ASSESSMENT OF WESTERN NAVAJO AND HOPI (WNH)
WATER SUPPLY NEEDS, ALTERNATIVES AND IMPACTS

TECHNICAL MEMORANDUM

WNH THREE CANYONS (WNH3C) GROUNDWATER FLOW MODEL

This memorandum describes the evaluation and revision of an existing groundwater flow model for the Three Canyons (Clear Creek, Chevelon Canyon, and Jack's Canyon) area between the southwest corner of the Navajo Nation and the Mogollon Rim. The existing model was developed HydroGeoChem, Inc. (1997) for the Bureau of Indian Affairs and the reader is referred to that document for supporting information. HydroGeoChem(1997) used a proprietary model code, called ABEL, to develop the existing model, now informally called the "Hopi Ranches Model". The revised model is called the Western Navajo-Hopi Three Canyons (WNH3C) model and is based on the freely-available MODFLOW model code. The purpose of the WNH3C model is to estimate the impacts from pumping on baseflows in Clear Creek and Chevelon Canyon. This memorandum only addresses the development and calibration of a steady state simulation using the WNH3C model.

1.0 Initial Model Preparation

The WNH3C model was developed from basic data, rather than conversion of the input files developed for the ABEL-based Hopi Ranches Model. The first step was to plot the basic data in the form of GIS files in ArcGIS ArcView version 8.2. The GIS files are in UTM Zone 12, NAD 1927 coordinates. The WNH3C model uses feet and days as units. The offset from the origin of UTM Zone 12 to model coordinates is: 1,570,505 feet in the X direction, 12,521,635 feet in the y direction, and no tilt from an easterly orientation. The steady state model was developed from GIS files using Groundwater Vistas Version 3.3.

The model grid was designed, following the HydroGeoChem (1997) report as a grid of 211 columns and 183 rows. Each grid cell is a square has the same size: 1320 feet on a side.

The next step was to plot and contour the available water-level measurements indicated in HydroGeoChem (1999) and provided as an EXCEL file by John Ward, one of the authors of the HydroGeoChem (1997) report. The resulting contours were similar to those presented in HydroGeoChem (1997) and were used to assign prescribed head boundary conditions around the model periphery.

The top of the C-Aquifer was delineated from surface elevations where the C-Aquifer is exposed at land surface (determined from the Arizona Geological Survey Geologic Map of Arizona). Where the Moenkopi and some younger units overlie the C-Aquifer, modifications were made to the land surface-based estimate for the top of the C-Aquifer. In the north and northeast areas of the model, where the C-Aquifer is deeply buried, contours on the base of the overlying Moenkopi Formation were transcribed from Ulrich & others (1984). The remaining areas covered by Moenkopi Formation were addressed manually by continuing land surface elevation contours across from opposing sides of limited areas of Moenkopi Formation occurrence.

The base of the C-Aquifer was derived by subtracting the saturated thickness presented by HydroGeoChem (1997) from the estimated water-level elevation in the C-Aquifer for areas of exposed C-Aquifer. For the north-northeast area, a thickness of approximately 650 feet was subtracted from the elevation of the base of the Moenkopi Formation.

The available hydraulic conductivity estimates were plotted by HydroGeoChem (1997). The supporting aquifer test data were not obtained or re-analyzed for this effort. Based on inspection of the plot of the available hydraulic conductivity estimates, a range of values of 0.1 to 20 feet per day (ft/d) was considered reasonable. No systematic trend or grouping is apparent for the WNH3C model area from inspection of the HydroGeoChem (1997) plot. The three-part distribution used by HydroGeoChem (1997) in their model (one zone each with 1, 6, or 6.5 ft/d) was used as an initial distribution.

The locations of channels potentially interacting with groundwater were identified by comparing the water-level elevation contours with land surface elevation contours shown on USGS 7.5 minute quadrangle sheets along Clear Creek and Chevelon Canyon. Three primary areas were identified as having potential groundwater interaction:

- Clear Creek in the vicinity of Blue Ridge Reservoir,
- Clear Creek near its confluence with the Little Colorado River, and
- Chevelon Canyon near its confluence with the Little Colorado River.

