Comparisons Among Ground-Water Flow Models and Analysis of Discrepancies in Simulated Transmissivities of the Upper Floridan Aquifer in Ground-Water Flow Model Overlap Areas

By Nicasio Sepulveda
U.S. Geological Survey, 224 West Central Parkway, Suite 1006, Altamonte Springs, FL 32714

Abstract

Discrepancies in simulated transmissivities of the Upper Floridan aquifer were identified in the overlap areas of seven ground-water flow models in southwest and west-central Florida. Discrepancies in transmissivity are generally the result of uncertainty and spatial variability in other aquifer properties. All ground-water flow models were used to simulate the potentiometric surface of the Upper Floridan aquifer for approximated steady-state conditions from August 1993 through July 1994 using the time-independent hydraulic properties assigned to the models. Specified-head and general-head boundary data used to generate boundary conditions appropriate to these models were obtained from the estimated annual average heads for the steady-state period. Water-use data and the approximated surficial aquifer system water table were updated to reflect conditions during the approximated steady-state period. Simulated heads at control points, vertical leakage rates to the Upper Floridan aquifer, and spring flows were used to analyze the discrepancies in transmissivities in model overlap areas. Factors causing transmissivity discrepancies in model overlap areas include differences among directly applied recharge rates, differences among model simulated vertical leakance values assigned to the overlaying confining unit resulting in varying leakage rates to the Upper Floridan aquifer, differences in heads and conductances used in general-head boundary cells, and differences in transmissivities assigned in the vicinity of springs. Additional factors include the grid resolution and algorithm used to approximate the heads of the surficial aquifer system when these are used as a source/sink layer.

INTRODUCTION

Seven ground-water flow models in southwest and south-central Florida were analyzed to identify discrepancies in the simulated transmissivity in model overlap areas. The seven ground-water flow models of the Upper Floridan aquifer (UFA) encompass southwest and west-central Florida (fig. 1); study area hydrology and model details are presented in Ryder (1985), Yobbi (1989, 1996), Barcelo and Basso (1993), Blandford and Birdie (1993), Hancock and Basso (1993), and Metz (1995). The transmissivities of the UFA used in the simulations range from about 8,000 feet squared per day (ft^2/d) in southwest Levy County to greater than 12,000,000 ft^2/d in Citrus County. This large range in transmissivity is typical in karst areas. In addition to the areal variations in transmissivities of the UFA, there are large differences among transmissivities used to simulate overlap areas in the ground-water flow models. For the purpose of this study, a discrepancy between simulated transmissivities within model overlap areas was identified whenever transmissivity values differed by more than twice or less than half the average transmissivity. Transmissivity discrepancies are a source of conflict for water-management regulators when evaluating water-use permits because they can result in different simulated potentiometric levels in the UFA under identical future water-use stresses.

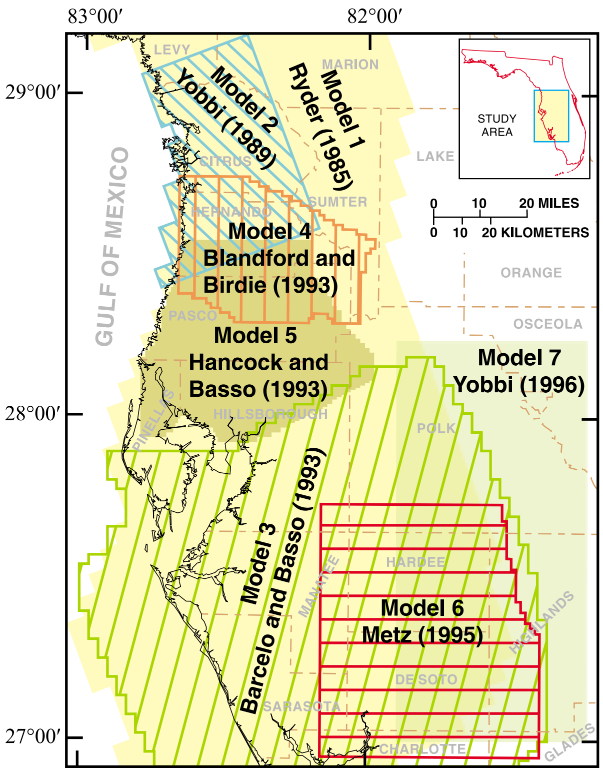

Figure 1. Location and extent of the simulated areas in the Upper Floridan aquifer of ground-water flow models considered in the study.

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DESCRIPTION OF PREVIOUS MODELS

The Floridan aquifer system is a layered system and the conceptualization of the system varied among the seven models considered in this study (fig. 2). All models assume that the confining unit underlying the UFA is not leaky and, therefore, is simulated as a no-flow boundary (fig. 2). The surficial aquifer system (SAS) is simulated as a dynamic or active layer only by models 5 and 7. Models 1, 3, 6, and 7 simulate parts of the intermediate aquifer system in southwest Florida (fig. 2). Model 5 uses two layers to simulate the UFA. Models 2 and 4 are the only one-layer models, where recharge to the UFA is directly assigned to the layer; all other models compute the leakage to the UFA from the vertical leakance of the confining units and the hydraulic gradients between the UFA and either the intermediate aquifer system or the SAS. Model 1 used the computer code generated by Trescott and Larson (1976); all other models used MODFLOW (McDonald and Harbaugh, 1988). All models used block-centered grids where heads are computed at the center of the grid cells. A detailed discussion of these models is beyond the scope of this report.

