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# MEMORANDUM

**TO:** Sonny Hall, Andrew Sutherland

**FROM:** INTERA

**DATE:** January 5, 2016

**RE: REVIEW OF LAKE APOPKA AND THE UPPER OCKLAWAHA RIVER MINIMUM FLOWS AND LEVELS HYDROLOGIC ASSESSMENT REPORT**

## Introduction

The Upper Ocklawaha River and Lake Apopka are located in central Florida in portions of Lake, Orange, Marion, and Polk counties within the St. Johns River Water Management District (the District). Together, these waterbodies form the Lake Apopka and Upper Ocklawaha River Basin (LAUORB). This report documents a comprehensive review of the hydrologic models and their associated documentation developed for use in Minimum Flows and Levels (MFL) development, including model boundary conditions, calibration, and application to the LAUORB (Huang and Smith, 2015). The LAUORB model is a process model simulated with Hydrologic Simulation Program-Fortran (HSPF) (Bicknell, et al. 2001). The model calibration uses the District's 1995 land use, while the baseline simulation used for MFL development uses the 2009 land use and a 48-year simulation beginning in 2009. The sub-basins in the LAUORB are characterized by a chain of lakes, with a general flow direction from south to north. Water control structures, including the Apopka-Beauclair Lock and Dam, Burrell Lock and Dam, and Moss Bluff Lock and Dam regulate water levels and discharges throughout the basin. Moss Bluff Lock and Dam serves as the outlet of the basin and controls the stage and flow at Lake Griffin.

The HSPF model of the LAUORB was reviewed with an emphasis on available data, model conceptualization, model calibration, and model uncertainty. Overall, the HSPF model generally follows standard engineering practice and utilizes the best available data, however, several deficiencies were noted in the model documentation. Addressing the deficiencies in the documentation will greatly improve the defensibility of the model and therefore the MFL.

This technical memorandum INTERA's review of the Lake Apopka and Upper Ocklawaha River Minimum Flows and Levels (MFLs) Hydrologic Assessment Draft report (Huang and Smith, 2015) and the associated model files including the following:

- UORB_MFLs_HSPF_Assessment_Method_draft2015.pdf
- Baseline_Model.zip, which contains the baseline model *uci* and its associated files, and
- Calibration_Model.zip, which contains the calibration model *uci* and its associated files.

**Review Questions**

The review questions below were provided by the District. In order to assess each question, model input files and model documentation was reviewed by INTERA. INTERA responses to the review questions are provided below.

**(1) Assess adequacy of hydro-meteorological records in terms of quality, spatial coverage, and length of record.**

Hydro-meteorological records used for model development include rainfall, potential evapotranspiration (PET), land use, bathymetry, and potentiometric surface. The hydro-meteorological records were reviewed in order to determine if the best available data was utilized for the model, and ultimately, for MFL development.

**Rainfall.** The LAUORB models utilized daily rainfall from the Isleworth, Leesburg, and Lisbon NOAA stations. The NOAA gauges were the best available long-term records since the District's radar rainfall data did not meet the temporal requirements for long-term MFL modeling. Gaps in the record were filled when necessary. Additionally, rainfall was disaggregated from daily to hourly in WDMUtil (WSIS, 2012). The use of a single rainfall gauge per basin (as opposed to a weighted average of several Theissen polygons) represents the best modeling practice since the use of multiple gauges can result in decreasing peak rainfall intensities due to averaging. Thus, the methodology used by the District is sound. It would be helpful to document the disaggregation method used by WDMUtil to derive hourly rainfall estimates.

**Potential Evapotranspiration.** Potential evapotranspiration (PET) is a required input timeseries for HSPF. PET for the LAUORB is defined using the Hargreaves method scaled with a factor to a detailed Priestly-Taylor estimate. Like rainfall, hourly evaporation data were assigned to each sub-basin using Theissen polygons. The Clermont evaporation record was assigned to Lake Apopka basin. The Lisbon station record was assigned to all other basins. Data was converted into potential ET (PET) using coefficients of 0.8714 and 0.9114 for Clermont and Lisbon. Given that PET is merely a potential and is rarely satisfied on the basin water balance, exact estimation of PET is not extremely critical for basin water budgets. For the lake water balances, however, PET is generally satisfied and therefore the uncertainty in the data may be of concern.