The lower Clear Creek and lower Chevelon Canyon reaches were documented by HydroGeoChem (1997) as perennial, but no discussion was provided of the perennial nature of Clear Creek and its tributaries near Blue Ridge Reservoir in the far southwestern corner of the Hopi Ranches Model. Nevertheless, comparison of water-level elevations and the land surface confirms the potential for groundwater-surface water interaction in the vicinity of Blue Ridge Reservoir. The model grid was overlain on the 7.5-minute quadrangle sheets in ArcView 8.2 and parameters for the MODFLOW Stream Package were estimated fro each cell representing Clear Creek, Chevelon Canyon, and a few tributaries of Clear Creek near Blue Ridge Reservoir.

Although HydroGeoChem (1997) did not incorporate recharge into their simulation, review of a recent white paper on recharge developed by HDR (2002) indicated that the exposed C-Aquifer should receive significant recharge, particularly at the elevations included in the WNH3C model. Simplified regions of equal recharge based on the elevations, precipitation, and percent of precipitation becoming recharge were adopted as initial recharge inputs for the WNH3C model for areas of exposed C-Aquifer.

An area in the southeastern portion of the WNH3C model, noted as dry by HydroGeoChem (1999) was set as inactive in the WNH3C model.

The depths to water across the model were calculated and reviewed. Based on this review, the potential or evapotranspiration from the groundwater was considered to be negligible at this time. Future evaluation may provide a basis for adding the simulation of evapotranspiration in limited areas.

The pre-conditioned conjugate gradient solver package (PCG2 – Hill, 1990) was selected for the WNH3C model. The solver was set to achieve a head residual of 1×10^{-4} feet and a mass balance residual of 1 cubic foot per day (ft^3/d) using 1,000 outer iterations and 10 inner iterations.

3.0 Water-Level Targets and Calibration

The water-level data provided by John Ward were input to Groundwater Vistas Version 3.3 as targets for calibration the model was operated with MODFLOW-2000 and the match of model simulation to measurements was observed. Overall match was relatively poor so calibration was pursued. Calibration consists of adjusting input parameters to improve the match of model-simulated water-level elevations to measured water-level elevations. The hydraulic conductivity and recharge distributions described above were modified to achieve an acceptable calibration. The required modifications were well within the range of reasonable values.

After acceptable calibration was achieved, a band of cells surrounding the inactive area in the southeast portion of the model were set to inactive as their bottom elevations were above the simulated water level elevations.

4.0 Results

The inflow portion of the WNH3C model mass balance for steady conditions consists of 16,915 acre-feet per year (ac-ft/yr) of inflow from prescribed head boundaries, joined by 35,450 ac-ft/yr of diffuse recharge, and 2,840 ac-ft/yr of recharge from streams. The outflow portion of the WNH3C model mass balance for steady conditions consists of 50,330 ac-ft/yr of outflow to prescribed head boundaries and 4,875 ac-ft/yr of baseflow out to streams. Total inflow or outflow under steady conditions is approximately 53,000 ac-ft/yr.

The base flow gains for Clear Creek and Chevelon Canyon simulated by the WNH3C model are as follows:

- 4 cubic feet per second (cfs) for Upper Clear Creek in the vicinity of Blue Ridge Reservoir
- 2.5 cfs for Lower Clear Creek
- 0.4 cfs for Lower Chevelon Canyon

These values are different than those derived from model simulations by HydroGeoChem (1997), who found:

- No flow for Upper Clear Creek in the vicinity of Blue Ridge Reservoir
- 4 cfs for Lower Clear Creek
- 5.5 cfs for Lower Chevelon Canyon.

A useful assessment of the meaning of the differences between the HydroGeoChem (1999) and WNH3C models would require detailed analysis of available stream flow records and observations. However, given the acceptable simulation of the water-level elevations by the WNH3C model, particularly in the areas of the groundwater-surface water interactions, such an analysis is not considered necessary at this time.

Figure 1 shows the extents of the WNH3C model, modified from the existing HydroGeoChem model (1997) as discussed in this memorandum. Also shown on Figure 1 are the inactive cells, prescribed head (constant water-level elevations in this case) cells, stream package cells, the Little Colorado River and lesser surface water channels, township and range boundaries, and the locations of major roads.

Figures 2 and 3 show the distributions of hydraulic conductivity and recharge in the calibrated WNH3C model. Figure 4 shows the measured water-level elevations at points, interpreted contours of the measurements, and the water-level elevations simulated by the WNH3C model.

