3 MODEL BUILDING

This Chapter describes how the conceptual model was implemented in a mathematical model. The chapter briefly describes the various model components in the Lake Toho ISGM. More details are provided in Appendices A through E.

In the following the terms "computer code" or "modeling system" refer to a generalized mathematical modeling system. The term "model" refers to a site-specific model, such as the Lake Toho model.

3.1 The MIKE SHE / MIKE11 Modeling System

The integrated MIKE SHE hydrologic modeling system (Refsgaard and Storm 1995) has been adopted for addressing various water resources and environmental challenges for the SFWMD from 1997 and onwards. The modeling studies comprise a variety of water resource management problems e.g. a nutrient removal study in the Everglades, which focuses on improving the understanding of the hydrologic system, in particular with regard to quantification of sub-surface flows and the overall water balance. Another small-scale study was carried out by DHI, using the MIKE SHE modeling system for assessing the impact on isolated wetlands from groundwater withdrawals. Recently, a large MIKE SHE study of the Caloosahatchee River basin (ISGM) was concluded, which focuses on the surface and subsurface water balance and the optimization of the conjunctive usage of water for irrigation given restrictions in upstream releases from Lake Okeechobee. Finally the Lake Alligator drawdown study was carried out jointly by SFWMD and DHI and this study has many similarities to the Lake Toho drawdown study.

Currently the model is being used in cooperation with SFWMD to model the Estero-Imperial-Cocohatchee basin, the Big Cypress basin and for the near coastal, saline part of the Caloosahatchee basin.

The integrated nature and the structure of MIKE SHE is illustrated in Figure 3-1

Table 3-1 Simulation Modules in the MIKE SHE / MIKE11 Modeling System

Model component	Simulates	Fully dynamic coupling with:	Dim.	Governing equation
MIKE SHE OL	Overland sheet flow and water depth, depression storage	MIKE SHE SZ, UZ and MIKE 11	2-D	Saint-Venants equation (kinematic wave approximation)
MIKE 11	Fully dynamic river and canal hydraulics (flow and water level)	MIKE SHE SZ, OL	1-D	Saint-Venants equation (dynamic wave approximation)
MIKE SHE UZ	Flow and water content of the unsaturated zone, infiltration and groundwater recharge	MIKE SHE SZ, OL	1-D	Richard's equation / gravitational flow (no effects of capillary potential)
MIKE SHE ET	Soil and free water surface evaporation, plant transpiration	MIKE SHE UZ, OL	-	Kristensen&Jensen / Penman-Monteith
MIKE SHE SZ	Saturated zone (groundwater) flows and water levels	MIKE SHE UZ, OL and MIKE 11	2-D/ 3-D	Boussinesqs equation
MIKE SHE IR	Irrigation demands (soil water deficit) and allocation (surface water/ groundwater)	MIKE SHE SZ, MIKE 11	-	-

Table 3-2 List of Model Input Data and Parameters for MIKE SHE / MIKE11

Model component	Model Input	Model parameters
MIKE SHE SZ Saturated zone flow	Geological model (lithological informa-tion Boundary conditions Drainage depth (drain maps) Wells and withdrawal rate	K_h, Horizontal hydraulic conductivity K_v, Vertical hydraulic conductivity S, confined storage coefficient S , unconfined storage coefficient Drainage time constant
MIKE SHE UZ Unsaturated zone flow	Map of characteristic soil types Hydraulic Conductivity Curves Retention curves	Ks, saturated hydraulic conductivity Θs Saturated water content Θ_{res} Residual water content Θ_{eff} Effective saturation water content pFc, Capillary pressure at field capacity pFw, Capillary pressure at wilting point n, Exponent of hydraulic conductivity curve
MIKE SHE ET Evapotranspiration	Time series of vegetation Leaf Area Index Time series of vegetation root depth	C_1, C_2, C_3 : Empirical parameters C_{int} : Interception parameter A_{root} :Root mass parameter Kc : Crop coefficient
MIKE SHE OC Overland and river/canal flow (MIKE11)	Topographical map Boundary conditions Digitized river/canal network River/canal cross sections	M, Overland Manning no. D , Detention storage L, leakage coefficient M, River/canal Manning no.
MIKE SHE IRR Irrigation module	Irrigated areas Irr. Sources (pumps/canals/reservoirs) Distribution method (sheet, sprinkler, drip) Source capacity	Eact/Epot, Maximum Allowed Water Deficit in the root zone for individual crops

3.2 Model Building Approach

Building an integrated surface water-groundwater model is not particularly different from building stand-alone groundwater models or hydraulic models. Perhaps the most important difference is that larger data amounts are involved and that an integrated approach is also an attempt to model the natural system in a more detailed and consistent manner. The integrated approach promotes thinking in terms of "nature" rather than "mathematics". The full description of the hydrologic cycle does however also increase the risk of flaws in the model and an error in one component of the model will typically spread to other parts of the model. For instance, a geometric flaw in the hydraulic control structure of a canal may cause too high water levels in the upstream canal, which may elevate the simulated groundwater table in a large area. In a large model it can sometimes be hard to identify the source of such a problem because it affects several components of the model. The above example problem could be caused by wrong aquifer properties, wrong recharge, wrong channel/aquifer contact or geometric errors. Often you may also overlook the "error" and try to adjust the model by calibration. In the best case, this is a waste of time; in the worst case it leads to poor models. In order to minimize the risk for such errors, a systematic model building approach must be adopted where the individual model components (groundwater, surface water, unsaturated zone, evapotranspiration) are built and systematically tested as stand-alone models before integration.

