# 4 MODEL CALIBRATION AND VALIDATION

The model calibration and validation phase is typically the most demanding and time-consuming phase in a modeling study. During the model calibration phase the model is tuned to match field data with a certain precision expressed in terms of calibration targets.

The Lake Toho model was calibrated and validated against measured groundwater tables and against surface water runoff and stage data. The calibration period covers a 3-year period from 1998 through 2000 and the validation period covered 1995-1997. The data density is highest for the last period (2000) as many of the wells were established in connection with the Alligator Lake drawdown study (1997 and onwards) and the Lake Toho drawdown study (2000 and onwards). There are, however, a few SFWMD and USGS wells with longer data records. The amount of data available for the model validation period is less than the amount of data available for the calibration period.

## 4.1 Calibration and Validation Approach

One of the basic assumptions of the Lake Toho model is that the model area does not exchange groundwater flows with the surrounding area. Since the model area is defined based on surface topographic watersheds, it also does not exchange significant overland flow volumes with the surrounding area. Hence, the model area is, at least from a modeling perspective, a well-defined hydrologic unit. The *sources* are:

- rainfall
- irrigation
- discharge from the Upper Floridan aquifer

Rainfall is the driving force and the only significant water source. Irrigation may locally play a role for the groundwater dynamics but for the overall water balance irrigation is insignificant. Irrigation water is predominantly pumped from the Upper Floridan aquifer and can therefore be considered as water import.

Discharge from the Upper Floridan aquifer takes place in a zone west of Lake Toho. For the overall water balance these inflows are of the same order of magnitude as irrigation and thus insignificant for the overall water balance.

The *sinks* are:

- evapotranspiration
- recharge of the Upper Floridan aquifer

- runoff at the surface water outlets south of Lake Cypress and at Lake Hatchineha

The actual evapotranspiration is on the order of 40 inches/year on average and is by far the largest water sink.

The net seepage to the Floridan aquifer may be on the order of 1-2 inches/year (Aucott, 1988). This is on the order of 10% of the surface water runoff and cannot be neglected.

Outflows are measured at S-61 and S-63 and together these gauging stations represents the bulk of the water that flows through the Alligator chain and the Lake Hart, East Lake Toho, Lake Toho system and matching the flows represents the calibration of the Lake Toho model water balance.

A model that has the ability to reproduce measured surface water flows, surface water stages and groundwater stages is the strongest possible tool for describing a complex hydrologic system such as the Lake Toho system. Such an integrated approach ensures that both the water balance and the hydraulic gradients in the system are well described.

Calibrating an integrated model is not very much different from calibrating a traditional groundwater model. However, the integrated model obviously puts more emphasis on water balance and surface water. The following overall approach has been used for calibrating the Lake Toho model:

1. The overall water balance was roughly calibrated by adjusting the actual evapotranspiration simulated by the model. The evapotranspiration is highly sensitive to both crop characteristics (LAI and root depth) and to the soil moisture available for evapotranspiration. The latter is primarily a function of field capacity and wilting point of the various soils. If potential ET, soil properties and crop characteristics are realistic the calculated ET is usually realistic as well. A realistic level for the Lake Toho project area will be around 40 inches per year on average.

2. The water balance (runoff volumes) was roughly calibrated by adjusting the contact to the Upper Floridan aquifer using specified leakage coefficients. A realistic level for the recharge to the Floridan is on the order of 0-5 inches/year reported in Planert and Aucott (1985) and Aucott (1988).

3. Hydraulic conductivities of the aquifer were adjusted to obtain a good fit between simulated and observed groundwater levels. Realistic values based on field tests and reported values are on the order of 1-100 ft/day for the horizontal hydraulic conductivity. As the groundwater model is 2-dimensional the vertical hydraulic conductivity is important only below the lakes, where the conductance used to calculate surface water-groundwater interactions are calculated based on the vertical hydraulic conductivity.

4. Hydraulic properties of the unsaturated zone soil-parameters have been adjusted to improve groundwater dynamics. The specific yield of the aquifer is derived from the unsaturated zone model, as it depends on the storage available in the unsaturated zone. A

rough estimate of the specific yield is the difference between saturated moisture content and field capacity.

There are obviously interrelations among the above steps – for instance the depth of the groundwater table may affect ET and vice-versa. Thus the calibration process becomes an iterative process.

During a calibration process, problems will always be encountered with individual wells or with certain geographic area. This study has not been an exception. For the Lake Toho model such local problems have often been attributed to swamps, ponds, canals or ditches that were not properly represented in the model. The surficial aquifer is very much controlled by surface water features and therefore it is important to represent these features in the model. This is, however, not always possible either due to lack of data or due to model scale limitations. Such features were identified during the Lake Toho model calibration. Some were included in the model as the calibration progressed while others have been ignored. Although such features may be locally significant, they typically do not have regional impact. For the Lake Toho model, features that are connected with the lake drawdown have been included to the maximum extent possible. Such features can for instance be canals or ditches that are connected to the lake and where backwater effects from the lake may affect upstream surface water and groundwater stages significantly.

## 4.2 Calibration Targets

The following set of calibration targets was agreed upon in the technical design phase of the project. It should be emphasized that these are not calibration success criteria. As described above some field measurements may be affected by local phenomena that are not described in detail in the mathematical model. This can for instance be a small creek or canal running just next to the well. In such situations poor model performance may be justified and not important for the overall simulation results. Whenever the model fails to meet the calibration targets a hydrologically justified explanation must be provided.

In connection with the first DHI project with SFWMD ("Small Scale Integrated Surface Water and Groundwater Model") a model calibration utility was developed based on existing SFWMD performance measures. The utility calculates statistical criteria for the deviation between observed and simulated time series of potential heads at each observation well:

$R1_j$ :

Percentage of time where the absolute value of ($RES_{i,j}$ - $RES_{std,j}$) is less than 25% of ($H_{obs,max,j}$ - $H_{obs,min,j}$) . The R1 criterion indicates that the difference between residuals and the standard deviation of the residuals is kept within limits relative to the range of the observed values.

$R2_j$ :

Percentage of time where $H_{sim,i,j}$ lies within the range ($H_{obs,i,j}$ - $H_{obs,std,j}$ ; $H_{obs,i,j}$ + $H_{obs,std,j}$) . The R2 criterion indicates that the difference between simulated and observed values is less than the standard deviation of observations.