Figure 5 shows the cross plot of simulated and measured water level elevations after calibration. The current standard deviation of the water-level elevation simulation residuals is 39 feet, which is approximately two percent of the overall range in measured water-level elevations (1758 feet). Figure 6 shows the distribution of WNH3C calibration residuals (measured water-level elevation minus simulated water-level elevation). The WNH3C model is ready for simulations of the response of base flows in Clear Creek and Chevelon Canyon to future pumping from the C-Aquifer.

4.0 REFERENCES

HDR Engineering, 2002. White Paper – Recharge Assessment of Western Navajo Hopi Water Supply N-Aquifer Model (WNHN), prepared for and presented to the Technical Support Group.

Hill, M. C., 1990, Preconditioned Conjugate-Gradient 2 (PCG2), a Computer Program for Solving Ground-Water Flow Equations: U.S. Geological Survey Water-Resources Investigations Report 90-4048, 43 pages.

HydroGeoChem, Inc. 1997. Results of Numerical Simulations of Impacts on Clear and Chevelon Creeks from Proposed Groundwater Developments on Clear Creek and Aja Ranches (Hopi Ranches), prepared for the U. S. Bureau of Indian Affairs, dated, December 4, 1997, 24 pages plus tables and figures.

Ulrich, G.E., Billingsley, G.H., Hereford, R., Wolfe, E.W., Nealey, L.D., and R.L. Sutton, 1984. Map Showing Geology, Structure, and Uranium Deposits of the Flagstaff 1 Degree by 2 Degree Quadrangle, Arizona, U.S. Geological Survey, Miscellaneous Investigation Series, Map I-1446.