The Lake Toho ISGM was constructed using such a systematic building and testing approach as described in the Acceptance Test Plan (SFWMD, 2001).

3.3 Coordinate System and Units

Most of the model input data were provided in State Plane, NAD83, Florida East – 0901, US survey feet. MIKE SHE/ MIKE11 does currently only support S.I. units as input. Results and input data can however, to a large extent, be converted and presented in US units using simple conversion factors. To the extent possible all input data and results are presented using US units.

3.4 Surface Topography and Model Area

Surface topography is used by the overland flow model, as a reference level by the unsaturated zone model and in order to calculate exchange flows between overland water and groundwater when the groundwater is above the ground surface elevation. In the study area the surface topography is in addition a very important factor for the simulation of the groundwater table because the shallow groundwater table in the area very much adjusts to the surface topography. Often the groundwater table is only 1-2 feet below ground surface. If the uncertainty of the surface topographic elevation is on the order of 2.5 feet you should expect a similar uncertainty on the absolute levels of the simulated groundwater tables. The relative changes (trends) that are perhaps the most important for this study will however not be affected by the same uncertainty as the absolute levels.

Surface topographic data was provided as 5-feet USGS quad sheets. This data was supplemented with spot elevations from USGS and SFWMD monitoring wells and geologic boreholes in the project area. The contour and spot elevation data were interpolated to a surface (1000 feet grid) using an inverse distance weighted interpolation method. Figure 3-2 shows the resulting surface topography.

The figure also indicates sub-basins defined by SFWMD as well as the regional model area that covers the topographic watersheds that drains to Lake Alligator, Lake Toho and further south to Lake Cypress.

3.5 Modeling Scales and Horizontal Discretization

The regional model covers an area of approximately 1100 square miles (see Figure 3-2) and forms the backbone of the study. The model is developed in a network of grid squares with a 1000x1000 feet resolution. The total number of computational cells in the overland flow and groundwater model adds up to about 30.000. The regional model will be used to simulate the regional impacts of the drawdown. The 1000 ft resolution is sufficiently detailed to represent geometric features such as lakes and major canals. Although the width of most of the canals are substantially smaller than the cell size, perhaps maximum on the order of 150 feet, MIKE SHE's river-aquifer exchange routing is still valid. The MIKE11 model models the hydraulics in detail, independent of the cell size used in the groundwater model. Lakes are considered large water bodies and will occupy a number of cells in MIKE SHE. The lakes are, however, large compared to the grid size. For instance Lake Toho occupies 835 cells (1000x1000 feet). The regional model is also capable of reproducing trends and levels with good precision. In areas with large hydraulic gradients, for instance in the immediate vicinity of lakes, the model may not be able to reproduce absolute groundwater elevations with more than 2 feet accuracy. This does not mean that the model is wrong and responds incorrectly to stresses. It's a simple fact that the groundwater table may change with 2-4 feet within one grid square. In high gradient areas, the model will represent groundwater table dynamics and trends, as well as the relative effects of the drawdown.

A local scale model was developed to study the Fanny Bass Pond area in more detail. The Sunset Tropicals farm is located just next to Fanny Bass Pond and any impact of the water level in the pond will impact the fish ponds accordingly. The local model uses a 200x200 feet discretization. In terms of computational requirements the regional model and the local model are almost identical both having about 30000 cells in the groundwater model and about 300000 cells in the unsaturated zone model. On a 700 MHz DELL Desktop one year of simulation requires about 1.5-2 computing hours.

3.6 Rainfall

The model uses daily rainfall for 15 stations located within the project area. The daily rainfall data are distributed spatially using Thiessen polygons (Appendix B provides more details on processing of the rainfall data. Figure 3-3 shows the distribution of rainfall data using Thiessen polygons.

Many of the rainfall series contained data gaps with various frequencies and durations. Missing data were replaced with data from neighboring stations. Rainfall measured at the 15 stations shows large spatial and temporal variation. The yearly average rainfall ranges from 47.7 inches/year at station S59_R to 65.6 inches/year at station STCLOUD_R.