**Land Use.** Huang and Smith (2015) provide ample data regarding 1995 and 2009 land use for each planning unit within the model domain. The tables presented for each planning unit clearly illustrate the prominent land uses in each sub-basin. Figures 5 and 7 in Huang and Smith (2015) illustrate the 14 land uses used in the models. These figures would best be presented together with some general discussion regarding the overall characterization of the LAUORB and changes from 1995 to 2009. In addition to land use, basin delineations should be discussed and field validation of delineations should be noted (if applicable). The division of wetlands into riparian and non-riparian areas is discussed in the model documentation, yet examination of the model files shows identical parametrization between riparian and non-riparian wetlands. Based on the documentation, these wetlands were divided based on whether or not they were directly connected to a reach. It is not clear whether this was done manually or programmatically within a GIS framework. These details should be discussed in the documentation.

**Bathymetry.** The LAUORB consists of a chain of interconnected lakes regulated by structures, including locks and dams. For the LAUORB HSPF models, bathymetric curves developed by ECT (1999) were used when possible. When elevations above normal lake levels were present, data from Van Sickle and Pachhai et al. (2013) were used in conjunction with ECT (1999) data. Van Sickle (2014) data was used for Lake Apopka and for Emeralda restoration cells connected with Lake Griffin. This information represents the best available data on LAUORB lake bathymetry. Bathymetry is utilized in the development of the HSPF F-Table, which relates stage to surface area, volume, and discharge of the reach or reservoir. This represents the best available bathymetry data.

**Potentiometric Surface.** Since there was no measured data to determine the discharge and recharge of water through lake bottoms, recharge and discharge quantities were estimated using the ECFT groundwater model. The ECFT transient simulation from 1995 through 2006 was used to simulate the average Upper Floridan Aquifer (UFA) level under each lake bottom. The MOVE-3 method was used to calculate regression equations between ECFT simulated UFA average level and observed UFA data at nearby wells. This allowed for the development of lake-bottom UFA head time series that extended through the long term simulation. The development of regressions to extend time series is a common engineering practice, and in this case, the best available tool for use was the ECFT model and the observed well data at the Blue House, Lake Yale Groves and Orlo Vista wells. Although Huang and Smith (2015) show the correlation coefficients for each lake and the best fit well (in Table 12), it may be helpful to see the scatter plots of the correlations and/or additional goodness-of-fit statistics. Additionally, the bias of the ECFT model in the vicinity of the LAUORB area should be documented in the draft report. The ECFT is a regional model. Regional models typically simulate heads well on average but can exhibit spatial biases based on geology, landforms, or other under-represented or unknown conditions. Does the ECFT exhibit a bias in head prediction for the UFA in the vicinity of the LAUORB? Calibration wells in the vicinity of the LAUORB should be shown and discussed in the draft documentation in order to quantify the error in the ECFT head estimates. If necessary, the ECFT predicted heads may need to be adjusted to account for this bias (if it is substantial) so that the bias does not propagate into the UFA head estimates. Based on the stage hydrographs presented in Figures 23 through 26, it appears that simulated lake stages replicate observed lake stages fairly well. The Lake Apopka model shows signification deviations from observed stages based on the stages presented in Figure 23. Is there an explanation for this deviation?

a. **Was "best information available" utilized to develop the hydrologic model?**
   As explained above, the best information available was utilized to develop the model.
b. **Are there any deficiencies regarding data availability?**
   There are no apparent deficiencies regarding data availability.
c. **Was relevant information available that was discarded without appropriate justification? Would use of discarded information significantly affect results?**
   Based on the data presented in the documentation and knowledge of additional data sources, relevant data was not discarded without appropriate justification.