The grids used by the ground-water flow models were variable in size and cells were not aligned along the same axis. Different grid scales generally caused some areas to be treated with higher resolution than others, increasing the spatial variability of hydraulic properties. The grid used to develop model 5 was of variable cell size, ranging from 0.25 square-mile cells to 1 square-mile cells (Hancock and Basso, 1993). All other models used grids of uniform, square cell size. The width of the cells of the uniform grids varied from 1 mile (model 7) to 4 miles (model 1). Grids of models 1 and 2 were rotated about 20 degrees west of due north. The variability in grid alignment required a scheme to identify the areas where discrepancies in transmissivity occur in overlap areas shown in figure 1.

IDENTIFICATION OF DISCREPANCIES IN SIMULATED TRANSMISSIVITIES

The study area (fig. 1) was discretized into 5,000 foot-wide square cells to establish a framework grid for storing and analyzing the values of transmissivity assigned in the original models. The center points of the framework grid cells were intersected with the original model grid and the transmissivities assigned by the original model at the center points were stored at the corresponding framework grid cells. In addition, the center points of the original model grid cells were intersected with the framework grid and the transmissivities assigned by the original model at the center points were also stored at the corresponding framework grid cells. In cases where more than one transmissivity value was stored in a framework grid cell from any of the seven models, the geometric mean was computed from the multiple values obtained from that model. The transmissivities used in this study for model 5 were the sum of the transmissivities assigned to layers 2 and 3, because model 5 simulated the UFA with layers 2 and 3 (fig. 2). The transmissivities for all other models were taken as assigned.

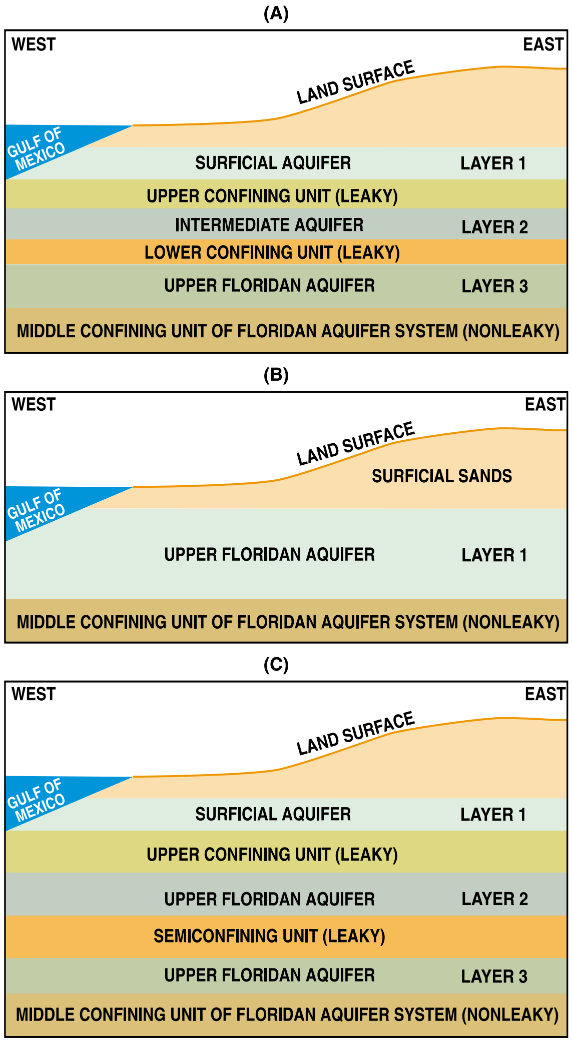

Figure 2. Layering conceptualization of models (A) 1, 3, 6, and 7; (B) 2 and 4; and (C) 5. (See figure 1 for location of models.)

A framework cell was identified as a transmissivity discrepancy if a transmissivity value from any model in an overlap area was either smaller than half or greater than twice the resulting geometric mean transmissivity. Cells with a discrepancy in transmissivity were grouped into 24 zones based on the geographical extent of the active areas of each model (fig. 3). The zones of

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transmissivity discrepancies were analyzed based on how well each model simulated the measured water levels and spring flows in the UFA and how realistic the assigned recharge rates or simulated leakage rates to the UFA seemed to be. All models were used to simulate average annual conditions in the UFA from August 1993 through July 1994.

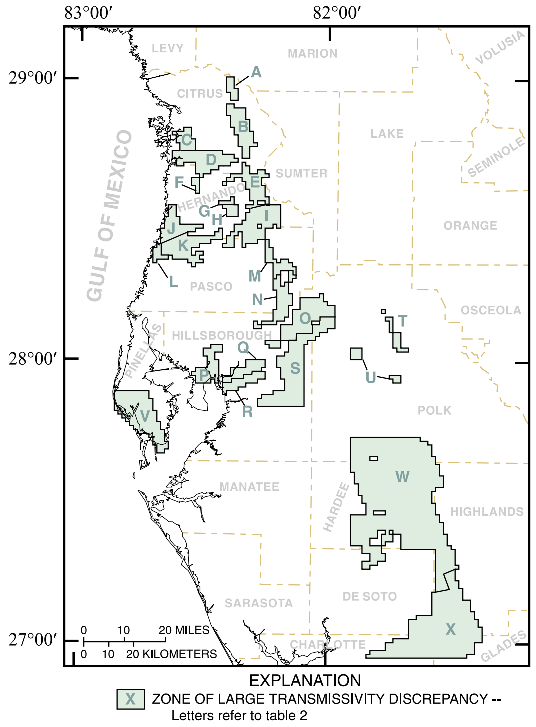

Figure 3. Zones of discrepancies in simulated transmissivities of the Upper Floridan aquifer in ground-water flow model overlap areas.

