Recalibration of Model Parameters For the Seven Rivers Area of the Roswell Basin

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June 23, 2004

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Prepared For:

State of New Mexico/Interstate Stream Commission

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REPORT

Section 1
Introduction

S. S. Papadopulos & Associates, Inc. (SSP&A) was requested by the Interstate Stream Commission (ISC) to conduct an evaluation of the potential impacts associated with proposed augmentation pumping and irrigation water use retirement scenarios on streamflows and groundwater levels in the Seven Rivers area of the Roswell Basin. The quantification of these potential impacts was accomplished using the Roswell Basin Groundwater Model.

The augmentation pumping scenarios, described in the report *Augmentation Pumping and Irrigation Use Retirement in the Seven Rivers Area of the Roswell Basin* (SSP&A 2004), would utilize proposed new wellfields, located in the southernmost portion of the model domain (Figure 1). Since previous calibration and recalibration of the model (SSP&A 2003a, 2003b) did not focus significantly on this southernmost portion of the model domain, an evaluation of the suitability of model parameters in this area was made based on additional groundwater level data assembled by the ISC and the Office of the State Engineer (OSE). This evaluation resulted in some recalibration of model parameters in the Seven Rivers area.

This report documents the recalibration of the Roswell Basin Groundwater Model. The method of analysis and recalibration of the model in the Seven Rivers area are described in Sections 2 and 3. Section 4 discusses the sensitivity of the analysis results to key model parameters. Section 5 summarizes the results and conclusions of the evaluation. Section 6 is a list of documents referenced in this report. The Appendix, which contains a tabulation of average residuals associated with data from individual wells, is located on the CD-ROM included with this report.

Section 2
Method of Analysis

The quantification of potential impacts of proposed augmentation pumping and irrigation retirement scenarios was accomplished using the Roswell Basin Groundwater Model (SSP&A, 2003a, 2003b). However, some of the proposed augmentation pumping may come from a new wellfield that will be developed in the Seven Rivers area. This area is located in the southernmost portion of the model area. In previous efforts to refine and recalibrate the model, this southernmost area received relatively little attention due to its location. As a result, the values and distributions of potentially important model parameters and conditions in this area, such as transmissivity of the regional aquifer, leakance of confining layers between the regional aquifer and the shallow aquifer, and conditions associated with Lake McMillan and Brantley Reservoir have not been thoroughly evaluated. Prior to using the model for evaluating potential impacts of proposed augmentation pumping and irrigation retirement, an evaluation of model parameters and conditions in the Seven Rivers area was conducted.

The evaluation of model parameters and conditions in the Seven Rivers area was based largely on groundwater level data that was not used during previous model refinements. A database of groundwater levels was assembled by the ISC/OSE and provided to SSP&A for this purpose. Specification of model conditions associated with Brantley Reservoir were also developed by ISC/OSE and provided to SSP&A. The updated model data and the groundwater level database served as the basis for SSP&A to refine and recalibrate model parameters and conditions in the Seven Rivers area.

Previous work on calibrating the Roswell Basin Groundwater Model (SSP&A, 2003a, 2003b) used baseflow data in addition to groundwater level data. The baseflow data that were used consisted of tabulations of monthly baseflow in the reach between Acme and Artesia. These tabulations were the result of detailed evaluations of inflow and outflow to the reach over a period of many decades. Similar data are not available for reaches in the Seven Rivers area. Furthermore, the operation of Lake McMillan and its replacement with Brantley Reservoir complicate the evaluations necessary to establish baseflow (groundwater discharge) within these reaches. As a result, baseflow data were not included in the recalibration of the Seven Rivers area.

Section 3
Recalibration of the Seven Rivers Area

The recalibration of model parameters in the Seven Rivers area was based on additional groundwater level data provided to SSP&A by the ISC/OSE. More than 3,800 water level measurements from 134 wells were reviewed for use in the recalibration process. The locations of these wells are shown on Figure 2. Water level data that were used in the previous calibration of the Roswell Basin Groundwater Model were also used to ensure that adjustments to model parameters in the Seven Rivers area did not adversely affect the calibration in other parts of the model domain. A limited amount of aquifer test data was available to describe transmissivity conditions in the area. While these data provided some information on aquifer properties, it was limited in scope and could only provide a general guideline as to appropriate values for aquifer properties. As a result, aquifer properties were determined primarily from the calibration process using historical water level data.

The groundwater level data were assembled into a format for use in the parameter estimation program PEST. PEST is a program that facilitates the calibration process by using a least-squares non-linear regression algorithm to estimate model parameters. The PEST program also includes a pilot-point procedure that facilitates the definition of spatial variation in model parameters. The PEST program and the pilot-point procedure were used to estimate model parameters in the Seven Rivers area and thus facilitate the recalibration process.

The groundwater level database included measurements that dated back to the early 1900s. Measurements were available at varying frequencies from that early time until 2001. The database included over 450 measurements taken between 1900 and 1920. Between 1920 and 1940, there were relatively few measurements, just over 100. Most of the water level data were for the period after 1940 when over 2,800 measurements were made. As a result, while data were available at 38 well locations for the period prior to 1920, the continuity of the data from those wells was limited. Furthermore, several of the wells reported water levels above land surface during this early period and would be flowing wells if they were not capped in some fashion. Since there is very little information regarding the status of these wells during the early period, the amount of water produced by these wells is very uncertain.

During the initial phases of the recalibration process, considerable effort was devoted to try to determine model parameters that would allow the model to reasonably simulate water levels in both the early (pre 1920) period and the later (post 1940) period. After experimenting with numerous model parameter combinations, it was concluded that reasonable simulation of both early and later period data could not be achieved with reasonable parameter values. The difficulty in obtaining a reasonable calibration for both periods likely stems from a lack of complete information on pumping and the conditions associated with flowing wells during the early period. Based on this experience, the recalibration process was subsequently focused on the groundwater level data from the later period.

The focus on this later period is also appropriate because the simulations of alternative scenarios need to focus on the current status of conditions in the Seven Rivers area. These conditions include the potential impacts of abandoned wells that might be providing an increased hydraulic connection between the shallow aquifer and the deeper regional aquifer. While there have been programs to plug or seal abandoned wells in the area, the number of remaining abandoned wells and the effectiveness of the plugging program remains uncertain. Thus, by focusing on the data from the later period, the impacts of abandoned or leaking wells will be incorporated to some degree into the model recalibration and parameter estimation process.