**(2) Assess methods and procedures for data analysis.**

a. **Are the analytical methods and procedures appropriate?**

Analytical methods and procedures used in this analysis include methods for extending time series, Theissen polygons, and rainfall disaggregation. The results of these data analyses are used as direct input to HSPF as model boundary conditions, and making it imperative to utilize defensible, well-accepted techniques.

**Theissen polygons.** Theissen polygons were used to determine percent area of each sub-basin that lies within the Theissen polygon for a given rainfall or ET gauge. The Isleworth rainfall record was assigned to the Lake Apopka Basin, the Leesburg rainfall record was assigned to the Lake Harris Basin, and the Lisbon rainfall record was assigned to all other basins. After Theissen polygons were constructed, the rainfall station whose polygon covered the majority of the sub-basin's area was assigned for use in that sub-basin. The use of a single rainfall gauge per basin (as opposed to a weighted average of several Theissen polygons) represents the best modeling practice since the use of multiple gauges can result in decreasing peak rainfall intensities due to averaging.

**Rainfall Disaggregation.** Many have sought to develop accurate rainfall disaggregation methods for sub-hourly disaggregation and have found that disaggregation methods introduce negative biases into maximum rainfall intensities (Ormsbee 1989; Durrans et al. 1999; Burian et al. 2000). This negative bias can cause underestimation of Hortonian runoff and lead to large cumulative errors during long-term continuous simulations. If used for calibration, these negative biases can lead to model parameterization that compensates for the low intensities used as model boundary conditions. More discussion of the disaggregation method used by WDMUtil would be helpful in the model documentation.

**Timeseries Extension.** The USGS Streamflow Record Extension Facilitator (SREF) was used to implement the MOVE-3 method for extending potentiometric surface levels below each lake. This method is generally accepted and defensible. Model boundary conditions were also extended for the Baseline Conditions simulation, which simulated 2009 land use for 48 years, beginning in 2009. This required additional extended rainfall, evaporation, and spring flow records. Huang and Smith (2015) note that, "Extension of rainfall, evaporation, and spring flows are readily available within the District." Additional discussion should be added to the draft report that summarizes how these time series were extended. Additional citations should be added to reference more-detailed reports on the development of the extended boundary conditions.

b. **Are there any deficiencies and/or errors in analytical methods?**
There are neither deficiencies nor errors in the analytical methods. Some items noted above could benefit from additional documentation as noted.

**(3) Assess hydrologic model/relationships.**

a. **Determine if the model is appropriate, defensible, and valid, given the District's MFLs approach.**
HSPF was selected as the modeling tool for the LAUORB. HSPF is a comprehensive watershed hydrology simulation package that continuously simulates water quantity and quality for surface water basins. It is a widely accepted modeling tool in the water resource community. It has the ability to simulate best management practices (BMPs) through Special Actions as well as address degradation processes in water quality. HSPF performs continuous water budget analysis of water quantity and quality based on the

principal of conservation of mass. An updated version of HSPF was used for the LAUORB application. This version allows for storage in pervious land segments through the use of a surface FTable. Given the District's approach to MFLs, the use of HSPF is appropriate.

b. **Was there adequate data to develop, calibrate, and apply the model/relationship?**
   There was accurate data to develop, calibrate and apply the model.

c. **Given the available data and the District's MFLs approach, are there more appropriate models/relationships for assessing the water body?**
   Given the available data and the District's MFL approach, HSPF is the most appropriate model for assessing the waterbodies for this application.