MODEL INPUT AND CONCEPTUALIZATION

The seven models analyzed in this study were used to simulate the average potentiometric surface of the UFA from August 1993 through July 1994. The time-independent model input parameters including transmissivities, vertical leakances, spring and riverbed conductances, and conductances used for the general-head boundaries were compiled from the original published models. Time-dependent model input parameters, including specified heads in the SAS, water-use data, river stages, drain elevations, specified heads in the UFA, and heads used to specify the general-head boundaries, were updated to represent the prevailing hydrologic conditions of the simulation period. The combination of original, time-independent data and updated, time-dependent data was compiled for use with the computer code MODFLOW-96 (Harbaugh and McDonald, 1996) to perform the August 1993 through July 1994 steady-state simulation for each model. The simulated water levels and spring flows in the UFA were used to assess the sets of hydraulic parameters that better matched the measured ground-water levels and spring flows among the models. The simulated water levels used in this study for model 5 were the average of layers 2 and 3, because the hydraulic gradients between these two layers were negligible. The water levels for all other models were taken as simulated by the models.

Water Table of the Surficial Aquifer System

The water table of the SAS was approximated using (1) the compiled data of lake elevations, river stages, and water-level measurements from surficial aquifer wells (fig. 4); (2) a digital elevation grid; (3) estimated lake elevations and river stages at ungaged lakes and rivers from the digital elevation grid; (4) an interpolated

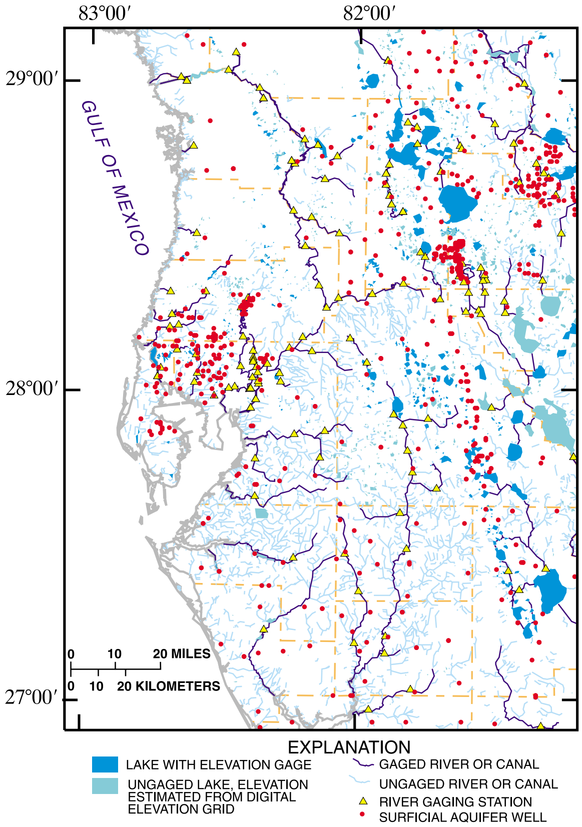

Figure 4. Lakes, rivers, locations of stream gaging stations, and surficial-aquifer wells used to estimate the areal distribution of the surficial aquifer system water table.

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surface based on lake elevations and river stages, referred to as the “minimum water table;” and (5) a multilinear regression among the water-level measurements at surficial aquifer wells, the estimated minimum water table, and the land-surface elevation relative to the estimated minimum water table. Results of the multilinear regression were used to approximate the water table from the corresponding regression coefficients, the estimated minimum water-table elevation, and the land-surface elevation relative to the minimum water table. Data used to approximate the water table of the SAS was compiled from the U.S. Geological Survey (USGS), Southwest Florida Water Management District (SWFWMD), South Florida Water Management District (SFWMD), and St. Johns River Water Management District (SJRWMD) data bases.

From August 1993 through July 1994, average lake elevations were computed for gaged lakes in the study area, and average river stages were computed for gaged rivers (fig. 4). These rivers were divided into segments according to the location of the lakes and river gaging stations. River stage was computed at all discrete nodes located along the meanderings of the river segments using a linear approximation based on distance to upstream and downstream gages. Applicable distances were computed at all nodes forming each river segment. The computed lake elevations and river stages were assumed to be representative of the water-table elevation at the same sites, and elevations were referenced to the National Geodetic Vertical Datum of 1929.

The digital representation of the topography in the area was generated from 5-foot contour interval hypsography digitized by SWFWMD, SFWMD, and SJRWMD from 7.5-minute USGS topographic quadrangle maps. A digital elevation grid of square cells 100 feet wide was generated using the digitized hypsography for the study area, the lake elevations from gaged lakes, and the river stages computed along the meanderings of gaged rivers. Using this digital elevation grid, the land-surface elevation could be interpolated at any point in the study area.

Ungaged lake and river stages were computed from the digital elevation grid. Stages were interpolated along the discrete nodes forming the digital representation of the ungaged rivers. Although some of the ungaged lakes may not be representative of the regional water table (some of these lakes may be perched), excluding these lakes from the set of all ungaged lakes used to assess the areal distribution of the water table was beyond the scope of this study.

