Technical Publication SJ2014-2

INDIAN LAKE SYSTEM
MINIMUM FLOWS AND LEVELS
HYDROLOGIC METHODS REPORT

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by

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Palatka, Florida

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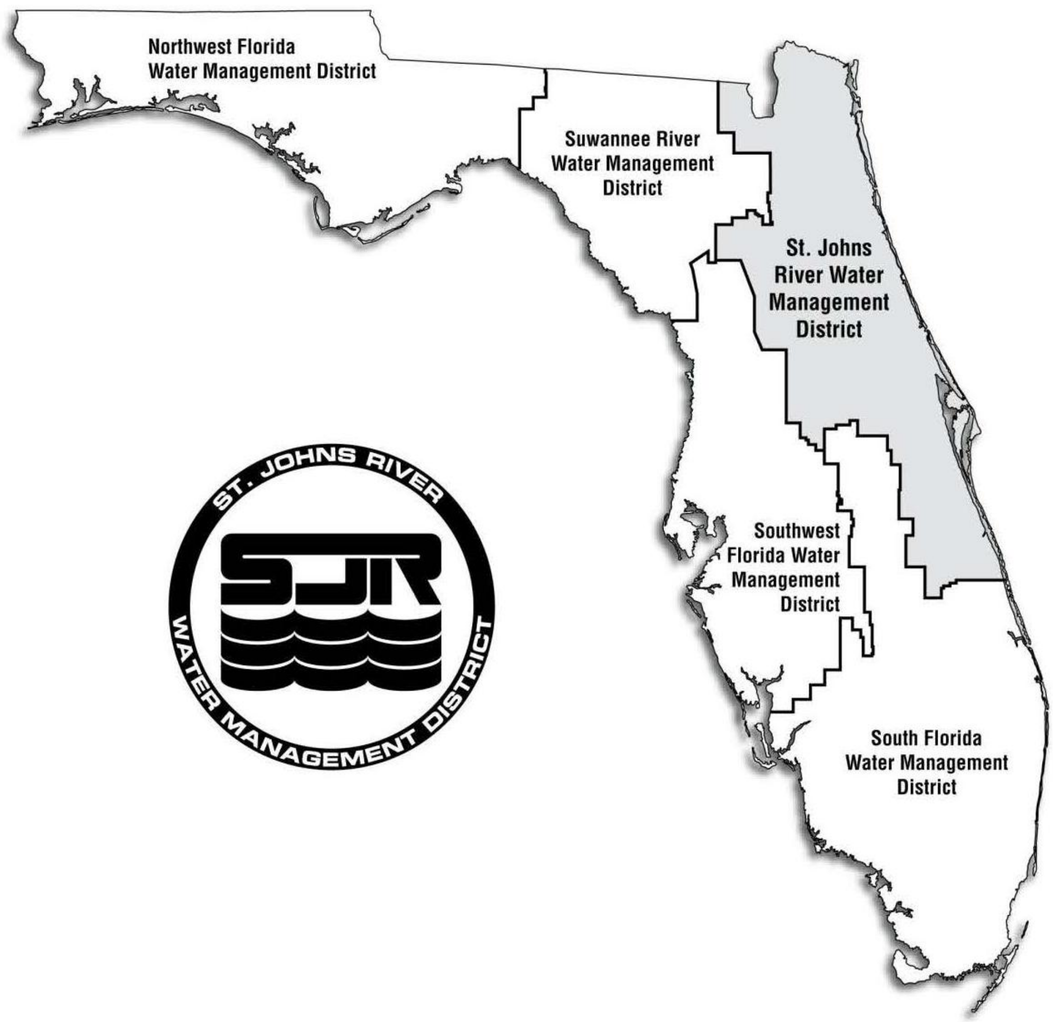

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ACRONYMS AND ABBREVIATIONS

ac-ft	acre-feet
cfs	cubic feet per second
DETI	evapotranspiration reduction factor
ET	evapotranspiration
ISPA	Institute of Science and Public Affairs
MA	minimum average
MFH	minimum frequent high
MFL	minimum frequent low
MFLs	minimum flows and levels
MSE	mean square error
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PET	potential evapotranspiration
ROP	runoff percentage
SJRWMD	St. Johns River Water Management District
SMI	Soil Moisture Index
SSARR	Streamflow Synthesis and Reservoir Regulation
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

INTRODUCTION

BACKGROUND

Indian Lake, Scoggin Lake, and Coon Pond (Indian Lake system) are located in Volusia County, Florida, approximately 8 miles west of the city of Daytona Beach (Figure 1). The system is located within a St. Johns River Water Management District (SJRWMD; District) priority water resource caution area (SJRWMD 2006). Therefore, setting minimum flows and levels (MFLs) for the Indian Lake system is of particular importance. Although other factors may ultimately be more limiting, MFLs will provide the initial limits to Floridan aquifer withdrawals from the area surrounding this system.

The basic task in analyzing changes to a hydrologic system is to quantify those changes and assess their acceptability. In the context of MFLs, SJRWMD uses analyses of results from long-term hydrologic models to make these assessments. Modeling results will provide the framework needed to implement MFLs for the Indian Lake system. By analyzing the output from a hydrologic model, informed management decisions can be made regarding consumptive uses of water in the area.

PURPOSE AND SCOPE

MFLs have been adopted by SJRWMD for Indian Lake (Valentine-Darby 1998), Scoggin Lake (Mace 1999), and Coon Pond (Hall 1999). In each case, a minimum frequent high level (MFH), a minimum average (MA) level, and a minimum frequent low (MFL) level were adopted. In conjunction with setting these MFLs, SJRWMD developed a hydrologic model including all three lakes. This model simulates lake stages using historical rainfall, evaporation, and groundwater levels.

The purpose of this report is to describe and document the following:

- Model selection
- Model calibration criteria
- Model development and calibration
- Model application assumptions
- Model performance assessment
- Statistical analyses used in implementing the Indian Lake system MFLs
- Analysis of Floridan aquifer drawdowns in the vicinity of the Indian Lake system related to MFLs

The model domain covers Indian Lake, Scoggin Lake, Coon Pond, and the corresponding surrounding drainage basins. The calibration targets for the hydrologic model were lake stages.

One purpose of the model is to determine whether or not MFLs are being met and, if they are, how much additional water withdrawal would be allowed. Modeling results indicate that all MFLs are being met on Scoggin Lake and Coon Pond under 2005 conditions, which refer to a hypothetical case where long-term simulation assumes average groundwater withdrawals at 2005 levels. Adopted MFLs for Indian Lake are not being met under 2005 conditions. However, newly recommended MFLs for Indian Lake would be met under 2005 conditions.

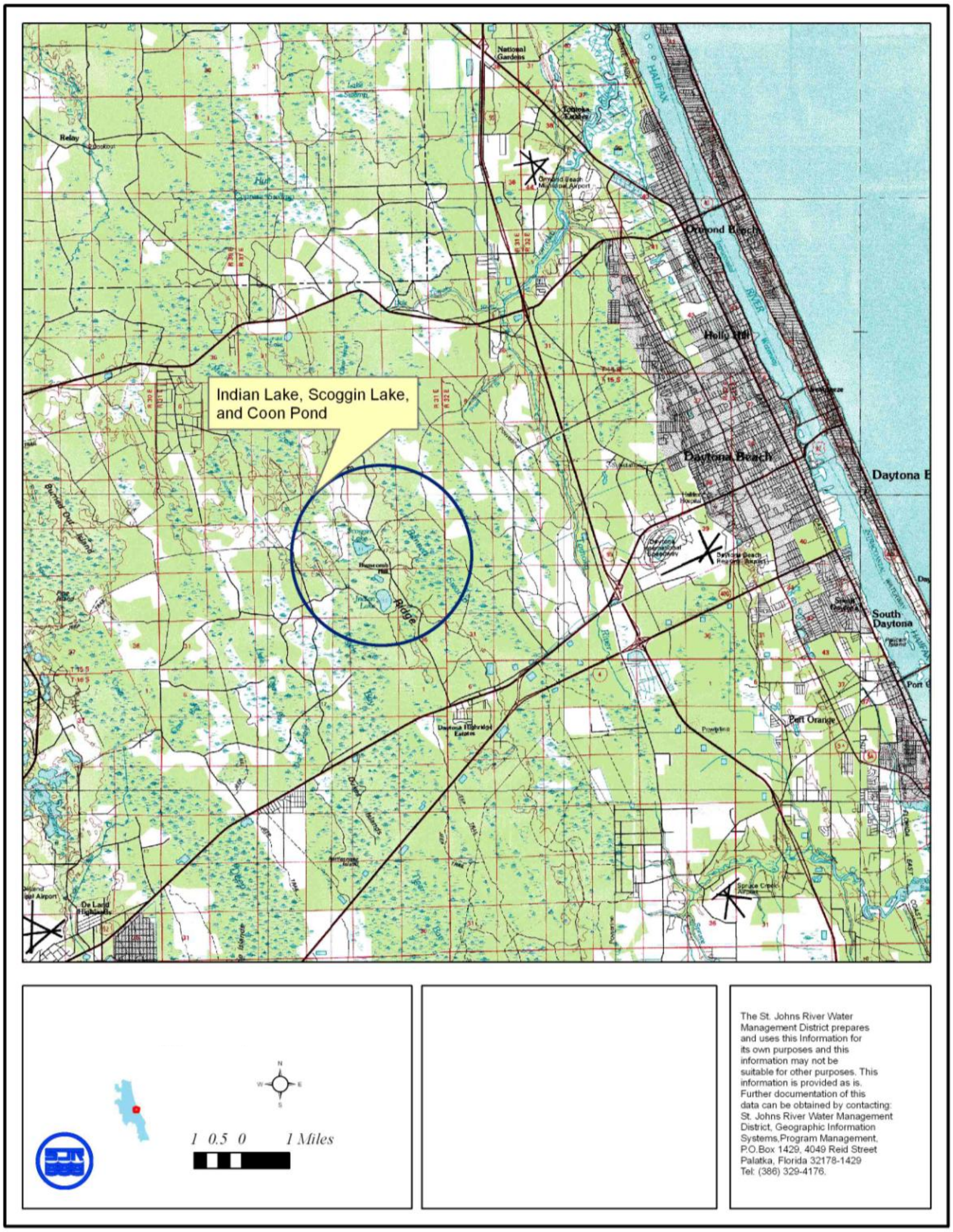

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Figure 1. Location map for Indian Lake, Scoggin Lake, and Coon Pond

Hydrologic Model of the Indian Lake System

Hydrologic modeling and analysis provide the framework needed to implement MFLs in the Indian Lake system. By analyzing the output from a hydrologic model, informed management decisions can be made regarding groundwater withdrawals from the Floridan aquifer in the vicinity of the system. This chapter of the Indian Lake system hydrologic methods report discusses the

- Model selection process
- Model calibration criteria
- Selected model—Streamflow Synthesis and Reservoir Regulation (SSARR)
- Model data requirements
- Principal modeling assumptions
- Model calibration
- Model calibration results

MODEL SELECTION

Before selecting a model to assess hydrologic changes in the context of MFLs, it must be established that the system in question and its relationship to MFLs cannot be represented adequately without a model. Often, simple operations are performed on gauge records to assess the effects of alterations on a hydrologic system. For example, the amount of surface water withdrawal might be subtracted from daily flows recorded at a gauge. Frequency analysis on the resulting time series (Appendix A) could be used to assess a system with respect to MFLs. CH2MHILL (1997) essentially shifted flow duration curves (Appendix A) to obtain preliminary analyses of the effects of water withdrawals on the Middle St. Johns River system. While these methods might be adequate in a preliminary analysis, the complexity of the Indian Lake system—especially as it relates to the Floridan aquifer—requires a predictive computer model to adequately examine the effects of hydrologic changes. This is especially true in the context of MFLs.

When selecting a model or combination of models to provide useful simulations of a hydrologic system, two principal factors should be considered. The first factor to consider is the model's ultimate purpose. If, for example, the model were designed to analyze an urban flooding problem, then the model would require sufficient detail and small enough time steps such that flooding effects in an urban setting could be adequately represented. In the context of the Indian Lake system MFLs, a long-term (covering 30 years or more) simulation of stages is important. In addition, the model should be capable of simulating changes to the hydrologic system to ensure that MFLs continue to be met.

The second factor that should be considered in selecting a model or combination of models is the hydrologic and physical data available to develop and calibrate the models. For instance, unless a dense network of hourly rainfall stations is available, the use of a highly detailed model capable of simulating a complex urban flood is inappropriate. In the case of the Indian Lake system model, a daily time step model is adequate.

The Streamflow Synthesis and Reservoir Regulation (SSARR) mathematical model, a rainfall runoff routing model developed by the Portland District of the U.S. Army Corps of Engineers (USACE 1986; Ponce 1989), was selected for the Indian Lake system MFLs modeling effort. SSARR is a standard hydrologic model that has been used in many parts of the world for many different applications. SSARR is a continuous simulation model, so in this sense it is well suited to the SJRWMD approach to MFLs.

SSARR is also appropriate for modeling the Indian Lake system because of its backwater mode. SJRWMD has developed a method of simulating seepage from a lake to the Floridan aquifer using this backwater mode. In the process of calibration of a model, it becomes fairly clear whether or not seepage to the Floridan aquifer is important part of the water budget of a lake. The estimation of seepage from these lakes to the Floridan aquifer will be discussed in detail later in this report.

Generally speaking, a hydrologic system should be modeled as simply as possible. If model results are unsatisfactory, then more detail can be added. If the SSARR simulations of the Indian Lake system are found to be inadequate, then a more complex model should be considered assuming, of course, that there is adequate data available for the task. Years of additional data collection might be needed to justify using a more complex model.

CALIBRATION CRITERIA

Calibration of a hydrologic model is a standard procedure in which measured and simulated values are compared. The particular aspects stressed in hydrologic model calibration depend on the model’s ultimate purpose. The Indian Lake system SSARR model will be used to determine the effects of consumptive use withdrawals on lake stages. Therefore, the model’s ability to simulate lake stages will be tested by calibration against historical stage measurements.

Calibration criteria, used to judge the adequacy of a model, are determined before model calibration. In the case of the Indian Lake system SSARR model, the calibration criteria will be based on simulation of stages. The goal is to maximize the number of simulated values within ±0.5 ft of the corresponding measured values for each of the individual lakes in the system. An additional goal is to meet this criterion over a wide range of stages.

MODEL DESCRIPTION

SSARR is comprised of watershed and river system submodels. The watershed submodel simulates rainfall runoff and accounts for interception, evapotranspiration, baseflow infiltration, and routing of runoff into the stream network. This submodel also accounts for groundwater flow through the local water table, but not for flow through the regional water table, the intermediate aquifer, or the Floridan aquifer.

The basic routing method used by SSARR to model a watershed is a cascade of reservoirs technique (USACE 1986; Ponce 1989). A watershed is represented as a series of lakes, which conceptually simulates the natural delay of runoff.

Lake routing is accomplished by an iterative solution of an equation involving inflow, outflow, and storage. The model accounts for evaporation losses and rainfall gains for each lake.

The SSARR User Manual (USACE 1986) contains a complete description of the model. Ponce (1989) also provides a description of SSARR.

As calibration of the model progressed, it became clear that to achieve low stages, a seepage component was needed. Therefore, a seepage simulation module was added to each lake in the SSARR model of Indian Lake system. This module will be discussed later in this report.

Input data needed to operate SSARR include the following:

- Job control parameters
- Constant characteristics
- Initial conditions data
- Time series data

Job Control Parameters

Job control parameters used by SSARR include the simulation period, data time intervals (e.g., daily, hourly), and output options (e.g., the stations for which output is required). The simulation period used in the Indian Lake system SSARR model was 1 year, and the time step was 1 day. Long-term simulations were composed of a series of 1-year segments.

Constant Characteristics

The constant characteristics of a watershed are physical features such as drainage area, characteristics affecting runoff, hydrograph shape, lake storage capacity curves, rating curves, drainage system configuration, and so on.

The constant characteristics discussed in detail here are soil moisture runoff relationships, drainage areas, relationship of lake storage capacity to lake stage, land use, and soils.

Soil Moisture Runoff Relationships. The Soil Moisture Index (SMI), measured in inches, is an indicator of relative soil wetness and, consequently, of watershed runoff potential (Figure 2). Rainfall input is divided by SSARR into surface runoff and soil moisture increases. The percentage of rainfall available for runoff (runoff percentage [ROP]) is based on an empirically derived relationship between soil moisture and ROP. This relationship determines the runoff percentage; rainfall that is not converted by the model into runoff is added to the SMI.

Soil moisture (the SMI) in SSARR is depleted only by evapotranspiration (ET). ET losses include transpiration by vegetation, interception losses, direct evaporation of groundwater, and infiltration into non-modeled groundwater. The total of these losses is referred to as potential ET (Ponce 1989). A set percentage of pan evaporation can be used to approximate the potential ET (Ponce 1989; Linsley et al. 1982); the final percentage is determined during model calibration. The monthly pan evaporation at a National Oceanic and Atmospheric Administration (NOAA) weather station is used to obtain daily potential ET.

The actual amount of simulated ET, referred to as effective ET, changes with changing soil moisture conditions. The soil moisture lost through ET decreases as the soil dries out. Thus, the potential ET is multiplied by a factor, based on the SMI, to obtain the effective ET (Figure 2). The final configuration of this relationship between the SMI and the effective ET is determined during model calibration. SSARR determines the effective ET and reduces the SMI by the effective ET before calculating runoff.

Drainage Areas. The drainage areas used in the Indian Lake system SSARR model were obtained based on U.S. Geological Survey (USGS) quadrangle map topography (Figure 3). The drainage areas obtained were as follows:

- 0.31 mi^2 for Indian Lake
- 0.51 mi^2 for Scoggin Lake
- 0.20 mi^2 for Coon Pond

Model Schematic. A schematic of the Indian Lake system SSARR model is a useful way to present the configuration of the various components of the hydrologic system

(Figure 4). The schematic shows the location of different model elements such as drainage basins, lakes, and seepage sinks.

Storage Capacity Curves. Detailed bathymetry exists for Indian Lake but not for Scoggin Lake or for Coon Pond. District staff obtained the Indian Lake bathymetry in April 2005 (SJRWMD Work Order #2859-05). Contour areas up to and including 36.75 ft National Geodetic Vertical Datum (NGVD) were based on this work (Figure 5). Contour areas above 36.75 ft were obtained from USGS quadrangle map topography. USGS quadrangle map topography was used in conjunction with Indian Lake bathymetry to estimate the bathymetry for Scoggin Lake and Coon Pond. The stage area values were used to determine the storage capacity curve for each of the lakes. The storage capacity curves (Figure 6) for the lakes are incorporated in SSARR as two-variable tables.

Lake Outlet Rating Curves. An outlet rating curve is a function that relates the stage of a lake with the amount of discharge leaving the lake (see Figure 6a). Invert elevations (where discharge is zero) were estimated by examining the stage hydrograph for each lake. The invert elevations for both Indian Lake and Coon Pond were estimated at 37 ft NGVD. The invert elevation for Scoggin Lake was estimated at 35 ft NGVD.

Initially, a very simple rating curve was constructed assuming 1 cfs at 1 ft above invert and discharge that doubled at each subsequent foot of stage. The same rating curve was used for each lake. As part of model calibration, discharge amounts at each stage were changed to obtain the best fit. However, as it turned out, only the rating curve for Scoggin Lake was changed during calibration. Because these rating curves are relatively simply constructed, both the invert elevations and the discharge amounts were the subject of sensitivity analyses.

Land Use and Soils. Beyond estimating the amount of impervious area, land use and soils are often not used in the development of SSARR models and, therefore, are not detailed here. Since there is virtually no building in the area surrounding the Indian Lake system, impervious area was not included in this model.

Initial Conditions Data

Initial conditions specify the watershed parameters on the starting day of a 1-year simulation. These parameters include the current value of the SMI, the initial runoff from each drainage basin, and the initial storage, elevation, and outflow for each lake. SSARR simulations were divided into periods of 1 year. Long-term simulations were composed of a series of 1-year segments. The model automatically uses conditions calculated at the end of 1 year of simulation to start the following year’s simulation.

Time Series Data

SSARR uses a number of different types of time series data as input. Rainfall, evaporation, stage gauge values, and potentiometric surface levels of the Floridan aquifer system were used for the Indian Lake system model.

Rainfall. The Indian Lake SSARR system model uses daily rainfall totals. OneRain (OneRain, Inc., Longmont, CO) radar daily rainfall data were used for model calibration (Table 1). Weather radar, when combined with rain gauge measurements, provides detailed information concerning rainfall intensities over specified areas. The District is divided into individual pixels 2,000 m^2, each of which has daily rainfall estimates. The pixel used for this analysis is number 130257 (see Figure 7). Data from the NOAA station at Daytona Beach were used to supplement the radar rainfall for the long-term simulations.

Lake Stages. Calibration of a hydrologic model is accomplished by comparing observed daily stage values to those generated by the model. Stage data for Indian Lake, Scoggin Lake, and Coon Pond (Table 2, Figure 7) were used in the development of the Indian Lake system SSARR model.

Floridan Aquifer Potentiometric Surface Levels. Potentiometric surface data from Floridan aquifer well V-0086 (Table 2, Figure 7) were used to develop the seepage-simulation module for the Indian Lake system SSARR model. Levels at this well were recorded at a variety of frequencies. To obtain a daily value well hydrograph, gaps were filled with straight-line interpolation. The simulation of seepage flows will be discussed in more detail later in this report.

Pan Evaporation. Pan evaporation data are important to the Indian Lake system SSARR model in two ways: 1) they are used in the calculation of direct lake evaporation, and 2) they are used in the estimation of potential ET.

The pan evaporation concept provides a standard method of measuring evaporation (Linsley et al. 1982). Monthly pan evaporation data are published at four NOAA stations in or near the SJRWMD: Gainesville (Alachua County), Lake Alfred (Polk County), Lisbon (Lake County), and Vero Beach (Indian River County). Average annual pan evaporation varies from 73.11 in. at Lake Alfred to 59.08 in. at Lisbon (Table 3). The maximum annual pan evaporation varies from 86.25 in. at Lake Alfred to 67.57 in. at Lisbon. Minimum annual pan evaporation varies from 53.68 in. at Gainesville to 66.76 in. at Lake Alfred.

Direct lake evaporation can be estimated using pan evaporation data multiplied by a coefficient (Ponce 1989; Linsley et al. 1982; USGS 1954). Although coefficients vary, SJRWMD often uses 0.81, based on a study at Lake Okeechobee (USGS 1954). Estimates of average annual lake evaporation using this coefficient vary from 59.22 in.

using Lake Alfred pan evaporation to 47.85 in. using Lisbon pan evaporation (Table 4). Values published by the National Weather Service (NWS) (Linsley et al. 1982) indicate that average annual evaporation for shallow lakes in the SJRWMD should vary from 45 to 48 in. per year. Therefore, Lisbon pan evaporation data were used to calculate direct lake evaporation for the Indian Lake system SSARR model.

Lake evaporation coefficients vary from month to month (USGS 1954). Monthly coefficients for the Indian Lake system SSARR model were obtained from a study of evaporation on Lake Okeechobee (USGS 1954). Using average monthly pan evaporation at Lisbon and the pertinent monthly coefficients yields an average yearly evaporation of 48.18 in. (Table 5). Again, this rate is very close to the range published by NWS (Linsley et al. 1982) for average annual evaporation from shallow lakes in the vicinity of the SJRWMD. Monthly pan evaporation was divided by the number of days in a month to obtain a daily pan evaporation value.

Potential ET from a watershed can be estimated using a set percentage of daily pan evaporation (Ponce 1989; Linsley et al. 1982). For the Indian Lake system SSARR model, this percentage was 75%. Because pan evaporation measured at the Lisbon NOAA station was used to calculate lake evaporation, as described above, it was also used to determine evapotranspiration for the Indian Lake system SSARR model (see "Soil Moisture Runoff Relationship" section for an explanation of how SSARR uses pan evaporation data for estimating ET).

Seepage Flow between a Lake and the Floridan Aquifer

Given sufficient connection between a lake and the Floridan aquifer, seepage between them forms an important part of the water budget of the lake. The amount of seepage between lake and aquifer will depend on the difference in elevation between the lake and the potentiometric surface level of the Floridan aquifer. The basic principle for describing the flow of groundwater dates from the middle of the nineteenth century and the work of Henri Darcy with flows through filter sand (Terzaghi and Peck 1967). Darcy's law can be expressed as

$$Q = K \frac{\Delta h}{2L} A \tag{1}$$

where

Q = seepage flow

K = coefficient of permeability or hydraulic conductivity

Δh = difference in elevation between lake and potentiometric surface

L = length of the material through which water seeps from lake to aquifer

A = cross–sectional area of material through which water seeps from lake to aquifer

If L and A are assumed to be constant, then equation (1) can be written

$$Q = \widehat{K}\Delta h \qquad (2)$$

where

$\widehat{K}$ = a constant that is a function of the local geology and is referred to as hydraulic conductance

Equation (2) is used to create a 3-variable family of curves (Figure 8) that becomes part of the SSARR model for the lake in question. The three variables in this case are seepage flow, the elevation of the lake being modeled, and the local potentiometric surface level of the Floridan aquifer. Determination of $\widehat{K}$ becomes part of the lake model calibration process.

MFLs hydrologic modeling at the SJRWMD is based on long-term (about 30 to 50 years) simulation with a daily time step. As described previously in this chapter, a three-variable relationship among seepage amount, lake stage, and potentiometric level of the Floridan aquifer is incorporated as part of the SSARR model for a lake. Therefore, the simulation of seepage from a lake requires a daily value hydrograph of the Floridan aquifer. Because of the expense involved, it is not practical to have a well drilled at each lake. Furthermore, there are very few wells with long-term records. For these reasons seepage modeling is based on the following assumptions:

- A number of District wells are read on a monthly or bimonthly basis. Straight-line interpolations of these data provide an adequate representation of the daily value hydrograph. Although some short–term fluctuations will be missed, interpolation should capture long–term trends.
- The Floridan aquifer can be considered a system that tends toward long-term equilibrium. When an array of consumptive uses is imposed on the aquifer, it will decline—though not necessarily in a spatially uniform manner—and in time it will reach a new state of long-term equilibrium. The assumption here is that the new equilibrium will have the same absolute range of fluctuation and, therefore, historical Floridan hydrographs can be shifted by a set amount to provide a new post-drawdown hydrograph.
- If the potentiometric slope is similar at two nearby locations, the Floridan aquifer at these locations will tend to fluctuate in concert. This assumption implies that points in the general vicinity of each other have a similar range of fluctuation and can thus be translated and shifted up or down.
- The Floridan aquifer is vast enough that localized transient effects caused by localized seepage can be discounted. The assumption is made that the well

hydrograph is a given, and that seepage from the modeled lake will not significantly affect the aquifer.

- Seismic profiling of numerous northeast Florida lakes shows a variety of collapse structures providing preferred paths toward the aquifer (Kindinger et al. 2000). Most of these collapse structures are relatively small when compared to the total bottom area of the lake. Therefore, the assumption is made that hydraulic conductance for a given lake is a constant that does not vary with lake area. Indian Lake, in particular, shows a number of collapse structures much smaller than the lake bottom area.

One scenario used in SJRWMD MFLs assessments is to project the decline in a lake's water surface caused by a proposed or projected decline in the Floridan aquifer. The proposed or projected decline is included in the SSARR model by shifting the historical well hydrograph downward by a set amount. This technique can be used to determine the amount of Floridan aquifer decline that would cause one or more MFLs to no longer be met. This in turn determines the limit, with respect to Floridan aquifer drawdowns, to future withdrawals in the vicinity of the lake in question.

MODELING ASSUMPTIONS

No model can include all factors that affect the hydrologic cycle. Therefore, any modeling study must include simplifying assumptions. In analyzing the final product of the model, a judgment is made as to the appropriateness of the assumptions. The principal assumptions made in developing the hydrologic model of Indian Lake system follow:

- SSARR accounts for local water table flow in the form of interflow and baseflow (Ponce 1989) from basins immediately surrounding a lake but not from those removed from it. The assumption is made that any flow from outside the immediate basin is small compared to the overall water budget.
- Given limited resources and the large number of lakes being modeled by SJRWMD, it is not always possible to obtain detailed outlet surveys and bathymetry for each individual lake. It was assumed that bathymetry for Coon Pond and Scoggin Lake could be estimated with USGS quadrangle maps and the Indian Lake bathymetry. It was also assumed that outlet rating curves for all three lakes could be determined during model calibration.
- The calibration period covers a great enough range of hydrologic conditions that the resultant model will provide a realistic simulation over the period of record.
- Coon Pond can go largely dry for significant periods of time (Hall 1999). As part of the MFLs determination, District personnel took soundings across much of the pond and found that the pond floor lies at about 34 to 35 ft NGVD. To account for the fact that it does go dry, Floridan aquifer seepage was assumed to cease at about 34 ft

NGVD. On the other hand, the capacity curve was assumed to go lower to allow for continued evaporation at low water levels.

CALIBRATION OF THE INDIAN LAKE SYSTEM STREAMFLOW SYNTHESIS AND RESERVOIR REGULATION (SSARR) MODEL

The Indian Lake system SSARR model was calibrated by comparing observed lake stages with simulated values. The calibration involved a series of trial and error runs to obtain the closest simulation to measured values, by adjusting some model parameters while leaving other parameters constant. The following model parameters were adjusted:

- The SMI versus ROP curves and the SMI versus effective ET curves (Figure 2)
- SSARR routing constants affecting the shape of hydrographs
- SSARR factors affecting division of runoff into base, subsurface, and surface flows
- The ratio of potential ET to effective ET
- The parameters for the rating curves for the outlets of Indian Lake, Scoggin Lake, and Coon Pond
- The hydraulic conductance (between lake and Floridan aquifer)

The following model parameters were held constant

- Drainage areas
- Storage capacity curves
- The ratio of lake evaporation to pan evaporation
- The ratio of potential ET to pan evaporation

Scatter plots comparing individual simulated values with the corresponding observed values are often used in model assessment. As discussed previously, in the case of the Indian Lake system SSARR model, the calibration criteria will concentrate on simulation of stages. To standardize the measure of model fit and to allow for comparison to other models, the mean square error (MSE) was used. The MSE is the average of the squares of the residuals (measured value minus simulated value). At a very simple level, if all residuals were equal to ±1 ft, the MSE would be 1.0 ft^2. Likewise, if all residuals were equal to ±0.5 ft, the MSE would be 0.25 ft^2. To give some context to the calibration results, one calibration goal will be to have a MSE less than 1.0 ft^2 but as close as possible to 0.25 ft^2. A second goal will be to have at least 67% (two thirds) of residuals within ±0.5 ft. A third goal will be to have at least 90% of residuals within ±1.0 ft. The size of these ranges was set based on a hypothetical lake with a 10-ft range of fluctuation. For a lake with 10 ft of total fluctuation, 0.5 ft corresponds to 5% and 1.0 feet corresponds to 10 %. A final goal is to meet the above criteria over a wide range of stages.

The Indian Lake system SSARR model was calibrated with data from 1996 to 2005. This period includes a variety of hydrologic conditions including a significant high (the 1998 El Niño peak) and a significant and sustained low period (1998–2001 drought). A nearby well, V-0086 (Table 2, Figure 7), was available during this period. OneRain radar daily rainfall totals for Pixel 130257 were used in the calibration (Table 1).

The final calibration replicates the trends of the historical data for Indian Lake (Figures 9 and 10). The MSE of the residuals was 0.471. Thus the MSE was less than 1.0 but greater than 0.25. Seventy percent of the residuals were within ±0.5 ft of the observed values (Figure 10) meeting the goal of 67%. Eighty-six percent of residuals were within ±1.0 ft of the observed values missing the goal of 90%. The agreement between simulation and gauge values covers about 7 ft, so the secondary calibration criterion, model agreement over a wide range of values, is also met. That being said, the model does not adequately simulate the stage increases between September and October 2001.

The final calibration replicates the trends of the historical data for Scoggin Lake (Figures 11 and 12). The MSE of the residuals was 0.098. Thus the MSE was less than both 1.0 and 0.25. Ninety-three percent of the residuals were within ±0.5 ft of the observed values (Figure 12) exceeding the goal of 67%. One hundred percent of the residuals were within ±1.0 ft of the observed values exceeding the goal of 90%. The agreement between simulation and gauge values covers nearly 6 ft, so the secondary calibration criterion, model agreement over a wide range of values, is also met.

The final calibration replicates the trends of the historical data for Coon Pond (Figures 13 and 14). The MSE of the residuals was 0.180. Thus the MSE was less than both 1.0 and 0.25. Eighty-two percent of the residuals were within ±0.5 ft of the observed values (Figure 14) exceeding the goal of 67%. Ninety-seven percent of residuals were ±1.0 ft of the observed values exceeding the goal of 90%. The agreement between simulation and gauge values covers nearly 4 ft, so the secondary calibration criterion, model agreement over a wide range of values, is met to some extent, taking into account that the range of the lake stages is limited.

Assessment of Appropriateness of Modeling Assumptions

Based on model results (Figures 9–14) during the calibration years, the modeling assumptions discussed previously (see “Modeling Assumptions”) appear to be warranted. Based on these results and the data available at present, a more elaborate model is not warranted at this time. The Indian Lake system SSARR model should provide a useful tool for comparing water management alternatives in the context of MFLs.

Table 1. Rainfall stations used in the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model

Station	County	NOAA* Number	Period of Record
Daytona Beach	Volusia	2158	1938–2005
OneRain radar	Volusia	Pixel 130257	1996–2005

* NOAA =National Oceanic and Atmospheric Administration

Table 2. Water level gauging stations used in developing the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model

Station	SJRWMD Number	Period of Record	Comment
Stage Gauges			
Indian Lake	DIST* 14702693	1988–1998 1999–2005	Approximately weekly, received from Volusia County Approximately weekly
Scoggin Lake	DIST 14712694	2000–2005	Approximately weekly
Coon Pond	DIST 14722695	1999–2005	Approximately weekly with occasional large gaps Daily from Aug. 2006 onward
Floridan Aquifer Wells			
V-0086 Tiger Bay FA 222 ft	DIST 14661279	11/1975–09/1992 10/1992–08/1997 09/1997–10/2005 11/2005–12/2005	Daily with occasional gaps Approximately quarterly Approximately monthly Daily

* DIST =St. Johns River Water Management District (SJRWMD)

Table 3. Summary of pan evaporation data from National Oceanic and Atmospheric Administration (NOAA) stations located in or near the St. Johns River Water Management District (SJRWMD)

Location	Period of Record	Maximum Annual Pan Evaporation (in.)	Minimum Annual Pan Evaporation (in.)	Average Annual Pan Evaporation (in.)
Gainesville	1954–98	73.63	53.68	63.88
Lake Alfred	1965–98	86.25	66.76	73.11
Lisbon	1960–98	67.57	54.37	59.08
Vero Beach	1952–98	79.41	55.35	67.67

Table 4. Estimated lake evaporation for National Oceanic and Atmospheric Administration (NOAA) stations in or near the St. Johns River Water Management District (SJRWMD)

Location	Average Annual Pan Evaporation (inches)	Estimated Annual Lake Evaporation (inches)*
Gainesville	63.88	51.74
Lake Alfred	73.11	59.22
Lisbon	59.08	47.85
Vero Beach	67.67	54.81

*Average annual pan evaporation amounts from Table 3 × 0.81

Table 5. Summary of average monthly lake evaporation applied in the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model

Month	Monthly Pan-to Lake Coefficients*	Average Monthly Pan Evaporation† (in.)	Estimated Lake Evaporation (in.)
January	0.77	2.37	1.82
February	0.69	2.94	2.03
March	0.73	4.92	3.59
April	0.84	6.52	5.48
May	0.82	7.39	6.06
June	0.85	6.91	5.88
July	0.91	6.89	6.27
August	0.91	6.33	5.76
September	0.85	5.24	4.45
October	0.76	4.05	3.08
November	0.71	2.72	1.93
December	0.83	2.19	1.82
Total	—	58.49	48.18

*USGS 1954

† Lisbon NOAA station

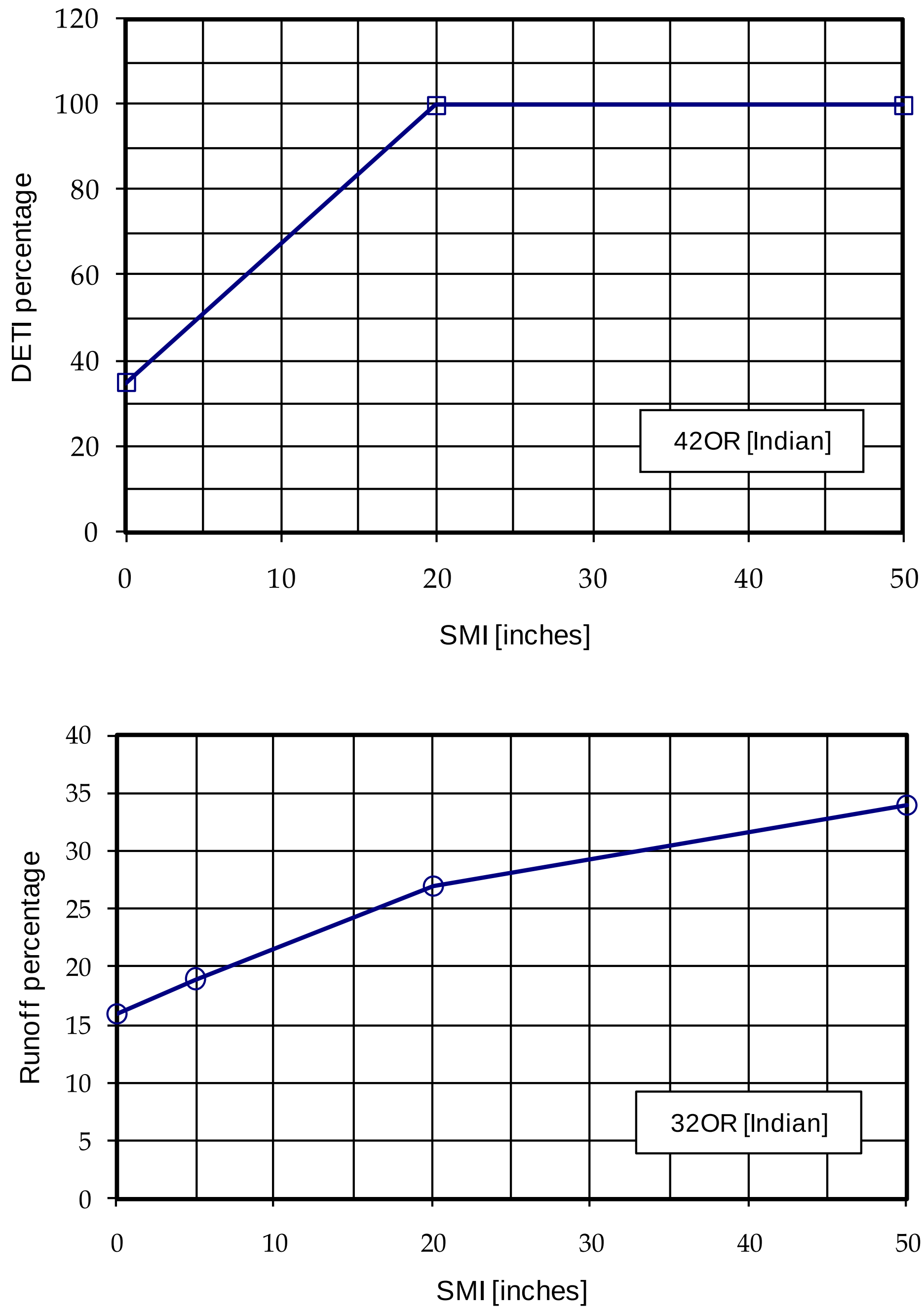

Figure 2. Soil moisture relationships for the Indian Lake system SSARR hydrologic model—runoff percentage versus soil moisture index (SMI) and evapotranspiration reduction factor (DETI) versus SMI. These relationships were developed in model calibration

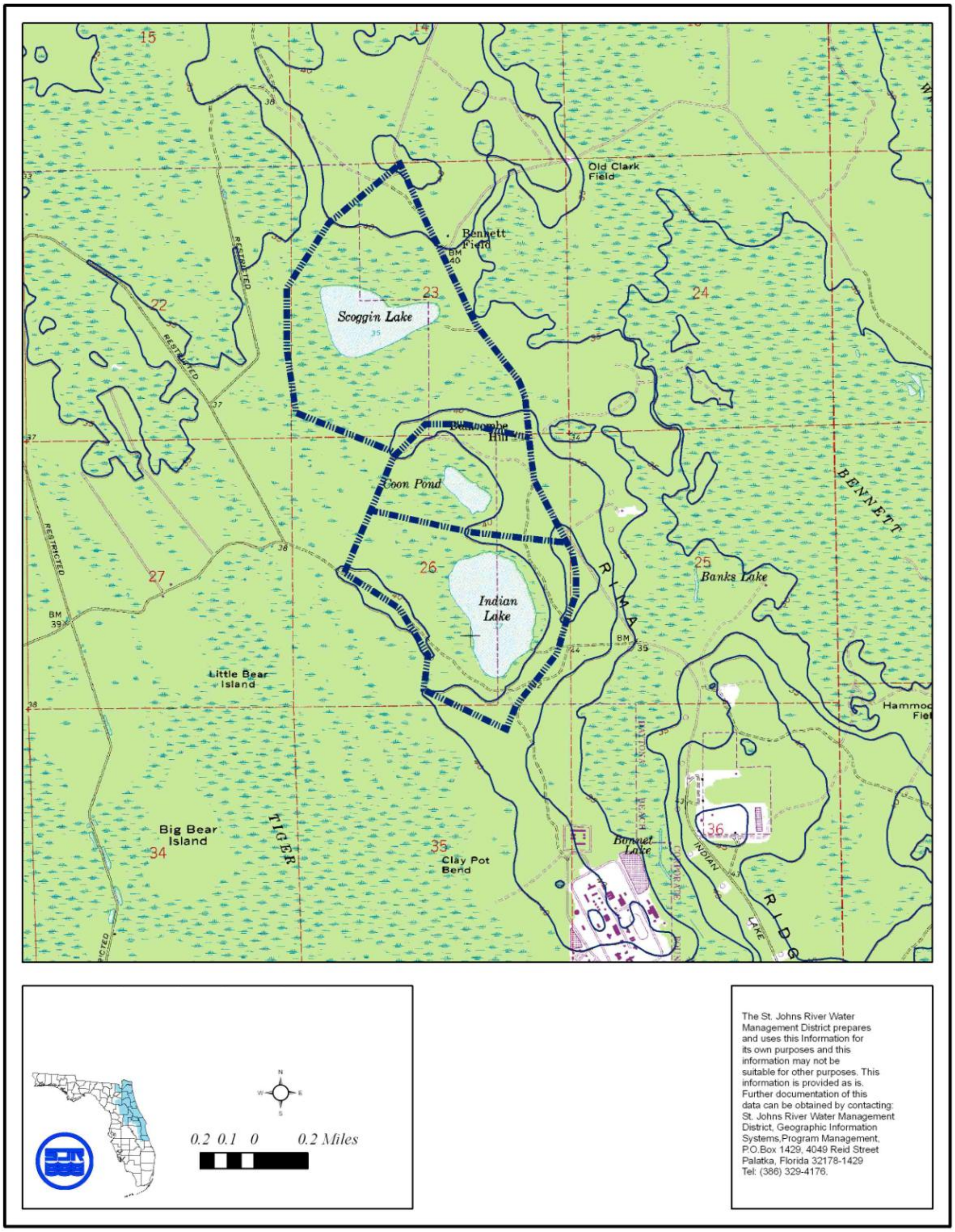

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Figure 3. Subbasins used in the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model

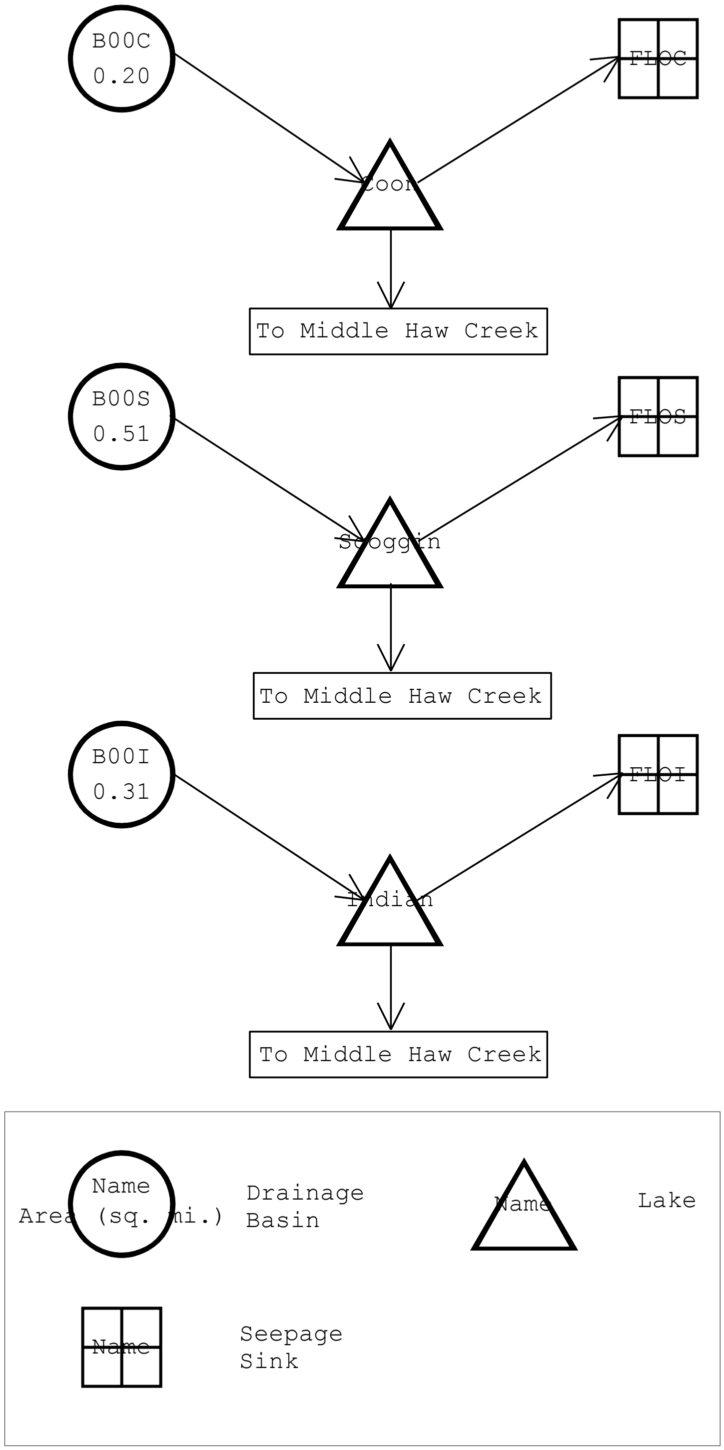

Figure 4. Schematic of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model

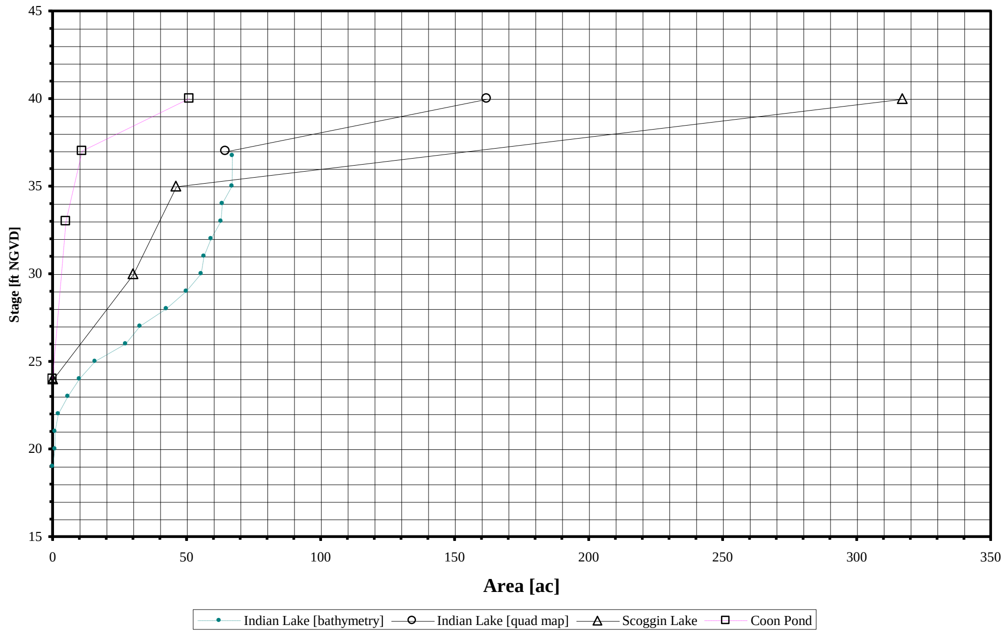

Figure 5. Stage area curves for the Indian Lake system

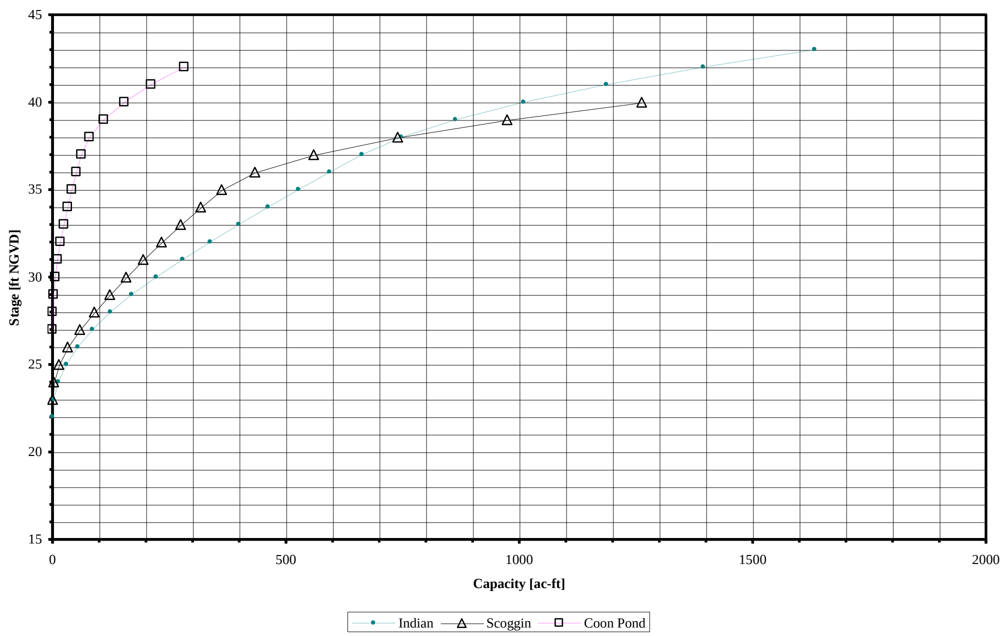

Figure 6. Stage capacity curves for the Indian Lake system

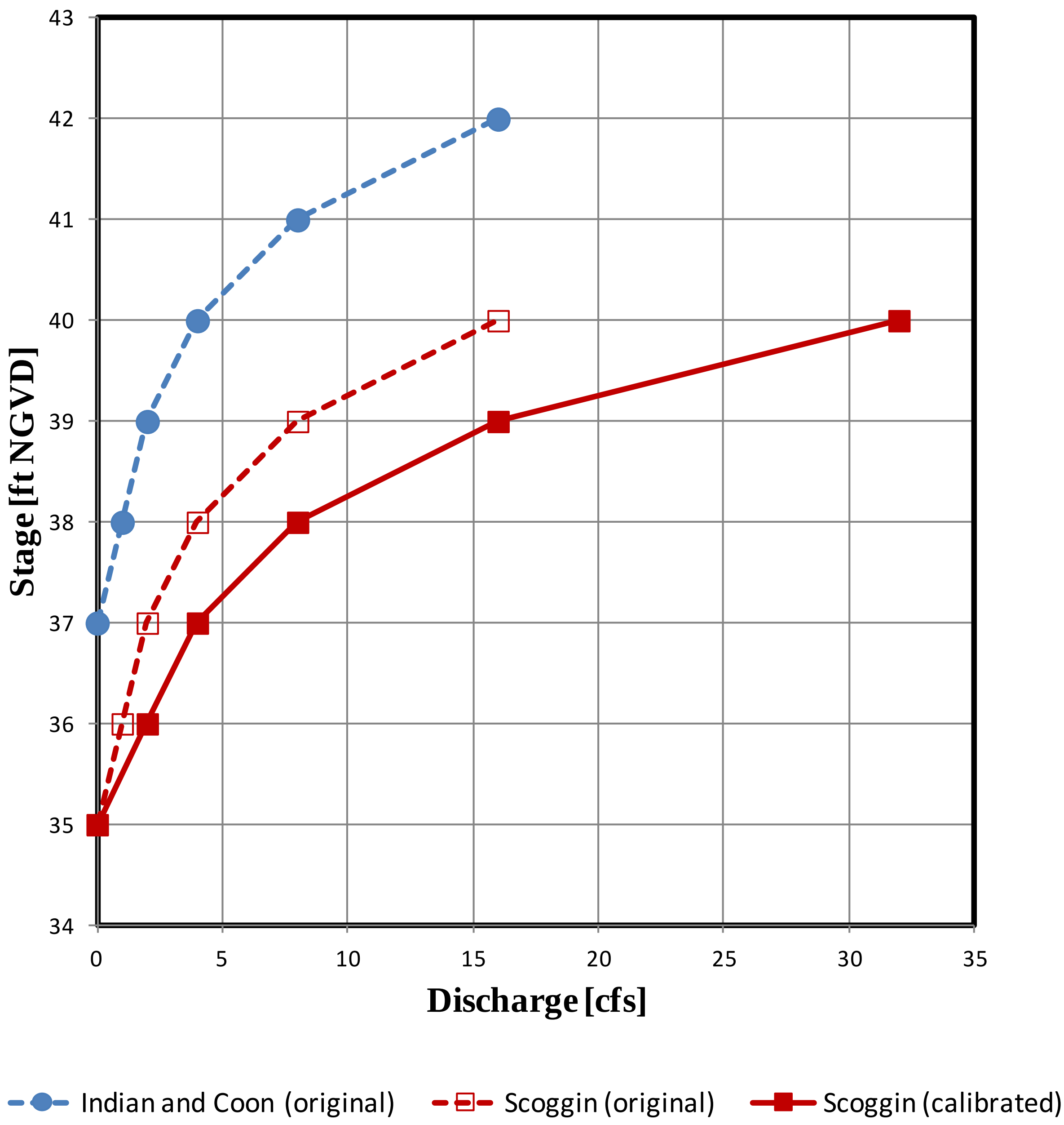

Figure 6a. Discharge rating curves for the Indian Lake system (cfs = cubic feet per second)

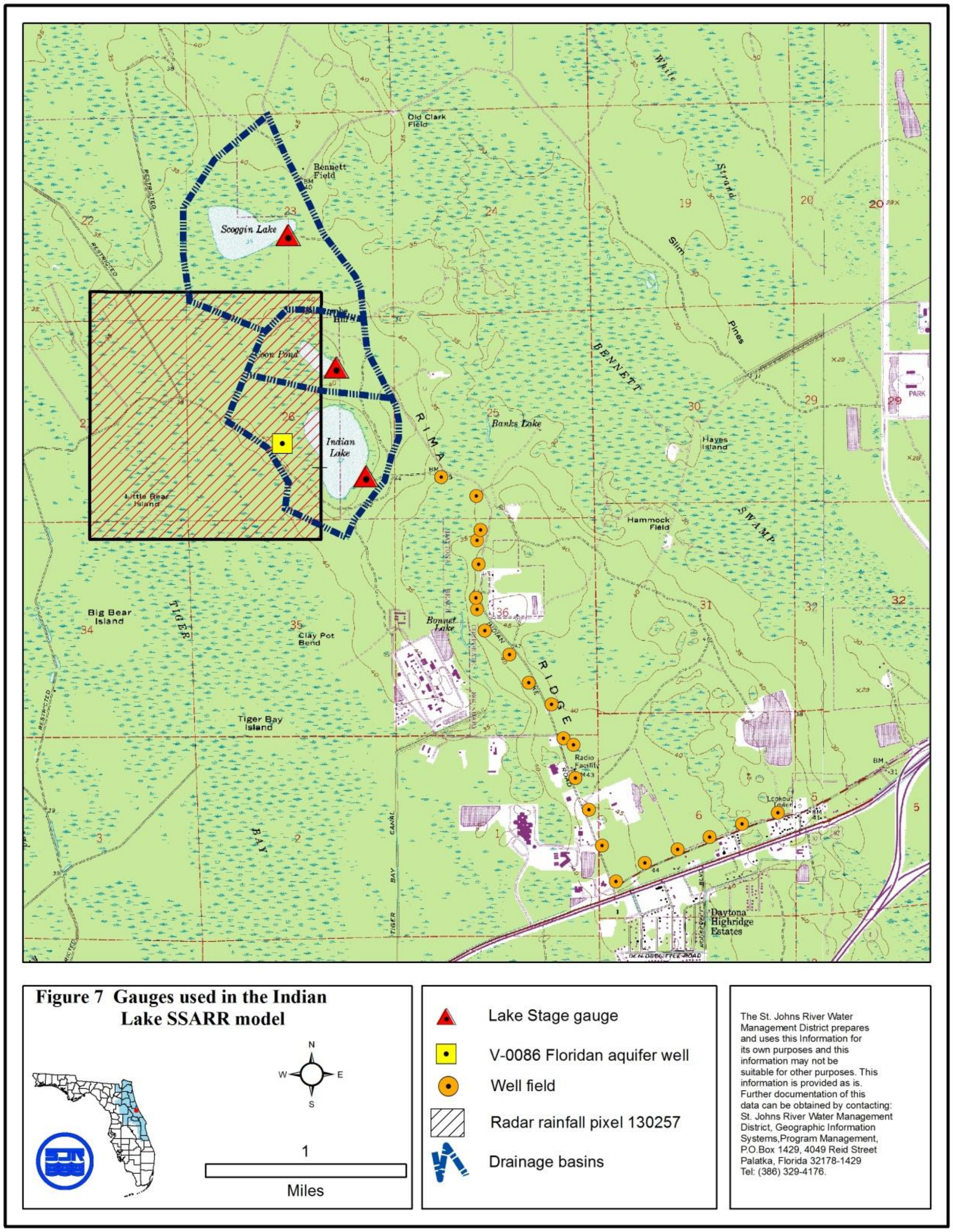

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Figure 7. Gauges used in the Indian Lake Streamflow Synthesis and Reservoir Regulation (SSAR) model

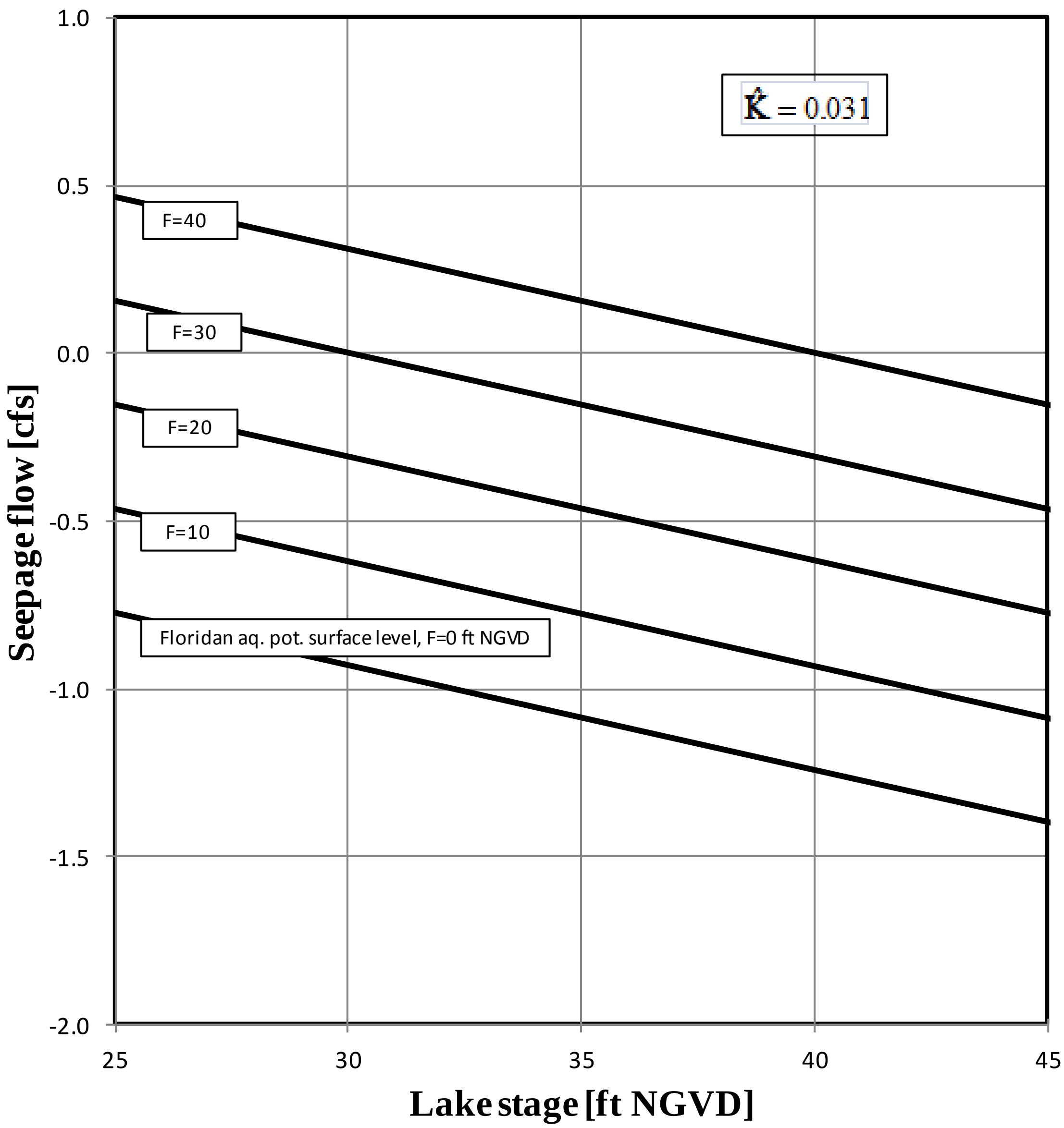


Figure 8. Graphical representation of the Darcy-based seepage relationship used in the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations. This particular set of curves corresponds to Indian Lake

