Final Report Final Report Final Report

Peer Review of the Johns Lake SSARR Model

Prepared for:

The St. Johns River Water Management District

Prepared by:

INTERA

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Johns Lake SSARR Model

Johns Lake is located in Orange County, Florida, approximately five miles southwest of Winter Garden. Currently, Johns Lake is listed on the *MFLs Priority Water Body List and Schedule* (SJRWMD 2008). Pursuant to Florida Statues 373.042(2), as an included waterbody, minimum levels must be established for the lake. Setting minimum flows and levels for this lake provides initial limits to Floridan aquifer withdrawals for the area surrounding the lake. The ultimate function of the Johns Lake SSARR model will be to evaluate the impacts of consumptive use withdrawals on lake stages to ensure that withdrawals do not cause a violation of the MFLs.

The recommended MFLs for Johns Lake are shown in Table 1. In order to evaluate proposed aquifer withdrawals and their impacts on the lake, a hydrologic model was developed for the lake. The Streamflow Synthesis and Reservoir Regulation (SSARR) model developed by the Portland District of the U.S Army Corps of Engineers (USACE 1986) was selected to develop a model of Johns Lake. SSARR is a continuous simulation model whose watershed model simulates rainfall-runoff and accounts for interception, evapotranspiration, baseflow infiltration and runoff routing into a stream network. This portion of the model accounts for groundwater flow through the local water table, but not through the regional water table, the intermediate, or the Floridan aquifer. The historical 14-foot fluctuation of Johns Lake indicates that Interaction between the Floridan Aquifer and Johns Lake is a significant portion of the water budget for the lake. Due to this fact, a seepage routine was developed in SSARR to simulate regional aquifer fluxes. The overall goal of the SSARR model was to maximize the number of simulated values within $\pm$0.5 feet of the measured values.

Table 1. Johns Lake MFLs

	Minimum Level (ft NGVD)	Duration (days)	Return Interval (years)
Frequent High	94.7	30	2
Frequent Low	92.1	120	3

This technical memorandum evaluates the current SSARR model for Johns Lake with regard to model selection, input data, calibration, and simulation results. The input data and model assumptions are examined, and the potential impacts of these assumptions on the MFL will be discussed.

Task A: Assess adequacy of hydro-meteorological records in terms of quality, spatial coverage, and length of record.

1) Was "best information available" utilized to develop the hydrologic model?
2) Are there any deficiencies regarding data availability?

There is a limited amount of information available for Johns Lake. That being said, the best information available was utilized to develop the model. For the calibration of the model, the following data was utilized:

1995 Land Use. Land use estimates from 1995 were utilized in order to determine the amount of impervious area draining into both Johns Lake and Black Lake. Analysis of land use resulted in approximately 0.28 square miles of impervious area for Johns Lake, and approximately 1.51 square miles of impervious area for Black Lake. The selected land use data might not be the best for calibration since the calibration begins back in 1989. This land use distribution represents a condition that captures the average condition throughout the calibration period.

Overall Basin Boundary. Given the graphics shown in the report documentation, USGS 5 foot contour topographic maps were utilized to develop the Johns Lake watershed. Using the 5 foot contours to define the basin gives a good overall description of the basin. Given the shallow slopes in Florida, higher resolution is desired. For example, topographic elevations such as the road crowns may serve as a hydrologic divide unless a culvert is present to allow the water to pass under the road (i.e., SR 50 and the turnpike). The Black Lake basin also shows signs of additional storage. The wetlands to the north and lakes to the south of Black Lake can provide a great deal of basin storage. This storage can significantly alter the basin response upstream of the wetlands.

Johns Lake Outlet Rating Curve. A rating curve for the Johns Lake outlet to Lake Apopka was modeled using HEC-RAS. Two conditions were modeled: with the weir gates open and with the weir gates closed. There are no observed field measurements available at the Johns Lake outlet. Hence, the modeled results represent the best available data for the outlet structure.

Black Lake/ Johns Lake Rating Curve. In order to model the interaction between Black Lake and Johns Lake, the backwater mode of SSARR was used. The majority of the time, the lakes are at similar levels, so the flow from Black Lake to Johns Lake depends on the level in both lakes. The rating curve characteristics were determined as a part of model calibration. The rating curve allows for modeling backflow from Johns Lake to Black Lake (although this rarely occurs). Since there is no gauge currently measuring the discharge from Black Lake to Johns Lake, the calibrated rating curve represents the best data currently available.

Best Available Bathymetry. Bathymetry was not available for the lakes. The storage capacity curves used for the SSARR model were based on areas derived from contours and the water surface from the USGS quadrangle map for the lake. It was assumed that the area at 86-feet, the historic low of Johns Lake, was 80% of the area at 94-feet for both lakes. Due to the lack of data, the storage capacity curve will have large uncertainties which may impact the model results. The storage capacity curve was developed using common engineering practices and represents the best available data.

Observed Stages. There is a good amount of stage data available for Johns Lake and Black Lake. Stage data was gathered by the District for both Johns Lake and Black Lake. For Johns Lake, data was available from 1959 to 2001. Data was recorded at various intervals, ranging from every 3-days to weekly. At times, there are data gaps that span several months. For Black Lake, data was available from 1960 to 2001. From 1960 to 1995, data was available monthly (with large gaps). From 1996 to 2001, data was available weekly to bi-weekly. This represents a fairly extensive data set and is the best available stage data for Johns Lake and Black Lake. This data served as the primary calibration targets during model development.

Daily Rainfall. Daily rainfall totals were utilized for the model calibration and long term simulation. The calibration of the model utilized daily rainfall recorded by the District (at the Turnpike and Winter Garden stations). The long term simulation utilized the Turnpike and Winter Garden stations as well as the Clermont and Isleworth NOAA daily rainfall records. The data processing of the rainfall appears to be produced with common engineering practices. Since the model was run at a daily time step, the use of daily rainfall is appropriate. However, the model parameters for the pervious basins will need to be adjusted in order to compensate for the low intensities of the daily precipitation record.

Potentiometric Surface. For the calibration period, the potentiometric surface beneath Johns Lake and Black Lake was simulated using data from the District's L-052 monitoring well. For the long-term simulation, the potentiometric surface was simulated using the L-052 well, with supplemental data from the Clermont and Mascotte wells, as described in Table 2. The L-052 data was available on a monthly basis. Using the monthly data, straight line interpolation between observed data points was utilized in order to develop a daily time series for model input. Other available observation wells recorded the aquifer level on a daily basis, as shown in Table 2. While it is possible that the L-052 was utilized because it was the closest well to the lakes, it should be noted that the Turnpike well, which has a daily record, is also located in close proximity to the lake. Justification for not using the Turnpike well should be included in the report. Additionally, a simple linear regression analysis might improve the fit when fitting data from other wells to fill missing data. A linear regression would provide not only an offset, which was used in the data preparation, but also a slope which would help fit the range in the wells.

