2_Wetland	1.08	**1.40**
11	Water_2_Wetland_2_Water_2_Water	1.08	**1.39**
12	**Cropland_2_Grassland(agriculture)_2_Agriculture_2_Developed**	**1.07**	**1.38**
13	Cropland_2_Shrub and brushland_2_Agriculture_2_Groves	1.00	**1.30**
14	Cropland_2_Wetland_2_Wetland_2_Wetland	0.94	**1.22**
15	Cropland_2_Open Water_2_Water_2_Water	0.88	**1.13**
16	**Cropland_2_Shrub and brushland_2_Forest_2_Developed**	**0.84**	**1.08**
17	Hammock_2_Shrub and brushland_2_Agriculture_2_Developed	0.74	0.96
18	Developed_2_Grassland(agriculture)_2_Developed_2_Developed	0.69	0.89
19	Cropland_2_Shrub and brushland_2_Wetland_2_Wetland	0.64	0.82
20	Cropland_2_Shrub and brushland_2_Upland nonforested_2_Range/Shrub	0.62	0.80
21	No Data_2_Open Water_2_Water_2_Water	0.62	0.80
22	Cropland_2_Shrub and brushland_2_Agriculture_2_Forest	0.60	0.77
23	Cropland_2_Shrub and brushland_2_Agriculture_2_Water	0.57	0.74
24	Cropland_2_Forest_2_Wetland_2_Wetland	0.56	0.72
25	Water_2_Shrub and brushland_2_Agriculture_2_Developed	0.56	0.72
26	Cropland_2_Shrub and brushland_2_Forest_2_Forest	0.56	0.72
27	Cropland_2_Shrub and brushland_2_Developed_2_Pasture	0.53	0.68
28	**Cropland_2_Grassland(agriculture)_2_Upland nonforested_2_Developed**	**0.52**	**0.67**
29	Pasture_2_Grassland(agriculture)_2_Developed_2_Developed	0.51	0.66
30	Hammock_2_Barren_2_Developed_2_Developed	0.51	0.66
31	Pasture_2_Shrub and brushland_2_Agriculture_2_Developed	0.50	0.64
32	Hammock_2_Forest_2_Wetland_2_Wetland	0.46	0.59
33	Cropland_2_Shrub and brushland_2_Agriculture_2_Range/Shrub	0.45	0.58
34	Cropland_2_Shrub and brushland_2_Agriculture_2_Open	0.44	0.57
35	Water_2_Wetland_2_Wetland_2_Water	0.43	0.56
36	Water_2_Wetland_2_Wetland_2_Wetland	0.41	0.53
37	Pasture_2_Barren_2_Developed_2_Developed	0.41	0.53
38	Cropland_2_Pinelands_2_Wetland_2_Wetland	0.39	0.50
39	Pasture_2_Grassland(agriculture)_2_Agriculture_2_Developed	0.35	0.45
40	Hammock_2_Open Water_2_Water_2_Water	0.34	0.44

Attachment C - 6. Watershed water balance components for the calibration, validation, and long-term periods. Water balance elements normalized over the surface water modeling domain.

	Calibration (2005-2018)		Validation (1995-2005)		long-term (1948-2018)	
Surface water balance	**Flux (in/yr)**	**% total inflow**	**Flux (in/yr)**	**% total inflow**	**Flux (in/yr)**	**% total inflow**
Total inflows	**94**		**84**		94	
Rainfall	51	54.1	46	54.1	50	53.4
Link inflow	0	0.0	0	0.0	0	0.0
Surface seepage inflow	29	31.3	27	32.2	30	31.9
Watershed runoff	14	14.6	11	13.6	14	14.6
Total outflows	**80**	**85.7**	**72**	**86.1**	**81**	**85.5**
ET	25	27.1	23	27.3	25	26.7
Initial abstraction	2	2.5	2	2.9	2	2.2
Rainfall excess	-1	1.6	-2	2.3	-2	2.0
Infiltration	24	26.0	22	26.2	25	26.6
Link outflow	3	2.9	2	2.4	5	5.0
Surface seepage out	25	27.2	23	27.3	24	25.0
Surface Storage Change	**0**	**0.3**	**0**	**0.2**	**0**	**0.1**
Sub-surface water balance						
Total inflows	**50**	**0.0**	**45**	**0.0**	**49**	**0.0**
Infiltration	24	48.9	22	49.0	25	51.5
Seepage inflow	25	51.1	23	51.0	24	48.5
Total outflows	**60**	**121.0**	**56**	**124.1**	**59**	**120.5**
Seepage out	29.3	58.9	27.1	60.2	30.1	61.9
Leakage	30.9	62.2	28.7	63.9	28.5	58.6
Sub-surface Storage Change	**-10**	**21.0**	**-11**	**24.1**	**-10**	**20.5**

