Final Report Final Report Final Report

Peer Review of the Lake Hiawassee SSARR Model

Prepared for:

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Lake Hiawassee SSARR Model

Lake Hiawassee is located in Orange County, Florida, and is currently 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 Lake Hiawassee 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 Lake Hiawassee are shown in Table 1. In order to evaluate proposed aquifer withdrawals and their impacts on Lake Hiawassee, 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 be utilized for the development of a model of Lake Hiawassee. SSARR is a continuous simulation model that 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. Interaction between the Floridan Aquifer and Lake Hiawassee is a significant portion of the water budget for the lake. Due to this fact, a seepage routine was developed in SSARR for the Lake Hiawassee model.

Table 1. Lake Hiawassee MFLs

Minimum Level	Level (ft NGVD)	Duration (days)	Return Interval (years)
Frequent High	76.4	30	3
Frequent Low	72.9	120	3

This technical memorandum evaluates the current SSARR model for Lake Hiawassee 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 Lake Hiawassee and West Lake Hiawassee. That being said, the best information available was utilized to develop the model. For the calibration of the model, the following data was utilized:

2000 Land Use. Land use from 1995 and 2004 was also examined. The changes in land use between the 3 data sets were very minimal. For the long term model simulation, 2004 land use was utilized. This resulted in a slight increase in impervious area for Lake Hiawassee, and no change for West Lake Hiawassee. This data represents the best available land use data.

Best Available Bathymetry. Bathymetry does not exist for Lake Hiawassee, but 1-foot contours exist for a large portion of the basin. For Lake Hiawassee, contours extended to 71-feet NGVD, while for West Lake Hiawassee, contours extended down to 64-feet NGVD. Contours below these elevations were estimated to complete the stage area curves for lakes. For the southern portion of the lake, 1-foot contours were compared to areas from USGS quadrangle maps in order to estimate bathymetry for stage area curves. The bathymetry data was developed using common engineering practices and represents the best available data.

Observed Stages at Lake Hiawassee. Observed stages were available for Lake Hiawassee from the Orange County Water Atlas from May 1960 to February 2001 on a monthly basis. Stage information was available District from March 2001 to December 2004 on an approximately weekly basis. Since the model calibration period is from 1996 to 2004, a combination of the two records was utilized. This represents the best available data for Lake Hiawassee.

Observed Stage at West Lake Hiawassee. A single stage data point for stage at West Lake Hiawassee was recorded on May 14, 2008. Since there is only one observed stage measurement for West Lake Hiawassee, the quality of this data is relatively poor, yet it represents the best available stage data for West Lake Hiawassee.

Daily Rainfall. Daily rainfall totals were utilized for the model calibration and long term simulation. The calibration of the model utilized a daily rainfall amount derived from OneRain radar. The long term simulation utilized the Isleworth NOAA daily rainfall record and the Winter Garden daily record available from the District. The data processing of the rainfall was produced with common engineering practices. However, it should be verified that the calibration rainfall is similar to the predictive rainfall. It would be incorrect to calibrate a model to a rainfall boundary condition that is consistently different than the rainfall used in the predictive simulation.

Potentiometric Surface. The potentiometric surface beneath Lake Hiawassee was estimated using the nearest available well (O-047) from the USGS. Using the May 1999 published potentiometric surface map, it was estimated that the potentiometric surface of the well was approximately 3 feet lower than the potentiometric surface beneath the lake. Thus, the observed well record was shifted up by 3 feet and utilized as input to the model. Although the methodology used here follows common engineering practices, it would be desirable to look at additional potentiometric surfaces (different years, as well as wet and dry conditions) to see if the 3 feet offset was consistently present.

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. The Pan data was organized into two separate time series, one for the basins and one for the lake. The lake ET data was aggregated into a weekly time series. 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 Lake Hiawassee and the surrounding basin. All available observed stage, bathymetry, rainfall, land use and potentiometric surface data was utilized. The primary data deficiency is the lack of stage data available for West Lake Hiawassee. Nevertheless, the best available data was utilized to develop the model. Based on review of "Lake Hiawassee 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?