$R3_j$ :

Percentage of time where $H_{sim,i,j}$ lies within the range ($H_{obs,min,j}$ ; $H_{obs,max,j}$) . R3 indicates that the simulated value is within the maximum and minimum observed values.

$R4_j$ :

Percentage of time where $H_{sim,i,j}$ lies within the range ($H_{obs,i,j}$ – ΔH ; $H_{obs,i,j}$ + ΔH) . The R4 criterion is perhaps the most direct performance measure indicating if the simulated value is within a certain target precision from the observed value.

Symbols are listed below:

$N_{time}$ : number of observed values in a time series ( i = 1,$N_{time}$)

$N_{wells}$ : number of observation wells (j = 1,$N_{wells}$)

$H_{obs,min,j}$, $H_{obs,max,j}$,$H_{obs,std,j}$ : Minimum, maximum and standard deviation of observation time series

$RES_{i,j}$ : Residual ($H_{obs,i,j}$ - $H_{sim,i,j}$)

$RES_{std,j}$ : Standard deviation on residuals

ΔH: target residual (difference between measured and simulated value), feet

The R1, R2, R3 and R4 criteria are not universally valid statistical criteria, which will ensure a satisfactory calibration in any model set up. They do, however, represent objective numerical criteria that may be indicative of calibration accuracy in general.

R1-R4 indicates the percentage of observations where the target is met. For the Lake Toho model, 75% was the value agreed upon for R1-R4, meaning that the calibration target is met if the criterion is met for 75% of the observations at a certain well. This percentage was used for the entire model area. The R1, R2 and R3 criteria have been used as indicators rather than targets while R4 has been used as the primary calibration target.

For R4 criterion the model area was divided into $1^{st}$ priority areas and $2^{nd}$ priority areas with different ΔH target. The $1^{st}$ priority area includes the sub-basins that surround the fish farms and the major lakes. The $2^{nd}$ priority area includes the more remote sub-basins such as Reedy Creek, Shingle Creek and Boggy Creek. R4 calibration targets for priority 1 and 2 areas as well as for the local and the regional model are described below:

<u>Regional Model Calibration Targets:</u>

For 1st priority areas $\Delta H$ is set at 2 feet and in 2nd priority areas 4 feet. When defining the targets it was expected that the model generally would perform better than the above targets. However, due to the relatively coarse model description in these areas and due to the limited amount of data there is a larger uncertainty involved in these areas.

Local Model Calibration Targets:

For the local model area $\Delta H$ was set to 1 foot for all wells. It was anticipated that this target would be meet in most of the local area. However, even in the local model there are structural features that are not known in detail or that are not represented in detail in the model. This locally affects the performance of the model.

The above listed criteria are applicable to the calibration of groundwater tables. In order to assess how well the model simulates the overall water balance, calibration targets should be defined for runoff as well. It was agreed that runoff data on S-61 downstream Lake Toho and S-63 downstream Lake Gentry be used for this purpose. Together these gates capture more or less the total runoff from the model area. The flows on S-61 and S-63 are obviously controlled by the operation of the gates. The gates are manually operated and thus influenced by a human factor. Consequently the operation of the gates and therefore also the runoff cannot be simulated in detail. A comparison of hourly or even daily observed and simulated data would be of limited value. Comparison of cumulated simulated and observed runoff, on the other hand, is not affected by structure operation to the same extent as daily or hourly values. Moreover, cumulated values contain valuable information about the overall catchment water balance. The following calibration targets were used for the two structures. Considering the uncertainties related to rainfall, ET, gate operation etc. these criteria are fairly ambitious:

*Table 4-1 Calibration Targets for Cumulated Runoff.*

| Period of Accumulation | Cumulative Mass Error |
|---|---|
| 5 days | 20% |
| 30 days | 10% |

Lake water levels are controlled by numerous hydraulic structures. Many of these are operated as a function of season in order to maintain a specific lake water level.

The model will always maintain a water level that is very close to the target water level (operation schedule) provided that sufficient water is available to maintain the level. If inflows to the lake are under-simulated, the model may not be able to reach target water levels Thus the models ability to model surface water levels precisely depends on how the gates were actually operated in practice. Despite these uncertainties the model should be able to predict lake water levels with an uncertainty of a few inches. A target of 0.3 ft for lake water levels was agreed upon with the SFWMD to be met for 75% of all stage observations.

Proposed 1st and 2nd priority areas as well as the approximate local model area are illustrated in Figure 4-1.

## 4.3 Calibration Results

The following section provides an overview of the model calibration process and presents key-calibration results. Comparison plots for all wells, runoff and stage data used for model calibration are presented in Appendix F.

### 4.3.1 Water Budget and General Results

The simulated water budget for the entire model area is illustrated in Figure 4-2. For the period June 22, 1997 through October 4, 2000 the rainfall amounted to 165 inches. Of that amount 132 inches evaporated (77.5 %). Irrigation water imports from the Upper Floridan aquifer amounts to 5 inches over the entire simulation period. Direct overland flow to rivers and lakes amounted to 1 inch. The storage change on the ground surface (lakes, wetlands and canals) amounts to 1 inch. Most of the net rainfall infiltrates through the unsaturated zone to the groundwater (46 inches). The boundary flows in the groundwater model represents the exchange of water with the Upper Floridan aquifer, as all other groundwater boundaries are closed. Thus in the simulation period the model delivered 7 inches to the Upper Floridan and got 1 inch in return (see Figure 4-3).

Groundwater flow (base flow) into canals and lakes amounted to 2 inches. By far the largest flow component is "drain flow" or "near surface runoff". As described in section 3-34 drainflow includes all the water that drains to lakes and canals in natural or artificial drainage systems. Thus the water budget indicates that most of the inflows to the lakes are near surface runoff in ditches, canals etc. This is consistent with the fact that the surficial aquifer has limited water transport capabilities due to the relatively small transmissivities. It is also supported by the relatively large hydraulic gradients that prevails around lakes and canals indicating that lakes and canals only drain a relatively narrow fringe.