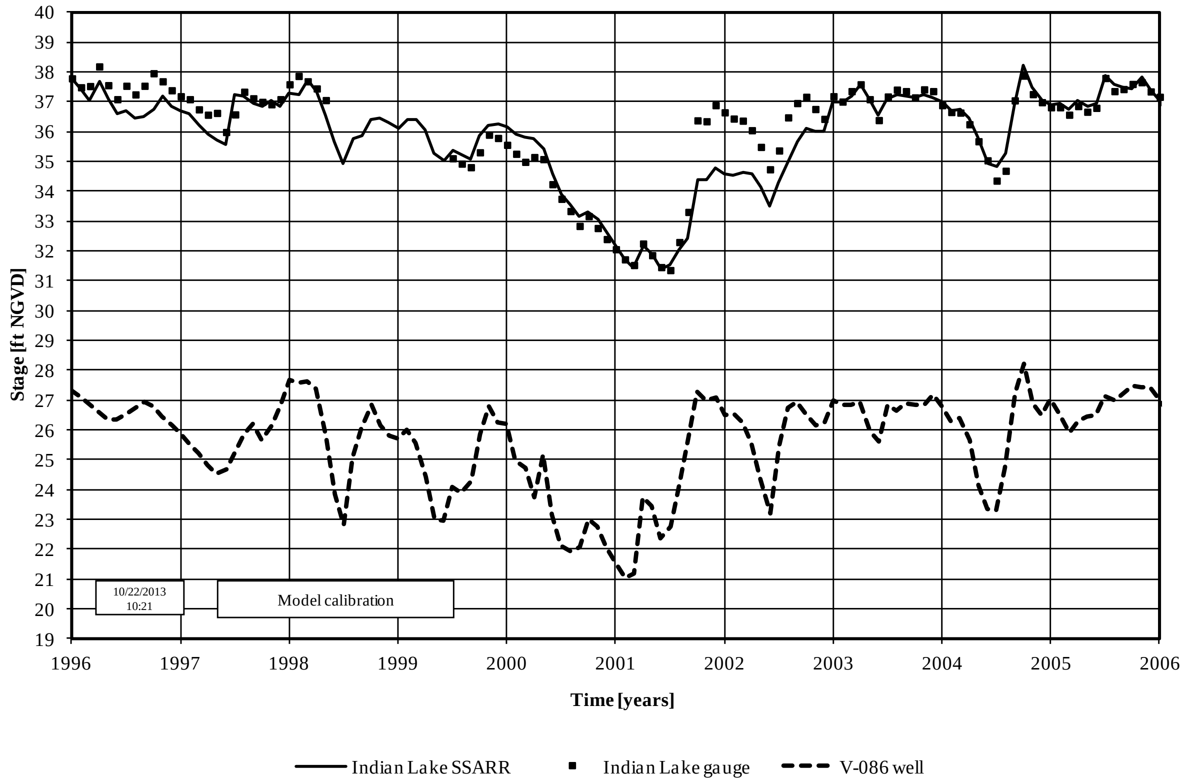


Figure 9. Observed and simulated hydrographs for Indian Lake from calibration of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model. Also shown is the V-0086 well hydrograph. These hydrographs correspond to start of month values

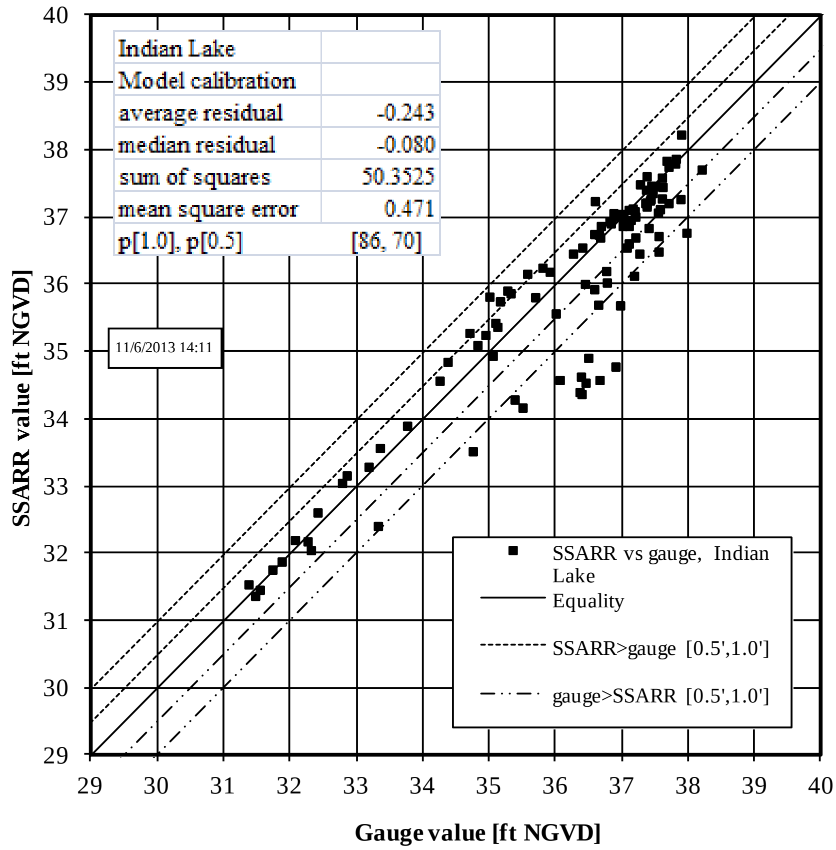


Figure 10. Scatter plot comparing simulated and observed stages for Indian Lake from calibration of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model (1996–2005). These values correspond to start of month stages

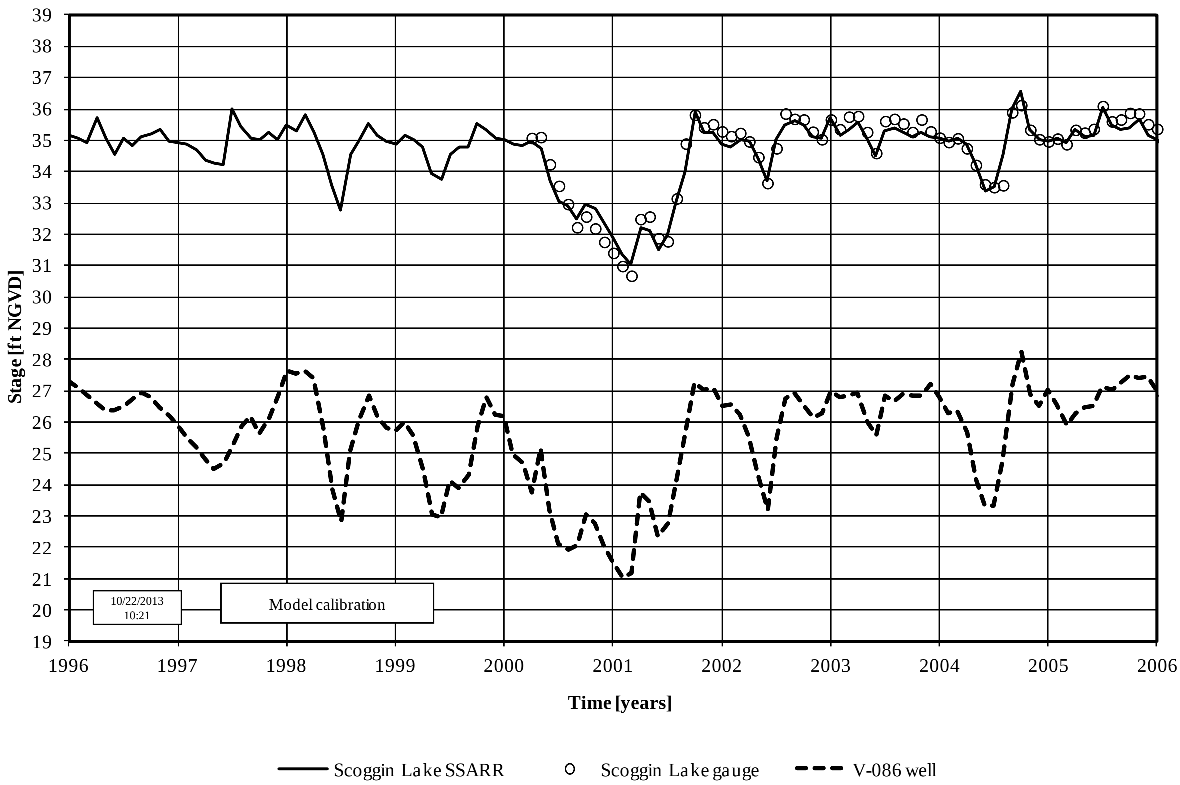


Figure 11. Observed and simulated hydrographs for Scoggin Lake from calibration of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model. Also shown is the V-0086 well hydrograph. These hydrographs correspond to start of month values

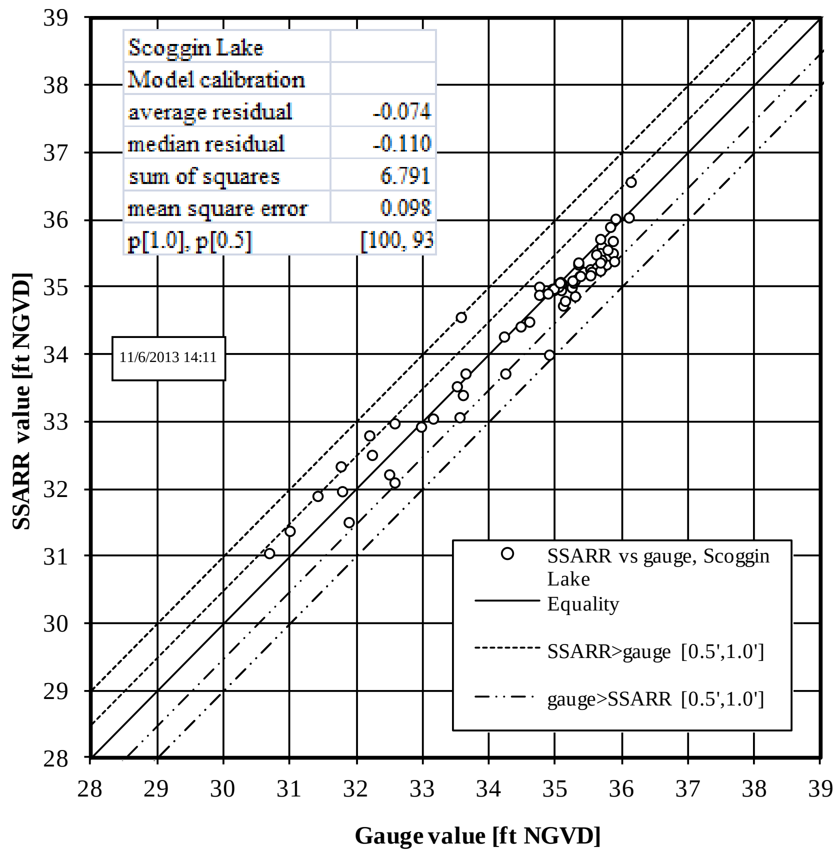


Figure 12. Scatter plot comparing simulated and observed stages for Scoggin Lake from calibration of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model (1996–2005). These values correspond to start of month stages

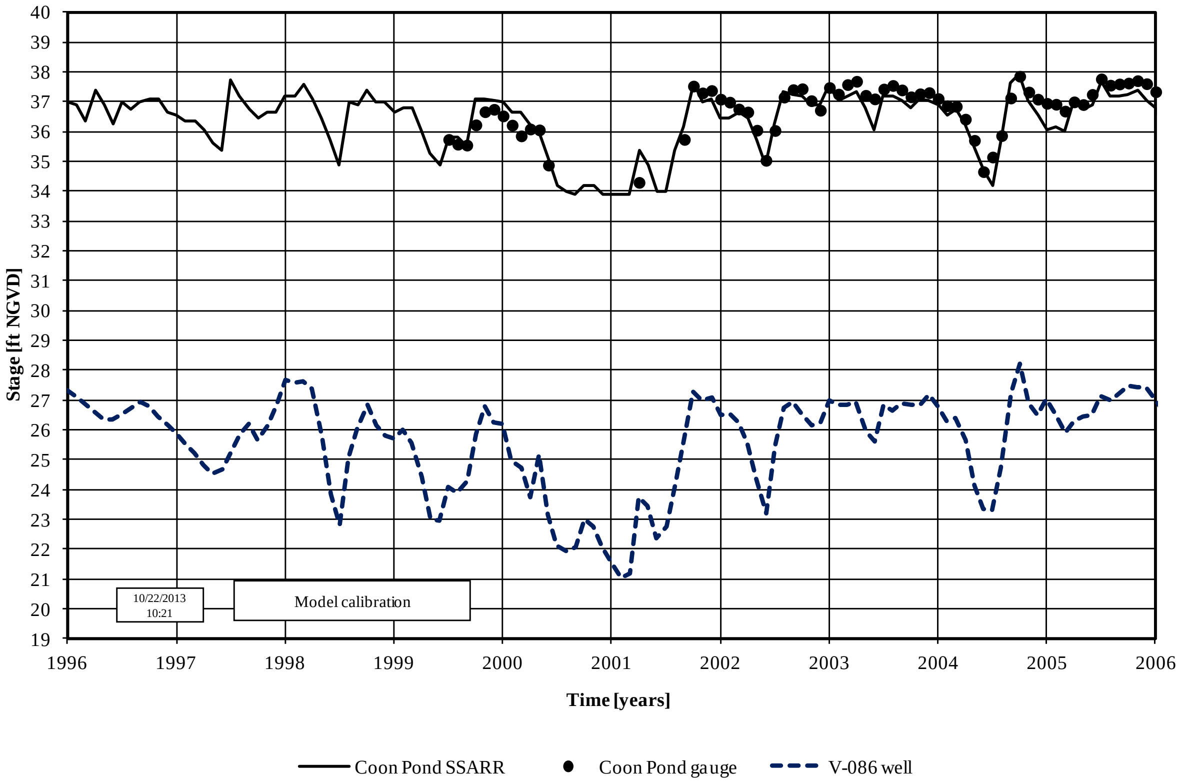


Figure 13. Observed and simulated hydrographs for Coon Pond from calibration of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model. Also shown is the V-0086 well hydrograph. These hydrographs correspond to start of month values

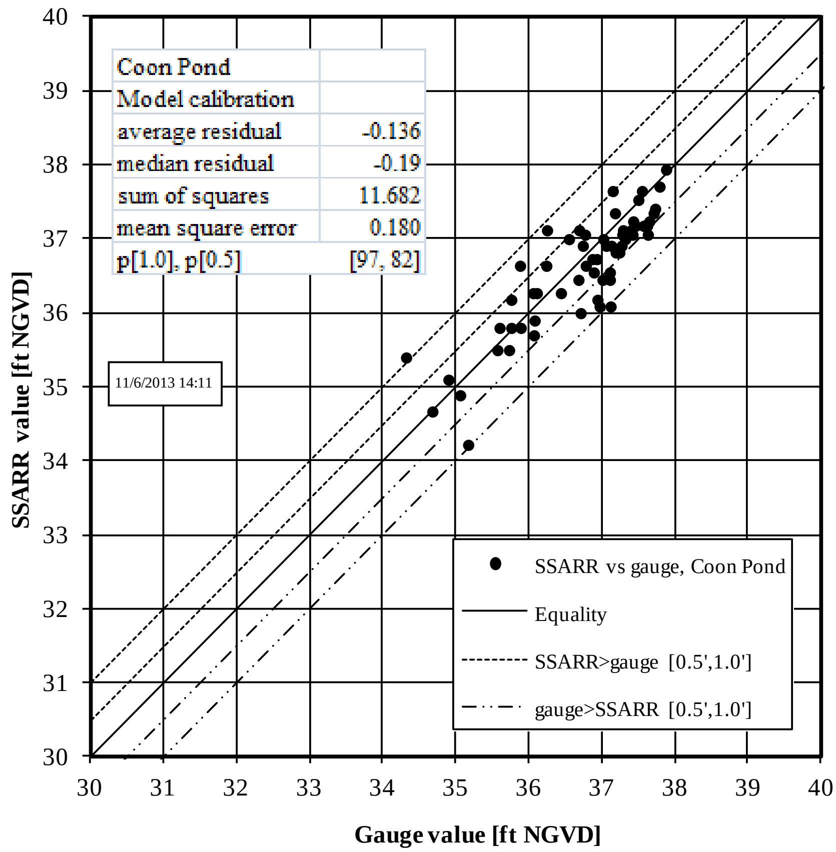


Figure 14. Scatter plot comparing simulated and observed stages for Coon Pond from calibration of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model (1996–2005). These values correspond to start of month stages

Assessment of Existing Hydrologic Conditions for the Indian Lake System in the Context of Minimum Flows and Levels (MFLs)

INTRODUCTION

The SJRWMD MFLs program relies on results of long-term hydrologic simulations to determine if MFLs are being met. The purpose of these simulations is to assess the characteristics of a water body over a wide variety of hydrologic conditions. Modeling results are compared to MFLs to ensure the levels are being met. It should be emphasized that the assumption inherent in this analysis is that the 30-year (1976–2005) data record used in the Indian Lake system SSARR model is a statistically realistic representation of the hydrology, absent significant anthropogenic or climatological changes, over the next 30 years. This chapter will address the following:

- Data composition of the long-term simulations for the Indian Lake system model
- Existing 2005 hydrologic conditions for Indian Lake system are assessed in the context of MFLs (2005 conditions) refers to a hypothetical case where long-term simulation assumes average groundwater withdrawals at 2005 levels

COMPOSITION OF THE LONG-TERM SIMULATIONS FOR THE INDIAN LAKE SYSTEM STREAMFLOW SYNTHESIS AND RESERVOIR REGULATION (SSARR) MODEL

Expansion of Indian Lake system simulations from the calibration years (1996–2005) to a long-term simulation requires extension of two time series: daily rainfall and daily Floridan aquifer potentiometric surface levels. All data used for model calibration were kept in the long-term simulations.

Daily rainfall recorded at the Daytona Beach NOAA station (see Table 1) was used to extend the rainfall record used in model calibration.

The V-0086 well used in calibration was also used for the long-term simulation (see Table 2, Figure 7). The period of record for this well limited the long-term simulations to 30 years (1976–2005).

The SJRWMD MFLs methodology includes double-mass analyses of well data to determine if significant historical drawdowns might be detected. In the present case, the analysis was performed using Daytona Beach rainfall and the V-0086 well (Figure 15). The slope of the trend line changes in about 1991 and may be an indication of the effect of the nearby Rima Ridge well field. To obtain an adjusted well hydrograph (Figure 16), the potentiometric values were lowered as indicated on the figure. This analysis indicates a total drawdown of some 3 ft. The adjustment covered the years between 1985 and 1990. The wells closest to Indian Lake were constructed in 1988 (Marc Minno, SJRWMD, pers. comm. 2006), so the times roughly correspond. The constant slope of the trend line after 1990 would be consistent with a fairly steady withdrawal rate. Put another way, from 1991 onward the well has reached a new long-term equilibrium. To better illustrate this process, the original and adjusted well hydrographs are shown in Figure 17. The assumption is that the adjusted well hydrograph represents well field conditions in 2005. Put another way, the adjusted hydrograph represents the approximate head that would have been measured at V-0086 if groundwater withdrawals would have occurred at post-1991 rates throughout the period of record. The long-term simulation used the adjusted well hydrograph.

Assessment of Existing Hydrologic Conditions for the Indian Lake System in the Context of MFLs

MFLs have been adopted by the SJRWMD for Indian Lake (Valentine-Darby 1998), Scoggin Lake (Mace 1999), and Coon Pond (Hall 1999). In addition, revised MFLs have been recommended for Indian Lake (Mace 2010). A MFH, a MA, and a MFL have been adopted (or recommended in the case of Indian Lake) for each of these lakes. Each of these MFLs is tied to characteristic durations and frequencies of occurrence , and all MFLs have been listed in Table 7. A more detailed description of the hydrologic analyses required to determine these frequencies and durations can be found in Appendix A of this report.

Indian Lake: Long-term Simulation and MFLs

Hydrographs for the long-term simulation of Indian Lake and the corresponding gauge record are shown in Figure 18.

The adopted MFH level for Indian Lake is 37.0 ft NGVD. Based on SJRWMD guidelines, this elevation should remain continuously wet for at least 30 days at least once every 3 years on average (at least 33% of the years).

The adopted MA level for Indian Lake is 36.1 ft NGVD. Based on SJRWMD guidelines, the lake should maintain this average low level for at most 180 days no more often than once every 1.7 years on average (at most 59% of the years).

The adopted MFL level for Indian Lake is 34.4 ft NGVD. Based on SJRWMD guidelines, this elevation should remain dry continuously for at most 120 days no more often than once every 5 years on average (at most 20% of the years).

To obtain a better understanding of the relationship between MFLs and the hydrology of a lake, MFLs can be examined in three different ways: 1) in the context of the long-term hydrograph of a lake, 2) in the context of the stage-duration curve of a lake, and/or 3) in the context of the frequency of events pertinent to each minimum level.

Figure 18 shows the Indian Lake MFLs superimposed on the long-term simulated hydrograph. In this context, one can see that the stage of a lake can remain above or below each of the MFLs for extended periods.

Figure 19 shows the Indian Lake MFLs superimposed on the stage-duration curve of the long-term simulation. From this representation of the MFLs, one can see that the three levels, in a sense, anchor the hydrology of the lake.

However, in the SJRWMD MFLs method, the ultimate determination of whether or not MFLs are being met is made through frequency analysis. Based on modeling results, the MFH (Figure 20), MA (Figure 21), and MFL (Figure 22) levels for Indian Lake are not being met under 2005 conditions. (For a description of SJRWMD MFLs concepts and procedures involved here see Appendix A.) If any pertinent event lies within the shaded box the minimum level is being met. As required by SJRWMD MFLs procedures, a re-evaluation of Indian Lake MFLs was started in 2007. Based on the re-evaluation, the District is recommending a MFH of 36.2 ft NGVD, a MA of 35.0 ft NGVD, and a MFL of 32.8 ft NGVD (Figures 18 through 22). All three of these levels are being met under 2005 conditions.

Scoggin Lake: Long-term Simulation and MFLs

Hydrographs for the long-term simulation of Scoggin Lake and the corresponding gauge record are shown in Figure 23.

The adopted MFH level for Scoggin Lake is 35.0 ft NGVD. Based on SJRWMD guidelines, this elevation should remain continuously wet for at least 30 days at least once every 3 years on average (at least 33% of the years).

The adopted MA level for Scoggin Lake is 34.1 ft NGVD. Based on SJRWMD guidelines, the lake should maintain this average low level for at most 180 days no more often than once every 1.7 years on average (at most 59% of the years).

The adopted MFL level for Scoggin Lake is 32.7 ft NGVD. Based on SJRWMD guidelines, this elevation should remain dry continuously for at most 120 days no more often than once every 5 years on average (at most 20% of the years).

Figure 23 shows the Scoggin Lake MFLs superimposed on the long-term simulated hydrograph. Figure 24 shows the Scoggin Lake MFLs superimposed on the stage-duration curve of the long-term simulation.

Based on modeling results, the MFH (Figure 25), MA (Figure 26), and MFL (Figure 27) levels for Scoggin Lake are being met under 2005 conditions. (For a description of SJRWMD MFLs concepts and procedures involved here see Appendix A.)

Coon Pond: Long-term Simulation and MFLs

Hydrographs for the long-term simulation of Coon Pond and the corresponding gauge record are shown in Figure 28.

The adopted MFH level for Coon Pond is 35.7 ft NGVD. Based on SJRWMD guidelines, this elevation should remain continuously wet for at least 30 days at least once every 3 years on average (at least 33% of the years).

The adopted MA level for Coon Pond is 34.6 ft NGVD. Based on SJRWMD guidelines, the lake should maintain this average low level for at most 180 days no more often than once every 1.7 years on average (at most 59% of the years).

The adopted MFL level for Coon Pond is 33.1 ft NGVD. Based on SJRWMD guidelines, this elevation should remain dry continuously for at most 120 days no more often than once every 5 years on average (at most 20% of the years).

Figure 28 shows the Coon Pond MFLs superimposed on the long-term simulated hydrograph. Figure 29 shows the Coon Pond MFLs superimposed on the stage-duration curve of the long-term simulation.

Based on modeling results, the MFH (Figure 30), MA (Figure 31), and MFL (Figure 32) levels for Coon Pond are being met under 2005 conditions. (For a description of SJRWMD MFLs concepts and procedures involved here see Appendix A.)

Table 6. Modeling parameters used in different Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) simulations

Simulation	Rainfall Station	Floridan Aquifer Well	Pan Evaporation Station
Calibration	OneRain radar Pixel 130257 (1996–2005)	V-0086	Lisbon
2005 conditions (1976–2005)	Daytona Beach (1976–95) OneRain radar Pixel 130257 (1996–2005)	V-0086	Lisbon

Table 7. Summary of minimum flows and levels (MFLs) for the Indian Lake system

Minimum Flows and Levels	Level (ft NGVD*)	Duration (days)	Series	Water Year	Statistical Type	Minimum Return period	Maximum Return period
Indian Lake (Adopted)							
Minimum frequent high	37.0	30	Annual	Jun 1–May 31	Maximum, continuously exceeded	NA†	3 yrs
Minimum average	36.1	180	Annual	Oct 1–Sep 30	Minimum mean, not exceeded	1.7 yrs	NA
Minimum frequent low	34.4	120	Annual	Oct 1–Sep 30	Minimum, continuously not exceeded	5 yrs	NA
Indian Lake (Recommended)							
Minimum frequent high	36.2	30	Annual	Jun 1–May 31	Maximum, continuously exceeded	NA	3 yrs
Minimum average	35.0	180	Annual	Oct 1–Sep 30	Minimum mean, not exceeded	1.7 yrs	NA
Minimum frequent low	32.8	120	Annual	Oct 1–Sep 30	Minimum, continuously not exceeded	5 yrs	NA
Scoggin Lake (Adopted)							
Minimum frequent high	35.0	30	Annual	Jun 1–May 31	Maximum, continuously exceeded	NA	3 yrs
Minimum average	34.1	180	Annual	Oct 1–Sep 30	Minimum mean, not exceeded	1.7 yrs	NA
Minimum frequent low	32.7	120	Annual	Oct 1–Sep 30	Minimum, continuously not exceeded	5 yrs	NA
Coon Pond (Adopted)							
Minimum frequent high	35.7	30	Annual	Jun 1–May 31	Maximum, continuously exceeded	NA	3 yrs
Minimum average	34.6	180	Annual	Oct 1–Sep 30	Minimum mean, not exceeded	1.7 yrs	NA

Minimum Flows and Levels	Level (ft NGVD*)	Duration (days)	Series	Water Year	Statistical Type	Minimum Return period	Maximum Return period
Minimum frequent low	33.1	120	Annual	Oct 1–Sep 30	Minimum, continuously not exceeded	5 yrs	NA

*ft NGVD = feet National Geodetic Datum
†NA = Not applicable

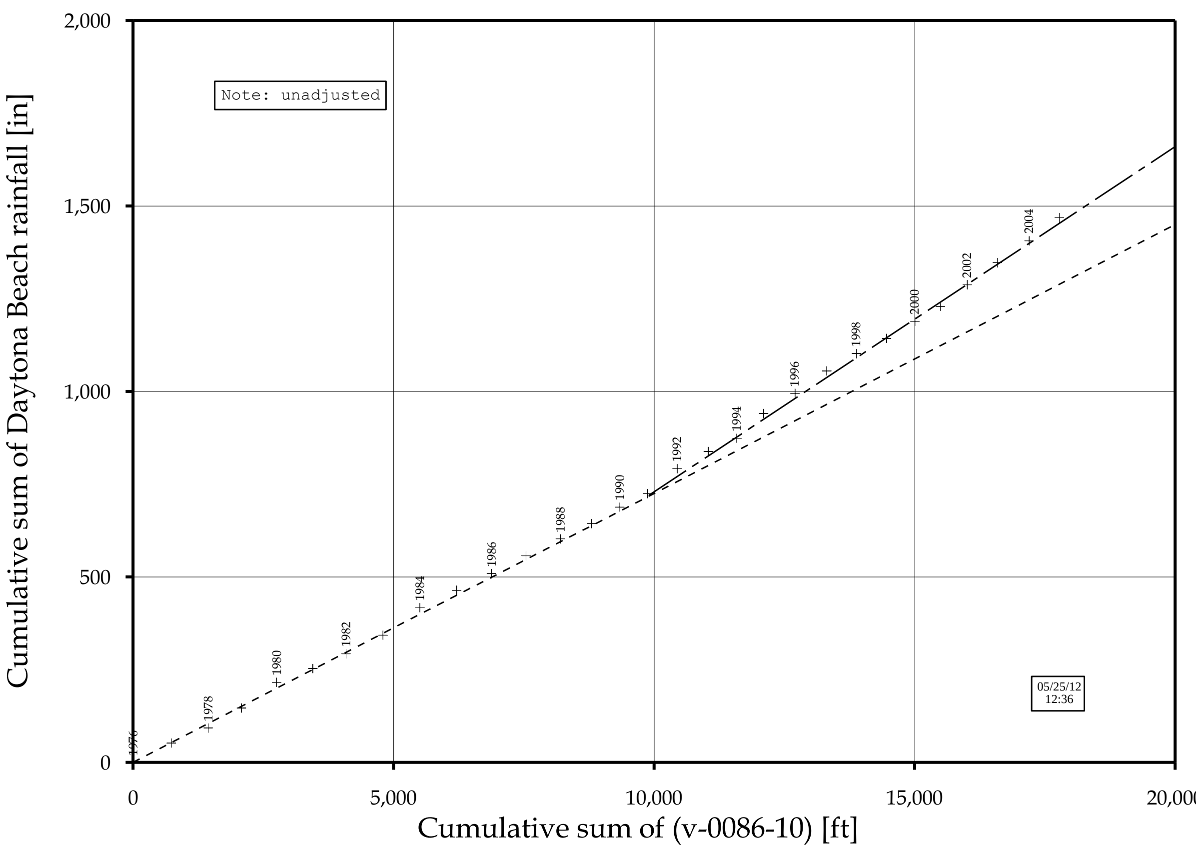


Figure 15. Double mass curve analysis for the V-0086 well versus Daytona Beach rainfall. The data show two distinct trends, changing in about 1991

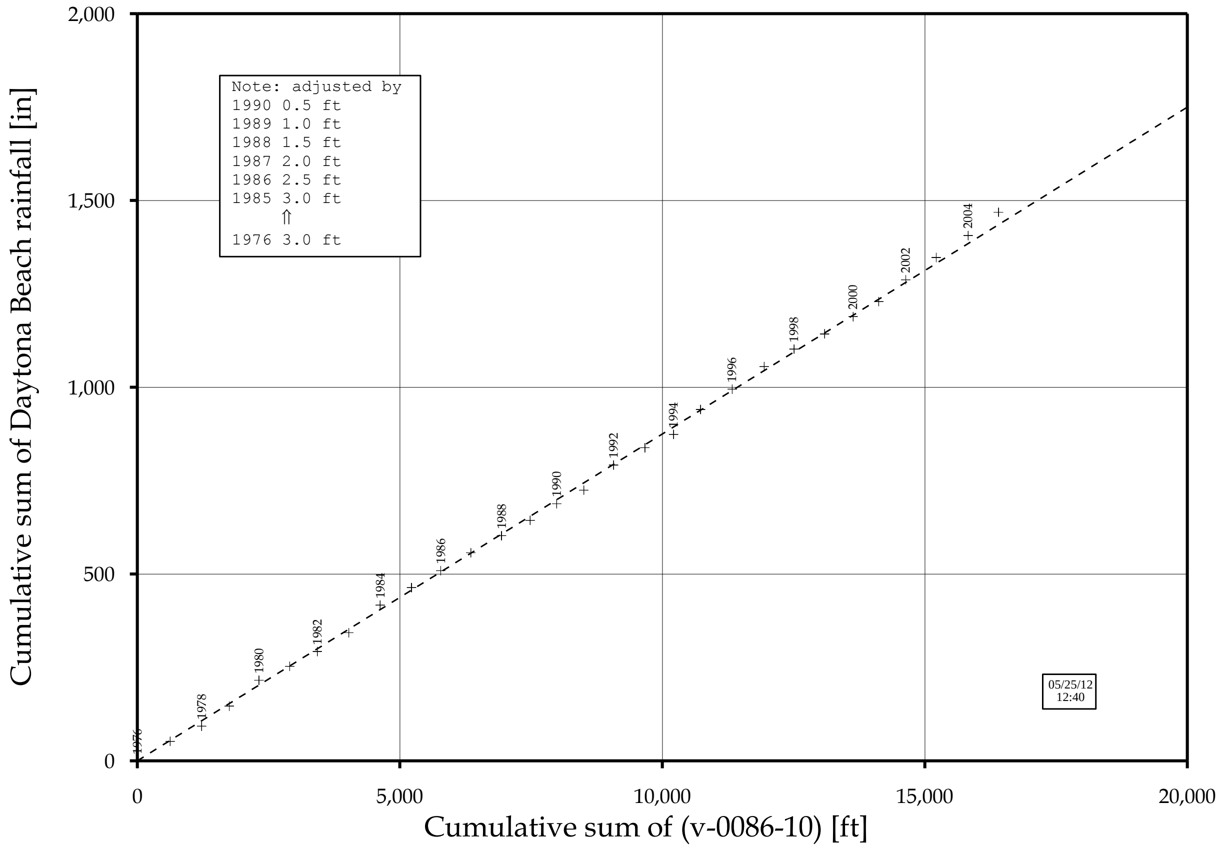


Figure 16. Double mass curve analysis for the adjusted V-0086 well versus Daytona Beach rainfall. To obtain a straight line for the entire period of record, well readings were adjusted (reduced) as noted in the inset note

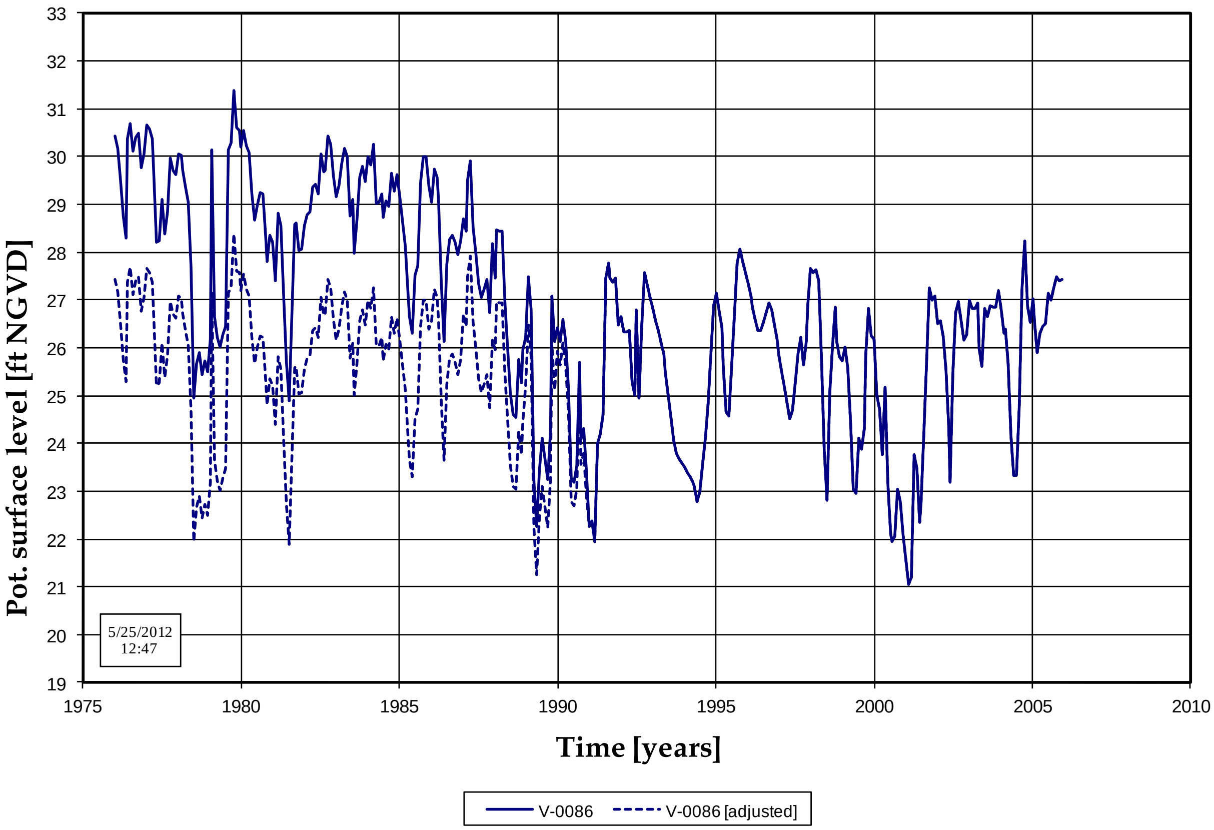


Figure 17. Illustration of the well adjustment process represented in Figures 15 and 16. The final Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model included the adjusted well hydrograph

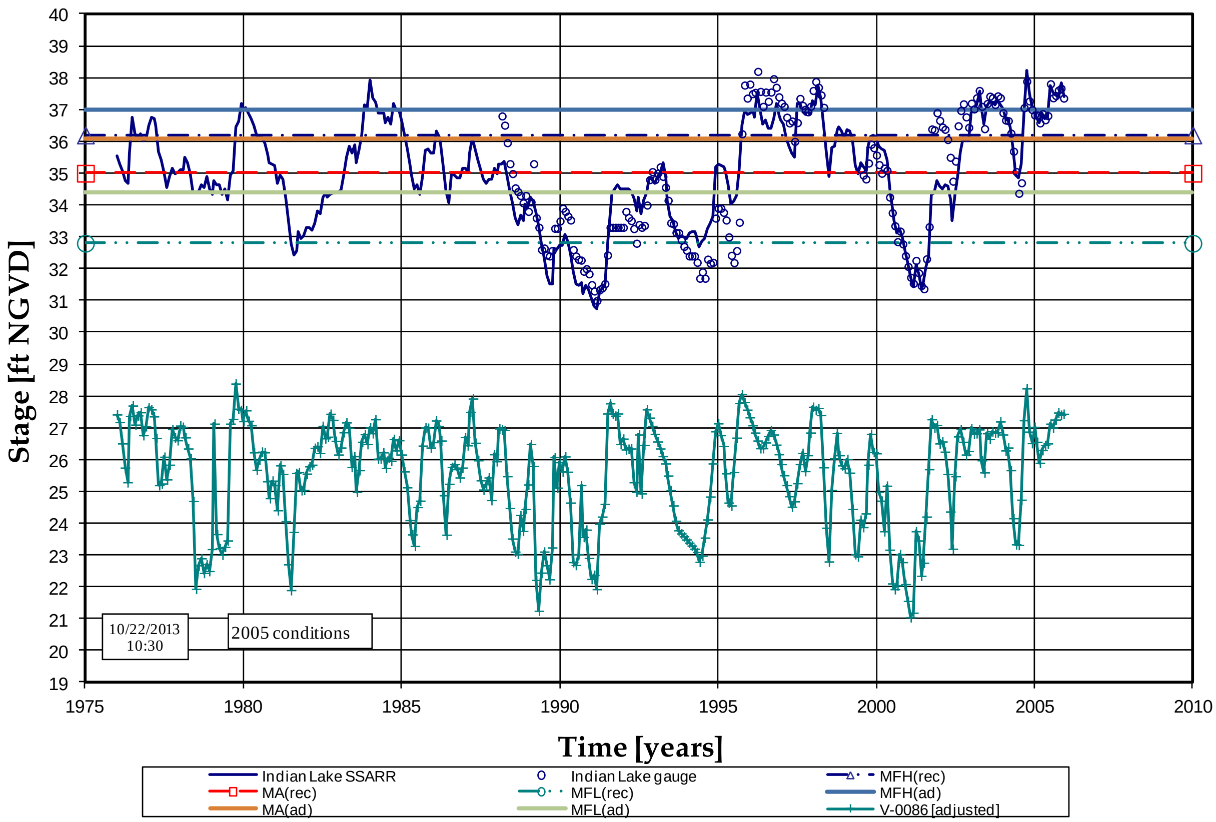


Figure 18. Hydrograph for the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation of Indian Lake. These values correspond to start of month stages. The adopted and recommended Indian Lake MFLs are superimposed

Note:
MA = minimum average
MFL = minimum frequent low
MFH = minimum frequent high
rec = recommended
ad = adopted

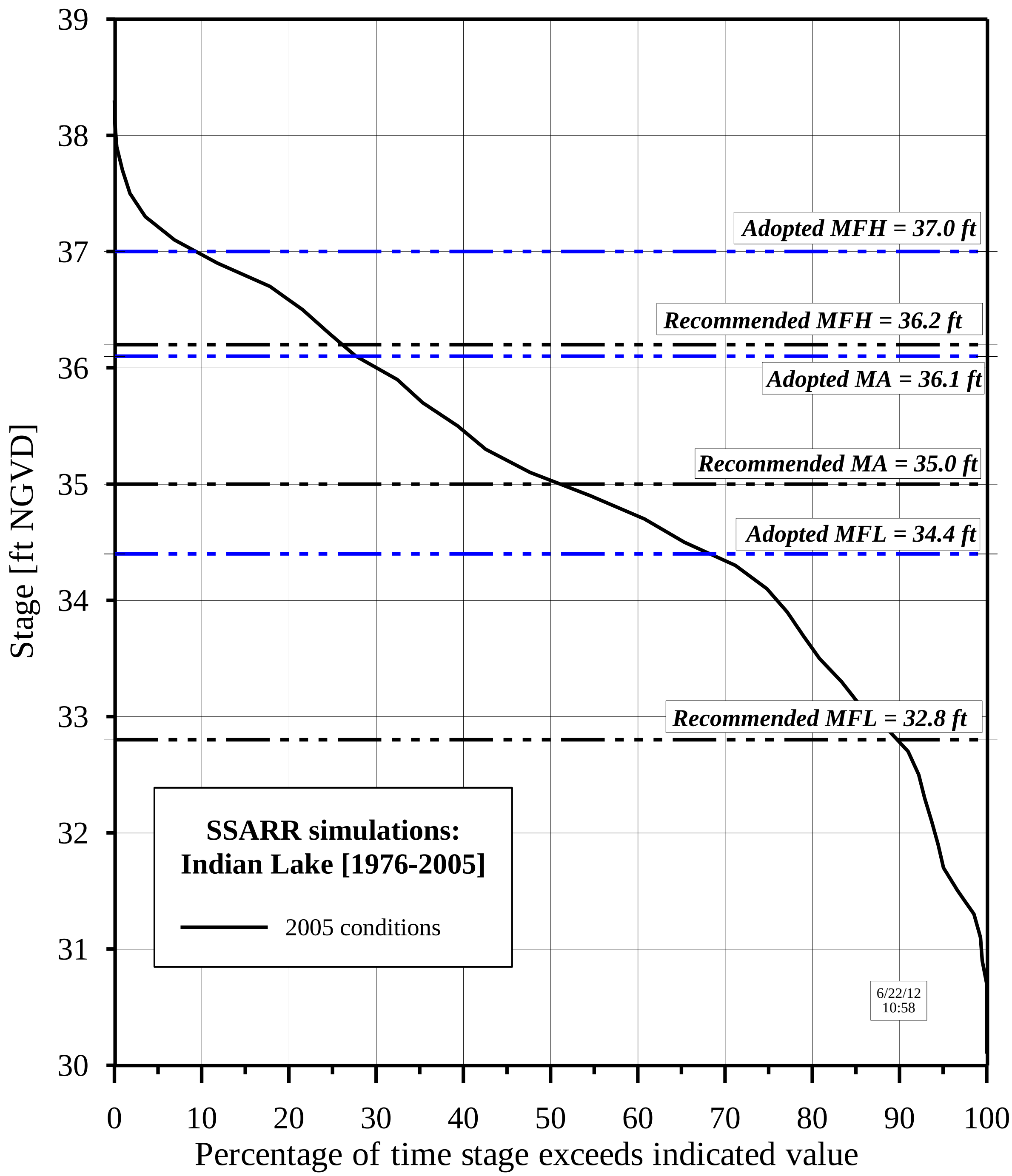


Figure 19. Stage duration curve from Streamflow Synthesis and Reservoir Regulation (SSARR) simulation of Indian Lake. The adopted and recommended minimum flows and levels (MFLs) are superimposed

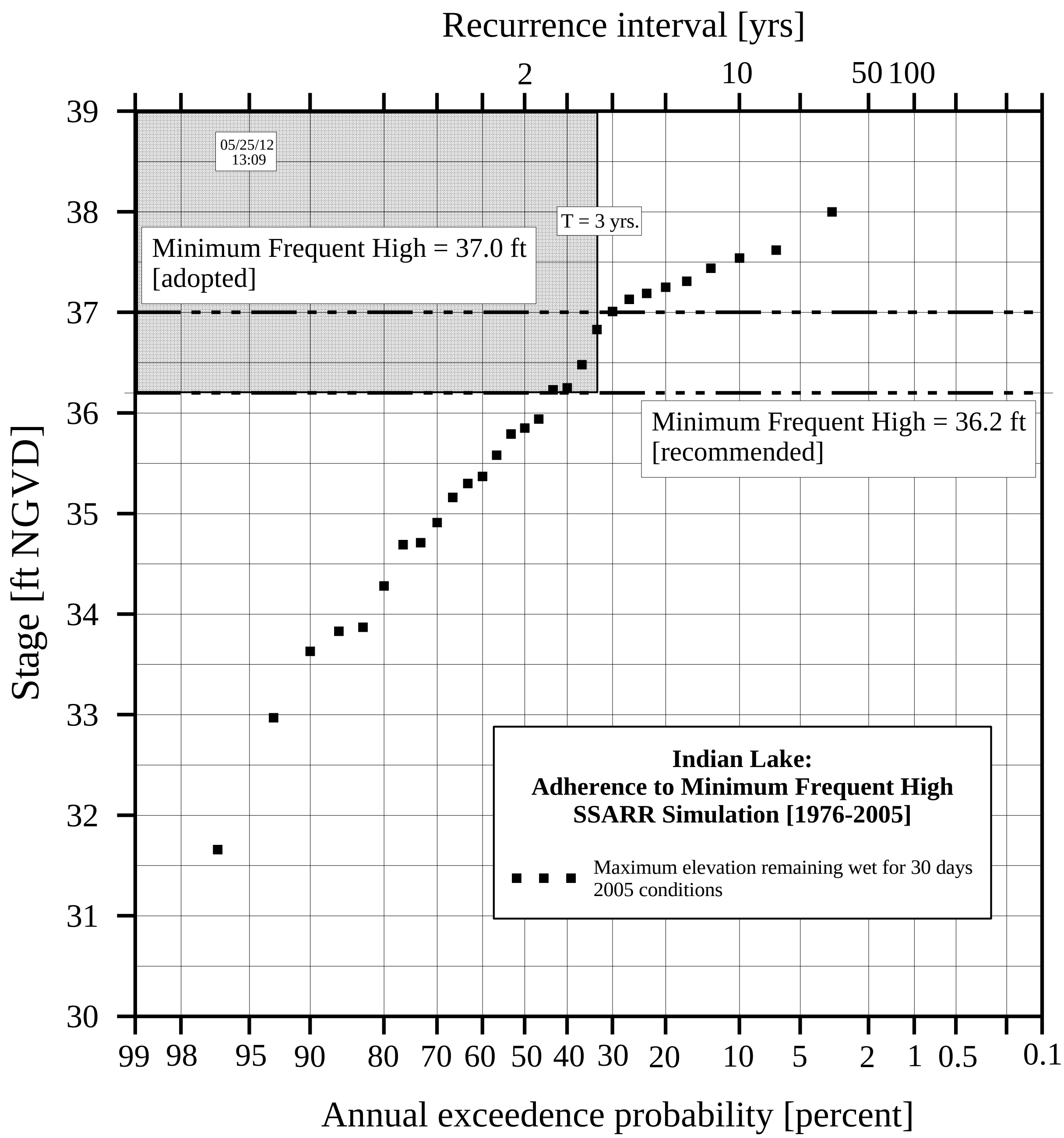


Figure 20. The adopted and recommended minimum frequent high (MFH) levels for Indian Lake as they relate to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

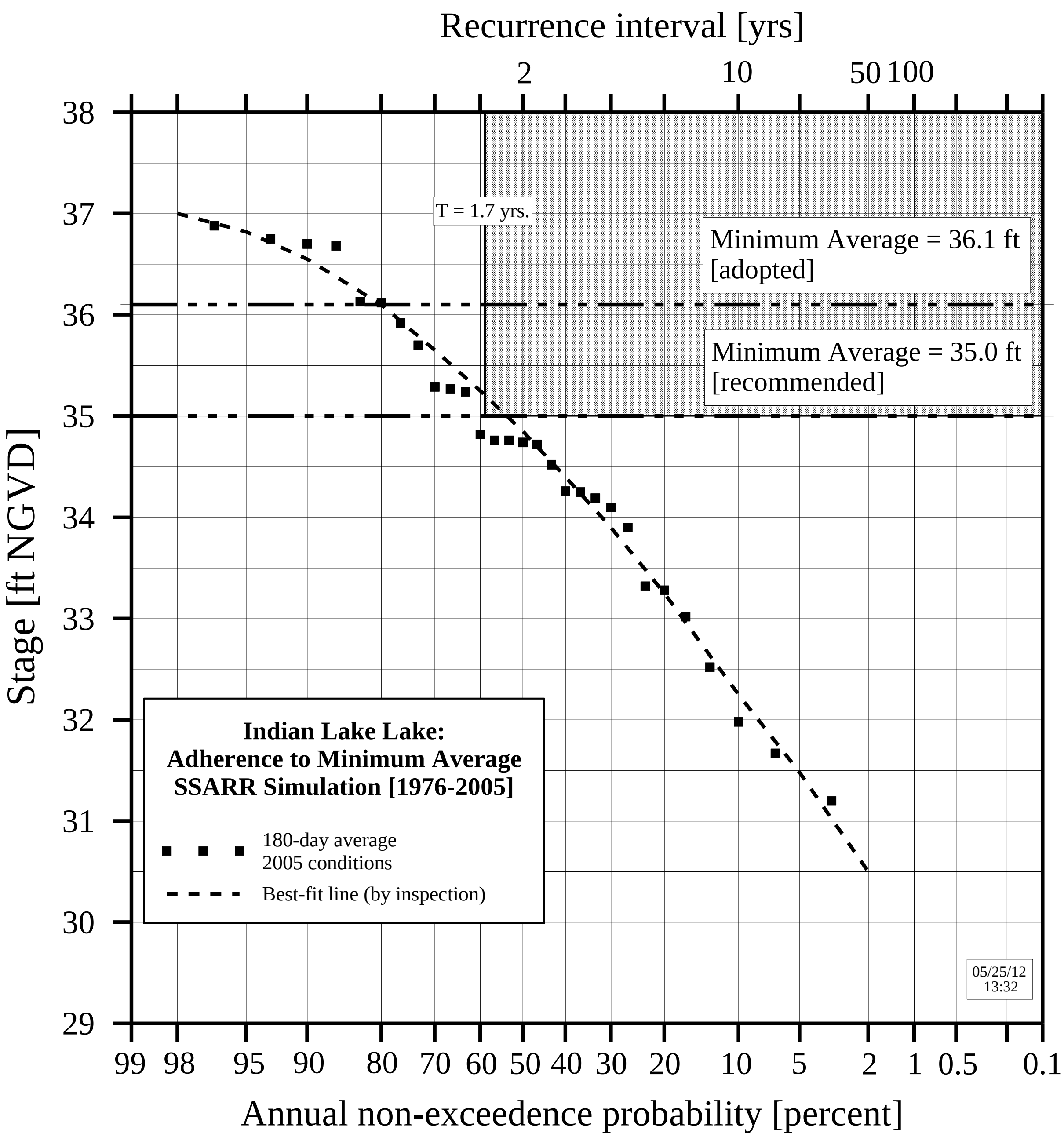


Figure 21. The adopted and recommended minimum average (MA) levels for Indian Lake as they relate to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

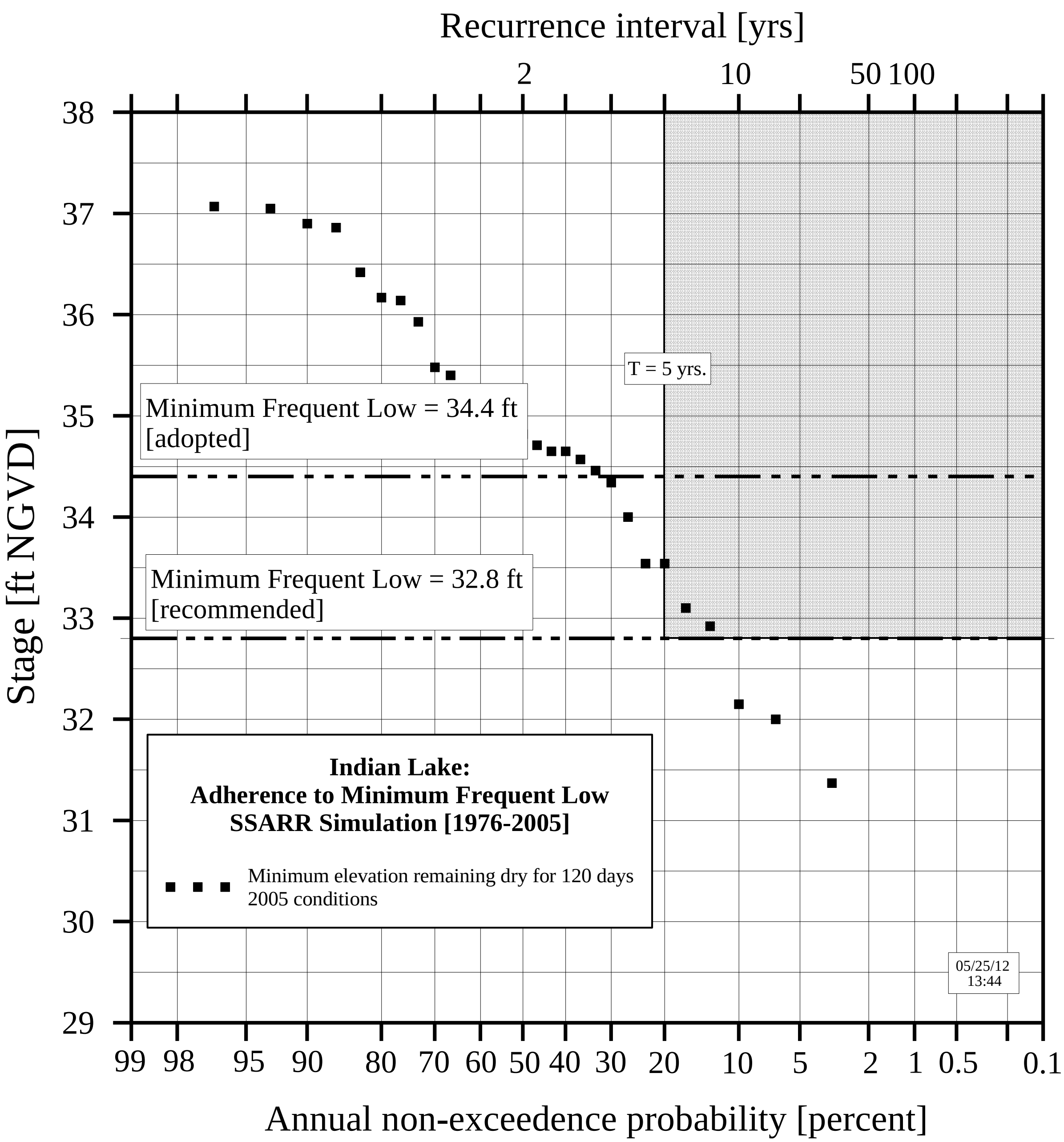


Figure 22. The adopted and recommended minimum frequent low (MFL) levels for Indian Lake as they relate to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

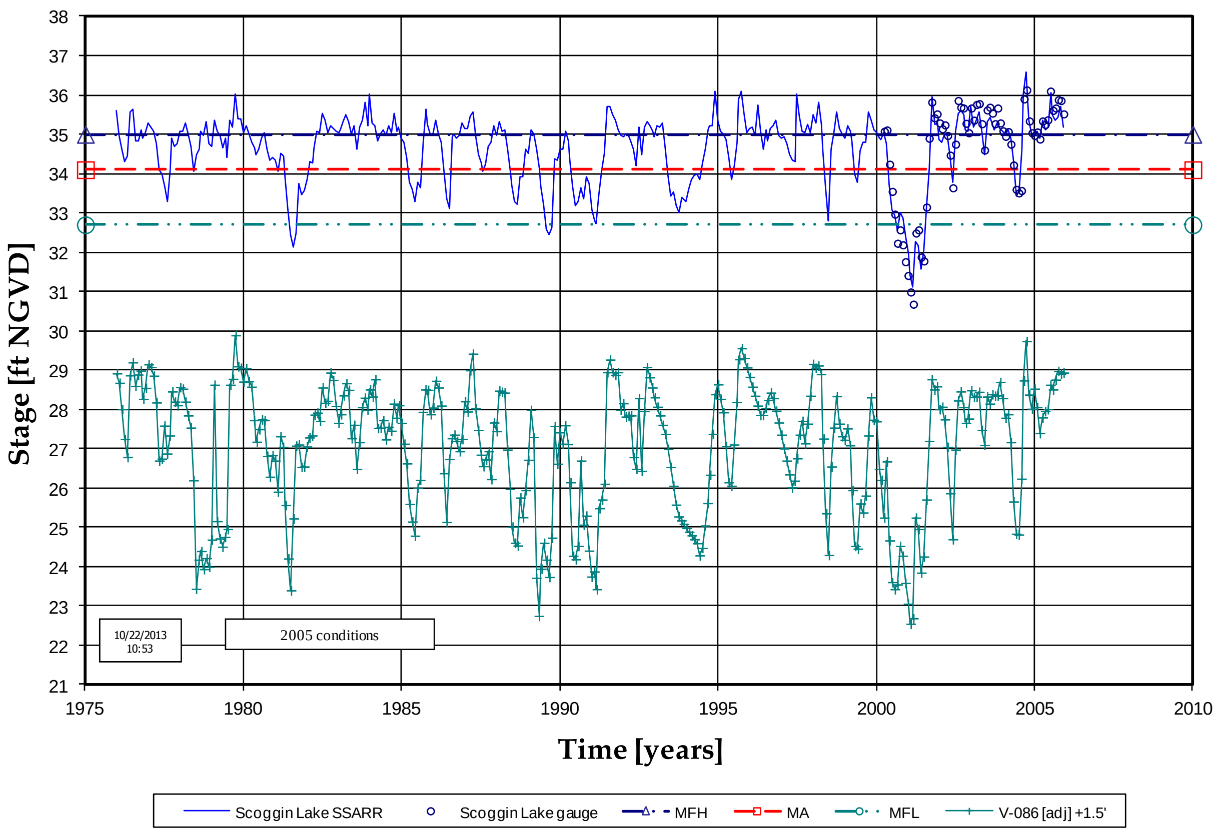


Figure 23. Hydrograph for the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation of Scoggin Lake. These values correspond to start of month stages. The Scoggin Lake minimum flows and levels (MFLs) are superimposed

Note:
MFH = minimum frequent high
MA = minimum average
MFL = minimum frequent low