d. **Evaluate the validity and appropriateness of all assumptions used in the development of the hydrologic model/relationship.**
   i. **Are the assumptions reasonable and consistent given the "best information available"?**
      The assumptions are reasonable and consistent given the best available information.
   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?**
      Based on the data presented in the report, it is clear that the District performed thorough data collection for the hydrologic assessment. When data was not available (such as spring flow for Harris Spring prior to 1991), standard engineering practices were employed to fill gaps and extend data. That being said, there is no information available that could have been used to eliminate modeling assumptions.
   iii. **Are the assumptions stated clearly?**
      Modeling assumptions are stated throughout the document. These include, but are not limited to:
      - The contributing flow of the Palatakaha River Planning Unit is relatively small and therefore not modeled,
      - Only DCIAs contribute to impervious areas,
      - Of the 14 land use types simulated, only residential and industrial (a total of 4 land use groups) have DCIA,
      - Spring flows for Harris Spring prior to 1991 were assumed at the average flow between 1991 and 2013,
      - During the model extension, anthropogenic changes will not significantly modify the baseline conditions during the 48-year simulation period; hydrologic characteristics of the basin will not change significantly during the simulation period, input time series of the historic data used in the extended model is a statistically realistic representation of the future hydrology and meteorology.

   iv. **What, if any, additional assumptions are implied or inherent in the development of the model/relationship?**

Implied assumptions include the assumption that the relationship between the potentiometric surface below each lake and the associated well used for extension remains constant throughout the extension period.

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?**

Alternative methodologies could include a statistical model to derive lake stages. Statistical models are best used when there is limited data available. Given the fact that there is adequate boundary condition data available, a process model such as HSPF is preferred over a statistical model because it simulates the hydrologic response of the watershed. If data were limited, a statistical model could be used, but given the available data, the use of a water budget model (such as HSPF) is appropriate and preferred.

e. **Are there deficiencies and/or errors in model/relationship 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.**

No major deficiencies or errors were noted in the model development, calibration or application. The following items could be addressed in order to strengthen model documentation.

The lakes are grouped into 4 groups for model calibration: (1) Lake Apopka, (2) Lakes Harris, Eustis, Dora, and Beauclair, and (3) Lake Griffin and (4) Lake Yale. This grouping should be substantiated within the hydrogeologic framework. The document should include a discussion on head changes in the UFA for each of the lakes and how they are correlated to one another. Based on the simulated heads (using ECFT and MOVE-3), what are the relative elevations of the UFA under each of the lakes? Do these relative elevations support the grouping of the basins into the modeled groups? Additionally, parameterization for pervious and impervious land segments should, in general, be consistent model-wide. For example, a low-density residential pervious land segment should have the same infiltration capacity in each sub-basin of the model unless there is substantial information to justify a different hydrologic response. The varied parameterization of each land use type should be discussed in the documentation.

Isolated basins are defined as catchments that do not have drainage features (either natural or manmade) that allow regular surface water discharge to downstream receiving water bodies. Section 2 on page 14 of Huang and Smith (2015) documents isolated basins and how they are handled within the modeling strategy. The isolated basins were carefully delineated but were not modeled as they lacked an observable surface water response. This procedure is adequate for surface water processes such as runoff and interflow (SURO and IFWO) but baseflow processes or Active Groundwater Outflow (AGWO) from these isolated basins could be routed to downstream receiving water bodies (see Figure 15 in Huang and Smith [2015]). If AGWO is normally distributed then slightly more than 30% of the baseflow going to the downstream receiving water bodies is not represented in the model. Even though this might be a limitation of the model, this results in only a fraction of a small flux that is not currently represented in the model.

**Table 1. Planning Unit Areas [modified from Huang and Smith (2015)]**

| Planning Unit Number | Planning Unit Name | Total Area | Modeled Area | Percent Difference |
|---|---|---|---|---|
| 7A | Palatlakaha River | 142,435 | **not modeled, used measured** | |
| 7B | Lake Apopka | 117,318 | 84,025 | 28% |
| 7C | Lake Harris | 152,721 | 101,799 | 33% |
| 7D | Lake Griffin | 118,217 | 70,410 | 40% |
| | | | | 34% |

Some additional details regarding model parameterization would enhance model documentation and defensibility. The slope of the pervious land segment surface (SLSUR) can be calculated using elevation data intersected with land use data. Based on the PARM2 summaries presented in the Appendix, it appears that SLSUR was defined by major basin. The justification for the parameterization of SLSUR should be documented in the modeling report. The hydraulic length (LSUR) should vary by land use. For example, a forested land segment would be expected to have a longer hydraulic length than a high density residential segment. To what extent was this considered during calibration? Lastly, the values presented for Manning's N (NSUR) in the appendix of the draft report are truncated and should be modified to reflect the model files.