Figure 4-3 shows the average annual recharge to the Upper Floridan aquifer (negative values indicate discharge from the Floridan to the surficial aquifer). The project area is generally a recharge zone with typical recharge rates on the order of 1-2 inches per year. In Reedy Creek and Lake Hatchineha basins west of Lake Toho there is a discharge zone where the Upper Floridan aquifer discharges to the surficial aquifer. These results are consistent with recharge rates reported in Aucott (1985) and in Planert and Aucott (1988). The above rates correspond to a total average inflow from the Upper Floridan of about 10 cfs and a total outflow from the surficial aquifer of 140 cfs. The vertical flows between the Surficial aquifer and the Upper Floridan aquifer are calculated based on the head difference between the simulated groundwater table elevation in the Surficial aquifer, the head in the Upper Floridan aquifer (defined as a general head boundary condition) and based on the conductance term that mimics the hawthorn formation.

Sumner (1996) reported actual evapotranspiration rates on the Lake Wales ridge of 27 inches. The Lake Wales ridge is located on the northwestern boundary of the model area. According to Sumner (1996), this low evapotranspiration rate represents the lower limit of actual ET in South Florida. On the ridge that forms the western model boundary the simulated ET varies from 26 inches to about 30 inches, which is consistent with the findings reported by Sumner (1996). The highest ET rates in the model are at the constantly inundated areas such as the lakes. The ET here equals the potential ET, which is 46 inches/year on average. On the higher end of the scale German (2000) reported ET in the everglades ranging from 42 to 56 inches/year. The simulated ET shows a distinct pattern with the highest ET rates in the constantly flooded areas such as the lakes. Irrigated areas also appear with distinct patterns of high ET. The average simulated annual ET for the project area for the period January 1998 through December 2000 amounted to 39.0 inches/year. Thus the simulated ET is within realistic limits and consistent with data reported in other South Florida studies. Figure 4-5 shows the simulated average depth to the groundwater table during the period January 1998 through December 2000. The groundwater table is generally located between 2-4 feet below ground surface on average. On the western ridge along the western boundary the groundwater table is located significantly deeper. The figure also illustrates where wetlands form in the model. All blue colors refer to areas that are either very wet or which are inundated (groundwater table above ground surface). The model reproduces very well the wetlands. The major lakes and canals are included in the hydraulic model. The model also reproduces wetlands that are not included in the hydraulic model (MIKE11). The blue polygons on the figure show areas that are land-use classified as lakes & wetlands and it is clearly seen that the model reproduces most of these wetlands. This indicates that both the simulated depth to the groundwater table and the surface topographic data are realistic.

### 4.3.2 *Runoff*

Perhaps the biggest challenge during the model calibration has been to calibrate the runoff and, at the same time, be able to reproduce groundwater dynamics. In general it has been difficult to get sufficient groundwater responses to rainfall while not over predicting the cumulated runoff.

When calibrating the runoff it should be kept in mind that the rainfall inputs to the model are uncertain. The measurements at the various rain gages may be of good quality but the spatial distribution of the rainfall data within the model area is unknown. Measured rainfall data at the different rain stations clearly shows that the rainfall is highly distributed in time and in space and although there is a good coverage with rainfall stations, the real distribution in time and in space is not represented in detail in the model. Hence, there is probably no doubt that the uncertainty on the cumulative catchment rainfall is, at least, on the order of 10-15%. On top of that come uncertainties on the ET data and uncertainties when measuring and calculating the runoff from Q-h relations. Finally, there are obviously uncertainties related to the model representation of the various features that affects runoff in the project area such as irrigation, land-use and soil types. All these combined uncertainties will somehow affect the simulated runoff. Finally, since the runoff from the lakes is largely controlled by hydraulic structures, both the storage-elevation characteristics of the lakes as well as the structure operation must be well represented by the model. Figure 4-6 and Figure 4-7 shows simulated and observed runoff at S-61, located on C-35 just south of Lake Toho, and S-63 located on C-33 just south of Lake Gentry. Together these two structures collect most of the runoff from the model area.

the target level the gate would close. If looking at each single time-step this obviously produces a gate that is too "lively" with water levels fluctuating around the target water level. The simulated discharge in the above figures shows 5-day running average and thus represents a smoother hydrograph. In order to simulate the runoff correctly, both the inflows to the lake and the storage-elevation characteristics for the lake must be well represented in the model. For instance, if the target water level in the lakes drops 1 foot over a certain period of time, the related releases from the lake will be correct only if the storage-elevation is reasonably correct. The same applies for a situation where the gates closes in order to increase the water table in the lake, for instance, when changing to high-pool regulation. Thus simulating the correct runoff is not a trivial task.

The model does, however, reproduce the observed hydrographs relatively well both with respect to timing and peaks. For both gates the model over-predicts the runoff in 1998. In particular at S-61 where the cumulative simulated runoff exceeds the measured by about 25%. The main reason is over prediction of the runoff events in January and March 1998. The maximum allowable discharge at S-61 is in the order of 2300 cfs. This limit has not been included in the structure operation part of the hydraulic model. Hence, some of the reason for the over-predicted runoff in 1998 may be found in this model limitation. At both gates, in particular at S-63, the model under-predicts the cumulated runoff for 1999. Several of the groundwater wells in the Alligator basin indicates that there are problems in the first half of 1999. For instance, well OS-181 clearly indicates that there is a water deficit in the May-June-July 1998. This coincides with the lack of runoff in 1998. Such large water deficits can probably only be explained as problems with the rainfall data in the first half of 1998. Poor or missing representation of just a couple of heavy rainfall events may cause all the problems. It has not been possible within this project to verify or reject this possibility. For both gates, the 2000 runoff is reproduced well by the model. Overall the simulated runoffs is considered satisfactory and within the uncertainties related to rainfall, ET, gate operation and lake storage characteristics.