The minimum water table was generated by fitting quintic polynomials of continuous first and second derivatives between any two nodes of measured or estimated lake elevations, river stages, or ocean shoreline (which was assigned a water table of zero foot elevation). The minimum water table, water table, and land-surface elevation coincide at lakes and rivers (fig. 5). Elevations of the minimum water table at the surficial aquifer wells were interpolated from the minimum water-table surface previously generated. Land-surface elevations at the surficial aquifer wells were interpolated from the digital elevation grid, and the resulting elevations relative to the minimum water table were computed. A multilinear regression was computed between the measured water-table elevation as the dependent variable, and the minimum water table and the land-surface elevation relative to the minimum water table as the independent variables. A correlation coefficient of 0.99 shows that these variables are strongly correlated. The approximated water table computed from the multilinear regression was used to specify the heads of layer 1 in models 1, 3, and 6, in which the SAS was simulated as a constant-head layer. The root-mean-square error between the regressed and measured water table at surficial aquifer wells was 3.81 feet, whereas the absolute maximum of regressed minus measured heads was –8.12 feet.

Errors in the approximation of the source/sink heads of the SAS lead to errors in simulated hydraulic gradients, which in turn lead to errors in simulated leakage rates between the UFA and the SAS, or between the surficial and intermediate aquifer systems. The source/sink heads for the SAS in models 1, 3, and 6 were estimated from the land-surface elevation (Ryder, 1985; Barcelo and Basso, 1993; Metz, 1995). The algorithm described herein represents a uniform method for approximating the water table in the study area and generally agrees well with measured data.

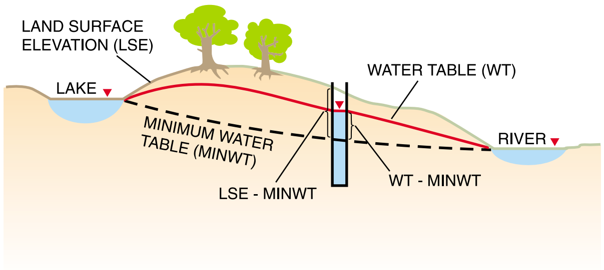

Figure 5. Relation among water table, minimum water table, and land-surface elevation.

Potentiometric Surface of the Upper Floridan Aquifer

Records of daily water levels from 1986 to 1996 from UFA wells equipped with continuous water-level recorders were evaluated to select a 1-year simulation period in which the error introduced by making a steady-state approximation was minimized. Only wells tapping the unconfined UFA were considered in this analysis, because the small storage coefficient typical of a confined aquifer generally make gain or loss of water from storage negligible. The smallest net changes in water levels in any 1-year period among the 22 unconfined UFA wells occurred from August 1993 through July 1994. Differences between water levels on July 31, 1994, and water levels on August 1, 1993, ranged from –1.07 to 1.23 feet, with a root-mean-square difference of 0.48 foot and a mean difference of –0.03 foot. If all 58 confined or unconfined UFA wells equipped with continuous water-level recorders were considered, then the differences ranged from –2.47 to 5.17 feet, with a root-mean-square difference of 1.89 feet and a mean difference of 0.89 foot. These differences indicate that the error introduced by making a steady-state approximation for this period is small.

Monthly averages for September 1993 and May 1994 and annual averages from August 1993 through July 1994 were computed from water levels in 58 UFA wells equipped with continuous water-level recorders. A multilinear regression was computed between the annual averages and the monthly averages for September 1993 and May 1994. A correlation coefficient of 0.99 for the multilinear regression indicated a strong correlation between the annual averages and the September 1993 and May 1994 averages. The multilinear regression equation used to compute the annual averages from August 1993 through July 1994 was: $h_{93\text{-}94} = 0.55\,h_{Sep93} + 0.45\,h_{May94} + 0.28$, where $h_{93\text{-}94}$ is the annual average for 1993-94 period, and h_{Sep93} and h_{May94} are the monthly averages for September 1993 and May 1994. This regression assumes that the water levels measured during September 1993 and May 1994 are representative of the monthly averages. The differences between the regressed and computed annual water-level averages at continuous water-level recorders tapping the UFA ranged from –0.67 to 3.50 feet, the root-mean-square difference was 0.74 foot, the mean difference was 0.15 foot.

A potentiometric-surface map of the UFA was generated to represent average hydrologic conditions from August 1993 through July 1994 in the SWFWMD and parts of SJRWMD and SFWMD (fig. 6). Approximately 90 percent of all water-level measurements were obtained from wells with surveyed land-surface elevations. The heads for the general-head boundaries for models 1-7 were interpolated from the potentiometric surface shown in figure 6. The conductances used to establish the general-head boundaries of these models were taken from the published models.

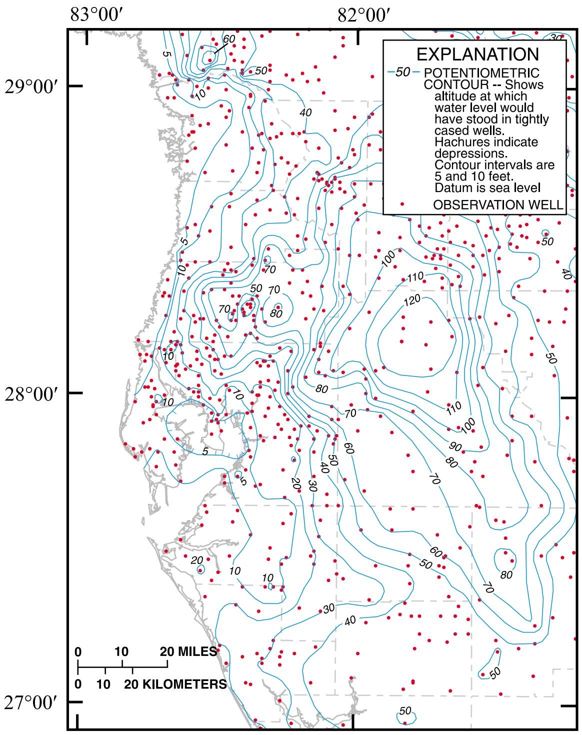

Figure 6. Estimated potentiometric surface of the Upper Floridan aquifer, average conditions for August 1993 through July 1994.