Table 2. Available Wells

Well Name	USGS Number	Period of Record	Comment
City well replacement at Clermont, FL	283314081455501	1977-2001	Daily with occasional gaps
Mascotte deep well	283204081544901	1959-2001	Daily with occasional gaps
L-052	DIST 05310981	1984-2001	Monthly
Lake Apopka at Turnpike	DIST 38003797	1989-2001	Daily with a gap between 03/93 and 08/94
OR-47 well at Orlovista, FL	283253081283401	1943-2001	Daily with occasional gaps

Pan ET Data. Pan evaporation data was available from 4 NOAA stations within the SJRWMD (Gainesville, Lake Alfred, Lisbon and Vero Beach). The Lisbon Pan data was utilized for the model calibration. Pan evaporation is utilized by SSARR in order to calculate direct evaporation from the lake and to estimate actual evapotranspiration from the basin. The Pan data was organized into two separate time series: one for the basins and one for the lake. The report states the potential ET from the watershed was estimates as 100% of the pan evaporation (Robison, 2008). This is not common engineering practice; typically potential ET is 0.7 to 0.8 of pan ET, with actual ET being less based on the available moisture. The lake ET data was aggregated into a weekly time series in order to prevent round off errors (Robison, 2009). This should have little effect on the accuracy of the lake water budget since the AET is never limited by available water in the lake simulation.

The above data represents the best data currently available for Johns Lake, Black Lake, and the surrounding basins. All available observed stage, bathymetry, rainfall, land use and potentiometric surface data was utilized. The best available data was utilized to develop the model. Based on review of "Johns Lake Minimum Flows and Levels Hydrologic Methods Report" and a review of the model input files, there was no information found to be discarded from the model development and calibration.

Task B: Assess methods and procedures for data analysis.

1) Are the analytical methods and procedures appropriate?
2) Are there any deficiencies and/or errors in the analytical methods?

Model Conceptualization. Overall, the analytical methods and procedures utilized were appropriate and sound engineering principles were adhered to. When conceptualizing a model, the available data and the ultimate purpose of the model should both be considered. SSARR is a numerical hydrologic model that simulates rainfall-runoff while accounting for interception, evapotranspiration, soil moisture, baseflow infiltration, and routing of runoff into the stream system. This is an appropriate model selection for the current purpose given the available data.

The conceptualization of the model included 2 basins (1 pervious and 1 impervious) draining into Black Lake. Flows from Black Lake were routed into Johns Lake using a rating curve developed for the model. Additional inputs to Johns Lake included 2 basins (1 pervious and 1 impervious). Flow from Johns Lake was routed to 3 outflows: Lake Apopka and 2 sinks. One seepage sink was operative for all lake stages, and the other seepage sink was assumed to stop seeping water when Johns Lake stages reached 89 feet. According to the model documentation, this assumption was checked by examination of aerial photographs and also documented in a publication of a local lake association, which verified that the lake could break up into 2 lobes at an approximate stage of 89.5 feet. Dividing the computation of separate land use (pervious and impervious) is a good engineering practice to follow. Lumping regions of different hydrologic processes together will produce very poor results.

There were several assumptions with regard to the conceptualization of the model. These assumptions include the following:

- Baseflow from outside the immediate basin is small compared to the overall water budget. Despite this assumption of the model, the inclusion of the groundwater fluxes from the potentiometric surface does account for the regional water budget and therefore flows from outside the immediate basin.
- Bathymetry below certain levels could be estimated using USGS quadrangle maps.
- The effect of Water Conserv II (WC II) project, a water re-use project located to the south and southwest of the lake, was assumed to primarily manifest itself by changing the Floridan aquifer levels (as reflected in the L-052 well).
- The potentiometric surface beneath Johns Lake and Black Lake can be estimated using the District's L-052 well. When this data was unavailable, it was supplemented with the USGS's Clermont and Mascotte wells.

Additional assumptions were made regarding the calibration of the model. All the noted assumptions follow typical engineering practices. Given the lack of data, best available methodologies were used in the hydrologic analysis. It was assumed that the calibration covers a wide enough range of flow regimes and hydrologic conditions to ensure that the long-term model simulation will be realistic.

Task C: Assess hydrologic models.

a. Determine if the model is appropriate, defensible, and valid, given the District's MFLs approach.

b. Was there adequate data to develop, calibrate and apply the model?

c. Given the available data and the District's MFLs approach, are there more appropriate models for assessing the water body?

d. Evaluate the validity and appropriateness of all assumptions used in the development of the hydrologic model.

   e. Are the assumptions reasonable and consistent given the "best information available"?

   f. Is there information available that could have been used to eliminate any of the assumptions? Would the use of this additional information substantially change the model results?

   g. Are the assumptions stated clearly?

   h. What, if any, additional assumptions are implied or inherent in the development of the model?

   i. Are other methodologies (modeling or non-modeling) available that would require fewer assumptions but could provide comparable or better results? Are adequate data available to support using these alternative methodologies?

      a. Are there deficiencies and/or errors in model development, calibration, or application?

         i. If so, describe each deficiency and/or error and enumerate and describe the necessary remedies, and provide an estimate of the time and effort required to develop and implement each remedy.

         ii. If the identified deficiencies cannot be remedied, then identify and describe one or more alternative methodologies (modeling or non-modeling) that are scientifically defensible given the available data. Provide an estimate of the time and effort required to develop and implement them.

Model Conceptualization. The model schematic is shown in Figure 1. The input to Black Lake consists of a pervious basin and an impervious basin consisting of areas of 13.82 and 1.51 square miles, respectively. The input to Johns Lake consists of a pervious basin and impervious basin consisting of areas of 6.30 and 0.28 square miles, respectively. Outflow from Johns Lake flows into Lake Apopka and two seepage sinks: one permanent sink, and one temporary sink, which is active below 89 feet NGVD. The second sink was added to the model during the calibration process because the simulated stages were systematically diverging from observed values at stages lower than about 89 feet. The development of this additional sink essentially assumes that the model breaks up into two separate lobes at stages lower than 89 feet. While this may be a valid assumption, if the lake breaks up into 2 separate lobes, the drainage areas should also be broken up into a pervious and impervious basin for each lobe. Otherwise, when the temporary sink is inactive, the model is utilizing the drainage areas for both lobes of the lake and applying the runoff generated to the actively seeping lobe. In reality, a portion of that drainage area is contributing to the other lobe. The effect of this is that there could be too much runoff contributing to the actively seeping lobe.

For the case of Johns Lake, the model documentation states that the lake stages rarely drop to levels below 89 feet, yet based on the observed data from Johns Lake shown in Figure 2, there are 2 periods where the stages in the lake drop significantly below 89 feet: from 1980 to 1983, and again in 2000. During the times that the lake is broken up into 2 lobes, the model is still simulating them as one waterbody. There may be different stresses and basin inflows on the individual lobes thus inducing different hydrologic response and therefore different stages. It would be desired to simulate the lobes separately, however, this might not be feasible given the available data. In addition, the MFL as defined by the District would not be impacted by this fairly infrequent event. The results of the long term simulation show a bias toward overprediction of lake stage (see Figure 2), particularly in the 1980s, when the observed lake stage was low (less than 89 feet). This could be due to the fact that the contributing basin areas are too high (lake was divided into two lobes) or some other physical process was not captured by the model. The model performs well during the 1960's and early 70's and very well during the calibration period.