| S-61 | 1998 | | | 1999 | | | 2000 | | |
|---|---|---|---|---|---|---|---|---|---|
| | sim | obs | error | sim | obs | error | sim | obs | error |
| | Mill. M3 | Mill. M3 | % of obs | Mill. M3 | Mill. M3 | % of obs | Mill. M3 | Mill. M3 | % of obs |
| jan | 198 | 130 | 52% | 0 | 0 | N/A | 4.2 | 6.9 | -39% |
| feb | 125 | 105 | 19% | 0 | 7.2 | -100% | 0 | 1.1 | -100% |
| mar | 165 | 141 | 17% | 0 | 4.6 | -100% | 27.4 | 26.7 | 3% |
| apr | 61 | 57 | 7% | 9.5 | 15.6 | -39% | 49.7 | 40.9 | 22% |
| may | 9.8 | 6.5 | 51% | 36.8 | 30.1 | 22% | 3.7 | 0 | N/A |
| jun | 1.1 | 0 | N/A | 0 | 0 | N/A | 7.8 | 0 | N/A |
| jul | 11.7 | 0 | N/A | 0 | 11 | -100% | 0 | 0 | N/A |
| aug | 11.7 | 0 | N/A | 0 | 34.6 | -100% | 0 | 0 | N/A |
| sep | 11.6 | 17.3 | -33% | 23.9 | 13.8 | 73% | 6.6 | 2.8 | 136% |
| oct | 3.4 | 0 | N/A | 98 | 75.6 | 30% | 0 | 0 | N/A |
| nov | 0 | 0 | N/A | 5.2 | 16.3 | -68% | 6.2 | 0 | N/A |
| dec | 0 | 0 | N/A | 11.7 | 18.3 | -36% | 2.3 | 0 | N/A |
| Year | 598.3 | 456.8 | 31% | 185.1 | 227.1 | -18% | 107.9 | 78.4 | 38% |

*Table 4-2 Cumulated monthly and Yearly Runoff at S-61 (Lake Toho Outlet)*

| S-63 | 1998 | | | 1999 | | | 2000 | | |
|---|---|---|---|---|---|---|---|---|---|
| | sim | obs | error | sim | obs | error | sim | obs | error |
| | Mill. M3 | Mill. M3 | % of obs | Mill. M3 | Mill. M3 | % of obs | Mill. M3 | Mill. M3 | % of obs |
| jan | 27.8 | 22.3 | 25% | 0 | 0 | 0% | 11.5 | 14.8 | -22% |
| feb | 32.7 | 31.6 | 3% | 0 | 0 | 0% | 18.2 | 17.3 | 5% |
| mar | 26.1 | 23.2 | 13% | 0 | 0.1 | -100% | 0.6 | 0.2 | 200% |
| apr | 20.2 | 17.9 | 13% | 0 | 0.5 | -100% | 0.3 | 0.1 | 200% |
| may | 0 | 0 | N/A | 1.2 | 2.2 | -45% | 0.7 | 0.1 | 600% |
| jun | 0.2 | 0.2 | 0% | 0.5 | 0.1 | 400% | 0.1 | 0 | N/A |
| jul | 0.3 | 0 | N/A | 0 | 1.7 | -100% | 0 | 0 | 0% |
| aug | 2 | 0 | N/A | 0 | 0 | 0% | 0.8 | 0 | N/A |
| sep | 0 | 4.6 | -100% | 0 | 2.5 | -100% | 0 | 0 | 0% |
| oct | 3.5 | 0 | N/A | 5.6 | 22 | -75% | 1.3 | 0.1 | 1200% |
| nov | 0 | 0 | 0% | 2.2 | 8.6 | -74% | 0.8 | 0.1 | 700% |
| dec | 0 | 0 | 0% | 2.8 | 6.6 | -58% | 0.2 | 0.1 | 100% |
| Year | 112.8 | 99.8 | 13% | 12.3 | 44.3 | -72% | 34.5 | 32.8 | 5% |

*Table 4-3 Cumulated monthly and Yearly Runoff at S-63 (Lake Gentry Outlet)*

Table 4-2 and Table 4-3 shows monthly and yearly cumulated runoff simulated and observed at S-61 and S-63. S-61 is located at the outlet of Lake Toho and S-63 at the outlet of Gentry. Together these two structures collect the major part of the runoff from the project area. Simulating runoff has proven a very complex matter and the calibration targets established in the beginning of the project are unrealistically ambitious. The target was set to 10% for monthly-cumulated runoff. In an area like Florida the rainfall is highly distributed and very intense rainfall events may not be captured by the rain gages. Similarly there may also be recorded events that have a very local distribution and thus do not contribute significantly to basin runoff. Most of the runoff is generated during the wet season, May through October, but is stored in the lakes until February/March depending on the lake regulation schedules. In the remaining part of the year there is practically no recharge. During the period May-October the evapotranspiration rate is close to potential rate. Hence, errors in rainfall recordings will affect the runoff by almost the full amount. On yearly average the runoff coefficients from the basins in the project area is only on the order of 0.2 – 0.25. Thus errors in rainfall during the wet season can contribute to a significant relative error in the simulated runoff. The runoff at S-61 is generally over-predicted while the runoff at S-63 is slightly under-predicted. The relative monthly error in the primary runoff periods is typically on the order of 10-30%. For months with little runoff, the relative errors can obviously be much higher. At both structures the model over estimates the cumulated runoff in 1998 and in 2000, while the runoff in 1999 is underestimated. In 1999 the relative error on yearly-cumulated runoff is as high as 72%. The groundwater levels show a similar pattern in 1999 in the Alligator and Gentry basins (eg. OS-181 is simulated too low in the first half of 1999) and there are indications that the rainfall is not representative in that area.

The runoff at S-63 in 1999 was very low and therefore errors in rainfall contribute to a very large relative error in the simulated runoff.

For the 3 years the model overestimates total runoff through S-61 and S-63 by 12%. Hence, the runoff simulation does not meet the calibration targets established in the beginning of the project. The calibration targets (10% on monthly cumulated runoff) is probably not even within the uncertainty on the rainfall data used in the model and therefore they are unrealistically ambitious. The problems with the runoff simulation probably illustrates how complex runoff modeling in Florida is and that extremely precise rainfall data is needed in order to get even close to 10% error on monthly cumulated runoff estimates. The 15 rainfall gages used to cover the 1100 square mile project area do not provide such accuracy for rainfall data. Furthermore errors in Q-h relations used to calculate runoff at S-61 and S-63 and in the lake storage-elevation relation also contributes to uncertainties in the observed and in the simulated runoff, respectively.