Water Use

Ground-water withdrawals in the study area from August 1993 through July 1994 from the intermediate aquifer system and the UFA for public-water supply, commercial or industrial (including thermoelectric-power generation and recreational uses), and agricultural purposes were compiled or estimated (depending on the water-use type). Most of the ground-water withdrawals were compiled from consumptive user permit data bases and water-use data files from SWFWMD, SFWMD, and SJRWMD. Artificial recharge rates from injection wells were obtained from the Florida Department of Environmental Protection. Estimates of self-supplied domestic ground-water withdrawals were obtained from Richard L. Marella (USGS, written commun., 1998). Wells located inside the simulation areas of each model were used to generate the MODFLOW well-package input file needed to run each model. Approximate total ground-water withdrawals from the simulation areas of models 1 through 7, including self-supplied domestic water use and recharge from injection wells, were 895, 65, 594, 125, 280, 231, and 400 million gallons per day, respectively.

Spring Flow

Spring flows within the study area originate mostly from the UFA. A major factor in spring flow is the net aquifer recharge from rainfall; however, spring response is delayed by aquifer-matrix storage. Higher spring flows usually occur in late fall after the rainy season, whereas lower discharges occur in late spring when rainfall has been low. Spring flows from the UFA tend to create depressions in the potentiometric surface. The areal extent of these depressions depends on the magnitude of the spring flow, and the aquifer and confining-unit properties in the vicinity of the spring.

Location and spring-flow data for springs originating from the UFA and located inside the zones of transmissivity discrepancies (fig. 3) were compiled in table 1 from several sources (Rosenau and others, 1977; Yobbi, 1989, 1992). Most of the flow measurements of springs in the zones of transmissivity discrepancies was estimated from previous flow measurements (Rosenau and others, 1977; Yobbi, 1989, 1992). A few spring-flow measurements in the zones of transmissivity discrepancies were made from August 1993 to July 1994 (table 1).

Average flows from May 1988 to April 1989 for a number of springs in parts of Citrus, Hernando, and Pasco Counties were calculated from Yobbi (1992). The average of flow measurements at Weeki Wachee Springs was 185 cubic feet per second (ft^3/s) from May 1988 to April 1989 (Yobbi, 1992); and 129 ft^3/s from August 1993 to July 1994 (USGS, 1993, 1994), or about 70 percent the average flow from May 1988 to April 1989. Due to the lack of additional spring-flow measurements from May 1988 to April 1989 and from August 1993 to July 1994, the average flow from August 1993 to July 1994 for springs in parts of Citrus, Hernando, and Pasco Counties was estimated to be 70 percent of the average of flow measurements in Yobbi (1992) from May 1988 to April 1989 (table 1). Average spring flows from August 1993 to July 1994 for springs in Yobbi (1989), not listed in Yobbi (1992), were also estimated to be 70 percent of the average spring flows listed in Yobbi (1989).

Average flows for springs in table 1 but not in Yobbi (1992) or Yobbi (1989) were estimated from the product of the flow measurement from Rosenau and others (1977) and the ratio of the August 1993 to July 1994 rainfall to the year of flow-measurement rainfall. During the study period (1993-94), total rainfall recorded at National Oceanic and Atmospheric Administration stations in Citrus, Hernando, and Pasco Counties was about 85 percent of the 1961-90 average and about 75 percent of the rainfall from May 1988 to April 1989. Although the spring flow does not follow an exact rainfall ratio, average spring flows for springs not listed in Yobbi (1992) or Yobbi (1989) were estimated assuming an approximate rainfall to spring-flow ratio.

COMPARISON OF MODEL RESULTS AND ANALYSIS OF DISCREPANCIES IN SIMULATED TRANSMISSIVITIES

The nonuniqueness of the solution to the ground-water flow equation and the uncertainty and spatial variability in hydraulic parameters generally yields discrepancies in parameter values among model overlap areas. Time-dependent parameters like specified heads, recharge rates to the unconfined UFA, and ground-water withdrawals from the UFA needed to be updated for the simulated time period. The transmissivity of the UFA, as well as the vertical leakance of the intermediate confining unit, generally are time-independent hydraulic parameters and, therefore, do not need to be updated. However, the uncertainty of hydraulic parameters can be reflected in the time-independent parameters, causing discrepancies among ground-water flow models.

The simulation of average conditions of the potentiometric surface of the UFA and average spring flows from August 1993 through July 1994 was accomplished for each model using the updated water-table distribution, UFA specified-head boundaries, ground-water withdrawals discussed earlier, and the hydraulic properties assigned to each original model. The residuals between simulated and measured water levels in the UFA were computed for zones of transmissivity discrepancies A through X (fig. 3). The residuals and a comparison of simulated and estimated spring flows for each model in zones A through X were used to analyze the reliability of the transmissivity and leakage rates of each model (table 2).