APPENDIX - 3

SENSITIVITY ANALYSIS

TECHNICAL MEMORANDUM

DATE: October 5, 2021

SUBJECT: Johns Lake ICPR4 Model Parameter Sensitivity Analysis – Task F

INTRODUCTION

St. Johns River Water Management District (SJRWMD) listed Johns Lake in the SJRWMD's 2020 Minimum Flows and Levels (MFLs) priority list, which is scheduled for completion in 2022. The lake's watershed is primarily located in northwest Orange County, Florida, just south of Lake Apopka, with a small portion in Lake County, in the west (Figure F - 1). SJRWMD set up, calibrated, and validated an Interconnected Channel and Pond Routing version 4 (ICPR4) model (Streamline Technologies, 2018) for simulating the hydrologic and hydraulic processes, surface water – groundwater (SW-GW) interaction, and water budget elements of Johns Lake. Model calibration covered the period from 2005 to 2018 while model validation used the period from 1995 to 2004. Then, the extended and long-term model utilized the period from 1948 to 2018 (see Task C & D report for details). SJRWMD used the calibration period of the extended model to perform model parameters sensitivity analysis (SA) by perturbing the calibrated parameter values of the ICPR4 model. This technical memorandum summarizes the SA results pertaining to some parameters of the model.

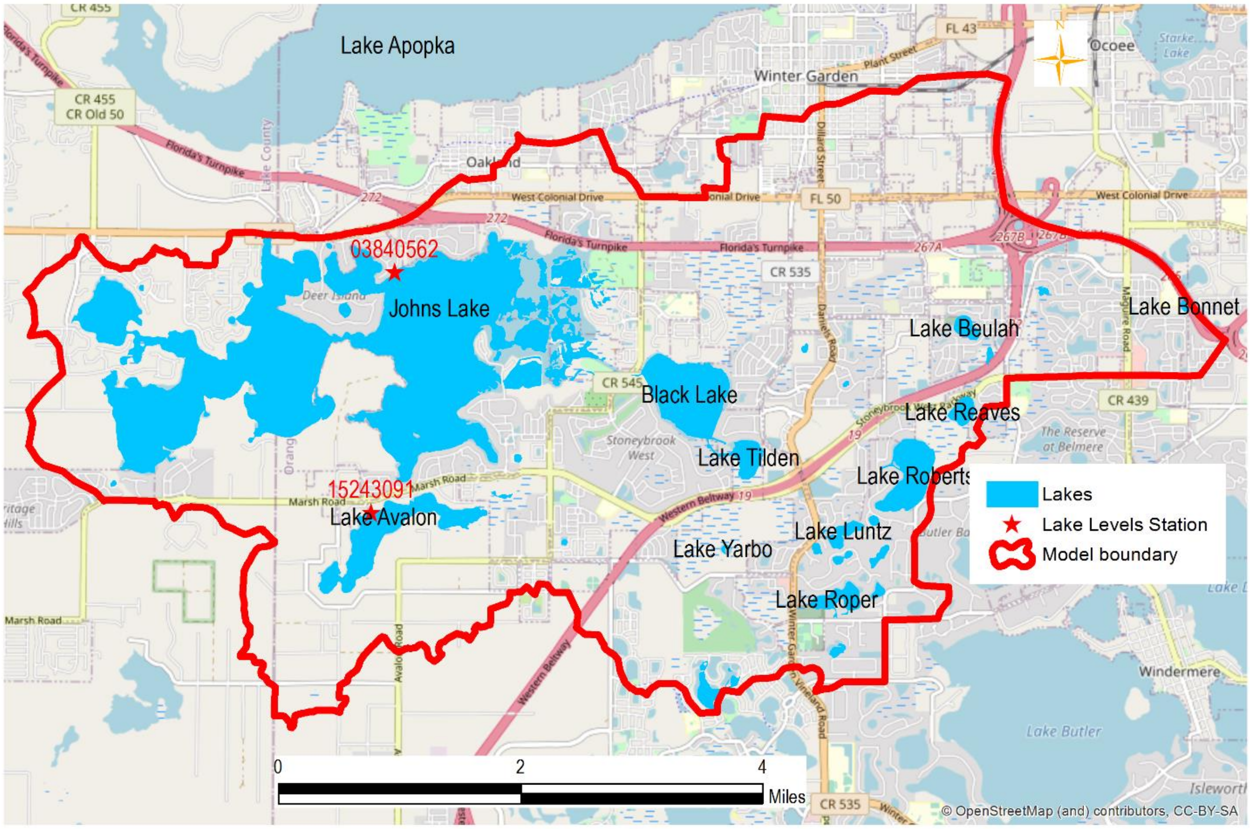


Figure F - 1. Johns Lake watershed along with locations of observed water levels for Johns and Avalon Lakes.