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.

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. Elevations for the divides between West Lake Hiawassee and Lake Hiawassee and the northwest sinkhole and Lake Hiawassee were estimated from 1-foot contours.
- The estimation of a rating curve for flow between Lake Hiawassee and West Lake Hiawassee. It was assumed water can flow in either direction between the two lakes and flow rate was a function of the difference in stage between the two lakes. Based on the experience of the model developer, a rating curve from a previous model was used in which flows at 0.2 feet, 0.5 feet, 1 foot, 3 feet and 5 feet were assumed to be 2 cfs, 6 cfs, 18 cfs, 60 cfs, and 200 cfs, respectively.
- The difference in the potentiometric surface between well O-047 and Lake Hiawassee observed in May 1999 (3 feet) is representative of the difference in potentiometric surface between these two locations over the entire calibration and long-term simulation period.

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.

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

   II. 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?

   III. Are the assumptions stated clearly?

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

   V. 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.

The model is appropriately conceptualized with 2 lakes (Lake Hiawassee and West Lake Hiawassee), each having an impervious basin and a pervious basin which contribute run-off. Outflow from Lake Hiawassee flows to two sinks: one permanent sink (the Floridan aquifer), and one temporary sink, a sinkhole, which is active below 72 feet NGVD. Outflow from West Lake

Hiawassee was to 1 permanent sink (the Floridan aquifer) and to the current active drainage well. 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. Based on the available data however, a daily time step is appropriate.

Model Adequacy and Assumptions. There was adequate data to develop, calibrate and apply the model. It would be desired to have more calibration data, but 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 potentiometric surface, the West Lake Hiawassee stages, and the interaction between the two lakes. These assumptions could potentially have implications to the performance of the model for the historical simulation period.

Correction of O-047 Well Data based on May 1999 Potentiometric Surface. Potentiometric surface maps are available in May and September of each year and reflect the dry and wet seasons, respectively. Since the calibration period encompassed 9 years (1996 to 2004), approximately eighteen potentiometric surface maps are available for the calibration period. These potentiometric surface maps should be analyzed in conjunction with the O-047 well data in order to determine if there is a seasonal correlation between the difference in the potentiometric surface between the lake and the well. If there is a seasonal fluctuation in the head differential between these two locations, it will be necessary to develop a time series that is shifted based on season. This time series can be used as a new input time series into the model. An accurate potentiometric surface is critical to the performance of the model because the model is heavily driven by the seepage routine, which causes flow from Lake Hiawassee and West Lake Hiawassee into the Floridan Aquifer based on the head differences between the lakes and the aquifer. If the potentiometric surface is estimated too high, there will be a smaller head gradient from the lake to the aquifer, resulting in less flow into the aquifer (and higher lake stages). If the potentiometric surface is estimated too low, there will be a higher head gradient, resulting in an overestimation in the head gradient and more flow in the aquifer (and lower lake stages).

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. It is this reviewer's opinion that these flows need not be included in the model for two reasons. First, they 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.

Lack of Calibration Data for West Lake Hiawassee. The lack of calibration data for West Lake Hiawassee is an issue that should be addressed in order to gain confidence in the model's predictive capabilities. Since there is no gauge on West Lake Hiawassee, SJRMWD surveyors surveyed the stages of Lake Hiawassee and West Lake Hiawassee on May 14, 2008 as 69.2 feet NGVD and 63.4 feet NGVD, respectively. (Robison, 2008). A date in 2002 was found in the Lake Hiawassee when the stage of the lake was 69.2 feet NGVD. The West Lake Hiawassee portion of the model was then calibrated to the observed difference in stage from May 14, 2008. This is the single calibration point for West Lake Hiawassee, as shown in Figure 1. More stage data for West Lake Hiawassee is needed in order to determine if the stage difference between the 2 lakes is representative of typical conditions, or it there is fluctuation in the stage differential of the lakes depending on hydrologic conditions. Additionally, the applicability of the stage difference observed on May 2008 between the two lakes to a day in 2002 is questionable without further understanding of the hydrodynamics of the lakes as a system; further data regarding the flow between the lakes and the amount of hysteresis observed when the lakes are staging up versus down is vital to increasing confidence in the current model. Given the single calibration point for West Lake Hiawassee, it is not possible to have a great deal of confidence in the model's prediction for West Lake Hiawassee stage at this time.