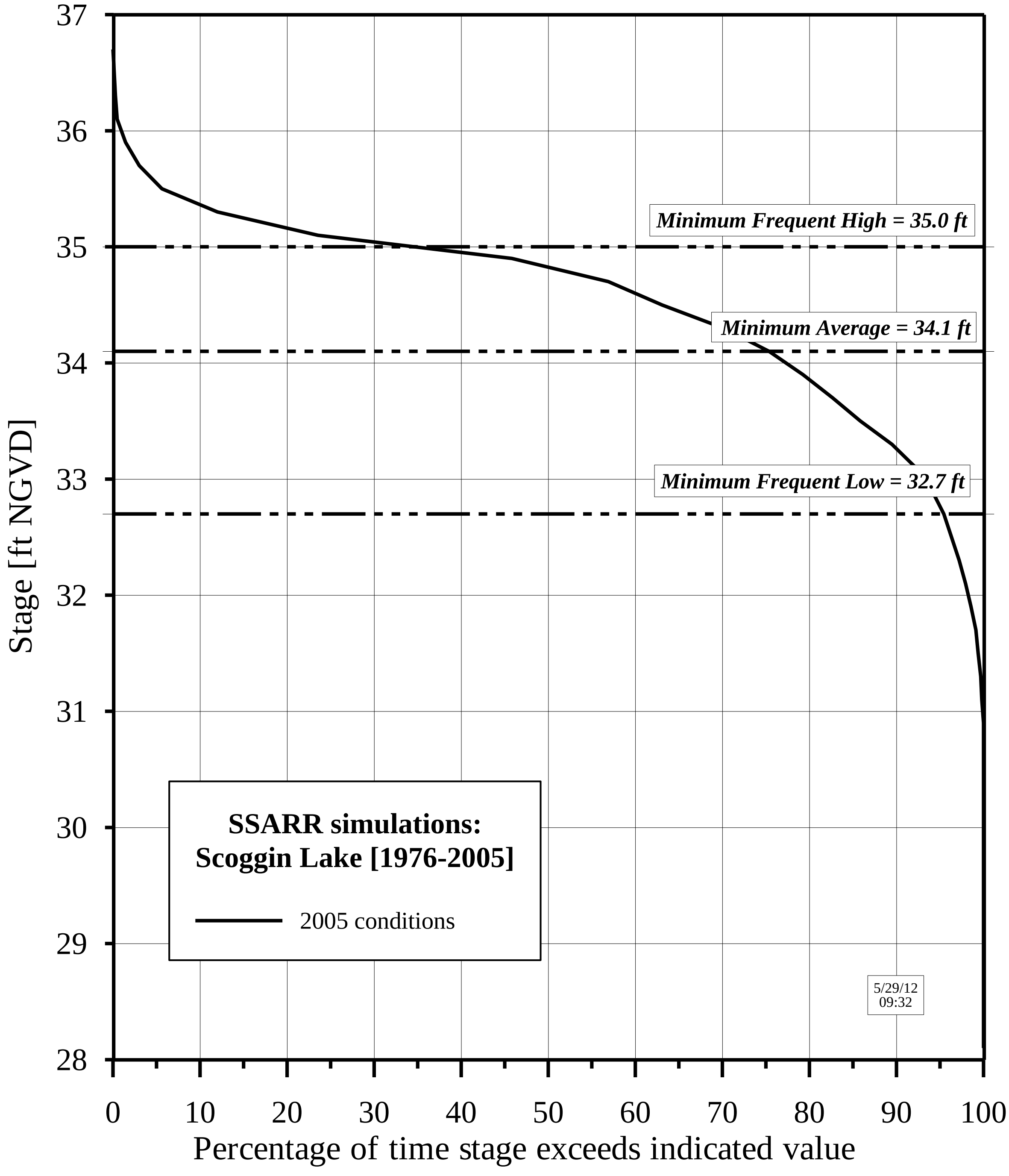


Figure 24. Stage duration curve from the Streamflow Synthesis and Reservoir Regulation (SSARR) simulation of Scoggin Lake. The minimum flows and levels (MFLs) are superimposed

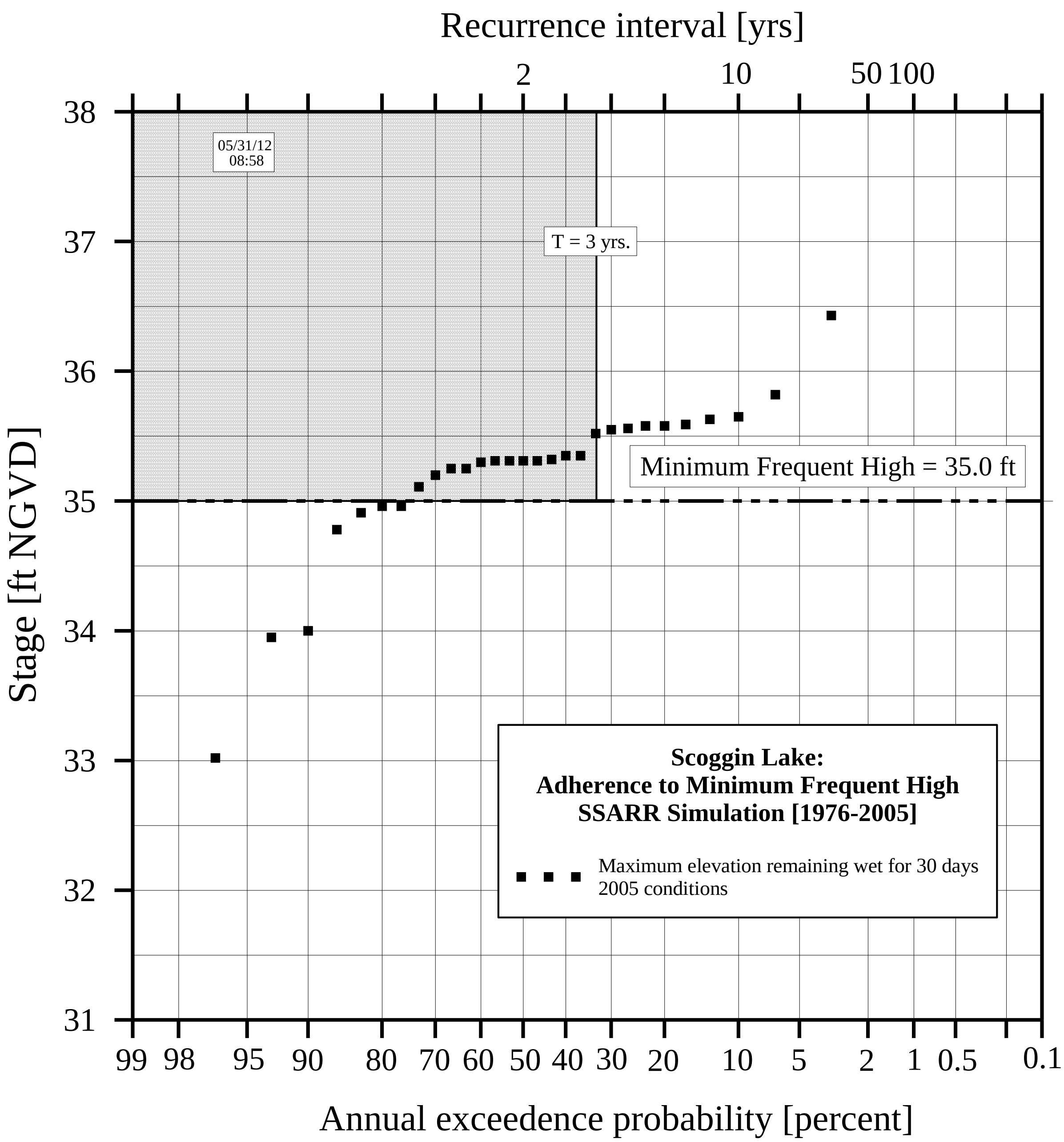


Figure 25. The minimum frequent high (MFH) level for Scoggin Lake as it relates to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

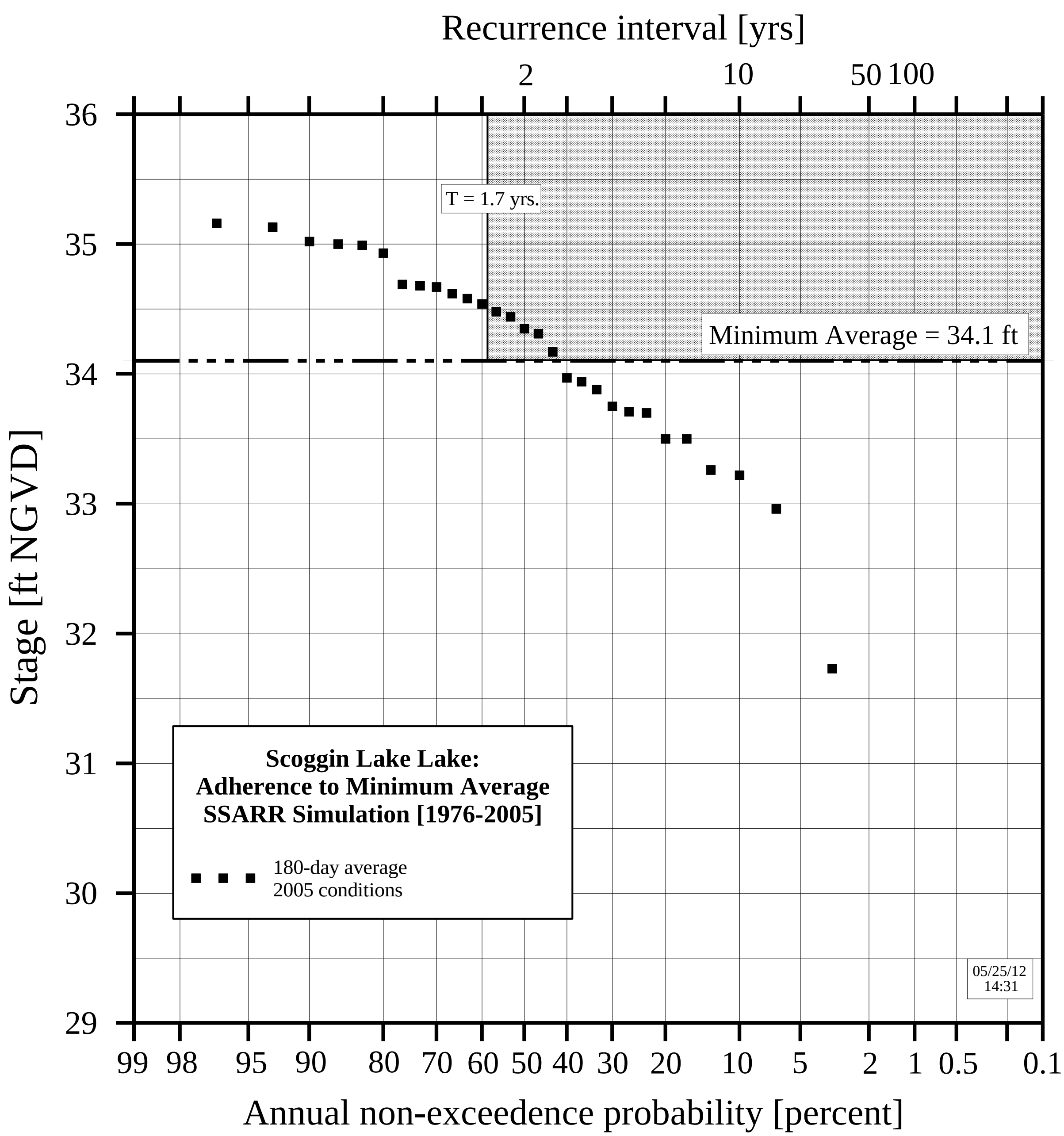


Figure 26. The minimum average (MA) level for Scoggin Lake as it relates to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

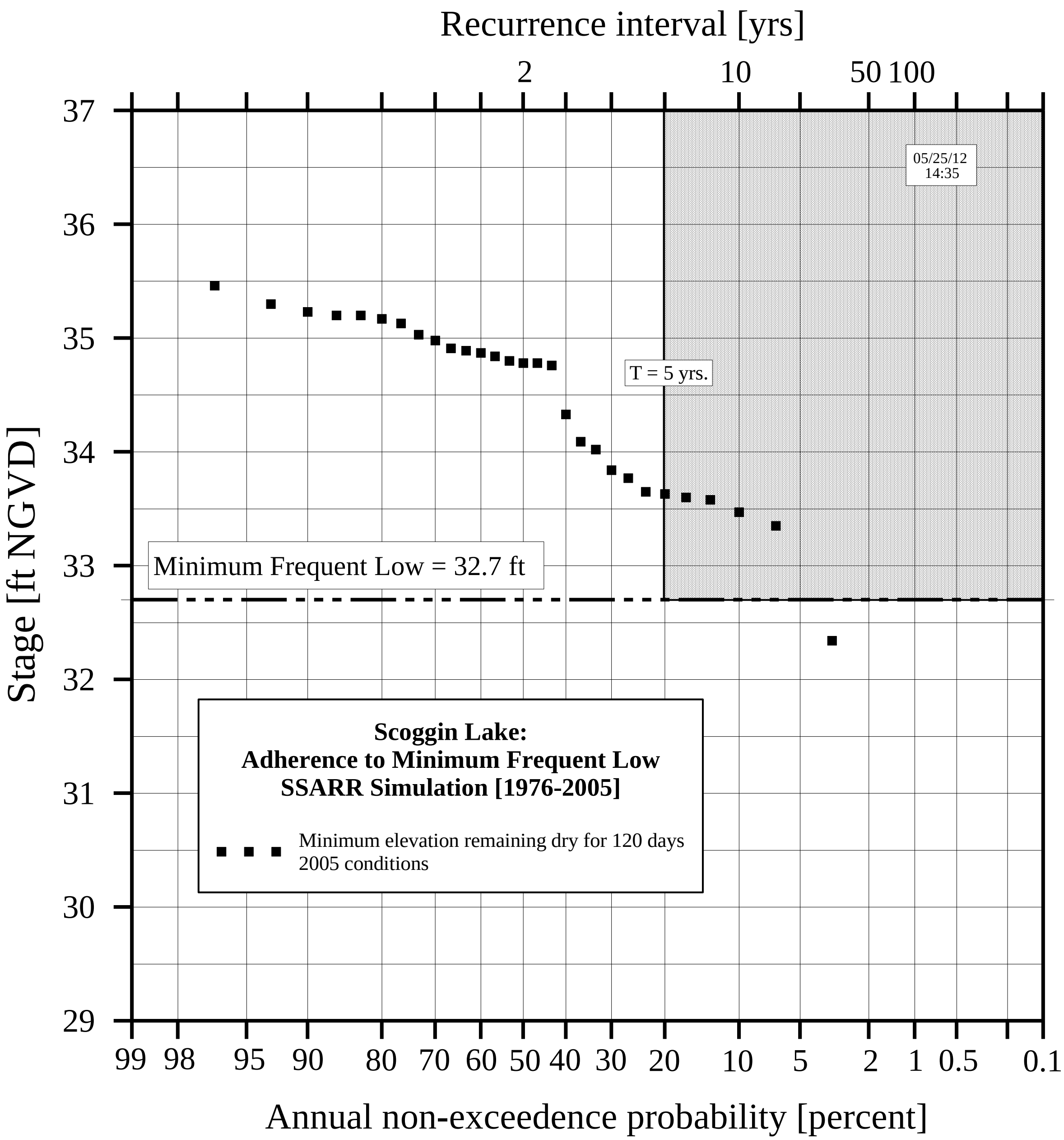


Figure 27. The minimum frequent low (MFL) level for Scoggin Lake as it relates to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

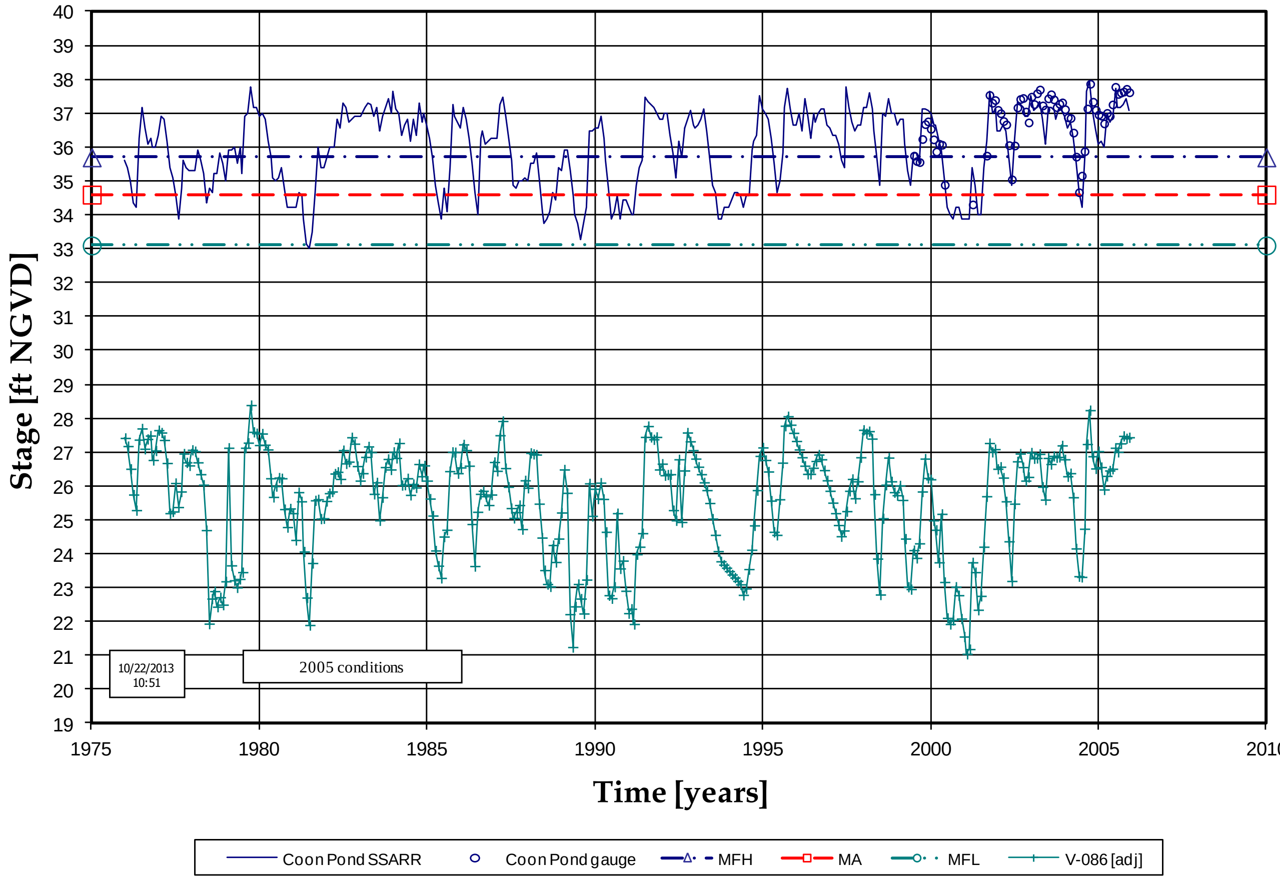


Figure 28. Hydrograph for the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation of Coon Pond. These values correspond to start-of-month stages. The Coon Pond minimum flows and levels (MFLs) are superimposed

Note:
MFH = minimum frequent high
MA = minimum average
MFL = minimum frequent low
adj = adjusted

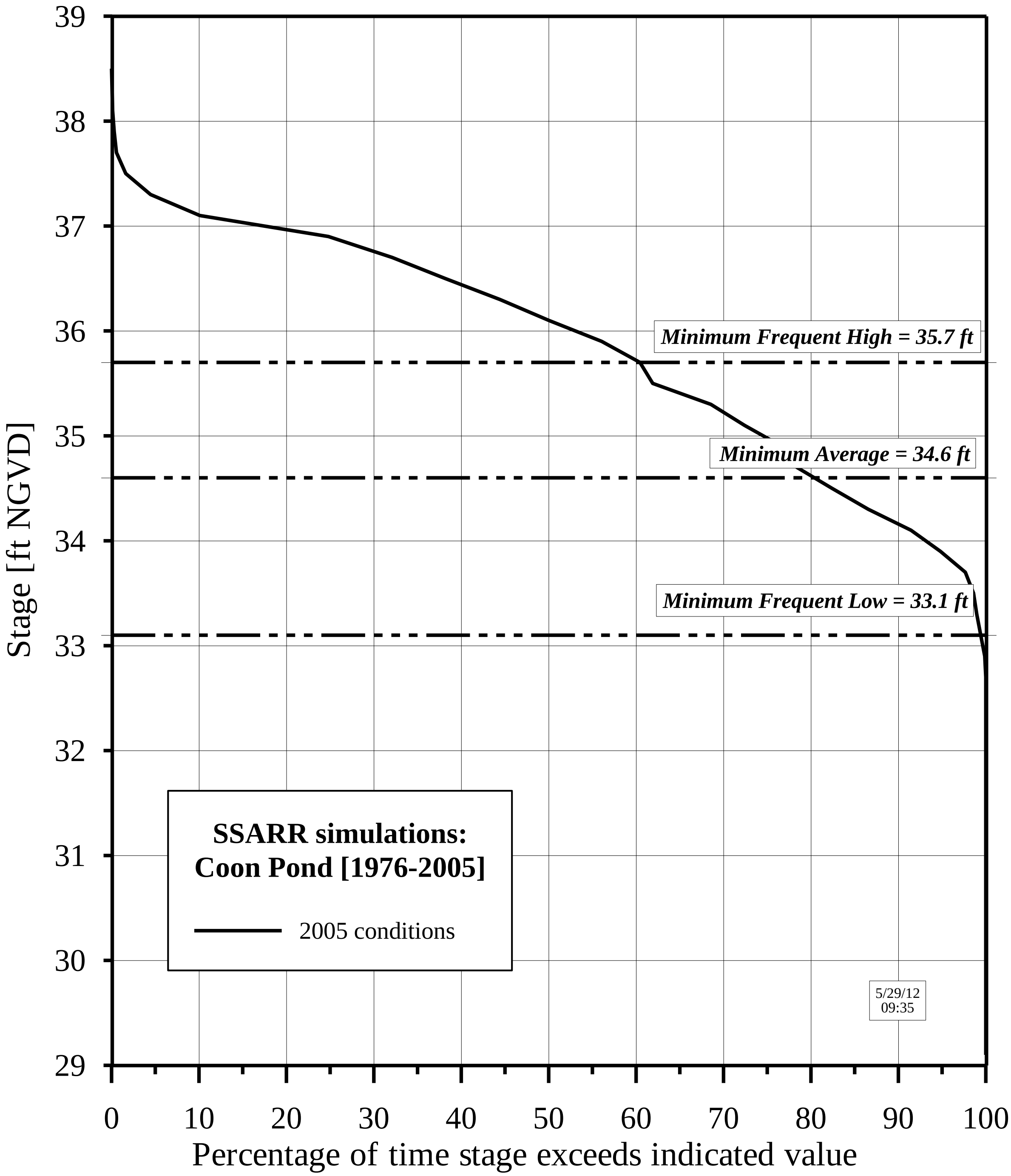


Figure 29. Stage duration curve from Streamflow Synthesis and Reservoir Regulation (SSARR) simulation of Coon Pond. The minimum flows and levels (MFLs) are superimposed

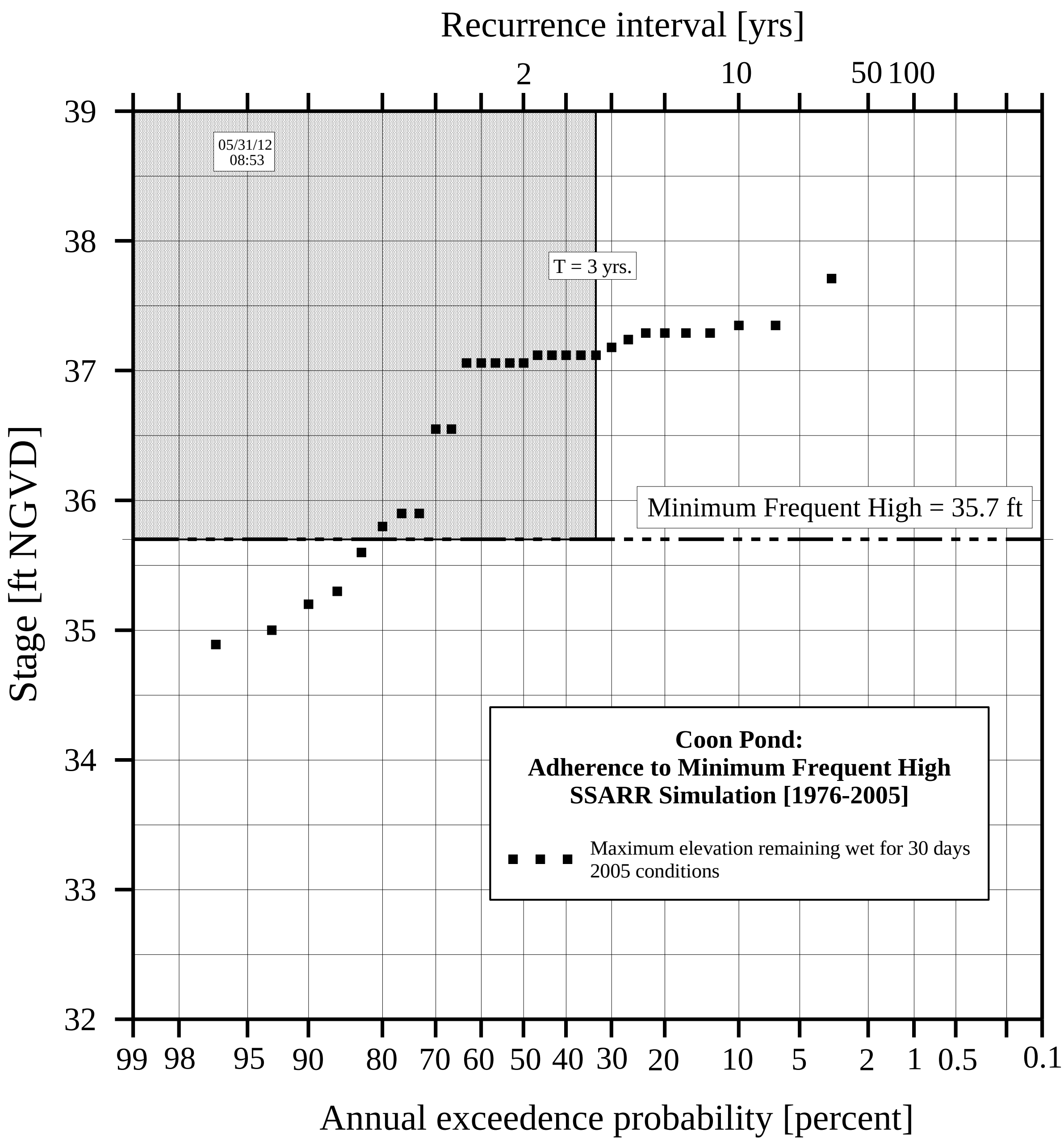


Figure 30. The minimum frequent high (MFH) level for Coon Pond as it relates to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

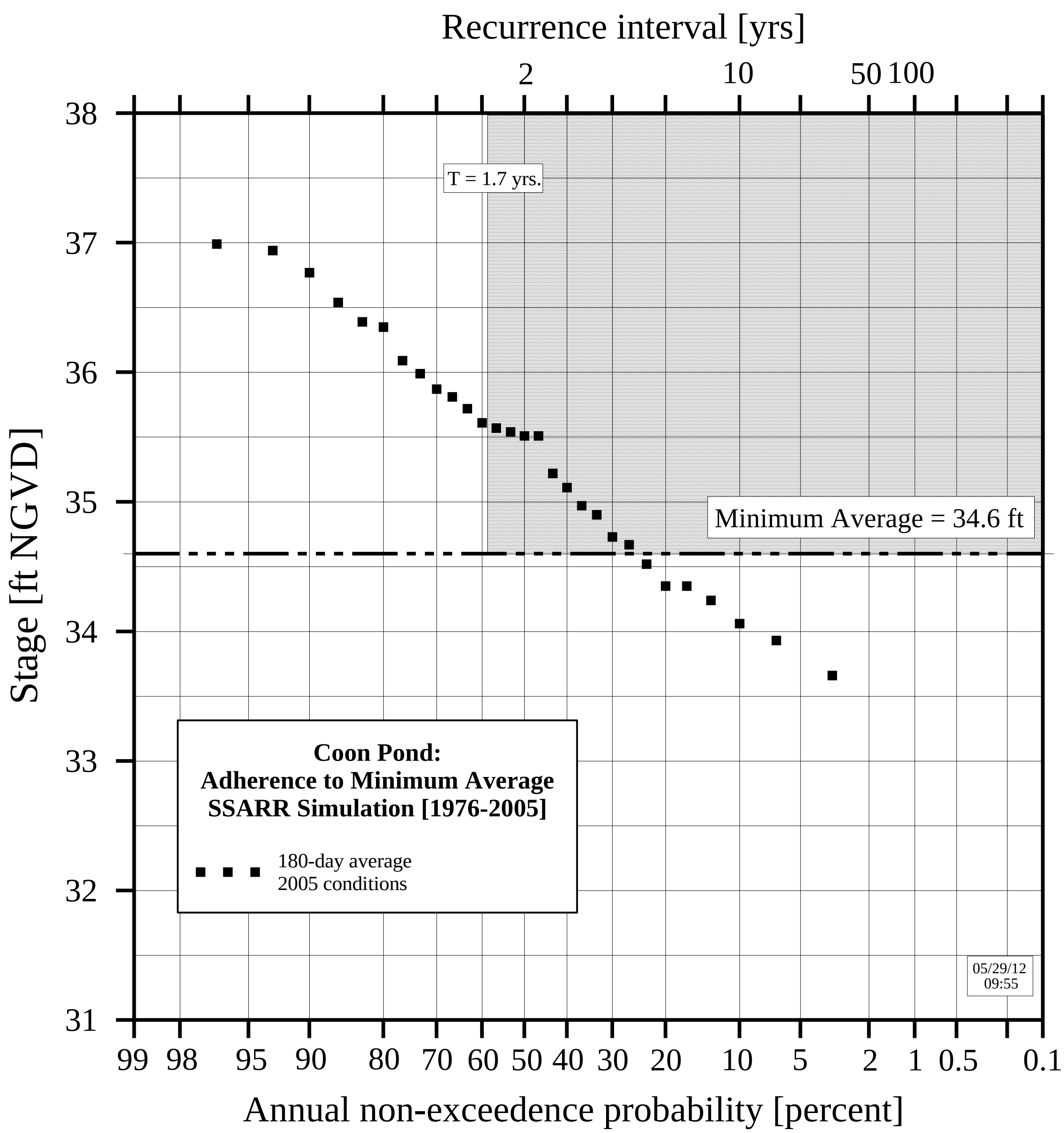


Figure 31. The minimum average (MA) level for Coon Pond as it relates to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

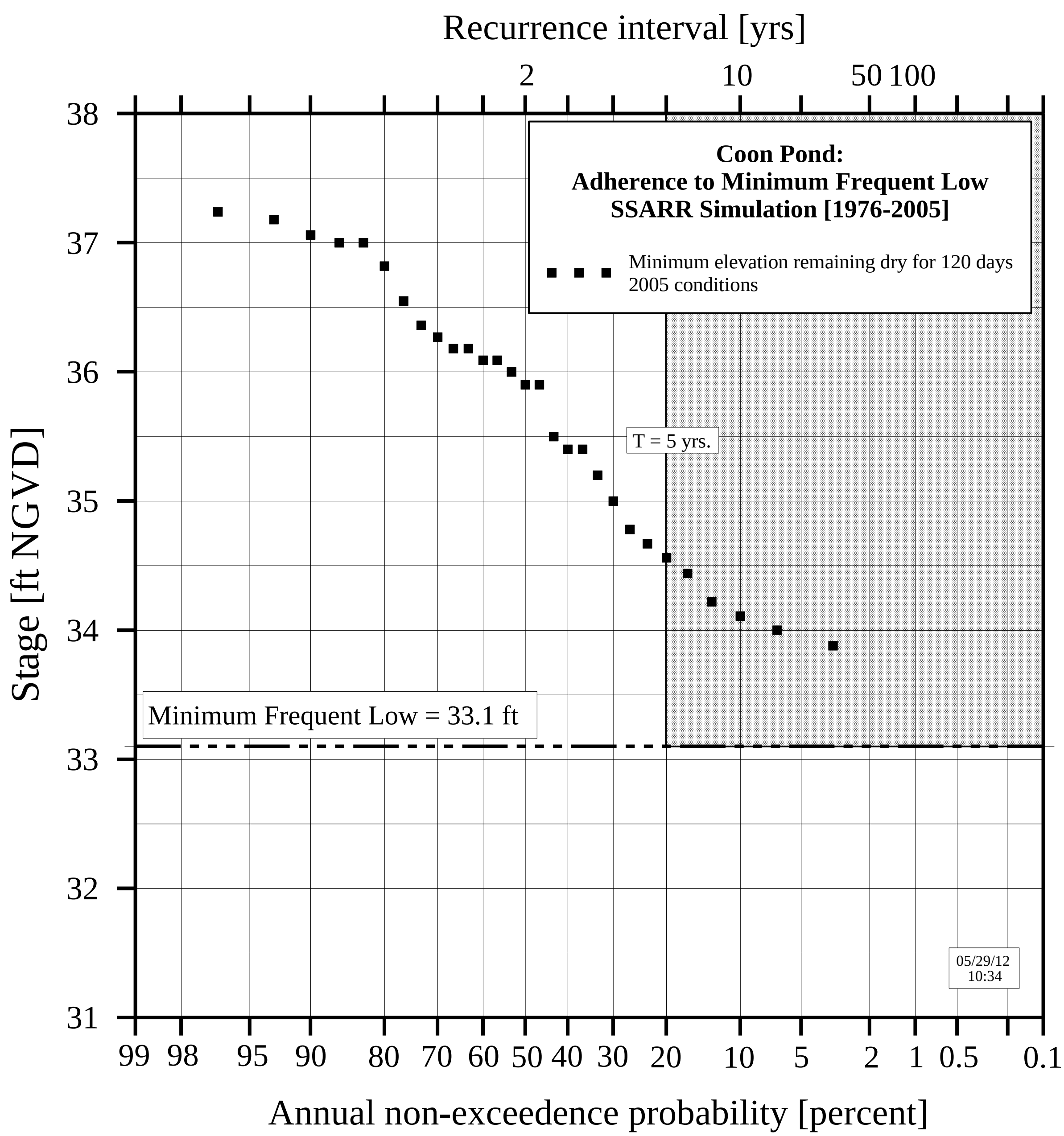


Figure 32. The minimum frequent low (MFL) level for Coon Pond as it relates to results of the 2005 conditions Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

ASSESSMENT OF HYPOTHETICAL WATER RESOURCE DEVELOPMENT IN THE INDIAN LAKE AREA IN THE CONTEXT OF MFLS

INTRODUCTION

The Indian Lake system is located within a SJRWMD priority water resource caution area (SJRWMD 2006). The hydrologic model described in this report was used to assess the hydrologic effects of Floridan aquifer drawdowns in the context of adopted MFLs. This chapter will document the determination of allowable Floridan aquifer declines beyond 2005 conditions for the Indian Lake system. These determinations involve a series of trial and error runs assuming different aquifer declines until one of the MFLs at each lake is no longer being met.

These simulations are based on the assumptions 1) that the 30-year (1976–2005) data record used in the Indian Lake system SSARR model is a statistically realistic representation of the hydrology, absent significant anthropogenic or climatological changes, over the next 30 years and 2) that any potential water resource developments under consideration would essentially continue indefinitely.

ASSESSMENT OF HYPOTHETICAL ALLOWABLE FLORIDAN AQUIFER DRAWDOWNS FOR THE INDIAN LAKE SYSTEM IN THE CONTEXT OF MFLS

As noted in the previous chapter, based on modeling results the adopted Indian Lake MFLs are not being met under 2005 conditions. The recommended revised MFLs for Indian Lake would be met under the same conditions. MFLs at both Scoggin Lake and Coon Pond would also be met. So, further drawdowns would be allowable at all three lakes. Based on the fact that the most probable water resource development in this area would be manifested in Floridan aquifer drawdowns (as opposed to direct surface water withdrawals) this analysis will include only drawdowns. As discussed previously (see “Seepage Flow between a Lake and the Floridan Aquifer”) drawdowns are simulated by subtracting a set amount from the V-0086 hydrograph used in the model.

To get a general idea of the allowable amount of Floridan aquifer drawdown in the vicinity of the Indian Lake system beyond 2005 conditions, a series of model simulations were performed. Drawdowns were gradually increased and each resulting simulation assessed with respect to MFLs.

Based on model results, all three recommended Indian Lake MFLs would be met with a drawdown of 0.4 ft beyond 2005 conditions (Figures 32a through 32c). With Floridan aquifer drawdowns greater than 0.4 ft, the MA would no longer be met.

Based on model results, all three Scoggin Lake MFLs would be met with a drawdown of 2.0 ft beyond 2005 conditions (Figures 33 through 35). With Floridan aquifer drawdowns greater than 2.0 ft the MFL would no longer be met.

Coon Pond lies between Indian Lake and Scoggin Lake, so it is highly unlikely drawdowns larger than the 2.0 ft at Scoggin Lake would be allowable. So, drawdowns at Coon Pond were limited to 3.0 ft beyond 2005 conditions. Based on model results, all three Coon Pond MFLs would be met with a drawdown of 3.0 ft beyond 2005 conditions (Figures 36 through 38).

Stage duration curves for each scenario and each lake are shown in Figures 38a, 39, and 40. These curves give an idea of the magnitude of the hydrologic changes involved.

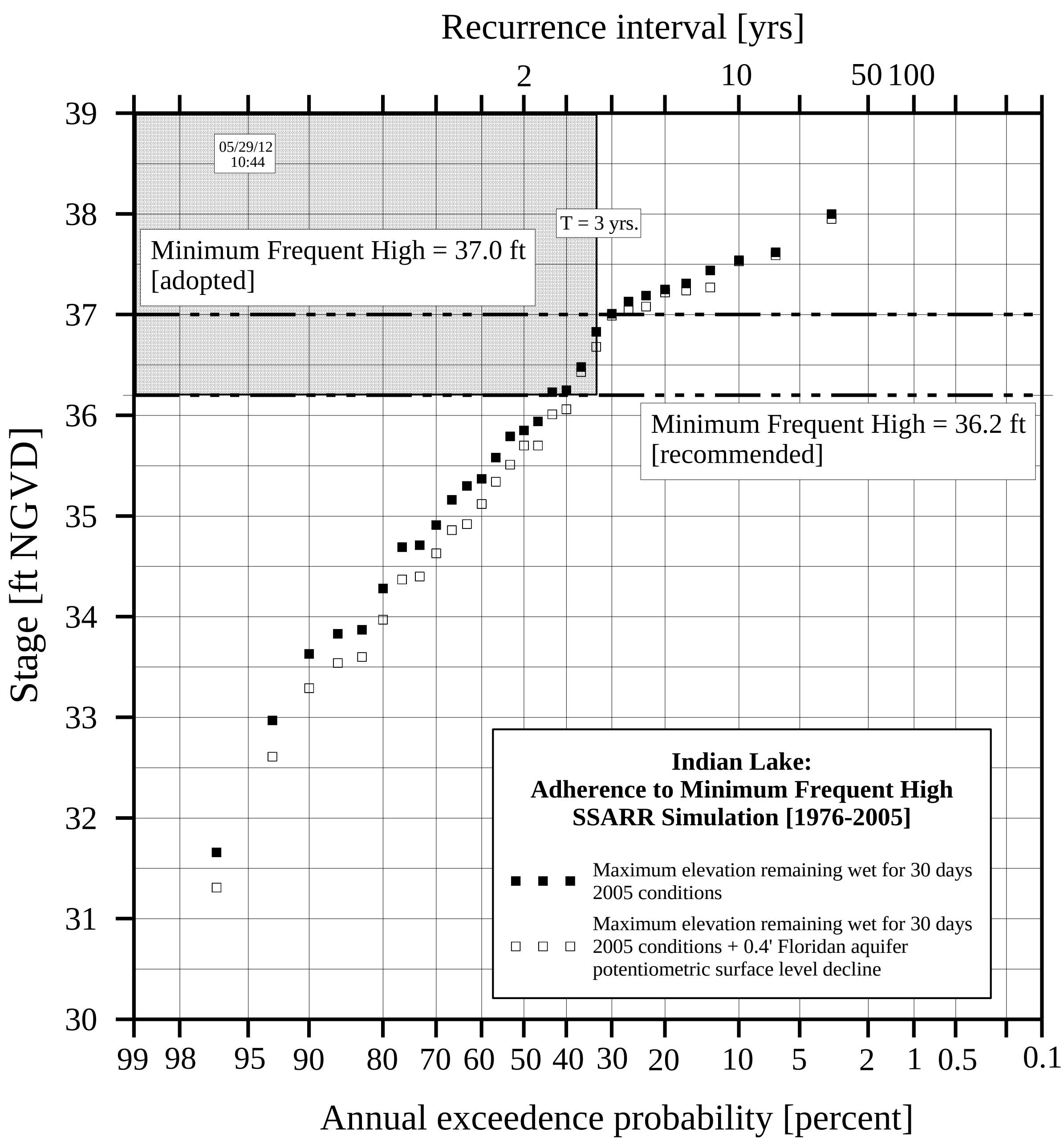


Figure 32a. The minimum frequent high (MFH) level for Indian Lake as it relates to results of the 2005 conditions + 0.4-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

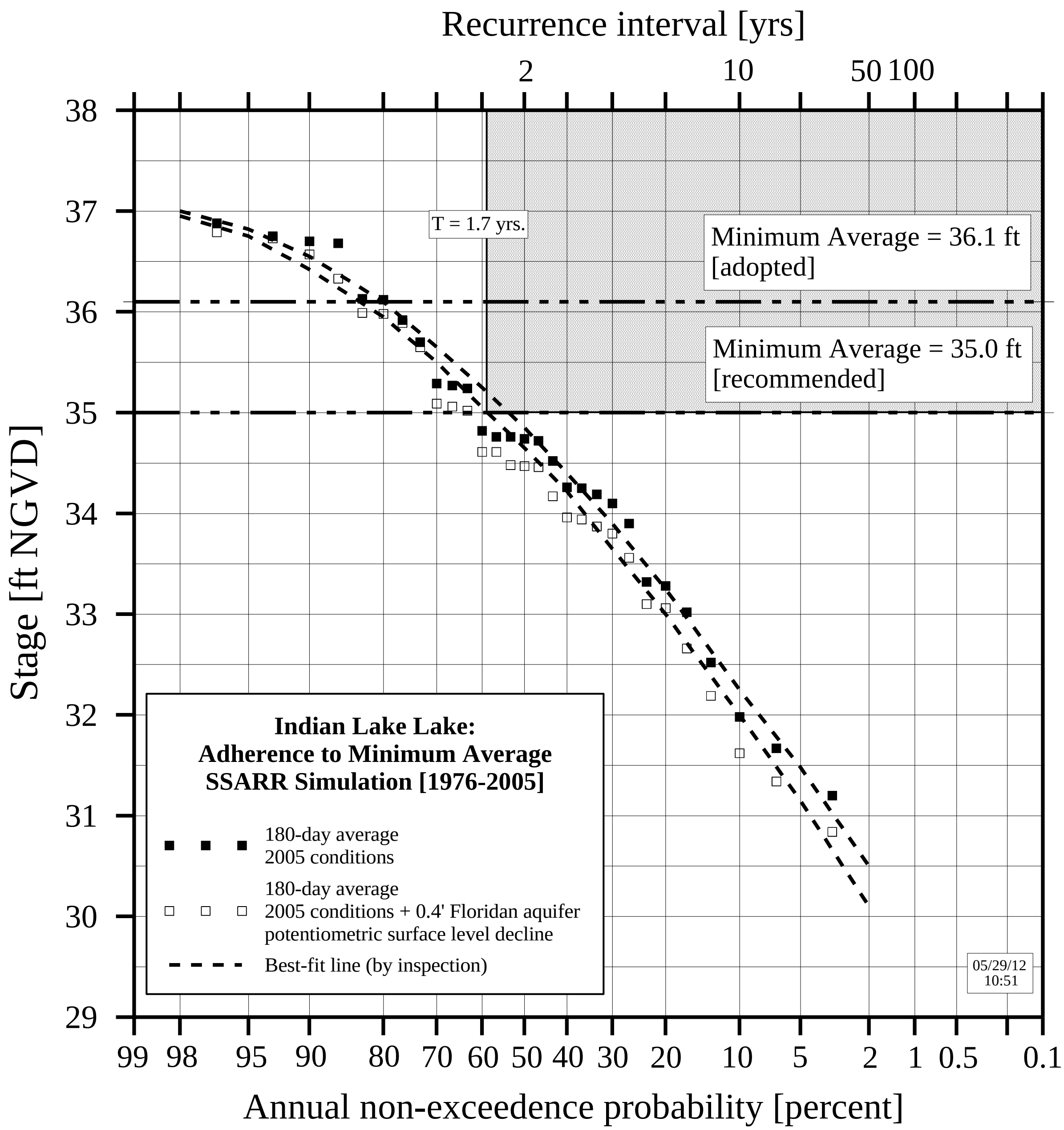


Figure 32b. The minimum average (MA) level for Indian Lake as it relates to results of the 2005 conditions + 0.4-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

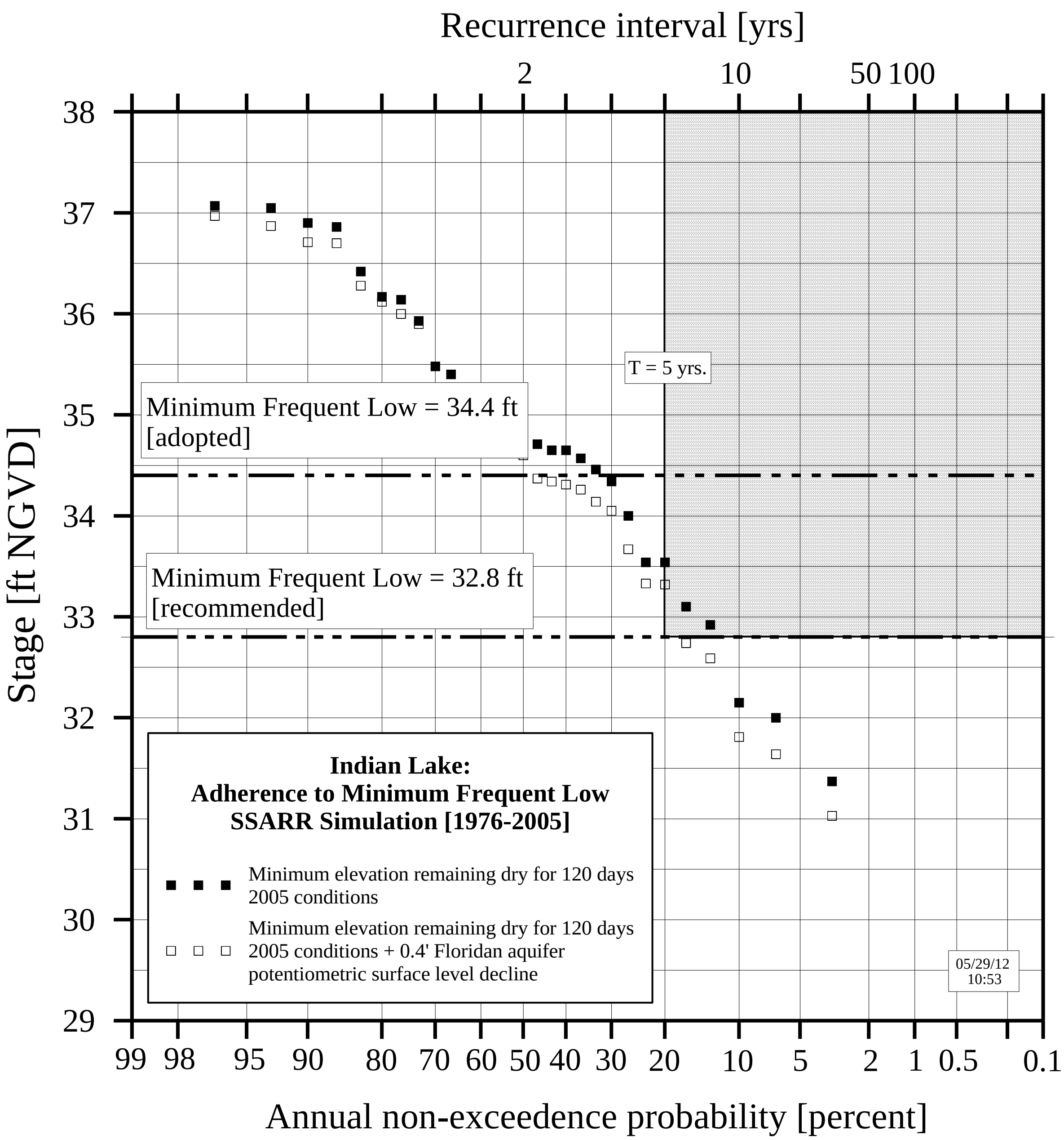


Figure 32c. The minimum frequent low (MFL) level for Indian Lake as it relates to results of the 2005 conditions + 0.4-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

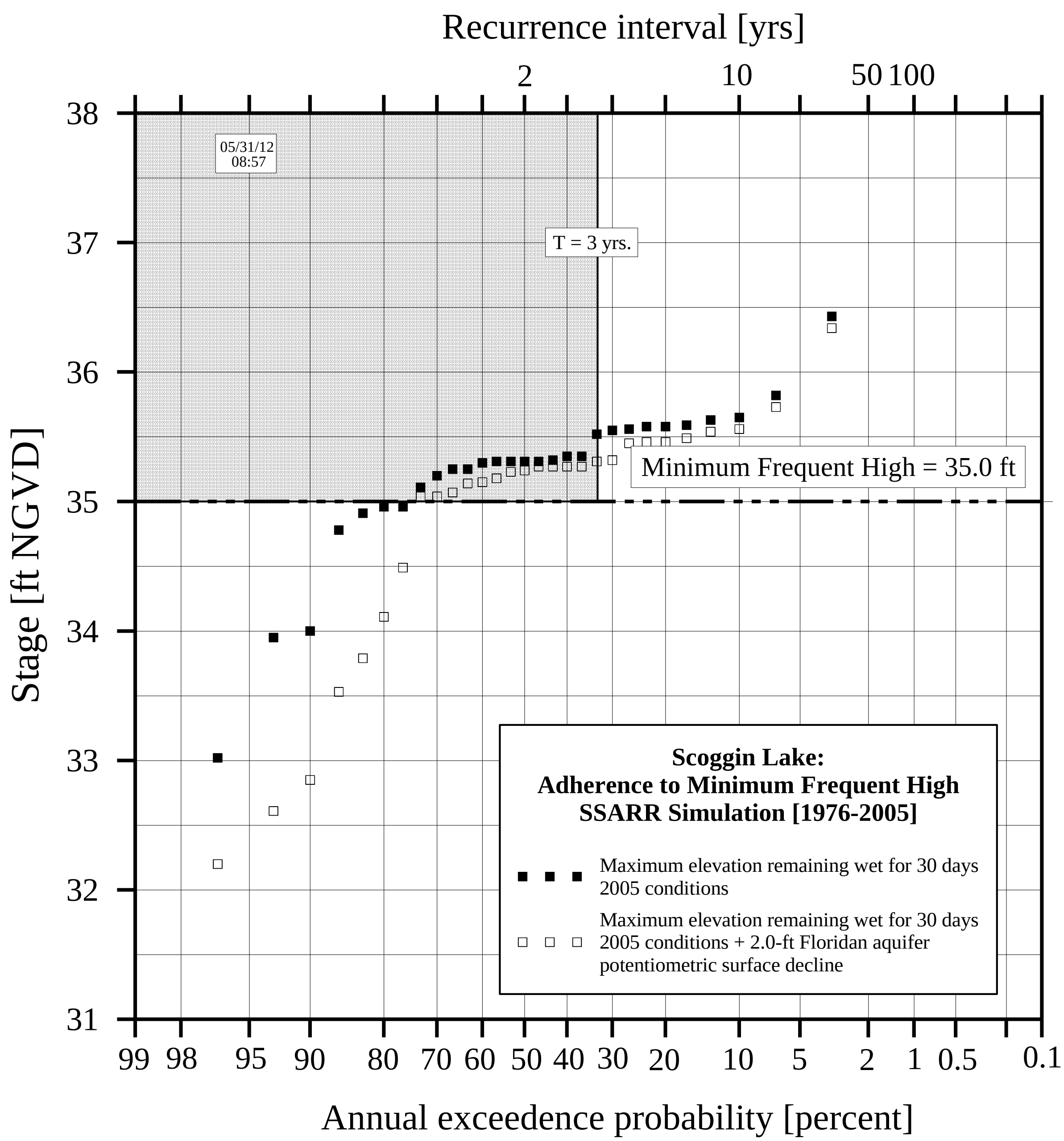


Figure 33. The minimum frequent high (MFH) level for Scoggin Lake as it relates to results of the 2005 conditions + 2.0-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

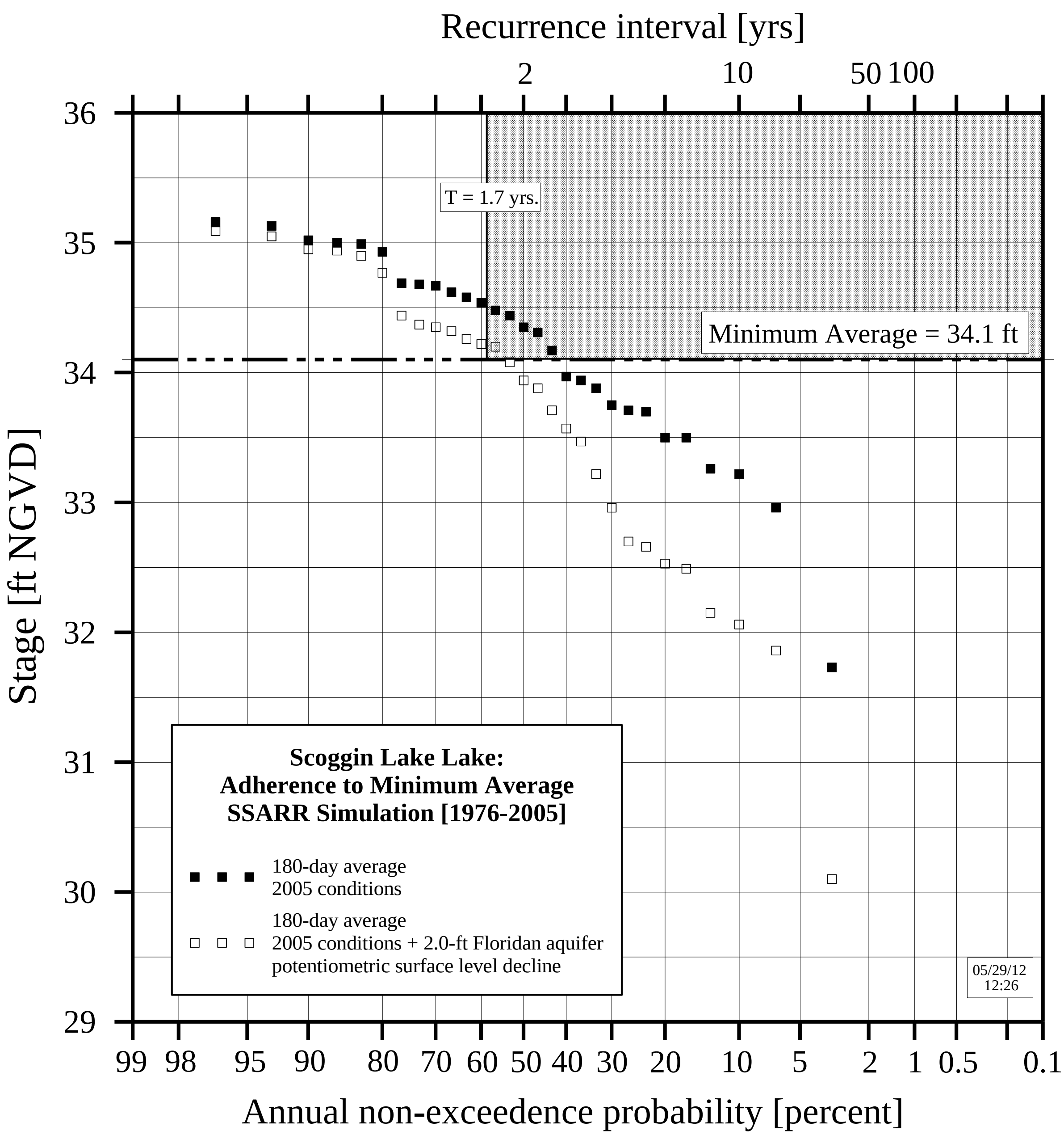


Figure 34. The minimum average (MA) level for Scoggin Lake as it relates to results of the 2005 conditions + 2.0-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

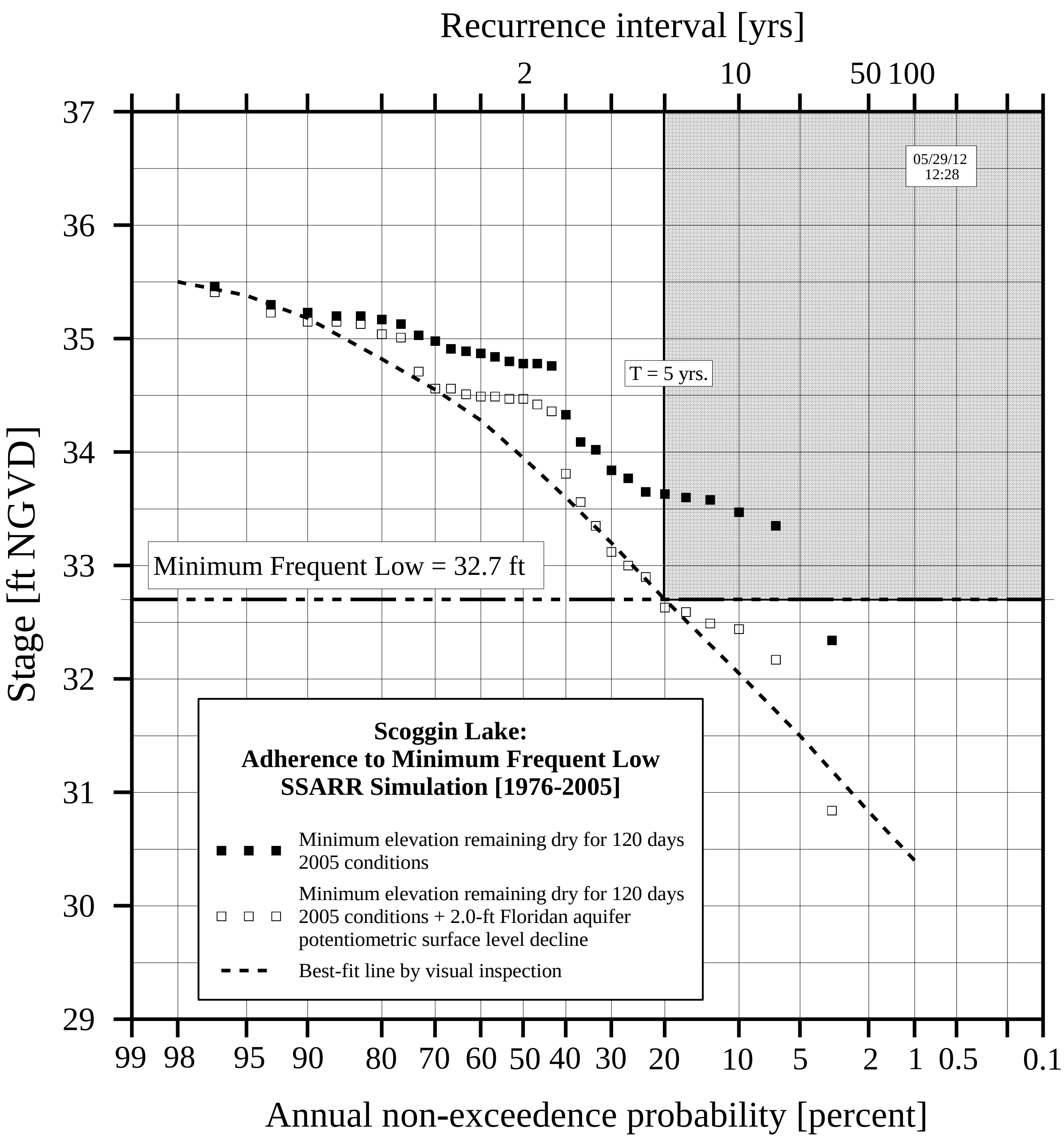


Figure 35. The minimum frequent low (MFL) level for Scoggin Lake as it relates to results of the 2005 conditions + 2.0-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