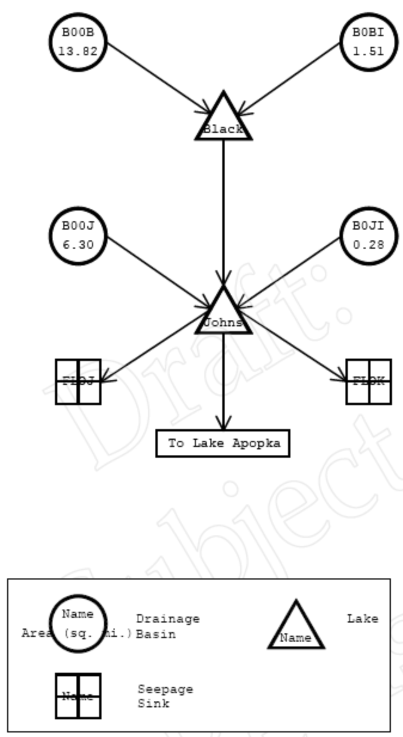


Figure 1. Johns Lake SSARR Model Schematic. Source: (Robison, 2008)

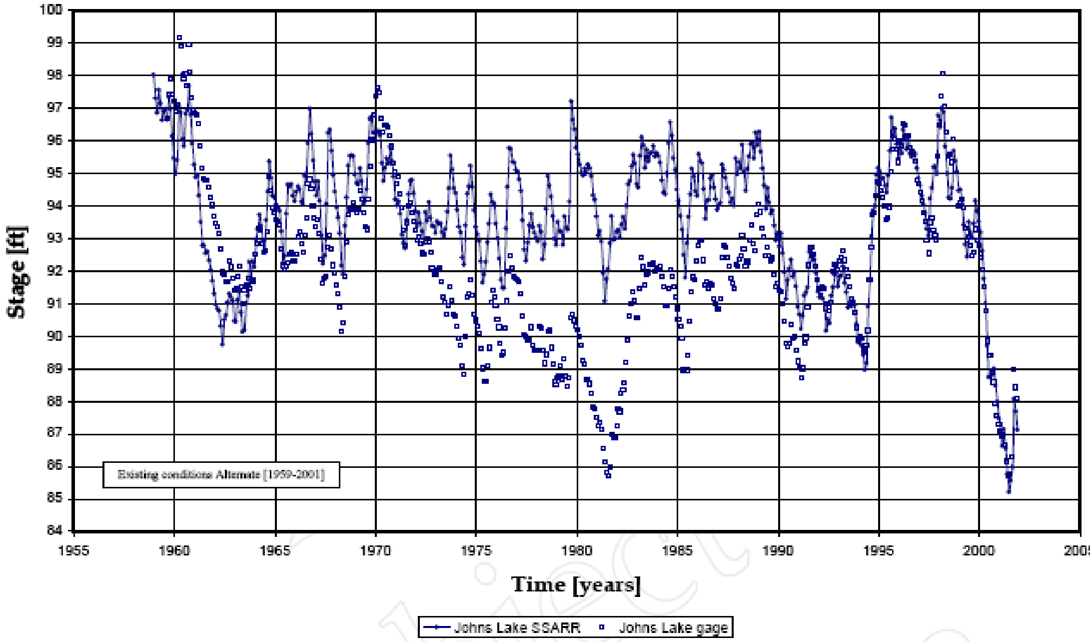


Figure 2. Johns Lake Observed versus Simulated Hydrographs. Source: (Robison, 2008)

The model is currently run at a 1-day time step. SSARR has the capability to utilize a time increment as short as 0.1 hours. Using daily time steps with infiltration excess modeling, such as the pervious basin, results in model calibration that tends to over estimate low flows and under estimate high flows. In effect, long time steps average a wide range of hydrologic conditions. There is no way for the model to differentiate the difference between 2 inches of rain in 0.5 hour versus 2 inches over 12 hours. Based on the available data however, a daily time step is appropriate, especially given the lack of flow data to use as a calibration target.

Model Adequacy and Assumptions. There was an extensive record of Lake stage for both Johns Lake and Black Lake, and a fair amount of observed well data. Other parameters, such as discharge from Black Lake to Johns Lake and discharge from Johns Lake to Lake Apopka, were estimated using modeling and other sound engineering practices. For the current SSARR model, it would be desirable to have more calibration data, especially basin flows and discharge flows from Johns Lake and Black Lake as additional calibration targets. Nevertheless, given the use of the best available data, the model development followed proper engineering procedures. There are several simplifying assumptions made in the conceptualization of the model which may affect the model's performance. The assumptions which are of the most concern are those associated with the utilization of the L-052 well data, and the development of an additional temporary sink in the model.

Utilization of L-052 Well Data. Data from the District's L-052 well was utilized for the calibration period (1989-2001). This data consisted of a monthly record with some additional data gaps. Linear interpolation was utilized to fill daily values between monthly readings. More information is needed with regards to why this well was chosen for use as the primary data source for potentiometric surface in the model. Based on the available well data shown in Table 1, there are more complete well records available. Comparison of the L-052 well data to the Clermont and Mascotte wells is shown in Figures 2 and 3, respectively. As shown in the figures, there is a good comparison between the L-052 and Clermont well records, with the exception of the higher stages recorded at L-052 in the 1990s (1995 and 1998) and the much lower levels recorded at L-052 in the early 2000s. It would be highly useful to run the model with one of these available well records (such as the un-shifted Clermont well) in order to determine the impact of using the L-052 well time series. Additionally, some simple statistical models might help to improve the fit when filling the data gaps. Simple shifts only correct for the mean, whereas scaling will correct the range.

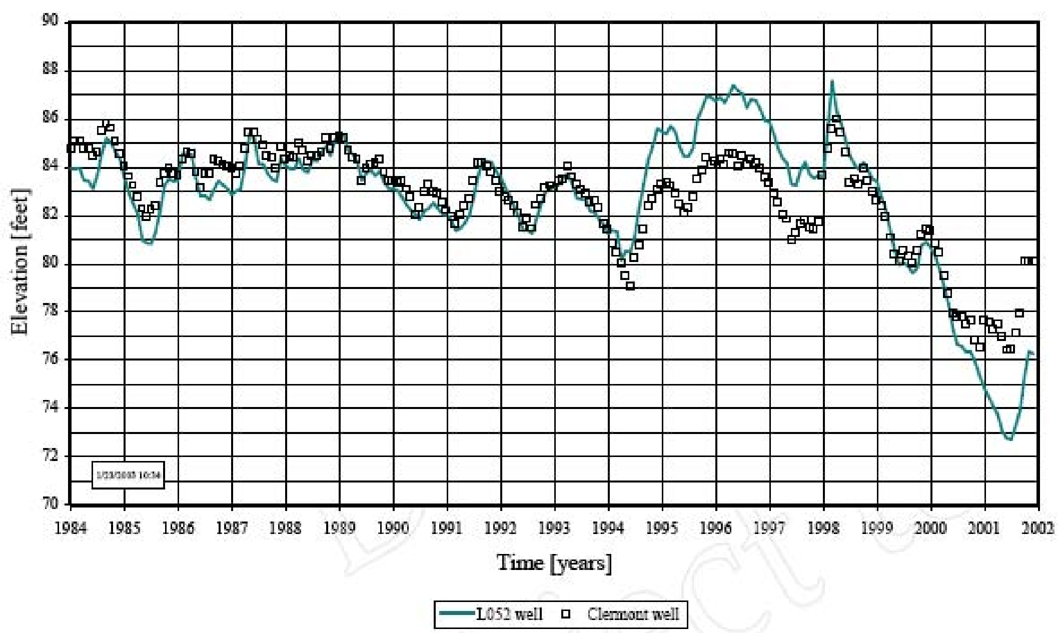


Figure 3. Comparison of L-052 and Clermont Wells. Source: (Robison, 2008)