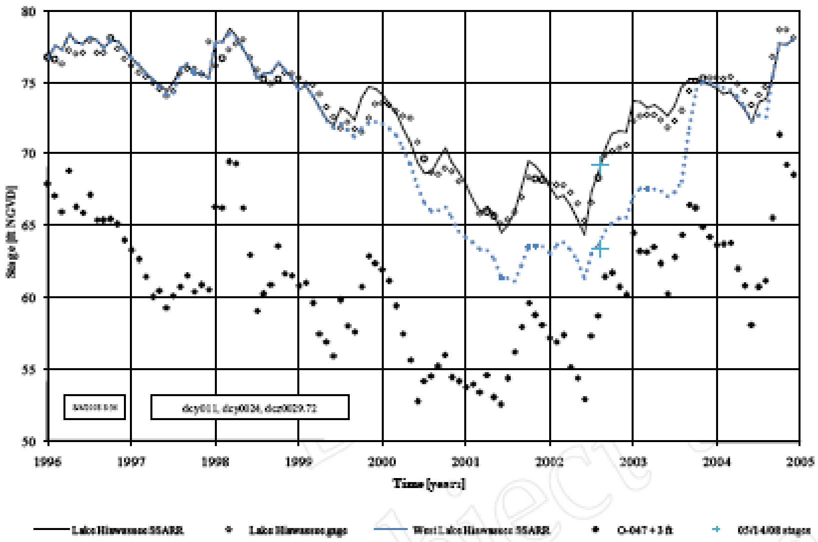

Figure 1. Lake Hiawassee SSARR Calibration Results. *Source: (Robison, 2008)*

This issue can be remedied by the collection of additional field data for West Lake Hiawassee. This can be done through the installation of a gauge at West Lake Hiawassee or through frequent surveying of the lake stage. With additional data points containing stage data for both Lake Hiawassee and West Lake Hiawassee encompassing a wide range of stages, a simple correlation can be developed between the stages of the two lakes. Once this correlation is developed, it can be applied to the Lake Hiawassee stage time series for the calibration period in order to develop a synthetic stage time series for West Lake Hiawassee. Comparison of the synthetic time series for West Lake Hiawassee to the SSARR output will determine the adequacy of the current model for the estimation of West Hiawassee Lake stages. The time and effort required to complete this task will depend on the amount of additional data points that are collected. It is desirable to collect as much additional field data as possible in order to develop the statistical model.

Representation of the Historical Observed Data. After the calibration was complete, a historical simulation was conducted using a 57-year period of record (1948 to 2004). The results of this simulation are shown in Figure 2. As shown in the Figure, the model performs very well during the calibration period (1996 to 2004), while there is less agreement between observed data and SSARR output data for data between 1960 and 1983. Documentation of the model speculates that these deviations could be from over-simplification of the lake system or day to day fluctuations of the true amount of rainfall over the system. There have also been land use changes within the basin which would account for the changes in the model performance. The deviations from observed data take two forms: underestimation of Lake Hiawassee stage, and overestimation of Lake Hiawassee stage.