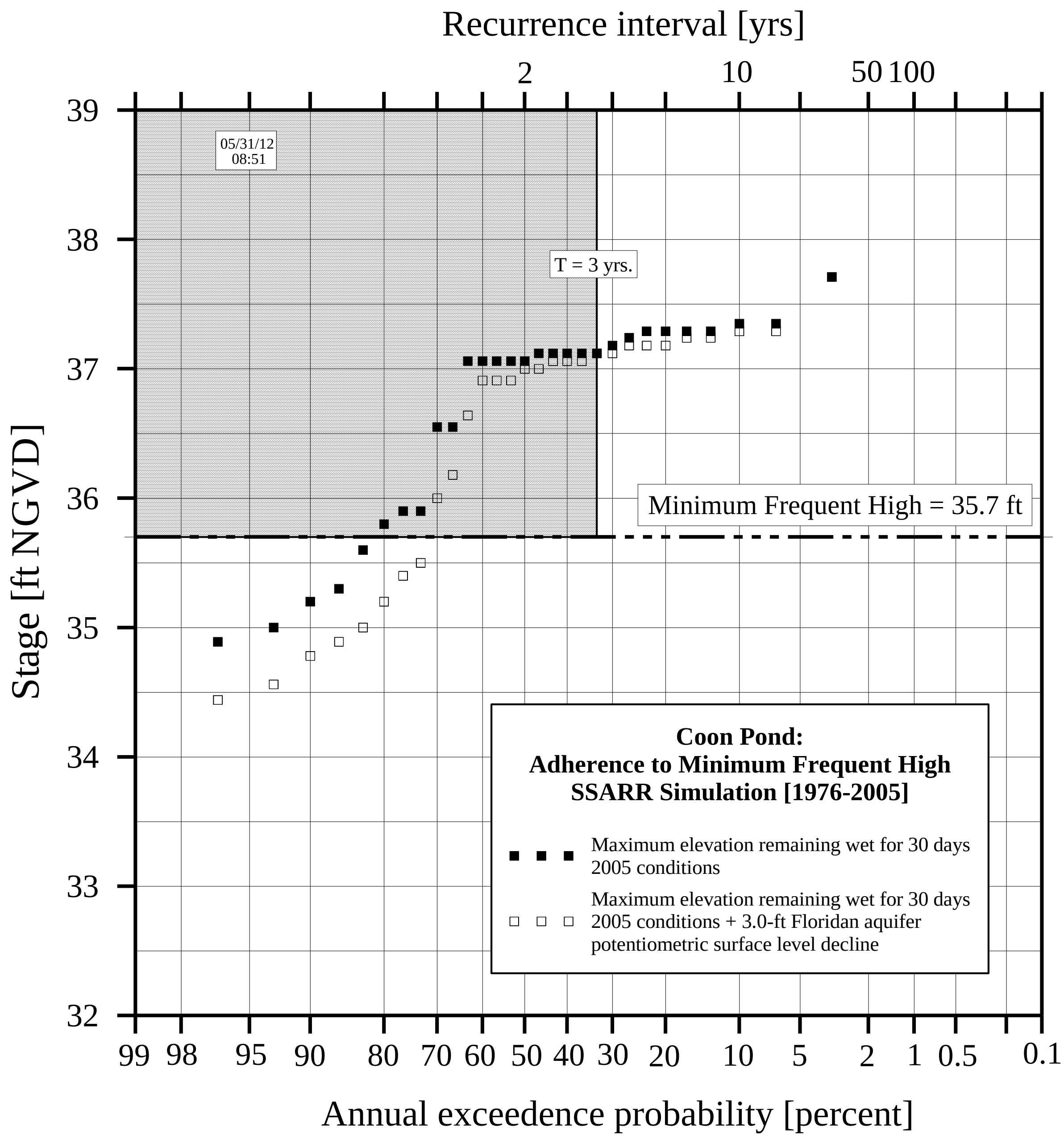


Figure 36. The minimum frequent high (MFH) level for Coon Pond as it relates to results of the 2005 conditions + 3.0-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

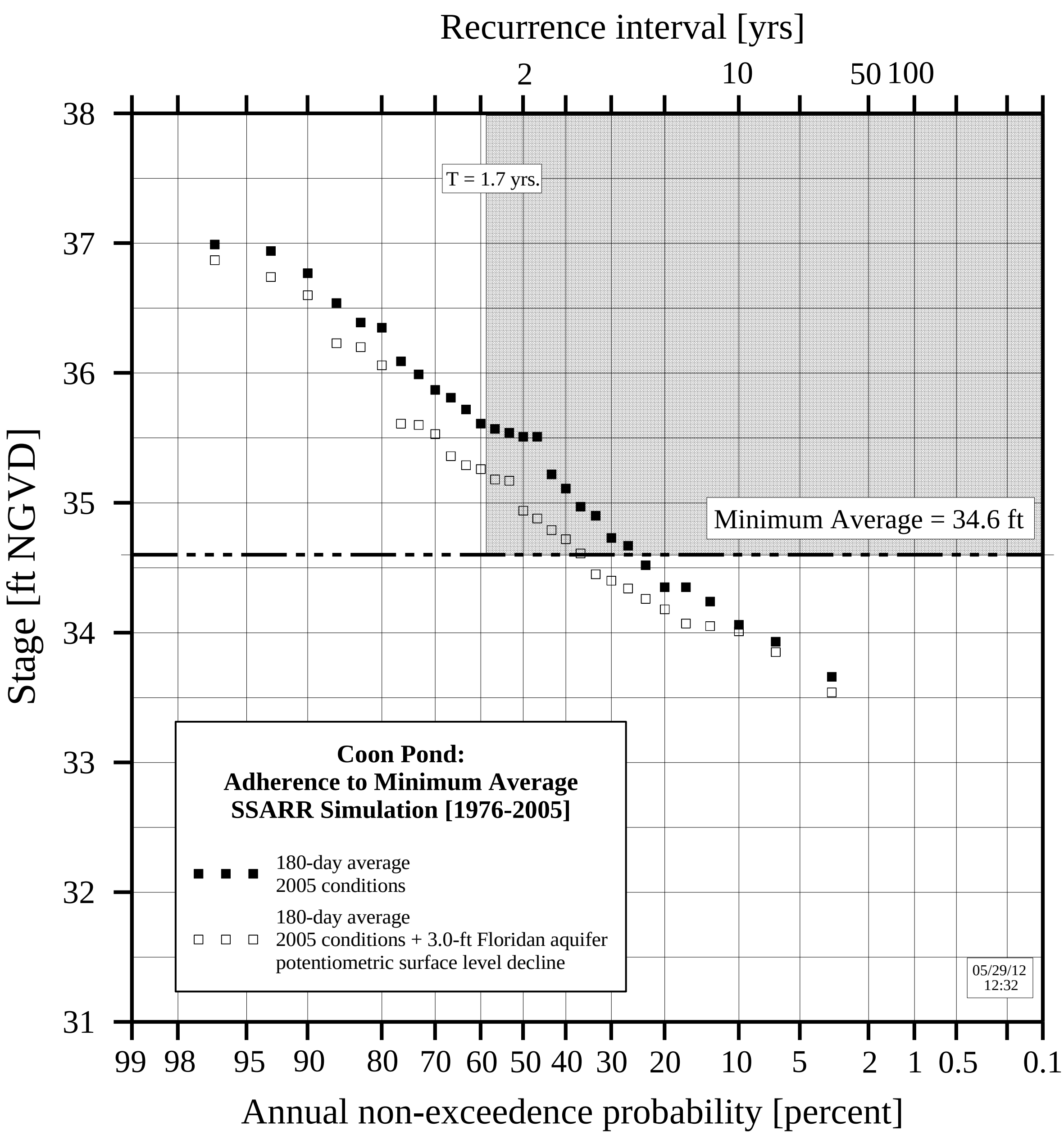


Figure 37. The minimum average (MA) level for Coon Pond as it relates to results of the 2005 conditions + 3.0-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

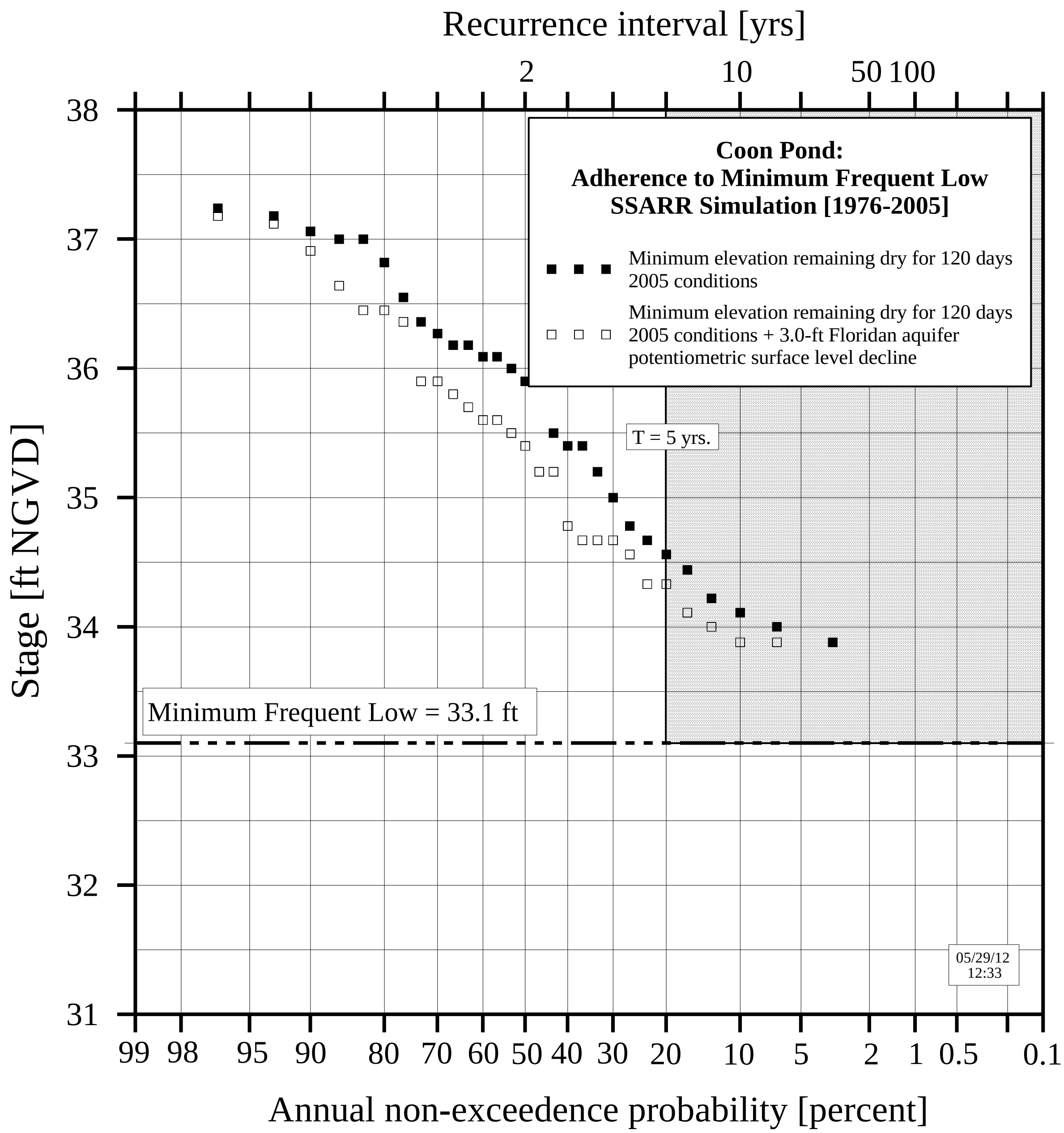


Figure 38. The minimum frequent low (MFL) level for Coon Pond as it relates to results of the 2005 conditions + 3.0-ft Floridan aquifer potentiometric surface level decline Streamflow Synthesis and Reservoir Regulation (SSARR) simulation

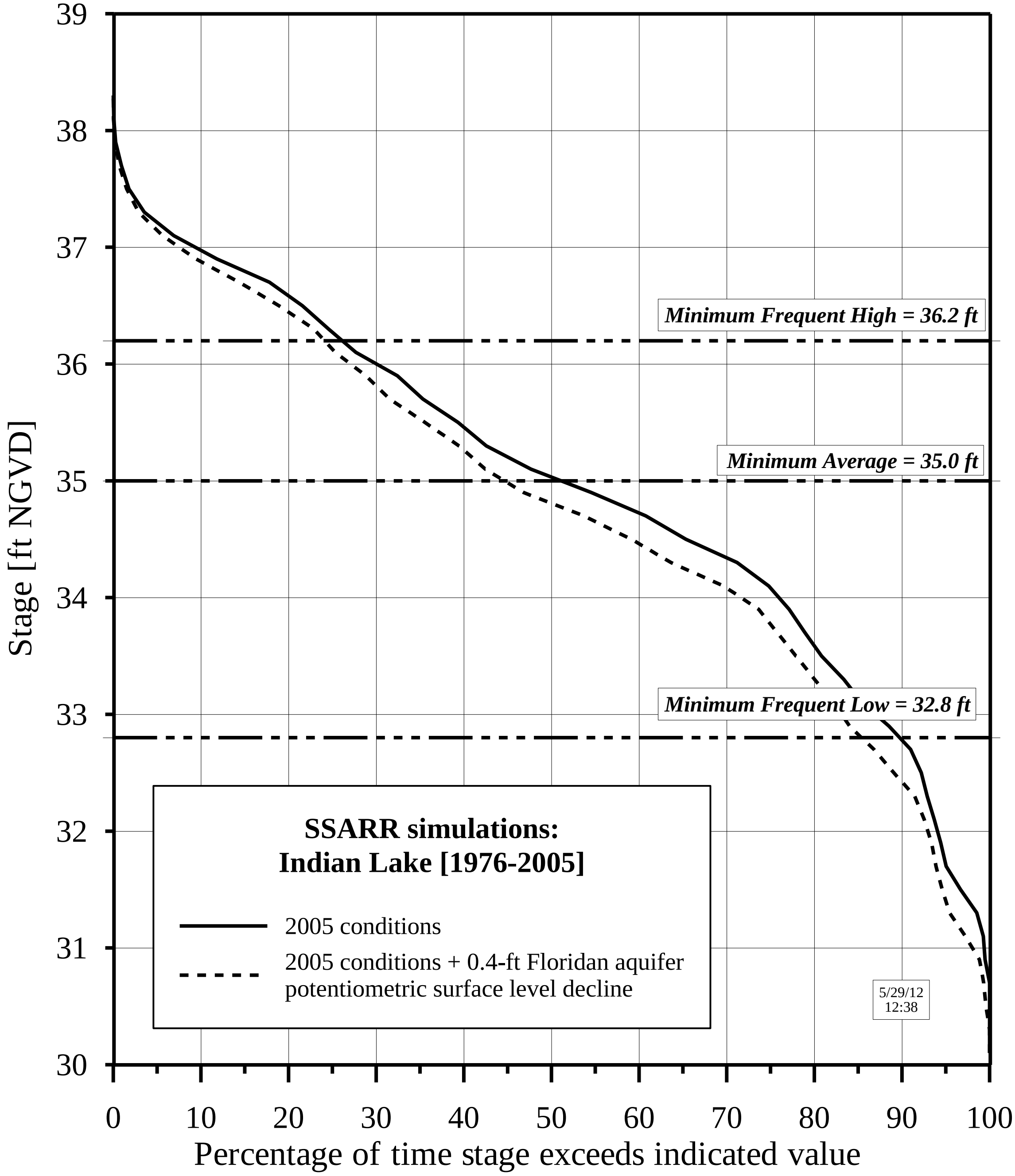


Figure 38a. Stage duration curves from Streamflow Synthesis and Reservoir Regulation (SSARR) simulations of Indian Lake. The minimum flows and levels (MFLs) are superimposed

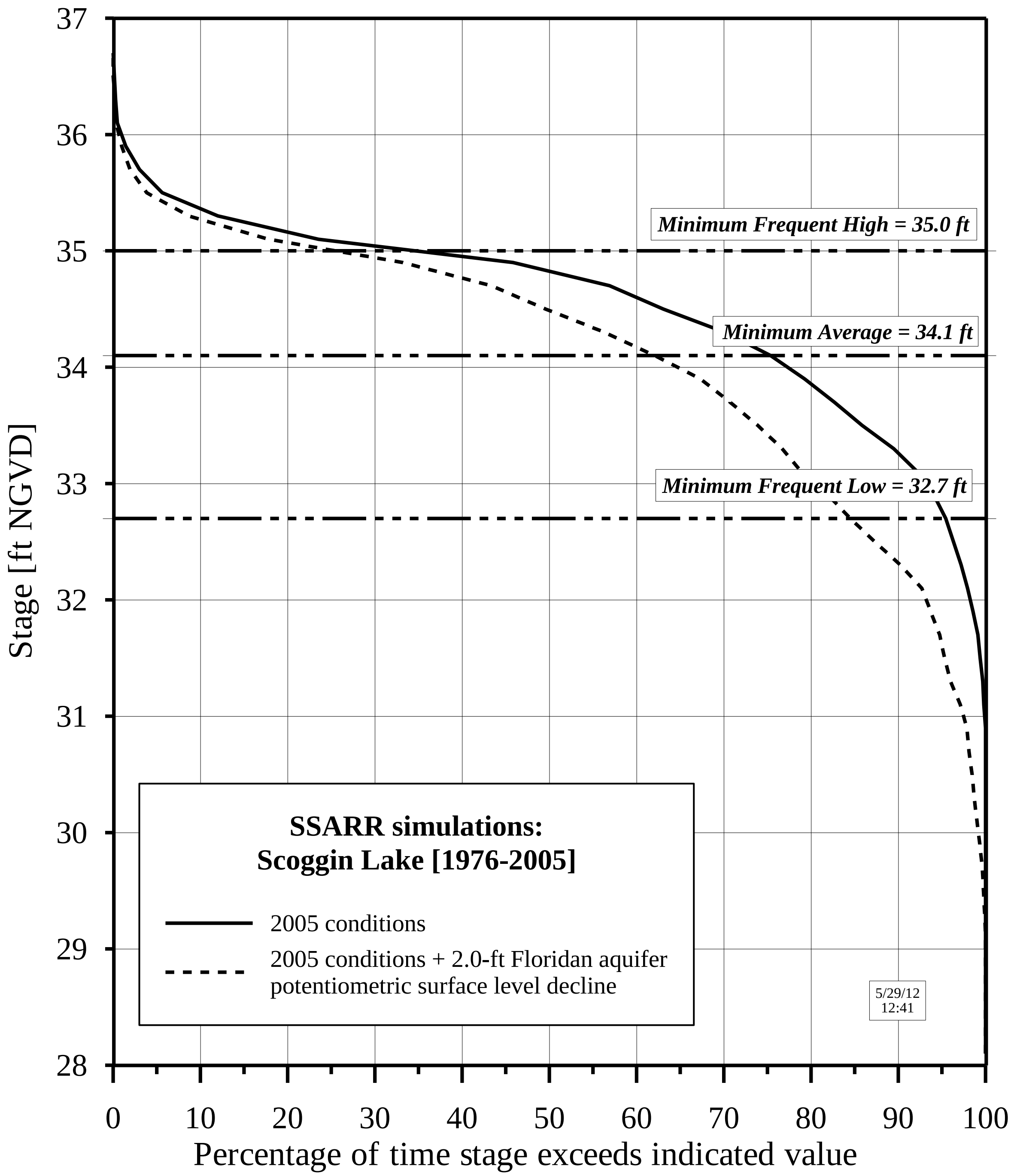


Figure 39. Stage duration curves from Streamflow Synthesis and Reservoir Regulation (SSARR) simulations of Scoggin Lake. The minimum flows and levels (MFLs) are superimposed

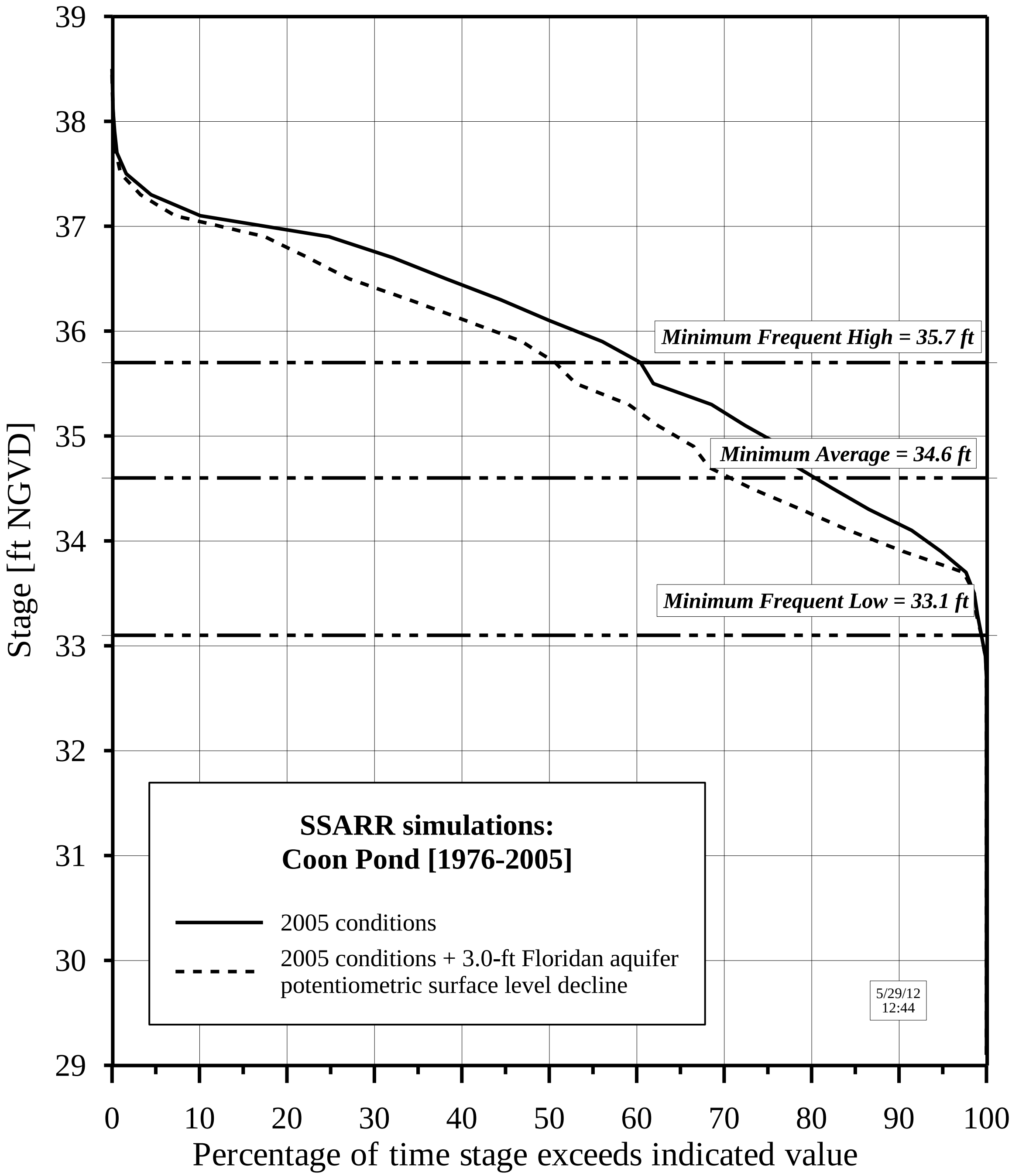


Figure 40. Stage duration curves from Streamflow Synthesis and Reservoir Regulation (SSARR) simulations of Coon Pond. The minimum flows and levels (MFLs) are superimposed

Sensitivity Analyses

INTRODUCTION

To examine some of the possible sources of error in the Indian Lake SSARR model, sensitivity analyses were performed. It is hoped that this can also provide for some context as to the level of uncertainty in the final results and help with the decisions based on the results. In concert with models of other systems, these results might provide an indication of the best parameters to use. The final model result that is used in decision making is the drawdown freeboard. The following process was used in the sensitivity analyses:

1) Select a possible source of model error.
2) Replace the selected parameter in the original, calibrated model.
3) Perform a recalibration of the new model The only parameter changed in the recalibration was the coefficient of hydraulic conductivity, $\hat{K}$.
4) Perform a long-term simulation with the newly recalibrated model.
5) Perform the MFLs analysis to calculate MFL-level events for the scenario in question.
6) Determine the drawdown freeboard allowed by MFLs for the scenario in question.

This process was performed for the following general parameter types:

a) Evaporation alternative to the one used in the original model
b) Outlet invert elevation higher than the one used in the original model
c) Outlet invert elevation lower than the one used in the original model
d) Outlet rating curve less efficient than the one used in the original model
e) Outlet rating curve more efficient than the one used in the original model
f) Drainage area larger than the one used in the original model
g) Drainage area smaller than the one used in the original model
h) Floridan aquifer well offset used in the original model raised by 1 ft
i) Floridan aquifer well offset used in the original model lowered by 1 ft
j) Variable drainage basin area

EVAPORATION ALTERNATIVE TO THE ONE USED IN THE ORIGINAL MODEL

As discussed previously (see “Pan Evaporation”), the Indian Lake SSARR model simulations used Lisbon pan evaporation multiplied by a coefficient to represent direct evaporation from the lake surface. Recently the District has tried to institute a standardized approach to calculating potential ET (Smith and Cera 2010) using the Hargreaves method. The Hargreaves method uses maximum air temperature, minimum air temperature, latitude, and solar declination. The District has been divided into Theissen polygons based on the network of NOAA stations. The Hargreaves method is used to calculate a daily potential ET for each of these polygons. The assumption here is that the daily lake evaporation is equal to the daily potential ET. In this sensitivity analysis run, the potential ET at Daytona Beach was used. Scatter plots of the measured values versus modeled values are shown in Figures 41 through 43. The resulting calibration performance measures are shown in Tables 8 through 10.

OUTLET INVERT ELEVATION HIGHER THAN THE ONE USED IN THE ORIGINAL MODEL

Based on examination of trends in observed lake levels, the invert elevations of the lake outlets were estimated at 37.0 ft NGVD, 37.0 ft NGVD, and 35.0 ft NGVD for Indian Lake, Scoggin Lake, and Coon Pond, respectively. Calibration results did not show any need to change these estimates. This sensitivity run consisted of raising the outlet elevations of each lake and performing a new calibration and long-term simulation. Scatter plots of the measured values versus modeled values are shown in Figures 44 through 46. The resulting calibration performance measures are shown in Tables 8 through 10.

OUTLET INVERT ELEVATION LOWER THAN THE ONE USED IN THE ORIGINAL MODEL

Based on examination of trends in observed lake levels, the invert elevations of the lake outlets were estimated at 37.0 ft NGVD, 37.0 ft NGVD, and 35.0 ft NGVD for Indian Lake, Scoggin Lake, and Coon Pond, respectively. Calibration results did not show any need to change these estimates. This sensitivity run consisted of lowering the outlet elevations of each lake and performing a new calibration and long-term simulation. Scatter plots of the measured values versus modeled values are shown on Figures 47 through 49. The resulting calibration performance measures are shown in Tables 8 through 10.

OUTLET RATING CURVE LESS EFFICIENT THAN THE ONE USED IN THE ORIGINAL MODEL

The original rating curve for each of the three lakes was assumed to start at 1 cfs at 1 ft of elevation above the invert and doubling at each subsequent foot of elevation (see Figure 6a). Based on model calibration, rating curves for Indian Lake and Coon Pond remained unchanged. The rating curve for Scoggin Lake was changed to 2 cfs at 1 ft of elevation above the invert and doubled at each foot of elevation thereafter. This sensitivity run consisted of halving the flow at each elevation (i.e., lowering the efficiency of the outlet by 50%) and performing a new calibration and long-term simulation. Scatter plots of the measured values versus modeled values are shown on Figures 50 through 52. The resulting calibration performance measures are shown in Tables 8 through 10.

OUTLET RATING CURVE MORE EFFICIENT THAN THE ONE USED IN THE ORIGINAL MODEL

The original rating curve for each of the three lakes was assumed to start at 1 cfs at 1 ft of elevation above the invert and doubling at each subsequent foot of elevation (see Figure 6a). Based on model calibration, rating curves for Indian Lake and Coon Pond remained unchanged. The rating curve for Scoggin Lake was changed to 2 cfs at 1 ft of elevation above the invert and doubled at each foot of elevation thereafter. This sensitivity run consisted of doubling the flow at each elevation (i.e., increasing the efficiency of the outlet by 100%) and performing a new calibration and long-term simulation. Scatter plots of the measured values versus modeled values are shown in Figures 53 through 55. The resulting calibration performance measures are shown in Tables 8 through 10.

DRAINAGE AREA LARGER THAN THE ONE USED IN THE ORIGINAL MODEL

Based on elevation contours from USGS topographic maps, the drainage areas for Indian Lake, Scoggin Lake, and Coon Pond were 0.31 mi^2, 0.51 mi^2, and 0.20 mi^2, respectively (see Figure 3). Due to the lack of significant relief around the lakes, these drainage areas could be off by a considerable amount. This sensitivity run consisted of increasing the drainage area of each lake by 10% and performing a new calibration and long-term simulation. Scatter plots of the measured values versus modeled values are shown on Figures 56 through 58. The resulting calibration performance measures are shown in Tables 8 through 10.

DRAINAGE AREA SMALLER THAN THE ONE USED IN THE ORIGINAL MODEL

Based on elevation contours from USGS topographic maps, the drainage areas for Indian Lake, Scoggin Lake, and Coon Pond were 0.31 mi^2, 0.51 mi^2 , and 0.20 mi^2, respectively (see Figure 3). Due to the lack of significant relief around the lakes, these areas could be off by a considerable amount. This sensitivity run consisted of decreasing the drainage area of each lake by 10% and performing a new calibration and long-term simulation. Scatter plots of the measured values versus modeled values are shown in Figures 59 through 61. The resulting calibration performance measures are shown in Tables 8 through 10.

FLORIDAN AQUIFER WELL OFFSET USED IN THE ORIGINAL MODEL RAISED BY 1 FOOT

In the SJRWMD, it is unusual to have a long-term Floridan aquifer well right next to an MFLs lake as is the case at Indian Lake (see Figure 7). A well located at a distance entails applying an offset to the well before it can be used to represent the potentiometric surface at the lake. Even though an offset of 0 ft was assumed for the Indian Lake system, it is possible that there is an offset that would produce a better simulation. To investigate this possibility, the well offset was increased from 0 ft to 1 ft for each of the lakes. Scatter plots of the measured values versus modeled values are shown on Figures 62 through 64. The resulting calibration performance measures are shown in Tables 8 through 10.

FLORIDAN AQUIFER WELL OFFSET USED IN THE ORIGINAL MODEL LOWERED BY 1 FOOT

In the SJRWMD, it is unusual to have a long-term Floridan aquifer well right next to an MFLs lake as is the case at Indian Lake (see Figure 7). A well located at a distance entails applying an offset to the well before it can be used to represent the potentiometric surface at the lake. Even though an offset of 0 ft was assumed for the Indian Lake system, it is possible that there is an offset that would produce a better simulation. To investigate this possibility, the well offset was decreased from 0 ft to -1 ft for each of the lakes. Scatter plots of the measured values versus modeled values are shown in Figures 65 through 67. The resulting calibration performance measures are shown in Tables 8 through 10.

VARIABLE DRAINAGE BASIN AREA

As the level of a lake falls ground is exposed, in effect increasing the basin area draining into the lake. Under normal circumstances, this increase is quite small when compared to the drainage basin as a whole, and the usual convention is to assume a constant area. To determine the sensitivity of the model to this factor, a variable drainage basin area for Indian Lake was included in the model. The original drainage basin for Indian Lake was 0.31 mi^2 (see Figure 4). The increase in area between two ground elevations is determined from the stage area curve (see Figure 5). The final relationship between lake level and drainage area is shown in Figure 68. This sensitivity run was limited to Indian Lake because it was the only lake to have detailed bathymetry, the widest range of fluctuation, and the smallest freeboards with respect to Floridan aquifer declines. A scatter plot of the measured values versus modeled values is shown in Figure 69. The resulting calibration performance measures are shown in Table 8.

Table 8. Sensitivity analysis results for Indian Lake

Sensitivity Run	Mean Square Error (ft^2)	Residuals between ±0.5 ft (%)	Residuals between ±1.0 ft (%)	Minimum Flows and Levels (MFLs) Freeboard (ft)
Original calibration	0.471	70	86	0.4
Daytona Beach evaporation	0.432	65	86	1.0
Outlet raised 1 ft	0.755	54	82	-0.3
Outlet lowered 1 ft	0.422	64	90	0.0
Outlet with 50% efficiency of the original	0.478	65	86	0.3
Outlet with 200% efficiency of the original	0.416	63	89	0.6
Increase drainage area by 10%	0.333	69	92	0.5
Decrease drainage area by 10%	0.503	65	86	0.0
Floridan aquifer well offset raised 1 ft	0.419	71	88	0.5
Floridan aquifer well offset lowered 1 ft	0.457	71	86	0.3
Variable drainage basin area	0.394	71	88	0.4

Table 9. Sensitivity analysis results for Scoggin Lake

Sensitivity Run	Mean Square Error (ft^2)	Residuals between ±0.5 ft (%)	Residuals between ±1.0 ft (%)	Minimum Flows and Levels (MFLs) Freeboard (ft)
Original calibration	0.098	93	100	2.0
Daytona Beach evaporation	0.149	83	99	2.0
Outlet raised 1 ft	0.433	36	96	2.0
Outlet lowered 1 ft	0.309	55	94	-1.2
Outlet with 50% efficiency of the original	0.145	84	96	2.0
Outlet with 200% efficiency of	0.163	81	99	1.8

Sensitivity Run	Mean Square Error (ft^2)	Residuals between ±0.5 ft (%)	Residuals between ±1.0 ft (%)	Minimum Flows and Levels (MFLs) Freeboard (ft)
the original				
Increase drainage area by 10%	0.126	90	99	1.7
Decrease drainage area by 10%	0.099	93	99	1.9
Floridan aquifer well offset raised 1 ft	0.101	91	100	1.9
Floridan aquifer well offset lowered 1 ft	0.102	91	100	2.0

Table 10. Sensitivity analysis results for Coon Pond

Sensitivity Run	Mean Square Error (ft^2)	Residuals between ±0.5 ft (%)	Residuals between ±1.0 ft (%)	Minimum Flows and Levels (MFLs) Freeboard (ft)
Original calibration	0.180	82	97	>3.0
Daytona Beach evaporation	0.152	89	97	>3.0
Outlet raised 1 ft	0.325	46	95	>3.0
Outlet lowered 1 ft	0.278	62	94	>3.0
Outlet with 50% efficiency of the original	0.150	83	98	>3.0
Outlet with 200% efficiency of the original	0.248	69	95	>3.0
Increase drainage area by 10%	0.202	78	95	>3.0
Decrease drainage area by 10%	0.174	82	97	>3.0
Floridan aquifer well offset raised 1 ft	0.181	77	98	>3.0
Floridan aquifer well offset lowered 1 ft	0.192	82	97	>3.0

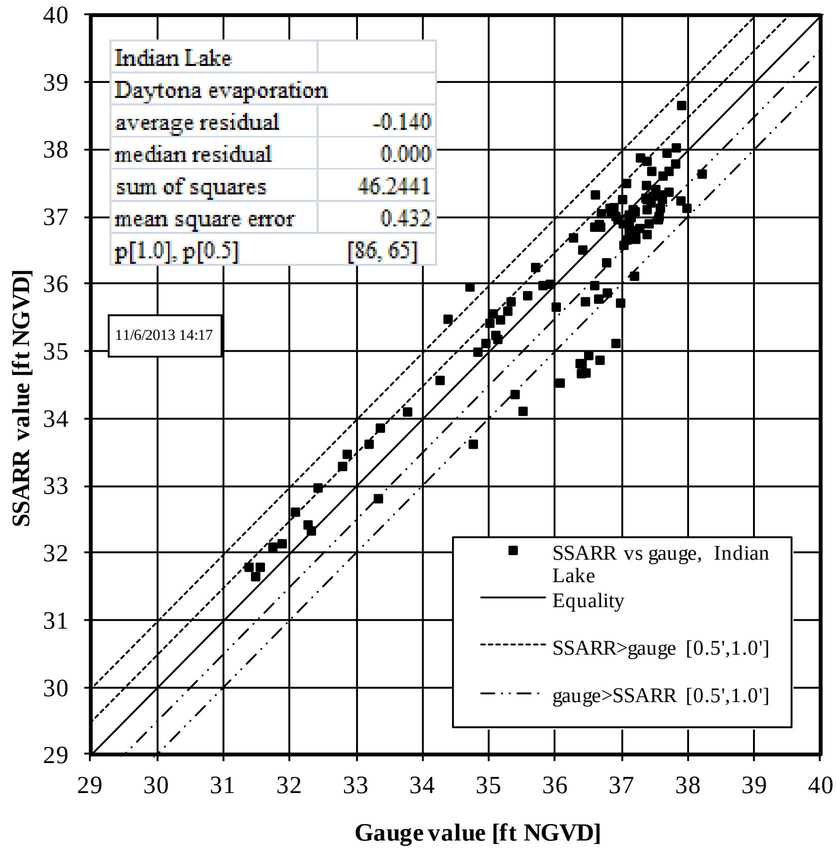


Figure 41. Scatter plot for Indian Lake from the alternative evaporation model calibration
Note: SSARR = Streamflow Synthesis and Reservoir Regulation model

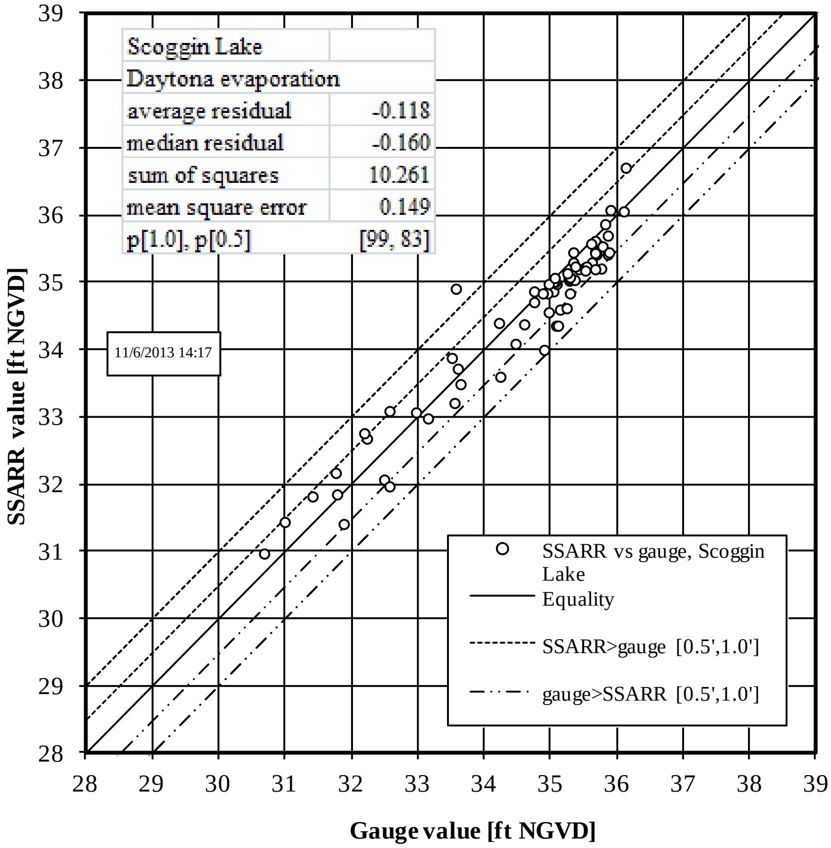


Figure 42. Scatter plot for Scoggin Lake from the alternative evaporation model calibration

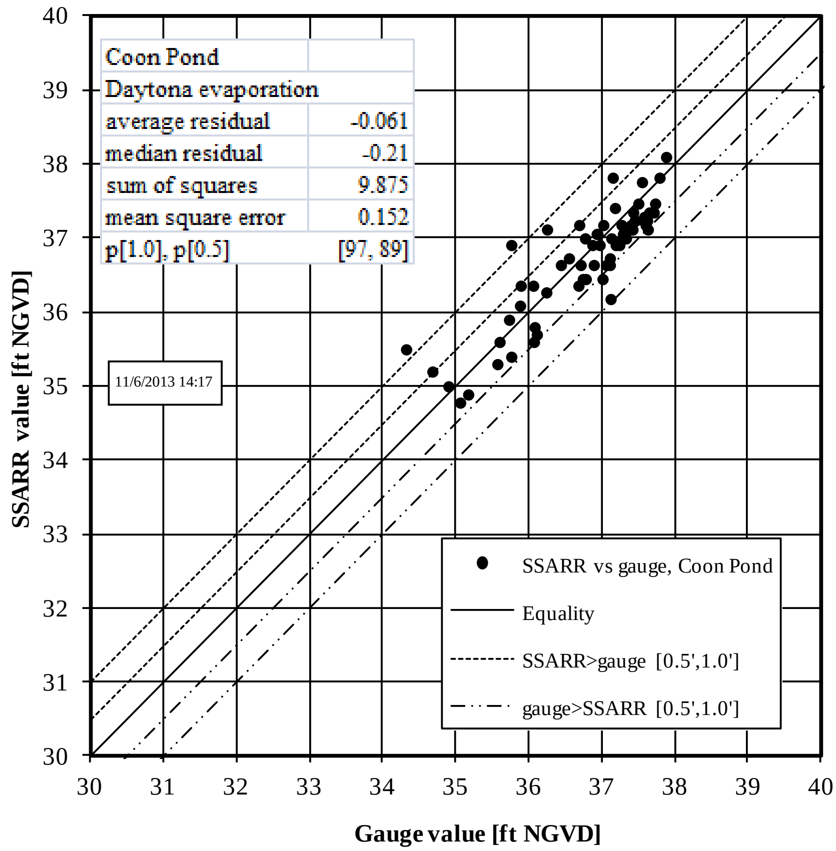


Figure 43. Scatter plot for Coon Pond from the alternative evaporation model calibration

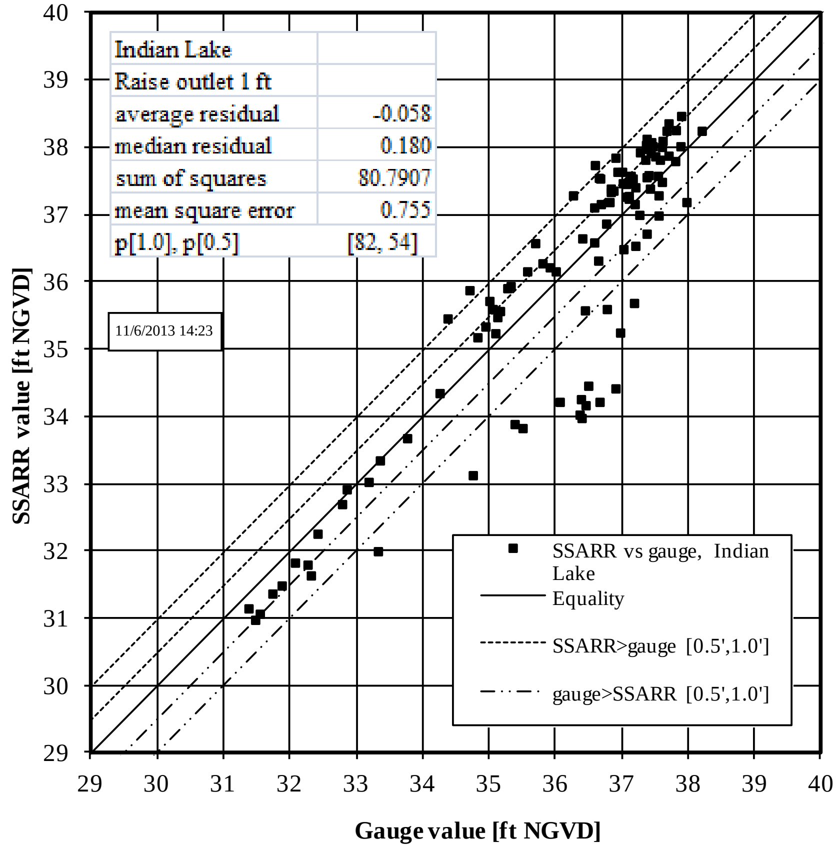


Figure 44. Scatter plot for Indian Lake from model calibration with the outlet invert elevation raised by 1 ft

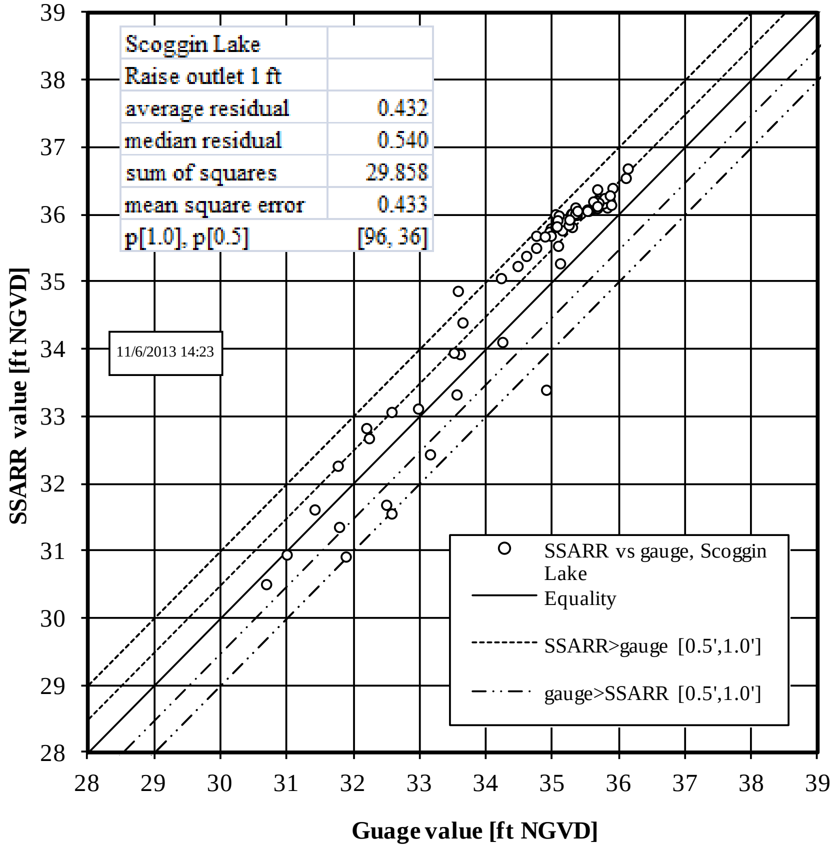


Figure 45. Scatter plot for Scoggin Lake from model calibration with the outlet invert elevation raised by 1 ft

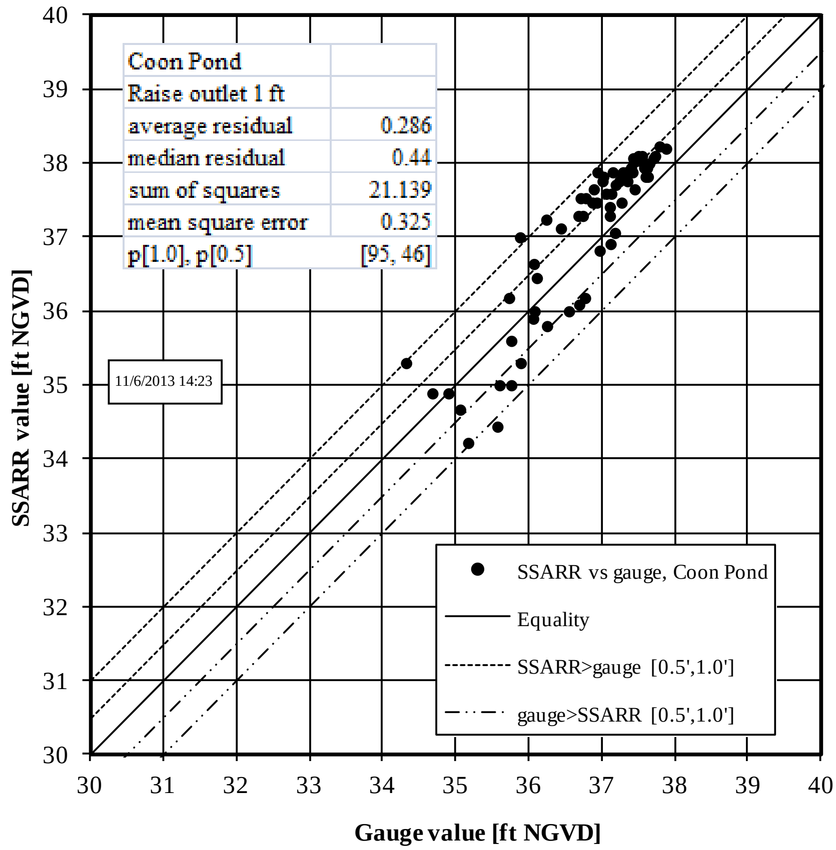


Figure 46. Scatter plot for Coon Pond from model calibration with the outlet invert elevation raised by 1 ft

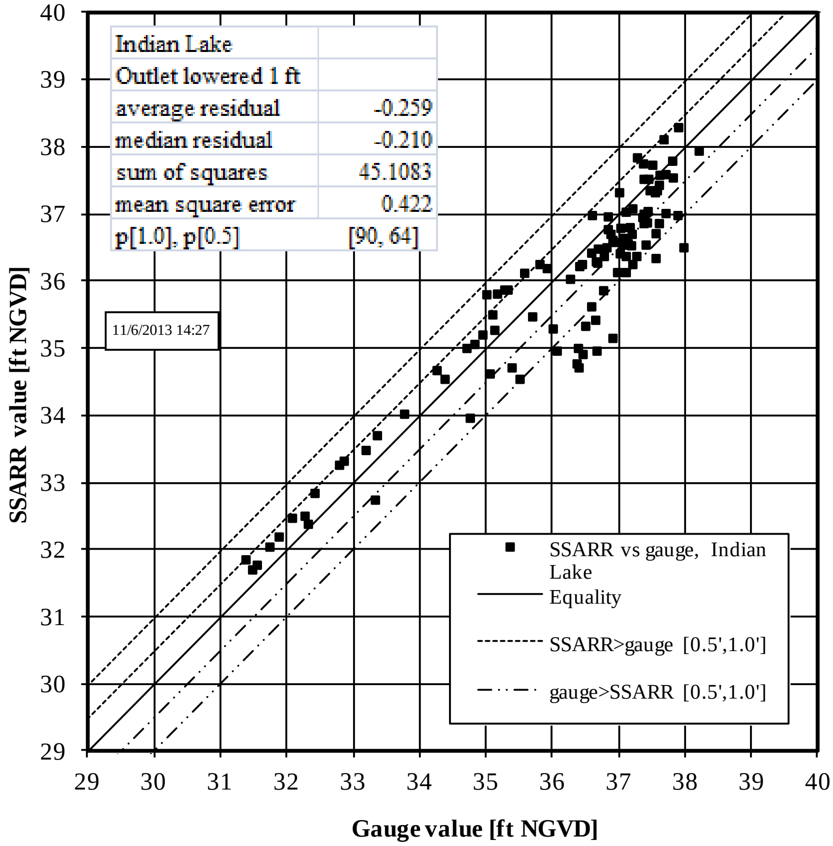


Figure 47. Scatter plot for Indian Lake from model calibration with the outlet invert elevation lowered by 1 ft

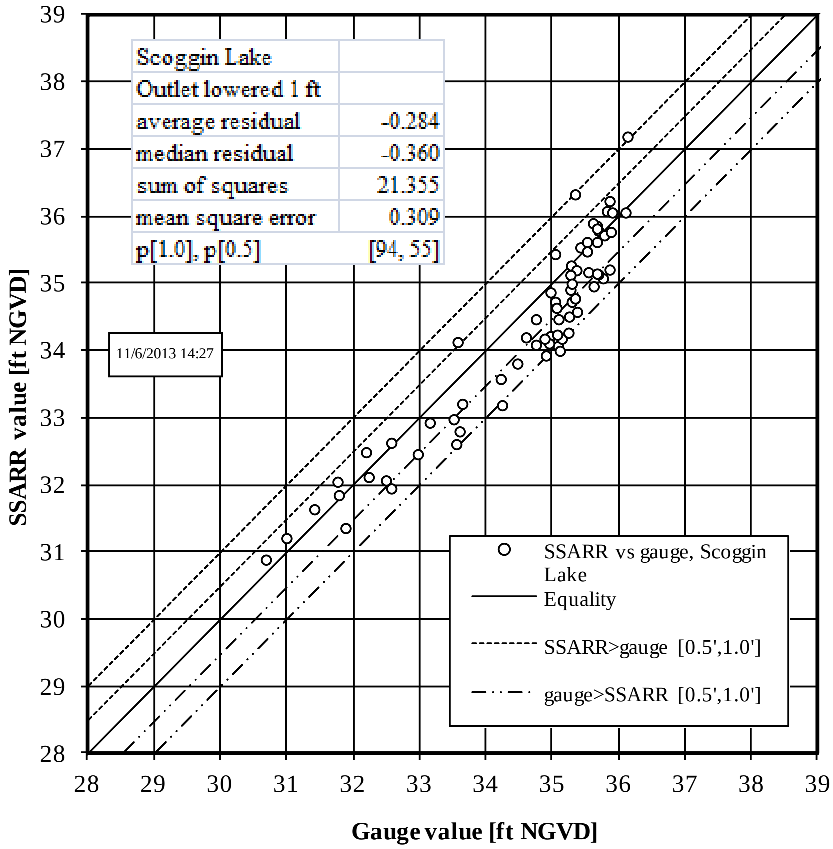


Figure 48. Scatter plot for Scoggin Lake from model calibration with the outlet invert elevation lowered by 1 ft

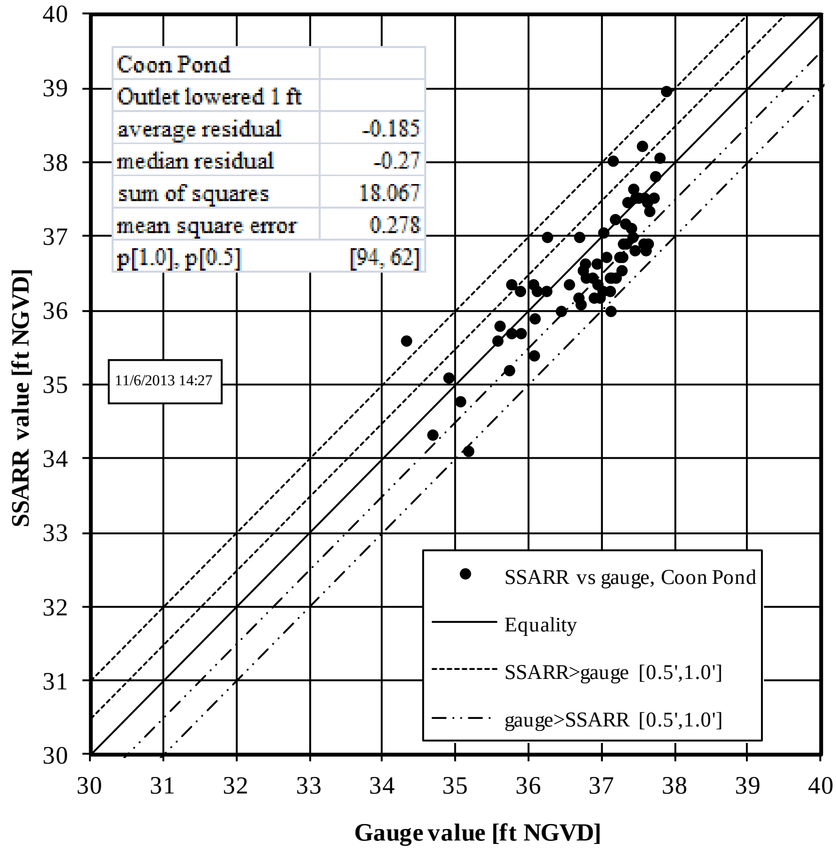


Figure 49. Scatter plot for Coon Pond from model calibration with the outlet invert elevation lowered by 1 ft

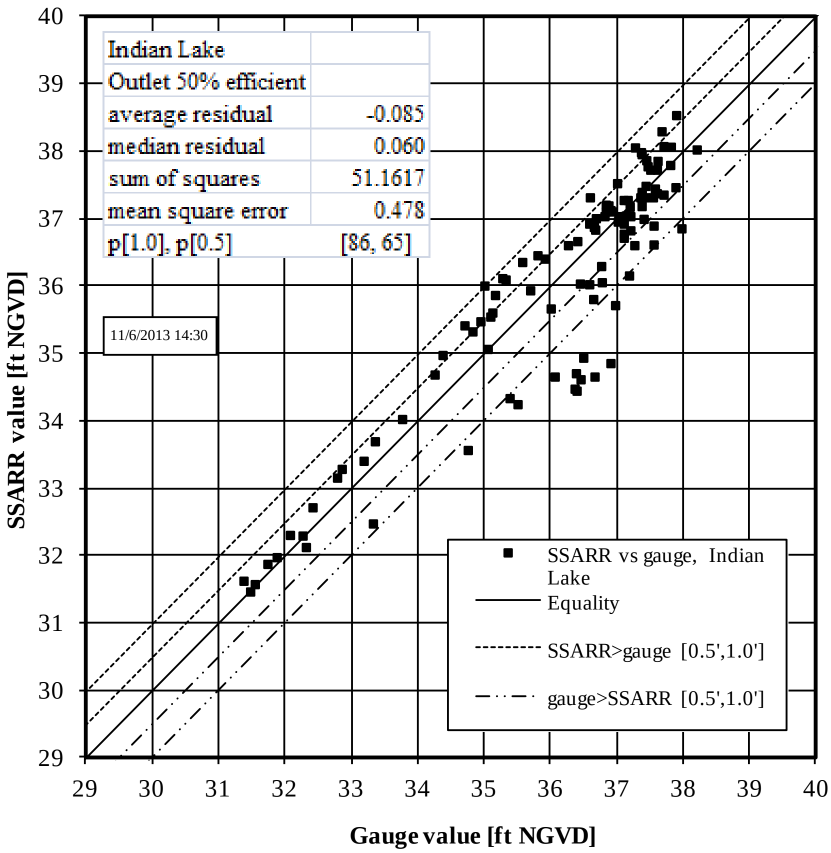


Figure 50. Scatter plot for Indian Lake from model calibration with the outlet with efficiency 50% of the original

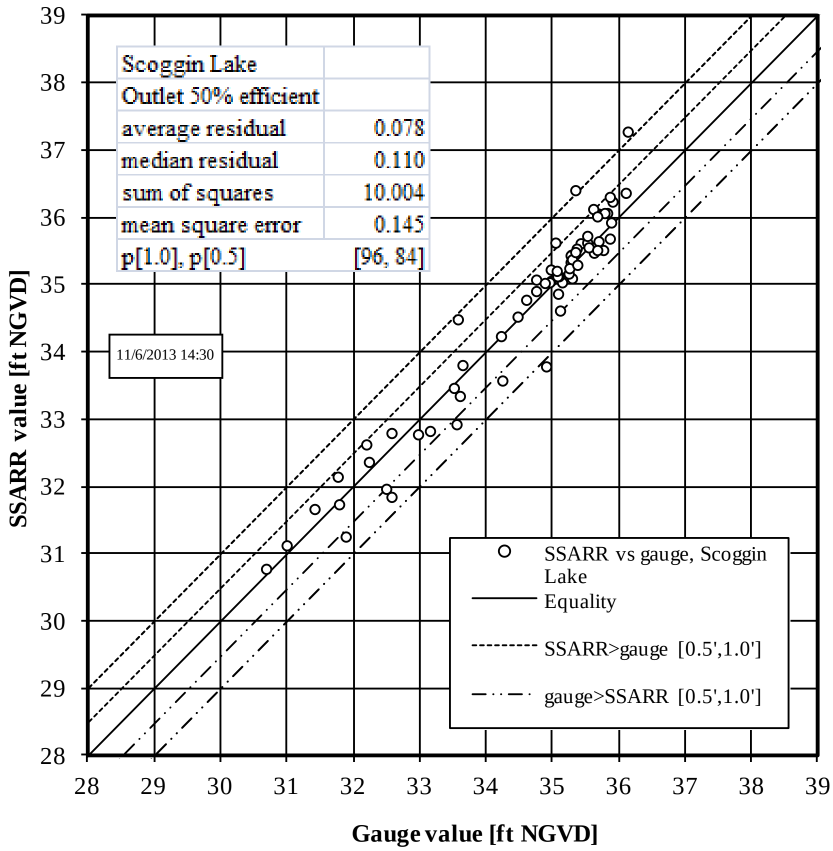


Figure 51. Scatter plot for Scoggin Lake from model calibration with the outlet with efficiency 50% of the original

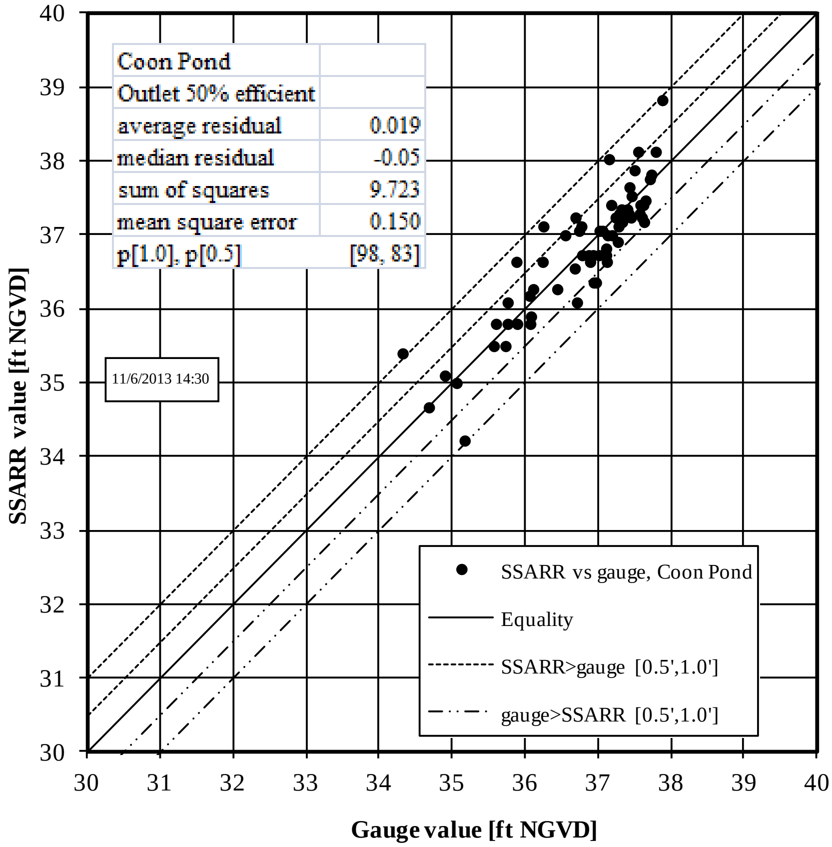


Figure 52. Scatter plot for Coon Pond from model calibration with the outlet with efficiency 50% of the original