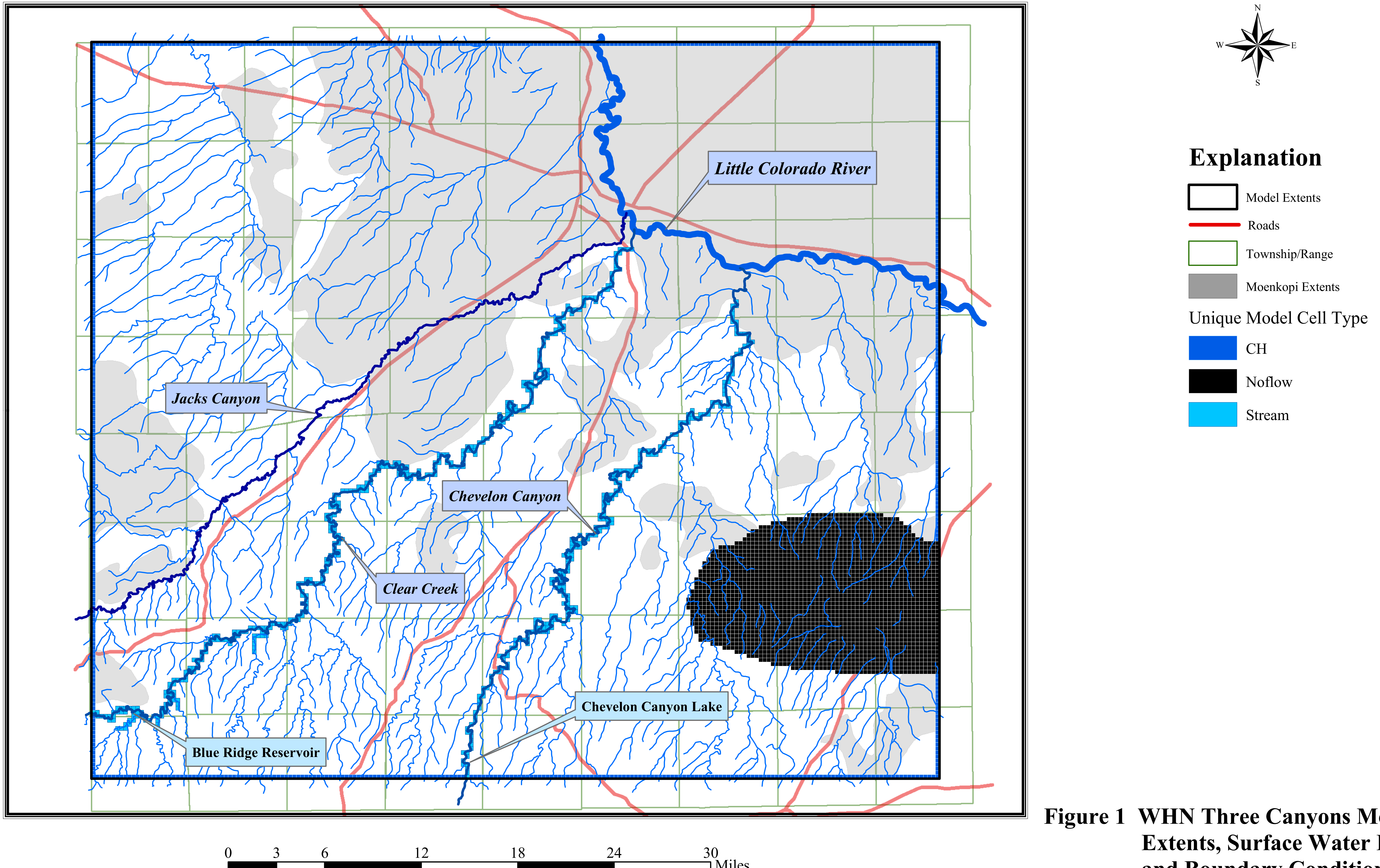


Figure 1 WHN Three Canyons Model Extents, Surface Water Features and Boundary Conditions