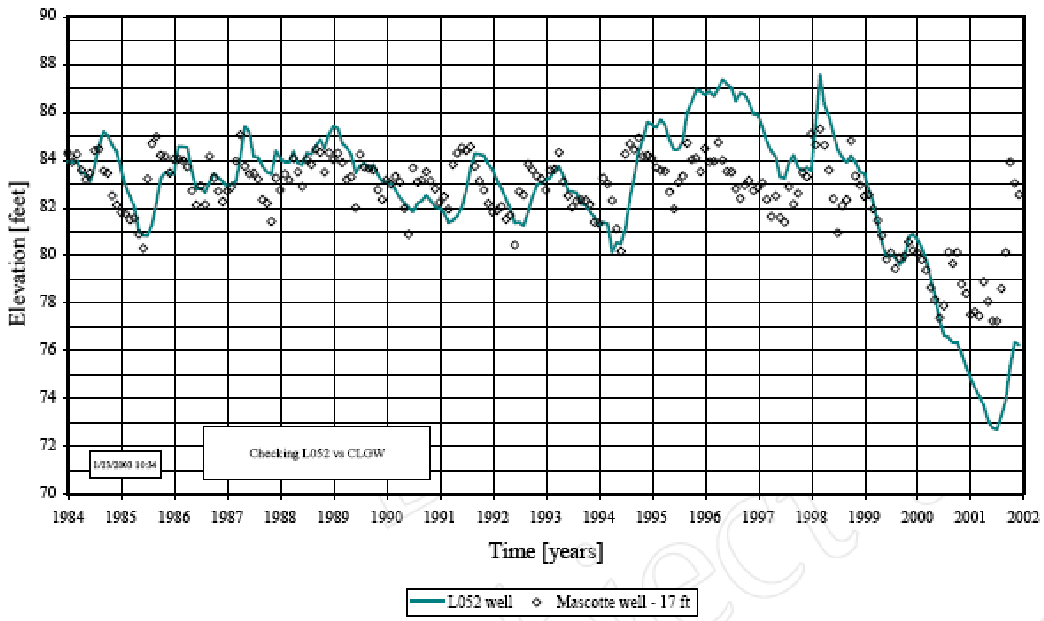


Figure **4**. Comparison of the L-052 and Mascotte Wells. Source: (Robison, 2008)

For the extended simulation (1959-2001), the Clermont and Mascotte wells were used to supplement the L-052 record. More information is needed in order to determine how the L-052 record was supplemented. As shown in the figures, although there is generally good agreement for the time series between the L-052 and Clermont and shifted Mascotte well, there are periods (such as in the 1990s and early 2000s) where there is a greater range of elevations shown at the L-052 well than the other 2 wells. When data from one well is supplemented with data from another, it is important to scale the data by both shifting the data based on the potentiometric suface difference, and scaling it by a factor to preserve the range of values seen at the original well. This will ensure that the characteristics of the original well (L-052) are preserved. A comparison of the approximate minimums, maximums, and well ranges is shown in Table 3. As shown in the table, although the wells generally compare favorably, the more extreme events seen at the L-052 well result in a much greater range of values than at the other 2 wells.

Table 3. Well Statistic Comparison

Well Name	Approximate Maximum Level, ft NGVD	Approximate Minimum Level, ft NGVD	Range, ft
L-052	87.3	72.9	14.4
Clermont	86.1	76.1	10
Mascotte (shifted 17-feet)	85.1	77.5	7.6

Based on the model documentation, it appears that a shift was applied to the Mascotte well, but no other processing was done. If this is the case, it would be beneficial to develop a time series for the extended simulation that also preserves the range of the L-052 record. This would be a fairly straightforward algorithm to run and would not require a great deal of additional effort. The SSARR model can be re-run with this new time series, and the difference in the lake stages between the two runs can be compared in order to determine the impact of developing a time series that preserves the original well characteristics.

Examination of Long Term Potentiometric Surface. In addition to preserving the range of the L-052 record, the long term potentiometric surface should be examined in order to verify that the shifts that were applied to the L-052 record (based on the September 1990 potentiometric surface maps) are representative of the entire calibration and extended simulation period. If the shifts (zero for the Clermont well, and 17-feet for the Mascotte well) are not representative of the entire simulation period, it may be necessary to apply a seasonal or decadal shift based on trends due to precipitation or water use. If the shifts that were applied to the current time series are representative of the entire simulation period, it would be helpful to add additional graphics to the model documentation illustrating that the potentiometric surfaces are similar between years and seasons. Again, this is a small recommended enhancement which would give more confidence in the time series used to drive the model.

Change in Basin Area Based on Lake Stage. The stage-area curve for Johns Lake and Black Lake is shown in Figure 5. As shown in the figure, the area of Johns Lake ranges from approximately 4300 acres at a stage of 110-feet to an area of 1000 acres at a stage of approximately 80-feet. During the calibration period, the observed lake stage ranged from approximately 85.5-feet to 98-feet. These stages correspond to Johns Lake areas of approximately 1900 acres and 3000 acres, respectively. Table 4 shows the range of the lake area during the calibration period as well as the areas of the basins used in the model. As shown in the table, the variability in the lake area represents a large percentage of the contributing basin. When the stage of the lake decreases, the amount of area lost by the lake should be added to the pervious basin area. Although SSARR has the ability to change the area of the lake with stage (for water budget calculations such as direct lake evaporation), when the lake stage is low, it does not add the difference in the lake area to the pervious basin area. This, in effect, is a mass balance error.

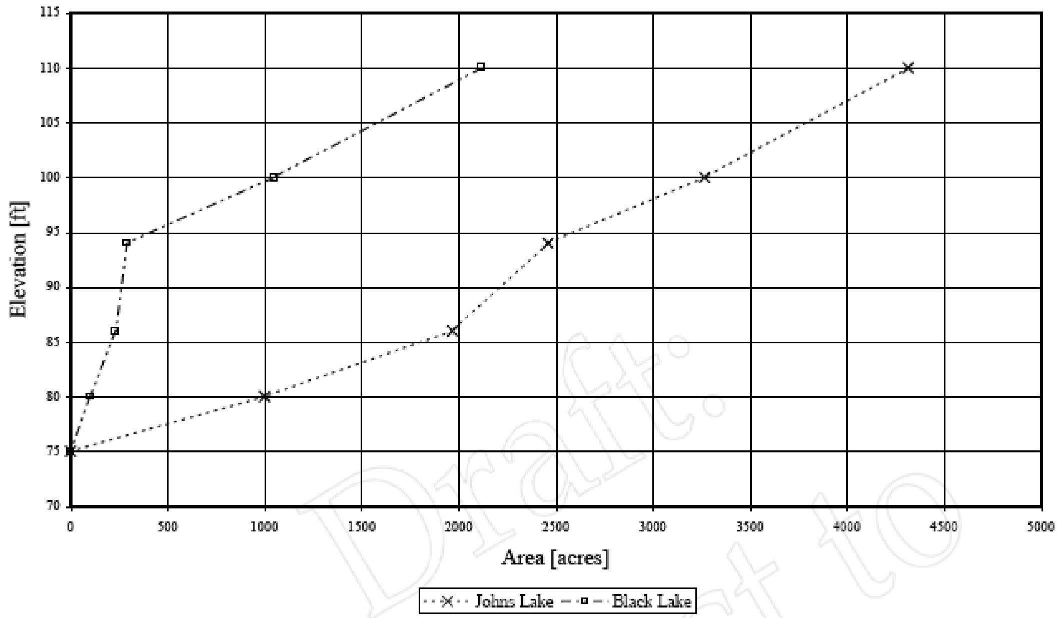


Figure 5. Black Lake and Johns Lake Stage Area Curve. Source: (Robison, 2008)

Table 4. Model Area Comparison (Johns Lake)

	Area, acres
Pervious basin	4032
Impervious basin	179.2
Lake (during calibration period)	1900-3000

Comparison of Long Term Simulations. A comparison of the Johns Lake SSARR results to the Johns Lake gauge for the calibration period and the long term simulation is shown in Figure 6. As shown in the figure, there is a excellent agreement between the observed and predicted stages for the calibration period (1989 – 2001). There is less agreement between the SSARR simulation and the historical data for the long term simulation.