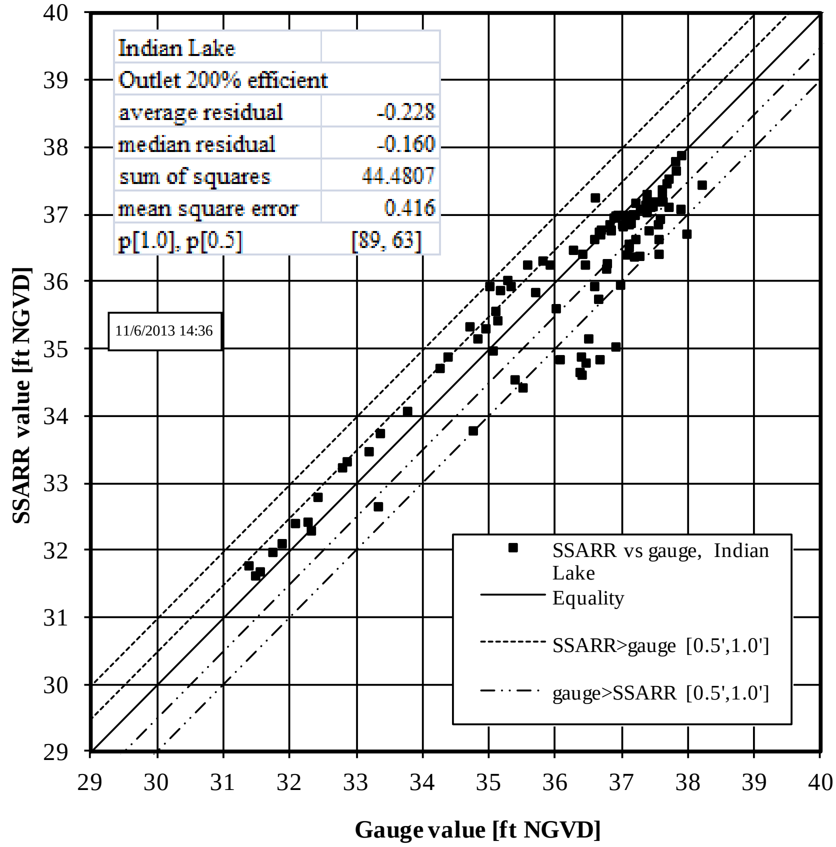


Figure 53. Scatter plot for Indian Lake from model calibration with the outlet with efficiency 200% of the original

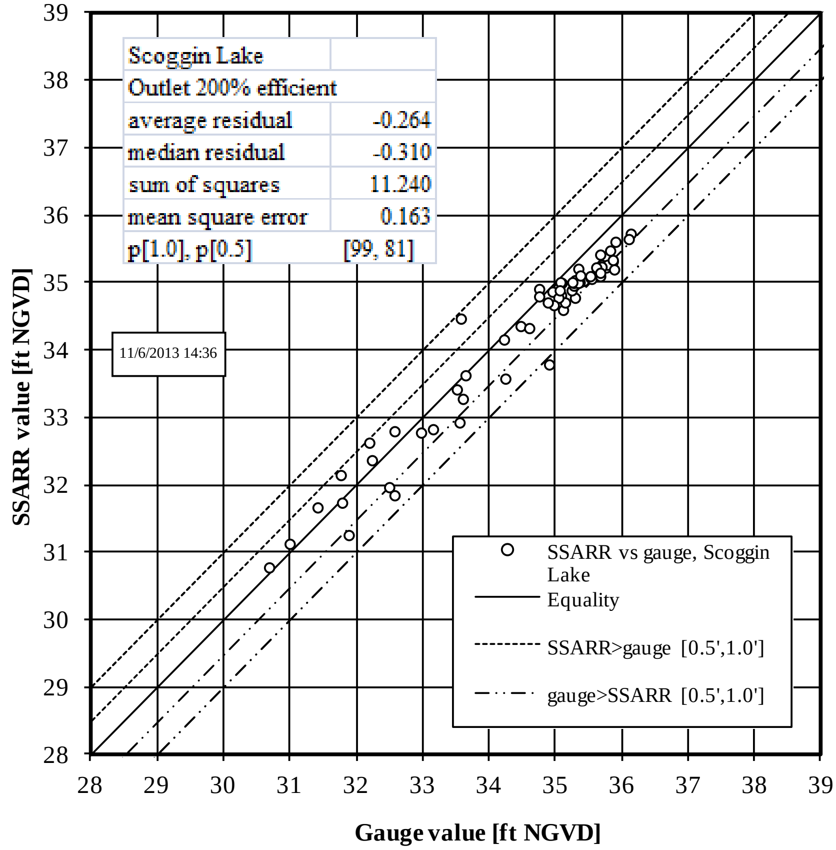


Figure 54. Scatter plot for Scoggin Lake from model calibration with the outlet with efficiency 200% of the original

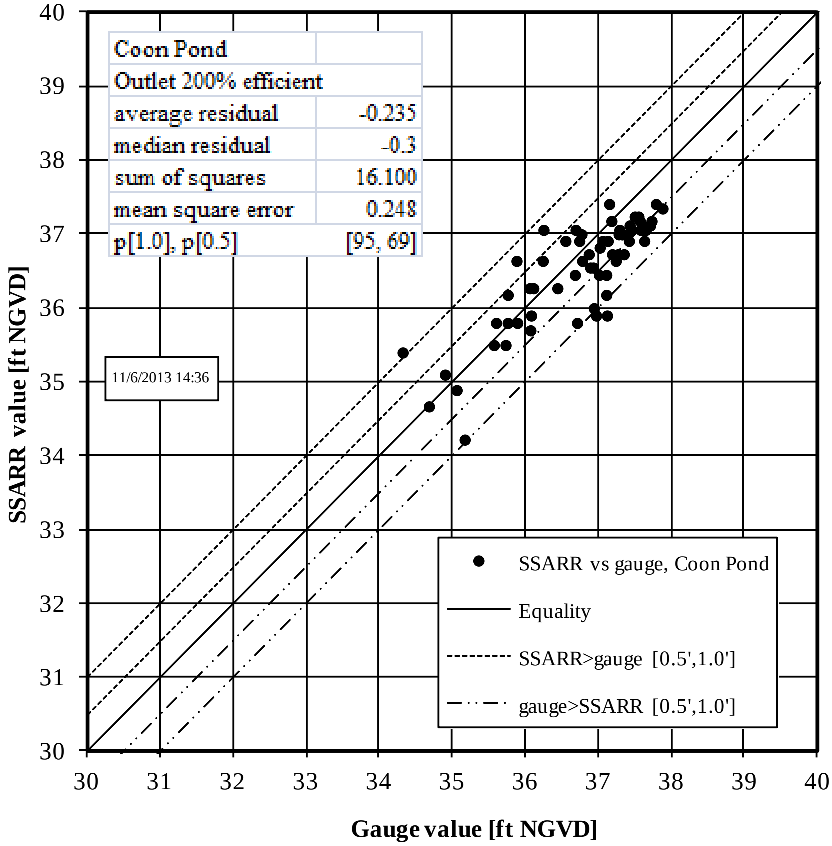


Figure 55. Scatter plot for Coon Pond from model calibration with the outlet with efficiency 200% of the original

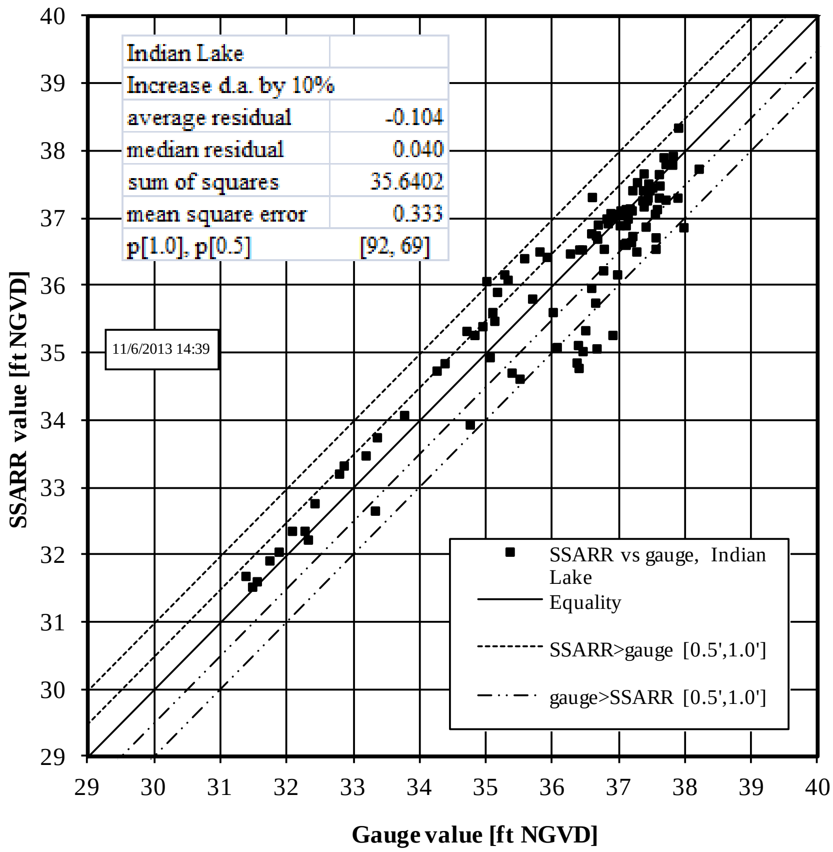


Figure 56. Scatter plot for Indian Lake from model calibration with increasing drainage area by 10%

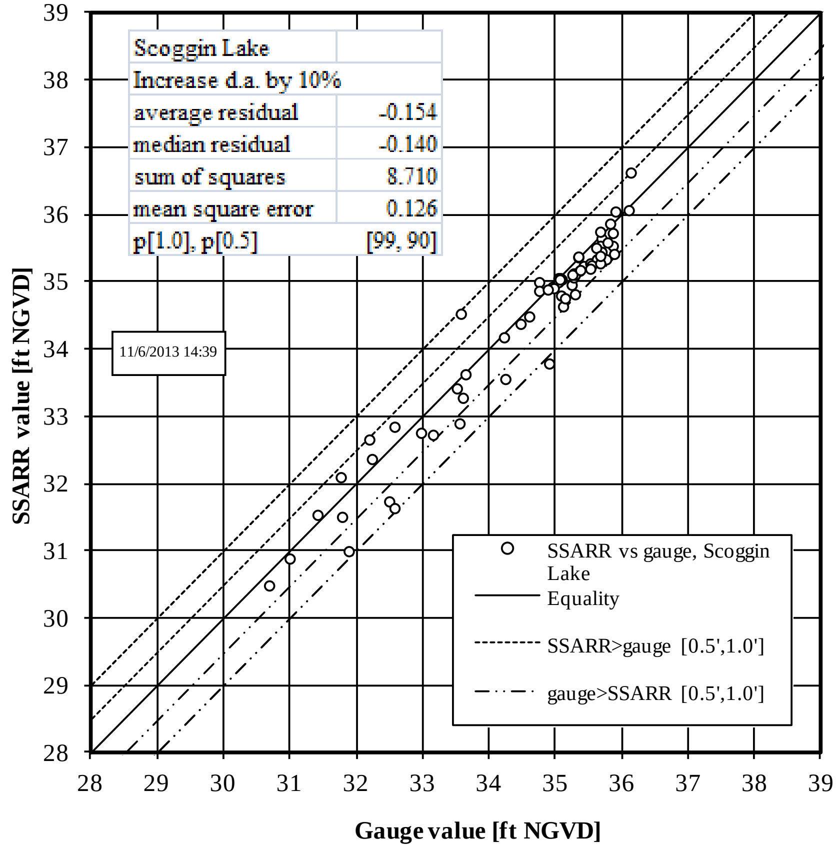


Figure 57. Scatter plot for Scoggin Lake from model calibration with increasing drainage area by 10%

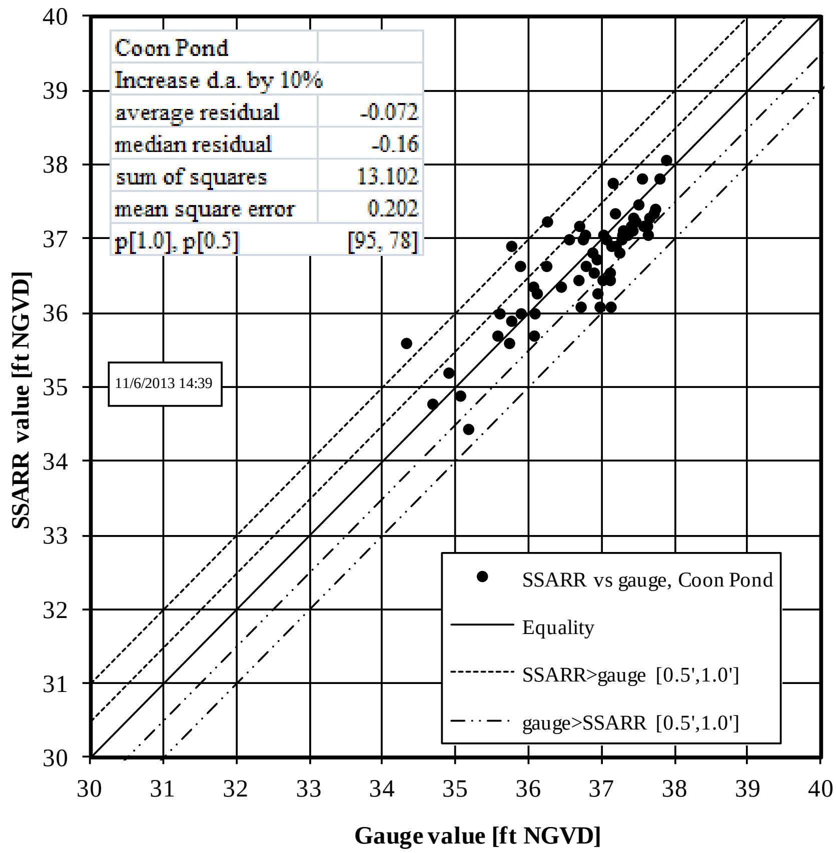


Figure 58. Scatter plot for Coon Pond from model calibration with increasing drainage area by 10%

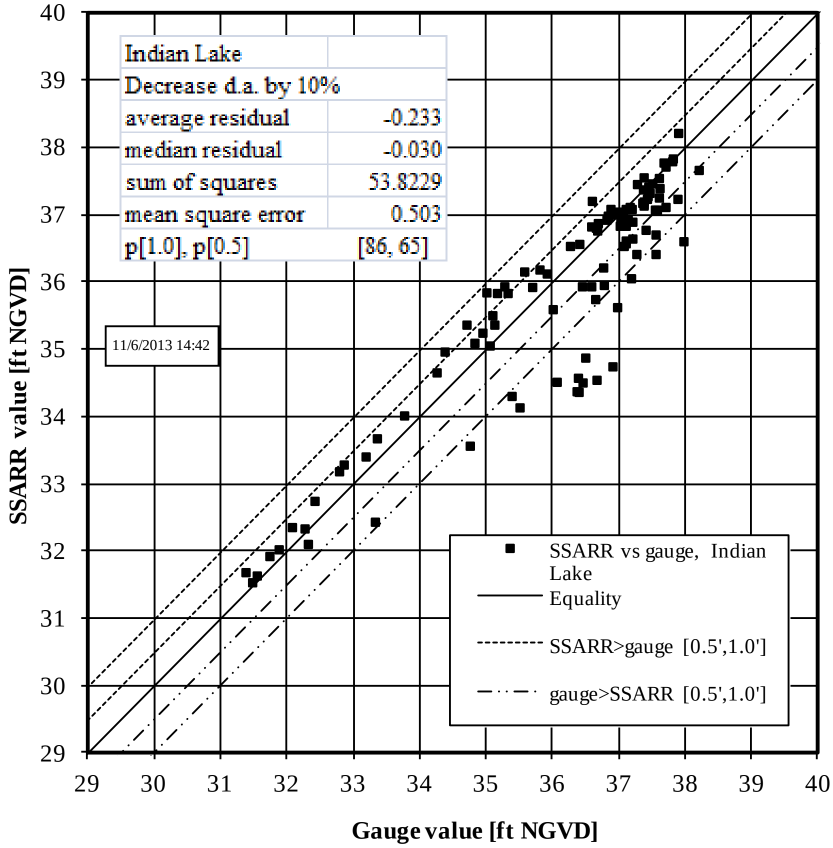


Figure 59. Scatter plot for Indian Lake from model calibration with decreasing drainage area by 10%

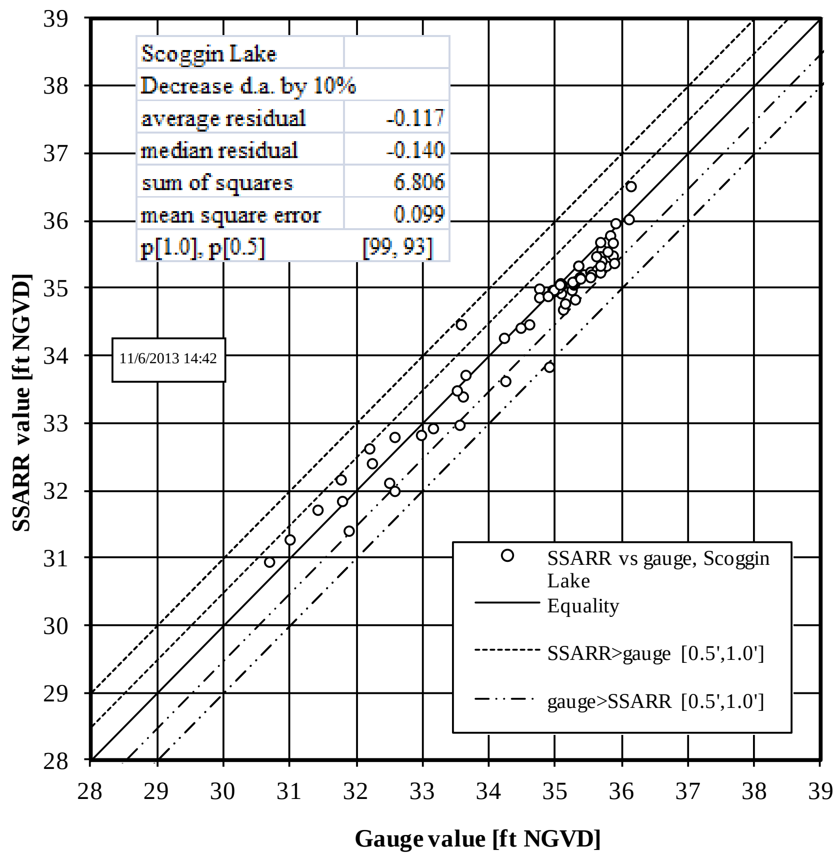


Figure 60. Scatter plot for Scoggin Lake from model calibration with decreasing drainage area by 10%

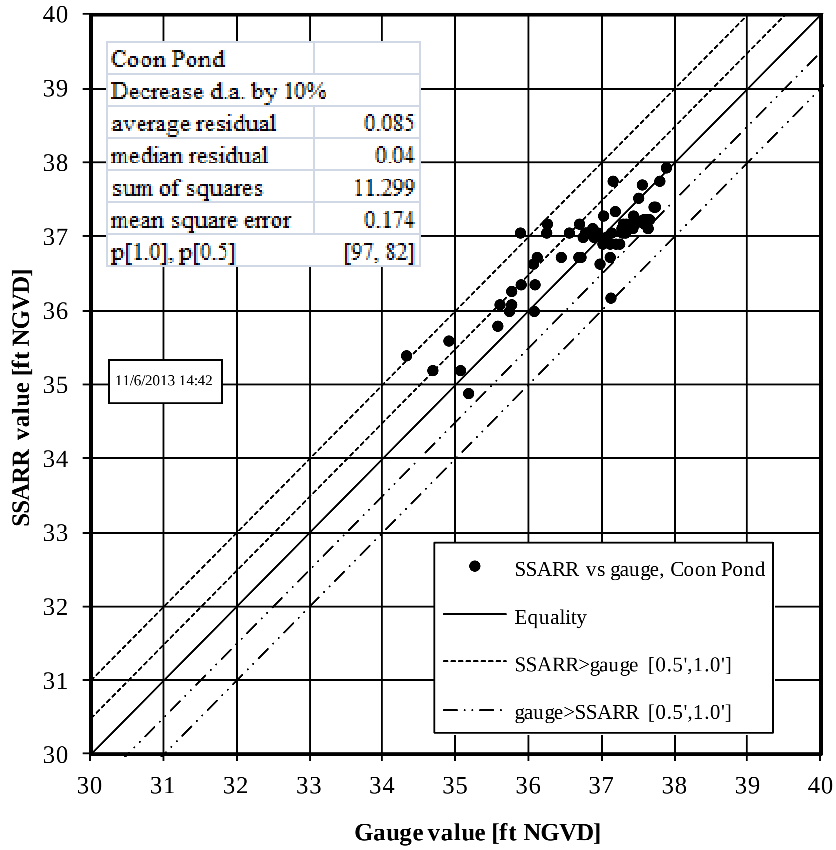


Figure 61. Scatter plot for Coon Pond from model calibration with decreasing drainage area by 10%

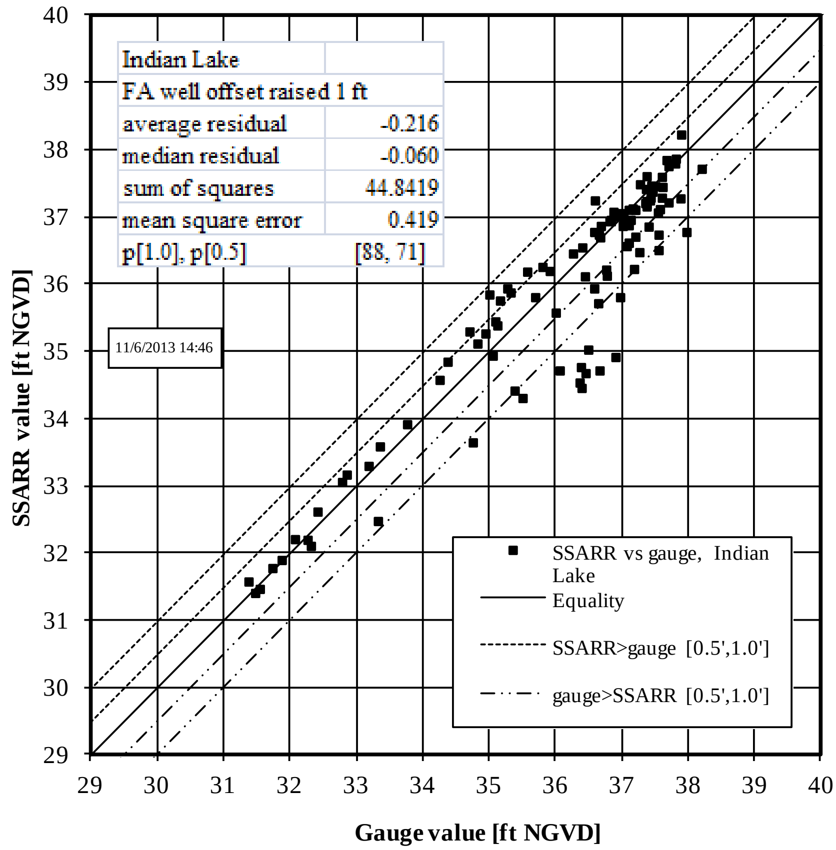


Figure 62. Scatter plot for Indian Lake from model calibration with the Floridan aquifer well offset raised by 1 ft

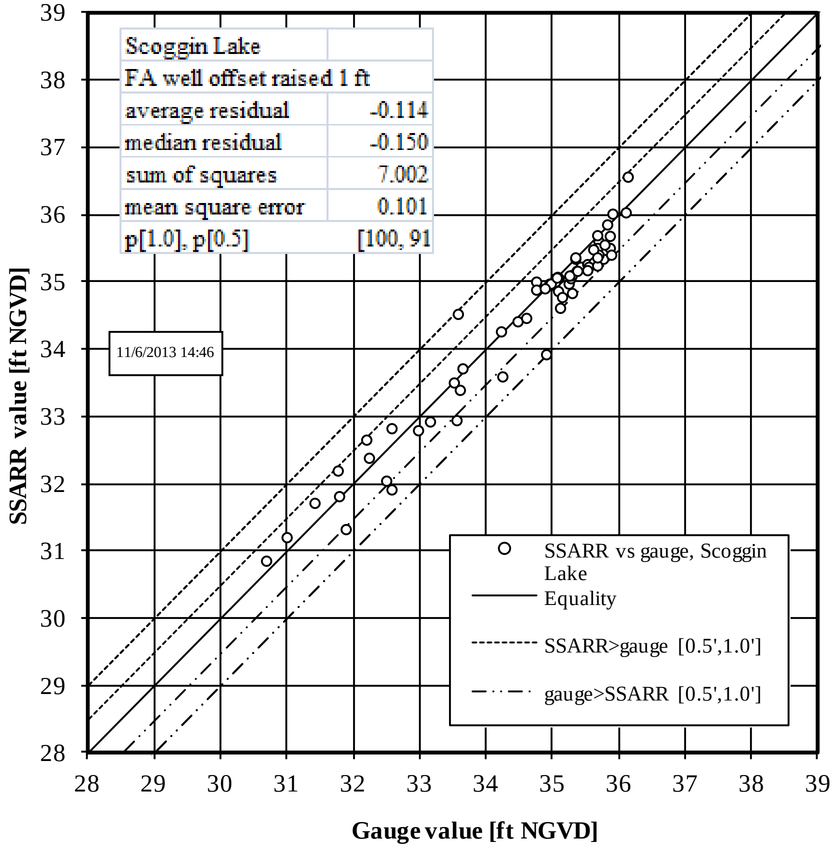


Figure 63. Scatter plot for Scoggin Lake from model calibration with the Floridan aquifer well offset raised by 1 ft

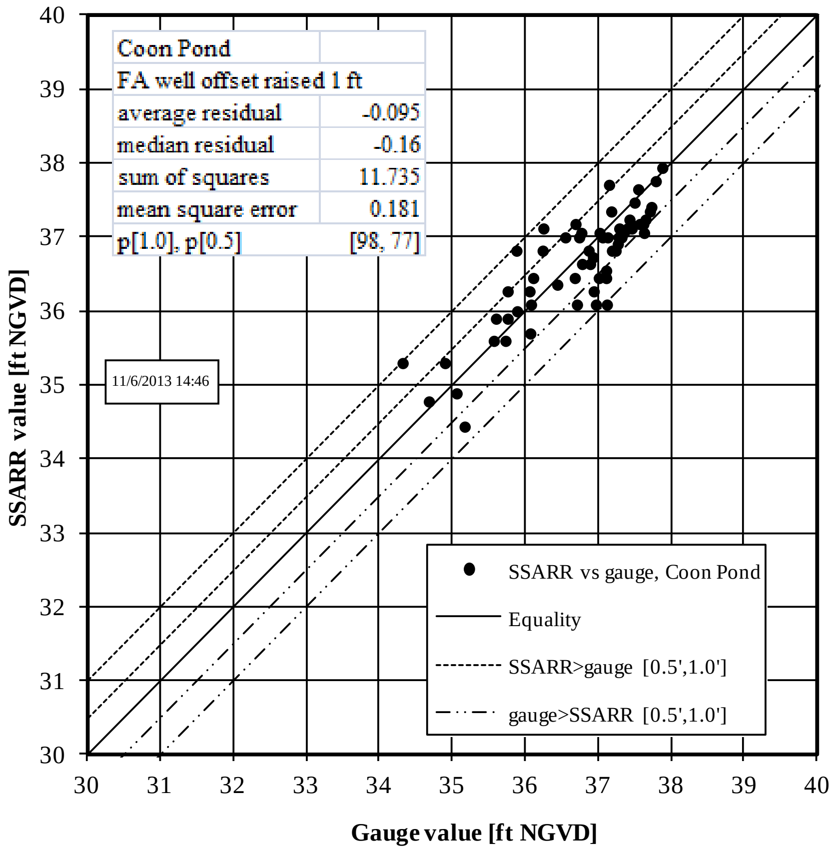


Figure 64. Scatter plot for Coon Pond from model calibration with the Floridan aquifer well offset raised by 1 ft

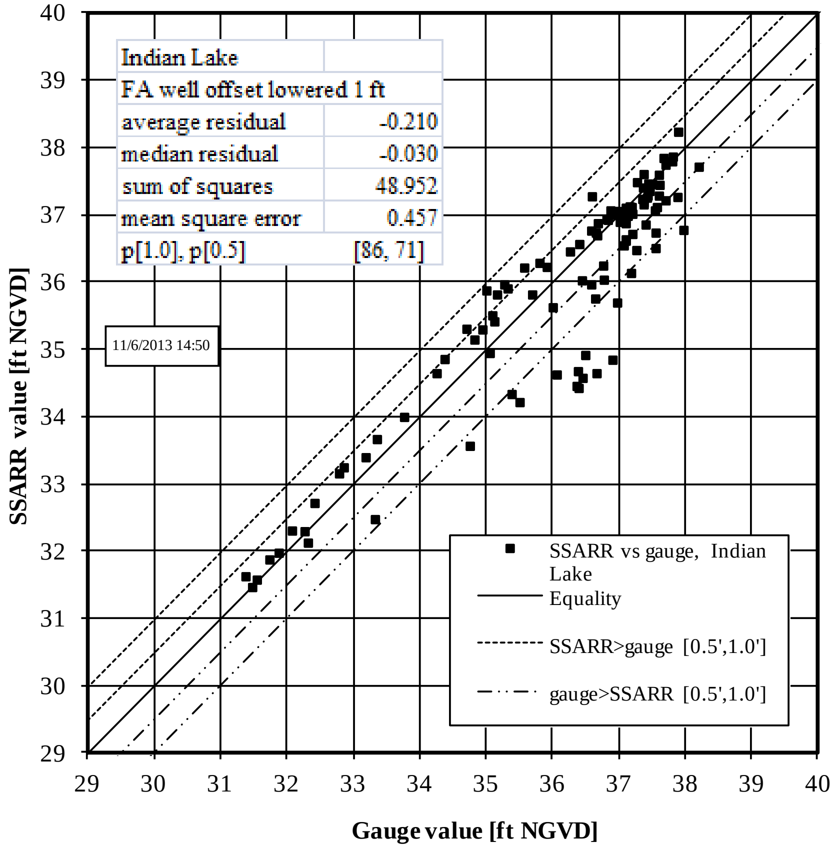


Figure 65. Scatter plot for Indian Lake from model calibration with the Floridan aquifer well offset lowered by 1 ft

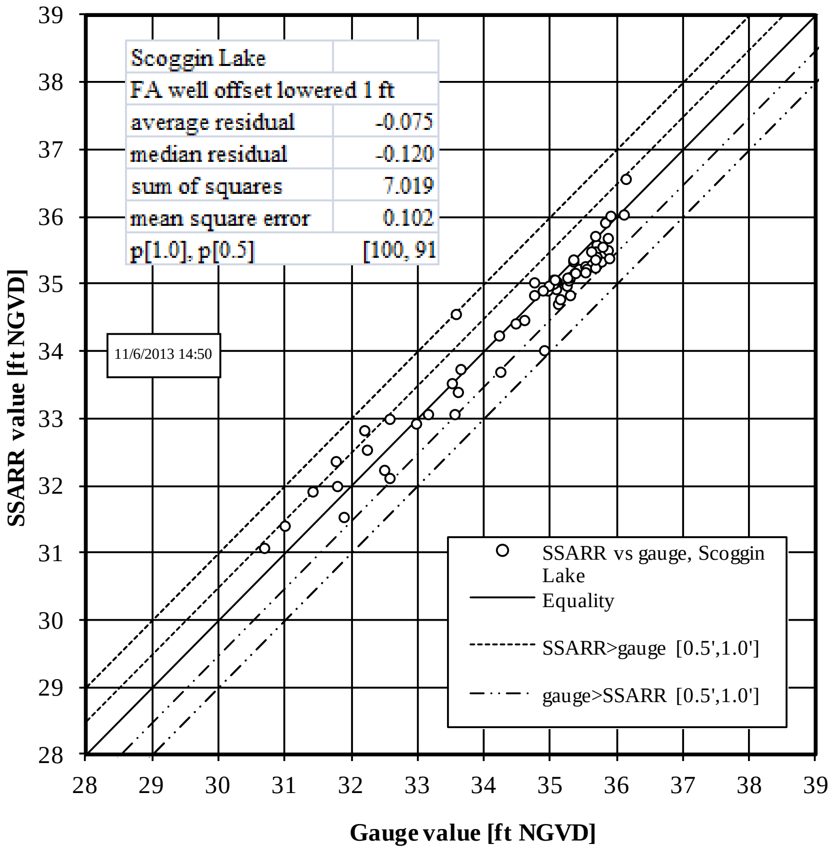


Figure 66. Scatter plot for Scoggin Lake from model calibration with the Floridan aquifer well offset lowered by 1 ft

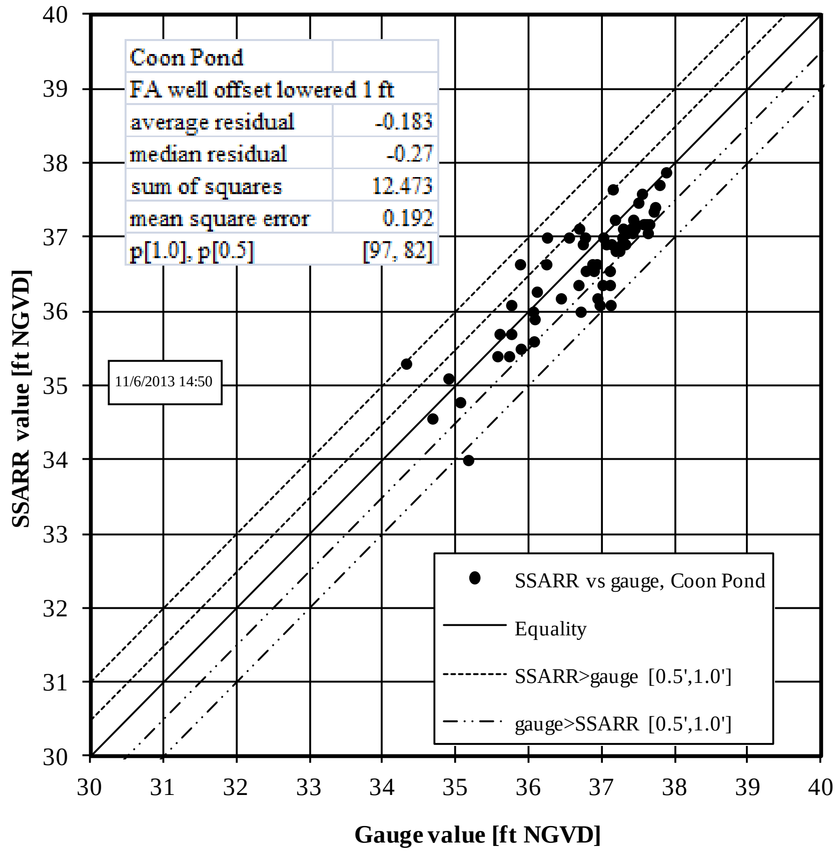


Figure 67. Scatter plot for Coon Pond from model calibration with the Floridan aquifer well offset lowered by 1 ft

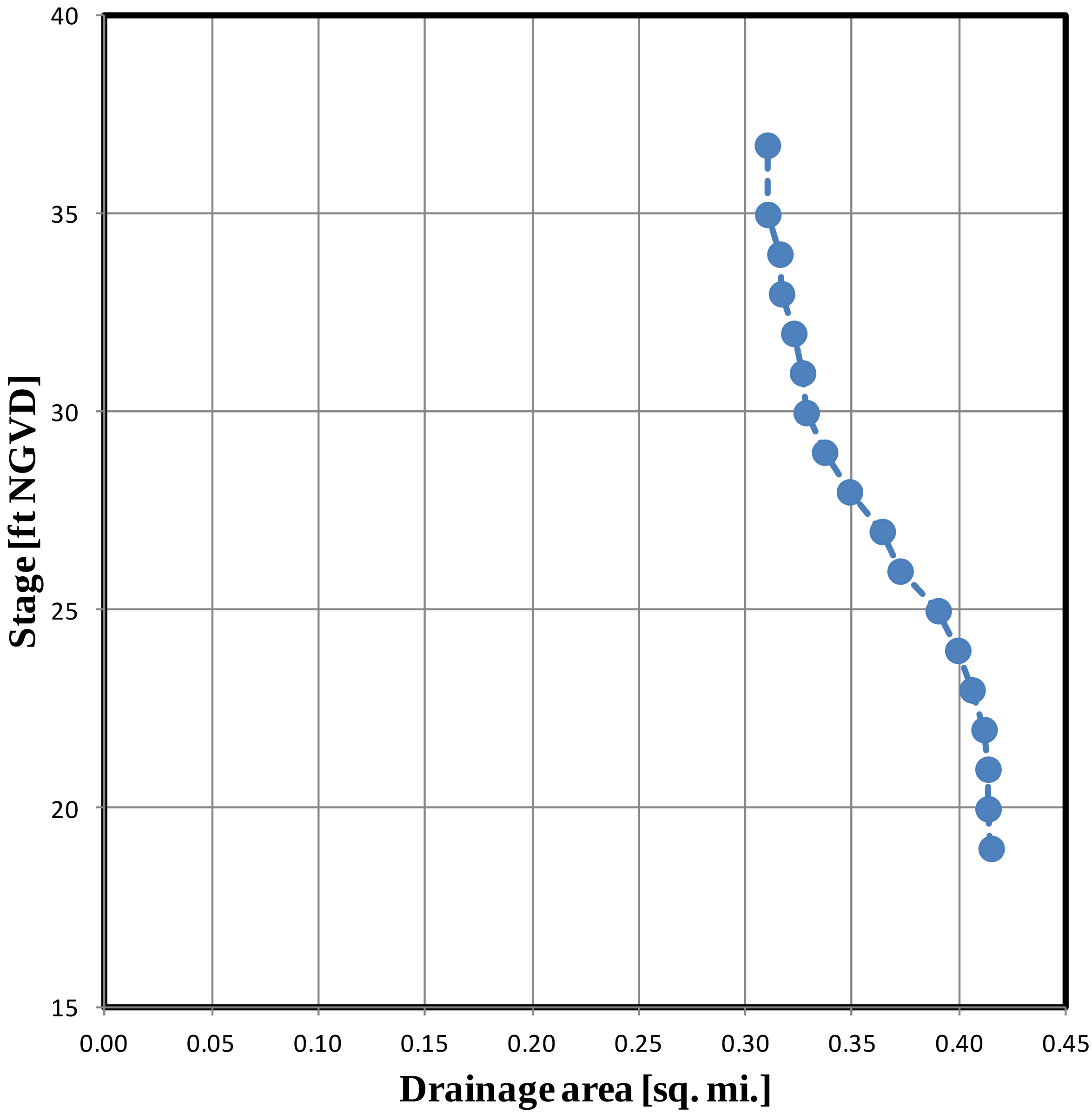


Figure 68. Variable drainage area for Indian Lake

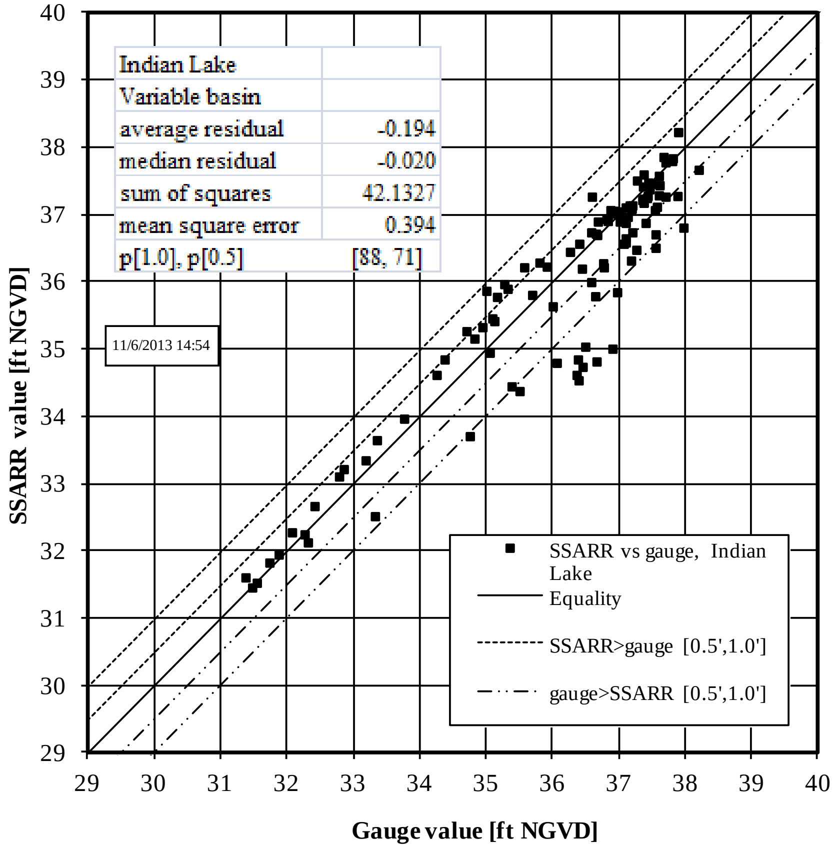


Figure 69. Scatter plot for Indian Lake from model calibration using a variable drainage basin area

RESULTS AND DISCUSSION

INDIAN LAKE SYSTEM WATER BUDGETS

The water budget of each lake in the Indian Lake system, as simulated by the SSARR model, consists of five components: basin runoff, direct rainfall, direct evaporation, seepage to a sink, and outflow downstream (see Tables 11 through 17 and Figures 70 through 72). For example, the SSARR simulation indicates that under 2005 conditions Scoggin Lake has, on average, a basin runoff of 324 ac-ft/yr, direct rainfall of 271 ac-ft/yr, direct evaporation of 246 ac-ft/yr, seepage to the Floridan aquifer of 162 ac-ft/yr, and outflow to the Middle Haw Creek of 179 ac-ft/yr (Figure 42).

Comparison of water budgets is one technique used to illustrate the effects of hydrologic changes within a basin. For example, with a 2.0-ft Floridan aquifer drawdown, seepage from Scoggin Lake would be expected to increase from 162 to 211 ac-ft/yr (Figure 42). This change would be offset with a decrease in flow to the Middle Haw Creek from 179 to 131 ac-ft/yr.

Comparison of water budgets can also provide clues as to the type of lake. Not including direct evaporation, seepage accounts for nearly 90% of outflows from Indian Lake; surface outflow accounts for the other 10% (see Table 11). On the other hand, for Scoggin Lake seepage and surface outflows each account for about 50% of outflows. This difference accounts for the different ranges of fluctuation of 7 ft for Indian Lake and 5 ft for Scoggin Lake (see Figures 19 and 24) and is also borne out by the fact that Indian Lake is more sensitive to Floridan aquifer withdrawals than Scoggin Lake (Murray 2012).

INDIAN LAKE SYSTEM RUNOFF

Runoff can be defined as the depth of water uniformly distributed over a drainage basin (computed as the discharge divided by the drainage area) and can provide some indication of the accuracy of a model. For the Indian Lake system SSARR model, the amount of runoff was dictated by rainfall and the SMI-ROP relationships (see Figure 2). The accuracy of simulated runoff amounts also depends on the correct determination of the contributing basin runoff area. For the 30-year simulation, the SSARR model estimated the average runoff from the pervious basin surrounding Scoggin Lake to be 324 ac-ft/yr (Figure 42). Given that Scoggin Lake has a drainage basin area of 0.51 mi^2 (see Figure 4) or 326 acres, this yearly flow translates to a runoff of 1.0 ft/yr or 12 in/yr. Regional runoff estimates for the state of Florida have been published (ISPA 1998, p. 69). The Indian Lake system lies in an area that is estimated to produce runoff of between 10 and 15 in/yr. The 12 inches of runoff estimated for the Indian Lake system is within this range, and therefore gives added credibility to model results.

OTHER STUDIES

There are two recent studies that pertain to modeling of the Indian Lake system. The first study consisted of seismic profiling of the bottoms of a number of SJRWMD lakes, including Indian Lake (Kindinger et al. 2000). A number of karstic collapse structures were identified in the bottom of Indian Lake, indicating a high potential for seepage from the lake to the Floridan aquifer. Modeling results bear this out.

The second study consisted of an analysis of the relations between precipitation, nearby groundwater withdrawals, and lake stage changes (Murray 2012). Indian Lake, Scoggin Lake, and Coon Pond were all part of the analysis. For Indian Lake under normal and dry conditions, the analysis indicates a high correlation between lake stage changes on the one hand, and precipitation and groundwater withdrawals on the other hand. This fits with the Indian Lake water budget (Table 11, Figure 70) that shows seepage to be the dominant part of outflow. Scoggin Lake stage changes are highly correlated with precipitation and groundwater withdrawals under drought conditions, but less so under normal conditions. This fits with the Scoggin Lake water budget (Table 13, Figure 71) that shows surface outflow and seepage to be of about the same magnitude. During wet and normal times, surface outflows would dominate outflows. During drier times, seepage would dominate outflows and the effects of pumping would be more apparent. Coon Pond stage changes were not found to be correlated with groundwater withdrawals. This is explained, in part, by the fact that Coon Pond essentially dries up on occasion.

The author concludes that “changes in Upper Floridan aquifer water levels and in water-surface stage at Indian and Scoggin Lakes tended to be highly correlated with both precipitation and withdrawals. The greater influence of withdrawals on stage changes … indicates that these karstic lakes may be better connected hydraulically with the underlying Upper Floridan aquifer than is the surficial aquifer system at the other monitoring sites.” For the model, the relative size of the freeboards determined at each lake confirms what was found in the analysis.

SENSITIVITY ANALYSES RESULTS

MFLs freeboards with respect to Floridan aquifer declines for Indian Lake (Table 8) ranged from a low of -0.3 ft to a high of 1.0 ft with most around 0.5 ft in ten sensitivity analysis runs. The single largest MSE was produced by raising the outlet elevation by 1.0 ft. This scenario also produced the smallest percentage of residuals within ±0.5 ft as well as an anomalous freeboard of -0.3 ft. The smallest MSE was produced by adding 10% to the drainage basin area, though the freeboard increased only by 0.1 ft. This may be an indication that for Indian Lake the true outlet is farther out than assumed (see Figure 3). The second lowest MSE was produced in the run with a variable drainage basin. Again, this is an indication that the true drainage basin might be somewhat larger than assumed. Although the MSE is smaller with a variable drainage basin, the percentage of residuals between ±0.5 ft and ±1.0 ft are similar to the original calibration. The freeboard of 0.4 with the variable basin is the same as with the original calibration. Thus, in this case, there does not seem to be great advantage to using variable drainage basin areas.

MFLs freeboards with respect to Floridan aquifer declines for Scoggin Lake (Table 9) ranged from a low of -1.2 ft to a high of 2.0 ft with all but the one clustered near 2.0 ft in nine sensitivity analysis runs. The two sensitivity scenarios that stand out are raising and lowering the outlet elevation. These two scenarios produced, by far, the two largest MSEs and, again by far, the smallest percentages of residuals within ±0.5 ft. The lowered outlet scenario produced the only anomalous MFLs freeboard at -1.2 ft, as well. The original calibration produced the lowest MSE and the highest percentages between ±0.5 ft and ±1.0 ft.

MFLs freeboards with respect to Floridan aquifer declines for Coon Pond (Table 10) were all greater than 3.0 ft in nine sensitivity analysis runs, indicating that Coon Pond is not very sensitive to Floridan aquifer declines. As with Scoggin Lake, the two Coon Pond sensitivity scenarios that stand out are raising and lowering the outlet elevation. These two scenarios provided the two largest MSEs and the two smallest percentages of residuals within ±0.5 ft.

The large MSEs and small percentages of residuals within ±0.5 produced by raising and lowering the outlet elevations for all three lakes indicate two things. First, for a successful model it is important to obtain the correct outlet elevation. That being said, the second thing indicated is that, given a sufficient period of stage records, a fairly accurate elevation can be obtained by inspection, without the need for a surveyed outlet.

Table 11. Indian Lake water budget for 2005 conditions (in ac-ft)

Year	Pervious basin	Direct rainfall	Direct evapo-ration	Seepage	To Middle Haw
1976	190	293	-268	-143	0
1977	134	223	-288	-159	0
1978	179	286	-298	-182	0
1979	274	381	-272	-186	-18
1980	131	215	-291	-207	-2
1981	115	200	-253	-172	0
1982	186	256	-232	-143	0
1983	283	436	-270	-185	-37
1984	199	288	-318	-216	-67
1985	153	241	-264	-183	0
1986	158	256	-263	-159	0
1987	166	247	-257	-165	0
1988	132	211	-255	-175	0
1989	139	218	-257	-163	0
1990	117	172	-256	-142	0
1991	250	328	-246	-130	0
1992	171	239	-263	-144	0
1993	106	182	-250	-143	0
1994	237	334	-236	-175	0
1995	213	296	-252	-153	-1
1996	235	335	-306	-208	-57
1997	220	345	-274	-213	-20
1998	201	292	-260	-208	-78
1999	175	259	-228	-210	0
2000	91	137	-244	-216	0
2001	226	298	-214	-156	0
2002	212	309	-199	-166	0
2003	236	359	-269	-215	-123
2004	262	411	-339	-214	-115
2005	303	490	-366	-212	-214
Average	190	284	-266	-178	-24
%	40.0	60.0	56.8	38.0	5.2
%*	100.0	—	—	88.0	12.0
Maximum	303	490	-366	-216	-214
Minimum	91	137	-199	-130	0
* without direct rainfall and direct evaporation					

Table 12. Indian Lake water budget for 2005 conditions plus 0.4-ft Floridan aquifer decline (ac-ft)

Year	Pervious basin	Direct rainfall	Direct evapo-ration	Seepage	To Middle Haw
1957	190	291	-267	-146	0
1958	134	220	-285	-164	0
1959	179	283	-295	-183	0
1960	274	374	-268	-189	-7
1961	131	212	-288	-216	0
1962	115	198	-251	-178	0
1963	186	255	-231	-143	0
1964	283	427	-263	-188	-22
1965	199	287	-317	-216	-62
1966	153	239	-263	-187	0
1967	158	254	-261	-171	0
1968	166	244	-253	-175	0
1969	132	209	-252	-179	0
1970	139	216	-254	-163	0
1971	117	170	-252	-142	0
1972	250	324	-242	-131	0
1973	171	236	-261	-144	0
1974	106	179	-246	-143	0
1975	237	332	-232	-178	0
1976	213	291	-247	-154	0
1977	235	330	-302	-215	-29
1978	220	340	-271	-215	-15
1979	201	291	-259	-216	-75
1980	175	256	-225	-211	0
1981	91	134	-240	-216	0
1982	226	295	-211	-156	0
1983	212	303	-195	-168	0
1984	236	346	-259	-215	-77
1985	262	408	-338	-216	-109
1986	303	483	-361	-215	-196
Average	190	281	-263	-181	-20
%	40.3	59.7	56.7	39.0	4.3
%*	100.0	—	—	90.2	9.8
Maximum	303	483	-361	-216	-196
Minimum	91	134	-195	-131	0
* without direct rainfall and direct evaporation					

Table 13. Scoggin Lake water budget for 2005 conditions (ac-ft)

Year	Pervious basin	Direct rainfall	Direct evapo-ration	Seepage	To Middle Haw
1976	328	305	-277	-143	-224
1977	234	184	-233	-142	-65
1978	309	281	-301	-199	-98
1979	463	412	-301	-178	-356
1980	222	179	-255	-148	-23
1981	195	136	-177	-163	0
1982	320	270	-259	-142	-131
1983	483	462	-293	-145	-405
1984	344	269	-306	-143	-208
1985	263	203	-211	-161	-91
1986	277	235	-233	-153	-95
1987	287	237	-240	-146	-135
1988	226	172	-208	-178	-51
1989	231	163	-199	-187	-6
1990	199	138	-210	-185	-3
1991	424	359	-271	-167	-277
1992	284	245	-275	-149	-102
1993	192	152	-201	-156	-57
1994	412	325	-216	-203	-203
1995	354	323	-249	-151	-297
1996	401	320	-291	-143	-275
1997	376	327	-259	-162	-230
1998	346	260	-221	-154	-251
1999	301	243	-205	-184	-131
2000	153	102	-186	-210	-4
2001	385	258	-172	-155	-167
2002	356	333	-209	-154	-264
2003	403	338	-255	-142	-377
2004	437	427	-312	-165	-387
2005	518	465	-348	-142	-457
Average	324	271	-246	-162	-179
%	54.5	45.5	41.9	27.6	30.5
%*	100.0	—	—	47.5	52.5
Maximum	518	465	-348	-210	-457
Minimum	153	102	-172	-142	0
* without direct rainfall and direct evaporation					

Table 14. Scoggin Lake water budget for 2005 conditions plus 2.0-ft Floridan aquifer decline (ac-ft)

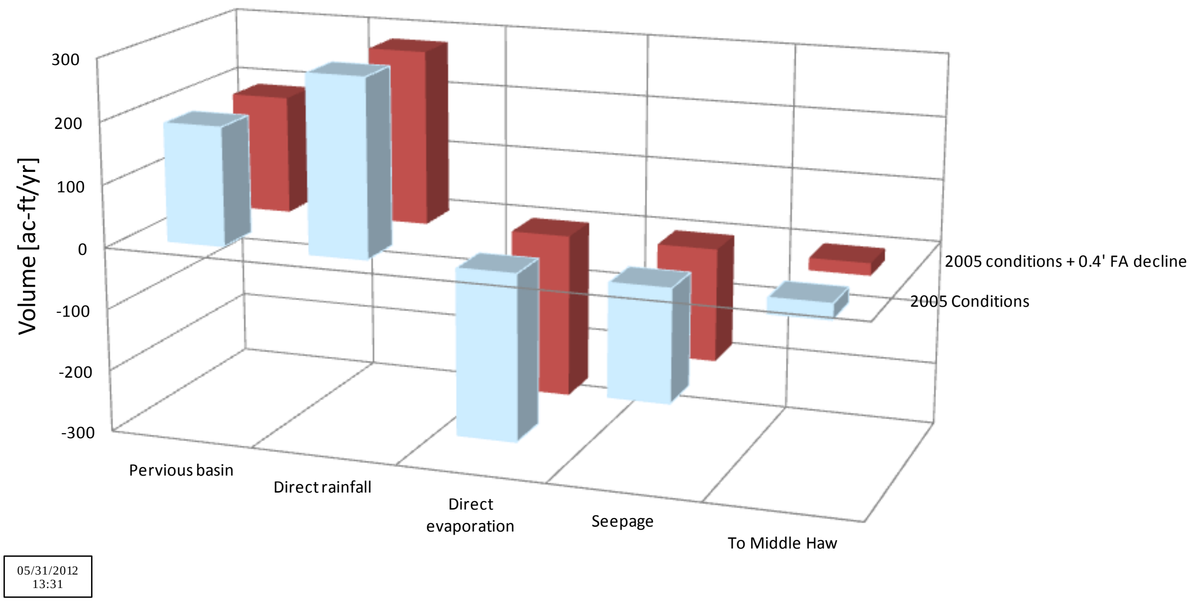
Year	Pervious basin	Direct rainfall	Direct evapo-ration	Seepage	To Middle Haw
1957	328	286	-263	-198	-182
1958	234	162	-206	-168	-55
1959	309	243	-264	-243	-29
1960	463	393	-288	-245	-290
1961	222	162	-231	-214	-9
1962	195	126	-162	-186	0
1963	320	223	-212	-191	-44
1964	483	450	-287	-215	-350
1965	344	263	-299	-215	-165
1966	263	177	-190	-209	-34
1967	277	208	-209	-210	-42
1968	287	219	-223	-213	-93
1969	226	162	-196	-214	-24
1970	231	143	-171	-219	0
1971	199	117	-173	-200	0
1972	424	308	-240	-204	-166
1973	284	209	-235	-213	-49
1974	192	147	-193	-215	-40
1975	412	275	-173	-215	-127
1976	354	301	-231	-197	-250
1977	401	309	-281	-215	-222
1978	376	302	-238	-220	-162
1979	346	238	-200	-214	-194
1980	301	215	-183	-236	-72
1981	153	87	-162	-216	0
1982	385	215	-155	-182	-72
1983	356	316	-196	-216	-197
1984	403	330	-248	-215	-321
1985	437	385	-284	-215	-322
1986	518	455	-341	-211	-407
Average	324	247	-224	-211	-131
%	56.7	43.3	39.7	37.3	23.1
%*	100.0	—	—	61.8	38.2
Maximum	518	455	-341	-245	-407
Minimum	153	87	-155	-168	0
* without direct rainfall and direct evaporation					

Table 15. Coon Pond water budget for 2005 conditions (ac-ft)

Year	Pervious basin	Direct rainfall	Direct evapo-ration	Seepage	To Middle Haw
1976	120	43	-42	-72	-21
1977	84	31	-40	-70	-5
1978	108	36	-40	-73	0
1979	172	72	-49	-72	-71
1980	87	27	-38	-72	0
1981	73	26	-31	-47	0
1982	118	50	-51	-72	-14
1983	175	98	-64	-72	-112
1984	126	48	-58	-72	-26
1985	97	34	-39	-67	-5
1986	101	40	-42	-72	-13
1987	104	40	-43	-72	-22
1988	88	25	-32	-59	0
1989	94	31	-34	-50	0
1990	77	25	-39	-68	0
1991	158	72	-55	-72	-71
1992	113	41	-46	-72	-15
1993	71	28	-40	-64	-3
1994	144	52	-34	-72	-28
1995	134	57	-44	-72	-59
1996	148	63	-60	-72	-64
1997	137	63	-49	-72	-43
1998	123	54	-48	-72	-60
1999	111	41	-33	-72	-19
2000	55	18	-33	-57	0
2001	137	57	-38	-56	-51
2002	132	66	-39	-72	-55
2003	149	70	-53	-72	-92
2004	166	81	-57	-72	-102
2005	189	91	-69	-72	-114
Average	120	49	-45	-69	-35
%	70.9	29.1	30.0	46.1	23.9
%*	100.0	—	—	65.9	34.1
Maximum	189	98	-69	-73	-114
Minimum	55	18	-31	-47	0
* without direct rainfall and direct evaporation					

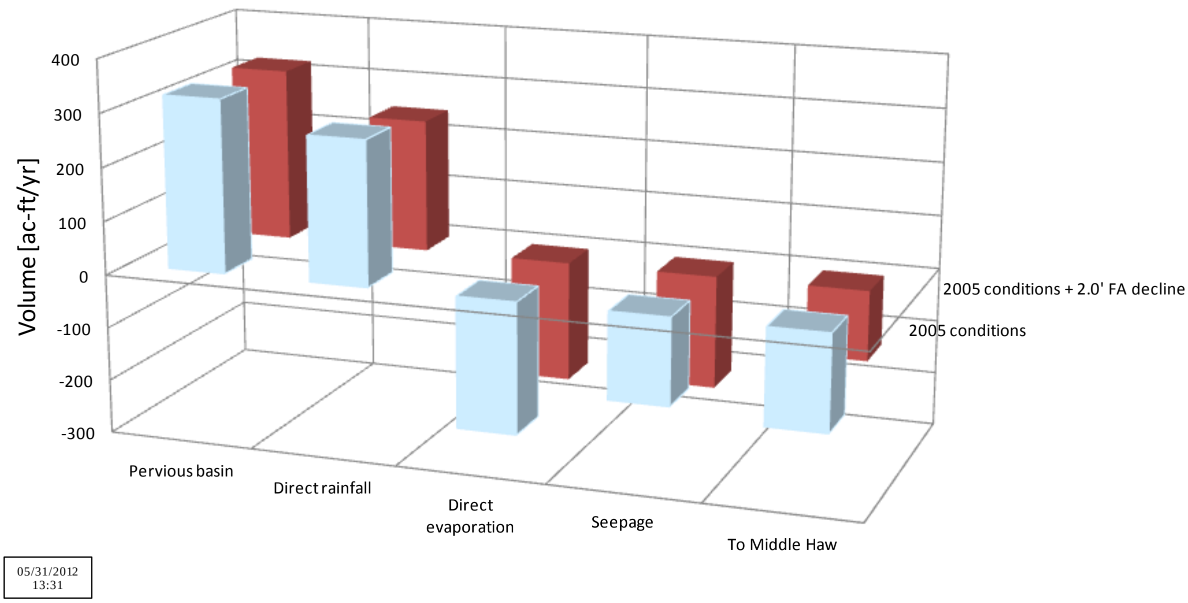
Table 16. Coon Pond water budget for 2005 conditions plus 3.0-ft Floridan aquifer decline (ac-ft)

Year	Pervious basin	Direct rainfall	Direct evapo-ration	Seepage	To Middle Haw
1957	120	39	-39	-65	-13
1958	84	28	-36	-64	0
1959	108	33	-36	-102	0
1960	172	64	-42	-104	-46
1961	87	25	-36	-61	0
1962	73	25	-31	-41	0
1963	118	40	-41	-77	0
1964	175	95	-63	-126	-82
1965	126	41	-50	-103	-17
1966	97	31	-35	-62	0
1967	101	35	-37	-76	-4
1968	104	35	-41	-77	-7
1969	88	25	-31	-53	0
1970	94	29	-32	-66	0
1971	77	23	-36	-82	0
1972	158	67	-51	-69	-50
1973	113	33	-40	-73	-2
1974	71	25	-36	-70	0
1975	144	47	-33	-120	-18
1976	134	52	-42	-76	-53
1977	148	61	-59	-108	-48
1978	137	58	-46	-110	-29
1979	123	51	-45	-121	-50
1980	111	35	-30	-127	0
1981	55	18	-31	-103	0
1982	137	56	-37	-91	-43
1983	132	60	-35	-120	-44
1984	149	67	-52	-117	-68
1985	166	77	-55	-96	-91
1986	189	85	-65	-87	-92
Average	120	45	-41	-88	-25
%	72.5	27.5	26.7	57.0	16.3
%*	100.0	—	—	77.8	22.2
Maximum	189	95	-65	-127	-92
Minimum	55	18	-30	-41	0
* without direct rainfall and direct evaporation					



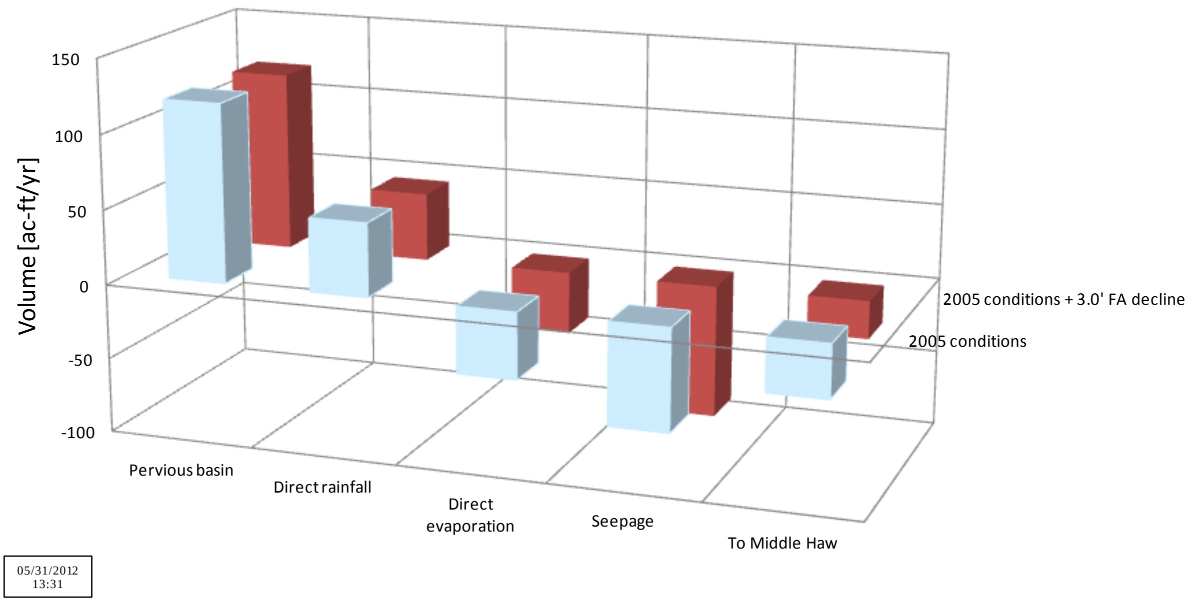
	Pervious basin	Direct rainfall	Direct evaporation	Seepage	To Middle Haw
2005 Conditions	190	284	-266	-178	-24
2005 conditions + 0.4' FA decline	190	281	-263	-181	-20

Figure 70. Water budgets for Indian Lake Streamflow Synthesis and Reservoir Regulation (SSARR) simulations



	Pervious basin	Direct rainfall	Direct evaporation	Seepage	To Middle Haw
2005 conditions	324	271	-246	-162	-179
2005 conditions + 2.0' FA decline	324	247	-224	-211	-131

Figure 71. Water budgets for Scoggin Lake Streamflow Synthesis and Reservoir Regulation (SSARR) simulations



	Pervious basin	Direct rainfall	Direct evaporation	Seepage	To Middle Haw
2005 conditions	120	49	-45	-69	-35
2005 conditions + 3.0' FA decline	120	45	-41	-88	-25

Figure 72. Water budgets for Coon Pond Streamflow Synthesis and Reservoir Regulation (SSARR) simulations

UPDATES TO THE DOUBLE MASS ANALYSIS

INTRODUCTION

The present report documents the MFLs analysis for the Indian Lake system. The report has been peer reviewed and the resulting comments addressed. As new information, data, or techniques become available, a hydrologic model can be updated. Rather than completely redo the analyses, updates are documented and changes to MFLs status discussed in this chapter.