The primary recalibration parameters were the transmissivity of the regional aquifer and the leakance coefficients of the confining units that separate the regional aquifer from the shallow aquifer in the Seven Rivers area. The transmissivity along the southern portion of the K-M structural zone was also evaluated in the recalibration process.

Prior to commencing the recalibration process, ISC/SEO staff provided a version of the Roswell Basin Groundwater Model that included adjustments in model boundary conditions to more accurately simulate the transition from the operation of Lake McMillan to the operation of Brantley Reservoir. Also, as part of the effort of trying to reconcile the early period data and later period data, it was noted that some of the trends in the shallow groundwater levels between Lake McMillan and Brantley Reservoir were not being simulated very well. To improve the simulation of these trends, some adjustments were made in the extent of the area of high hydraulic conductivity in the shallow aquifer and in the connection between Lake McMillan and the shallow aquifer.

The coefficients that describe the connection between the lake and the shallow aquifer were decreased over time to account for a decrease in leakage from the lake, most likely associated with increased sediment deposition. Specifically, the coefficient for each model cell representing Lake McMillan was scaled from about 2×10^5 feet squared per day to 5×10^3 feet squared per day in a linear fashion from the beginning of the simulation period to the time when Lake McMillan was no longer used. This change resulted in a better simulation of the trends in shallow groundwater levels over time in the area between Lake McMillan and Brantley Reservoir.

The SSP&A recalibration process utilized the PEST parameter estimation program to estimate optimal parameter values from a least-squares perspective. In general, model parameters were defined using pilot points or groups of pilot points to scale parameter values that were specified in the prior version of the Roswell Basin Groundwater model.

Pilot points are essentially control points distributed geographically within the model domain. Values at the pilot points are used to interpolate/extrapolate values to the model grid using a kriging algorithm available in the PEST software. A value of one for a model grid location would signify that the parameter value from the prior model would not be changed Values greater or less than one would cause the parameter value from the prior model to be scaled up or down accordingly. This procedure facilitated comparison with the prior model parameters since the effective parameters were simply scalars of the prior values.

The PEST program was applied in a guided fashion to facilitate convergence of the non-linear regression process. Generally, a limited number of parameters (or pilot points) were optimized at any one time. After one set of parameters was optimized and the objective function (sum of squares of residuals between computed and measured groundwater levels) was reduced, other parameters or groups of parameters were evaluated using the values of parameters from the prior optimization. This procedure of "guided sequential" optimization generally prevented the non-linear regression process from producing extreme results due to parameter insensitivity or correlation.

The groundwater level data used in the non-linear regression analysis was also reviewed and evaluated to prevent anomalous data points from skewing the analysis. As described previously, groundwater level data from before 1940 were not included because of the uncertainty regarding well conditions (especially flowing wells) in the early period. All of the data after 1940 were used with the exception of 33 measurements from three different wells. These measurements were considered either as anomalous or were associated with the transition period (change from a flowing to a non-flowing well) for what was originally a flowing well.

Various statistical and graphical measures were used to evaluate the model recalibration for the Seven Rivers area. A summary of the recalibration statistics is presented in Table 1. A check was also made to evaluate the impact of model parameter changes on the calibration of the previous version of the model. The purpose of this check was to ensure that the changes made to the model parameters in the Seven Rivers area did not adversely affect the calibration of the model as a whole. The model parameter changes in the Seven Rivers area had very little impact on the overall model calibration. There was a slight increase in the mean square error between the computed and measured groundwater levels used in the previous calibration. However, only a few well locations used in the previous calibration process were located in the southern part of the model domain. Consequently, the recalibration effort was focused on an area that did not significantly affect the previous calibration process.

The recalibration results are also demonstrated graphically in Figures 3 and 4. Figure 3 shows various scatter diagrams that were used to evaluate model results. Note that data from the early period (pre 1940) have been distinguished from the later period (post 1940) to enable evaluation of model performance during the more recent times when pumping data are likely to be more accurate and general groundwater conditions are better defined. Figure 4 shows a cumulative frequency diagram of residual groundwater levels (computed minus measured). Again, the data after 1940 have been separated from the total universe of data to enable evaluation of model performance during the more recent times. The reference on Figure 4 to layer 1/3 refers to wells with screen intervals that are open to both the shallow and regional aquifers or where water levels in the well are influenced by both the shallow and regional aquifers. In general, the groundwater level residuals tend to be normally distributed and clustered around zero, which indicates no apparent bias in model results.

Spatial distributions of residuals were also evaluated and again, no apparent bias was noted. A tabulation of average residuals associated with data from individual wells can be found in the Appendix. Hydrographs of computed and measured groundwater levels for individual wells were also evaluated. Some example well hydrographs are shown on Figure 5. Other calibration graphics and well hydrographs used in the recalibration process are presented in the Appendix.

The primary results of the recalibration process were to increase the vertical conductance (leakance) for the confining bed separating the regional aquifer from the shallow aquifer and to adjust the distribution of transmissivity within and near the proposed wellfield area. The conductance parameters associated with the K-M structural zone were evaluated in the recalibration process and reducing those conductance parameters along the southern portion of the zone made a slight statistical improvement in the recalibration. However, reducing these conductance parameters had a negative affect on the calibration statistics and two well hydrographs for the previous model calibration. Since the benefit to the recalibration was limited, these conductance parameters were not adjusted from their previous values. If aquifer test data from the proposed wellfield become available in the future and adjustments in aquifer transmissivity are indicated by such data, conditions along the K-M Structural Zone should be reevaluated.

The distribution of transmissivity values in the Seven Rivers area was adjusted in the recalibration process. The results of that process are shown on Figure 6. This figure shows that the area of the wellfield has an estimated transmissivity on the order of 20,000 feet squared per day and that it increases in a southeasterly direction toward the river. The results also show an area of lower transmissivity located northeast of the proposed wellfield area. The transmissivity as adjusted in the recalibration process was constrained to be more than 10 percent of the values obtained from the previous model calibration which, for the proposed wellfield area, were approximately 15,000 to 19,000 feet squared per day. The purpose of this constraint was, in part, to prevent the parameter estimation process from computing negative transmissivity values and, in part, to keep estimated values within a reasonable range. However, data on transmissivity values in the Seven Rivers area are limited and if aquifer testing data from the proposed wellfield becomes available in the future, these constraints and the distribution of transmissivity in the wellfield area may need to be reevaluated.

As described previously, the hydraulic conductivity for the shallow aquifer in the area of Lake McMillan was also adjusted. A map depicting the adjusted distribution of hydraulic conductivity is shown on Figure 7.