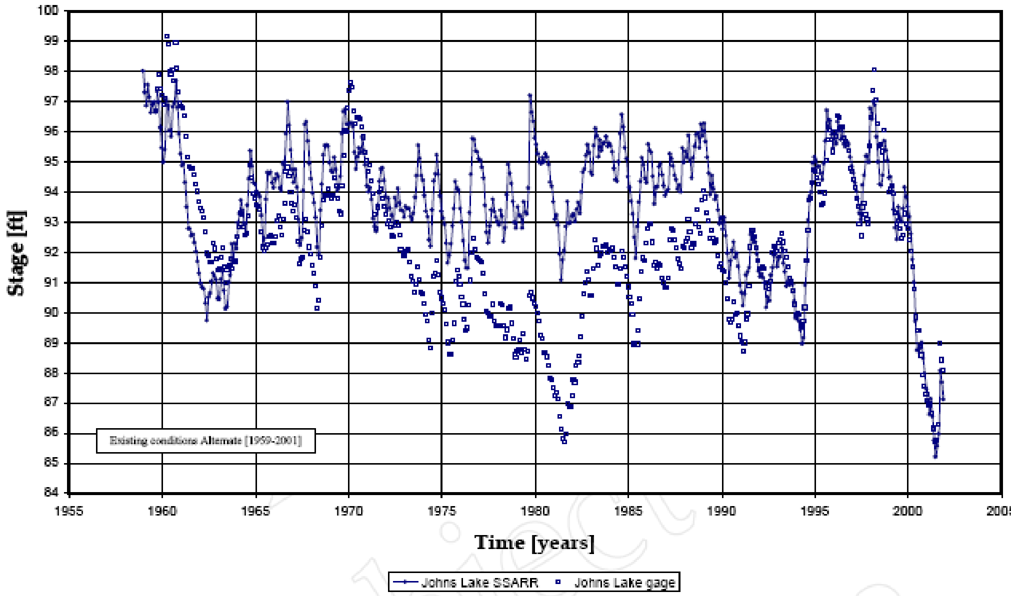


Figure 6. Observed and Simulated Hydrographs (Calibration Period). Source: (Robisoon, 2008)

The report documentation discusses two long term simulations, as shown in Table 5. These two long term simulations utilize identical input data with the exception of the input rainfall time series, as shown in the table. In the model documentation, the output stage hydrograph is given for the 'Existing Conditions' simulation (shown above in Figure 5). As shown in the figure, there is limited agreement between the SSARR model and the recorded stage data from 1974 through 1990. This represents a large portion of the long term simulation (1959 through 2000). The output stage hydrograph for the 'Existing Conditions- Alternate' simulation should also be added to this graphic in order to determine the impact of the rainfall timeseries on the output hydrographs. The report documentation also shows the 'Existing Conditions- Alternate' simulation plotted with the observed Johns Lake stage data, as shown in Figure 7. There is a significant amount of observed data during this time period. In order to determine the magnitude of the differences between the observed and simulated data, scatter plots of the calibration period and the long term simulations were plotted, as shown in Figures 8 and 9.

Table 5. Long-Term Simulation Descriptions. Source: (Robison, 2008)

Simulation	Rainfall Station	Floridan Aquifer Well)	Pan Evaporation Station
Calibration	Turnpike	L-052	Lisbon
Existing Conditions [1959–2001]	Turnpike [1989–2001] Winter Garden [1983–88] Isleworth [1959–1982]	L-052 [1984–2001] Clermont [1978–83] Mascotte [1959–77]	Lisbon
Existing Conditions- Alternate [1959–2001]	Turnpike [1989–2001] Clermont 7S [1959–88]	L-052 [1984–2001] Clermont [1978–83] Mascotte [1959–77]	Lisbon

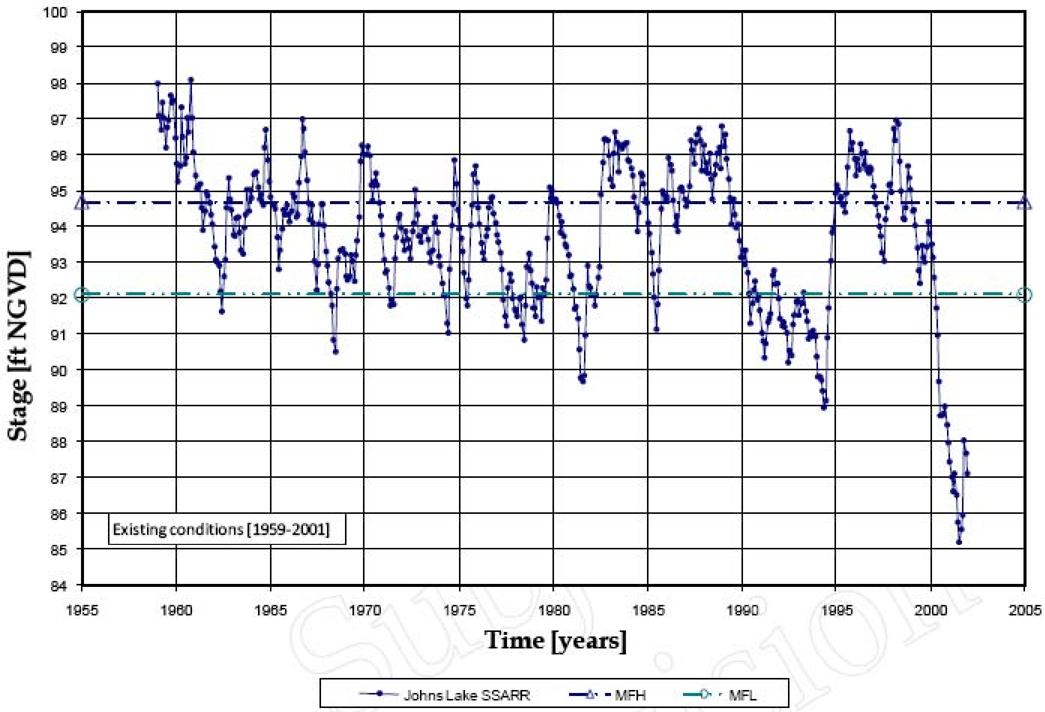


Figure 7. Existing Conditions SSARR Simulation Hydrograph. Source: (Robison, 2008)