DOUBLE-MASS ANALYSIS UPDATE

The double mass-analysis of the V-0086 well was updated by adding data from 2006 through 2012 to the analysis. In addition, the method that is used has been refined to include two (or more) linear regressions. The analysis was conducted by adding potentiometric surface level to the later years as opposed to subtracting from earlier years (see Figures 15 through17).

Although no additional potentiometric surface decline was detected for the years 2006 through 2012, the refined method indicates a total decline of 4.7 ft compared to the 3.0 ft detected previously. The resulting graphs appear in Figures 73 and 74.

INDIAN LAKE MFLS ANALYSIS UPDATE

The additional 1.7 ft of decline identified in the double mass analysis update means that freeboards expressed throughout this report (e.g., see “Assessment of Hypothetical Water Resource Development in the Indian Lake Area in the Context of MFLs” and Tables 8 through 10) should be reduced by 1.7 ft. To illustrate this effect, the MFLs analysis for Indian Lake was revisited. The 2005 conditions Indian Lake model was run with V-0086 lowered by an additional 1.7 ft. None of the adopted nor recommended MFLs would be met under these conditions (see Figures 75 through 77). As discussed previously, recovery of potentiometric surface levels is accounted for by adding a set amount to historic well levels. Potentiometric surface levels are gradually increased until all MFLs are met for a given lake. For the recommended MFLs for Indian Lake, a recovery of 1.3 ft is needed for all three MFLs to be met. The 0.4 ft of freeboard for the Indian Lake recommended MFLs (see “Assessment of Hypothetical Water Resource Development in the Indian Lake Area in the Context of MFLs”) added to the 1.3 ft of recovery correspond to the 1.7 ft of additional decline. None of the adopted MFLs are met with this amount of recovery.

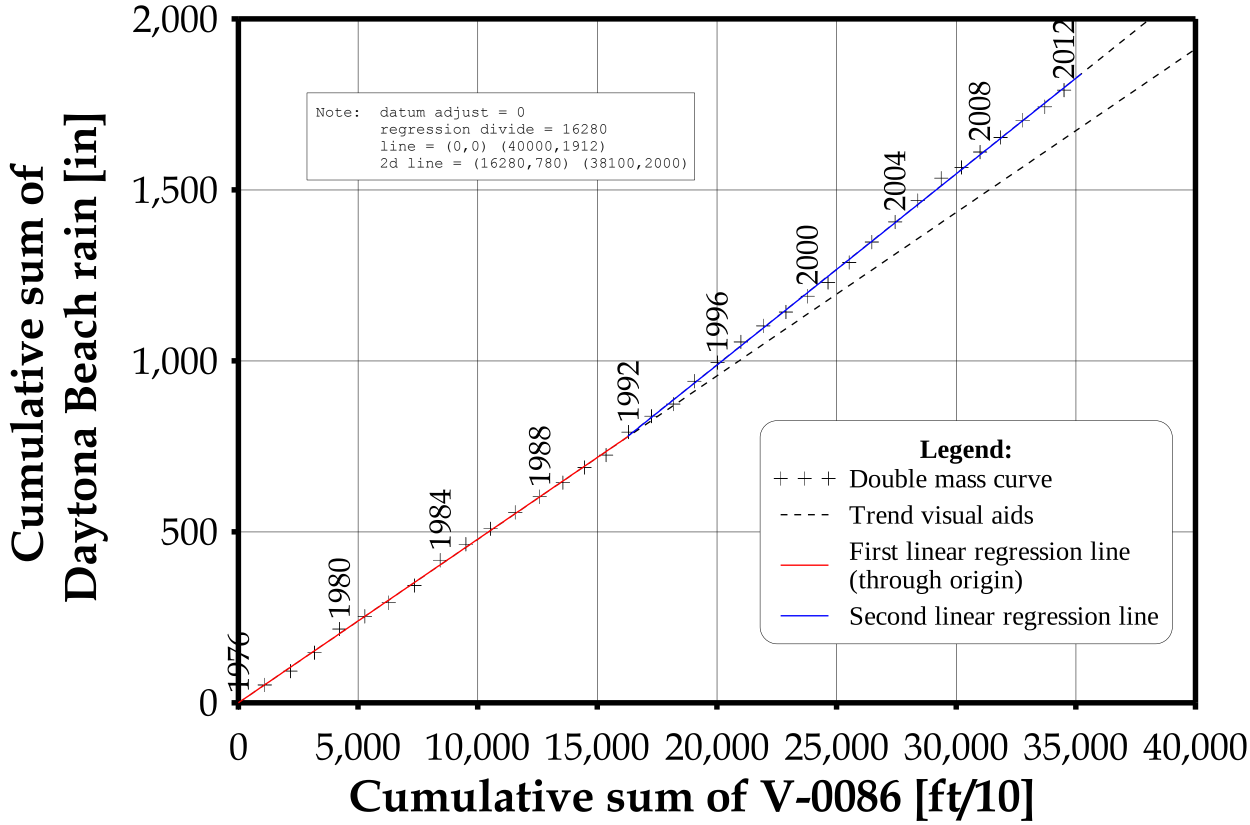


Figure 73. Double-mass analysis update for the V-0086 well vs. Daytona Beach rainfall.

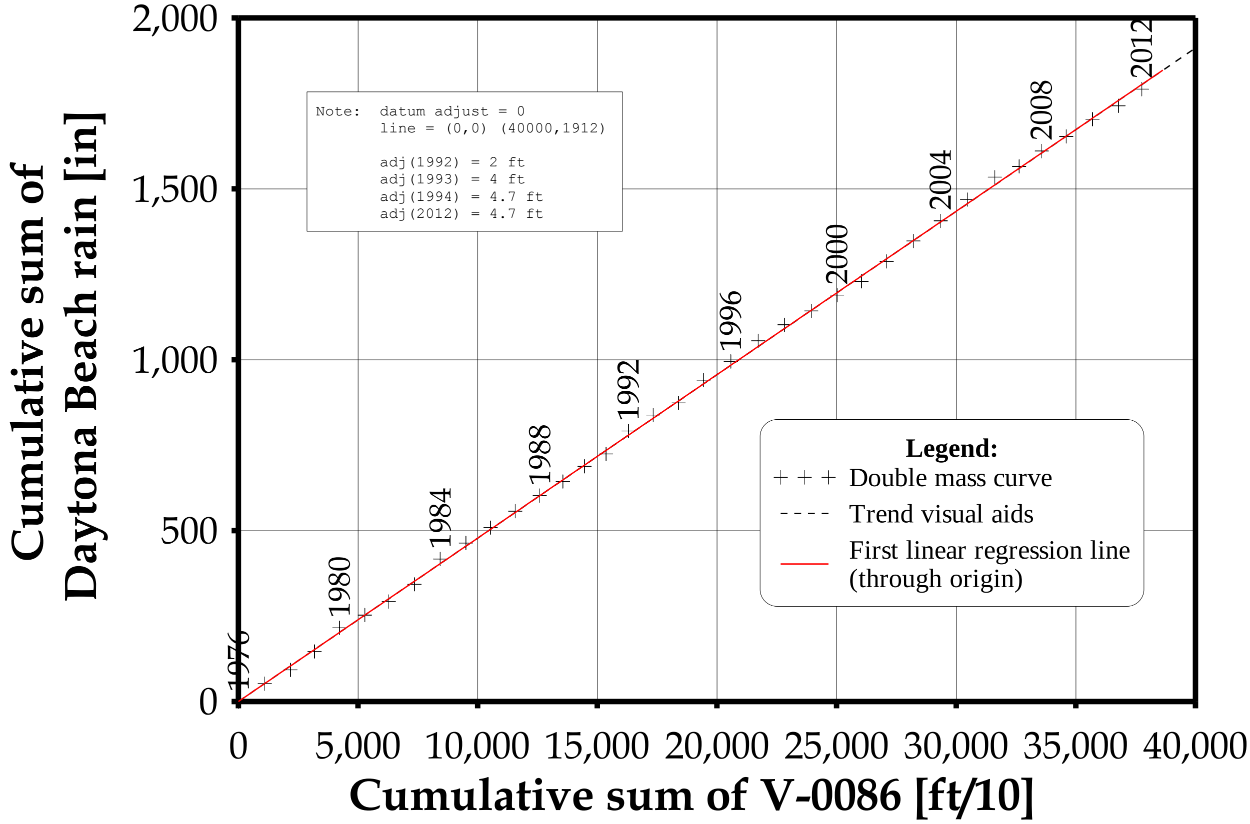


Figure 74. Double-mass analysis update for the adjusted V-0086 well vs. Daytona Beach rainfall.

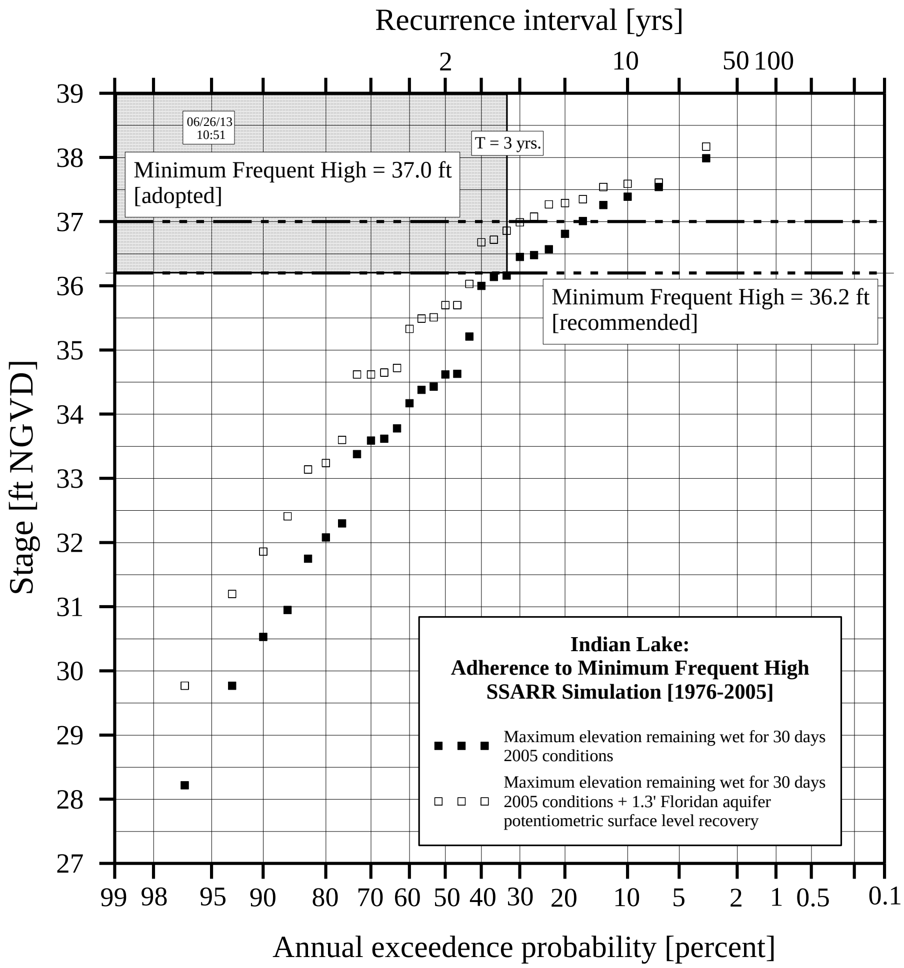


Figure 75. The MFH level for Indian Lake as it relates to results of the 2005 conditions and the 2005 conditions + 1.3-ft Floridan aquifer potentiometric surface level recovery SSARR simulations

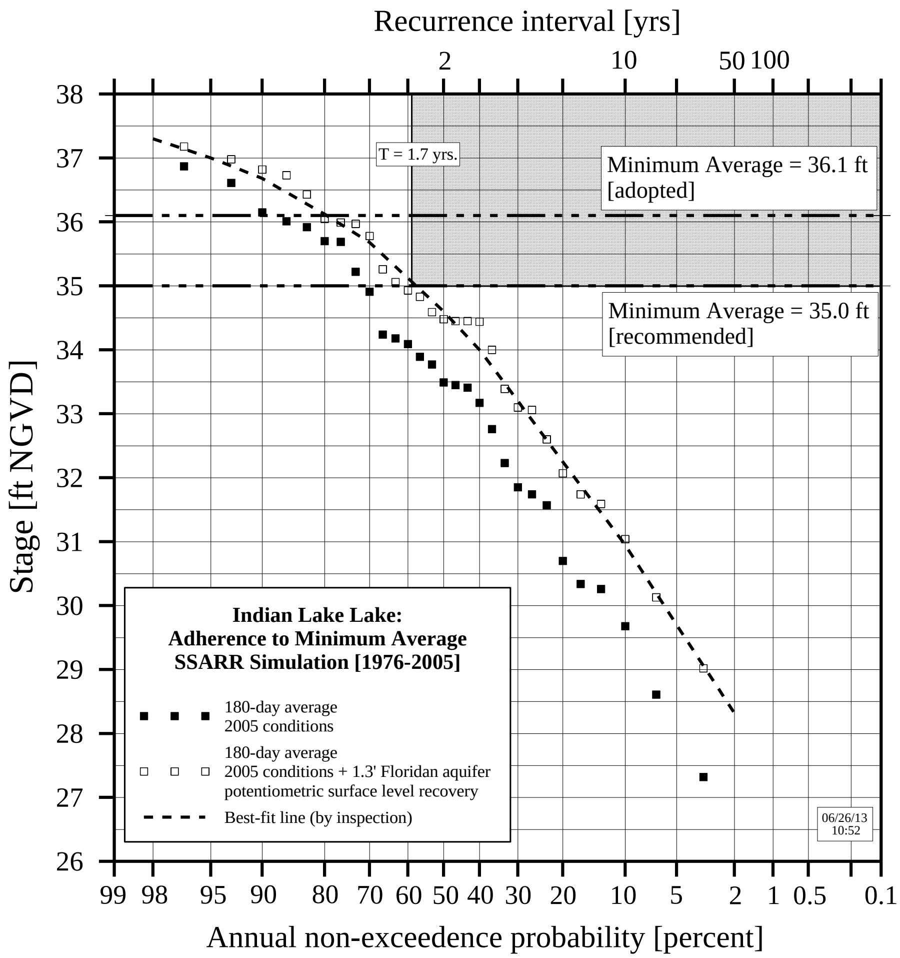


Figure 76. The MA level for Indian Lake as it relates to results of the 2005 conditions and the 2005 conditions + 1.3-ft Floridan aquifer potentiometric surface level recovery SSARR simulations

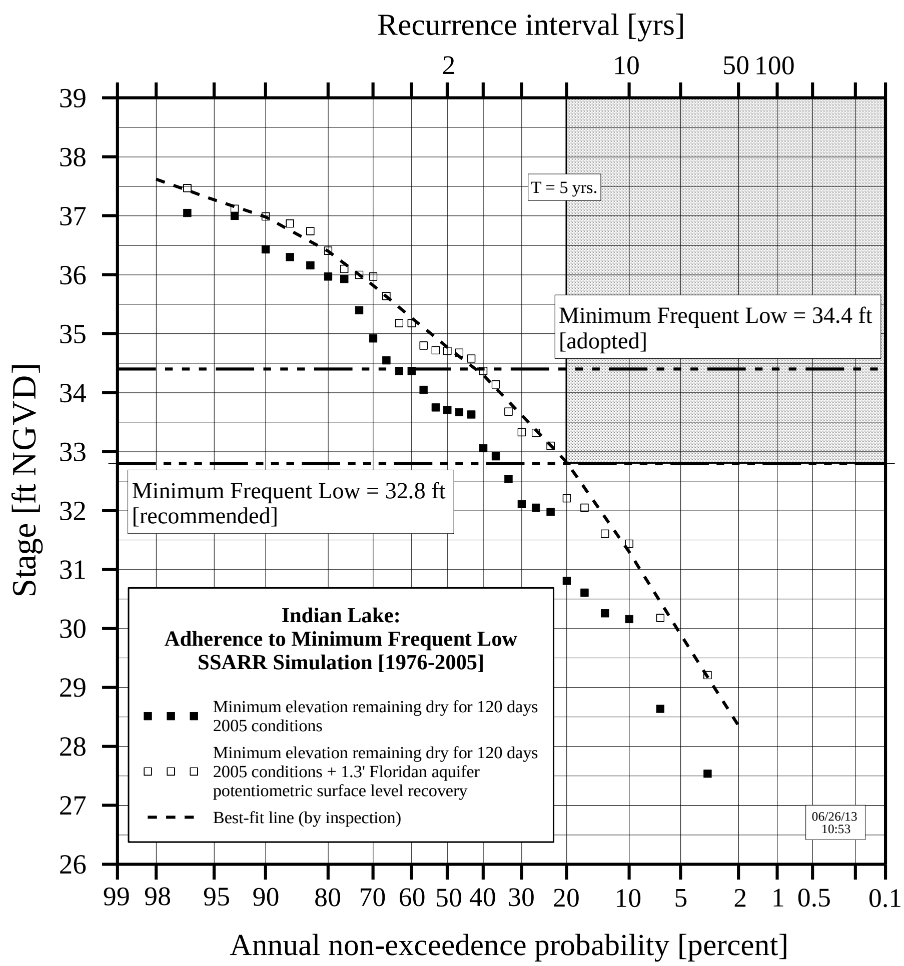


Figure 77. The MFL level for Indian Lake as it relates to results of the 2005 conditions and the 2005 conditions + 1.3-ft Floridan aquifer potentiometric surface level recovery SSARR simulations

REFERENCES

CH2MHILL. 1997. *Water supply needs and sources assessment—Alternative water supply strategies investigation—Surface water availability and yield analysis*. Special Publication SJ97-SP7. Palatka, Fla.: St. Johns River Water Management District.

Hall, G.B. 1999. M*inimum surface water levels determined for Coon Pond, Volusia County*. Internal memorandum dated May 12, 1999. Palatka, Fla.: St. Johns River Water Management District.

[ISPA] Institute of Science and Public Affairs. 1998. *Water resources atlas of Florida*. Tallahassee, Fla.: Florida State University.

Kindinger, J.L., J.B. Davis, and J.G. Flocks. 2000. Subsurface Characterization of Selected Water Bodies in the St. Johns River Water Management District, Northeast Florida. USGS Open File Report 00-180. U.S. Geological Survey. Reston, Virginia.

Li, B., V.K. Garga, and M.H. Davies. 1998. Relationships for non-Darcy flow in rockfill. *Journal of Hydraulic Engineering* 124(2):206–212.

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1982. *Hydrology for engineers*. 3d ed. New York: McGraw-Hill, Inc.

Mace, J. 1999. M*inimum surface water levels determined for Scoggin Lake, Volusia County*. Internal memorandum dated October 4, 1999. Palatka, Fla.: St. Johns River Water Management District.

Mace, J. 2010. M*inimum levels reevaluation: Indian Lake, Volusia County, Florida*. Draft Technical Publication. Palatka, Fla.: St. Johns River Water Management District.

Murray, L. C. 2012. Relations between Precipitation, Groundwater Withdrawals, and Changes in Hydrologic Conditions at Selected Monitoring Sites in Volusia County, Florida, 1995–2010. Scientific Investigations Report 2012-5075. U.S. Geological Survey. Reston, Virginia.

Ponce, V.M. 1989. *Engineering hydrology: Principles and practices*. Englewood Cliffs, N.J.: Prentice Hall.

[SJRWMD] St. Johns River Water Management District. 2006. *Water Supply Assessment, 2003, St. Johns River Water Management District.* Technical Publication SJ2006-1. Palatka, Fla.: St. Johns River Water Management District.

Smith, D.S. and Cera, T. 2010. *Watershed Hydrology and Modeling of the St. Johns River Watershed*. Draft report to the National Academy of Sciences. St. Johns River Water Management District, Palatka, Fla.

Terzaghi, K., and R.B. Peck. 1967. *Soil mechanics in engineering practice*. New York: John Wiley and Sons.

[USACE] U.S. Army Corps of Engineers. 1986. *Streamflow synthesis and reservoir regulation: User manual*. North Pacific Division. Portland, Oreg.

[USGS] U.S. Geological Survey. 1954. *Water-loss investigations: Lake Hefner studies, technical report*. Professional Paper 269. Washington, D.C.: U.S. Government Printing Office.

———. 1982. *Guidelines for determining flood flow frequency*. Bulletin 17B. Interagency Advisory Committee on Water Data. Reston, Va.

Valentine-Darby, P. 1998. *Recommended minimum surface water levels determined for Indian Lake, Volusia County*. Internal memorandum dated July 22, 1998. Palatka, Fla.: St. Johns River Water Management District.

APPENDIX A—IMPLEMENTATION OF MINIMUM FLOWS AND LEVELS FOR INDIAN LAKE

Prepared by

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The objective of minimum flows and levels (MFLs) is to establish limits to allowable hydrologic change in a water body or watercourse, to prevent significant harm to the water resources or ecology of an area. Hydrologic changes within a water body or watercourse may result from an increase in the consumptive use of water or the alteration of basin characteristics, such as down-cutting outlet channels or constructing outflow structures.

MFLs define a series of minimum high and low water levels and/or flows of differing frequencies and durations required to protect and maintain aquatic and wetland resources. MFLs take into account the ability of wetlands and aquatic communities to adjust to changes in hydrologic conditions. MFLs allow for an acceptable level of change to occur relative to existing hydrologic conditions, without incurring significant ecological harm to the aquatic system.

Before MFLs can be applied, the minimum hydrologic regime must be defined or characterized statistically. Resource management decisions can then be made predicated on maintaining at least these minimum hydrologic conditions as defined by the appropriate statistics.

One way to understand how changes within a watershed alter a hydrologic regime and, therefore, how aquatic and wetland resources might be affected, is by simulating the system with a hydrologic model. Significant harm can be avoided by regulating hydrologic changes based on the comparison of statistics of the system with and without changes.

MFLs determinations are based on a concept of maintaining the duration and return periods of selected, ecologically based stages and/or flows. Thus, a water body can fall below the selected stage and/or flow, but if it does so too often and/or for too long, then the MFLs would no longer be met.

Statistical analysis of model output provides a framework to summarize the hydrologic characteristics of a water body. The St. Johns River Water Management District (SJRWMD) MFLs program relies on a type of statistical analysis referred to as frequency analysis.

Frequency Analysis

As discussed previously, aquatic resources are sustained by a certain hydrologic regime. Depending on the resource in question, a selected ground elevation might need to

- Remain wet for a certain period of time with a certain frequency
- Remain dry for a certain period of time with a certain frequency
- Be under a given minimum depth of water for a certain period of time with a certain frequency, etc.

Frequency analysis estimates how often, on average, a given event will occur. If annual series data are used to generate the statistics, frequency analysis estimates the probability of a given hydrologic event happening in any given year.

A simple example illustrates some of the concepts basic to frequency analysis. A frequently used statistic with respect to water level is the yearly peak stage of a water body. If a gauge has been monitored for 10 years, then there will be 10 yearly peaks $S_1, S_2, \cdots, S_{10}$. Once sorted and ranked, these events can be written as $\hat{S}_1, \hat{S}_2, \cdots, \hat{S}_{10}$, with $\hat{S}_1$ being the highest peak. Based on this limited sample, the estimated probability of the peak in any given year being greater than or equal to $\hat{S}_1$ would be

$$P(S \geq \hat{S}_1) = \frac{1}{n} = \frac{1}{10} = 0.1 \qquad \text{(A1)}$$

The probability of the 1-day peak stage in any year being greater than $\hat{S}_2$

$$P(S \geq \hat{S}_2) = \frac{2}{10} = 0.2 \qquad \text{(A2)}$$

The probability of the stage equaling or exceeding $\hat{S}_{10}$ would be

$$P(S \geq \hat{S}_{10}) = \frac{10}{10} = 1.0 \qquad \text{(A3)}$$

Because this system of analysis precludes any peak stage from being lower than $\hat{S}_{10}$, the usual convention is to divide the stage continuum into 11 parts: nine between each of the 10 peaks, one above the highest peak, and one below the lowest peak ($n - 1 + 2 = n + 1 = 11$). This suggests what is known as the Weibull plotting position formula:

$$P(S \geq \hat{S}_m) = \frac{m}{n+1} \tag{A4}$$

where

$P(S \geq \hat{S}_m) =$ probability of S equaling or exceeding $\hat{S}_m$

$m =$ rank of the event

Thus, in the example, the probability of the peak in any year equaling or exceeding $\hat{S}_1$ would be

$$P(S \geq \hat{S}_1) = \frac{1}{n+1} = \frac{1}{11} = 0.0909 \tag{A5}$$

The probability of the 1-day peak stage in any year being greater than $\hat{S}_{10}$

$$P(S \geq \hat{S}_{10}) = \frac{10}{11} = 0.9091 \tag{A6}$$

The probability the stage in any year is smaller than $\hat{S}_{10}$ would be

$$P(S < \hat{S}_{10}) = 1 - P(S \geq \hat{S}_{10}) = 1 - \frac{10}{11} = 1 - 0.9091 = 0.0909 \tag{A7}$$

The return period (in years) of an event, T, is defined as

$$T = \frac{1}{P} \tag{A8}$$

so the return period for $\hat{S}_1$ would be

$$T(\hat{S}_1) = \frac{1}{P(S \geq \hat{S}_1)} = \frac{1}{\frac{1}{11}} = 11 \tag{A9}$$

Said another way, $\hat{S}_1$ would be expected to be equaled or exceeded, on average, once every 11 years.

As the size of the sample increases, the probability of $\hat{S}_1$ being exceeded decreases. Thus, with n = 20,

$$P(S \geq \hat{S}_1) = \frac{1}{n+1} = \frac{1}{21} = 0.048 \qquad \text{(A10)}$$

and

$$T(\hat{S}_1) = \frac{1}{P(S \geq \hat{S}_1)} = 21 \qquad \text{(A11)}$$

The stage or flow characteristics of a water body can be summarized using the Weibull plotting position formula and a frequency plot. For example, Figure A1 shows a flood frequency plot generated from annual peak flow data collected at the U.S. Geological Survey (USGS) gauge on the Wekiva River.

Minimum events are treated in much the same way as maximum events, except with minimums the events are ranked from smallest to largest. Thus $\hat{S}_1$ is the smallest or lowest event in a sampling. The minimum stage or flow characteristics of a gauge or water body can be summarized using the Weibull plotting position formula and a frequency plot. For example, Figure A2 shows a drought frequency plot generated from a hydrologic simulation of the middle St. Johns River**.**

One of the purposes of performing this process of sorting, ranking, and plotting events is to estimate probabilities and return periods for events larger than $\hat{S}_1$, smaller than $\hat{S}_n$, or any event between sample points. There are two methods of obtaining these probabilities and return periods. The first method is to use standard statistical methods to mathematically calculate these probabilities and return periods (Figure A3). This method is beyond the scope of this appendix; therefore, the reader is referred to a standard hydrology text (Ponce 1989, Linsley et al. 1982) or the standard flood frequency analysis text, Bulletin 17B (USGS 1982).

With the second method, interpolated or extrapolated frequencies and return periods can also be obtained by the graphical method. Once the period-of-record or period-of-simulation events have been sorted and ranked, they are plotted on probability paper. Probabilities and return periods for events outside of the sampled events can be estimated by drawing a line through the points on the graph to obtain an estimated best fit (Figure A4).

Frequency analysis is also used to characterize hydrologic events of durations longer than 1 day. Frequency analysis encompasses four types of events: 1) maximum average stages or flows, 2) minimum average stages or flows, 3) maximum stages or flows continuously exceeded, and 4) minimum stages or flows continuously not exceeded.

Maximum average stages or flows. In this case, an event is defined as the maximum value for a mean stage or flow over a given number of days. For example, if the maximum yearly values for a 30-day average are of interest, the daily value hydrograph is analyzed by using a moving 30-day average. Therefore, a 365-day hydrograph would have 336 (365 –30 + 1 = 336) different values for a 30-day average. These 336 values are searched and the highest is saved. After performing this analysis for each year of the period of record or period of simulation, the events are sorted and ranked. The analytical process is then the same as for the 1-day peaks.

Minimum average stages or flows. In this case, an event is defined as the minimum value for a mean stage or flow over a given number of days. For example, if the minimum yearly values for a 30-day average are of interest, the daily value hydrograph is analyzed by using a moving 30-day average. Therefore, a 365-day hydrograph would have 336 (365 – 30 + 1 = 336) different values for a 30-day average. These 336 values are searched and the lowest is saved. After performing this analysis for each year of the period of record or period of simulation, the events are sorted and ranked. The process is then the same as for the 1-day low stages.

Maximum stage or flow continuously exceeded. In this case, an event is defined as the stage or flow that is exceeded continuously for a set number of days. For example, if the maximum yearly ground elevation that continuously remains under water for 60 days is of interest, the stage hydrograph of each year is analyzed by taking successive 60-day periods and determining the stage that is continuously exceeded for that period. This is repeated for 306 (365 – 60 + 1 = 306) periods of 60 days. The maximum stage in those 306 values is saved. Once that operation is performed for all years of record or of simulation, the results are sorted and ranked as for the 1-day peaks.

Minimum stage or flow continuously not exceeded. In this case, an event is defined as the stage or flow that is not exceeded continuously for a set number of days. For example, if the minimum yearly ground elevation that continuously remains dry for 60 days is of interest, the stage hydrograph of each year is analyzed by taking successive 60-day periods and determining the stage that is continuously not exceeded for that period. This is repeated for 306 (365 – 60 + 1 = 306) periods of 60 days. The minimum stage in those 306 values is saved. Once that operation is performed for all years of record or of simulation, the results are sorted and ranked as for the 1-day low stages.

In frequency analysis, it is important to identify the most extreme events occurring in any given series of years. Because high surface water levels (stages) in Florida generally occur in summer and early fall, maximum value analysis is based on a year that runs from

June 1 to May 31. Conversely, because low stages tend to occur in late spring, the year for minimum events runs from October 1 to September 30.

Hydrologic Statistics and their Relationships to the Indian Lake Minimum Flows and Levels (MFLs)

This section describes the process used to relate long-term hydrologic statistics to the establishment of MFLs. SJRWMD has determined three recommended MFLs for Indian Lake: 1) a minimum frequent high (MFH) level, 2) a minimum average (MA) level, and 3) a minimum frequent low (MFL) level. The MFH level for this lake is used here to illustrate how long-term hydrologic statistics of a lake relate to MFLs.

Each of the three MFLs is tied to characteristic stage durations and return frequencies. For example, the ground elevation represented by the MFH level is expected to remain wet continuously for a period of at least 30 days. This event is expected to occur, on average, at least once every 3 years.

The standard stage frequency analysis described previously in this appendix was performed on stage data from lake model simulations of Indian Lake (Robison 2007). In particular, stages continuously exceeded (ground elevations remaining wet) for 30 days were determined, sorted, ranked, and plotted (Figure A5). These stages were obtained assuming that long-term groundwater withdrawals occurred at the same level at which they occurred in 2005. The ground elevation of the MFH level can be superimposed on the plot (Figure A6) to demonstrate how the level is related to the pertinent hydrologic statistics. Finally, a box bounded by 1) the MFH level on the bottom, 2) a vertical line corresponding to a frequency of occurrence of once in every 3 years on the right, and 3) a vertical line corresponding to a frequency of occurrence of once in every 2 years on the left, is superimposed on the plot (Figure A7). Similar analyses were performed for the MA level (Figure A8) and for the MFL level (Figure A9). All three levels are being met under these conditions.

A summary of the recommended MFLs for Indian Lake is shown in Table A1. Values in this table will be used as benchmarks for modeling outputs to determine if groundwater withdrawals in the vicinity of Indian Lake will cause water levels to fall below MFLs.

Evaluation of the Potential Impacts of Proposed Increased Withdrawals of Water from the Floridan Aquifer

This section describes the process used by SJRWMD to determine if proposed or projected increased withdrawals of water from the Floridan aquifer in the vicinity of Indian Lake would cause water levels in the lake to fall below established MFLs. SJRWMD uses two modeling tools in this process: a regional groundwater flow model and the lake model described above. The following steps are included in the process.

1) Estimation of Floridan aquifer water level drawdown (1995 through the last year of model simulation)

2) Estimation of Floridan aquifer freeboard in the year of calibration of the lake model

3) Estimation of Floridan aquifer water level decline from 1995 to the year of calibration of the lake model

4) Estimation of Floridan aquifer water level drawdown from the year of calibration of the lake model through the last year of model simulation

5) Comparison of Floridan aquifer water level drawdown from the year of calibration of the lake model through the last year of simulation (Step 4) to the year of calibration freeboard (Step 2)

Step 1. Estimation of Floridan aquifer water level drawdown (1995 through the last year of model simulation). When evaluating consumptive use permit applications for increased withdrawals of groundwater from the Floridan aquifer or when performing water supply planning evaluations, SJRWMD estimates the projected drawdown in the potentiometric surface of the Floridan aquifer in the vicinity of lakes with established MFLs. The analysis includes all existing permitted uses in addition to the proposed increased withdrawals. SJRWMD uses the appropriate regional groundwater flow model to produce these estimates. In the case of Indian Lake, at the time of preparation of this document, SJRWMD was using the Volusia Regional Groundwater Flow Model (Williams 2006) for this purpose. This steady state model is calibrated to 1995 conditions; therefore, the projected drawdown in the potentiometric surface represents the estimated drawdown that would occur from 1995 to the last year of simulation. In association with consumptive use permit evaluations, the last year of simulation represents the year through which issuance of the permit is contemplated. In SJRWMD's water supply assessment and planning processes the last year of simulation represents the planning horizon year and/or other intermediate years that may represents significant water use targets.

Step 2. Estimation of Floridan aquifer freeboard in year of calibration of lake model. As stated previously, the model simulation results depicted in Figures A7 through A9 assume long-term Floridan aquifer withdrawals at 2005 levels. Any withdrawal increases beyond 2005 would tend to lower potentiometric levels in the area and, therefore, would tend to lower levels in Indian Lake. To determine the freeboard present at Indian Lake from the standpoint of Floridan aquifer water level drawdowns, a trial and error process was undertaken assuming incrementally increasing drawdowns. Drawdowns are represented by subtracting a set amount from the well hydrograph used in simulation of Indian Lake. In the case of Indian Lake, for a Floridan aquifer water level drawdown of 0.5 ft, the MA level would still be met (Figure A10). However, any drawdowns greater than 0.5 ft would cause water levels to fall below the established MA level. At a drawdown of 0.5 ft, the MFH level (Figure A11) and the MFL level would still be met (Figure A12). Therefore, future Floridan aquifer water level drawdowns beyond 2005 conditions will be limited to 0.5 ft in the Indian Lake area.

Step 3. Estimation of Floridan aquifer water level decline from 1995 to the year of calibration of the lake model. Because the calibration years of lake models and the applicable regional groundwater flow models do not coincide, an adjustment of projected drawdown in the potentiometric surface of the Floridan aquifer in the vicinity of the lake of interest must be made for purposes of comparison to the previously described Floridan aquifer freeboard value. The adjusted value should represent the projected drawdown from the calibration year of the lake model to the final year of simulation of the applicable regional groundwater flow model.

To determine this adjusted value, drawdown in the potentiometric surface of the Floridan aquifer in the vicinity of a lake of interest from 1995 through the calibration year of the lake model is estimated. This estimated value is subtracted from the projected drawdown from 1995 to the final year of simulation of the applicable regional groundwater flow model to determine the adjusted value.

Estimated drawdown in the potentiometric surface of the Floridan aquifer in the vicinity of a lake of interest from 1995 through the calibration year of the lake model is calculated using one of the following approaches.

- A water use data set for the calibration year of the lake model is prepared and used in the applicable regional groundwater flow model. The resulting drawdowns represent drawdowns from 1995 to the calibration year of the lake model. Based on drawdowns projected for 2005 conditions by the Volusia Regional Groundwater Flow Model, drawdown in the vicinity of Indian Lake between 1995 and 2003 was approximately 0.6 ft.
- Estimated drawdowns in the potentiometric surface from 1995 to the calibration year of the lake model are interpolated based on estimates of drawdowns projected to occur from 1995 to some simulation year beyond the lake calibration year. This approach requires assuming a straight line increase of the projected drawdown from 1995 to the final year of simulation and selecting the appropriate interpolated value for the period 1995 to the year of calibration for the lake model.

Step 4. Estimation of Floridan aquifer water level drawdown from the year of calibration of the lake model through the last year of model simulation. The Floridan aquifer water level drawdown from the year of calibration of the lake model through the last year of model simulation is estimated by subtracting the drawdown from 1995 through the year of calibration of the lake model (Step 3) from the total drawdown (Step 1).

Step 5. Comparison of Floridan aquifer water level drawdown from the year of calibration of the lake model through the last year of model simulation (Step 4), to the freeboard in the year of calibration of the lake model (Step 2). If the Floridan aquifer water level drawdown from the year of calibration of the lake model through the last year of groundwater model simulation (Step 4) is greater than the year of calibration of the lake model freeboard (Step 2), then proposed or projected increased withdrawals through the last year of groundwater model simulation would cause water levels to fall below MFLs. If the Floridan aquifer water level drawdown from the year of calibration of the lake model through the last year of groundwater model simulation (Step 4) is less than the year of calibration of the lake model freeboard (Step 2), then proposed or projected increased withdrawals through the last year of groundwater model simulation would not cause water levels to fall below established MFLs.

Because the estimated 2005 freeboard for Indian Lake is 0.5 ft and the drawdown in the vicinity of Indian Lake between 1995 and 2005 was approximately 0.6 ft, then the allowable drawdown from 1995 to some future year would be limited to 1.1 ft.

Table A1. Summary of minimum flows and levels for the Indian Lake system

Minimum Flows and Levels (MFLs)	Level (ft NGVD*)	Duration (days)	Series	Water Year	Statistical Type	Minimum Return Period	Maximum Return Period
Indian Lake (Recommended)							
Minimum frequent high	36.2	30	Annual	Jun 1–May 31	Maximum, continuously exceeded	NA[†]	3 yrs
Minimum average	35.0	180	Annual	Oct 1–Sep 30	Minimum mean, not exceeded	1.7 yrs	NA
Minimum frequent low	32.8	120	Annual	Oct 1–Sep 30	Minimum, continuously not exceeded	5 yrs	NA
Scoggin Lake (Adopted)							
Minimum frequent high	35.0	30	Annual	Jun 1–May 31	Maximum, continuously exceeded	NA	3 yrs
Minimum average	34.1	180	Annual	Oct 1–Sep 30	Minimum mean, not exceeded	1.7 yrs	NA
Minimum frequent low	32.7	120	Annual	Oct 1–Sep 30	Minimum, continuously not exceeded	5 yrs	NA
Coon Pond (Adopted)							
Minimum frequent high	35.7	30	Annual	Jun 1–May 31	Maximum, continuously exceeded	NA	3 yrs
Minimum average	34.6	180	Annual	Oct 1–Sep 30	Minimum mean, not exceeded	1.7 yrs	NA
Minimum frequent low	33.1	120	Annual	Oct 1–Sep 30	Minimum, continuously not exceeded	5 yrs	NA

*ft NGVD = feet National Geodetic Vertical Datum
[†]NA = Not applicable

References

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1982. *Hydrology for Engineers*. 3d ed. New York: McGraw-Hill.

Ponce, V.M. 1989. *Engineering Hydrology: Principles and Practices*. Englewood Cliffs, N.J.: Prentice Hall.

Robison, C.P. 2007 (draft). *Indian Lake System Minimum Flows and Levels Hydrologic Methods Report*. Palatka, Fla.: St. Johns River Water Management District,

[USGS] U.S. Geological Survey. 1982. *Guidelines for Determining Flood Flow Frequency*. Bulletin 17B. Reston, Va.: Interagency Advisory Committee on Water Data.

Williams, S.A., 2006. *Simulation of the effects of groundwater withdrawals from the Floridan aquifer system in Volusia County and vicinity*. Technical Publication SJ2006-4. Palatka, Fla.: St. Johns River Water Management District.

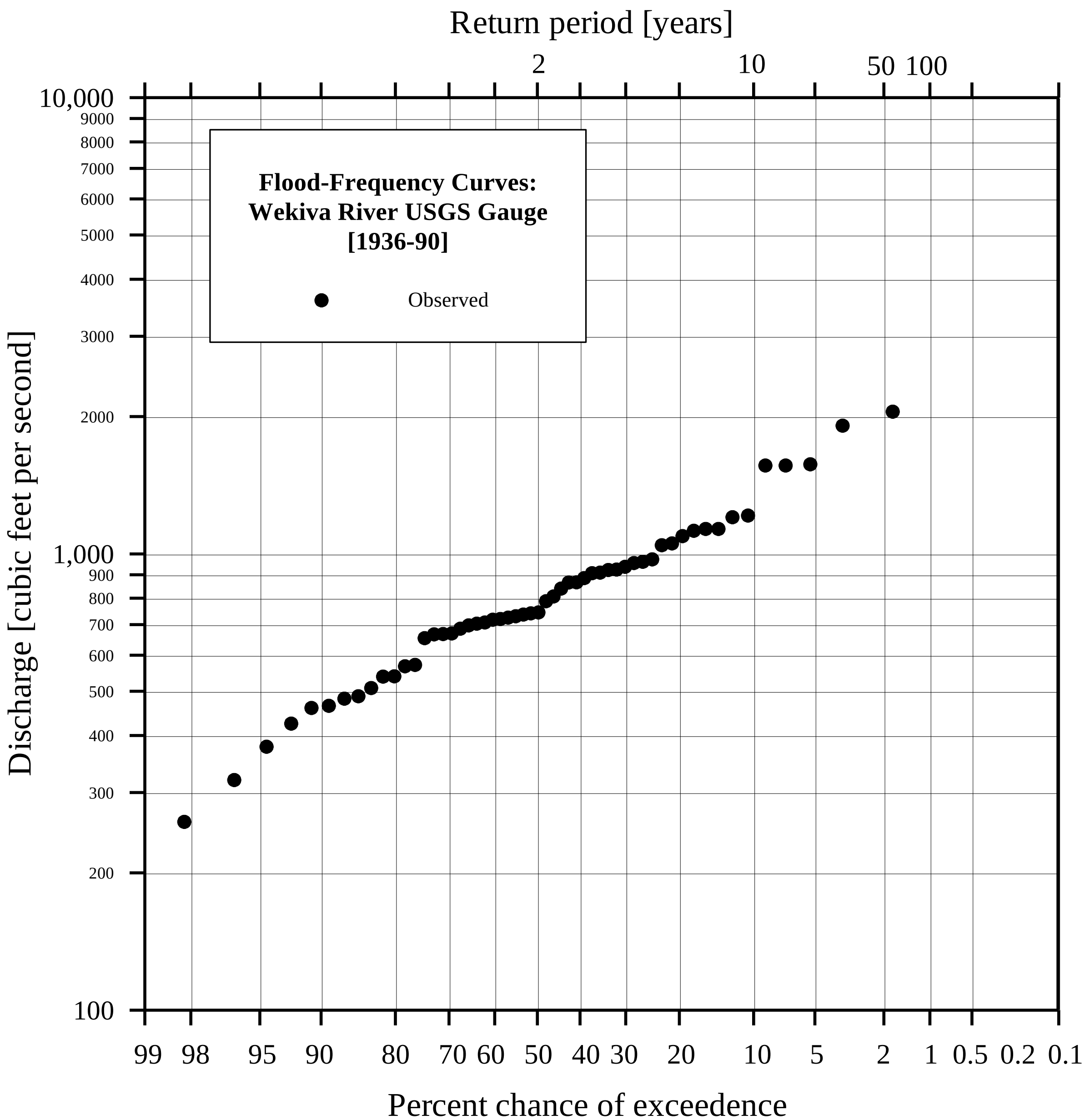

Figure A1. Flood frequencies for the Wekiva River at the USGS gauge near Sanford, Florida. The 1–day peak flows have been sorted, ranked, and plotted according to the Weibull plotting position formula

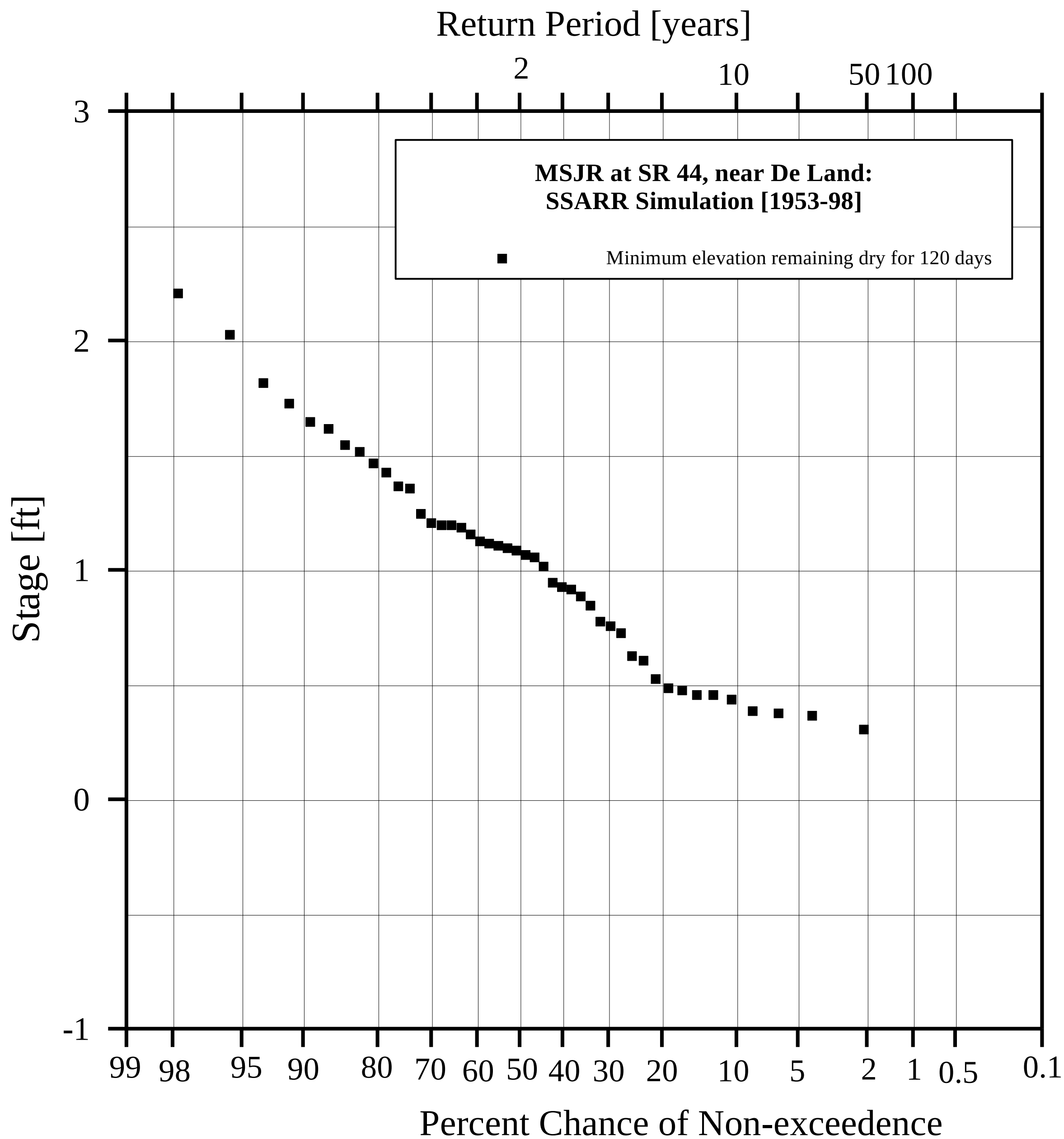

Figure A2. Drought frequencies computed using daily stages simulated by the Middle St. Johns River (MSJR) Streamflow Synthesis and Reservoir Regulation (SSARR) model at State Road 44, near DeLand, Florida. The minimum stages continuously not exceeded for 120 days have been sorted, ranked, and plotted according to the Weibull plotting position formula

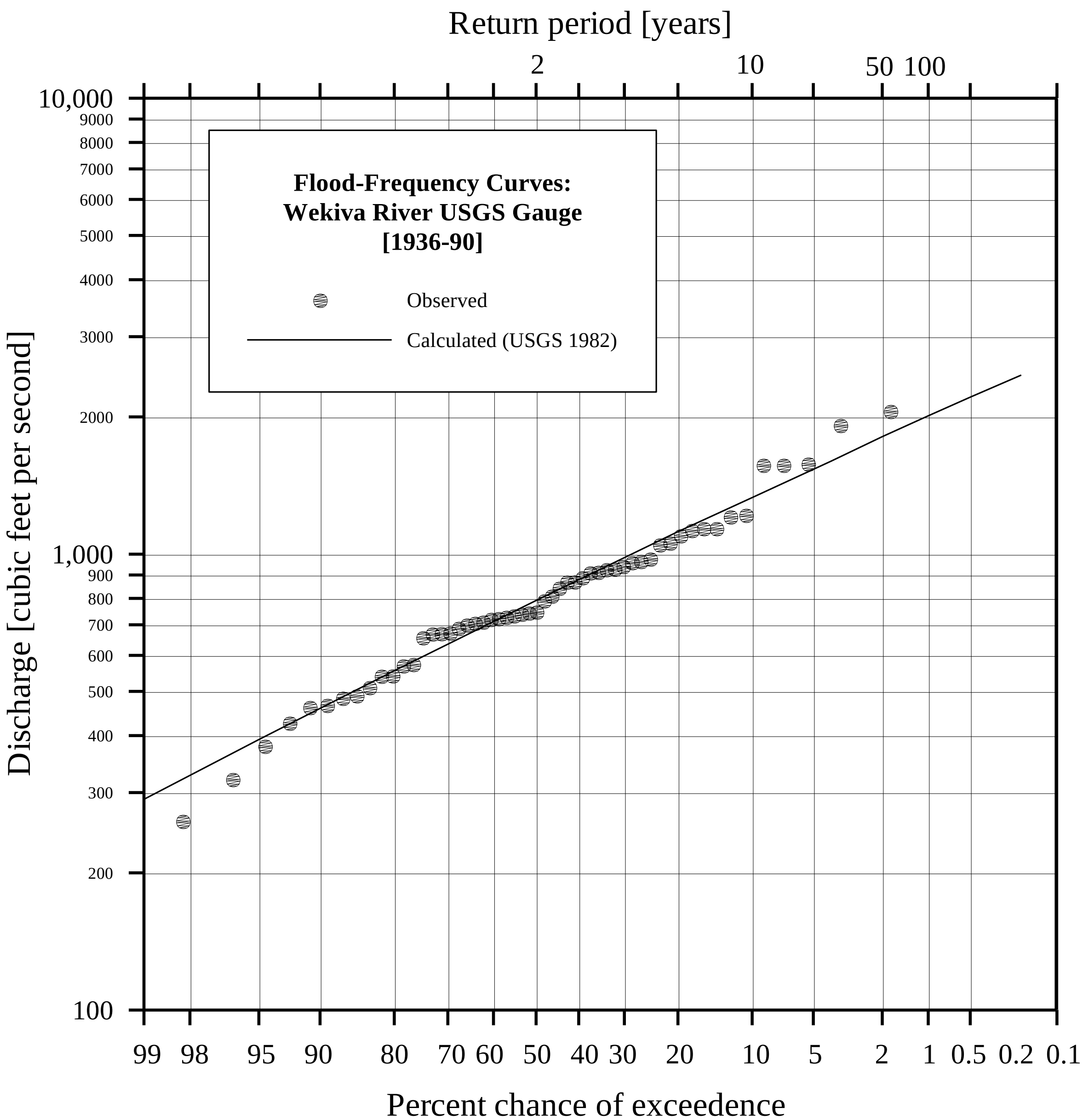

Figure A3. Flood frequencies for the Wekiva River at the USGS gauge near Sanford, Florida, fitted by standard mathematical procedure

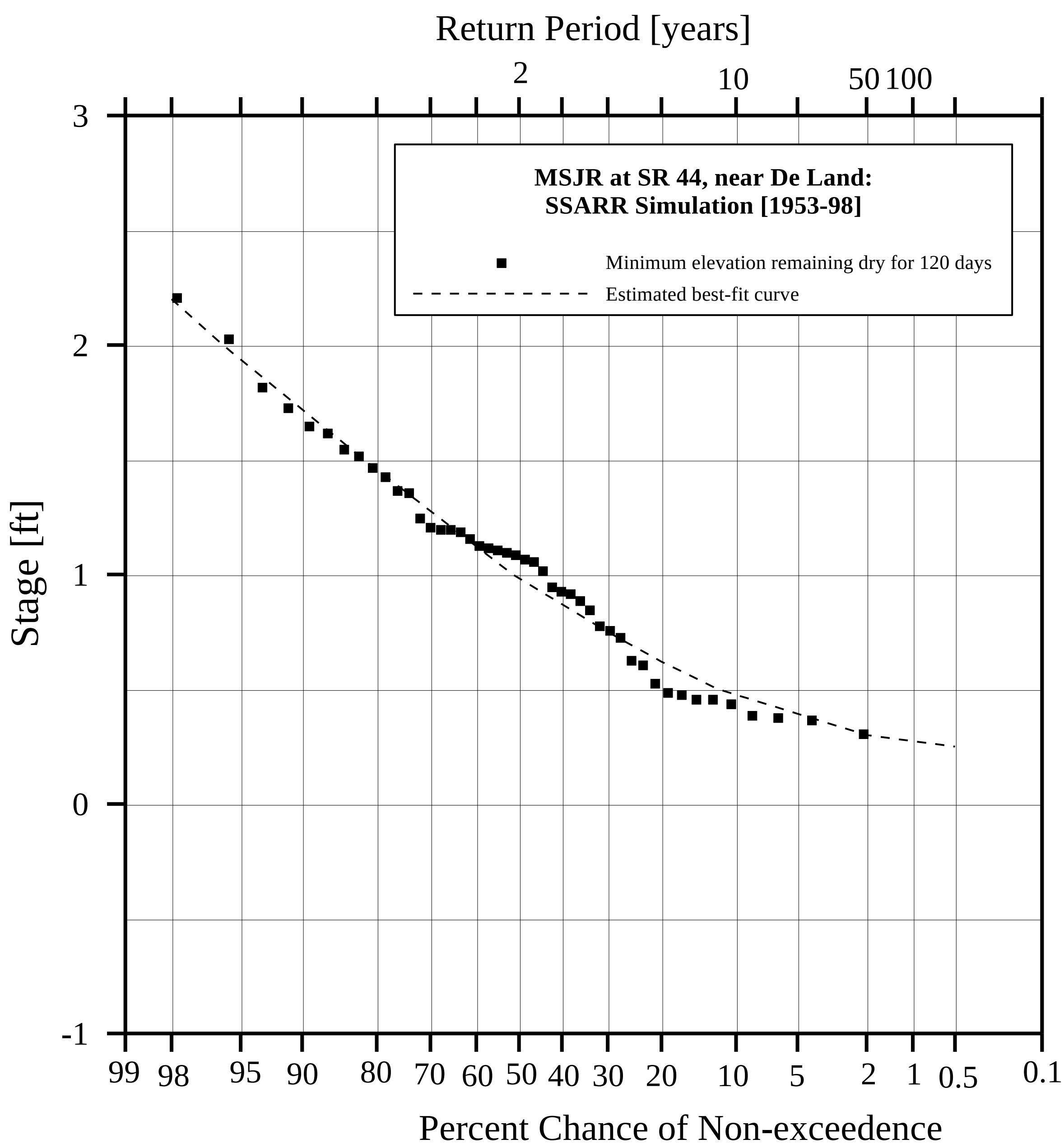

Figure A4. Drought frequencies computed using daily stages simulated by the Middle St. Johns River (MSJR) Streamflow Synthesis and Reservoir Regulation (SSARR) model at State Road (SR) 44, near DeLand, Florida, fitted by the graphical method