The leakance parameter was generally increased by a factor of about 2 to 10 from the values used in the original model. This generally increased the leakance to a value on the order of 10^{-4} per day from the original value that was on the order of 10^{-5} per day. The recalibrated leakance coefficients are shown on Figure 8. While the recalibrated value is somewhat higher than values reported by Hantush (1955), it may be influenced by the presence of abandoned wells that provide increased leakage between the deep regional aquifer and the shallow aquifer.

To the extent that such wells exist and are not explicitly included in the model, they will create an apparent leakance coefficient that is higher than the physical coefficient. Groundwater levels in some wells strongly suggest that leakage through abandoned wells is occurring, at least in some areas. Although a program to locate and seal abandoned wells has been active in the Seven Rivers area, the success of the program in terms of locating and fully sealing abandoned wells in the area is uncertain. Consequently, until further information is available to better understand the number and impact of abandoned wells, the increased leakance coefficient from the recalibration process is the most appropriate value to use in projecting impacts from the proposed augmentation pumping.

Section 4
Sensitivity Analysis

As part of the calibration process using the PEST software, parameter sensitivities are calculated as a routine part of the parameter estimation process. These sensitivities measure how changes in model parameters impact the computed water levels at the locations and times of the measured water levels. The PEST software provides an overall quantification of the parameter sensitivities through a variable referred to as a composite scaled sensitivity.

Parameter sensitivity is defined as the derivative of a predicted value, in this case groundwater level, relative to a model parameter, such as transmissivity. In simple terms it is the change in the groundwater level caused by a change in a model parameter value divided by the change in the parameter value. In the case of the parameter transmissivity, the sensitivity would have units of feet divided by the units of transmissivity, such as feet squared per day. As a result, the units for sensitivity will be different depending on which model parameter is being considered. In order to compare sensitivities among parameters, values are normalized by multiplying the sensitivity by the parameter value. The resulting scaled sensitivity has the units of feet regardless of which model parameter is being considered.

Sensitivities values are calculated by the PEST software for each measurement location and time. In this case, several thousand values are calculated corresponding to each groundwater level measurement. To facilitate comparison of sensitivity values, composite sensitivities are calculated. Numerically, for each parameter, it is the square root of the weighted sum of the squared sensitivity at each measurement location and time divided by the number of measurements. Hence the term composite sensitivity. This metric provides a simple measure of parameter sensitivity that, when scaled, can be compared to sensitivity for other parameters.

The composite scaled sensitivities were estimated for the general transmissivity in the proposed well field area, for the leakance coefficients of the confining units and for the conductance parameter along the southern part of the K-M structural zone. In general terms, the wellfield area is located in an area about 2 miles wide extending several miles west from Brantley Reservoir (see Figures 1 and 2). The leakance coefficients represent the confining units beneath the wellfield area and extending eastward to Brantley Reservoir and the former area of Lake McMillan. The estimated composite scaled sensitivity values for these generalized parameters are tabulated below.

	Composite scaled sensitivity, feet
Transmissivity in the proposed well field area	0.07
Leakance coefficients of the confining units	0.18
Conductance along southern part of K-M zone	0.06

The sensitivities tabulated above reflect how parameters affect computed water levels at the specific locations and times associated with the measured data. They indicate that for these three parameters, the computed water levels are more sensitive to the leakance of the confining units and less sensitive to the other two parameters.

The parameter sensitivities are also used by the PEST software to estimate parameter confidence intervals. The 95-percent confidence interval on the transmissivity and leakance parameters were calculated to be about 15 to 20 percent of the estimated value. In theory, these confidence intervals might be used to calculate ranges in predicted or forecasted values. In this case, they might be used to calculate ranges in computed water levels or river depletions or accretions. However, the calculated confidence intervals for the parameters are very narrow and produce only a small range in predicted values. This result can be misleading, however, because it assumes that the other model parameters and conditions are known or given. While the overall model parameters and conditions have been determined through a model calibration process that considered both groundwater levels and groundwater flow (river base flows), information on the groundwater flow in the Seven Rivers area is limited. As a result, the model parameters and conditions in this area are not likely as well determined as in other areas.

While specific ranges in predicted values (of water levels or river depletions and accretions) cannot be computed, sensitivities of the predicted values can be at least qualitatively determined. For example, river depletions or accretions are more sensitive to the leakance of the confining units than to the transmissivity in the well field area. Conversely, water level declines in the well field area are more sensitive to the transmissivity of the well field area than to the leakance of the confining units.

Section 5
Summary and Conclusions

SSP&A completed a recalibration of the Roswell Basin Groundwater Model so the model could be used to evaluate the potential impacts of augmentation pumping and irrigation retirement scenarios. The recalibration focused on the Seven Rivers area and utilized over 2,800 water level measurements. The recalibration ultimately focused on transmissivity in the proposed well field area and on the leakance of the confining units separating the regional aquifer from the shallow aquifer. The estimation of parameter values was guided by both subjective and objective factors to arrive at the final selected values.

Based upon the model recalibration described above, the following conclusions have been reached.

- Recalibration of the groundwater model in the Seven Rivers area resulted in an estimated transmissivity for the artesian aquifer of about 20,000 feet squared per day in the well field area.

- The recalibration also resulted in an estimated leakance for the confining units in the Seven Rivers area that was on the order of 10^{-4} per day.

- Although the computed confidence intervals for the model parameters that were estimated through the recalibration process span a relatively narrow range, the parameter estimates and the confidence intervals are contingent upon other parameters and conditions that were specified in the model.

- The sensitivity of computed water levels to model parameters was quantified from results of the parameter estimation process and indicated that leakance of the confining units was the most sensitive parameter.

Section 6
References

S.S. Papadopulos & Associates, Inc. 2003a. Roswell Basin Groundwater Model Report. January 14.

S.S. Papadopulos & Associates, Inc. 2003b. Update and Recalibration of Roswell Basin Groundwater Model. December 24.

S.S. Papadopulos & Associates, Inc. 2004. Augmentation Pumping and Irrigation Water Use Retirement in the Seven Rivers Area of the Roswell Basin. June 23.