Table 3-3 Average yearly rainfall (1997-2000) at rainfall stations used in the model

	Mean Rainfall (1997-2000)		
Station ID	inch/day	inch/year	mm/year
CHEST_R_H6070	0.141	51.510	1308.354
CREEK_R_05841	0.148	53.960	1370.584
KIRCHOFF_R_05862	0.132	48.100	1221.740
KISS.FS_R_06305	0.155	56.650	1438.910
S59_R_16567	0.131	47.690	1211.326
S61_R_05868	0.150	54.600	1386.840
S61_R_16570	0.141	51.510	1308.354
SHING.RG_15323	0.146	53.240	1352.296
STCLOUD_R_16619	0.184	67.260	1708.404
TAFT_R_06042	0.149	54.290	1378.966
TOHO10_R_JW234	0.146	53.330	1354.582
TOHO15_R_JW235	0.183	66.850	1697.990
L_MARIO2_R_05884	0.177	64.560	1639.824
ALL2R_HA469	0.183	66.850	1697.990
BEELINE_R_05963	0.166	60.410	1534.414
MC_COY_16634	0.180	65.570	1665.478
PINE_ISL_R_05876	0.155	56.530	1435.862
KISS.FS2	0.165	60.300	1531.620

During the modeling it was chosen to omit the Kirchoff station due to unrealistically low rainfall volumes in 1998. Kirchoff was replaced with data from S-61_R_05868.

3.7 Unsaturated Zone Model Component

The unsaturated zone extends from the ground surface to the groundwater table. The depth varies throughout the year with groundwater fluctuations simulated by the model. During periods of the year, the unsaturated zone may occasionally disappear in depression areas where the water table rises above ground, e.g. in swamp areas. Unsaturated flow is computed based on Richard's equation and infiltration rates thus depend on a number of soil parameters such as hydraulic conductivity of the soil, soil retention, residual soil moisture and water content at field capacity. The model computes infiltration rates and soil moisture, which in turn affects evapotranspiration losses from the root zone, irrigation demands etc.

The unsaturated zone in Florida is in general shallow with a high groundwater table and the soils are sandy and highly permeable. The soil porosity is typically high and little or no capillary rise is observed. The model therefore adopts a simplified version of Richard's equation that ignores capillary rise (only gravity flow considered). The texture and properties of soils vary on both local and regional scale. This simplified Richard's equation benefits of being computationally faster than the full, highly non-linear, Richards equation.

The spatial distribution of soil types (columns) is based on digitized general soil maps for Orange and Osceola counties (USDA, 1977 and 1986).

Soil physical properties for each soil were derived from a soil-database developed by SFWMD. Some soil parameters were adjusted during model calibration in order to simulate groundwater dynamics correctly. In particular the moisture contents at saturation, field capacity and wilting point are important for the groundwater dynamics and the evapotranspiration processes. The digitized general soil maps are illustrated in Figure 3-4. For each general soil type a representative soil-type was chosen from the SFWMD database. Key hydraulic properties for each representative soil type are listed in .Table 3-4 for Osceola county soils and in Table 3-5 for Orange county soils. θ_s, θ_{fc}, θ_{wp} refers to volumetric moisture content at saturation, field capacity and wilting point, respectively. K_s is the hydraulic conductivity at saturation. These parameters are important both for the groundwater dynamics and for the recharge and evapotranspiration process. A good estimate of the specific yield is (θ_s-θ_{fc}) while the amount of water available for root zone transpiration will be roughly equivalent to (θ_{fc}-θ_{wp}). During dry periods, such as the spring of 2000, the root zone may dry out and the water content will get close to wilting point. Once the wet season starts again the storage in the root zone must first be filled before groundwater recharge starts. Therefore both the general groundwater dynamics and the recovery in the beginning of the wet period are very sensitive to the soil properties. MIKE SHE does allow lumping of unsaturated zone calculation profiles in order to save computational time. If the lumped approach is used the pre-processor will find cells that have identical properties (rainfall, ET, soil-type, vegetation type, depth to groundwater). If, for instance, 100 identical cells are found only 1 simulation will be conducted and results transferred to the 99 "transfer cells". Such an approach can however only be used if the hydrological conditions remain fairly identical in all 100 cells during the simulation. For the Lake Toho model the flooding regime is quite dynamic and may change the hydrologic regime on simulation cells and transfer cells during a simulation. Therefore it has been necessary to use the unsaturated zone model for all cells in the model area. This implies that the model solves for 30,000 profiles each perhaps with 10 active cells on average. Hence, on top of the 30,000 cells in the groundwater model the model solves for about 300,000 cells in the unsaturated zone.

Table 3-4 General Soil, Representative Soil types and Soil Physical Properties, Osceola County.