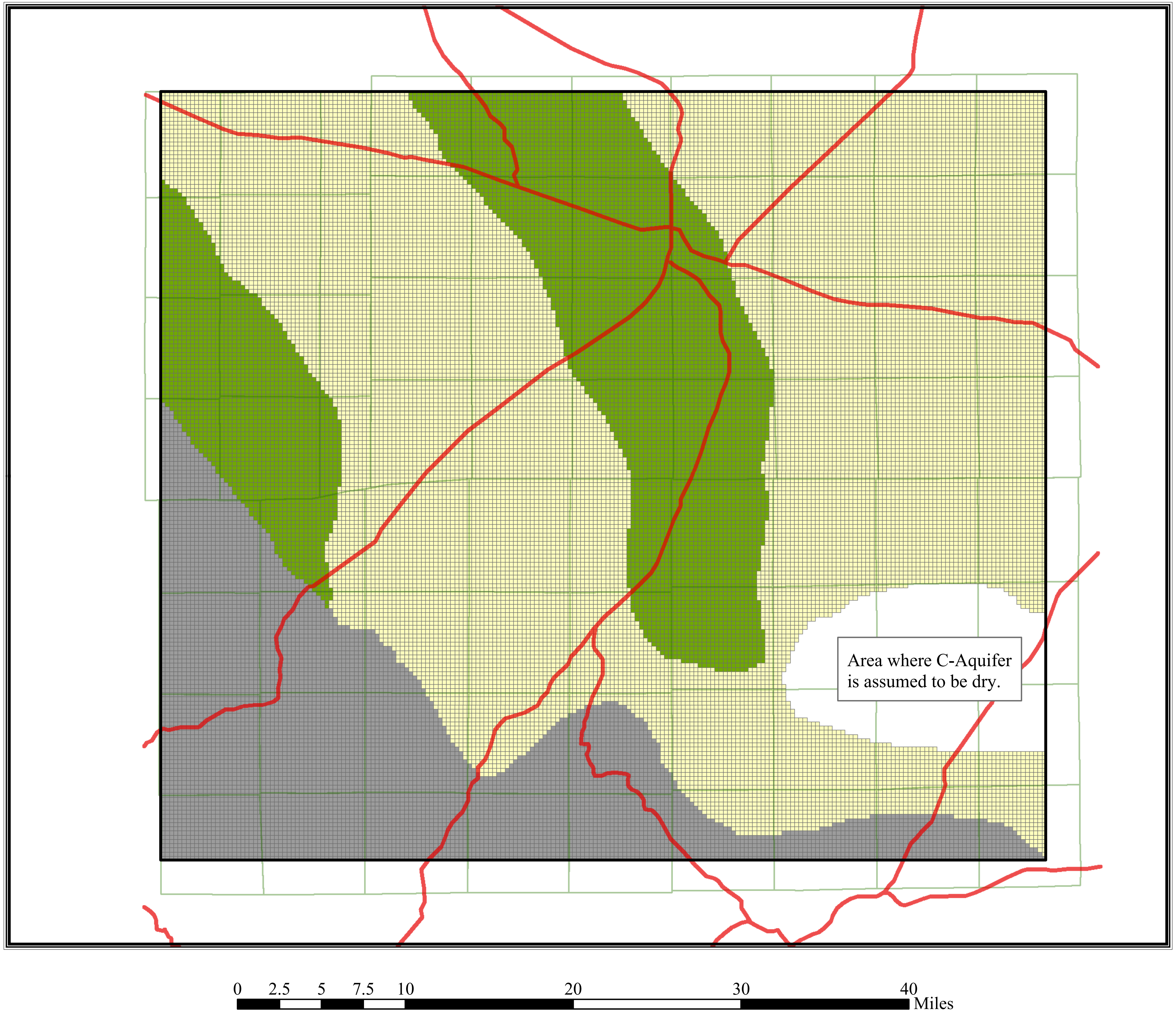


Figure 2 Distribution of Calibrated Hydraulic Conductivity WNH Three Canyons Model