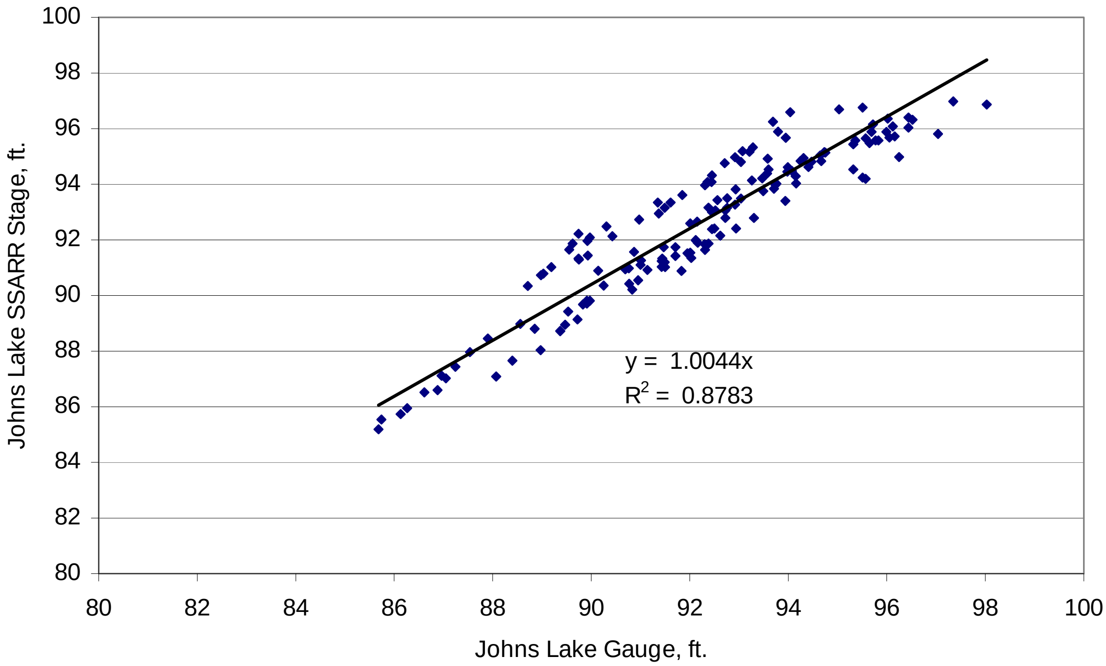


Figure 8. Observed versus Predicted Stage, Calibration Period (1989-2001)

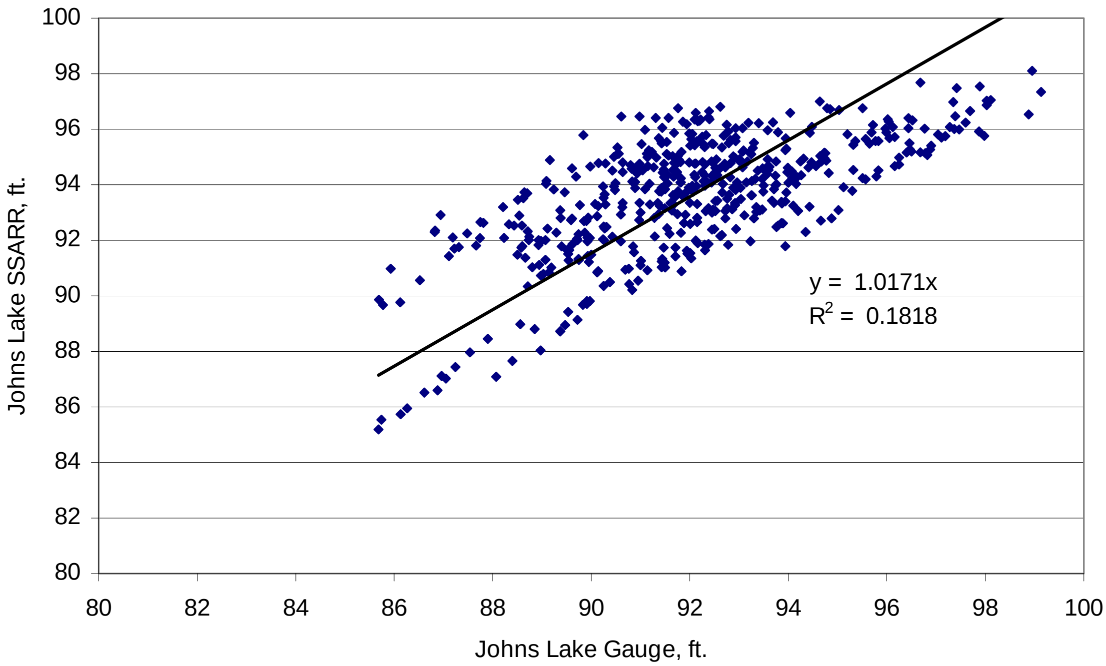


Figure 9. Observed versus Predicted Stage, Long Term Simulation (1959-2001)

As shown in Figure 8, the calibration of the model resulted in a regression coefficient of 0.8783, and the model was unbiased. When the model is used for predictive purposes, the regression coefficient decreases to 0.1818. This sharp decline in the regression coefficient when the model is used for predictive purposes indicates that there are factors which are not being accurately represented in the model that are affecting predictive model results. It could be any number of factors which were estimated for the model development, including the land use distribution, rainfall time series, the well data, the rating curve between Johns Lake and Black Lake, the Johns Lake discharge rating curve, or the lake seepage. Unlike some of the other lakes where SSARR was used for MFL modeling (i.e. Lake Avalon and Lake Hiawassee), Johns Lake is a more hydraulically complicated system due to the outlet structure, the inflow from Black Lake, and the separation of the lake into lobes. Although some of the other local lakes possess some of these hydraulic features, Johns Lake possesses all of these complexities. The lack of observed hydraulic data for any of these features makes it particularly difficult to use a hydrologic model without making many assumptions. A statistical model may be better suited for Johns Lake. With a statistical model, all observed data can be examined, and a model can be developed based only on the available data. This would alleviate the need to make many assumptions that hydrologic models require.

Development of a Statistical Model. A statistical model was developed to better understand the processes occurring within the John's Lake watershed. The available L-052 well data and the observed Johns Lake stage were plotted as shown in Figure 10. The regression equation shown in Figure 10 was applied to all data from L-052 and Clermont (spliced together as was done for the SSARR model). The resulting predicted Johns Lake stages are shown with the observed data and the SSARR results in Figure 11. Much can be learned from statistical models such as the relative impact each process or boundary condition has on the resulting simulated lake stages. In this example a strong correlation between the lake stages and the Floridan heads is found. This information can help in the SSARR model calibration.