Overall, the model calibration appears to be adequate given the stage hydrographs and the Nash Sutcliffe efficiencies presented. It should be noted that the model simulates flows and stages at an hourly time step, while the data was aggregated to monthly to calculate Nash Sutcliffe efficiencies. Aggregating data to a more coarse time scale will result in improved statistics. Since the intended use of the model is for MFL analyses using a daily time series as its basis, the Nash Sutcliffe efficiencies should be presented using daily data in order to get an accurate measure of how well the model replicates daily stages.

In addition to daily Nash Sutcliffe efficiencies, the model documentation would benefit from a land use based water balance. Land use based water balances serve as a check to ensure that each segment simulates an appropriate hydrologic response particularly when compared to segments of other land use types. For example, the actual ET (TAET) from a wetland segment should be much higher than the actual ET (TAET) from a residential segment. The effort required to derive this water balance is minimal yet it yields valuable information regarding land segment response.

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.**
All suggested improvements discussed above can be remedied.

f. **Identify all sources of model uncertainty and assess their impact on applying the model to assess whether an MFL will be achieved.**
Uncertainty in a hydrologic model can be due to many sources including uncertainty associated with input data as well as uncertainty associated with calibrated model parameters. The more uncertainty present in a model, the less confidence in a model's predictive capability. If the model is overconceptualized, that is, the complexity of the model conceptualization exceeds the availability of data to support the conceptualization, it may be more practical to utilize a statistical model instead of a process model for a given system.

There are many sources of uncertainty in the LAUORB models. These uncertainties include:

- Propagation of bias from other models. Due to limited available data, the LAUORB HSPF model utilized the output of the ECFT groundwater model. Model bias from the ECFT model will propagate into the UFA estimates developed for the LAUORB model. The extent of this bias in the vicinity of the LAUORB should be documented. Bias from the Dora Canal model should also be noted.
- Seepage rates within the LAUORB. Seepage rates are generally unknown, and therefore this flux is somewhat unconstrained. Relative elevations of lake stage to UFA stage can be used to provide weight of evidence support for the water balance. Although comparisons can be made to the ECFT results, this is also a modeled flux and not a field observation. The water balances presented in Tables 24 through 29 of the draft report were cross referenced with Figure 23 through 26 in order to verify that the discharge/recharge from each lake was consistent. Care should be taken to present all water balance terms defined as positive noted into the lake, with appropriate descriptive titles.
- The non-uniqueness of the modeled solution due to lack of constraint. Since HSPF is a process model, observed data of each process, or ancillary data regarding each process is vital in order to constrain the solution. Essentially, the lake stages are based on the difference between lake inflows and outflows. For the LAUORB model, inflows include runoff, direct rainfall, and baseflow. For each lake, outflows include seepage to the UFA, evaporation and discharge downstream. Direct rainfall is a measured quantity, making it constrained. Runoff and baseflow, however, are

unconstrained. The regulated discharges are generally uncertain, and though there is a discharge schedule, the operator can adjust the discharges at any time. Since these outflows lack constraint, the model solution may be non-unique. This can become problematic when the model is utilized for prediction.

- Unknown model sensitivity. A full sensitivity analysis has not been conducted on the LAUORB HSPF model. Evaluating the sensitivity of the model to changes in calibrated parameters, particularly the conductance values used for the seepage routine and the UFA head boundary condition, is essential in order to have a more thorough understanding of model sensitivity. Quantifying the sensitivity to calibrated parameters will increase confidence in the predictive capability of the model.

**g. Are the conclusions in the model report supported by the modeling results?**
In general, there were not specific conclusions reached in the model report, but rather, model results were presented in the form of flow and stage hydrographs, exceedance plots, and calibration statistics. Overall, the calibration appears adequate for the intended purposed of the modeling application.

## References


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