FIGURES

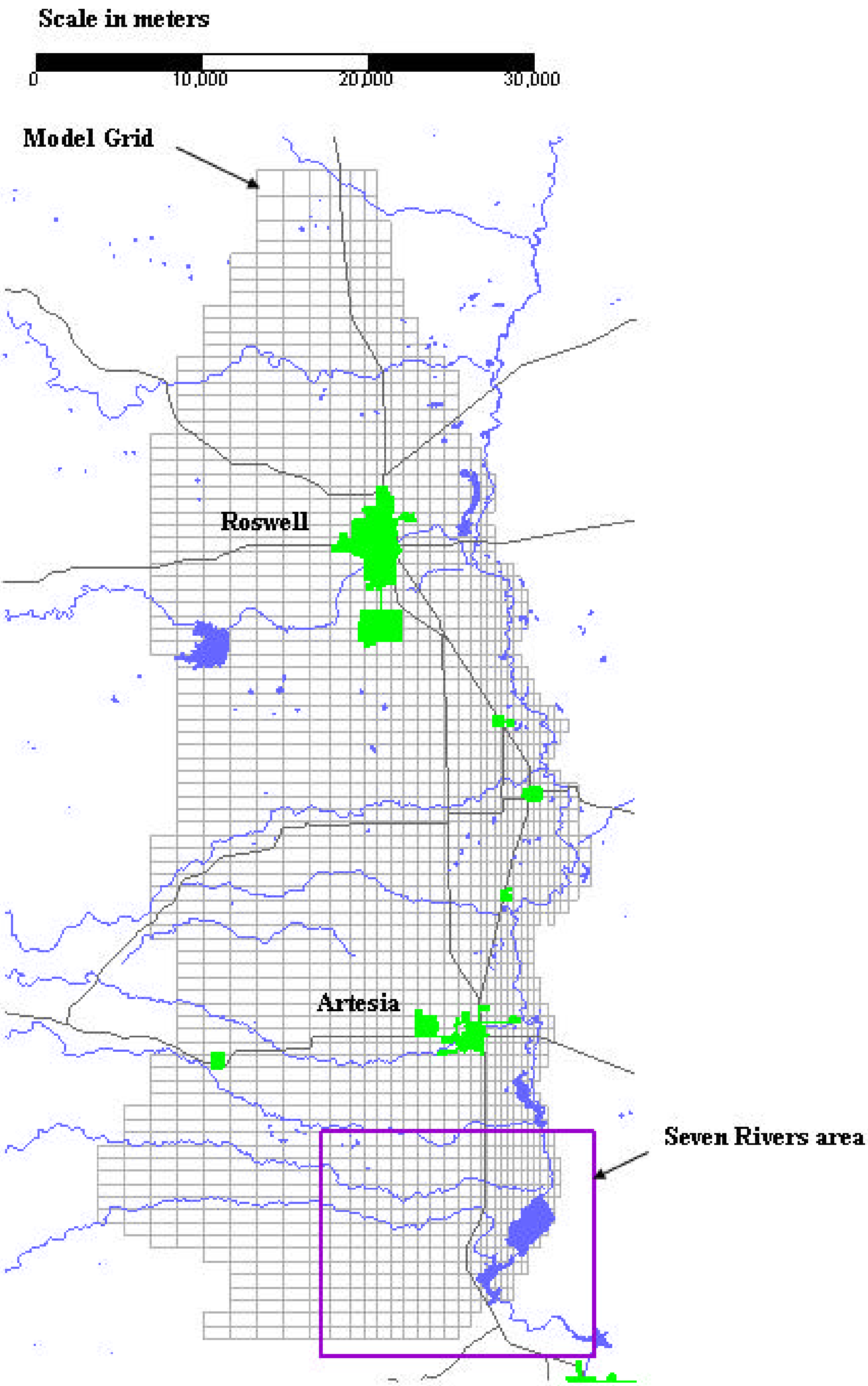


Figure 1 Location Map of Seven Rivers Area

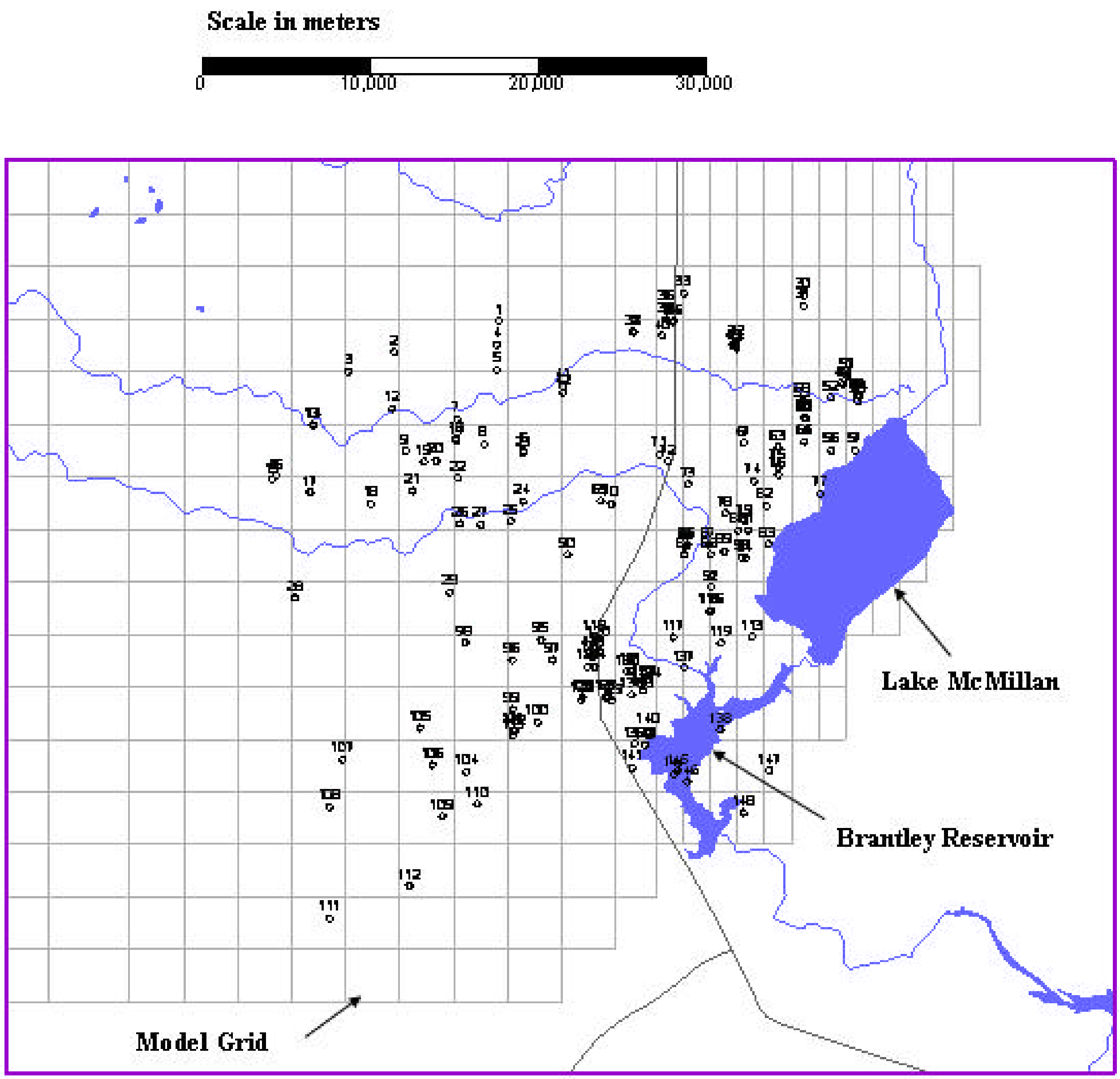


Figure 2 Location Map of Wells with Measurements Used in Model Recalibration of Seven Rivers Area