### 4.3.3 Lake Stages

The water levels in the lakes are controlled primarily by the operation of hydraulic structures. As described in section 4.3.2 the hydraulic structures in the model attempts to maintain a certain target water level. For all lakes the measured water levels have been the target water levels. In principle, if there is sufficient inflows to the lakes, the model will be able to simulate the observed (target) water level with very good precision (within 1-2 inches). In terms of simulating a precise water level the water level recovery periods are more challenging. During recovery periods the gates will be closed and the water level recovery then depends only on inflows, depletion by ET, and the lake storage-elevation characteristics only. Hence, if the model under simulates the inflows the lake water level will not be able to reach the target water level. Figure 4-8 shows the simulated and observed water levels in Lake Toho and in Lake Alligator. As described the most challenging part is to reproduce the measured water level during the lake recovery periods. During the recovery period the gates are closed and thus the water levels depends only on inflows on depletion by ET and on lake-storage characteristics. Thus a very precise simulation of the recovery process requires a 100% correct simulation of the above which is not possible in practice. For both lakes, the water level does not recover to the high pool stage in 1998 and there is also a delayed recovery in 1999. These problems are particularly evident for Lake Alligator. For Lake Alligator the model does not reach the lowest level during the Alligator draw down in 2000. The reason is that the measured water level in Lake Gentry exceeds the water level in Lake Alligator. In reality water has been pumped out of Lake Alligator, which is not represented in the model.

The established water level calibration was that the residual should be within 0.3 foot for 75% of all observations. This criterion is meet for Lake Toho but not for Lake Alligator.

Figure 4-10 shows both the location of the wells used for model calibration and provides an overview of the general quality of the model calibration. As seen from the figure the average difference between simulated and observed data is generally within 1 –2 feet (green and blue colors). The calibration target in the priority 1 area for the regional model was 2 feet, thus the model generally meets this target. Inside the priority 1 area there are however 2 wells that do not meet the 2-feet target. Toho 2 is generally simulated lower than the observed data. Toho 2 is located near the Sunset Tropicals fish farm. The Fanny Bass creek and Fanny Bass pond drain this area. Detailed geometric information on Fanny Bass creek is available and is included in the hydraulic model. Topographic information on Fanny Bass pond is however not available and has therefore been estimated based on visual observations made in the field. The crest elevation of the weir at the outlet of Fanny Bass pond is 61 feet. At this water stage it was roughly estimated that average water depth would be around 4 feet. Thus the bottom of the lake was estimated to be 57 feet. The only way the lake water level can get below 61 feet is through evaporation depletion or through seepage to the downstream part of Fanny Bass creek. The drainage pattern in the area is complicated and since detailed field data are not available the exact drainage pattern is somewhat uncertain. The effect of the drainage features as represented in the model is exaggerated in order to ensure that the potential drawdown at Sunset Tropicals, is not under estimated. The wetland/swamp on Fanny Bass Creek on the western side of the Florida Turnpike is included in the model as a pond with bottom elevation of 54 feet. In the model this wetland will be flooded whenever the water table in Fanny Bass creek (or Lake Toho) exceeds 54 feet. The well Toho 2 is located just next to that pond and the effects on the well are clearly higher than in reality. This is also why the simulated groundwater levels at Toho 2 is about 2 feet lower, on average, than the observed data. Finally, the ditch on the western side of the Florida Turnpike is included in the model with a bottom elevation of 53 feet and direct connection with Fanny Bass creek. Hence, if the water level in Lake Toho, and consequently also Fanny Bass creek, gets as low as 53.6 feet, the water level in the ditches along the Turnpike will also be 53.6 feet (53.6 feet is the invert elevation at culvert LTD#2 in Fanny Bass creek, see Figure 3-18). In order to allow for efficient contact between the surface water drainage features and the lake the horizontal hydraulic conductivity of the aquifer has been set as high as 100 feet/day, which is also on the upper limit of realistic values for the surficial aquifer. Hence, all drainage features around the Sunset Tropical farms have been exaggerated even beyond realistic limits. Thus if there are any potential drawdown effects at Sunset Tropicals the model will exaggerate these effects substantially. Figure 4-11 shows the simulated and the observed groundwater table at the Sunset well. It should be mentioned that the well is located just next to Fanny Bass Pond while the model simulated average conditions within the entire 1000x1000 feet cell. In spite of the exaggerated drainage the model is not able to reproduce the low value observed in 1999 when the groundwater table drops as low as 59 feet. Since the well is located just next to the pond, this can probably only happen if the lake drops lower than 59 feet, which does not happen in the model. There is no correlation between the low groundwater tables in 1999 and unusually low water level in Lake Toho. In 1999 the minimum water level in Lake Toho was just above 52 feet, while the minimum level in 2000 was 51.4 feet (see Figure 4-9). Consequently, the model can not explain the reason for the very low groundwater table in 1999. Both field data and model results however indicates that there is no correlation between the low level and the water level in Lake Toho. The local model described in section 3.12 provides a

Figure 4-12 and Figure 4-13 shows calibration results from Toho 1 and from OS-181. The latter illustrates a problem that is also observed in other wells located in the Alligator basin, namely that the groundwater table does not recover properly after the dry season of 1999. The same problem also shows in the simulated runoff, in particular, in the Alligator chain of lakes. Thus it is likely that extreme rainfall events are missing in the rainfall data used in the model during the June and/or July 1999.

All hydrographs used for model calibration are included in Appendix F. In general the model reproduces groundwater levels and groundwater dynamics well. Exceptions are the wells located along the eastern model boundary (Castelli wells and Exotic) where the level is reasonably well described but where groundwater dynamics are poorly reproduced by the model. Moreover, there are wells, such as Toho 13 and Beekman, where the 1000x1000 feet scale adopted in the model is not sufficiently detailed to represent the relatively steep hydraulic gradients that occur near the lakes.