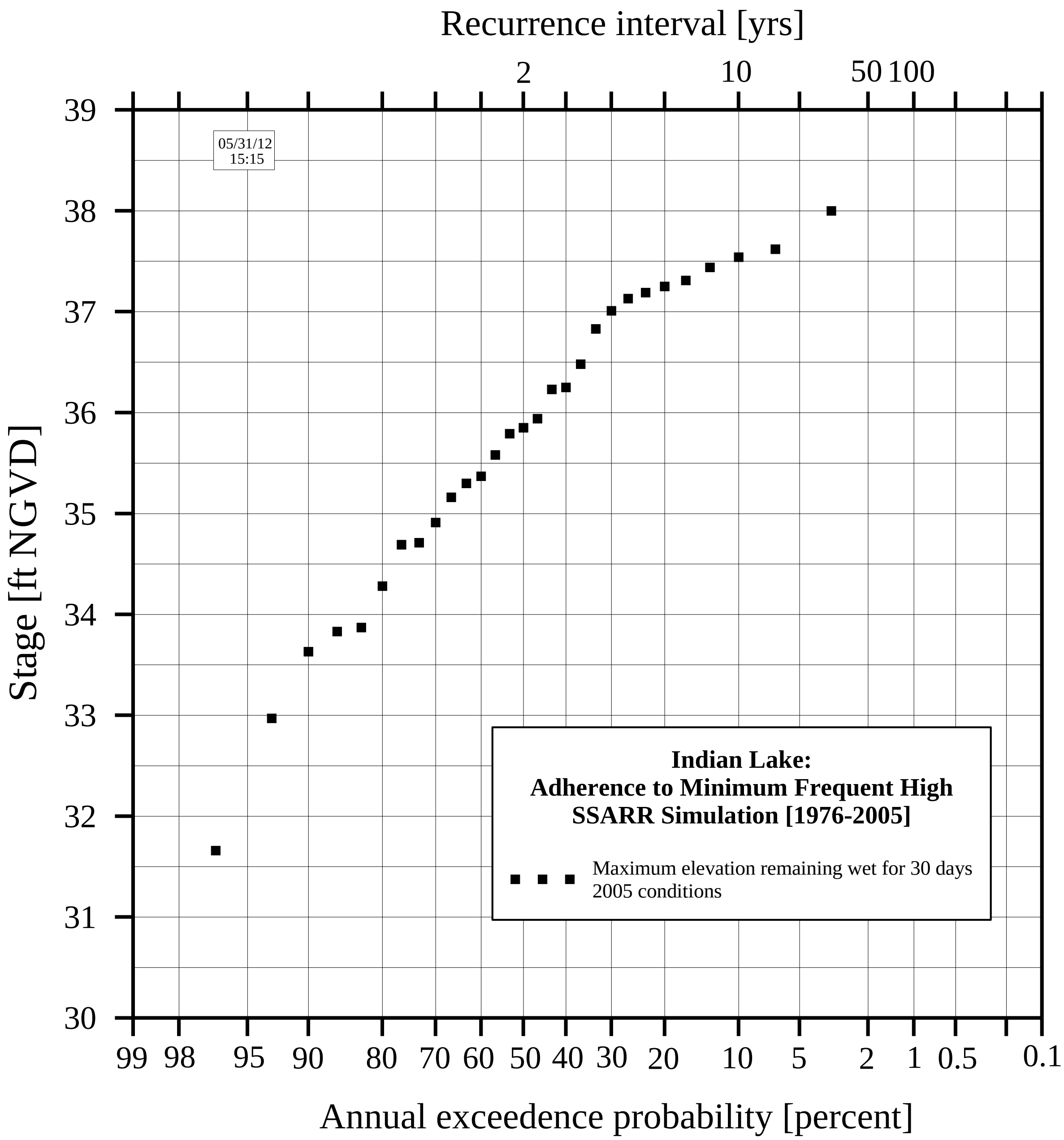

Figure A5. Flood frequencies computed using daily stages from model simulations of Indian Lake, for elevations continuously wet for 30 days and 2005 conditions

Note: SSARR = Streamflow Synthesis and Reservoir Regulation model

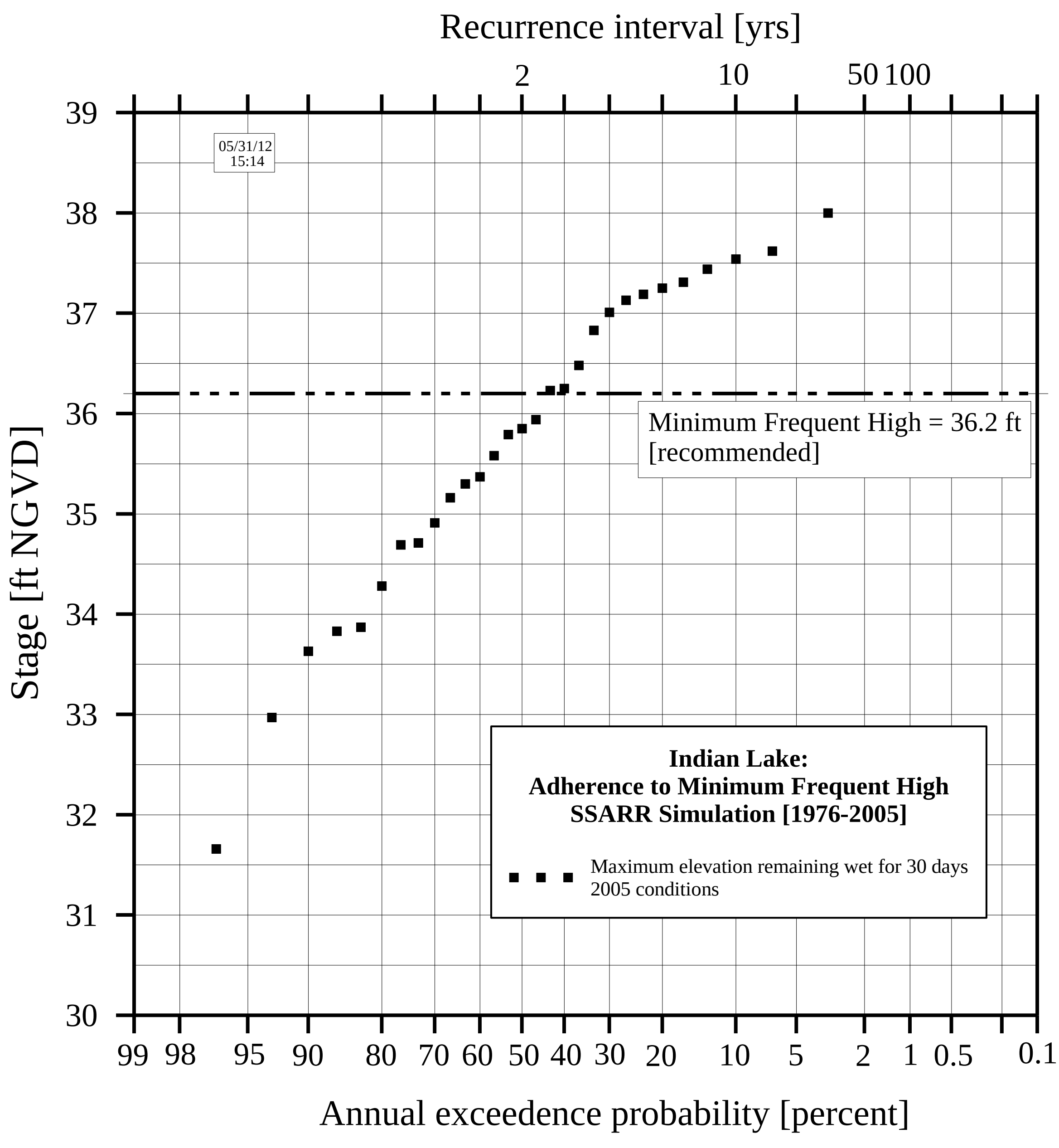

Figure A6. Flood frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Indian Lake, for elevations continuously wet for 30 days and 2005 conditions with the recommended minimum frequent high (MFH) of 36.2 ft NGVD superimposed

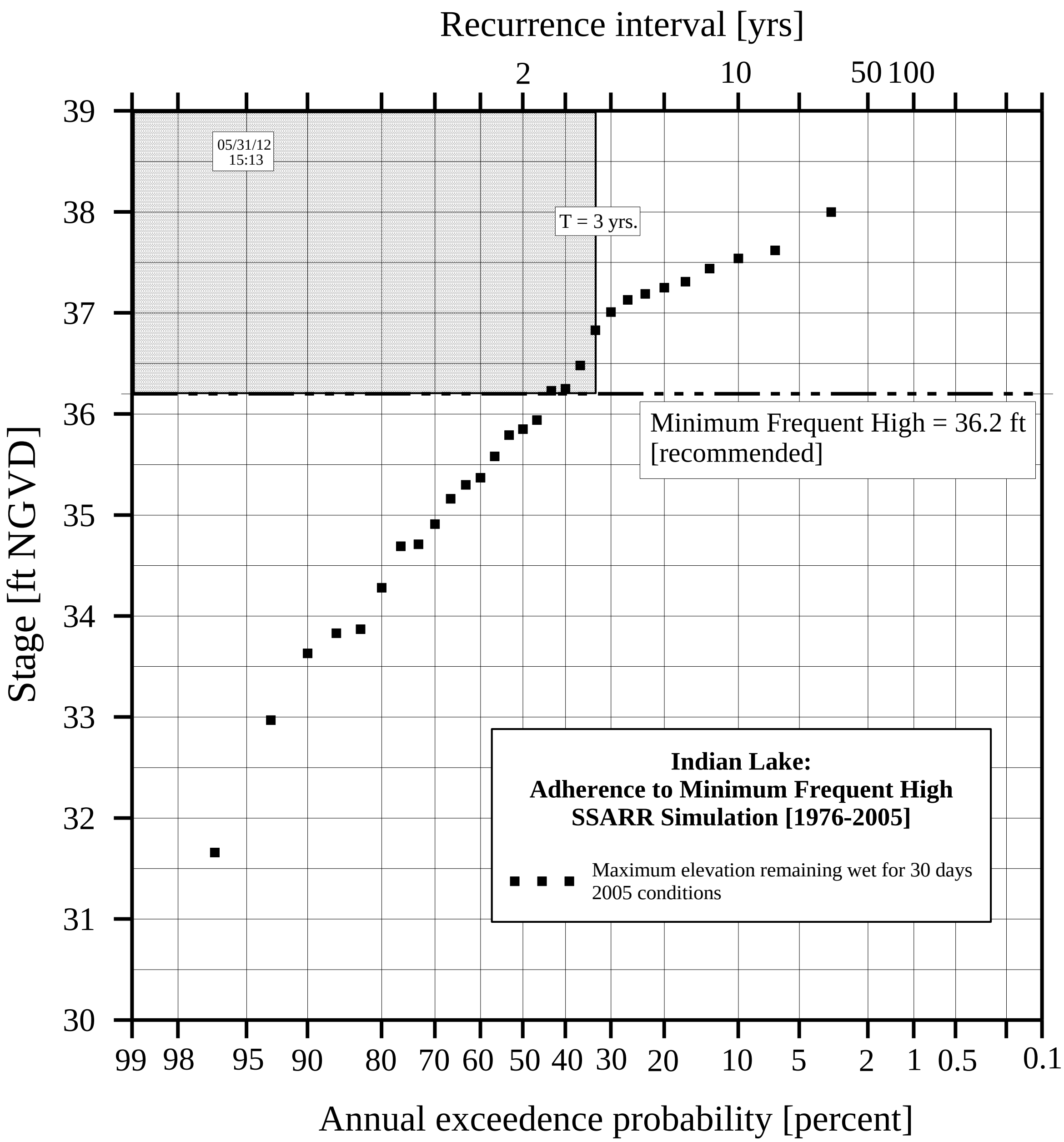

Figure A7. Flood frequencies computed using daily stages from model simulations of Indian Lake, for elevations continuously wet for 30 days and 2005 conditions with a superimposed box bounded on the bottom by the recommended minimum frequent high (MFH), and on the right by a vertical line corresponding to a return period of 3 years. Any part of the frequency curve crossing this shaded box indicates that the MFH is being met.

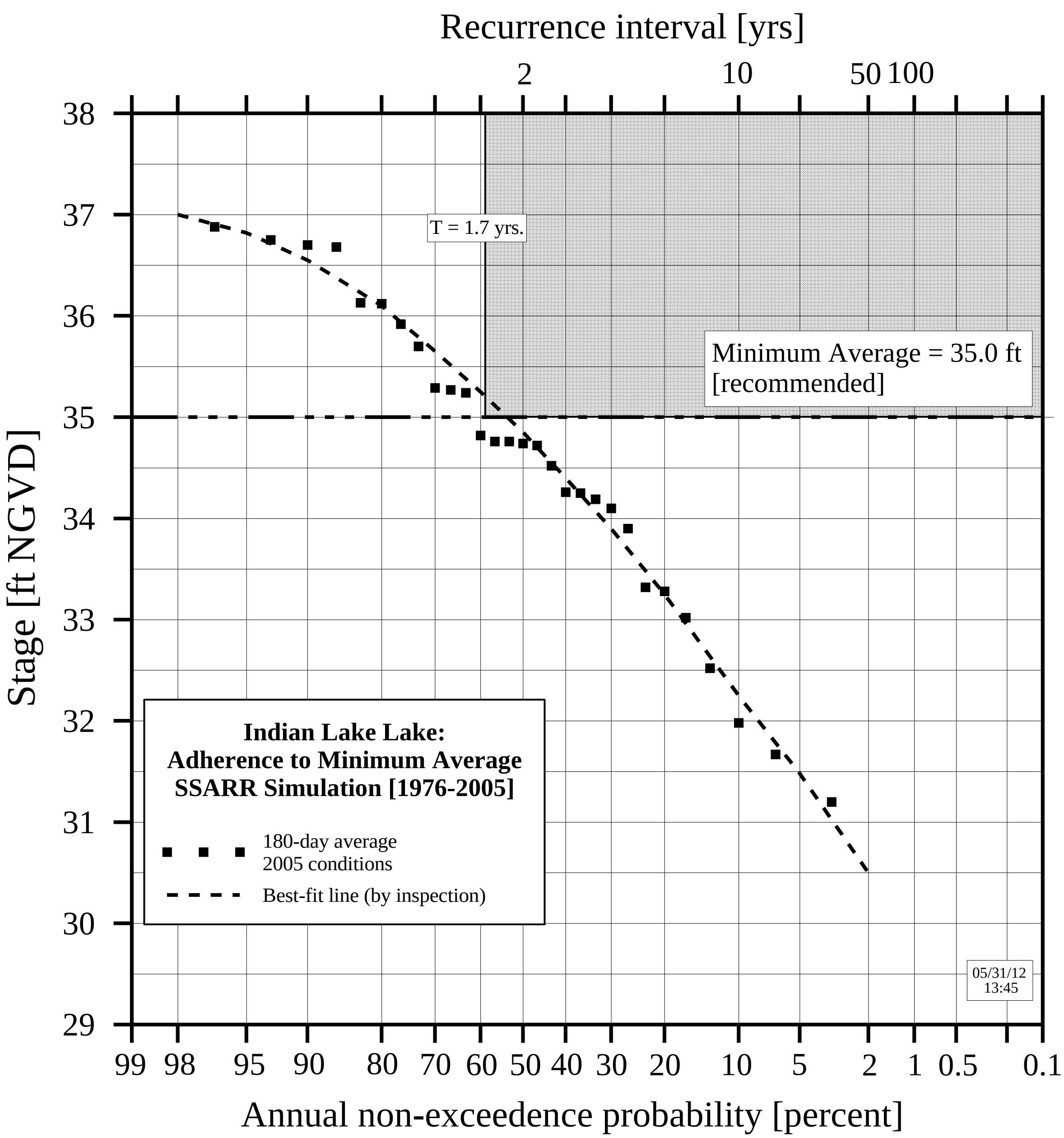

Figure A8. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation SSARR model simulations of Indian Lake, for the recommended minimum average (MA) level and 2005 conditions

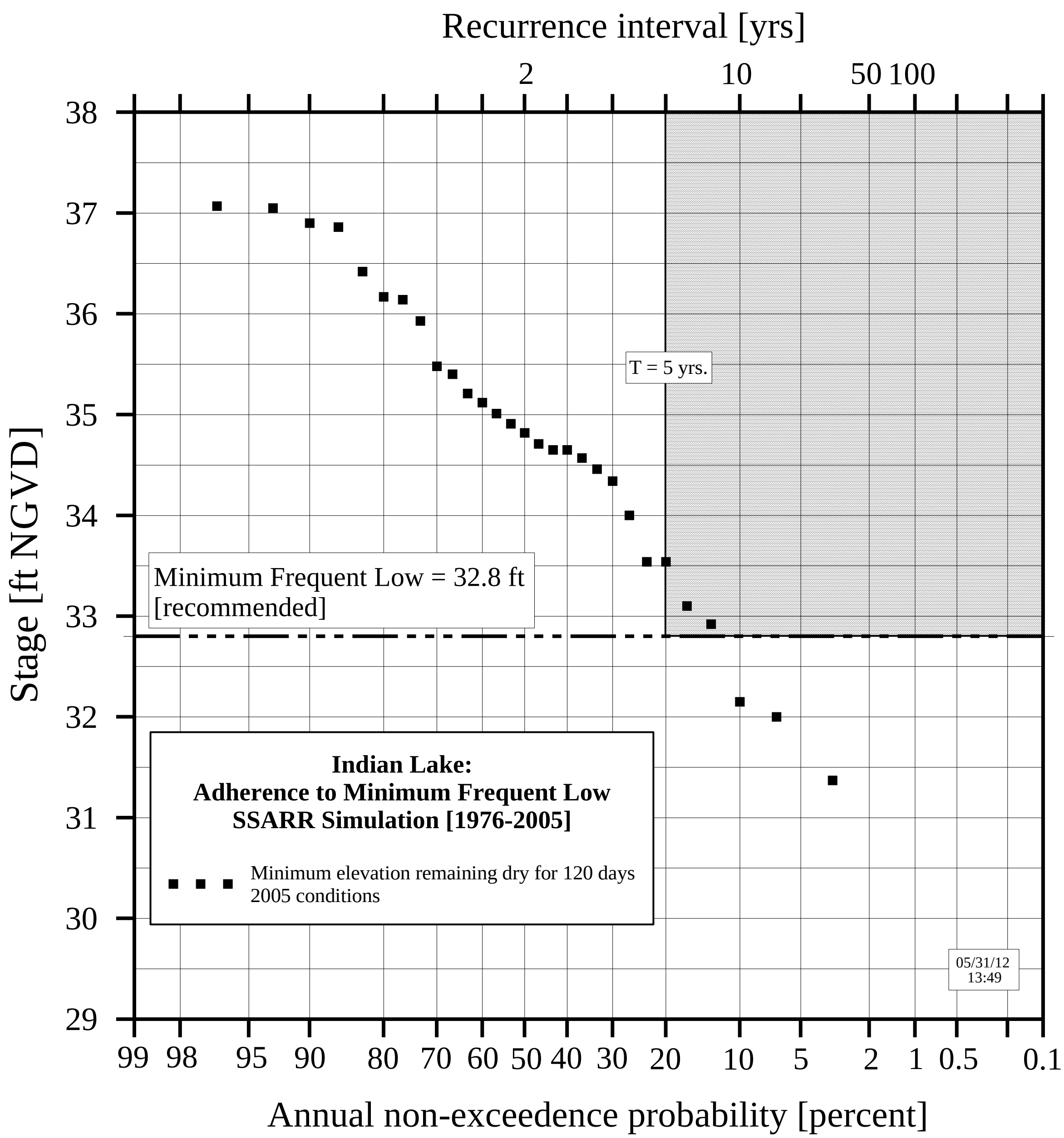

Figure A9. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Indian Lake, for the recommended minimum frequent low (MFL) level and 2005 conditions

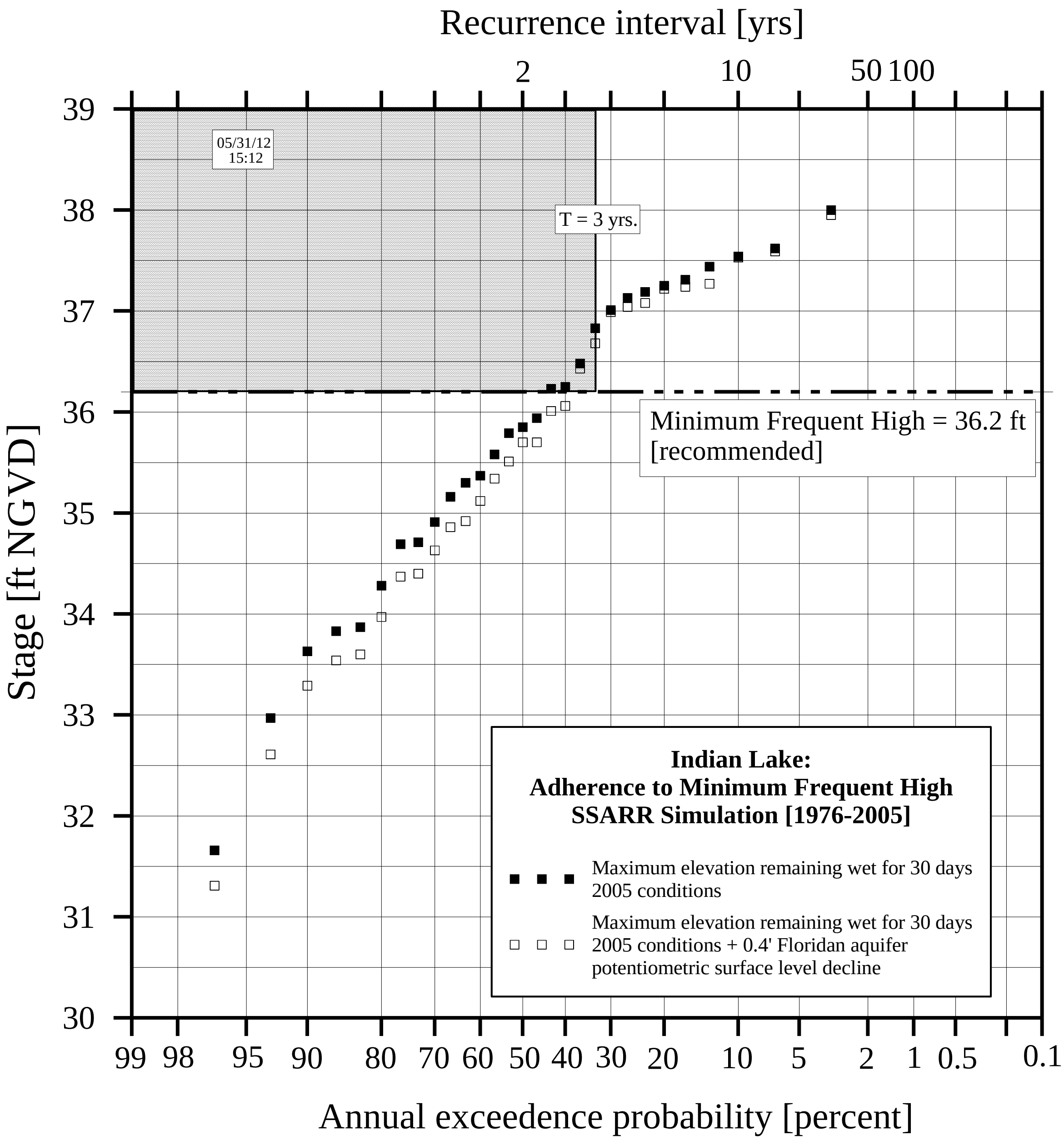

Figure A10. Flood frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Indian Lake, for the recommended minimum frequent high (MFH) level and 2005 conditions plus a 0.4-ft Floridan aquifer potentiometric surface level decline

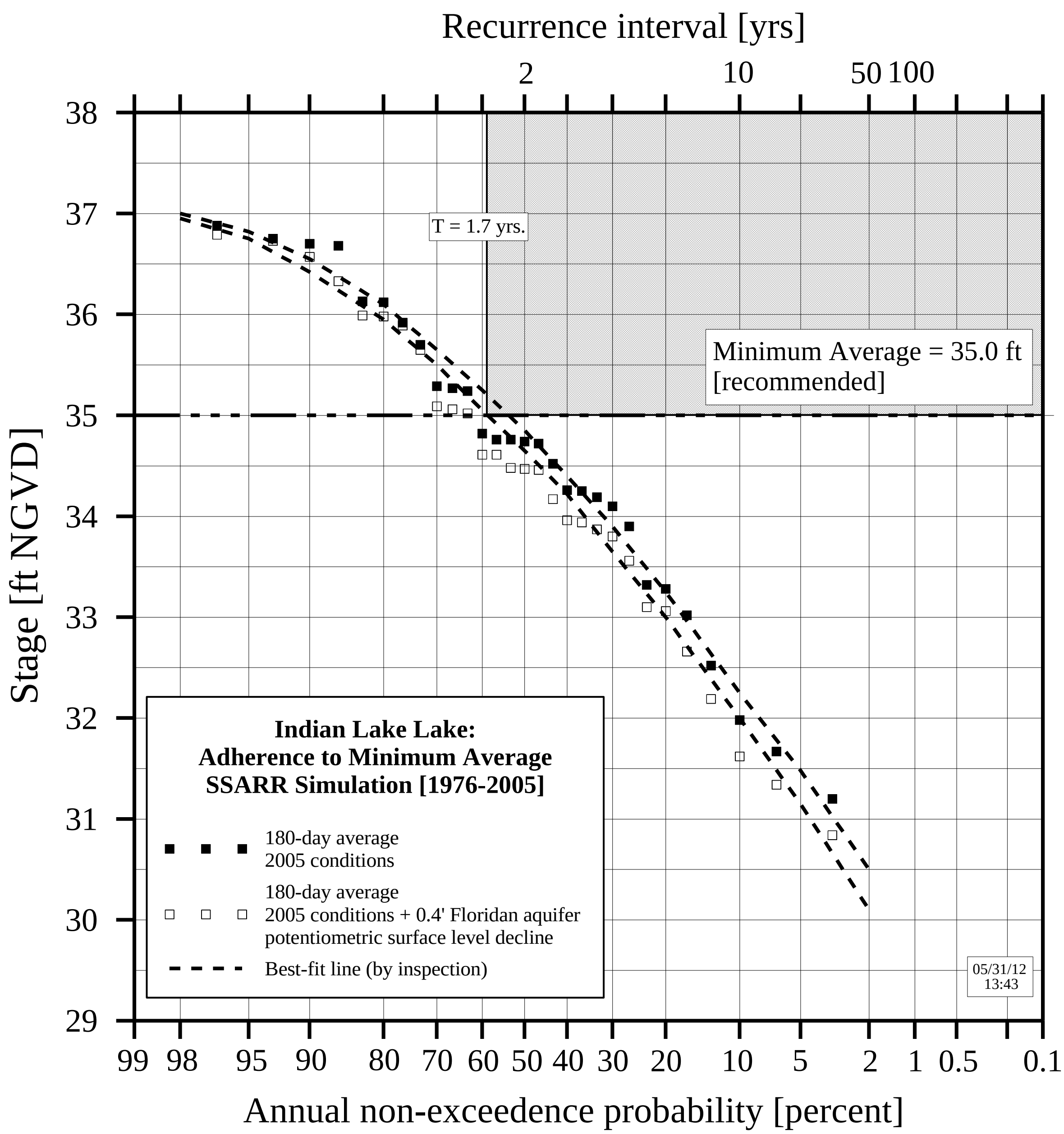

Figure A11. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Indian Lake, for the recommended minimum average (MA) level and 2005 conditions plus a 0.4-ft Floridan aquifer potentiometric surface level decline

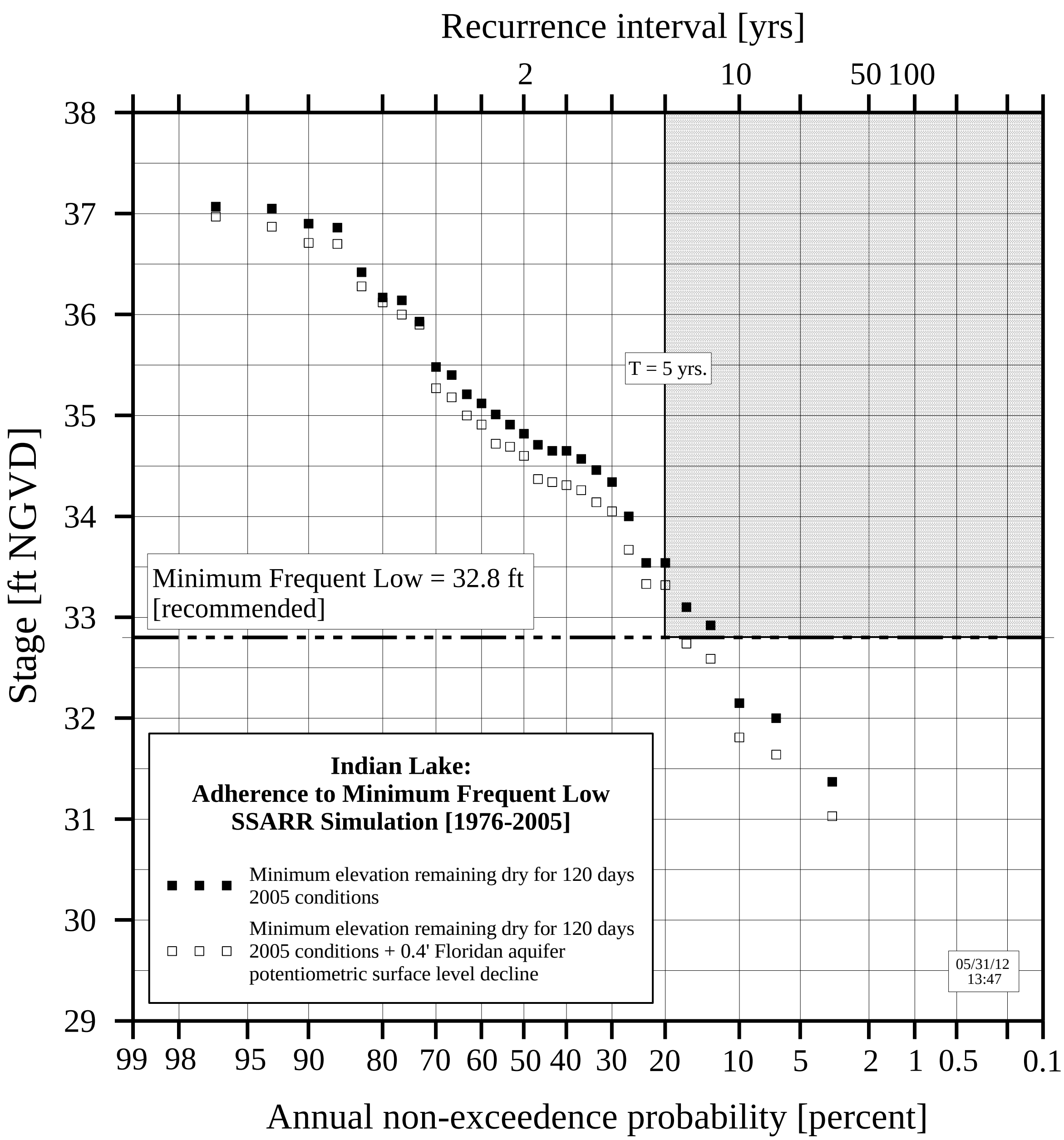

Figure A12. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Indian Lake, for the recommended minimum frequent low (MFL) level and 2005 conditions plus a 0.4-ft Floridan aquifer potentiometric surface level decline

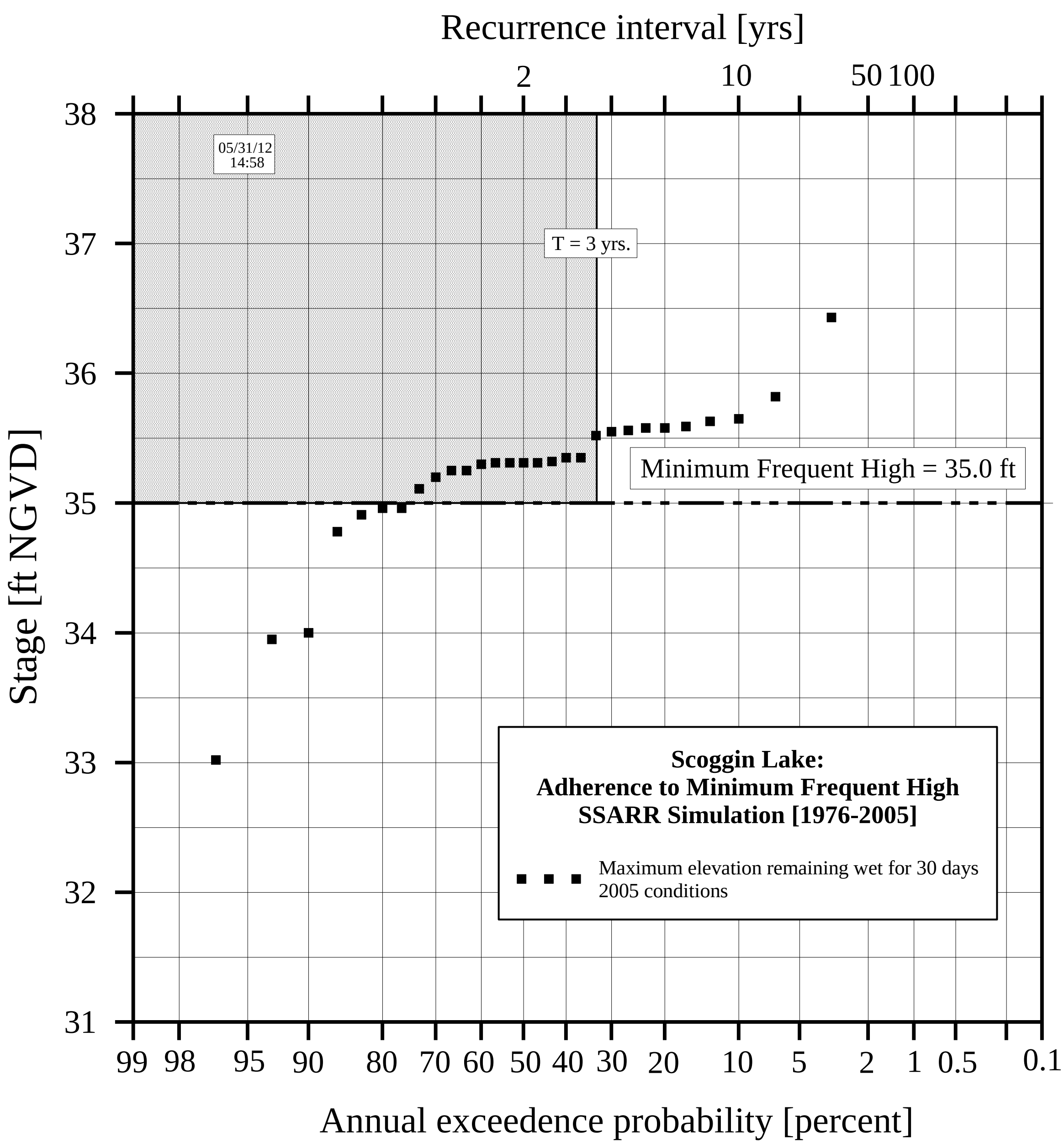

Figure A13. Flood frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Scoggin Lake, for elevations continuously wet for 30 days and 2005 conditions

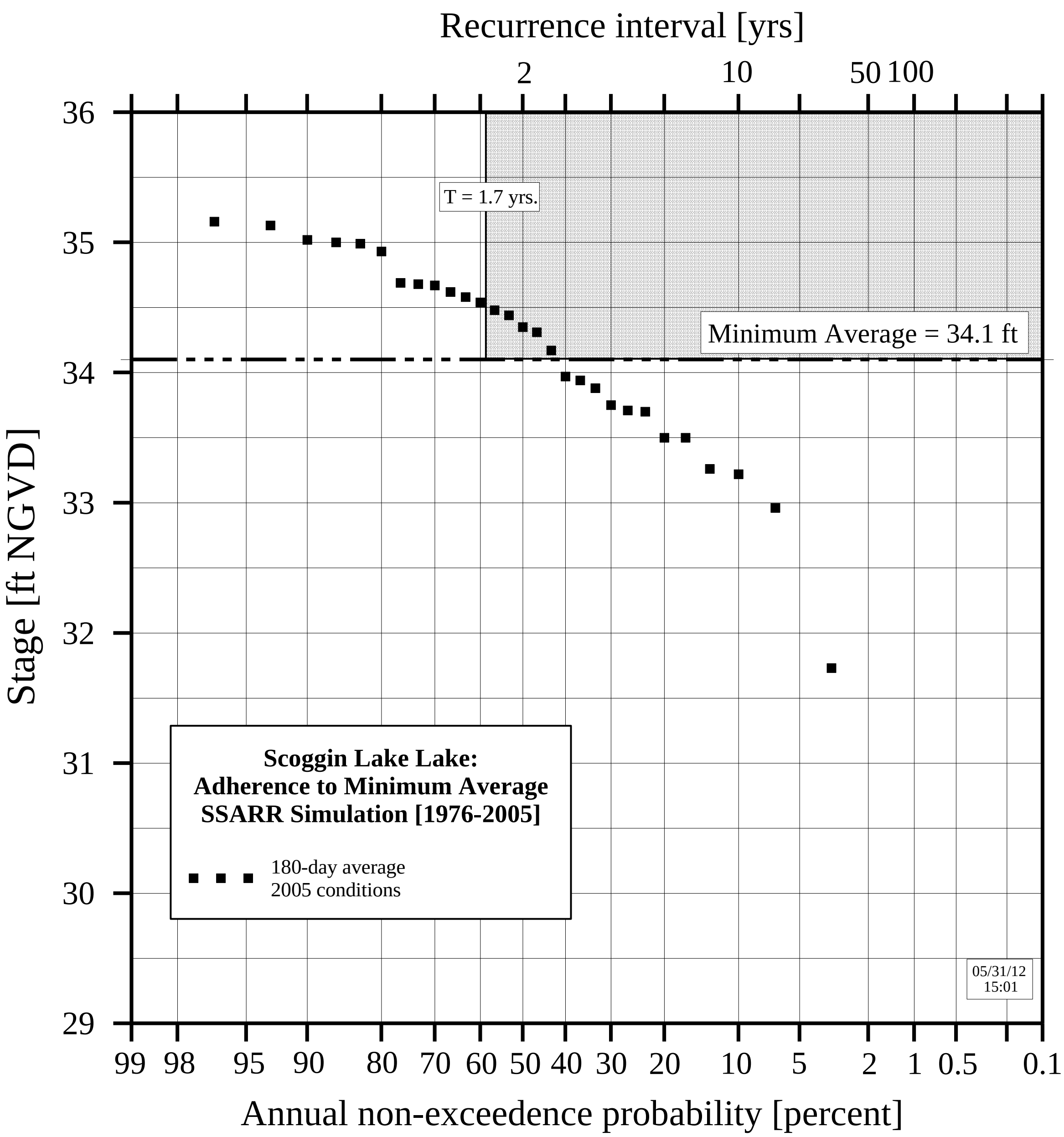

Figure A14. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Scoggin Lake, for the minimum average (MA) level and 2005 conditions

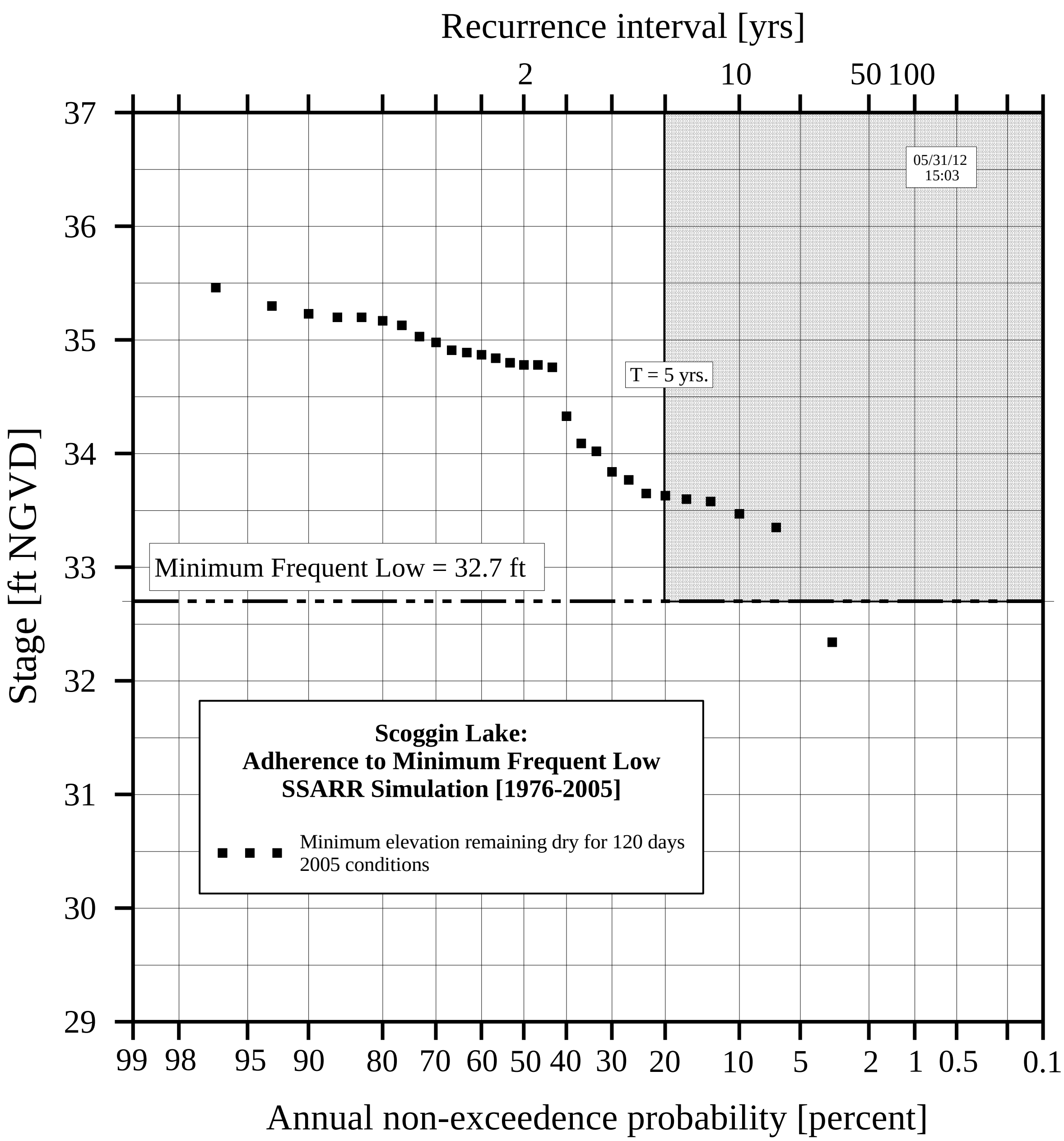

Figure A15. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Scoggin Lake, for the minimum frequent low (MFL) level and 2005 conditions

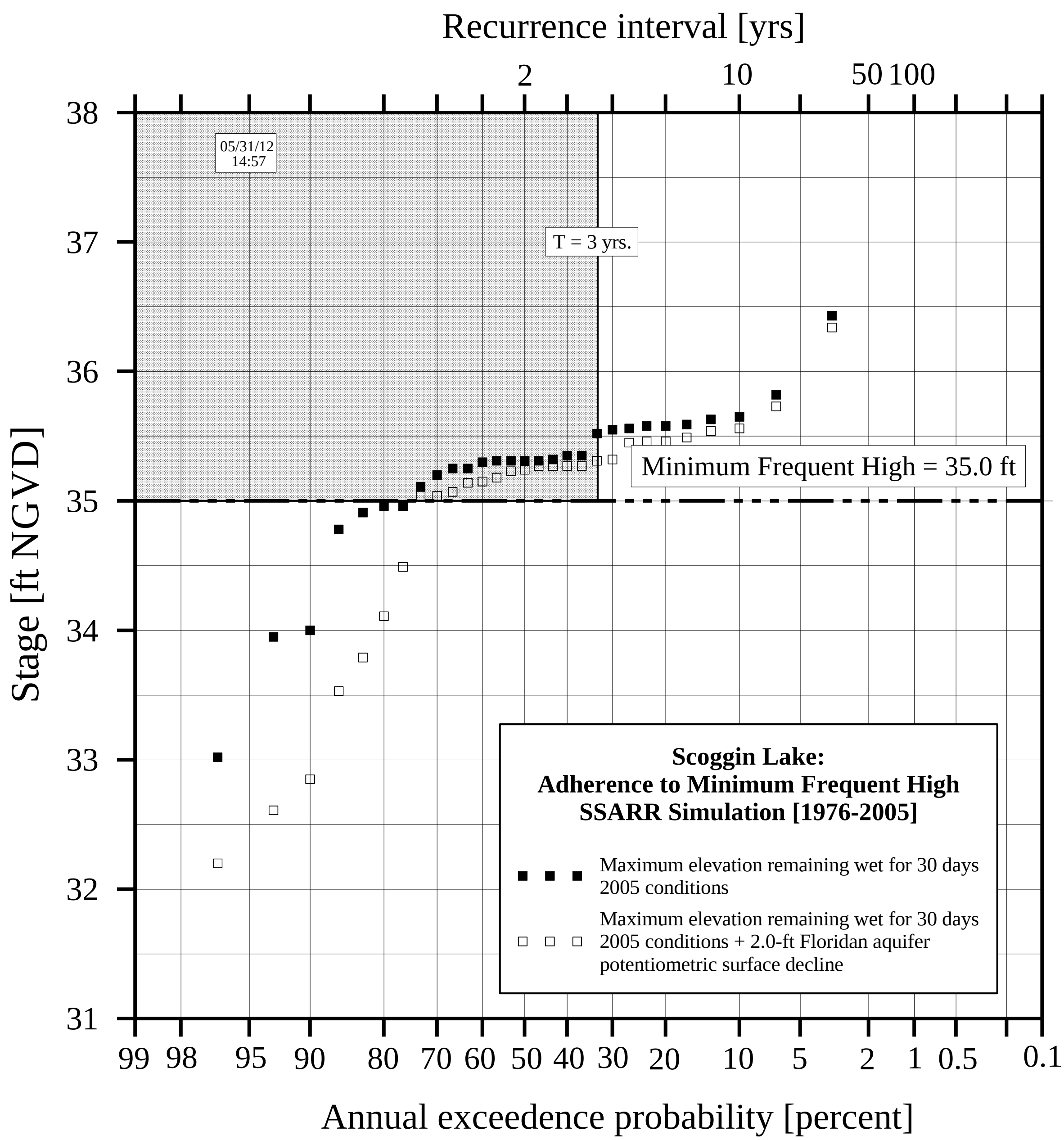

Figure A16. Flood frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Scoggin Lake, for the minimum frequent high (MFH) level and 2005 conditions plus a 2.0-ft Floridan aquifer potentiometric surface level decline

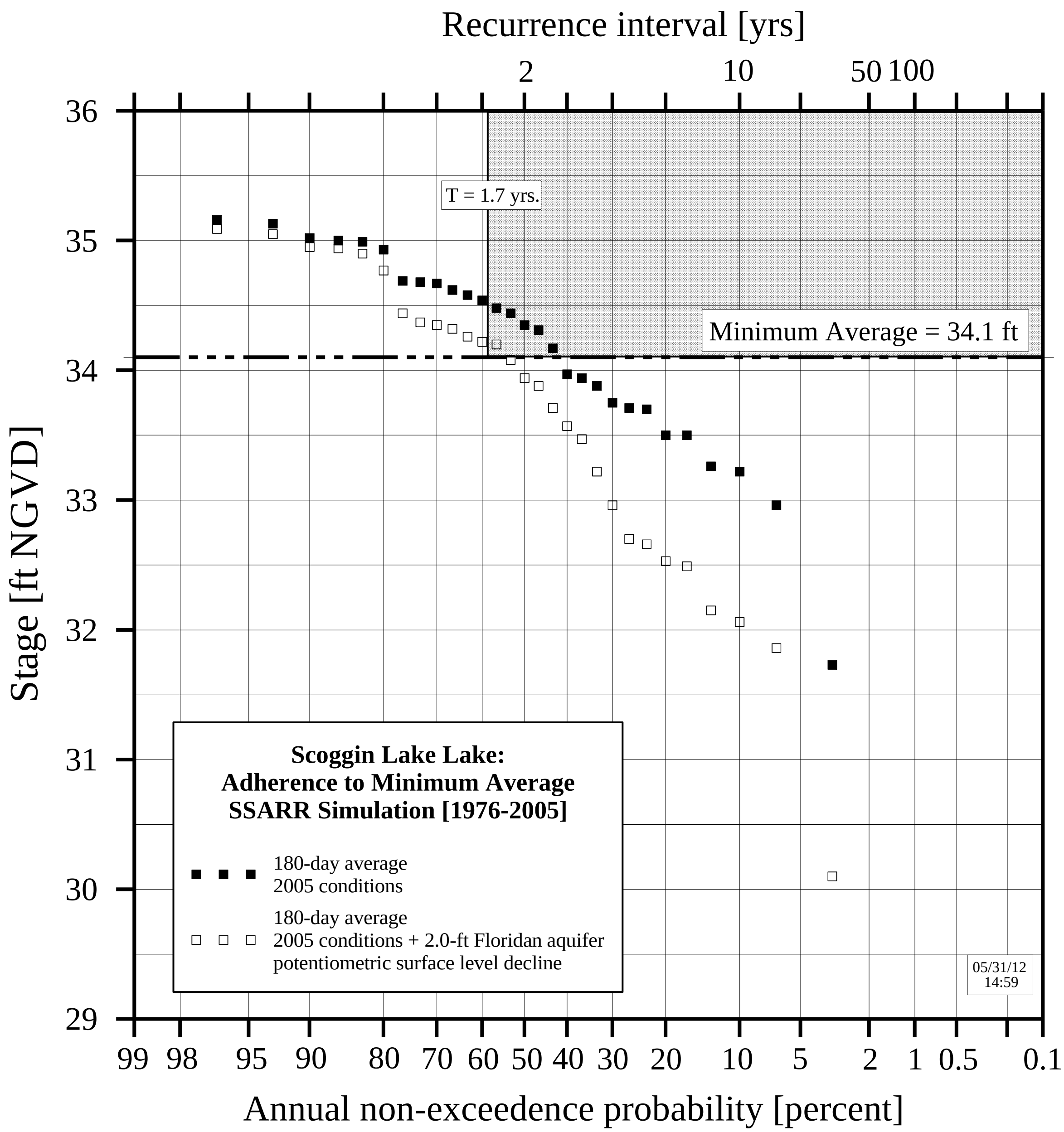

Figure A17. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Scoggin Lake, for the minimum average (MA) level and 2005 conditions plus a 2.0-ft Floridan aquifer potentiometric surface level decline

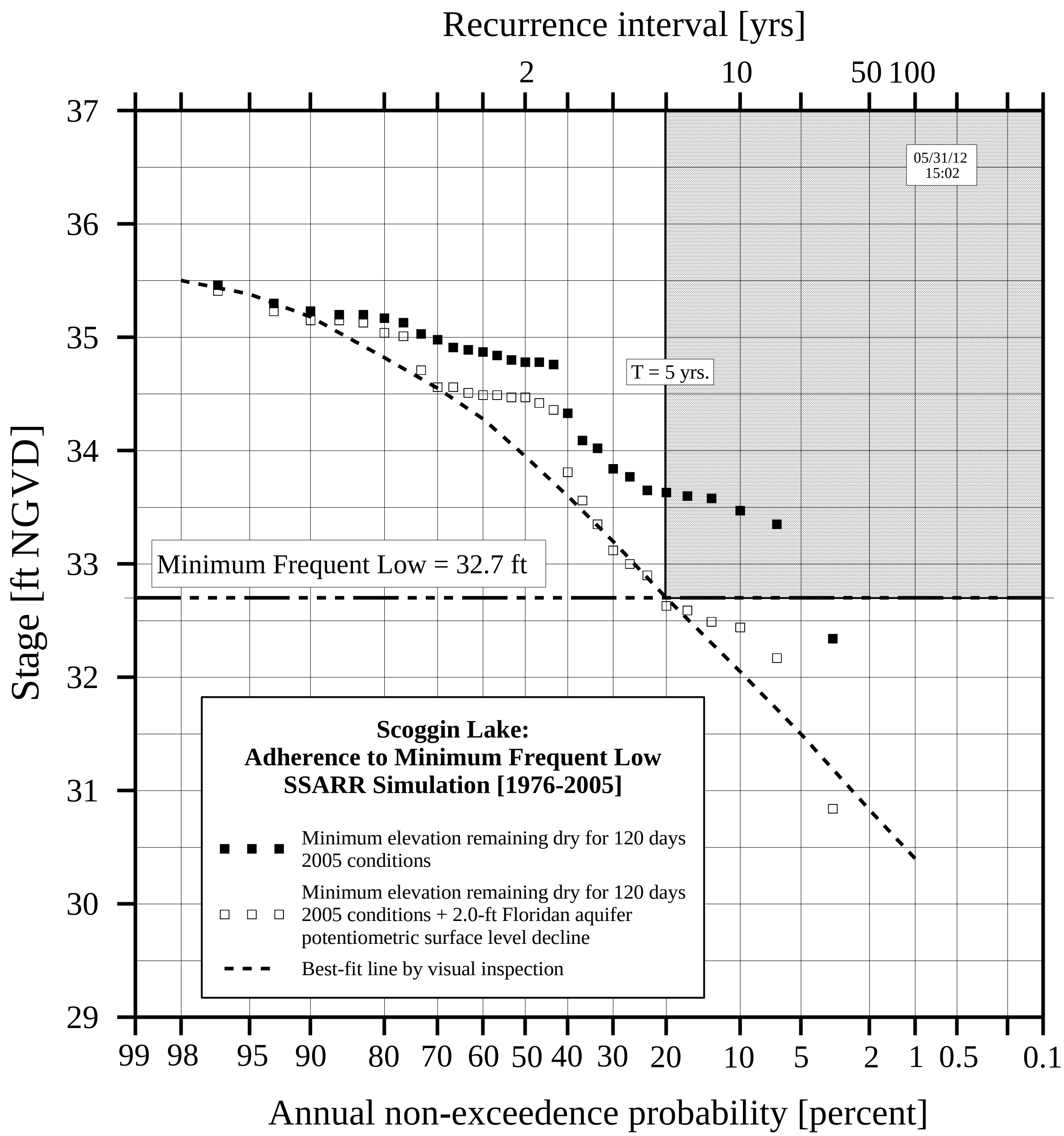

Figure A18. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Scoggin Lake, for the minimum frequent low (MFL) level and 2005 conditions plus a 2.0-ft Floridan aquifer potentiometric surface level decline

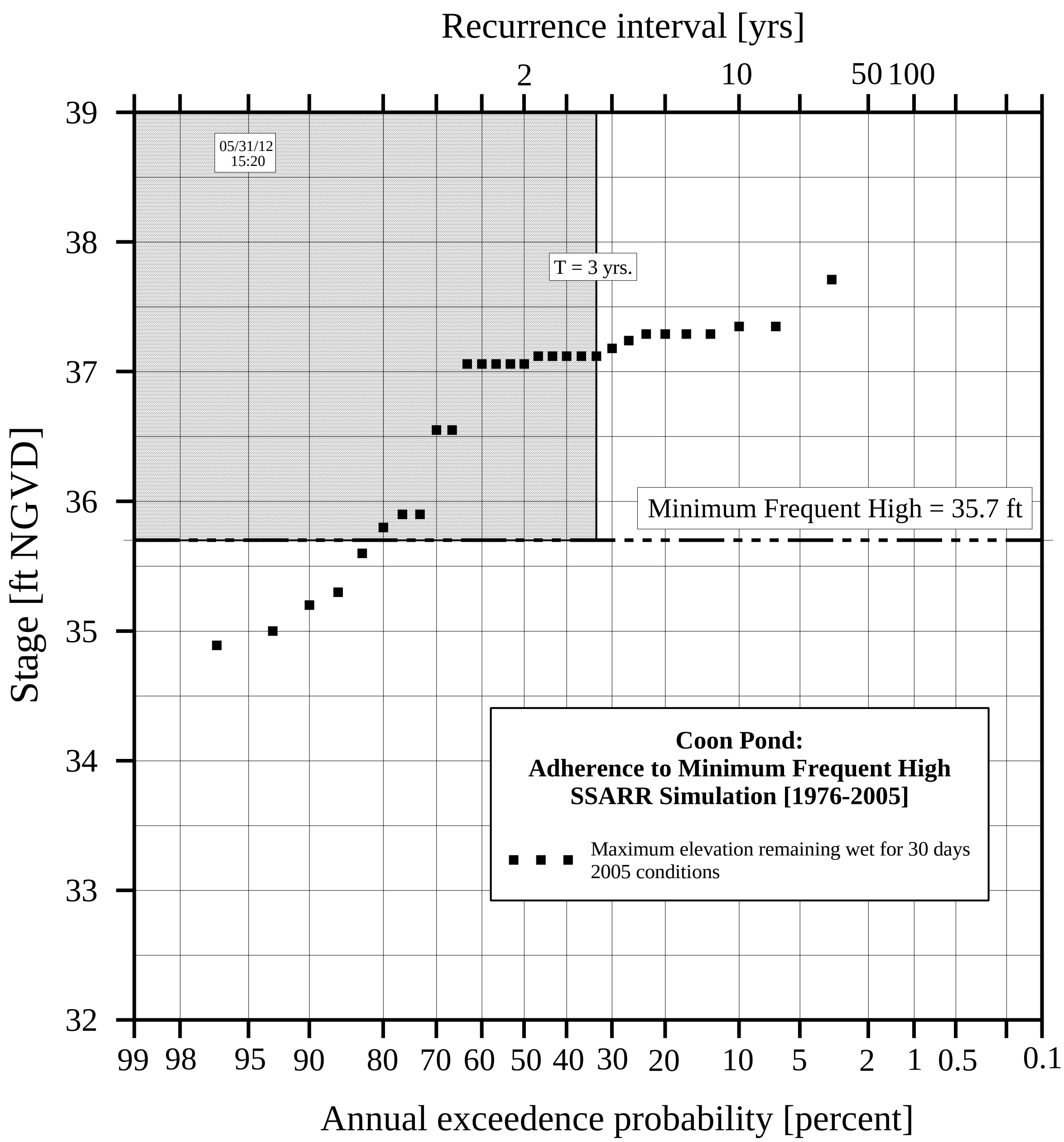

Figure A19. Flood frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Coon Pond, for elevations continuously wet for 30 days and 2005 conditions

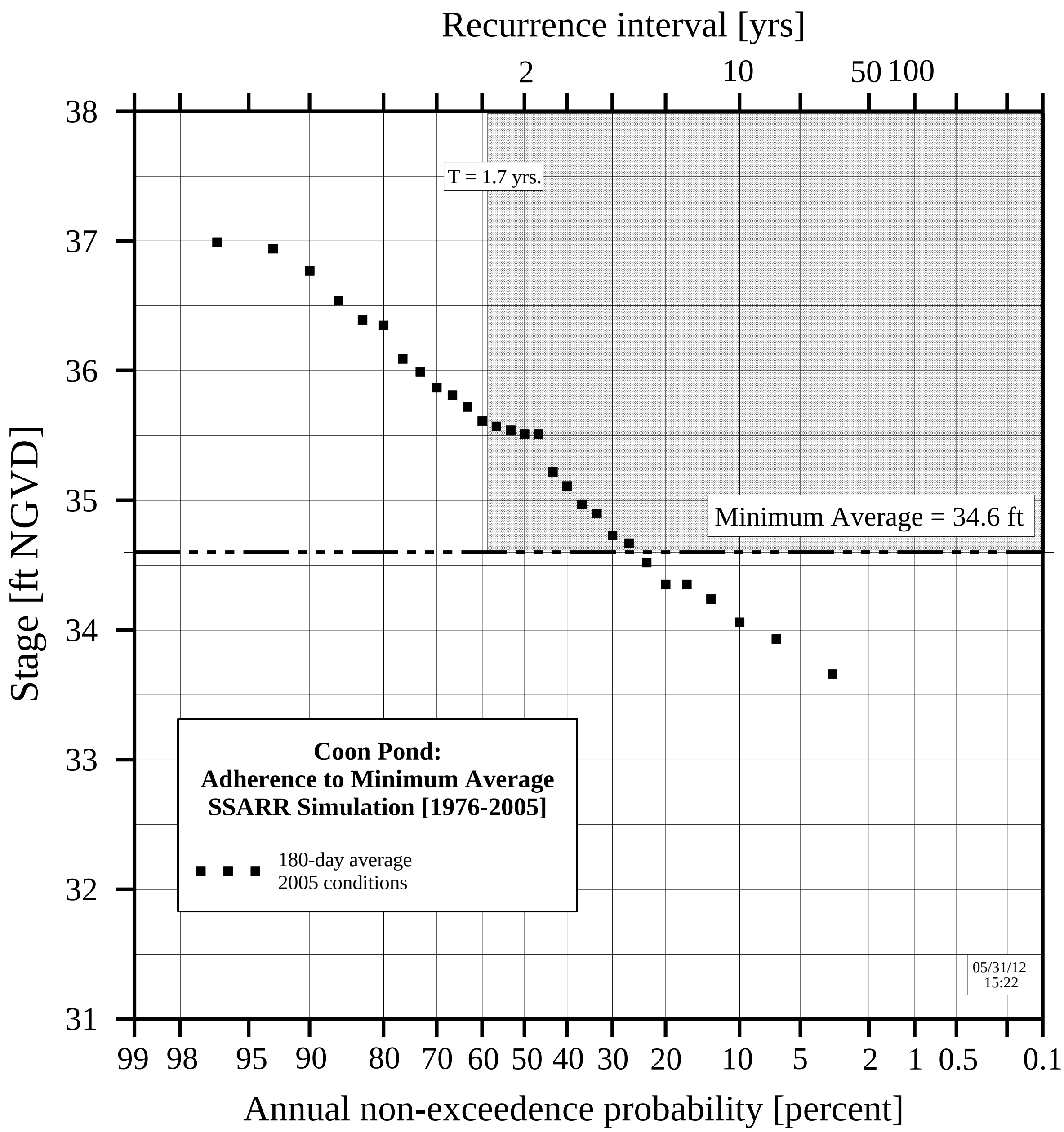

Figure A20. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Coon Pond, for the minimum average (MA) level and 2005 conditions