SENSITIVITY ANALYSIS

We performed model sensitivity analysis (SA) using a one-factor-at-a-time (OAT) method (Campolongo et al., 2010). The method varies one model input parameter value at a time while other model input parameter values remain constant. The OAT method is commonly called “local” method since it does not study the impact on model outputs by simultaneously varying all the model parameters (Saltelli et al., 2004; Campolongo et al., 2010). Such approach is informative if there is minimal interaction among parameters (Link et al., 2018). By changing one parameter value at a time, we evaluated the influence/importance of certain parameters of the ICPR4 model on the simulated stages of Johns Lake and model performance. We compared and assessed the sensitivity with respect to the calibration results. As proposed in the scope of work (SOW), we selected five parameters of the ICPR4 model of Johns Lake and increased or decreased their calibrated values. Table F - 1 summarizes the selected parameters along with the perturbation factors applied to each parameter.

Table F - 1. Selected parameters with applied change methods.

Parameter	Description	Calibrated value	Change method
Ia	Initial abstraction	Varied with LULC type (see Task C & D report)	Decreased by 10% or 20% Increased by 10% or 20%
kc	Crop coefficient	Varied with LULC type (see Task C & D report)	Decreased by 10% or 20% Increased by 10% or 20%
kv	Vertical Saturated Hydraulic Conductivity	Varied with soil type (see Task C & D report)	Divided by 2 or 3 Multiplied by 2 or 3
kh	Horizontal saturated hydraulic conductivity	40 feet per day	Divided by 2 or 3 Multiplied by 2 or 3
k	Leakance	Varied with zones (see Task C & D report)	Divided by 2 or 3 Multiplied by 2 or 3

To assess and evaluate the sensitivity of the model to parameters listed in Table F - 1, we used the model performance goodness-of-fit statistics as proposed in the SOW. This includes the Nash-Sutcliffe efficiency (NSE), Root Mean Squared Error (RMSE), and Percent Bias (PBIAS). We also used percent change in simulated stages with respect to the calibrated stages, including graphical method such as stage duration curves to assess the sensitivity of low, medium, and high stages as compared to the calibrated stages.

RESULTS AND DISCUSSION

Sensitivity of model performance statistics

The effect of increasing or decreasing the calibrated parameter values on the model performance metrics is summarized in Table F - 2. The table indicates that increasing or decreasing the calibrated initial rainfall abstraction values by 10-20% has minimal effect on model performance metrics. However, increasing or decreasing the leakance values shows the highest impact on NSE, RMSE, and PBIAS followed by the vertical and horizontal saturated hydraulic conductivities of the surficial aquifer system (SAS). For example, increasing the calibrated leakance value by a factor of 2 and 3 significantly lowers the NSE values from 0.73 to -11.34 and -18.28, respectively (Table F - 2). In general, k, kv, and kh parameters have showed significant effects on the ICPR4 model performance and thus identified as important parameters for the study area. However, when compared to the calibration period goodness-of-fit statistics, none of the perturbed values of these parameters noticeably improved the model performance (Table F - 2).

Although further reducing the calibrated crop coefficient values by 10% slightly improved the performance of the model during the calibration period, the low stages seemed to be overestimated especially during the validation period (Figure F - 2). In addition, the model performance metrics of the validation period were generally reduced. For example, PBIAS and RMSE changed from 0.17, and 0.92 to 0.48 and 1.05, respectively. More importantly, when the reduced Ia value is combined with the kc, kv, and kh values that provides best SA goodness-of-fit statistics (Table F - 2), the simulated stage hydrographs are noticeably overestimated as compared to both the calibration and validation results (Figure F - 2). This also substantially changed the calibration's NSE, RMSE, and PBIAS from 0.73, 0.93, and -0.78 to 0.54, 1.21, and 0.46, respectively. Furthermore, the validation period model performance is significantly deteriorated as the NSE, RMSE, and PBIAS values changed from 0.92, 0.92, and 0.17 to 0.39, 2.57, and 1.86, respectively. Therefore, it is concluded that the calibrated values documented in Table C – 3 of Tasks C and D report are reasonable for simulating lake stages outside the calibration period.

Table F - 2. Impact on model goodness-of-fit statistics compared to calibrated values. Bold refers to ≥ |±1| change.