At some monitoring wells, for instance Beeline, Taft and Moonlight, either the topographic information is not sufficiently accurate or the cell size is too large to represent the topographic variations. As shown on the plots (see Appendix F), the observed groundwater table would seem to rise 1-2 feet above ground-surface during the wet period, which is not correct at these locations. This makes the simulated groundwater table substantially lower than the observed and obviously hampers the model's performance. Although the simulated groundwater tables are lower than the observed, the simulated groundwater table variations are similar to the observed.

| Number | Well identification | Observed Data | | | Simulation Statistics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No. of observations | Min (ft) | Max (ft) | Mean absolute residual (feet) | % of obs. within target | | | |
| | | | | | | R1 | R2 | R3 | R4 |
| 1 | Simmons #1 | 1047 | 67.0 | 73.6 | 1.0 | 100 | 74 | 86 | 90 |
| 2 | Simmons #2, well 1 | 1041 | 63.4 | 69.9 | 0.4 | 100 | 98 | 99 | 100 |
| 3 | Simmons #2, well 2 | 1047 | 63.4 | 69.8 | 0.4 | 100 | 98 | 98 | 100 |
| 4 | Beekman | 963 | 61.9 | 66.9 | 1.7 | 100 | 15 | 62 | 73 |
| 5 | Exotic | 965 | 67.7 | 70.8 | 0.8 | 100 | 47 | 78 | 92 |
| 6 | Toho 10 | 556 | 65.5 | 70.5 | 0.5 | 100 | 92 | 95 | 100 |
| 7 | Toho 12 | 225 | 66.8 | 69.8 | 1.0 | 100 | 62 | 66 | 78 |
| 8 | Toho 13 | 234 | 57.5 | 60.9 | 2.7 | 99 | 1 | 39 | 27 |
| 9 | Toho 15 | 548 | 69.6 | 75.2 | 2.0 | 100 | 10 | 69 | 47 |
| 10 | Toho 16 | 571 | 63.6 | 67.2 | 0.8 | 100 | 36 | 94 | 99 |
| 11 | Toho 1 | 632 | 56.9 | 62.0 | 0.2 | 100 | 100 | 100 | 100 |
| 12 | Toho 2 | 556 | 58.4 | 64.3 | 2.0 | 100 | 31 | 67 | 63 |
| 13 | Toho 3 | 185 | 53.6 | 58.2 | 0.8 | 100 | 85 | 100 | 99 |
| 14 | Toho 5 | 215 | 63.5 | 68.3 | 0.9 | 100 | 92 | 87 | 100 |
| 15 | Toho 4 | 231 | 54.7 | 59.8 | 0.6 | 100 | 87 | 98 | 98 |
| 16 | Toho 6 | 226 | 60.8 | 65.9 | 0.6 | 100 | 84 | 100 | 91 |
| 17 | Toho 8 | 41 | 59.6 | 60.6 | 2.9 | 0 | 0 | 0 | 15 |
| 18 | Toho 7 | 159 | 65.2 | 67.4 | 1.1 | 98 | 8 | 52 | 87 |
| 19 | Toho 9 | 223 | 68.1 | 71.9 | 1.0 | 100 | 66 | 62 | 77 |
| 20 | Taft | 937 | 92.5 | 97.2 | 1.8 | 100 | 6 | 42 | 72 |
| 21 | Sunset | 964 | 59.0 | 65.4 | 0.8 | 100 | 86 | 100 | 98 |
| 22 | Pine Island | 961 | 73.7 | 79.2 | 0.8 | 100 | 63 | 95 | 99 |
| 23 | OS-181 | 823 | 71.7 | 78.5 | 0.6 | 100 | 89 | 100 | 93 |
| 24 | Moonlight #2 well 2 | 1042 | 65.5 | 70.3 | 0.7 | 100 | 69 | 97 | 100 |
| 25 | Moonlight #2 well 1 | 1054 | 65.5 | 70.5 | 0.7 | 100 | 70 | 98 | 100 |
| 26 | Moonlight #1 well 1 | 1055 | 66.6 | 72.4 | 0.8 | 100 | 76 | 81 | 95 |
| 27 | Moonlight #1 well 2 | 1055 | 66.6 | 72.2 | 0.8 | 100 | 77 | 81 | 95 |
| 28 | Mako | 1046 | 71.2 | 76.3 | 1.3 | 100 | 40 | 81 | 79 |
| 29 | Kiss.FS2 | 981 | 65.7 | 71.3 | 0.8 | 100 | 77 | 99 | 94 |
| 30 | Disney | 939 | 94.3 | 99.2 | 0.7 | 100 | 88 | 99 | 96 |
| 31 | Chestnut, well 1 | 1024 | 63.4 | 72.2 | 0.7 | 100 | 87 | 100 | 90 |
| 32 | Chestnut, well 2 | 966 | 63.4 | 72.1 | 0.8 | 100 | 87 | 100 | 90 |
| 33 | Castelli, well 1 | 1054 | 67.2 | 71.2 | 1.9 | 100 | 13 | 61 | 63 |
| 34 | Castelli, well 2 | 1049 | 66.7 | 70.6 | 1.1 | 100 | 47 | 99 | 86 |
| 35 | Blackwater | 1048 | 67.5 | 71.9 | 0.8 | 100 | 59 | 78 | 100 |
| 36 | Beeline_g | 899 | 81.6 | 86.9 | 2.8 | 100 | 1 | 33 | 13 |
| Average residual and no. of wells meeting 75% criteria | | | | | 1.1 | 35 | 15 | 24 | 28 |

*Table 4-4 Groundwater Calibration Statistics, Regional Model.*

Table 4-4 provides an overview of the model performance in relation to the calibration targets defined at an early stage in the project (see Section 4.2). Out of the 36 wells used in the model calibration, 25 wells are simulated with an average absolute residual of 1.0 foot or less, and the average absolute residual equals 1.1 feet. The residuals range from 0.4 feet at to 2.9 feet at Toho 8. All wells that show large deviations, perhaps with the exception of Castelli, well 1, are most likely attributed to local phenomena not described in the model. For instance, Toho 8 (residual 2.9 feet) is located in Kissimmee city and there is little doubt that local drainage features affect Toho 8, which is simulated too high by the model. As mentioned earlier, the topographic information for wells like Beeline_g and Taft is inconsistent with the groundwater table elevations recorded at the well, either due to erroneous reference datum for the monitoring well or to insufficient detail or flaws in the topographic data used in the model. Other wells with high residuals are Toho 13 and Beekman, which are located in zones with steep hydraulic gradients, near East Lake Toho and Alligator Lake. These gradients can not be properly described with the 1000x1000 feet resolution used in the regional model. At Toho 2, Toho 15 and Toho 16 the calibration is affected by the exaggerated drainage that is deliberately imposed around Fanny Bass creek, Fanny Bass Pond and Sunset in order to amplify potential simulated impacts from the drawdown in that area. For all these wells, the simulated groundwater table is lower than the observed.