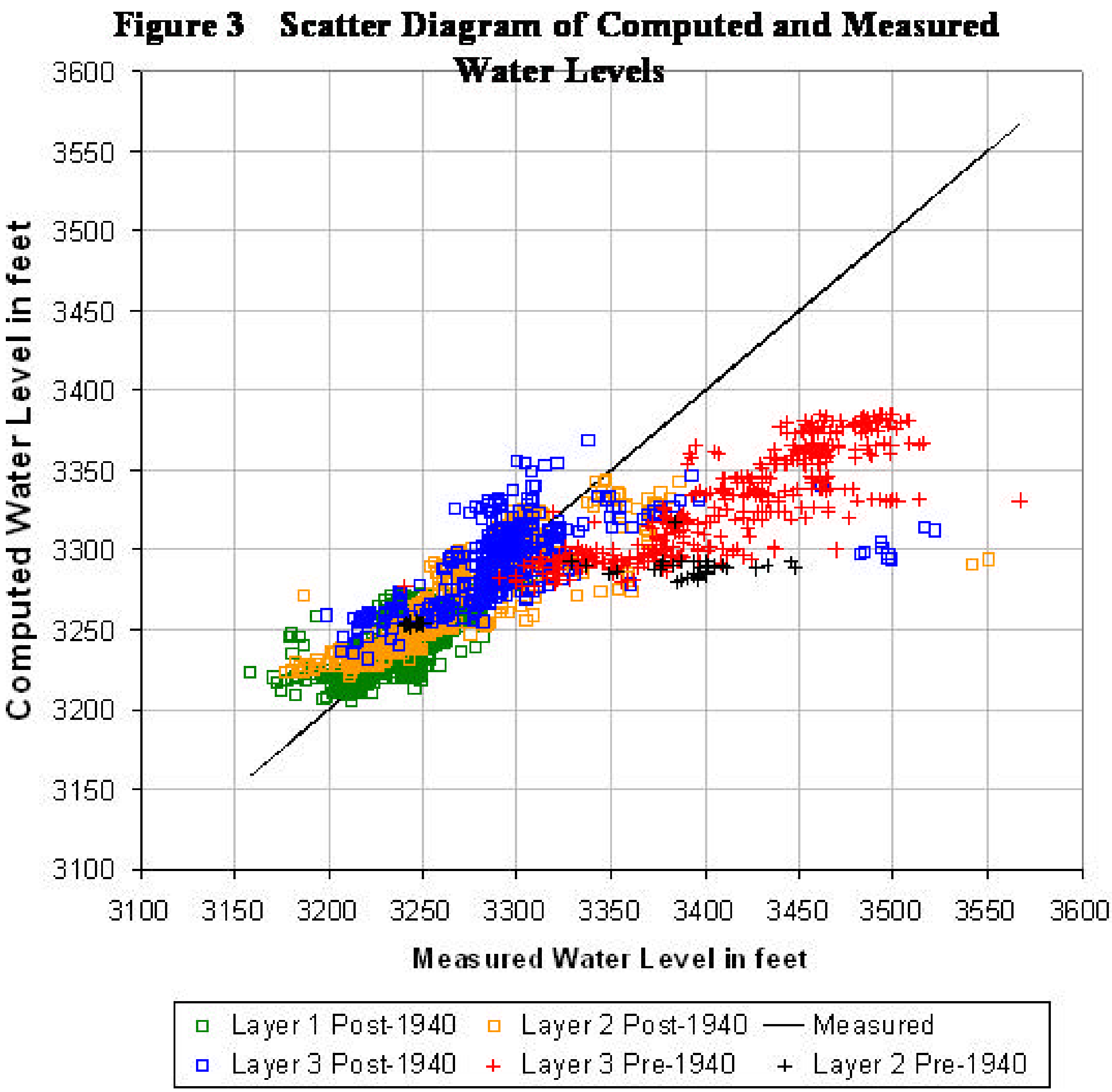


Figure 3 Scatter Diagram of Computed and Measured Water Levels