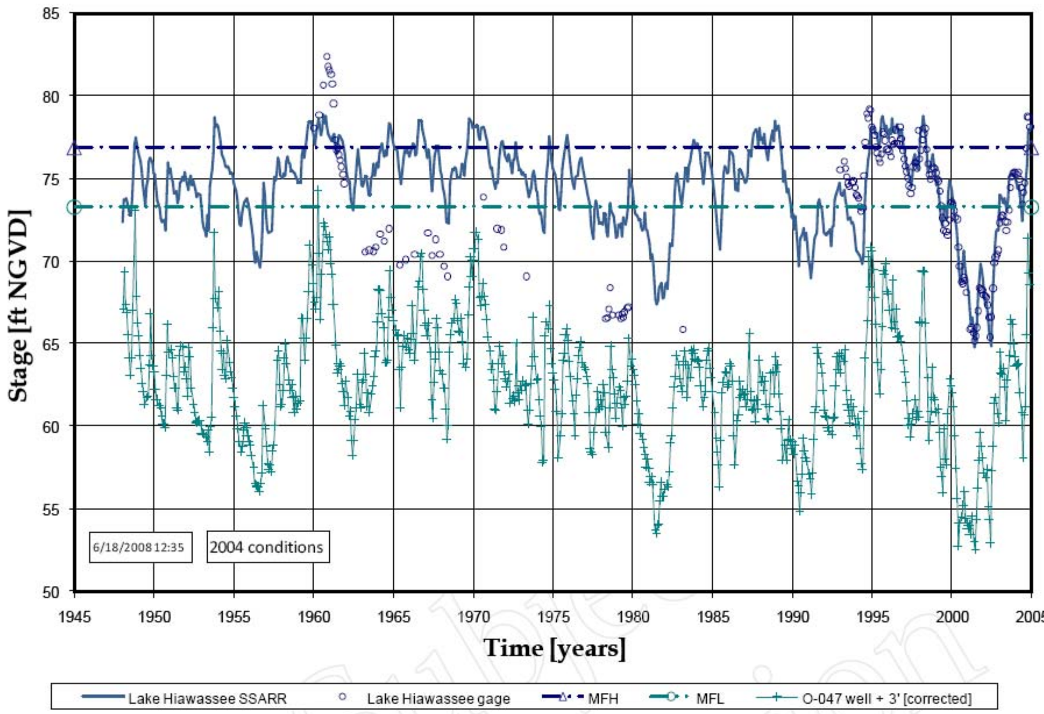

Figure 2. Results of SSARR Simulation for Lake Hiawassee. *Source: (Robison, 2008)*

Overestimation of Lake Hiawassee Stage. With the exception of simulation results in the early 1960s, all historical data simulated resulted in overestimation of Lake Hiawassee stage. It is speculated that the overestimated lake stages are due to the land use changes that have occurred within the basin within the past 50 years. Examination of old aerial photographs shows that, until recent years, the contributing basins to Lake Hiawassee and West Lake Hiawassee were rural areas, primarily composed of pervious lands with much higher losses than currently exist. The development of the basin in recent years has increased the impervious areas of the basin, resulting in more runoff and therefore higher lake stages. Because the model was calibrated with 2004 land use, it would be expected that the model would overestimate lake stage for periods where there was less impervious area compared to 2004 land use. This is indeed the case for many of the observed stages in the 1960s through the 1980s.

Underestimation of Lake Hiawassee Stage. In the early 1960s, Lake Hiawassee observed stages peak to stages above 80-feet NGVD, a level not seen again in the observed stage hydrograph. The SSARR simulation is unable to capture this peak. Due to the limited amount of observed historical data, the frequency of historical high stages such as those seen in the early 1960s is not known. The underestimation of stage is peculiar because with the utilization of 2004 land use, it would be expected that the model would overestimate lake stage due to larger impervious areas. There could be several explanations for this deviation which were not addressed in the original model documentation.

Error in the prediction of lake stage may be due to the correction of the O-047 well data utilized as the potentiometric surface beneath the lake. The O-047 (+ 3-feet) well data was corrected using a double mass analysis in order to correct for the effect of regional groundwater withdrawals on the potentiometric surface. As indicated in Figure 3, the cumulative sum of the Clermont rainfall was plotted against the cumulative sum of the potentiometric surface at O-047. As shown in the Figure, in 1961, 1962, and 1963, the observed data was corrected by adding -8 feet, -6 feet, and -2 feet to the record. The process of correcting the potentiometric surface in order to balance the double mass curve results in lowering the potentiometric surface for the early 1960s, which is precisely the period that the model in unable to predict peak stages. The effect of utilizing this time series should be examined by running the model with the original uncorrected time series (O-047 + 3 feet). The double mass analysis could also be conducted with a different rainfall station, or a combination of stations. For the historical SSARR simulation, Isleworth and Winter Garden rain gauge data were utilized. For the sake of consistency, it would be beneficial to conduct a double-mass analysis with this data, if possible, in order to verify the correction obtained with the Clermont rainfall data.