Looking strictly at the R1-R4 criteria the, R1 criteria is meet by 35 out of the 36 wells. In order to meet the R2 criteria the simulated groundwater table must be within the observed value +/- a standard deviation of the observed values. This criterion is often very hard to meet, in particular if the observed data has a low standard deviation. A well-calibrated model should be able to simulate groundwater dynamics (seasonal variation, response to rainfall) rather than just accurately reproduced average water level. Thus although it may claimed that a model is well calibrated, it will often be the case that simulation results are either consistently lower or higher than the observed values. If the standard deviation is low, say 0.5 feet, the R2 criteria can be very hard to meet. For the lake Toho model the R2 criteria is meet only in 15 out of the 36 wells.

In order to meet the R3 criteria the simulated groundwater table must be within the maximum and minimum observed groundwater table for 75% of all observations. The R3 criterion is meet for 24 out of 36 wells.

The primary calibration target for the regional model is the R4 criteria, which is an absolute residual criterion. For priority 1 areas the target was 2 feet and for priority 2 areas 4 feet. It was, however, anticipated that the model generally would perform better than these criteria. The 2 feet criterion is meet by 28 of the 36 wells and the average residual is 1.1 feet. None of the wells exceeds the 4 feet criteria. Two wells within the priority 1 area fail to meet the criteria. Toho 13, Toho 2, Toho 15, Toho 8 and Beekman fail to meet the R4 criteria for more than 75% of the simulations. As mentioned earlier, all these wells are affected by either local features that are not represented in detail in the model or by high hydraulic gradients that cannot be properly represented in the 1000x1000 feet model. Only two of the wells have average residuals that exceed 2 feet (Toho 8 and Toho 13).

### 4.3.5 *Calibrated Hydraulic Conductivities*

The horizontal hydraulic conductivities calculated from field tests (see section 3.11.1) were used to interpolate an initial hydraulic conductivity field. These values were subsequently modified as part of the model calibration. In general the field data seems to be about 1 order of magnitude lower than the calibrated values. The calibrated horizontal hydraulic conductivities range from 1 ft/day around Mako to 140 feet/day around Toho 4, with an average value around 14 ft/day. The calibrated horizontal hydraulic conductivities are shown in Figure 4-14.

### 4.3.6 *Local Model Calibration*

The local model (see Section 3.12) covering the Fanny Bass Pond area (see Figure 3-16) uses boundary conditions from the calibrated regional model. Often, when establishing a local scale model from a calibrated regional model, there is not much additional calibration needed for the local scale model. However, the local scale model does better simulate the hydraulic gradients near the lakes and other water bodies and it also provides a more detailed description of natural topographic drainage and storage features. The combination of these two factors often requires minor adjustments of the horizontal hydraulic conductivities. For the local Fanny Bass Pond model only small adjustments of the horizontal hydraulic conductivity were made. All adjustments lead to slightly lower horizontal hydraulic conductivities than in the regional scale model. Results of the local model calibration for wells located inside the local model area are shown in Figure 4-15 through Figure 4-17.

The local scale model does not perform substantially better than the regional scale model. The average absolute difference between simulated and observed groundwater levels is generally within 1 foot. The reason is probably that the input data does not support a very high degree of detail. The topographic input is based on relatively rough 5 feet contour data and data for a detailed calibration of the water levels and flows in Fanny Bass Pond is not available. The model suffers the same problems, in particular at Sunset Tropicals, as the regional model. The model does not reproduce the low groundwater level (below 59 feet) at Sunset in 1999. None of the available field data explains the reason for this very low groundwater level at Sunset. There is no correlation between the low stage and a similar low water stage in Lake Toho. The water level in Lake Toho actually drops lower after the drought in 2000 while the groundwater level at Sunset stays close to the 61 feet which is the crest-elevation of the weir that controls the water level in Fanny Bass Pond. Hence, there is no indication that the low groundwater level at Sunset is caused by low water levels in Lake Toho.

Appendix F includes additional results of the local model calibration.

## 4.4 Validation Results

A validation run was made using data for 1996-1997. For those data reliable ET data was not available due to data problems at the S-61 weather station during that period. As an alternative to field ET data, daily average ET for the calibration period 1998-2000 was used.

Limited groundwater data was available for model calibration. Only 6 of the wells used for the model calibration had data records before January 1998, which was the start of the calibration process. Figure 4-18 shows the simulated and observed groundwater levels at OS-181. The dynamics at OS-181 are perhaps not as well simulated as in the calibration although trends and seasonal variations are well described.

Table 4-5 shows the validation statistics for the 6 wells. As seen in the table the validation comes out almost identical to the residuals for the calibration period. In general the validation results appears to have the same qualities as the calibration runs. For three of the monitoring wells, all four calibration targets (R1-R4) are met and four of the wells meet the R4 criterion for the priority 1 area. The only two wells that do not meet the priority 1 R4 criterion are Taft and Beeline. They are, however, both within the 4 feet target established for the priority 2 areas. As described in the model calibration section, the reason for the rather poor fit is primarily problems with the topographic data at Taft and Beeline.

With regard to flows the validation run shows a general underestimation of the observed flows varying from 1% to 20%. Figure 4-19 and Figure 4-20 shows simulated and observed runoff at S-61 and S-63 respectively. Table 4-6 and Table 4-7 shows cumulated monthly and yearly runoff at S-61 and S-63. As in the calibration run, there is large variation in the relative error from month to month. For most of the months with large runoff volumes, the model reproduces observed monthly runoff with an error on the order of 10-30%. Total runoff through S-61 and S-63 in 1996 and 1997 is underestimated by 17%. The consistent underestimation of flows in the validation run may be attributed to the evapotranspiration data, which are average values for 1998-2000. Especially 1999 and 2000 were very dry years with above average number of sunshine hours. Thus the potential ET may be overestimated for 1996 and 1997.