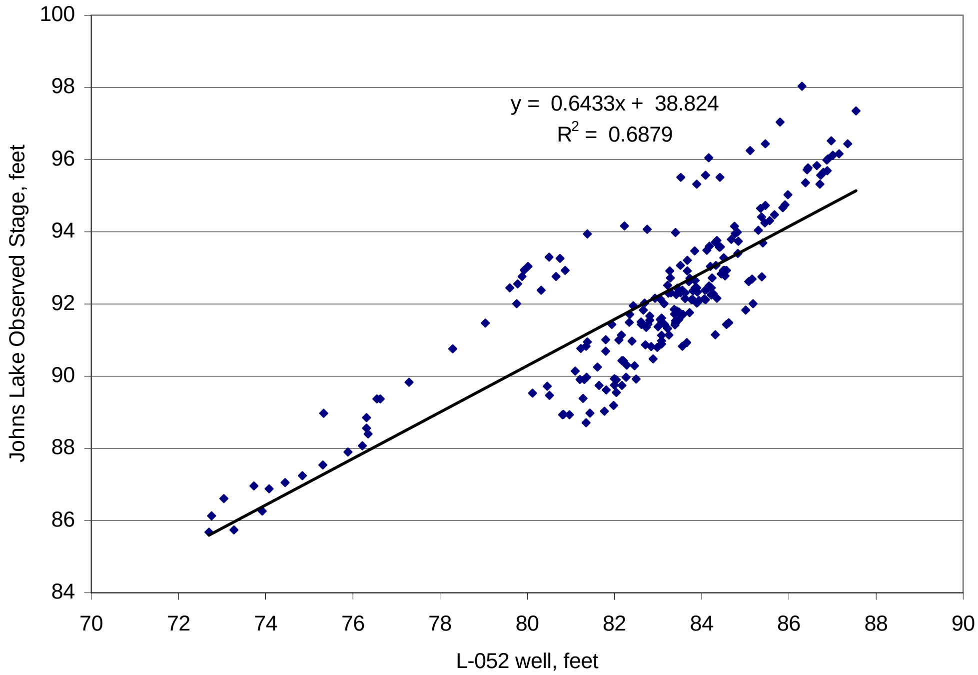


Figure 10. Linear Regression, L-052 Well and Johns Lake Stage, 1989-2001

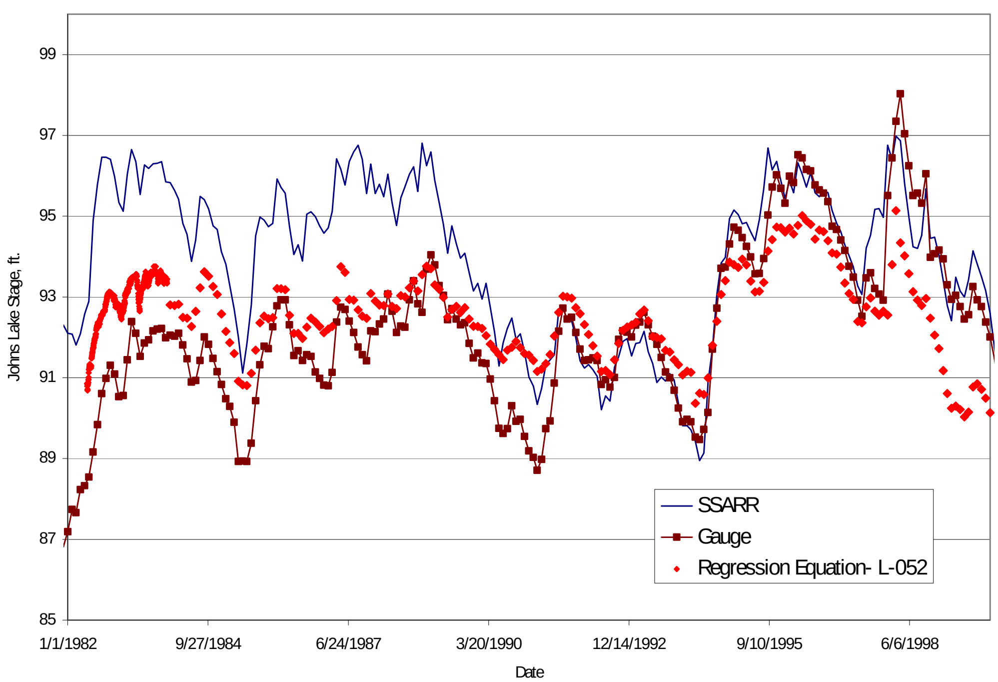
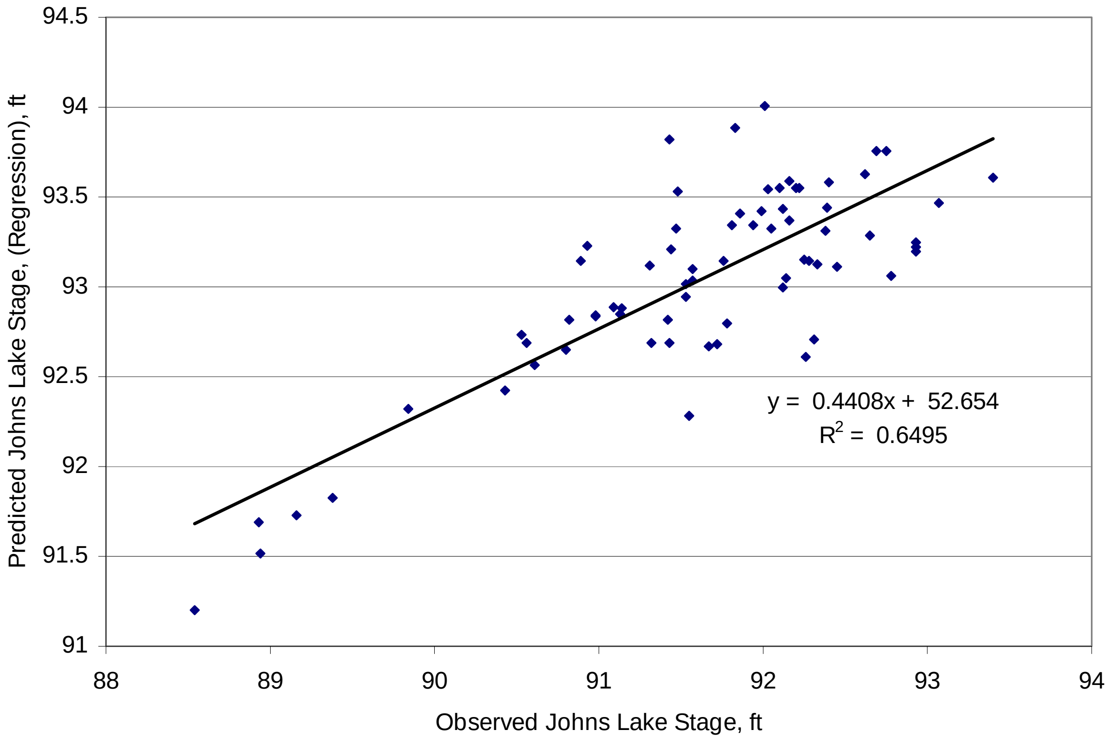


Figure 11. Statistical Model Results Using Clermont Well as Input



Implications of Input Data to MFLs. The MFL curves were developed using both long term simulations. It is important to note that the only difference between these simulations is the rainfall input time series. Despite this slight difference between the models, there are visible differences in the probability plots resulting from these simulations (and used to evaluate the MFH and MFL). The rainfall time series for each of these models should be detailed further (annual totals, event totals, etc.) in order to further investigate the differences in the simulations.

It is important to emphasize that the only difference between the two models was the rainfall input time series. Based on this difference alone, different MFL evaluations were made by the two models. For each model, the amount of potentiometric surface decline was increased until one of the MFLs was no longer being met. For the 'Existing Conditions' scenario, the MFH would no longer be met under a 0.2-feet Floridan Aquifer potentiometric surface decline (but the MFL would still be met). For the 'Existing Conditions – Alternate' simulation, the MFH would no longer be met with a decline of greater than 0.5-feet (but the MFL would still be met). This is a significantly different result considering that the only difference between the models is the rainfall input time series. That being said, great care should be taken when determining which model to utilize for MFL evaluation. The degree of confidence in the model will depend on the amount of confidence in the input data used. It is therefore very important to further examine the statistical differences between the rainfall input data sets.