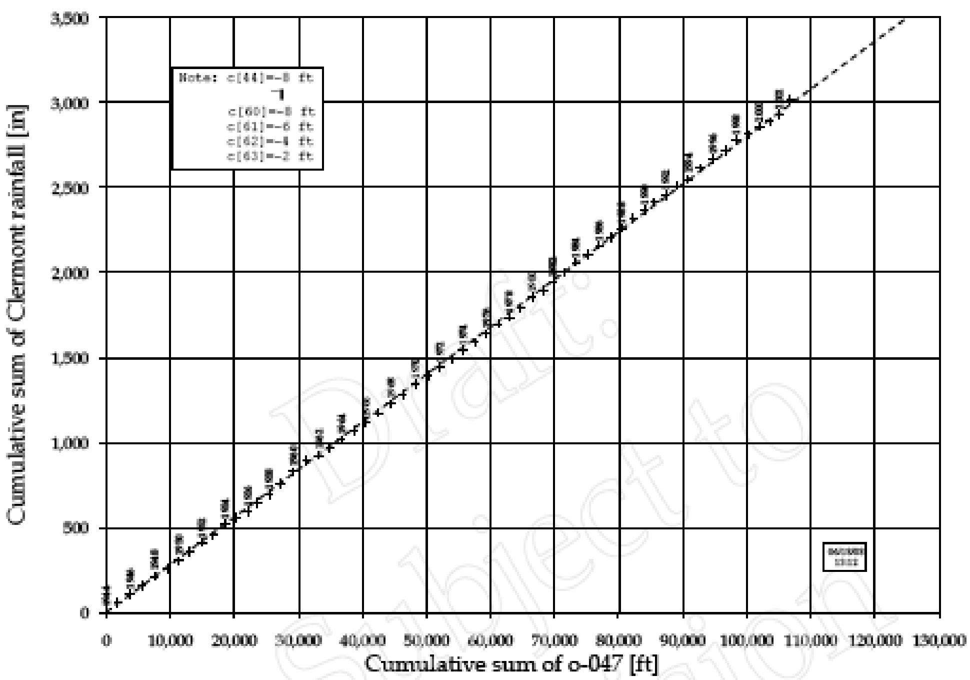

Figure 3. Double Mass Curve Analysis. *Source: (Robison, 2008)*

Long-Term Well Correction. In addition to running the model with the uncorrected O-047 time series (I.e.., O-047 + 3 feet), historical potentiometric surface maps should be examined in order to verify the accuracy of the assumption that a 3-foot shift is representative for the entire historical simulation period. As was previously mentioned for the calibration period, there may be a seasonal fluctuation in the potentiometric surface which the 3-foot shift is not currently accounting for. Additionally, there may be a decadal shift in the potentiometric surface based on development of the basin and pumping associated with development over the 57 years of historical simulation. The examination of this data would not be time intensive and would be highly beneficial in order to help explain some of the deviations in the model performance during the historical simulation.

Directly Connected Impervious Area. Directly Connected Impervious Area or DCIA is an important factor to hydrologic models. The DCIA produces most of the basin contribution to the lake. The factor describes the area of developed or impervious surfaces that is directly connected (via stormwater drainage) to the simulated receiving water body. The DCIA is a very difficult number to estimate (some studies have gone to extreme measures and digitized the DCIA on small scales) and is usually a calibration parameter. However, the Lake Hiawassee model has no data to calibrate the basin inflows. The DCIA factors used in the Lake Hiawassee model may be on the high range as compared to other literature values for DCIA. Without observed data, however, comparison of the model response to actual hydrologic response is impossible. The Lake Hiawassee Model followed typical engineering practices as far as the treatment of pervious and impervious conceptualization.