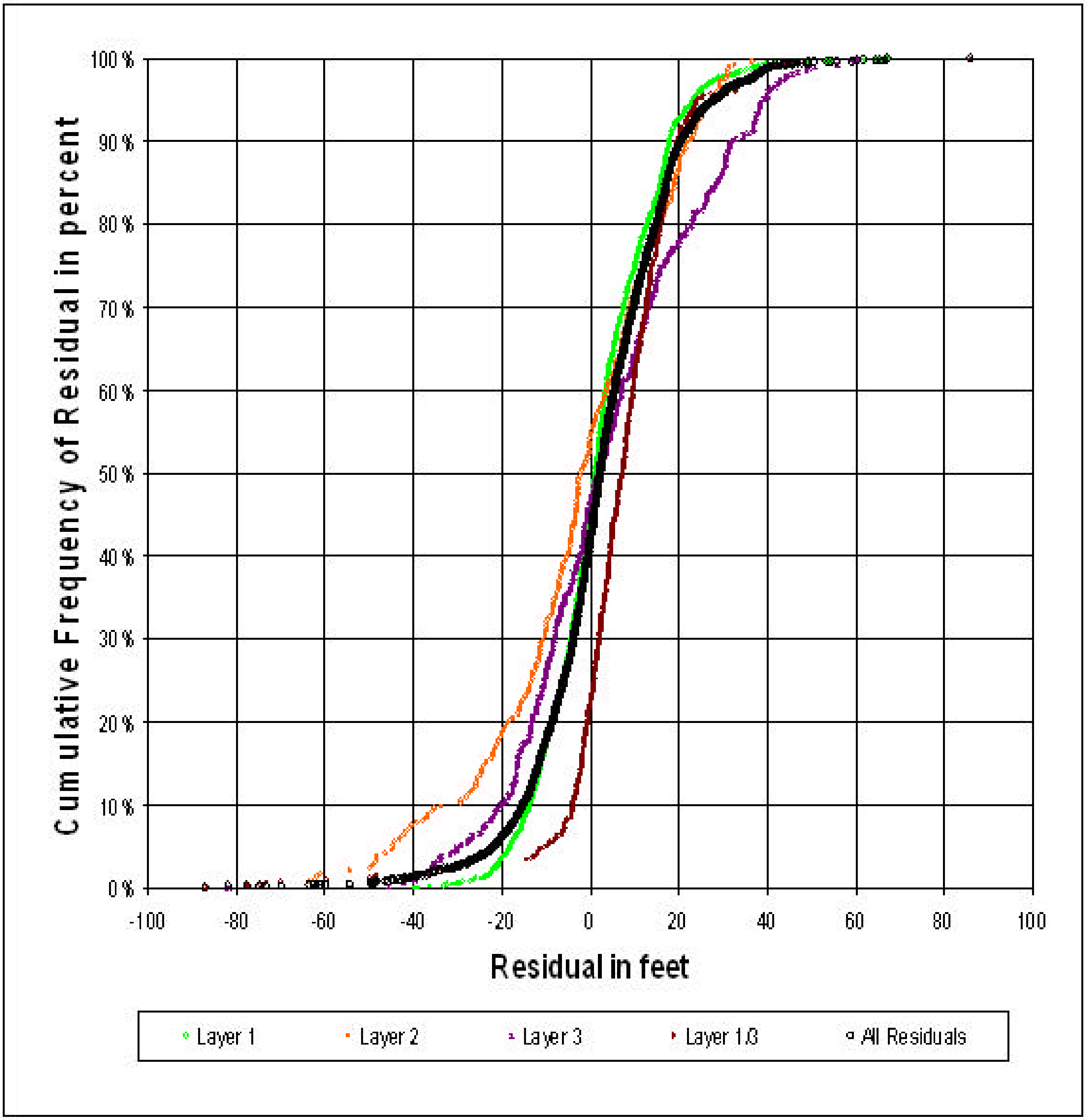


Figure 4 Cumulative Frequency Diagram of Residuals (Computed Minus Measured Water