ISGM soil code	USDA classification as indicated on General Soil Map, Osceola County	Soil used in ISGM	θ_s [-]	θ_{fc} [-]	θ_{wp} [-]	K_s [ft/d]
1	Candler-Immokalee	Imms28	0.36	0.21	0.07	17.0
2	Immokalee-Pomello-Myakka	Imms28	0.36	0.21	0.07	17.0
3	Myakka-Tavares-Immokalee	Imms28	0.36	0.21	0.07	17.0
4	Smyrna-Myakka-Immokalee	Imms28	0.36	0.21	0.07	17.0
5	Eugallie-Smyrna-Malabar	Eaufs49	0.35	0.22	0.11	7.4
6	Riviera-Vero	Imms28	0.36	0.21	0.07	17.0
7	Malabar-Pompano-Delray	Dellfs49	0.37	0.16	0.03	7.9
8	Basinger-Placid-Samsula	Plafs55	0.37	0.16	0.06	9.6
9	Kaliga-Nittaw-Gentry	Imms28	0.36	0.21	0.07	17.0
10	Hontoon-Samsula	Hontoon	0.60	0.40	0.15	10.0
11	Pompano	Pomfs55	0.39	0.22	0.08	7.3

Table 3-5 General Soil, Representative Soil types and Soil Physical Properties, Orange County.

ISGM soil code	USDA classification as indiciated on General Soil map, Orange County	Soil used	θ_s [-]	θ_{fc} [-]	θ_{wp} [-]	K_s [ft/d]
21	Candler	Imms28	0.36	0.21	0.07	17.0
22	Candler-Urban land-Tavares	Imms28	0.36	0.21	0.07	17.0
23	Tavares-Zolfo-Milhopper	Myafs49	0.39	0.14	0.06	19.8
24	Urban land-Tavares-Pomello	Imms28	0.36	0.21	0.07	17.0
25	Smyrna-Pomello-Immokalee	Imms28	0.36	0.21	0.07	17.0
27	Urban land-Smyrna-Pomello	Imms28	0.36	0.21	0.07	17.0
29	Samsula-Hontoon-Basinger	Hontoon	0.60	0.40	0.15	10.0

3.8 Evapotranspiration Model Component

MIKE SHE calculates actual evapotranspiration from potential (reference) evapotranspiration in combination with soil and vegetation data. Reference ET was calculated based on solar radiation at station WRWX located in the southern part of the model area (see Figure 3-3), using the Priestley-Tailor model (see Appendix B).

Actual evapotranspiration is calculated as the sum of evapotranspiration from:

- ponded water (removed with potential rate)
- canopy storage (removed with potential rate)
- soil evaporation (removed from upper node in the unsaturated zone model)
- transpiration (removed over the entire root zone depending on root development and soil moisture regime).

In principle the model always attempts to meet potential evapotranspiration demands and. if sufficient water is available in the above 4 water storages, the potential rate will be met. During water limiting conditions the actual evapotranspiration depends on the actual moisture content in the root zone and on the crop development. The crop development is described in terms of time-series of root depth and leaf-area-index (LAI) for each vegetation type. LAI and root depth used for the different crop types in the model is shown in Appendix D.

Land use is described in terms of crop types and each crop is described by time-series of leaf-area-index (LAI) and root depth. Figure 3-5 illustrates the land use pattern in the project area based on the Florida Landuse, Cover and Forms Classification System (FLUCCS). FLUCCS operates with 4 different levels of details. The figure below illustrates the upper level, which only identifies the principal land use category. Land use level 2 sub-divides level 1 into a number of sub-categories. For instance level 2 would identify different types of forest within forested area or different types of wetlands for the wetland category (see Figure 3-5).

In connection with previous MIKE SHE studies the SFWMD land-use codes have further been categorized in 10 different crop-groups. A similar approach has been used for the Lake Toho ISGM. Applied crop categories are listed in Table 3-7. Each category is described using a single representative crop described in terms of LAI and root depth. These crop characteristics will be copied from DHI/SFWMD crop-databases used in Lake Alligator and /or the Caloosahatchee basin.

Table 3-6 Land Use Statistics within the Project Area

LAND USE		Area	
level 2	Text	(sq. miles)	%
100	URBAN AND BUILT-UP	168.0	16%
110	Residential, low density	44.8	4%
120	Residential, Medium density	37.3	4%
130	Residential, High density	25.3	2%
140	Commercial and Services	14.9	1%
150	Industrial	11.8	1%
160	Extractive	1.9	0%
170	Institutional	3.6	0%
180	Recreational	12.2	1%
190	Open Land	16.3	2%
200	AGRICULTURE	284.2	27%
210	Cropland and pastureland	182.9	18%
220	Tree crops	75.2	7%
240	Nurseries and vineyards	6.8	1%
250	Specialty farms	0.6	0%
260	Other open lands rural	18.8	2%
300	RANGELAND	11.8	1%
310	Herbaceous	0.3	0%
320	Shrub and Brushland	5.4	1%
330	Mixed Rangeland	6.0	1%
400	UPLAND FORESTS	144.6	14%
410	Coniferous forest	94.6	9%
420	Hardwood forest	12.4	1%
430	Hardwood forest, continued	35.6	3%
440	Tree plantations	1.9	0%
500	Water	122.0	12%
510	Streams and waterways	1.9	0%
520	Lakes	113.3	11%
530	Reservoirs	6.8	1%
540	Bays and Estuaries	0.0	0%
560	Slough waters	0.0	0%
600	Wetlands	260.8	25%
610	Hardwood Forests	90.1	9%
620	Coniferous forest	64.9	6%
630	Forested mixed	65.9	6%
640	non-forested wetlands	39.9	4%
650	non-vegetated	0.0	0%
700	Barren land	11.8	1%
710	Beaches	0.0	0%
720	sand other than beaches	0.1	0%
740	disturbed land	11.7	1%
800	TRANSPORTATION & UTILITIES	32.8	3%
810	Transportation	25.3	2%
820	Communication	0.1	0%
830	Utilities	7.4	1%