Parameter	Calibrated value	Calibration statistics			Sensitivity statistics			Absolute change		
		NSE	RMSE	PBIAS	NSE	RMSE	PBIAS	NSE	RMSE	PBIAS
Ia	Decreased by 10%	0.73	0.93	-0.78	0.74	0.91	-0.73	0.01	-0.02	0.04
	Decreased by 20%				0.75	0.90	-0.72	0.02	-0.03	0.05
	Increased by 10%				0.71	0.96	-0.82	-0.02	0.03	-0.04
	Increased by 20%				0.75	0.96	-0.82	0.02	0.03	-0.05
kc	Decreased by 10%	0.73	0.93	-0.78	0.81	0.78	-0.42	0.09	-0.16	0.35
	Decreased by 20%				0.81	0.79	-0.07	0.08	-0.15	0.70
	Increased by 10%				0.54	1.21	-1.15	-0.19	0.28	-0.37
	Increased by 20%				0.19	1.60	-1.60	-0.53	0.67	-0.82
kv	Divided by 2	0.73	0.93	-0.78	-0.81	2.40	-2.42	**-1.54**	**1.46**	**-1.64**
	Divided by 3				-2.35	3.26	-3.29	**-3.07**	**2.33**	**-2.52**
	Multiplied by 2				0.76	0.88	-0.26	0.03	-0.05	0.52
	Multiplied by 3				0.65	1.06	-0.54	-0.08	0.13	0.24
kh	Divided by 2	0.73	0.93	-0.78	0.76	0.87	-0.01	0.03	-0.06	0.77
	Divided by 3				0.69	1.00	0.20	-0.04	0.06	0.97
	Multiplied by 2				0.05	1.74	-1.74	-0.68	0.81	-0.97
	Multiplied by 3				-0.85	2.43	-2.44	**-1.58**	**1.49**	**-1.66**
k	Divided by 2	0.73	0.93	-0.78	-0.23	1.98	1.46	**-0.96**	**1.05**	**2.24**
	Divided by 3				-0.69	2.32	1.86	**-1.42**	**1.39**	**2.64**
	Multiplied by 2				-11.34	6.26	-6.49	**-12.07**	**5.33**	**-5.71**
	Multiplied by 3				-18.28	7.82	-8.14	**-19.00**	**6.89**	**-7.36**

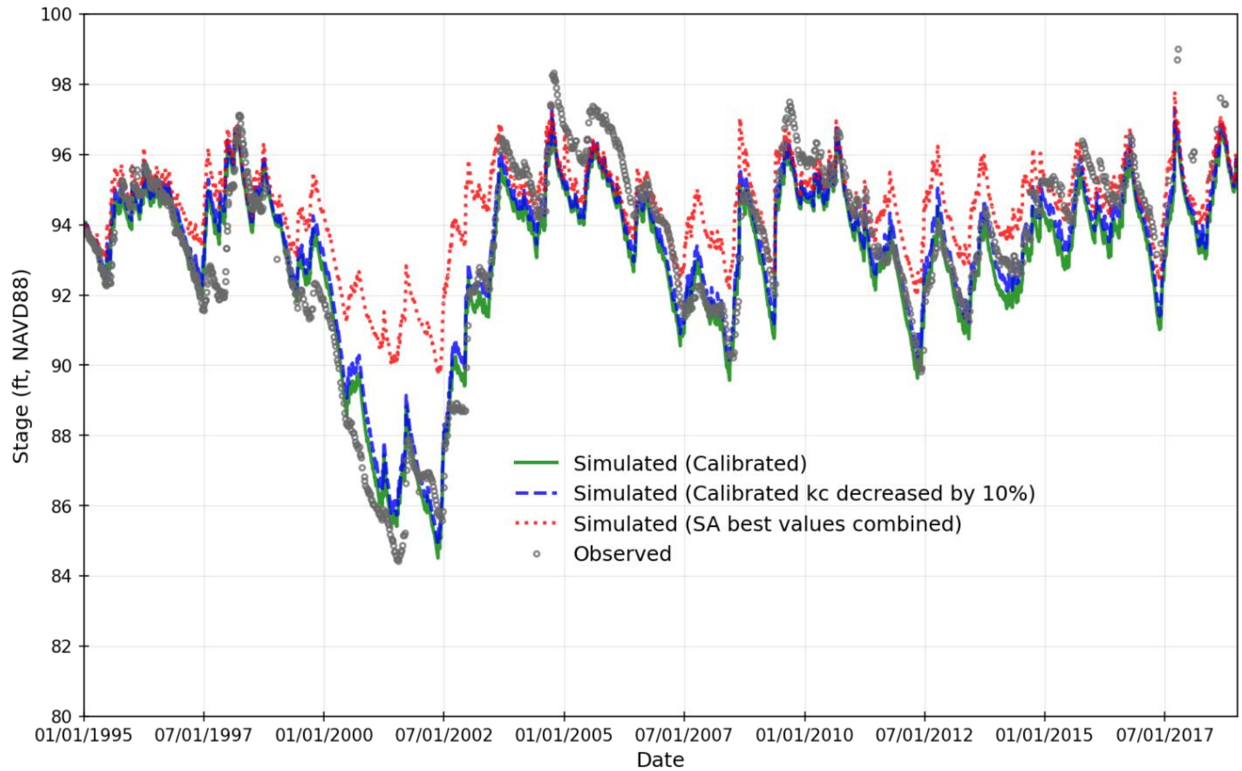


Figure F - 2. Impact of further reducing the calibrated crop coefficient value and when combined with all best sensitivity analysis (SA) values on simulated stages of Johns.