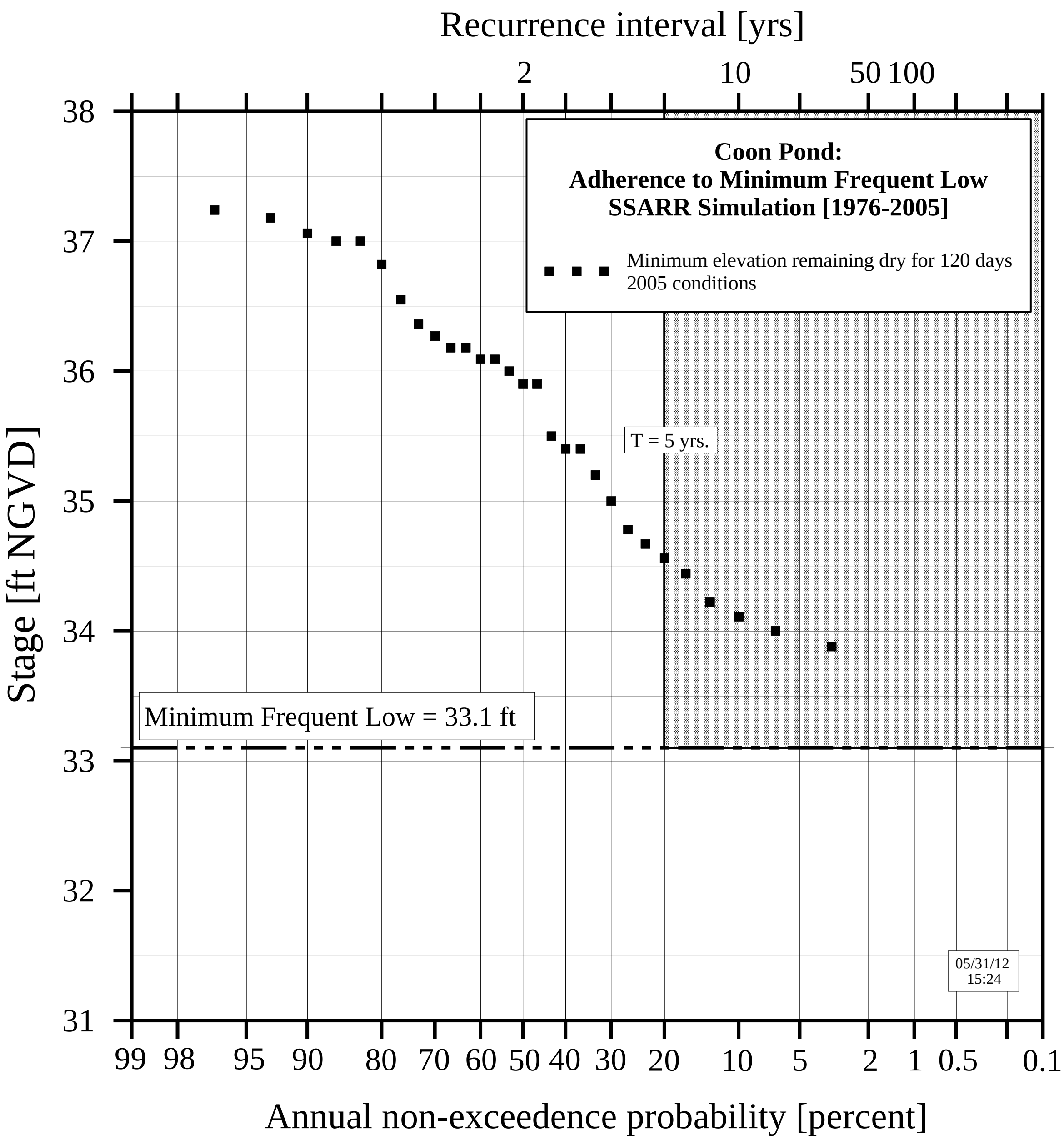

Figure A21. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Coon Pond, for the minimum frequent low (MFL) level and 2005 conditions

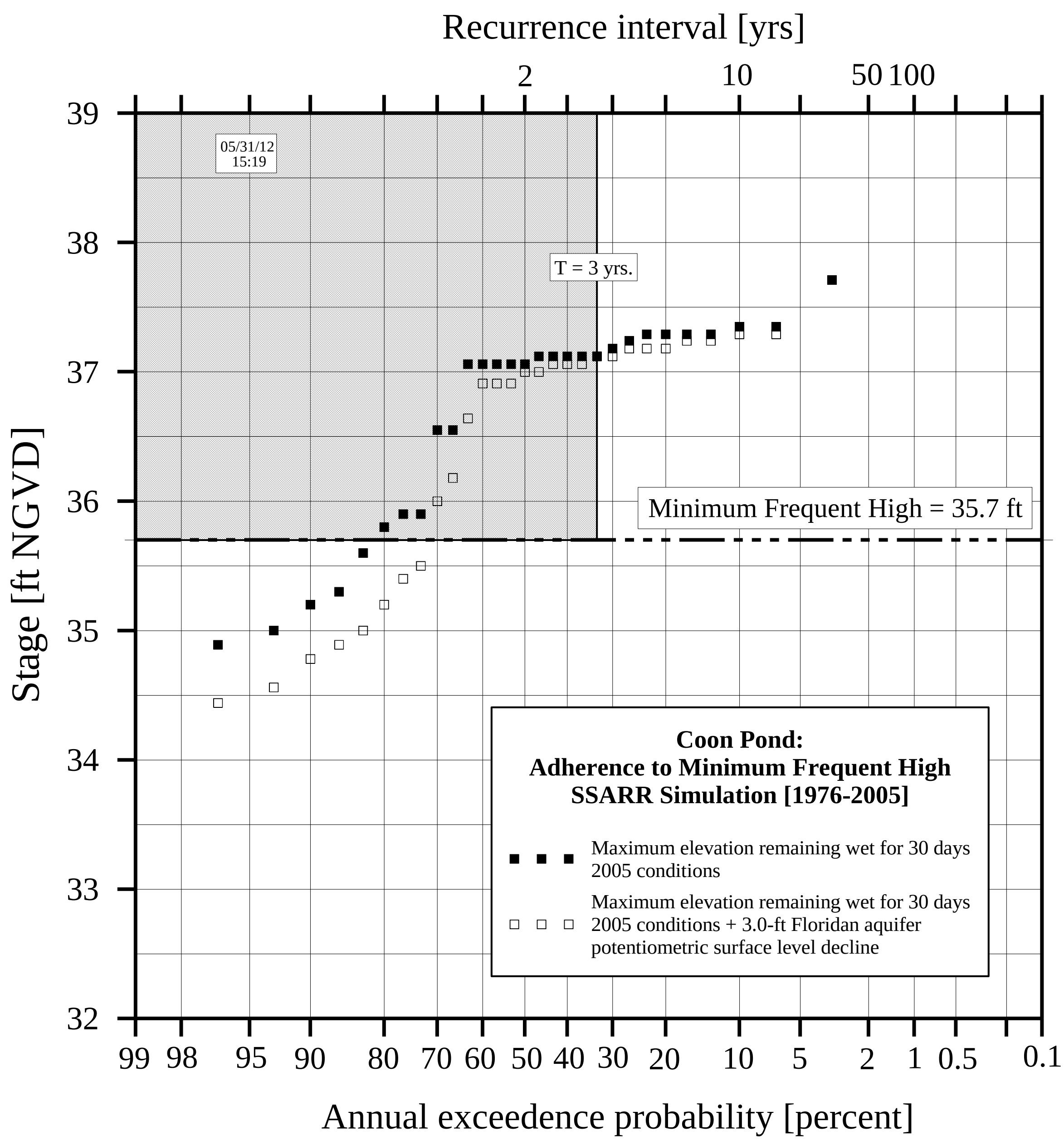

Figure A22. Flood frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Coon Pond, for the minimum frequent high (MFH) level and 2005 conditions plus a 3.0-ft Floridan aquifer potentiometric surface level decline

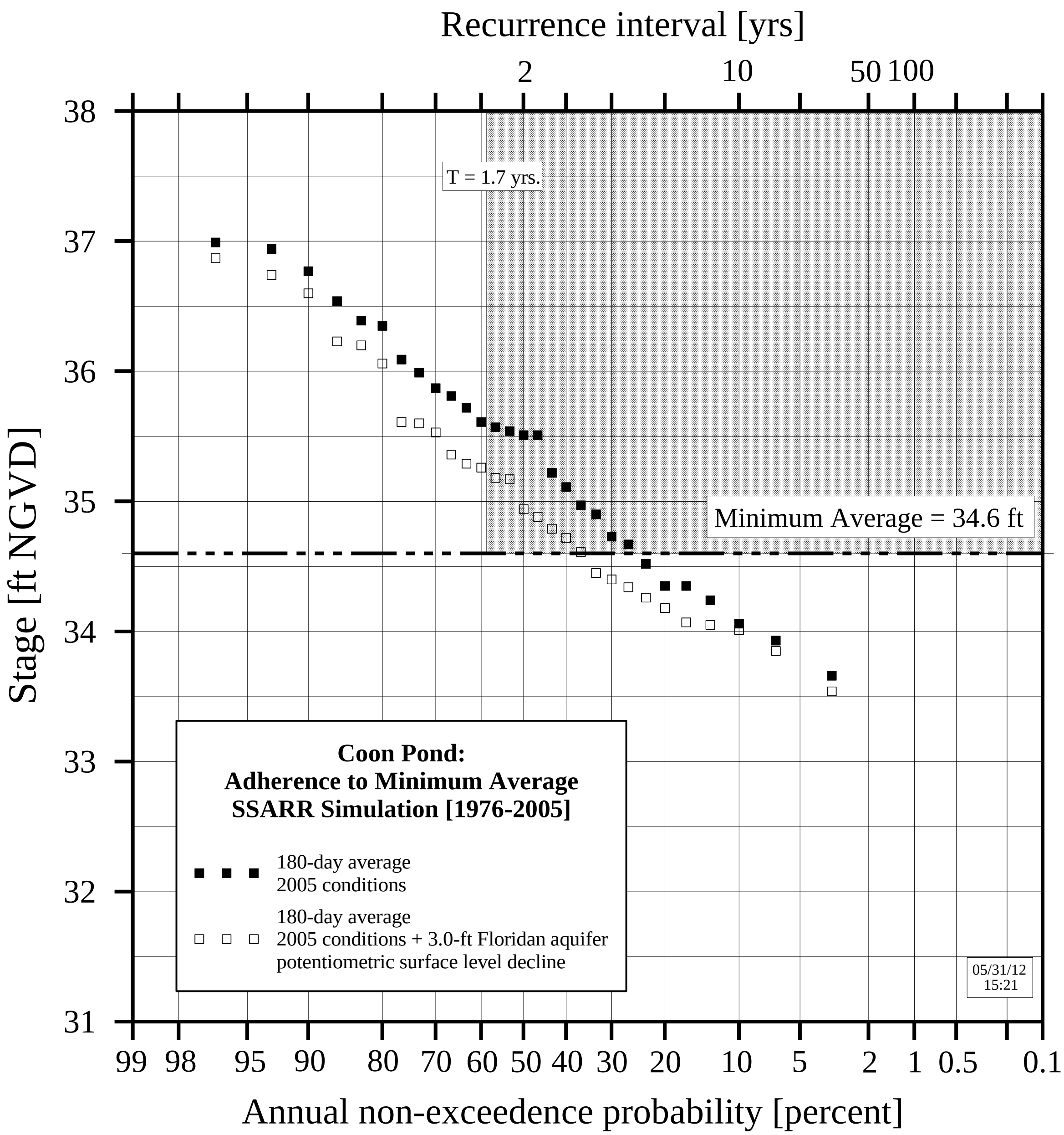

Figure A23. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Coon Pond, for the minimum average (MA) level and 2005 conditions plus a 3.0-ft Floridan aquifer potentiometric surface level decline

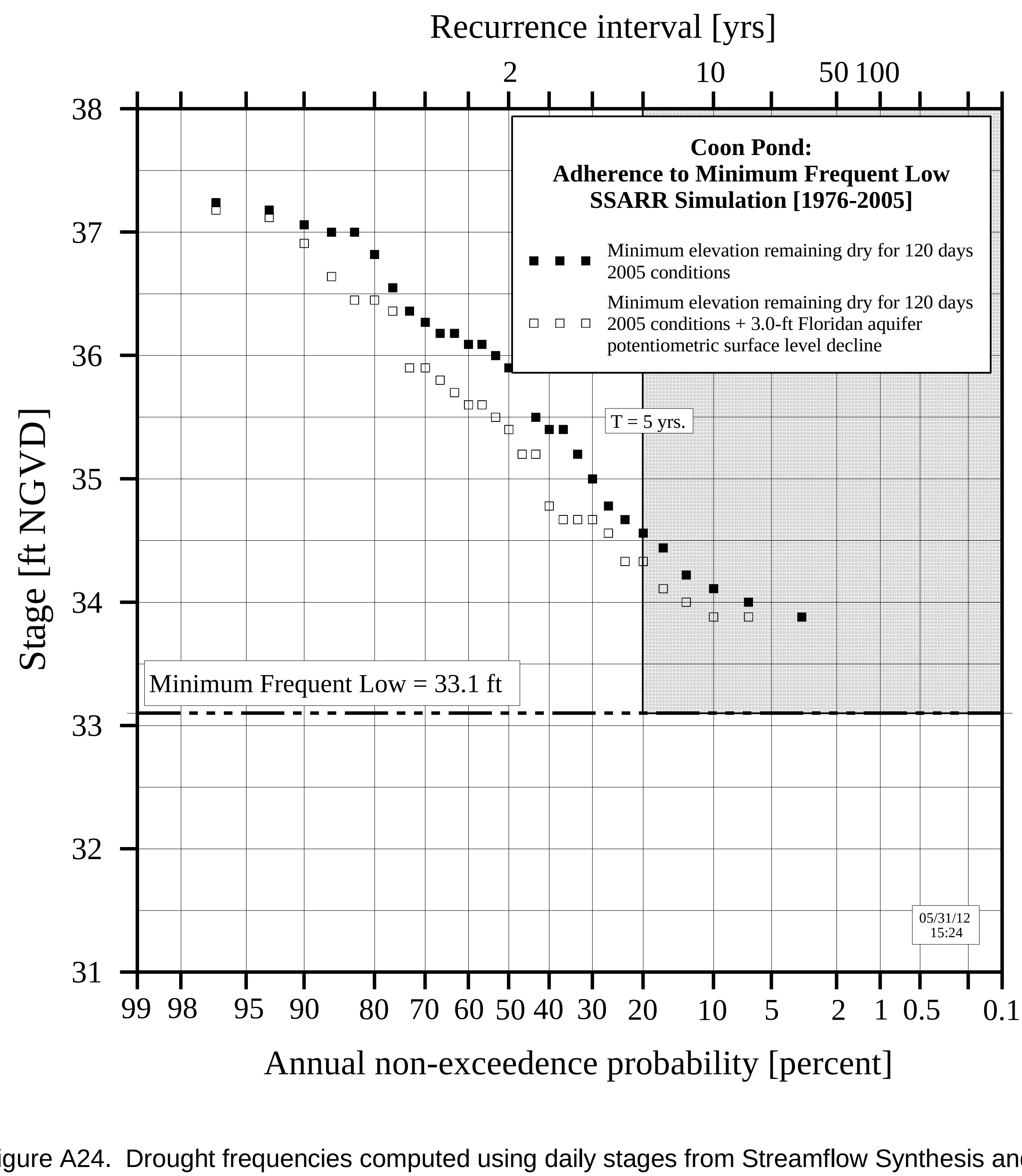

Figure A24. Drought frequencies computed using daily stages from Streamflow Synthesis and Reservoir Regulation (SSARR) model simulations of Coon Pond, for the minimum frequent low (MFL) level and 2005 conditions plus a 3.0-ft Floridan aquifer drawdown

APPENDIX B—PRINTOUT OF THE INDIAN LAKE SYSTEM STREAMFLOW SYNTHESIS AND RESERVOIR REGULATION (SSARR) MODEL

Following is a printout of the Indian Lake system Streamflow Synthesis and Reservoir Regulation (SSARR) model.

```
CL01    INDI       2       INDIAN LAKE
CL02    INDI                         50      10
C101    INDI    2200    .01             0   2300    .01          2
C101    INDI    2400    .01            12   2500    .01         30
C101    INDI    2600    .01            54   2700    .01         85
C101    INDI    2800    .01           124   2900    .01        169
C101    INDI    3000    .01           222   3100    .01        279
C101    INDI    3200    .01           338   3300    .01        399
C101    INDI    3400    .01           462   3500    .01        527
C101    INDI    3600    .01           594   3700    .01        663
C101    INDI    3800      1           748   3900      2        863
C101    INDI    4000      4          1009   4100      8       1186
C101    INDI    4200     16          1394   4300     32       1633
CF02    430I        -200    2200     .00    2300    -.53    2500   -1.74
CF02    430I        -200    2700   -2.91    2900   -4.08    3100   -4.83
CF02    430I        -200    3300   -5.17    3500   -5.50    3700   -6.41
CF02    430I        -200    3900  -10.91    4100  -16.03    4300  -19.87
CF02    430I          00    2200     .00    4300     .00
CF02    430I         200    2200     .00    2300     .53    2500    1.74
CF02    430I         200    2700    2.91    2900    4.08    3100    4.83
CF02    430I         200    3300    5.17    3500    5.50    3700    6.41
CF02    430I         200    3900   10.91    4100   16.03    4300   19.87
CF02    430I         400    2200     .00    2300    1.05    2500    3.48
CF02    430I         400    2700    5.82    2900    8.16    3100    9.67
CF02    430I         400    3300   10.33    3500   11.00    3700   12.82
CF02    430I         400    3900   21.82    4100   32.06    4300   39.74
CF02    430I        2000    2200     .00    2300    5.26    2500   17.42
CF02    430I        2000    2700   29.12    2900   40.80    3100   48.33
CF02    430I        2000    3300   51.66    3500   55.00    3700   64.10
CF02    430I        2000    3900  109.12    4100  160.31    4300  198.68
CC01    IEVA      3  122    INDIAN EVAPORATION
CC02    IEVA      INDI      EVAP 430I
CC01    IRAI      3  122    INDIAN DIRECT RAINFALL
CC02    IRAI      INDI      RAIN 430I

CL01    SCOG       2       SCOGGIN LAKE
CL02    SCOG                         50      10
C101    SCOG    2300    .01             0   2400    .01          2
C101    SCOG    2500    .01            13   2600    .01         32
C101    SCOG    2700    .01            58   2800    .01         89
C101    SCOG    2900    .01           122   3000    .01        157
C101    SCOG    3100    .01           194   3200    .01        233
C101    SCOG    3300    .01           274   3400    .01        317
C101    SCOG    3500    .01           362   3600      2        433
C101    SCOG    3700      4           559   3800      8        739
C101    SCOG    3900     16           973   4000     32       1262
CF02    430S        -200    2300     .00    2400    -.56    2600   -1.87
CF02    430S        -200    2800   -2.67    3000   -3.00    3200   -3.33
CF02    430S        -200    3400   -3.66    3600   -8.21    3800  -17.27
CF02    430S        -200    4000  -24.04       0     .00       0     .00
CF02    430S          00    2300     .00    4000     .00
CF02    430S         200    2300     .00    2400     .56    2600    1.87
CF02    430S         200    2800    2.67    3000    3.00    3200    3.33
CF02    430S         200    3400    3.66    3600    8.21    3800   17.27
CF02    430S         200    4000   24.04       0     .00       0     .00
```

```
CF02     430S         400    2300     .00    2400    1.13    2600    3.73
CF02     430S         400    2800    5.33    3000    6.00    3200    6.67
CF02     430S         400    3400    7.33    3600   16.42    3800   34.55
CF02     430S         400    4000   48.08       0     .00       0     .00
CF02     430S        2000    2300     .00    2400    5.64    2600   18.66
CF02     430S        2000    2800   26.66    3000   30.00    3200   33.33
CF02     430S        2000    3400   36.64    3600   82.12    3800  172.74
CF02     430S        2000    4000  240.38       0     .00       0     .00
CC01     SEVA       3  122   SCOGGIN EVAPORATION
CC02     SEVA       SCOG     EVAP 430S
CC01     SRAI       3  122   SCOGGIN DIRECT RAINFALL
CC02     SRAI       SCOG     RAIN 430S

CL01     COON         2      COON POND
CL02     COON                          50      10
C101     COON      2700    .01             0   2800     .01            0
C101     COON      2900    .01             2   3000     .01            6
C101     COON      3100    .01            10   3200     .01           17
C101     COON      3300    .01            24   3400     .01           32
C101     COON      3500    .01            41   3600     .01           51
C101     COON      3700    .01            62   3800       1           79
C101     COON      3900      2           109   4000       4          154
C101     COON      4100      8           211   4200      16          282
CF02     430C        -200    2700     .00    2800    -.11    3000    -.35
CF02     430C        -200    3200    -.57    3400    -.72    3600    -.85
CF02     430C        -200    3800   -1.99    4000   -4.23    4200   -5.90
CF02     430C          00    2700     .00    4200     .00
CF02     430C         200    2700     .00    2800     .11    3000     .35
CF02     430C         200    3200     .57    3400     .72    3600     .85
CF02     430C         200    3800    1.99    4000    4.23    4200    5.90
CF02     430C         400    2700     .00    2800     .21    3000     .70
CF02     430C         400    3200    1.14    3400    1.43    3600    1.70
CF02     430C         400    3800    3.99    4000    8.46    4200   11.80
CF02     430C        2000    2700     .00    2800    1.05    3000    3.48
CF02     430C        2000    3200    5.70    3400    7.16    3600    8.48
CF02     430C        2000    3800   19.94    4000   42.32    4200   59.02
CC01     CEVA       3  122   COON EVAPORATION
CC02     CEVA       COON     EVAP 430C
CC01     CRAI       3  122   COON DIRECT RAINFALL
CC02     CRAI       COON     RAIN 430C

 ** RELATIONSHIPS
 ** SMI-RI-ROP CURVES
 **PRECIP INTENSITY VS. KE
CT01     42OR           2       0      35      20     100      50     100
CT01     32OR           2       0      16       5      19      20      27
CT01     32OR          50      34
 **SURFACE + SUBSURFACE VS. SURFACE INPUT
CT01     0206           2       0       0    0.05   0.025     0.1    0.05
CT02     0206        0.15   0.075     0.2     0.1     0.5    0.25     900
CT03     0206         900
 **BII CURVE
CT01     220C           3       0      80     .08     0.1      40     .08
CT02     220C         0.2      20     .08     0.4      10     .08     0.8
CT01     220C          10     .08     999      10     .08
 ** BASIN CHARACTERISTICS
CB01     B00I         2      BASIN 1 - TO INDIAN LAKE
```

```
CB02     B00I   0.316 12 6  30 2 200    60 42OR           32OR
CB03     B00I     220C  1000206
CB04     B00I     3PTN11005DETI100
CB01     B00S         2        BASIN 1 - TO SCOGGIN LAKE
CB02     B00S   0.516 12 6  30 2 200    60 42OR           32OR
CB03     B00S     220C  1000206
CB04     B00S     3PTN11005DETI100
CB01     B00C         2        BASIN 1 - TO COON POND
CB02     B00C   0.206 12 6  30 2 200    60 42OR           32OR
CB03     B00C     220C  1000206
CB04     B00C     3PTN11005DETI100
CC01     FLOI       3  122     INDIAN: SEEPAGE TO FLORIDAN
CC02     FLOI       INDI       V086 330I
CC01     FLOS       3  122     SCOGGIN: SEEPAGE TO FLORIDAN
CC02     FLOS       SCOG       V086 330S
CC01     FLOC       3  122     COON: SEEPAGE TO FLORIDAN
CC02     FLOC       COON       V086 330C

 ** SEEPAGE TO FLORIDAN AQUIFER [INDIAN LAKE] ** kappa =  .03
 **                   FLOR    LAKE    SEEP    LAKE    SEEP    LAKE    SEEP
CF02     330I        -2000   -5333       1   -2000       0    1333      -1
CF02     330I        -2000    4666      -2    8000      -3   11333      -4
CF02     330I        -1000   -4333       1   -1000       0    2333      -1
CF02     330I        -1000    5666      -2    9000      -3   12333      -4
CF02     330I            0   -3333       1       0       0    3333      -1
CF02     330I            0    6666      -2   10000      -3   13333      -4
CF02     330I         1000   -2333       1    1000       0    4333      -1
CF02     330I         1000    7666      -2   11000      -3   14333      -4
CF02     330I         2000   -1333       1    2000       0    5333      -1
CF02     330I         2000    8666      -2   12000      -3   15333      -4
CF02     330I         3000    -333       1    3000       0    6333      -1
CF02     330I         3000    9666      -2   13000      -3   16333      -4
CF02     330I         4000   -2666       2     666       1    4000       0
CF02     330I         4000    7333      -1   10666      -2   14000      -3
CF02     330I         5000   -1666       2    1666       1    5000       0
CF02     330I         5000    8333      -1   11666      -2   15000      -3
CF02     330I         6000    -666       2    2666       1    6000       0
CF02     330I         6000    9333      -1   12666      -2   16000      -3
CF02     330I         7000   -3000       3     333       2    3666       1
CF02     330I         7000    7000       0   10333      -1   13666      -2
 ** SEEPAGE TO FLORIDAN AQUIFER [SCOGGIN LAKE] ** kappa =  .040
 **                   FLOR    LAKE    SEEP    LAKE    SEEP    LAKE    SEEP
CF02     330S        -2150   -4500       1   -2000       0     500      -1
CF02     330S        -2150    3000      -2    5500      -3    8000      -4
CF02     330S        -1150   -3500       1   -1000       0    1500      -1
CF02     330S        -1150    4000      -2    6500      -3    9000      -4
CF02     330S         -150   -2500       1       0       0    2500      -1
CF02     330S         -150    5000      -2    7500      -3   10000      -4
CF02     330S          850   -1500       1    1000       0    3500      -1
CF02     330S          850    6000      -2    8500      -3   11000      -4
CF02     330S         1850    -500       1    2000       0    4500      -1
CF02     330S         1850    7000      -2    9500      -3   12000      -4
CF02     330S         2850   -2000       2     499       1    3000       0
CF02     330S         2850    5500      -1    8000      -2   10500      -3
CF02     330S         3850   -1000       2    1499       1    4000       0
```

```
CF02     330S          4850       0       2    2500       1    5000       0
CF02     330S          4850    7500      -1   10000      -2   12500      -3
CF02     330S          5850   -1500       3     999       2    3500       1
CF02     330S          5850    6000       0    8500      -1   11000      -2
CF02     330S          6850    -500       3    1999       2    4500       1
CF02     330S          6850    7000       0    9500      -1   12000      -2
 ** SEEPAGE TO FLORIDAN AQUIFER [COON POND] ** kappa =  .017
 **                    FLOR    LAKE    SEEP    LAKE    SEEP    LAKE    SEEP
CF02     330C         -2000   -7882       1   -2000       0    3882      -1
CF02     330C         -1000   -6882       1   -1000       0    4882      -1
CF02     330C             0   -5882       1       0       0    5882      -1
CF02     330C          1000   -4882       1    1000       0    6882      -1
CF02     330C          2000   -3882       1    2000       0    7882      -1
CF02     330C          3000   -2882       1    3000       0    8882      -1
CF02     330C          4000   -1882       1    4000       0    9882      -1
CF02     330C          5000    -882       1    5000       0   10882      -1
CF02     330C          6000   -5764       2     117       1    6000       0
CF02     330C          7000   -4764       2    1117       1    7000       0

 ** BASIN CONFIGURATION
N    INDIAN
P008     EVAP
P008     RAIN
P008     V086
P019     ILGG
P019     SLGG
P019     CPGG
P001     IEVA      INDI
P001     IRAI      INDI
P013     B00I      INDI
P013     FLOI      INDI
P018     INDI      C001
P019     C001
P001     SEVA      SCOG
P001     SRAI      SCOG
P013     B00S      SCOG
P013     FLOS      SCOG
P018     SCOG      C001
P019     C001
P001     CEVA      COON
P001     CRAI      COON
P013     B00C      COON
P013     FLOC      COON
P018     COON      C001
P019     C001
```

APPENDIX C—PEER REVIEW DOCUMENTS

Contained in this appendix is the peer review document pertaining to this report.

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MODEL DOCUMENTATION REVIEW

Document:	**DRAFT** *Indian Lake System Minimum Flows and Levels Hydrologic Methods Report* by C. Price Robison, P.E., SJRWMD, 2007
Project:	Blue Spring Minimum Flow Regime (MFR) Peer Review
For:	St. Johns River Water Management District (SJRWMD)
Reviewer:	Gregory W. Council, GeoTrans
Review Date:	September 28, 2007

Price Robison of SJRWMD developed a hydrologic model of the Indian Lake System, which consists of three lakes: Indian Lake, Scoggin Lake, and Coon Pond. These lakes are all part of the Minimum Flows and Levels (MFLs) program. The subject document describes a model calibration analysis and modeling assessments regarding (1) whether the lakes are currently meeting MFLs and (2) what amount of Floridan Aquifer groundwater drawdown would cause the lakes to not meet MFLs. This information is used to assess the potential need for alternative water supply in Volusia County in the report *Implementation Strategy for Achieving the Minimum Flow Regime for Blue Spring and Other Water Resource Constraints in Volusia County, Florida* by Stan Williams, Price Robison, P.E., Sonny Hall, Ph.D., Patrick Burger, P.E., Doug Munch, P.G., and Barbara Vergara, P.G., SJRWMD, 2007.

This review pertains specifically to the subject lake model documentation, a separate review is provided regarding the overall methodology used to estimate alternative water supply needs in order to meet lake MFLs.

Main Comments

Comment 1: The modeling methodology used here is in keeping with best modeling practices. The time step length of 1 day is appropriate and the SSARR simulator is appropriate.

Comment 2: Overall, the calibration quality is very good.

Comment 3: Important details of model input are left out of the documentation. For instance, details of the outlet rating equations are not provided. All model input should be presented.

Comment 4: No calibration sensitivity or predictive sensitivity analysis is conducted. There is, therefore, no indication of the uncertainty in model results or conclusions. One may infer from the calibration criteria and results that predictions are accurate to within approximately 0.5 to 1.0 ft. A calibration sensitivity analysis and a predictive sensitivity analysis should be conducted.

Comment 5: It is concluded that Indian Lake is not meeting its MFLs under 2005 conditions. I agree that it is likely not meeting its MFLs, but I think adding "likely" would be appropriate given potential uncertainty in the results.

Comment 6: It is concluded that Lake Scoggin and Coon Pond are meeting their MFLs under 2005 conditions. I agree with these conclusions.

Comment 7: It is concluded that a Floridan drawdown of 2.5 ft or more will result in not meeting MFLs for Scoggin Lake. This is an uncertain result and should be qualified, especially in light of the subjective best-fit line drawn in Figure 35 (but not drawn in other figures such as Figure 33). One could question whether it is appropriate to draw a subjective best-fit curve through modeling results on a stage-exceedance graph

Comment 8: It is concluded that a Floridan drawdown of 1.9 ft or more will result in not meeting MFLs for Lake Colby. This is an uncertain “best-estimate” result and should be qualified.

Comment 9: The legend of Figure 23 indicates that the (adjusted) Floridan Aquifer hydrograph was shifted up by 1.5 ft for assessment of Scoggin Lake MFLs under current (2005) pumping conditions. This adjustment was not made for Indian Lake or Coon Pond and was not addressed in the text. This adjustment was also not made for calibration simulations at Scoggin Lake. Such an adjustment does not appear to be justified. An explanation should be provided.

Comment 10: The model data sets were not reviewed in detail for potential discrepancies between reported input/results and actual input/results.

Comment 11: I recommend not abbreviating minimum frequent low (MFL) because of potential confusion with minimum flows and levels (MFLs).

Comment 12: Typographical errors are not identified in this review.

Specific Comments by Report Section

Introduction

Comment 13: Direct withdrawals from lakes are mentioned here (and elsewhere). The document should indicate if there are any such withdrawals and if they are modeled. If so, details should be provided.

Introduction: Purpose and Scope

Comment 14: This section should indicate that one purpose of the modeling is to identify the amount of Floridan Aquifer drawdown that would cause one or more lakes not to meet MFLs.

Comment 15: The concept of “2005 conditions” needs to be explained. I believe this has to do with a hypothetical case where long-term transient groundwater levels are set to approximate expected levels with 2005 pumping.

Comment 16: The measured lake stages are calibration targets, not calibration parameters.

Comment 17: A table of the MFLs would be helpful.

Hydrologic Model of the Indian Lake System (SSARR): Model Selection

Comment 18: More discussion is warranted (perhaps in an Appendix or separate document) about the adaptation of the “backwater mode” of SSARR to simulate lake-to-aquifer flow.

Comment 19: Provide justification for the claim that 7 ft variation in stage indicates seepage is an important component of the water budget.

Hydrologic Model of the Indian Lake System (SSARR): Calibration Criteria

Comment 20: Provide justification for selecting a ±0.5 ft calibration criterion.

Hydrologic Model of the Indian Lake System (SSARR): Model Description: Job Control Parameters

Comment 21: Explain use of many 1-year simulations run back-to-back rather one longer calibration simulation. Identify the calibration period here or earlier.

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Hydrologic Model of the Indian Lake System (SSARR): Model Description: Constant Characteristics: Soil Moisture/Runoff

Comment 22: The only outflow from stored soil moisture in the model is ET. Conceptually, there would also be infiltration to the (unmodeled) groundwater. Some discussion of the implication of this conceptual inaccuracy is warranted.

Hydrologic Model of the Indian Lake System (SSARR): Model Description: Initial Conditions Data

Comment 23: This section should provide initial conditions for the first year of the simulation.

Hydrologic Model of the Indian Lake System (SSARR): Model Description: Time Series Data: Rainfall

Comment 24: The OneRain data should be generally described; the pixel used should be mapped.

Hydrologic Model of the Indian Lake System (SSARR): Model Description: Time Series Data: Pan Evaporation

Comment 25: Provide justification for the assumed 100% ratio for PET/pan evaporation. Also, later (p. 20) this ratio is identified as a calibration parameter; the discussion here makes it sound like a fixed (non-adjustable) value. Please clarify.

Hydrologic Model of the Indian Lake System (SSARR): Model Description: Time Series Data: Seepage flow between a lake and the Floridan aquifer

Comment 26: This subsection seems out of place within the section on time series

Comment 27: $\hat{K}$ is commonly called hydraulic conductance.

Comment 28: The assumption that area is constant should be justified. One might instead assume that conductance is proportional to the area of the lake, which varies in time. If the conceptual model is that there is a relatively high-conductance sinkhole of constant area in the Intermediate Confining Unit that is the main resistance layer, then that conceptual model should be presented.

Comment 29: There is no need to discuss alternatives (which are not used) to the Darcy Law formulation for flow between lakes and groundwater.

Comment 30: Text states that assumptions regarding hydrographs "will be examined in more detail later in this chapter." No such examination was found.

Comment 31: The discussion about the Floridan Aquifer tending toward equilibrium is confusing and probably unnecessary. The idea of shifting the hydrograph up and down should be presented in a way that doesn't discuss equilibrium. The last paragraph in this section is probably all that is needed.

Hydrologic Model of the Indian Lake System (SSARR): Calibration of the Indian Lake System SSARR Model

Comment 32: There is no mention of adjustments made to hydraulic conductance. Details of all initial assumptions and changes made should be provided.

Comment 33: The adjusted "SSARR factors…" are not specified. This term is very vague.

Comment 34: A table of calibration (adjustable) parameters should be provided, along with initially assumed values and final calibrated values.

Comment 35: Calibration statistics should be provided for each lake: mean error, maximum positive/negative residuals, mean absolute error, and root-mean-square error.

Hydrologic Model of the Indian Lake System (SSARR): Tables & Figures

Comment 36: Table 1. The first note identifies the abbreviation DIST, which is not used in the table.

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Comment 37: Table 2. The first note identifies the abbreviation NA, which is not used in the table. The title of the second column is USGS Number, but all of the gages listed appear to be District gages; it is not clear if the IDs are USGS IDs or District IDs.

Comment 38: Table 3. Caption identifies the NOAA pan evaporation sites as "in the SJRWMD;" the text states that the locations are "in *or near* the SJRWMD." Identify how far (and in what direction) the pan evaporation sites are from the study area.

Comment 39: Table 4: Table not needed. The pan coefficient of 0.81 is actually not used; Table 5 provides monthly coefficients that average slightly greater than 0.81 (the referencing text should also be clarified and the 0.81 coefficient reference removed in favor of the monthly rates only).

Comment 40: Table 5: Implies that the same lake evaporation and PET are being used for each year. A discussion of this assumption and its reasonableness is needed.

Comment 41: Figure 2: Should be identified either as an initial assumption or calibrated result. Some discussion of the slight slope change in the runoff/SMI curve is also warranted.

Comment 42: Figure 4: Recommend avoiding variable names in this figure in favor of short, descriptive text (e.g., "Coon: Floridan Aquifer Sink/Source")

Comment 43: Figure 5: There appears to be a discontinuity in the stage-area relationship for Indian Lake at stage = 37 ft. It also appears that the lake area decreases slightly here relative to the area at slightly lower stages. This should be corrected.

Comment 44: Figure 8: "k" here is hydraulic conductance, called $\hat{K}$ in text. This figure is not necessary because the relationship is simple. Figure implies that $\hat{K}$ is the same for all lakes, even though they have different areas. This needs to be justified. Was this value used in calibration?

Assessment of Existing Hydrologic Conditions for the Indian Lake System in the Context of MFLs: Introduction

Comment 45: This section should clearly state that these are 30-year *predictive* simulations for the case where transient aquifer heads are reflective of current (2005) pumping conditions and future rainfall is equal to the historical rainfall in 1976-2005.

Assessment of Existing Hydrologic Conditions for the Indian Lake System in the Context of MFLs: Composition of Long-Term Simulations for the Indian Lake System

Comment 46: This double-mass analysis appears to contradict one of the results in *Implementation Strategy for Achieving the Minimum Flow Regime for Blue Spring and Other Water Resource Constraints in Volusia County, Florida* by Stan Williams, Price Robison, P.E., Sonny Hall, Ph.D., Patrick Burger, P.E., Doug Munch, P.G., and Barbara Vergara, P.G., SJRWDMD, 2007. That *Implementation* document suggests that increasing withdrawals since 1995 are causing water levels to decline in the Floridan Aquifer at these lakes. But the double-mass analysis seems to indicate that no drawdown due to pumping has occurred since 1991, when the Rima Ridge Well Field came on line. This inconsistency should be addressed here or in the *Implementation* report.

Comment 47: Suggest using "adjusted" rather than "corrected" when referring to the change in the V-0086 hydrograph. I would add text such as this: The adjusted hydrograph represents the approximate head that would have been measured at V-0086 if the Rima Ridge Well Field had been pumping at post-1991 rates throughout the period of record. Show the location of the Rima Ridge Well Field on a map. I would not mention a "new equilibrium" here.

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Assessment of Existing Hydrologic Conditions for the Indian Lake System in the Context of MFLs: Assessment of Existing Hydrologic Conditions for the Indian Lake System in the Context of MFLs

Comment 48: Section and subsection have same title.

Comment 49: The concepts behind the probability-exceedance definitions of the MFLs are difficult to comprehend in the text and in Appendix A. Perhaps descriptions of the mathematical steps taken in each case are warranted (in Appendix).

Comment 50: Suggested definition: The minimum frequent high stage should be flooded for 30 or more consecutive days during the year for 33% or more of the years.

Comment 51: Suggested definition: The minimum frequent low stage should not be dry for 120 consecutive days in more than 20% of the years.

Comment 52: Suggested definition: The lowest 180-day rolling average stage in each year should be equal to or greater than the minimum average stage for 67% or more of the years.

Assessment of Existing Hydrologic Conditions for the Indian Lake System in the Context of MFLs: Tables & Figures

Comment 53: Table 6: How similar are the two precipitation data sets in the period of overlap?

Comment 54: Figure 18: It appears that there are approximately 20 years of stage data available for Indian Lake. It would be useful to plot stage-duration and frequency-exceedance graphs using the actual stage data and compare to the MFLs. Arguably, 20 years of real data are better than 30 years of simulation results for statistical analysis.

Comment 55: Figures 19, 24, 29, 39, and 40: The rule-of-thumb stage-duration ranges presented in these figures should be discussed in the text.

Comment 56: Figures 25, 30, 33 and 36: The rectangles are drawn incorrectly. Based on the text, the minimum recurrence interval is 3 years. Therefore the rectangle should have its right edge at probability = 0.33 rather than 0.5 (it is correct in Figure 20).

Assessment [sic] Hypothetical Water Resource Development in the Indian Lake Area in the Context of MFLs: Introduction

Comment 57: It appears that multiple scenarios were run, at increasing drawdown levels, and that the 2.5 and 1.9 ft drawdown scenarios resulted in not meeting MFLs at Scoggin Lake and Coon Pond, respectively. The introductory text should be more explicit about the fact that many scenarios were run, and that the presented results are for the critical drawdown scenarios.

Results and Discussion

Comment 58: This section is one of several that present model results and discussion. Suggest changing section title.

Results and Discussion: Indian Lake System Water Budgets

Comment 59: The second to last sentence in this section does not agree with Figure 42: the word "partially" should be removed and 160 should be changed to 120. The last sentence should be stricken.

Comment 60: Figures 42 and 43: Direct rainfall (and evaporation) decreased in the drawdown scenarios, presumably because the lake area decreased. However, this should have resulted in slightly more runoff due to increased drainage basin size. The relevant assumptions and implications should be discussed.

APPENDIX D—PEER REVIEW RESOLUTION DOCUMENT

Contained in this appendix is the peer review resolution document pertaining to this report.

Indian Lake System Minimum Flows and Levels Hydrologic Methods Report

Peer Review: Gregory W. Council, GeoTrans

Peer Review Resolution by C. Price Robison, P.E., SJRWMD

September 28, 2007

Peer Review Comments	Resolution
Comment 3: Important details of model input are left out of the documentation. For instance, details of the outlet rating equations are not provided. All model input should be presented.	A section on outlet rating curves was added (see the “Constant Characteristics” section and Figure 6a).
Comment 4: No calibration sensitivity or predictive sensitivity analysis is conducted. There is, therefore, no indication of the uncertainty in model results or conclusions. One may infer from the calibration criteria and results that predictions are accurate to within approximately 0.5 to 1.0 ft. A calibration sensitivity analysis and a predictive sensitivity analysis should be conducted.	An extensive sensitivity analysis section has been added. I disagree with the interpretation that predictions of the model are accurate to within 0.5 to 1.0 ft. I think that is the correct interpretation for predicting specific events, but for MFLs we are not concerned with predicting specific events (as you might for a flooding simulation, for example). Rather we are concerned with predicting the overall hydrology of a system. The model is going to predict high for some events and low for others and much of the error will even out. I believe that more significant are the uncertainties introduced with such things as how representative historical rainfall is of long-term conditions and climate change.
Comment 5: It is concluded that Indian Lake is not meeting its MFLs under 2005 conditions. I agree that it is likely not meeting its MFLs, but I think adding “likely” would be appropriate given potential uncertainty in the results.	I believe that the fact that these results are “likely” is understood, and it does not need to be stated. The only way we will know with more certainty is after years of monitoring and, likely, adaptive management.
Comment 7: It is concluded that a Floridan drawdown of 2.5 ft or more will result in not meeting MFLs for Scoggin Lake. This is an uncertain result and should be qualified, especially in light of the subjective best-fit line drawn in Figure 35 (but not drawn in other figures such as Figure 33). One could question whether it is appropriate to draw a subjective best-fit curve through modeling results on a stage-exceedence graph.	See response to Comment 5. I strongly disagree with the notion that we should not be drawing best-fit lines through modeled data. As data is added to the model in coming years, there will be less of a need to draw best-fit lines. Best-fit lines are not needed in every case.
Comment 8: It is concluded that a Floridan drawdown of 1.9 ft or more will result in not meeting MFLs for Lake Colby [*sic*]. This is an uncertain “best-estimate” result and should be qualified.	See response to Comment 5.

Peer Review Comments	Resolution
Comment 9: The legend of Figure 23 indicates that the adjusted Floridan aquifer hydrograph was shifted up by 1.5 ft for the assessment of Scoggin Lake MFLs under current (2005) pumping conditions. This adjustment was not made for Indian Lake or Coon Pond and was not addressed in the text. This adjustment was also not made for calibration simulations at Scoggin Lake. Such an adjustment does not appear to be justified. An explanation should be provided.	The shift was used for both calibration and long-term simulations for Scoggin Lake and was based on groundwater model results. However, I now believe it is appropriate for all three lakes to have no shift. The Scoggin Lake model has been recalibrated without the shift. Shifts in the well (both upward and downward) are now part of the sensitivity analysis that has been added to the report.
Comment 11: I recommend not abbreviating minimum frequent low (MFL) because of potential confusion with minimum flows and levels (MFLs).	I appreciate the suggestion, but this convention has been used for years.
Comment 13: Direct withdrawals from lakes are mentioned here (and elsewhere). The document should indicate if there are any such withdrawals and if they are modeled. If so, details should be provided.	There are no surface water withdrawals from the lakes. The mention of them was deleted.
Comment 14: This section should indicate that one purpose of the modeling is to identify the amount of Floridan aquifer drawdown that would cause one or more lakes not to meet MFLs.	A statement to that effect has been added to the report. In addition, since the report was peer reviewed, the District has re-evaluated MFLs for Indian Lake and recommended new ones. This is also reflected in the report.
Comment 15: The concept of “2005 conditions” needs to be explained. I believe this has to do with a hypothetical case where long-term transient groundwater levels are set to approximate expected levels with 2005 pumping.	An explanation of “2005 conditions” has been added in both the “Purpose and Scope” section as well as the MFLs section.
Comment 16: The measured lake stages are calibration targets, not calibration parameters.	The change was made.
Comment 17: A table of the MFLs would be helpful.	A summary table of MFLs was added (see Table 7).
Comment 18: More discussion is warranted (perhaps in an Appendix or separate document) about the adaptation of the backwater mode of SSARR to simulate lake-to-aquifer flow.	I do not see that this is warranted.
Comment 19: Provide justification for the claim that 7 ft variation in stage indicates seepage is an important component of the water budget.	Based on experience with previous lake models and the fact that these lakes have outlets (i.e., are not isolated lakes) I believe it is warranted to make this statement. Regardless, I have removed the statement.
Comment 20: Provide justification for selecting a ±0.5 ft calibration criterion.	Calibration criteria are now much more comprehensive than they were in the original report; the report has been updated accordingly

Peer Review Comments	Resolution
Comment 21: Explain use of many 1-year simulations run back-to-back rather than one longer calibration simulation. Identify the calibration period here or earlier.	The model run was broken up purely for reasons of personal preference. Of course, it does not affect final results. A couple of reasons I prefer it is that one deals with smaller files and it fits with the concept of analyzing output for annual probability of events. I think the calibration period is properly introduced in the “Calibration of the Indian Lake System SSARR Model” section.
Comment 22: The only outflow from stored soil moisture in the model is ET. Conceptually, there would also be infiltration to the (unmodeled) groundwater. Some discussion of the implication of this conceptual inaccuracy is warranted.	In SSARR, ET constitutes kind of a catchall for such things as interception losses and direct evaporation from groundwater. Infiltration to groundwater was added to that list.
Comment 23: This section should provide initial conditions for the first year of simulation.	I appreciate the suggestion, but I do not feel it adds anything to the understanding of the model.
Comment 24: The OneRain data should be generally described; the pixel used should be mapped.	A general description of the radar rainfall has been added to the text. The pertinent pixel has been added to Figure 7.
Comment 25: Provide justification for the assumed 100% ratio for PET/pan evaporation. Also, later (p. 20) this ratio is identified as a calibration parameter; the discussion here makes it sound like a fixed (non-adjustable) value. Please clarify.	The correct ratio is 75% (Ponce 1989; Linsley et al. 1982). The number has been corrected in the text. The potential ET is not calibrated. The actual evapotranspiration is what is calibrated (see Figure 2).
Comment 26: This subsection seems out of place within the section on time series.	I agree. This subsection is now parallel to the time series section, under “Model Description.”
Comment 27: $\hat{K}$ is commonly called hydraulic conductance	I added the term to the narrative
Comment 28: The assumption that area is constant should be justified. One might instead assume that conductance is proportional to the area of the lake, which varies in time. If the conceptual model is that there is a relatively high-conductance sinkhole of constant area in the Intermediate Confining Unit that is the main resistance layer, then that conceptual model should be presented.	An item pertaining to the concept of discreet sinkhole features was added to the report. Included is a reference to seismic profiling done by SJRWMD at numerous district lakes, including Indian Lake.
Comment 29: There is no need to discuss alternatives (which are not used) to the Darcy Law formulation for flow between lakes and groundwater.	The reference to alternatives has been removed.
Comment 30: Text states that assumptions regarding hydrographs “will be examined in more detail later in this chapter.” No such examination was found.	The statement was removed.

Peer Review Comments	Resolution
Comment 31: The discussion about the Floridan aquifer tending toward equilibrium is confusing and probably unnecessary. The idea of shifting the hydrograph up and down should be presented in a way that doesn't discuss equilibrium. The last paragraph in this section is probably all that is needed.	I disagree. I find the concept of equilibrium to be useful in thinking of the assumption that one can shift a well hydrograph by a set amount to represent some future condition with average withdrawals that do not vary. I have added the term "long-term" to equilibrium to, I hope, clarify the concept a little.
Comment 32: There is no mention of adjustments made to hydraulic conductance. Details of all initial assumptions and changes made should be provided.	Hydraulic conductance was added to the list of adjustable parameters. I do not think that adding the step-by-step changes in a parameter really adds much to the report. The important value is the final value.
Comment 33: The adjusted "SSARR factors…" are not specified. This term is very vague.	"Factors" was changed to "routing constants."
Comment 34: A table of calibration (adjustable) parameters should be provided, along with initially assumed values and final calibrated values.	I appreciate the suggestion, but I do not think it will be particularly useful to have this table. A printout of the model is provided in Appendix B. If someone is interested in the values, they can look them up there.
Comment 35: Calibration statistics should be provided for each lake: mean error, maximum positive/negative residuals, mean absolute error, and root-mean-square error.	Calibration statistics have been added.
Comment 36: Table 1. The first note identifies the abbreviation DIST, which is not used in the table.	Item deleted.
Comment 37: Table 2. The first note identifies the abbreviation NA, which is not used in the table. The title of the second column is USGS Number, but all of the gages listed appear to be District gages; it is not clear if the IDs are USGS IDs or District IDs.	Items corrected.
Comment 38: Table 3. Caption identifies the NOAA pan evaporation sites as "in the SJRWMD;" the text states that the locations are "in *or near t*he SJRWMD." Identify how far (and in what direction) the pan evaporation sites are from the study area.	The word "near" refers to the Lake Alfred site that lies just outside the SJRWMD in Polk County. I have added counties in the text to better locate the sites.
Comment 39: Table 4: Table not needed. The pan coefficient is actually not used; Table 5 provides monthly coefficients that average slightly greater than 0.81 (the referencing text should also be clarified and the 0.81 coefficient reference removed in favor of the monthly rates only).	The 0.81 coefficient *is* used.

Peer Review Comments	Resolution
Comment 40: Table 5: Implies that the same lake evaporation and PET are being used for each year. A discussion of this assumption and its reasonableness is needed.	The same evaporation is *not* used every year. Published monthly pan evaporation was used. For lake evaporation, monthly evaporation amounts are multiplied by the monthly coefficients (see Table 5) to obtain monthly evaporation amounts. For potential ET, a coefficient of 0.75 (Ponce 1989 and Linsley et al. 1982) was used.
Comment 41: Figure 2: Should be identified either as an initial assumption or calibrated result. Some discussion of the slight slope change in the runoff/SMI curve is also warranted.	A sentence was added to the caption identifying the curves as calibration results. The correct curves are now in the report, and they do not have the “slight slope change” referred to in the comment.
Comment 42: Figure 4: Recommend avoiding variable names in this figure in favor of short, descriptive text (e.g., “Coon: Floridan Aquifer Sink/Source”).	I appreciate the suggestion, but I prefer the way it is. The legend has enough information to identify items in the chart.
Comment 43: Figure 5: There appears to be a discontinuity in the stage-area relationship for Indian Lake at stage = 37 ft. It also appears that the lake area decreases slightly here relative to the area at slightly lower stages. This should be corrected.	As noted in the legend for Figure 5, The data comes from two different sources. The value at slightly less than 37 ft obtained from bathymetry is more precise than what was obtained from the USGS quad map; so the value from the bathymetry was used for that stage.
Comment 44: Figure 8. “k” here is hydraulic conductance, called $\hat{K}$ in text. This figure is not necessary because the relationship is simple. Figure implies that $\hat{K}$ is the same for all lakes, even though they have different areas. This needs to be justified. Was this value used in calibration?	I disagree that the figure is not necessary. I think a relatively casual reader might find it useful to help visualize the process that goes on in the model. A note has been added to the caption to identify the figure as corresponding to Indian Lake. Each lake has a different $\hat{K}$. This implies an assumption that the sinkhole features in these lakes are discreet features much smaller than the area of the lake. I believe this to be a good assumption based on results from a seismic profiles at a number of SJRWMD lakes.
Comment 45: This section could clearly state that these are 30-year predictive simulations for the case where transient aquifer heads are reflective of current (2005) pumping conditions and future rainfall is equal to the historical rainfall in 1976-2005.	The report states that one assumption is that the rainfall in the model is statistically similar to 1976–2005 rainfall. I think this is more appropriate than assuming that they are equal. A statement has been added stating the assumption that average groundwater withdrawals at 2005 levels would occur indefinitely for the 2005 conditions

Peer Review Comments	Resolution
Comment 46: This double-mass analysis appears to contradict one of the results in *Implementation Strategy for Achieving the Minimum Flow Regime for Blue Spring and Other Water Resource Constraints in Volusia County, Florida* by Stan Williams, Price Robison, P.E., Sonny Hall, Ph.D., Patrick Burger, P.E., Doug Much, P.G., and Barbara Vergara, P.G., SJRWMD, 2007. That *Implementation* document suggests that increasing withdrawals since 1995 are causing water levels to decline in the Floridan Aquifer at these lakes. But the double-mass analysis seems to indicate that no drawdown due to pumping has occurred since 1991, when the Rima Ridge Well Field came on line. This inconsistency should be addressed here or in the *Implementation* report.	As I recall, those groundwater model runs were made with either permitted amounts or projected amounts. Thus the difference.
Comment 47: Suggest using “adjusted” rather than “corrected” when referring to the change in the V-0086 hydrograph. I would add text such as this: The adjusted hydrograph represents the approximate head that would have measured at V-0086 if the Rim a Ridge Well Field had been pumping at post-1991 rates throughout the period of record. Show the location of the Rima Ridge Well Field on a map. I would not mention a “new equilibrium” here.	“Corrected” has been changed to “adjusted” throughout the text. The suggested text has been added to the report. The well field has been added to Figure 7.
Comment 49: The concepts behind the probability-exceedence definitions of the MFLs are difficult to comprehend in the text and in Appendix A. Perhaps descriptions of the mathematical steps taken in each case are warranted (in Appendix).	The definitions have been clarified (see next three comments). In my opinion, the mathematical steps *are* described in Appendix A.
Comment 50: Suggested definition: The <u>minimum frequent high</u> stage should be flooded for 30 or more consecutive days during the year for 33% or more of the years.	The definition has been clarified partly based on this suggestion.
Comment 51: Suggested definition: The <u>minimum frequent low</u> stage should not be dry for 120 consecutive days in more than 20% of the years.	The definition has been clarified partly based on this suggestion.
Comment 50: Suggested definition: The lowest 180-day rolling average stage in each year should be equal to or greater than the <u>minimum average</u> stage for 67% of the years.	The definition has been clarified partly based on this suggestion.
Comment 53: Table 6: How similar are the two precipitation data sets in the period of overlap?	They are exactly the same.

Peer Review Comments	Resolution
Comment 54: Figure 18. It appears that there are approximately 20 years of stage data available for Indian Lake. It would be useful to plot stage duration and frequency exceedence graphs using the actual stage data and compare to the MFLs. Arguably, 20 years of real data are better than 30 years of simulation results for statistical analysis.	The District gauge was installed in 1999. Much of the earlier data was estimated, so I am not comfortable using the early data in a frequency analysis.
Comment 55: Figures 19, 24, 29, 39, and 40: The rule-of-thumb stage-duration ranges presented in these figures should be discussed in the text.	We no longer use the concept, so they have been removed.
Comment 56: Figures 25, 30, 33 and 40: The rectangles are drawn incorrectly. Based on the text, the minimum recurrence interval is 3 years. Therefore the rectangle should have its right edge at probability = 0.33 rather than 0.5 (it is correct in Figure 20).	The return periods have been corrected to 3 years for all three lakes.
Comment 57: It appears that multiple scenarios were run, at increasing drawdown levels, and that the 2.5 and 1.9 ft drawdown scenarios resulted in not meeting MFLs at Scoggin Lake and Coon Pond, respectively. The introductory text should be more explicit about the fact that many scenarios were run, and that the presented results are for the critical drawdown scenarios.	The introduction to the chapter was changed to reflect the comment.
Comment 58: This section is one of several that present model results and discussion. Suggest changing section title.	I appreciate the suggestion. I have added another section discussing other studies in the area as well as one discussing sensitivity analysis results, so perhaps the title is a little more appropriate.
Comment 59: The second to last sentence does not agree with Figure 42: the word "partially" should be removed and 160 should be changed to 120. The last sentence should be stricken.	The corrections were made.
Comment 60: Figures 42 and 43: Direct rainfall (and evaporation) decreased in the drawdown scenarios, presumably because the lake area decreased. However, this should have resulted in slightly more runoff due to increased drainage basin size. The relevant assumptions and implications should be discussed.	Inclusion of a variable drainage area for Indian Lake was one scenario added to the sensitivity analysis. Although the calibration was improved (see Figure 69 and Table 7), the hydraulic conductance did not change nor did it increase the resultant Floridan aquifer decline freeboard.
Comment 61: Figure 42: The "outflow" (to Middle Haw Creek) component is very important for Scoggin Lake; further discussion and evaluation of this flow is warranted.	A discussion of this outflow has been added to the "Water Budget" section as part of a comparison of water budgets for Indian Lake and Scoggin Lake.
Comment 62: Figure 43: At least two significant digits should be shown in the table (and used for the graph).	To provide for better comparison of scenarios, all values in the water budget tables have been rounded off to the nearest unit.

Peer Review Comments	Resolution
Comment 63: Figures 41, 42, and 43: I recommend not using perspective 3D view for the column graphs of the water budget figures. Side-by-side bars would be appropriate for cases where two simulations are presented.	This is a personal preference. If one is interested in the comparison of one item, then one can read the table at the bottom of each figure.
Comment 64: Not referenced in text: Chow, 1959; Henderson, 1966; USACE, 1997 (HEC-RAS); USGS, 1997. Bedient and Huber, 1988 referenced in Appendix A but full citation not found.	All these references have been removed.
Comment 65: Equations A1 through A3 should be deleted, along with the sentence before (“Based on this …”), the text between the equations, and the opening phrase after A3. This presentation doesn’t make sense because these estimated probabilities indicate that there is a 10% chance of being greater than the highest measurement (A1) but a 0% chance of being lower than the lowest measurement (A3). It is recommended to start with the concept in the second part of the sentence after A3: “The usual convention is to divide …”	I disagree with this recommendation. That it does not make sense is exactly the point being made and the reason for introducing the division of the range into 11 portions.
Comment 66: It should be noted that the P in Equation A8 represents the probability of some event occurring in a year.	This was clarified just before Equation A1.
Comment 67: It is not clear here if there is a problem when a MFLs-designated stage/flow is exceeded more frequently than the target return period range. If not, only one end of the target return period needs to be presented.	It is certainly possible for a system to become too wet. However, as the name implies, MFLs deal with the possibility of causing the system to become too dry. This is made clear in the way we now depict the MFLs (see, for example, Figures 25 through 27).