Inclusion of Additional Source Flows. There has been discussion regarding the lack of inclusion of additional sources in the model, specifically flows due to septic tank seepage and the rapid infiltration basins (RIBS) at the Water Conserv Project. The septic discharges are small and unregulated, making it difficult to accurately estimate actual flow rates. Second, flows due to septic tank seepage would have very little effect on the overall lake water budget because the majority of septic tank discharge is lost to root uptake and evapotranspiration. Moreover, any additional inflows would be offset with increased losses to the aquifer due to the potable supply pumping. With regards to the Water Conserv Project, this review agrees with the Johns Lake report that any impacts of the Water Conserv Project may have on the lake should be represented by the local Floridan well, provided that the well is close to the project. Since the primary source of Floridan Aquifer data (the L-052 well) is located much closer to Johns Lake than to the RIBs, the impact of the RIBs on the L-052 well would be essentially the same as the impact of the RIBs on Johns Lake.

Figure 12. Water Conserv II Project

Basin Water Balance. The documentation for Johns Lake briefly discussed the water balance for the 'Existing Conditions- Alternate' simulation. The most significant water budget term for Johns Lake is input from Black Lake. Additionally, the basins provide a significant source of water to the lakes. The runoff for the pervious and impervious basin is shown in Table 6. These values represent the average annual runoff magnitudes for the long term simulation, and are reasonable values for runoff. It would be expected that, for an impervious basin, the basin runoff would be slightly less than the annual rainfall (minus initial abstractions for each event, which are eventually lost to ET) or approximately 20-40 inches per year. With impervious basin runoff averaging 24 inches per year, these results are reasonable and expected. The pervious basin area should fluctuate as the lake area is fluctuating. As previously shown, the amount of fluctuation is on the order of 1000 acres (or 20% of the pervious basin area). As per the water balance shown below, the lost area is a significant inflow to the lake especially given the fact that rainfall and ET (which typically are balanced on an annual time scale) are at different time scales seasonally.

Table 6. Basin Water Budget, 'Existing Conditions-Alternate' Simulation

Pervious Basin Runoff, ac-ft/year	Impervious Basin, ac-ft/year	Pervious Basin Runoff, ft/year (Pervious basin area = 4032 acres)	Impervious Basin Runoff, ft/year (Impervious basin area = 179.2 acres)
5090 ac-ft/year	360 ac-ft/year	1.26 ft/year	2.00 ft/year

Sources of Model Uncertainty. There are several sources of uncertainty in the model, including, but not limited to:

1. Impacts in lake leakage or potentiometric surface estimation,
2. The estimation of the rating curve between Johns Lake and Black Lake,
3. The estimation of the outlet rating curve for Johns Lake,
4. The placement of the temporary sink in the lake,
5. Errors in the assumed soil moisture relationship, and
6. Selection of rainfall time series.

A sensitivity analysis was conducted by the model developer with regard to the rainfall time series by using 2 different rainfall time series for the long term simulations. Nevertheless, the output stage hydrographs for these two simulations need to be compared, which was not done in the original documentation. In order to address some of the additional sources of uncertainty in the model, additional sensitivity analyses can be conducted by creating additional input time series for additional model runs. The impact of potentiometric surface, for example, can be evaluated by using input time series from other wells instead of the L-052 well.

Conclusions and Recommendations

SSARR is a continuous simulation lumped parameter rainfall runoff model. The selection and utilization of this model to support Johns Lake MFL protection was an appropriate use of the model and followed sound engineering principles. The development of the model included the utilization of best available data. The SSARR model developed for Johns Lake is well documented (Robison 2008) and contains detailed descriptions of all input data sets and model assumptions. The model performs very well during the calibration period. A comparison of the observed data with the simulated data reveals that the model overestimates lake stage for a portion of the long term simulation period. This is most likely due to the fact that many assumptions were made model due to the lack of available data. A simple statistical model developed for the lake demonstrates that a statistical model may be a good supplement to the current SSARR model for Johns Lake.

The performance of the two SSARR models must be considered within the context for which their use was intended: the evaluation of MFLs. Two SSARR models were developed using different rainfall input time series. These models each resulted in a different conclusion regarding MFL impacts. The MFH was no longer met with a 0.2-feet potentiometric surface decline using the 'Existing Conditions' simulation, while the MFH was no longer met with a 0.5-feet potentiometric surface decline using the 'Existing Conditions-Alternate' simulation. This discrepancy should be further investigated in order to determine which model has a more appropriate rainfall input time series for Johns Lake. Additionally, the development of a simple statistical model could enhance the District's ability to evaluate Johns Lake MFLs.

Due to the lack of field data, it is recommended that additional field data be collected and/or a statistical model be developed in order to verify the assumptions and performance of the SSARR model. The collection of additional field data could serve to greatly enhance the model. Given the fact that MFLs are to be defined using best available data, the following recommendations are suggestions for future MFL revisions. The recommendations include:

- Collecting additional field data for Johns Lake including flow data from Black Lake to Johns Lake and at the Johns Lake outlet,
- Collecting bathymetry data for the lake storage capacity,
- Examining additional potentiometric surface maps for Johns Lake in order to verify the assumption of the September 1990 potentiometric surface being representative of the entire simulation period. If it is not, a seasonally corrected potentiometric surface time series for Johns Lake based on published potentiometric surfaces should be developed,
- Supplementing the current documentation by adding additional graphics for the long term simulation as recommended in this report,
- Analyzing the rainfall time series used for the long term simulations in order to quantify the differences between the input data sets,
- Providing justification as to why the L-052 monthly well data was used, as opposed to a nearby daily well,
- Developing an L-052 time series for the extended simulation that preserves the range of the well levels in the original observed record,
- Utilizing statistical regressions to aide in the development of a continuous well time series,
- Conducting additional sensitivity analysis for model parameters, and
- Developing a statistical model to model Johns Lake stage.

It should be noted that while all of these recommendations may improve the performance of the model, the implementation of these recommendations must be considered within the context of available data and the District's MFL program. The final goal of the model is to determine stages that can be used to develop MFL curves and evaluate impacts of consumptive use withdrawals on the MFL. Ultimately, the determination of whether or not an MFL is being met is made through frequency analysis. This frequency analysis relies heavily on the selection and definition of key ecological signatures. These ecological features define the stages in the lake that will be considered as "significant harm". It is the selection of these features which the defined MFL will heavily rely upon. The frequency analysis, which is a component of the hydrologic modeling, is the optimal method for assessing environmental impacts. Harm in any system can be defined in terms of exposure to events. It is the frequency, duration, and intensity of the events that allow accurate assessment of "significant harm" in numerical terms. That being said, given the available data, the overall modeling methodology in defining the MFLs for Johns Lake follows sound engineering practices.

It is highly recommended that the District adopt a standard report format for all lake MFL studies, which must include both a lake water budget and a basin water budget. It is critical to include a water balance report of all basins and basin budget terms. Careful examination of both of these water budgets will give confidence in the reliability of the model for predictive purposes, and hence, in the ability of the model to evaluate the MFL and potential future MFL impacts.

References

Robison, C.P. (2008). *Johns Lake Minimum Flows and Levels Hydrologic Methods Report.* Report for the St. Johns River Water Management District, Draft 12/19/2008.