Sensitivity of simulated stages

Table F - 3 presents the effect of changing calibrated parameter values on simulated minimum, mean, and maximum stages. Compared to the calibrated stages, the percent change on mean and maximum stages are small (< 1%) except for the saturated vertical hydraulic conductivity and leakance values. As expected, leakance value shows the highest effect on the simulated minimum stages. For example, multiplying the calibrated leakance value by a factor of 3 is expected to decrease the simulated minimum stage by approximately 8% (Table F - 3). This is reasonable as the Johns Lake is in the high recharge area to the Upper Floridan Aquifer (UFA) (Boniol and Mouyard, 2016) and such process largely dominates during the dry period.

Table F - 3. Impact on minimum, maximum, and mean simulated stages. Bold refers to ≥ |±1%| change.

Parameter	Calibrated value	Calibration			Sensitivity			Percent change		
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Ia	Decreased by 10%	89.6	97.0	93.6	89.7	97.0	93.6	0.08	0.01	0.04
	Decreased by 20%				89.7	97.1	93.6	0.09	0.07	0.05
	Increased by 10%				89.6	97.0	93.6	-0.03	-0.01	-0.04
	Increased by 20%				89.5	97.0	93.6	-0.08	-0.03	-0.04
kc	Decreased by 10%	89.6	97.0	93.6	90.1	97.3	93.9	0.63	0.31	0.35
	Decreased by 20%				90.7	97.6	94.2	**1.28**	0.57	0.70
	Increased by 10%				89.0	96.8	93.2	-0.68	-0.22	-0.37
	Increased by 20%				88.5	96.8	92.8	**-1.25**	-0.22	-0.82
kv	Divided by 2	89.6	97.0	93.6	86.8	96.8	92.1	**-3.10**	-0.22	**-1.62**
	Divided by 3				85.7	96.8	91.3	**-4.32**	-0.22	**-2.50**
	Multiplied by 2				90.8	97.3	94.1	**1.36**	0.34	0.50
	Multiplied by 3				90.8	97.1	93.8	**1.41**	0.12	0.22
kh	Divided by 2	89.6	97.0	93.6	91.0	97.6	94.3	**1.54**	0.59	0.76
	Divided by 3				91.3	97.7	94.5	**1.95**	0.76	0.96
	Multiplied by 2				87.8	96.8	92.7	**-1.98**	-0.22	-0.95
	Multiplied by 3				86.8	96.8	92.1	**-3.10**	-0.22	**-1.64**
k	Divided by 2	89.6	97.0	93.6	93.8	98.5	95.7	**4.70**	**1.54**	**2.20**
	Divided by 3				94.5	98.8	96.0	**5.47**	**1.88**	**2.60**
	Multiplied by 2				83.6	96.8	88.2	**-6.70**	-0.22	**-5.80**
	Multiplied by 3				82.7	96.8	86.6	**-7.70**	-0.22	**-7.46**

Increasing or decreasing the calibrated initial rainfall abstraction (Ia) value barely changes the stage duration curves of Johns as shown in Figure F - 3. In addition, perturbing the calibrated crop coefficient value by 10 or 20% also shows the second minimal effect on simulated stage duration curves of Johns, with a maximum change of about 1.5% (Figure F - 4).

Leakage can move the simulated lake stage hydrographs downward by increasing the vertical saturated hydraulic conductivity (kv) and upward by decreasing it. However, simulated stages of Johns Lake are shifted upward when the kv value is multiplied by a factor of 2 or 3 (Figure F - 5). Further analysis indicates that multiplying the kv value by 2 is expected to increase the annual average leakage only by 4 inches. More importantly, while the annual average direct runoff contribution from Johns' mapped-basin is similar, multiplying kv by a factor of 2 is appeared to increase the upstream annual average link inflows and seepage to the lake by 23 and 24 inches, respectively (Table F - 4). This could be related to increase in hydraulic gradient between the SAS and lake along with lateral seepage as SJRWMD also noticed that the simulated SAS stages are higher than the calibrated stages. SJRWMD reached similar conclusions when the kv value is multiplied by 3. In general, increasing kv is expected to cause an upward shift in simulated stages of Johns Lake (Figure F - 5), which could be due to dominant link and sub-surface inflows from the upstream areas.