Levels) for Data after 1940

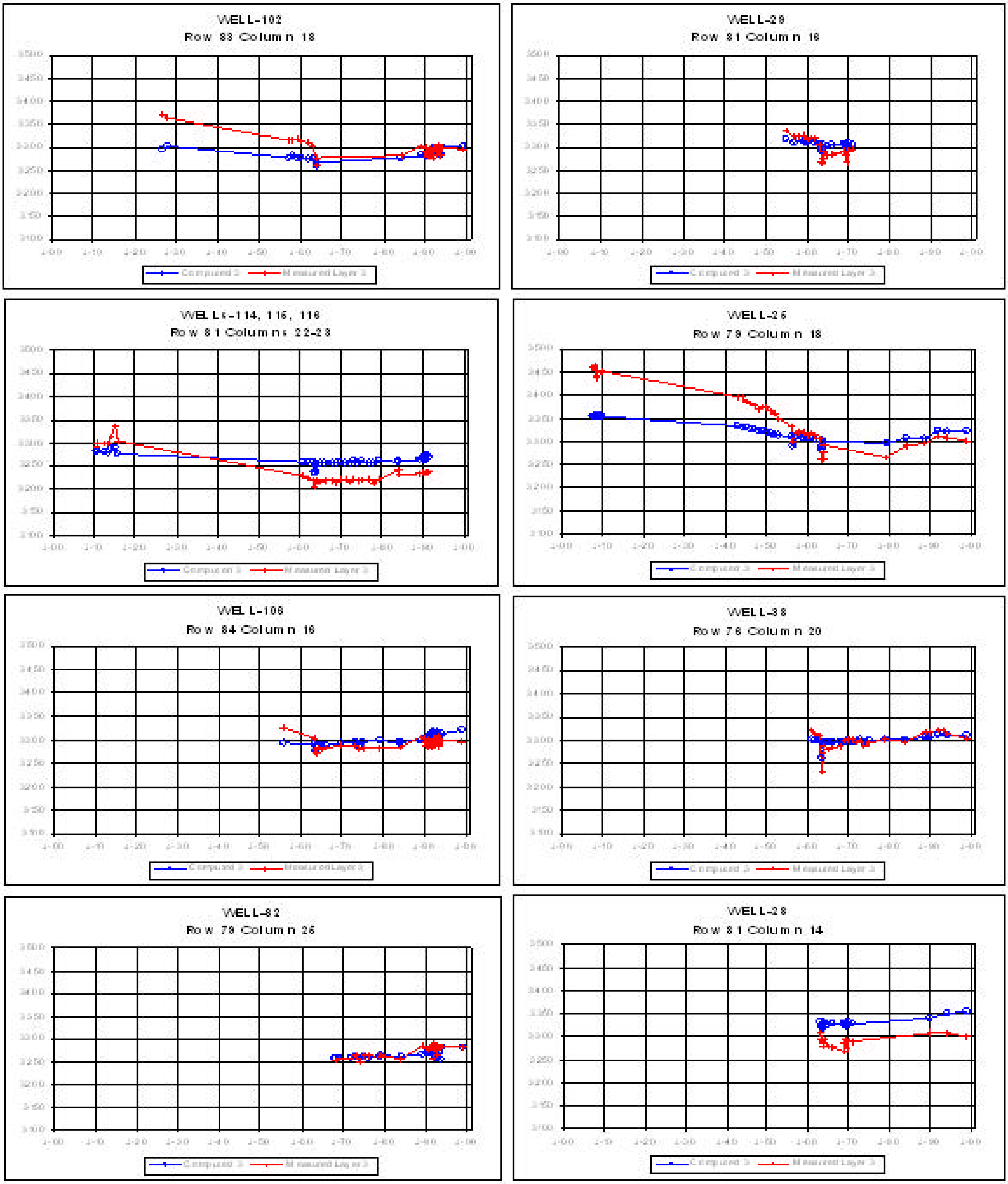
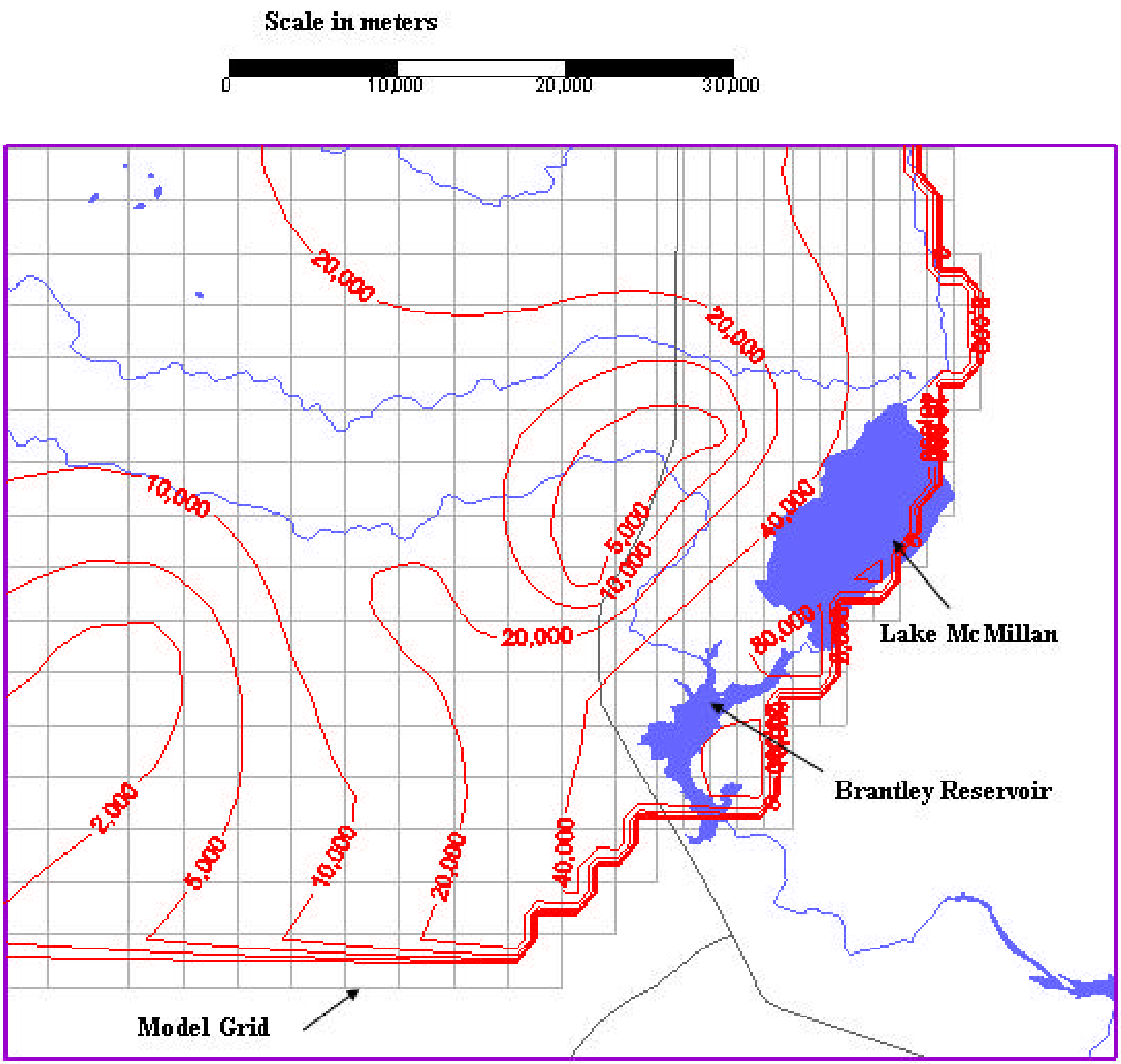