Measured heads and reliable UFA spring-flow measurements were used to determine which transmissivity values and leakage rates to the UFA are realistic among the considered models. Springs were located in zones C, D, J, L, N, P, and S (table 1). Zone D is an example of an area where both head measurements and spring flows are needed to assess the reliability of the hydraulic parameters used by models 1, 2, and 4. Zones F, G, and H suggest the need for

Table 1. Description and flow measurements of Upper Floridan aquifer springs in zones of transmissivity discrepancies

[Zone labels indicate zone where springs are located, see fig. 3 for zone locations; if more than one date of measurement is listed, flow is an average of measurements; ft^3/s, cubic feet per second; dates are shown in month-year format]

Spring name	Zone	Latitude	Longitude	County	Flow, in ft^3/s	Date(s) of flow measurement(s)
Halls River Springs	C	284804	823610	Citrus	[a]102.2	
Hidden River Springs near Homosassa (including Hidden River Head Spring)	C	284559	823520	Citrus	[b]6.7	
Homosassa Springs at Homosassa Springs	C	284758	823520	Citrus	[b]72.4	
Southeast Fork Homosassa Springs at Homosassa Spring	C	284751	823523	Citrus	[a]43.1	
Trotter Spring at Homosassa Springs	C	284747	823510	Citrus	[b]5.2	
Baird Creek Head Spring near Chassahowitzka	D	284230	823440	Citrus	[b]3.2	
Beteejay Lower Spring near Chassahowitzka (including Beteejay Head Spring)	D	284131	823535	Citrus	[b]7.3	
Chassahowitzka Springs near Chassahowitzka	D	284254	823435	Citrus	[b]64.8	
Crab Creek Spring	D	284300	823434	Citrus	[b]34.8	
Lettuce Creek Spring	D	284308	823437	Citrus	[b]3.7	
Potter Spring near Chassahowitzka (including Ruth Spring)	D	284354	823548	Citrus	[b]14.4	
Rita Maria Spring near Chassahowitzka	D	284126	823528	Hernando	[b]3.3	
Salt Creek Head Spring	D	284323	823506	Citrus	[b]0.4	
Unnamed Tributary above Chassahowitzka Springs (including Bubba Spring)	D	284254	823438	Citrus	[b]20.5	
Boat Spring at Aripeka	J	282621	823929	Hernando	[b].4	
Bobhill Springs	J	282607	823834	Hernando	[b]1.8	
Jenkins Creek Spring No. 5	J	283120	823804	Hernando	[b]15.3	
Magnolia Springs at Aripeka	J	282558	823926	Pasco	[b].5	
Mud Spring near Bayport	J	283240	823701	Hernando	[b]17.0	
Salt Spring near Bayport	J	283246	823709	Hernando	[b]22.3	
Unnamed Spring No. 1	J	282600	823926	Hernando	[a]6.3	
Unnamed Spring No. 2	J	282720	823830	Hernando	[a].7	
Unnamed Spring No. 4	J	283118	823806	Hernando	[a]6.3	
Unnamed Spring No. 6	J	283254	823737	Hernando	[a]2.8	
Horseshoe Spring near Hudson	L	282350	824121	Pasco	[c]9.7	12-72
Unnamed Spring No. 3 near Aripeka	L	282352	824027	Pasco	[c]17.8	08-60
Crystal Springs near Zephyrhills	N	281030	821120	Pasco	37.0	09-93, 05-94
Sulphur Springs at Sulphur Springs	P	280115	822705	Hillsborough	25.0	09-93, 05-94
Lithia Springs Major near Lithia	S	275158	821352	Hillsborough	31.1	09-93, 05-94
Lithia Springs Minor near Lithia	S	275201	821349	Hillsborough	8.0	09-93, 05-94

[a] Estimated to be 70 percent of average of flow measurements from Yobbi (1989).

[b] Estimated to be 70 percent of average of flow measurements from Yobbi (1992).

[c] Estimated from product of measured flow from Rosenau and others (1977) and ratio of August 1993 – July 1994 rainfall to year of flow-measurement rainfall recorded at nearest station.

reliable evapotranspiration data to better estimate leakage rates to the UFA. In zones where only head measurements were available (A, B, I, K, M, Q, R, T, U, and W), only generalizations can be made about the validity of transmissivity and leakage rates. In many of these zones, the mean residual can only indicate the direction in which the transmissivity and leakage rates should be changed once one parameter is kept constant, but not the direction in which both parameters should be changed.

The nonuniqueness of the solution to the ground-water flow equation implies, for example, that different combinations of transmissivities and vertical leakances can result in similar simulated heads. Matching

Table 2. Description of zones with transmissivity discrepancies in model overlap areas

[Tn, average transmissivity of the Upper Floridan aquifer (UFA) assigned by model n, in thousand feet squared per day; Ln, average leakage or recharge rate to the UFA, as the case may apply, assigned by model n, in inches per year; Rn, root-mean-square error of residuals from control points of UFA for model n, in feet, mean of residuals, in feet, and number of control points; Qn, sum of simulated spring flows by model n, in cubic feet per second (ft^3/s); Q, sum of measured or estimated spring flows, in ft^3/s. Several values of Tn are shown if T is areally variable. See figure 3 for zone labels; see figure 1 for model numbers]