Table F - 4. Impacts of saturated hydraulic conductivities on simulated water budget elements of Johns Lake.

Water balance components	Calibrated	kh divided by 2	kh multiplied by 2	kv divided by 2	kv multiplied by 2
Surface water	**Flux (in/yr)**	**Flux (in/yr)**	**Flux (in/yr)**	**Flux (in/yr)**	**Flux (in/yr)**
Total inflows	**219**	**240**	**200**	**177**	**266**
Direct rainfall	50	50	50	50	50
Link inflow	125	146	109	100	148
Surface seepage inflow	33	32	31	16	56
Mapped-basin direct runoff	11	11	11	12	11
Total outflows	**221**	**242**	**202**	**179**	**267**
ET	45	45	44	43	45
Initial abstraction	2	2	2	2	2
Infiltration	53	58	46	30	89
Link Outflow	10	17	6	4	13
Surface seepage out	111	119	104	100	119
Surface storage change	**-2**	**-2**	**-2**	**-2**	**-2**
Sub-surface water					
Total inflows	**164**	**177**	**150**	**130**	**207**
Infiltration	53	58	46	30	89
Seepage inflow	111	119	104	100	119
Total outflows	**157**	**162**	**147**	**127**	**184**
Seepage out	33	32	31	16	56
Leakage	124	129	117	111	128
Sub-surface storage change	**8**	**16**	**3**	**3**	**23**

kh = horizontal saturated hydraulic conductivity; kv = vertical saturated hydraulic conductivity.

As opposed to kv, increasing kh appeared to decrease the simulated stages of Johns, especially the low to medium stages and vice versa (Figure F - 6). For example, when kh is multiplied by a factor of 3, the simulated stage is expected to decrease by up to 3% (Figure F - 6). Increasing kh also reduces the simulated stages of SAS. For instance, increasing the kh value by a factor of 2 reduces the simulated upstream annual average inflows by 17 inches (Table F - 4). This is consistent with the results reported by SLT (2021). As the majority of Johns Lake inflows are from the upstream areas (see Table C – 5 of Task C & D report for detail), decrease in the upstream inflow values most likely caused a downward shift in simulated stage duration curves of the lake (Figure F - 6). The impacts of kh on seepage inflow is very minimal compared to kv (Table F - 4).The effects of kh and kv are more pronounced on low to medium simulated stages (Figure F - 5 and Figure F - 6). This is reasonable as more seepage (baseflow) is expected during the dry period.

Compared to the other parameters, the simulated stages of Johns Lake show the highest sensitivity to leakance value (Table F - 3). For example, multiplying the calibrated leakance value by a factor of 3 is appeared to decrease the simulated low stages by up to 9% (Figure F - 7). Overall, the simulated stages and water budget components of Johns Lake are highly sensitive to leakance value, followed by vertical and horizontal saturated hydraulic conductivities of the SAS (Table F - 3 and Table F - 4). This highlights that if these parameter values are not well identified during the calibration process, they may drive most of the uncertainty on the simulated stages of the lake.

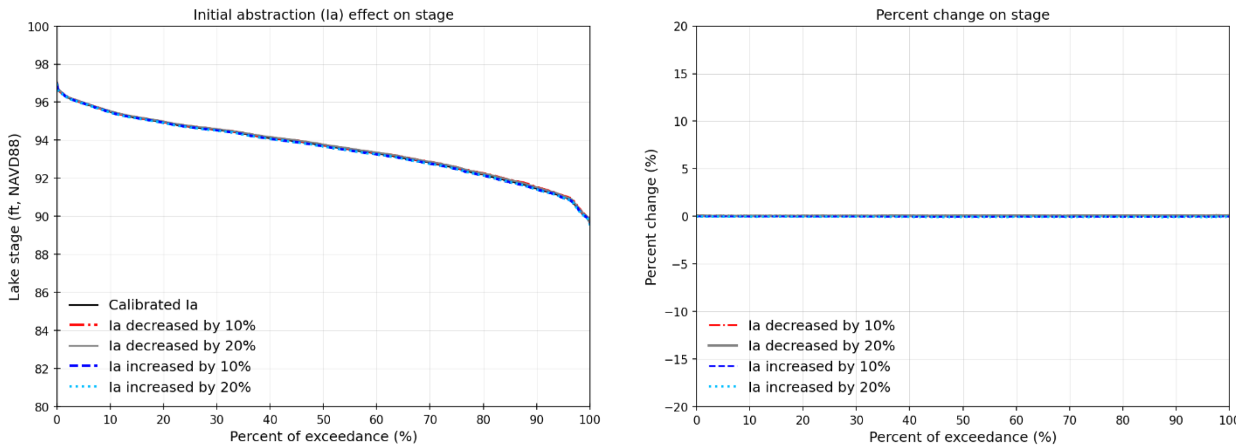


Figure F - 3. Stage duration curves sensitivity to changed initial abstraction value.