Figure 5 Example Hydrographs Comparing Computed and Measured Water Levels



Contours of equal transmissivity in feet squared per day.

Figure 6 Map of Recalibrated Transmissivity for the Regional Aquifer in the Seven Rivers Area

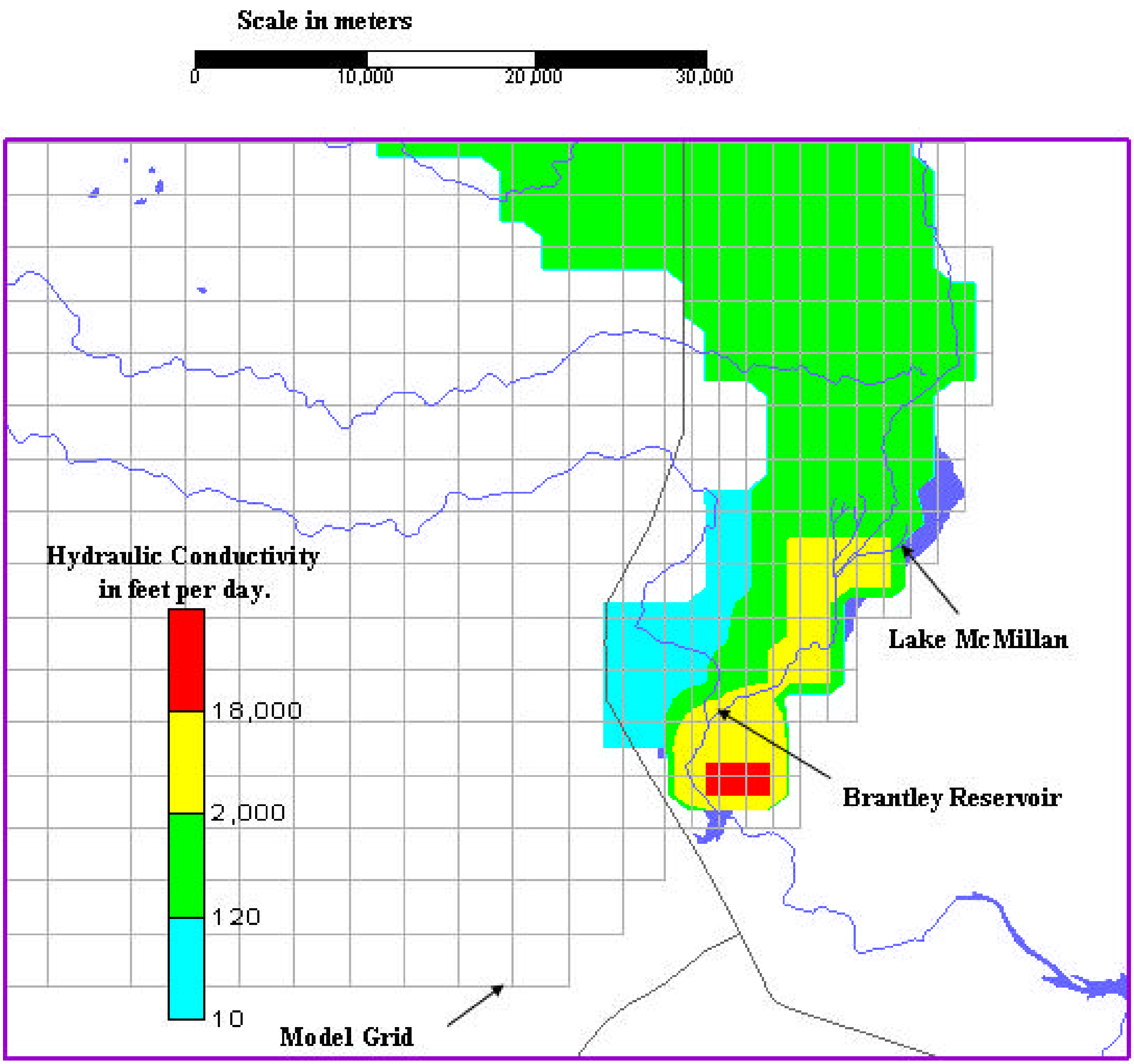


Figure 7 Map of Hydraulic Conductivity for the Shallow Aquifer in the Seven Rivers Area

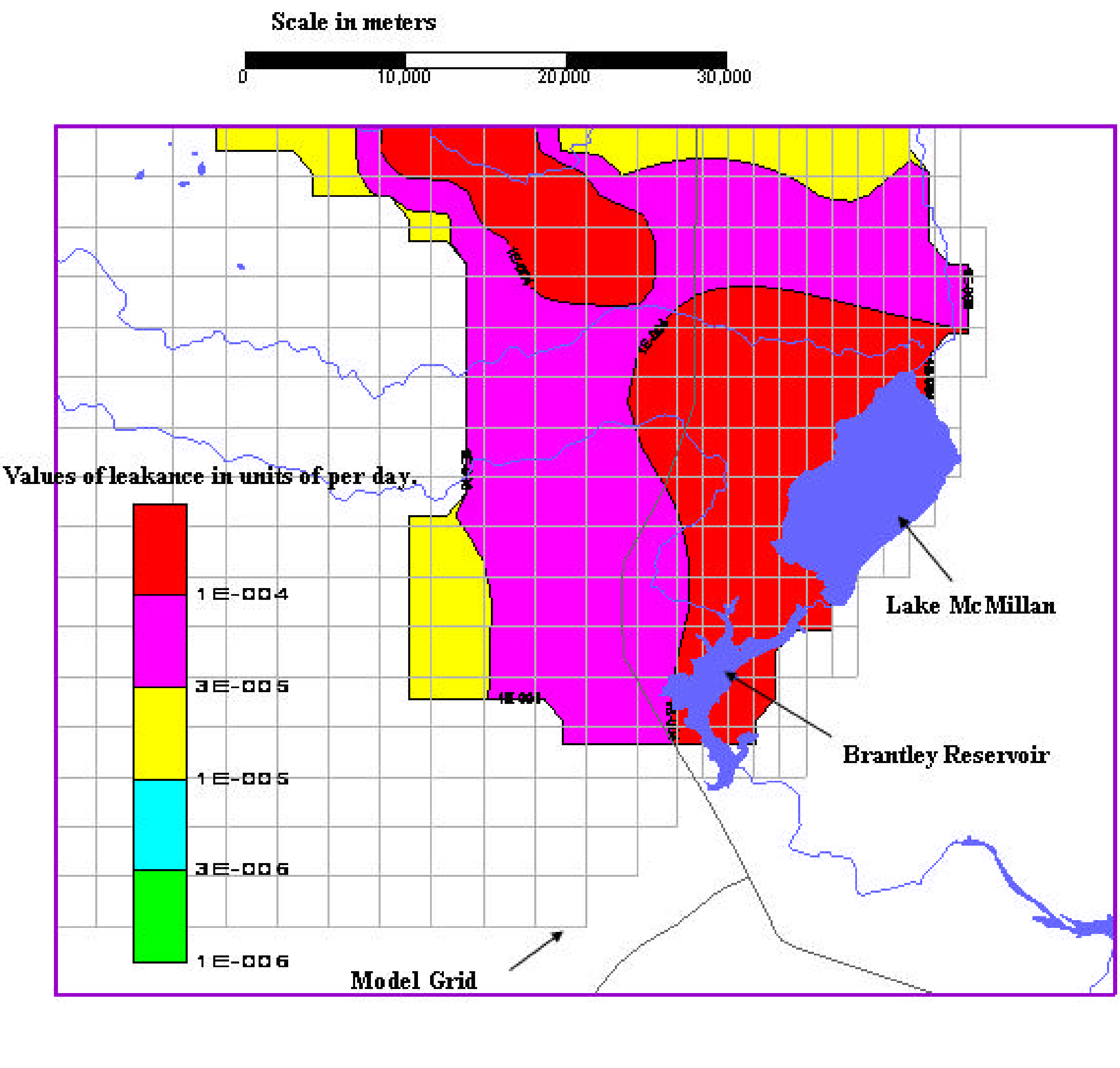


Figure 8 Map of Recalibrated Leakance for the Lower Confining Unit in the Seven Rivers Area

TABLES

Table 1 – Summary of Recalibration Statistics

Statistics of Residuals (Computed minus Measured Water Levels in feet)

	Count	Mean	Standard Deviation	Percentiles 10%	25%	50% Median	75%	90%
All residuals	3,413	-10.4	37.7	-71.6	-12.9	-0.1	10.0	18.8
Post-1940 residuals	2,832	2.5	17.3	-15.2	-6.0	2.3	12.2	20.6
Layer 1 Post-1940	1,585	2.0	13.1	-13.6	-6.2	1.1	10.2	18.0
Layer 2 Post-1940	294	-4.3	16.8	-32.5	-13.2	-2.2	12.0	21.8
Layer 3 Post-1940	424	3.6	20.8	-20.4	-10.4	1.8	15.9	31.6
Layer 1/3 Post-1940	529	6.7	15.1	-3.9	0.9	7.2	14.0	19.6

APPENDIX

Appendix

Tabulation of Average Residuals (on CD attached to back cover)