| Number | Well identification | Observed Data | | | Simulation Statistics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | No. of observations | Min (ft) | Max (ft) | Mean absolute residual (feet) | % of obs. within target | | | |
| | | | | | | R1 | R2 | R3 | R4 |
| 1 | Taft | 672 | 92.4 | 96.7 | 2.0 | 100 | 6 | 42 | 72 |
| 2 | Pine Island | 703 | 75.2 | 79.2 | 1.4 | 100 | 63 | 95 | 99 |
| 3 | OS-181 | 723 | 73.0 | 77.7 | 0.8 | 100 | 89 | 100 | 93 |
| 4 | Kiss.FS2 | 731 | 66.2 | 71.5 | 0.9 | 100 | 77 | 99 | 94 |
| 5 | Disney | 691 | 93.2 | 99.8 | 1.0 | 100 | 88 | 99 | 96 |
| 6 | Beeline_g | 687 | 82.5 | 86.7 | 2.6 | 100 | 1 | 33 | 13 |
| Average residual and no. of wells meeting 75% criteria | | | | | 1.5 | 6 | 3 | 4 | 4 |

*Table 4-5 Groundwater Validation Statistics, Regional Model.*

*Table 4-6 Cumulated Runoff at S-61 (Outlet of Lake Toho) for the Validation Run.*

| S-61 | 1996 | | | 1997 | | |
|---|---|---|---|---|---|---|
| | sim | obs | error | sim | obs | error |
| | Mill. M3 | Mill. M3 | % of obs | Mill. M3 | Mill. M3 | % of obs |
| jan | 19.7 | 58.8 | -66% | 0 | 4.6 | -100% |
| feb | 13.8 | 37.7 | -63% | 0 | 7.6 | -100% |
| mar | 50.5 | 73.8 | -32% | 0 | 0 | 0% |
| apr | 77.4 | 80.7 | -4% | 36.9 | 50.2 | -26% |
| may | 1.5 | 3 | -50% | 52.8 | 47.5 | 11% |
| jun | 55.4 | 66.5 | -17% | 1 | 0 | N/A |
| jul | 48.6 | 55.9 | -13% | 0 | 15 | -100% |
| aug | 14 | 9.5 | 47% | 52.8 | 88.9 | -41% |
| sep | 29.1 | 9.6 | 203% | 0 | 0 | 0% |
| oct | 7.8 | 2.7 | 189% | 0 | 0 | 0% |
| nov | 0 | 0 | 0% | 0 | 0 | 0% |
| dec | 0 | 0 | 0% | 152 | 146 | 4% |
| Year | 317.8 | 398.2 | -20% | 295.5 | 359.8 | -18% |

*Table 4-7 Cumulated Runoff at S-63 (Outlet of Lake Gentry) for the Validation Run.*

| S-63 | 1996 | | | 1997 | | |
|---|---|---|---|---|---|---|
| | sim | obs | error | sim | obs | error |
| | Mill. M3 | Mill. M3 | % of obs | Mill. M3 | Mill. M3 | % of obs |
| jan | 5.8 | 5.9 | -2% | 0 | 0.7 | -100% |
| feb | 2.5 | 3.9 | -36% | 0 | 0.6 | -100% |
| mar | 5.2 | 13.1 | -60% | 0.9 | 2.2 | 0% |
| apr | 8.6 | 11.3 | -24% | 1.8 | 3 | -40% |
| may | 0.8 | 1.1 | -27% | 4.4 | 6.4 | -31% |
| jun | 18.8 | 19.2 | -2% | 0 | 10.5 | N/A |
| jul | 5.2 | 0.2 | 2500% | 3.3 | 9.2 | -64% |
| aug | 3 | 0 | N/A | 17.9 | 18.7 | -4% |
| sep | 2.3 | 0.2 | 1050% | 1.2 | 1.4 | 0% |
| oct | 4.2 | 0.5 | 740% | 1.3 | 0.8 | 0% |
| nov | 0 | 0.8 | 0% | 5.13 | 3.1 | 0% |
| dec | 0 | 0.5 | 0% | 50.4 | 41.2 | 22% |
| Year | 56.4 | 56.7 | -1% | 86.33 | 97.8 | -12% |

## 4.5 Assessment of the Predictive Power of the Model

The model has undergone a comprehensive calibration process and although there is not much data available for model validation, it has also undergone a split-sample validation process using both groundwater level data and runoff data.

The model represents an integration of all field data available and incorporates knowledge collected in past studies in the area. Thus the model probably represents the most integrated hydrological study ever conducted in the project area.

The model calculates actual ET rates which are consistent with findings from other studies in the project area and the model also produces recharge/discharge rates to the Upper Floridan aquifer that are consistent with results of past studies.

Simulating the water releases from the major lakes in the project area is perhaps the most challenging and difficult part of the model building process. All uncertainties related to rainfall, ET, land-use and irrigation, drainage etc. would ultimately affect the runoff in a very direct manner. The model generally simulated yearly-cumulated runoff with a precision of 10-15% although there are gates and years with higher uncertainty. The model also simulates the seasonal variations in the runoff hydrographs with good precision and the model has the ability to reproduce the principal functioning of the gates that control water releases from the lakes in the project area. As a general assessment the model probably has a tendency to under predict the runoff although this is not consistent for all years and locations. There is scope for improvement of the model performance in relation to runoff but it would require a detailed review of land-use and agricultural practices as well as a more rigorous analysis of the meteorological data (rainfall and ET) that drives the system.

For both the calibration and validation periods the model reproduces groundwater table levels with average residuals generally within 1-2 feet in the primary interest area. The model is also able to reproduce small-scale groundwater dynamics as well as seasonal variations with good precision which indicates that the model responds correctly to stresses such as rainfall, ET and water level variations in lakes and canals.

A model can always be better and the same applies to the Lake Toho model. However, overall the model appears consistent, sound and solid with a good handle on the overall catchment water balance, lake water level and runoff dynamics and groundwater dynamics.

In situations where lack of data has hampered detailed model development, assessments that amplify potential surface water impacts on groundwater levels have been made. For instance surface water drainage efficiency has been implemented beyond realistic level and hydraulic conductivities of the aquifer have been increased to, at least, the upper realist limit. Thus, the model will tend to over-predict any impacts resulting from the Lake Toho drawdown.

The model has demonstrated predictive power and ability to reproduce the measured groundwater table elevations with an accuracy of 1 foot for most wells within the regional model. In relation to a lake drawdown, however, correct simulation of groundwater dynamics is even more important. The model has demonstrated the ability to reproduce measured groundwater dynamics and seasonal variations.

The model appears to provide a consistent and reliable tool for assessing impacts on the groundwater regime due to the lake drawdown.