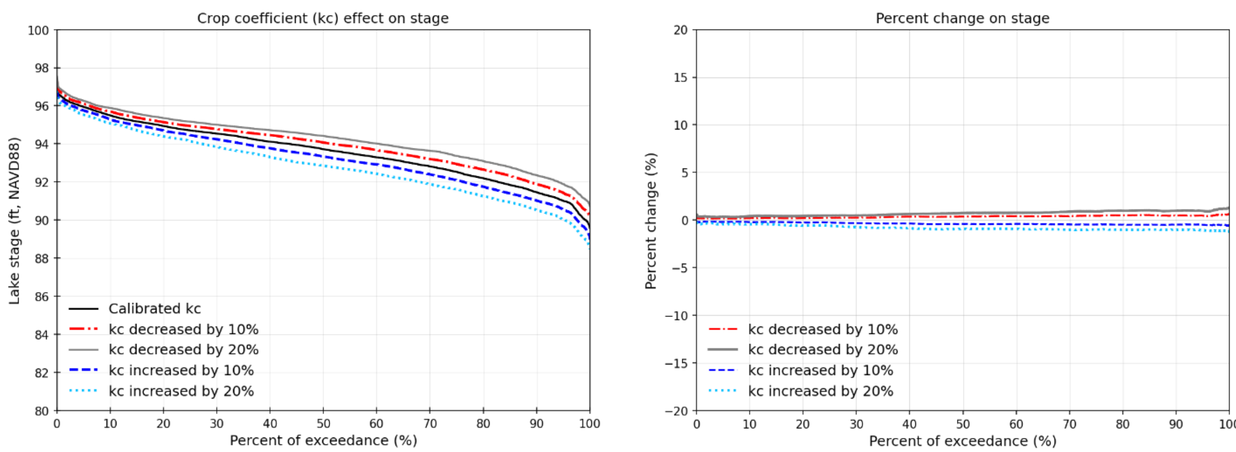


Figure F - 4. Stage duration curves sensitivity to changed crop coefficient value.

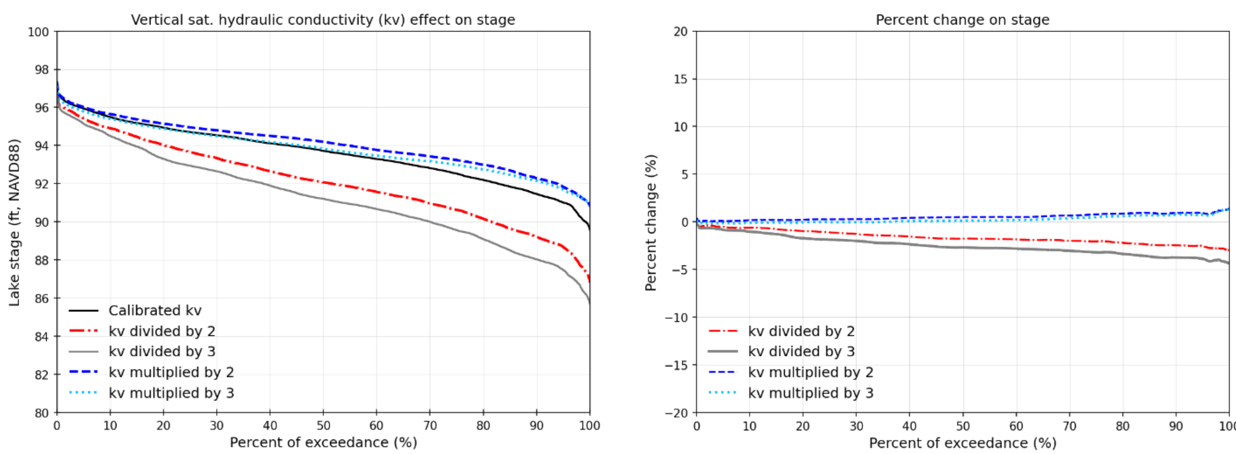


Figure F - 5. Stage duration curves sensitivity to changed vertical saturated hydraulic conductivity value.