Zone	Models with active cells	Simulated transmissivity	Simulated leakage or recharge	Statistics of residuals and spring flow	Explanation or comment
A, B	1, 2	T1= 2,000, 500 T2= 450, 155	L1= 11.0 L2= 16.4	R1= 7.54, -4.87, 7 R2= 4.57, 3.06, 7	T should be between T1 and T2 and L rate should be between L1 and L2.
C	1, 2	T1= 1,000 T2= 9,000	L1= 10.0 L2= 9.0	R1= 0.20, -0.20, 1 R2= 1.17, 1.17, 1 Q1=77, Q2=375 Q=230	Similar L rates and Q1 lower than Q suggest T should be higher than T1. Higher Q2 than Q suggests T should be lower than T2.
D	1, 2, 4	T1= 1,000 T2= 6,500 T4= 900	L1= 12.6 L2= 17.7 L4= 14.7	R1= 3.80, 2.34, 2 R2= 3.78, 2.93, 2 R4= 0.94, 0.04, 2 Q1= 189, Q2=199 Q4= 28, Q=152	Low R4 and low Q4 show the solution of the ground-water flow equation is not unique and calibration should make use of spring flows in addition to heads. T and L should vary areally, with T increasing towards the springs.
E	1, 2, 4	T1= 1,000 T2= 1,500 T4= 475	L1= 11.6 L2= 13.5 L4= 11.1	R1= 6.73, 6.26, 3 R2= 0.80, 0.61, 3 R4= 3.30, 2.24, 3	Outflux through lateral boundaries of model 4 is four times higher than flux through same cells in models 1 and 2. T should be higher than T4.
F	1, 2, 4	T1= 250 T2= 250 T4= 1,300	L1= 14.0 L2= 21.0 L4= 39.9	R1= 1.63, 1.63, 1 R2= 3.03, 3.03, 1 R4= 0.25, 0.25, 1	L rate should be between L1 and L2. Low R4 could also be achieved with T lower than T4 and L lower than L4. L4 seems too high.
G	1, 2, 4	T1= 1,000 T2= 1,500 T4= 160	L1= 18.0 L2= 27.0 L4= 39.5	R1= 9.14, -9.14, 1 R2= 1.40, 1.40, 1 R4= 6.79, 6.79, 1	T should be between T1 and T2. L rate should be between L1 and L2. L4 seems too high.
H	1, 2, 4, 5	T1= 1,000 T2= 1,500 T4= 190 T5= 400	L1= 16.5 L2= 16.5 L4= 37.6 L5= 5.8	R1= 9.93, -9.93, 1 R2= 0.00, 0.00, 1 R4= 5.08, 5.08, 1 R5= 0.56, -0.56, 1	Contrasting T and L values can produce similar water levels. Additional data, such as evapotranspiration estimates, are needed to determine L rates that are physically possible.
I	1, 4, 5	T1= 500, 130 T4= 575, 300, 18 T5= 150, 80, 35	L1= 3.8 L4= 11.7 L5= 18.3	R1=32.71,-28.63,7 R4= 8.04, -1.26, 7 R5= 7.75, 3.77, 7	T could vary areally between T4 and T5 and L rate should be between L4 and L5. Mean residual for model 1 suggests L rate should be higher than L1.
J	1, 2, 4, 5	T1= 2,000, 1,000, 500, 250 T2= 2,000, 1,000, 500, 43 T4= 2,000, 1,000, 675, 420 T5=575,400,120	L1= 10.3 L2= 1.8 L4= 5.7 L5= -2.9	R1= 1.38, -0.72, 3 R2= 3.05, -1.63, 3 R4= 3.26, -2.40, 3 R5= 4.31, -3.75, 3 Q1= 82, Q2= 67 Q4= 91, Q5= 0 Q= 73	Areal distribution of T is highly variable and contrasts from one model to another. No simulated spring flow by model 5 suggests T should be higher than T5 and L rate should be higher than L5. L rates vary areally because both recharge and discharge areas are included in zone.
K	1, 4, 5	T1= 500, 130 T4= 1,800, 790, 110, 26 T5= 115, 80, 55	L1 = 17.0 L4 = 32.3 L5 = 9.4	R1=24.08,-14.11,6 R4= 5.16, 3.48, 6 R5= 8.04, 0.79, 6	T should be higher than T1 in areas where T1=130. Mean residuals for models 4 and 5 suggest L rate should be lower than L4 and T should be higher than T5.
L	1, 5	T1= 250 T5= 80	L1= 0.0 L5= -4.8	R1= 1.79, 1.79, 1 R5= 0.40, 0.40, 1 Q1= 13, Q5 = 8 Q= 27	If T5 is increased near springs then Q5 would increase. Zone is mainly a discharge area, which suggests L could be lower than L1.
M	1, 4, 5	T1= 500, 40 T4= 150, 100, 20 T5= 400, 150, 55	L1= -1.5 L4= 4.6 L5= 14.6	R1=29.86,-29.49, 4 R4= 0.81, 0.44, 4 R5= 7.10, 7.01, 4	L rate should be higher than L1. Mean residual for model 5 suggests L rate should be lower than L5.

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Table 2. Description of zones with transmissivity discrepancies in model overlap areas--Continued

[Tn, average transmissivity of the Upper Floridan aquifer (UFA) assigned by model n, in thousand feet squared per day; Ln, average leakage or recharge rate to the UFA, as the case may apply, assigned by model n, in inches per year; Rn, root-mean-square error of residuals from control points of UFA for model n, in feet, mean of residuals, in feet, and number of control points; Qn, sum of simulated spring flows by model n, in cubic feet per second (ft^3/s); Q, sum of measured or estimated spring flows, in ft^3/s. Several values of Tn are shown if T is areally variable. See figure 3 for zone labels; see figure 1 for model numbers]