Model land cover types	MIKE SHE code	FLUCSS land use codes
Urban	5	100-180,710,740,720, 810,820,830
Citrus	1	220
Pasture	2	210
Sugar cane	3	2156
Truck crops	10	214,215
Grass	4	190,250,260
Dense upland forest	6	400
Sparse upland forest	7	610,620,630
Grassland, shrub	8	300
Wetlands, marsh	9	640

Table 3-7 Link between Crop Types used in MIKE SHE and FLUCSS Land Use Codes

3.9 Irrigation Model Component

Irrigation is not a major issue within the project area and there is not much information available on irrigation. Irrigation probably does not play a major role for the overall water balance but locally it does play a role for groundwater dynamics. Irrigated areas will maintain a relatively high moisture content during the dry season and thus ground recharge will start earlier than for non-irrigated areas in the beginning of the wet season.

Irrigation is included in the model using a relatively simple, automated approach, where the model calculates irrigation demands based on the actual simulated soil moisture regime in the unsaturated zone.

The model assumes that irrigation potentially takes place in all areas that have obtained an irrigation permit. The irrigation permit map provided by SFWMD is shown in Figure 3-6. The model allows the user to define a target moisture regime that should be maintained by the irrigation module. This moisture regime is expressed in terms of Maximum Allowable Soil Moisture Deficit (often referred to as MAD). MAD can be defined as a function of the season for each single crop type in the model. In the model irrigation starts when the average soil moisture content in the root zone drops below the threshold:

$\theta_{root} < \theta_{fc} - 0.3(\theta_{fc}\text{-}\theta_{wp})$,

and continues until reaching the upper threshold defined as:

$\theta_{root} \geq \theta_{fc} - 0.1(\theta_{fc}\text{-}\theta_{wp})$,

where θ_{root} is the average water content in the root zone, θ_{fc} is water content at field capacity and θ_{wp} is water content at wilting point for the respective soils.

Hence, the irrigation model will maintain the water content in the high end of the range in between field capacity and wilting point. In reality the water content will probably be kept closer to wilting point. However, it is assumed that the irrigation permit area covers a larger zone than the area actually irrigated and therefore the user defined thresholds (0.1 and 0.3) have been defined in the low end, leading to lower irrigation application rates than expected in reality.

It is assumed that irrigation water is applied as drip irrigation below the canopy and that water is pumped from the Upper Floridan aquifer. Since the Upper Floridan is not included in the groundwater model component the water derived from it is treated as an unlimited water import.

3.10 *Hydraulic Model Component*

MIKE11 HD constitutes the hydraulic model for the Lake Toho ISGM. MIKE11 simulates water levels and flows in 1-dimension for all major lakes and canals of the project area. Areas that are not included in MIKE11 are dealt with by MIKE SHE's 2-dimensional overland flow model that also links to MIKE11. Figure 3-7 illustrates the layout of the hydraulic model in the area surrounding the lakes.

Canal cross-section data were provided from floodplain studies carried out in Osceola and Orange County. Lake bathymetry was digitized from U.S. Army Corps of Engineers contour maps as illustrated in Figure 3-8. A DEM (Digital Elevation Model) was subsequently developed based on the digitized contour maps and cross-sections were derived from the DEM using MIKE11 GIS. An example of a lake cross-section is illustrated in Figure 3-9. The hydraulic model incorporates all major hydraulic structures in the areas. Most of these structures are gates that operate using a seasonal lake water level regulation schedule. Geometric data and operation schedules for these structures are listed in Guardo (1992).

3.11 Saturated Zone Model Component

The primary input data for a saturated zone model is a geologic model that is described in terms of layers or lenses and related hydraulic properties (horizontal hydraulic conductivity, vertical hydraulic conductivity, specific yield and storage coefficient). Once the geologic model is implemented computational layers can be defined. The computational layers may be identical to the geologic layers or they may be defined arbitrarily. For the Lake Toho model the surficial aquifer system is described in one (1) geologic layer which also serves as the computational layer. In addition initial conditions and boundary conditions must be specified.

3.11.1 Geology and Hydrogeology

Various sources of information have been reviewed during the project. A summary of this review is provided in the following sections. Additional information on development of the geologic model is provided in Appendix E.

As described in Section 2.2.3 the Lake Toho groundwater model will only consider the surficial aquifer represented as one (1) computational layer. Exchange of water with the Upper Floridan aquifer is described in a simplified manner using a general head boundary condition that allows both recharge and discharge from the Floridan aquifer. This is described further in Section 3.11.2.