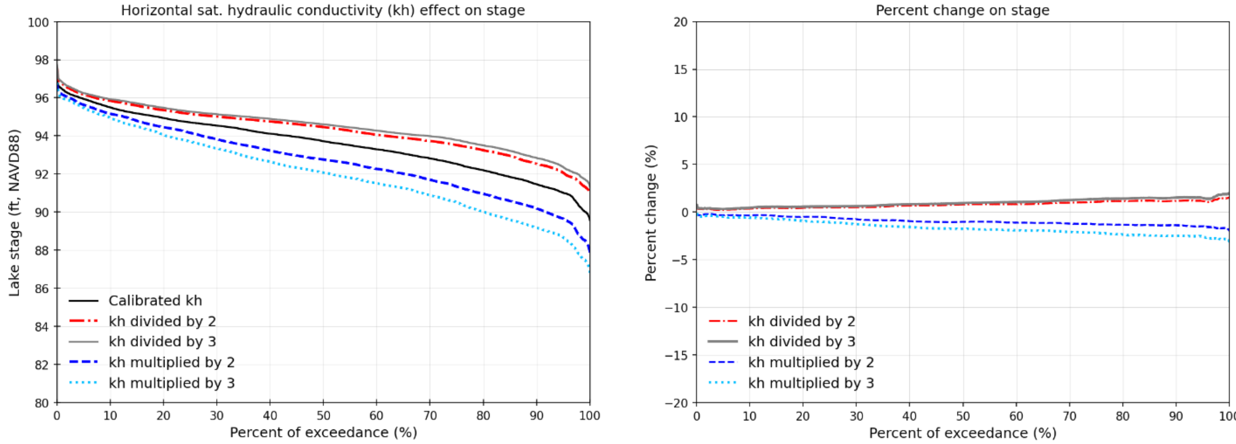


Figure F - 6. Stage duration curves sensitivity to changed horizontal hydraulic conductivity value.

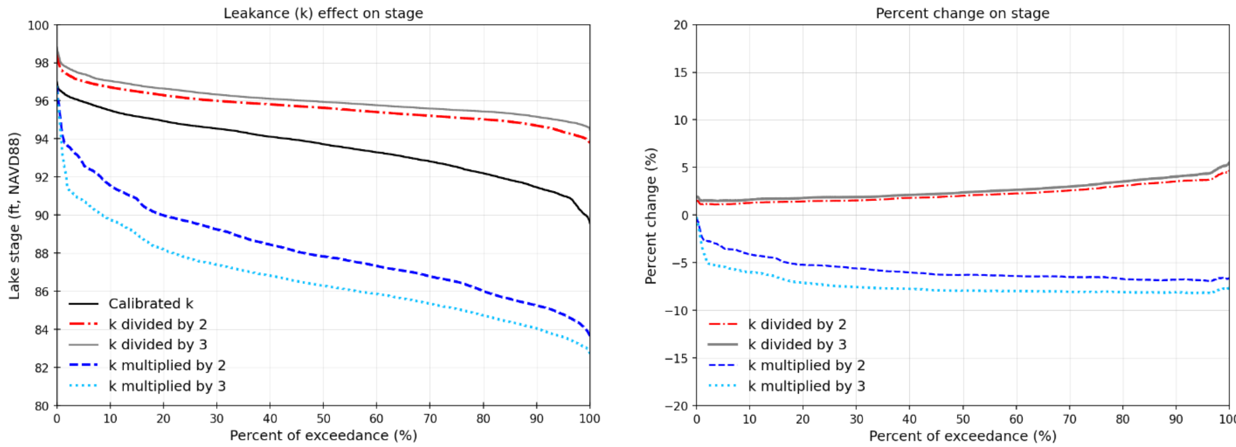


Figure F - 7. Stage duration curves sensitivity to changed leakance value.

SUMMARY AND CONCLUSIONS

Based on the calibrated ICPR4 model of Johns Lake, we performed one-factor-at-a-time (OAT) sensitivity analysis for initial rainfall abstraction (Ia), crop coefficient (kc), horizontal (kh) and vertical (kv) saturated hydraulic conductivities of surficial aquifer system, and leakance (k) parameters. While we increased or decreased the calibrated Ia and kc values by 10 and 20%, we divided or multiplied the calibrated kh, kv, and k values by 2 and 3. Then, we assessed and compared the sensitivity of the parameters on simulated stages and model performance metrics with respect to the calibrated stages and model performance evaluation metrics. Ia is identified as the least sensitive parameters to simulated stages and model performance metrics. Consequently, its effect on the simulated stage is very minimal. On the other hand, we found that the simulated stages and model performance metrics are highly sensitive to the k value followed by kv and kh values, respectively. This signifies that these parameters are highly important for simulating Johns Lake stages. However, none of these sensitive parameters significantly improved the model performance when compared to the calibrated stages and model performance evaluation metrics.

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