Zone	Models with active cells	Simulated transmissivity	Simulated leakage or recharge	Statistics of residuals and spring flow	Explanation or comment
N	1, 5	T1= 100 T5= 400	L1= 1.8 L5= -2.0	R1=21.03,-20.83, 2 R5= 5.49, 5.40, 2 Q1=0, Q5=36, Q=37	No simulated spring flow simulated by model 1 suggests T should be higher than T1. L rates need to vary areally. L rates in discharge area could be less than L5.
O	1, 5	T1= 100 T5= 30	L1= -0.9 L5= 10.0	R1=40.50,-40.33, 7 R5=14.60,-17.39, 7	L rate should be higher than L1. Conductances in model 5 on general-head boundary in northeast are too low. T should be higher than T5.
P	1, 5	T1= 200 T5= 50	L1= 0.6 L5= 15.4	R1=10.88, -8.48, 6 R5= 6.01, 5.64, 6 Q1= 0, Q5= 27 Q= 25	T should be lower than T1 in a discharge area. L rate should be lower than L5 and higher than L1.
Q	1, 3, 5	T1= 200 T3= 33 T5= 400, 150	L1= 0.3 L3= 0.7 L5= -29.4	R1= 6.91, -5.18, 6 R3= 4.38, 2.48, 6 R5= 2.99, -2.07, 6	L rate should be higher than L1. T should be near T3 in discharge area.
R	1, 3	T1= 200 T3= 33	L1= 1.1 L3= 1.7	R1= 3.47, -0.87, 3 R3= 8.03, 4.70, 3	T should be higher than T3 and lower than T1 if L rates remain between L1 and L3.
S	1, 3, 5	T1= 130 T3= 130, 33 T5= 40	L1= 5.8 L3= 10.0 L5= 5.9	R1=22.33,-10.83,13 R3= 5.47, 3.53, 13 R5=10.01, -9.44, 3 Q1=13, Q3=18 Q5=0, Q=39	Areally variable T as in model 3 should be used. Mean residual for model 3 suggests L rate should be lower than L3 or if L3 is used, then T should be higher than T3. Only a subset of zone is simulated in model 5.
T	3, 7	T3= 67 T7= 12	L3= 5.6 L7= 6.2	R3= 0.93, 0.93, 1 R7= 2.73, 2.73, 1	L rates could be lower than L3 if T3 is used. T could be higher than T7 if L7 is used.
U	1, 3, 7	T1= 130 T3= 130 T7= 40	L1= 6.3 L3= 4.1 L7= 6.6	R1= 10.90, -7.71, 2 R3= 4.14, -2.89, 2 R7= 3.00, -2.95, 2	These are small areas of recharge to the UFA. T should be closer to T7 and L rate should be closer to L7.
V	1, 3	T1= 30, 17 T3= 200	L1= -1.3 L3= 1.3	R1= 5.29, 4.20, 8 R3= 2.21, 2.40, 8	Higher T requires higher L rate, lower T requires lower L rate. Aquifer test result suggests T could be even higher than T3.
W	1, 3, 6, 7	T1= 400, 130 T3= 134 T6= 400, 100 T7= 400, 130, 66	L1= 2.4 L3= 3.2 L6= 1.4 L7= 2.1	R1= 6.86, 4.87, 19 R3= 6.09, 3.31, 19 R6= 5.58, -1.87, 19 R7= 3.04, -0.19, 19	If L rates remain between L6 and L3, then T should vary areally. If T is uniform, then L rates should vary areally.
X	3, 6, 7	T3= 400 T6= 100 T7= 400	L3= 0.4 L6= -0.6 L7= 0.2	R3= 4.00, 0.65, 6 R6= 4.26, -2.93, 5 R7= 1.86, -1.05, 5	Fluxes through lateral boundaries are small for all models. Low T6 and low L6 yield a high R6 value. Model 3 extends further south than models 6 or 7.

measured and simulated heads can indicate whether the simulated transmissivity should be increased or decreased if the vertical leakance values are not changed (or vice versa), but heads alone cannot indicate how both parameters should be changed. Zones I, K, Q, and W are examples of uncertainties where either the transmissivity or the vertical leakance (reflected by the leakage rates) could vary areally while the other parameter remains unchanged (table 2). The availability of either known flux rates or reliable aquifer performance tests could answer which hydraulic parameters are more representative of the aquifer properties.

Fluxes through general-head boundaries in zones E and O can be compared among models. In these zones, the reliability of the data used to establish lateral boundaries in some models can be analyzed by comparing fluxes simulated by models. Specified heads used for some general-head boundaries in models 4 and 5 suggest that unrealistic fluxes are simulated to be entering (model 5, zone O) or leaving (model 4, zone E) the model areas when compared to fluxes simulated by models 1 or 2. Errors in the interpolation scheme used to estimate the specified heads at the general-head boundaries may have translated into errors in the conductances specified at the general-head boundary cells in models 4 and 5.

SUMMARY AND CONCLUSIONS

Seven ground-water flow models in southwest and south-central Florida were analyzed to identify discrepancies in the simulated transmissivity in model overlap areas. Average conditions from August 1993 through July 1994 in the UFA were simulated for each model in their respective areas using updated water-table elevations, UFA specified-head boundaries, water-use data for the period, and the hydraulic properties used by the original models. The simulated and measured heads and spring flows were compared to identify and analyze some of the reasons for the transmissivity discrepancies.

In general, the factors causing transmissivity discrepancies in model overlap areas include differences among directly applied recharge rates, differences among model simulated vertical leakance values assigned to the overlaying confining unit resulting in varying leakage rates to the UFA, differences in heads and conductances used in general-head boundary cells, and differences in transmissivities assigned in the vicinity of springs. Additional factors causing transmissivity discrepancies are the grid resolution and the algorithm used to approximate the heads of the surficial aquifer when these are used as a source/sink layer. This study underlines the need for reliable data to improve the quantification of some hydraulic parameters, particularly the recharge and leakage rates to the Upper Floridan aquifer.

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