The surficial aquifer consists of sand, silt and clay sediments that vary horizontally and vertically in both the thickness and proportion of the various components. The surficial aquifer system is generally sandy toward the surface and becomes clayey with depth. The contact between the surficial aquifer system and the clayey upper unit of the underlying intermediate confining unit (Hawthorn Formation) is indistinct in many places. The thickness of the surficial aquifer system in Osceola County ranges from about 30 feet in the northwestern part of the county to about 270 feet in the southern part of the county (Schiner, 1993).

In the Lake Tohopekaliga area, the South Florida Water Management District installed eighteen wells at fifteen Toho well sites. Shallow and deep borehole logs of these wells indicate that the surficial aquifer unit consists of fine sands and silts to depths of about 48 to 110 feet (Valdes, 1999). At two sites (Site Toho-1 and Site Toho-8), an intervening shallow aquitard layer (semi confining unit), composed primarily of silty clay, occurs within the surficial silty sands. This confining unit is not present at the other deep Toho well sites. Due to the close proximity (0.75 mile) of Sites 1 and 8 to Lake Toho, the SFWMD thought that this thick, localized clayey layer might have been deposited during past episodes of higher lake stages (Valdes, 1999). At Toho 1 and Toho 8 there are vertical head gradients. At Toho 1 the difference between the upper and the lower screening is in the order of 0.25 feet. In general the Toho wells shows none or very small vertical head gradients.

In Orange County, the surficial aquifer system is made up of marl, red clayey sand, and marine terrace deposits that are 0 to 200 feet thick. The terrace deposits consist mostly of loose unsorted quartz sand with varying amounts of organic matter, shell, and occasional seams of clay (Lichtler and others, 1968).

In Polk County, the surficial aquifer system is composed primarily of quartz sands that are fine to medium grained near the surface and that grade with depth to silty and clayey sands with increasing amounts of phosphate grains and pebbles (Barr, 1992). Organic sediments and peat occur near the bottom in some areas. In eastern Polk County, the deposits are up to 50 feet thick.

Hydraulic Properties

The surficial aquifer system is generally unconfined but permeable sections may be locally confined or semiconfined between beds of low permeability (Valdes, 1999). The most permeable part of the surficial aquifer system generally is the top 100 feet (Schiner, 1993).

The hydraulic properties of the surficial aquifer system in Osceola County vary considerably from place to place depending on characteristics such as grain size, sorting, packing, cementation, and the thickness of the unit (Schiner, 1993). These properties are reflected in values of transmissivity, storage, hydraulic conductivity, and specific capacity that indicate the ability of the aquifer to yield water.

In Osceola County, an aquifer test (Planert and Aucott, 1985) was conducted near Holopaw in a 75-foot deep surficial Aquifer well. The well was completed in a shell and limestone gravel unit that was semi-confined from above and below. Results of the aquifer test indicated a transmissivity of 2,000 ft^2/d and a storage coefficient of 0.0004 (Planert and Aucott, 1985). Reported vertical conductivity for the upper confining layer was 0.05 ft/d and for the lower confining layer it was 1.2 ft/d.

Another aquifer test (Planert and Aucott, 1985) was conducted in the Three Lakes Wildlife Management area of Osceola County in a 90-foot deep well. The sediments were fine sand and shell of lower hydraulic conductivity. The results of the test yielded a transmissivity of 400 ft^2/d for the fine sand and shell. A vertical hydraulic conductivity of 0.005 ft/d was calculated for the overlying confining bed, and a value of 0.09 ft/d was calculated for the underlying confining bed. The results of the two aquifer tests in Osceola County gave values of hydraulic conductivity that ranged from 20 to 100 ft/d for the aquifer zones tested.

Tibbals (1981) selected an arbitrary value of 1,000 ft^2/d for the transmissivity of the surficial aquifer system in Osceola County and about 0.05 to 0.2 for storage coefficients.

Results of a pumping test conducted in the SFWMD well Toho1-0, using observation wells Toho1-2 to Toho1-4, showed that the average horizontal hydraulic conductivity was 7 ft/d and the average storativity was 0.01. The vertical hydraulic conductivity at this site is about 3×10^{-7} ft/d (Valdes, 1999).

Results of bail tests in the Toho wells showed that the hydraulic conductivity in Toho1-2 was 12 ft/d, confirming the results of the aquifer pump test in Toho1-0. The bail test results from all the other Toho well sites tested, however, indicate hydraulic conductivity values on the order of 1 ft/d (an order of magnitude lower than at Site 1) (Valdes, 1999). According to the SFWMD (Valdes, 1999), these results may suggest that localized higher permeability conditions may occur at Site 1. Alternatively, it is possible that the bail test results for Toho1-2 may have been due to fortuitous circumstances whereas those for all the other sites may be in error by an order of magnitude (Valdes, 1999).