Table 2. DCIA Values Used in Lake Hiawassee SSARR Model. *Source: (Robison, 2008)*

FLUCCS	Description	DCIA %
1100	Residential, low density - less than 2 dwelling units/acre	0.10
1200	Residential, medium density - 2-5 dwelling units/acre	0.23
1300	Residential, high density - 6 or more dwelling units/acre	0.65
1400	Commercial and services	0.81
1460	Oil & gas storage (except areas assoc. with industrial)	0.23
1490	Commercial & services under construction	0.81
1700	Institutional	0.65

Overall Water Balance. The water balance for the Lakes was documented and appears reasonable. However, the report poorly documented the basin or contributing watershed water balance. The basins provide a significant source of water to the lakes. Additionally, the impervious runoff is an order of magnitude more compared to the pervious basin. Due to the importance of the basin inflows to the lake, the report should document the basin water budget in more detail in order to defend the validity of these flows. The most significant term in the basin water budget is ET (second to precipitation). A time series of simulated ET rates was transmitted via personal communication (Robison 2009). The ET time series in SSARR actually simulates the combined loss of soil moisture to both the atmosphere and leakage to the groundwater system. The rates reported averaged 43 inches per year. This rate seems reasonable especially given all the uncertainty in the model conceptualization and calibration.

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. Lack of calibration data for West Lake Hiawassee,
3. Errors in basin evaporation data,
4. Assumed invert elevation of the sinkhole (sink 2),
5. Errors in the assumed soil moisture relationship,
6. Accuracy of the rating curve between Lake Hiawassee and West Lake Hiawassee, and
7. The amount of DCIA within the contributing basin.

In order to determine the effect of the uncertain parameters on the performance of the model, a sensitivity analysis was conducted by the model developer. When the sensitivity analysis was conducted, the parameter in question was slightly modified, the model was re-calibrated, and a long term simulation was performed with the newly calibrated model. The MFL analysis was performed in order to determine the effect of the parameter on the MFL events. Ultimately, new MFL curves were generated based on the newly calibrated models. Generally, these curves showed slight shifts from the original curves (in the range of tenths of feet). It would be helpful to conduct the sensitivity analysis by slightly perturbing a given parameter and not re-calibrating the model. This would reveal the effect that errors in each parameter have on the model results (i.e. lake stage) and potentially allow for better understanding of the calibrated parameter set as well as the performance of the model during the historical simulation.

Conclusions and Recommendations

SSARR is a continuous simulation lumped parameter rainfall runoff model. The selection and utilization of this model to support Lake Hiawassee 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 Lake Hiawassee and West Lake Hiawassee is very well documented (Robison 2008) and contains detailed descriptions of all input data sets and model assumptions. The model performs well during the calibration period. For the long term simulation, there are deviations in the model estimation of both high and low lake stages. Some possible reasons for this include changes in land use, the utilization of different rainfall timeseries for the calibration and long term simulation periods (radar versus gauge), the use of a standard 3-foot correction to estimate the potentiometric surface beneath the lake, and correction effects from the double mass analysis. An additional assumption of the model is that the rainfall that occurred over the past 50 years will again be repeated in the future.

There are some additional items that could be investigated in order to attempt to further explain the deviations between the modeled results and the historical data for the long term simulation. These recommendations, in some cases, do rely on collecting additional data. Given the fact that MFLs are to be defined using best available data, these recommendations are merely suggestions for future MFL revisions. The recommendations include:

- Developing a seasonally corrected potentiometric surface time series for Lake Hiawassee based on published potentiometric surfaces,
- Collecting additional stage data for West Lake Hiawassee,
- Utilizing a potentiometric surface time series that is not corrected based on the double mass analysis in order to attempt to better simulate higher lake stages in the early 1960s,
- Running the model with historical land use in order to attempt to replicate observed historical stages. This will reveal whether or not the overprediction of simulated historical stages is due to land use changes, and
- Conducting additional sensitivity analysis for model parameters.

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 Lake Hiawassee follows sound engineering practices.

References

Robison, C.P. (2008). *Lake Hiawassee Minimum Flows and Levels Hydrologic Methods Report.* Report for the St. Johns River Water Management District, Draft 1/22/2009.