In Orange County, the surficial aquifer system varies widely in the quantity of water produced. The water table can be 0 to 20 feet below land surface, but it is generally less than 10 feet deep (Lichtler and others, 1968). Several secondary artesian aquifers occur locally within confining units of the surficial aquifer system.

In Polk County, transmissivity of the surficial aquifer system ranges from 240 to 2,200 ft^2/d, hydraulic conductivity is between 2.7 and 24.1 ft/d, and specific yield averages about 0.25 (Barr, 1992). Also, there is an "uppermost artesian aquifer" within the surficial aquifer deposits (Stewart, 1966).

Recharge and Discharge

The surficial aquifer system in Osceola County (Schiner, 1993), and in Orange and Polk Counties, is recharged primarily by rainfall. Other sources of recharge are seepage from streams, lakes, and irrigated land. The Hawthorn formation generally constitutes an efficient flow barrier and there is generally little seepage/recharge from the Floridan aquifer. However Planert and Aucott (1985) and Aucott (1988) suggests recharge rates on the order of 0-5 inches in the western and the northern portions of Osceola County (Orlando area). Along the Kissimmee River Valley in Osceola county the heads in the Floridan aquifer are evidently lowered as a result of discharges to the surficial aquifer.

Geologic Model

In order to establish a geologic model of the project area the available geologic borehole data were imported into a DHI Software tool named *GeoEditor*. The *GeoEditor* is an ArcView application that links database functionality with GIS and graphical editing facilities. Basically the GeoEditor functions as follows:

1. Query the data base and select borehole/geoelectric data to be used in the geologic interpretation

2. Digitize profile lines to be used in the geologic interpretation. Boreholes within a certain distance from the profile line (bandwidth) will be displayed in a vertical cross-section view.

3. Digitize layers or lenses in a vertical cross-section view.

4. Interpolate cross-sectional information to a surface that can be used as geologic layers in a mathematical model.

Figure 3-10 shows geological borehole lines along which the bottom of the surficial aquifer and the Hawthorn formation were digitized. The 'x' on the profile lines indicates points where a layer elevation was digitized. The final surface is thus interpolated based on spot elevations at all the digitized points marked with an 'x'.

3.11.2 *Initial Conditions*

In order to run the groundwater model needs the initial groundwater level in all cells within the project area. Initial conditions were developed using the model as follows. For the first simulation, the groundwater table was set 1 foot below ground surface and a model simulation for a 3-year period was carried out. Then the model was restarted using results at the end of the first 3-year simulation period as initial conditions. This approach was repeated a few times to get the model in equilibrium. For the calibration runs the model was started in January 1996 allowing a 2-year warming up period before the start of the calibration period (January 1, 1998). Effects of initial conditions have been tested during model calibration, and after the 2 year warm up period the effects are marginal even if the model is started from poor initial conditions.

3.11.3 *Boundary Conditions*

Boundary conditions must be specified along the entire model boundary. As described in Section 2.2, the selected model area follows largely the topographic watershed to Lake Cypress and major groundwater flow across the model boundary is not expected. Therefore the model uses a no-flow boundary along the entire model boundary.

The Floridan aquifer is not included as a computational layer in the model. Seepage flows between the surficial and the Floridan aquifer is, however, considered using a general-head-boundary condition in all points of the computational layer. The general head boundary requires specification of both a reference head and a leakage coefficient for all grid points. The potential head in the Upper Floridan aquifer represents the reference head. Contour lines of the potential head were digitized from a map in Planert and Aucott (1985). This map was developed as part of a USGS modeling study focusing on the Floridan aquifer system. This potential head represents average conditions in the Upper Floridan aquifer. In order to make conservative recharge/discharge estimates it was chosen to subtract 3 feet from the average head. Thus the reference head in the model represents a low head situation in the upper Floridan aquifer. This is a conservative representation in the sense that the hydraulic gradients in recharge areas are larger than in reality and smaller in discharge areas. Thus, it potentially underestimates discharge from the Upper Floridan to the surficial and overestimates recharge of the Upper Floridan aquifer. The head in the Upper Floridan is kept constant in time but varies in space (see Figure 3-15)

The leakage coefficients were calculated by dividing an assumed vertical hydraulic conductivity for the Hawthorn formation, by the thickness of the Hawthorn formation. Initially the vertical hydraulic conductivity of the Hawthorn formation was estimated to $2.8 \cdot 10^{-4}$ ft/day ($1.0 \cdot 10^{-9}$ m/s). This value was subsequently slightly adjusted during the model calibration. Figure 3-15 shows the potential head in the Florida aquifer used as general head boundary condition throughout the model area.

3.11.4 *Drainage*

Major lakes, canals and some of the most important minor canals and ditches are represented in the hydraulic model. However, the surficial aquifer is drained by numerous smaller natural or artificial drainage systems that cannot be represented in detail in a hydraulic model. In order to account for this near-surface/surface water drainage, MIKE SHE adopts a relatively simple drain-flow module. The drainflow module requires that drainage level and a time constant be specified for all drained areas (cells). Whenever the ground water level in a cell is above the drainage level, drain flow is produced. Drainage water is then routed to a river or a lake or simply exported from the catchment. The time-scale of the water routing is described using a linear reservoir approach where the specified time-constant is the mean retention time in a linear reservoir. The drainflow recipient (typically a river or a lake) is identified by MIKE SHE's pre-processor either based on the slope of the drains or by "drain code maps" that can be constructed to reflect the actual drainage scheme in the area. The Lake Toho model uses the latter approach. The drain-code maps used are identical to the drainage basin. That implies that drainflow produced inside a certain drainage basin can only go to a lake or a canal located inside the same basin. The pre-processor will make a reference system where each single cell refers to the nearest point on a river or on a lake located inside the same drainage basin. The model adopts a constant drainage depth of 1.5 feet throughout the model area. Lakes, swamps and wetlands do not use the simplified drainage option. These areas are drained either by overland flow or as part of the 1-D hydraulic model (MIKE11).

3.12 *Local Model of the Lake Toho Area*

A local model was established for a small area surrounding the Fanny Bass Pond located east of Lake Toho. The purpose of the local scale model was to study the potential impacts of the drawdown on the water level in Fanny Bass Pond. If the water level in Fanny Bass Pond is affected by the drawdown the fishponds at Sunset will be affected accordingly. The local scale model uses a 200x200 feet discretization. The model provides a better resolution of the relatively large hydraulic gradients that prevail around Lake Toho and around Fanny Bass Pond and Fanny Bass Creek.

The local scale model was developed using the same conceptual model and data as the regional model although point data such as topographic data, lake bathymetry data etc. was interpolated into the more detailed 200x200 feet mesh. Thus, regarding input data for the local scale model, please refer to previous sections describing the regional model building. The location of the local model is shown in Figure 3-16. The model covers approximately one third of the Lake Toho basin. In terms of computational requirements the model is, however, similar to the regional model. The local model comprises about 30,000 computational cells in the groundwater model and about 300,000 cells in the unsaturated zone model.

Boundary Conditions

Along the eastern and northern boundary the local scale model largely follows the Lake Toho drainage basin. Along the western and northwestern boundary the local model boundary is located in Lake Toho. The northern boundary is simply a straight west-east line that connects the western and the eastern model boundaries. Figure 3-16 also indicates the model boundary conditions. Along the model boundary located in Lake Toho a zero-flow boundary is adopted implying that there is no horizontal groundwater flow across that boundary. The regional model showed that the groundwater level below the lake is essentially the same as the water level in the lake. Hence, there is not substantial horizontal groundwater flow below the lake. Also, the vertical hydraulic gradients are very small due to the high (direct) contact between the lake and the surficial aquifer. Thus the water level in the lake is almost identical to the water level in the surficial aquifer. The local model works the same way. Hence, for the part of the local model covered by Lake Toho, the simulated ground water level will be almost identical to the simulated lake water level.

For the remaining parts of the model area, the groundwater model adopts a time-varying head boundary condition where the head is extracted from regional scale simulation results.

The upstream inflow boundary condition to Lake Toho is derived from the regional hydraulic model and the same applies for downstream water level boundaries. The hydraulic model includes the part of the lake located within the local model area. The downstream boundary condition for the hydraulic model is the water level just downstream of S-61. In addition the hydraulic model includes Fanny Bass Pond, Fanny Bass Creek and the ditch along the Florida Turnpike (see Figure 3-17).

Figure 3-18 illustrates the geometric characteristics of the Fanny Bass Creek and Fanny Bass Pond system as implemented in the model. During high pool stages in Lake Toho backwater effects may extend as far as to the Florida Turnpike. The ditch on the west side of Florida's turnpike may collect seepage from Fanny Bass Pond and has therefore been included in the hydraulic model. Cross-sections for the ditch are, however, not available. It has been estimated that the ditch is directly connected to Fanny Bass creek. The bed elevation in Fanny Bass creek at the connection point is around 54 feet. Hence, the ditch has the ability to drain and convey water whenever the water level in the ditch is above 54 feet. Backwater effects from Lake Toho can contribute to water levels higher than 54 feet but the lake can never contribute to lowering the ditch water levein the Turnpike ditch below 54 feet (as this is the bed elevation at Fanny Bass creek at the ditch-creek connection point). The water level in Fanny Bass creek upstream of LTD#2 will be independent of the lake water level for all lake water levels below 53.6 feet (if not considering changes in seepage due to groundwater level differences).

Further downstream, the culvert at LTD#2 will keep the water level at 53.6 feet or higher if the creek carries water. Thus for water stages in Lake Toho lower than 53.6 feet the aquifer properties will determine if a drawdown will have impacts as far away as Sunset Tropicals fish farms.

At the outlet of Fanny Bass pond a weir with crest elevation 61 feet controls the water level in the lake. The lake water level may drop below 61 feet due to evaporation depletion or due to seepage to the ditch system along the Turnpike.