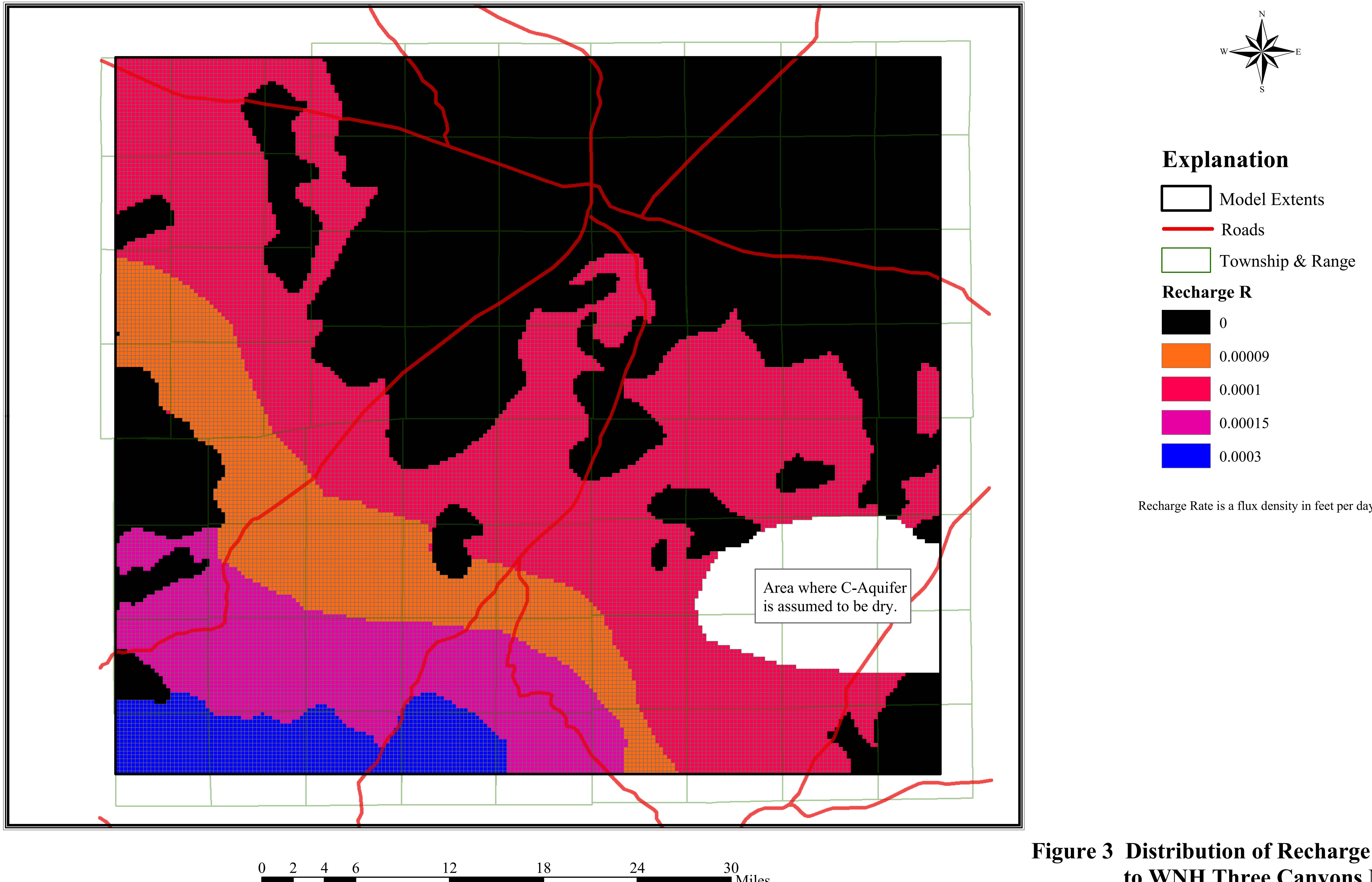


Figure 3 Distribution of Recharge Applied to WNH Three Canyons Model

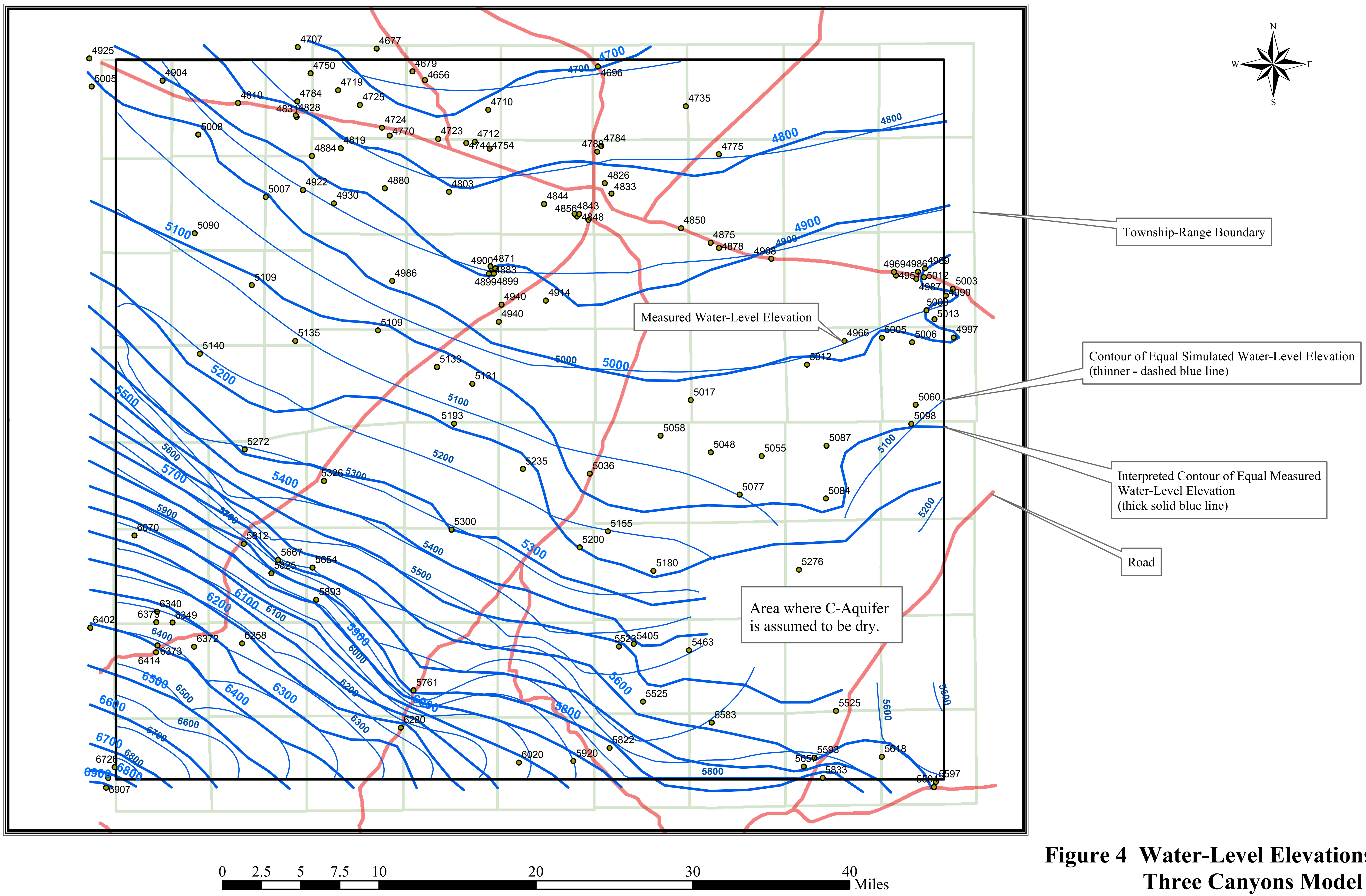
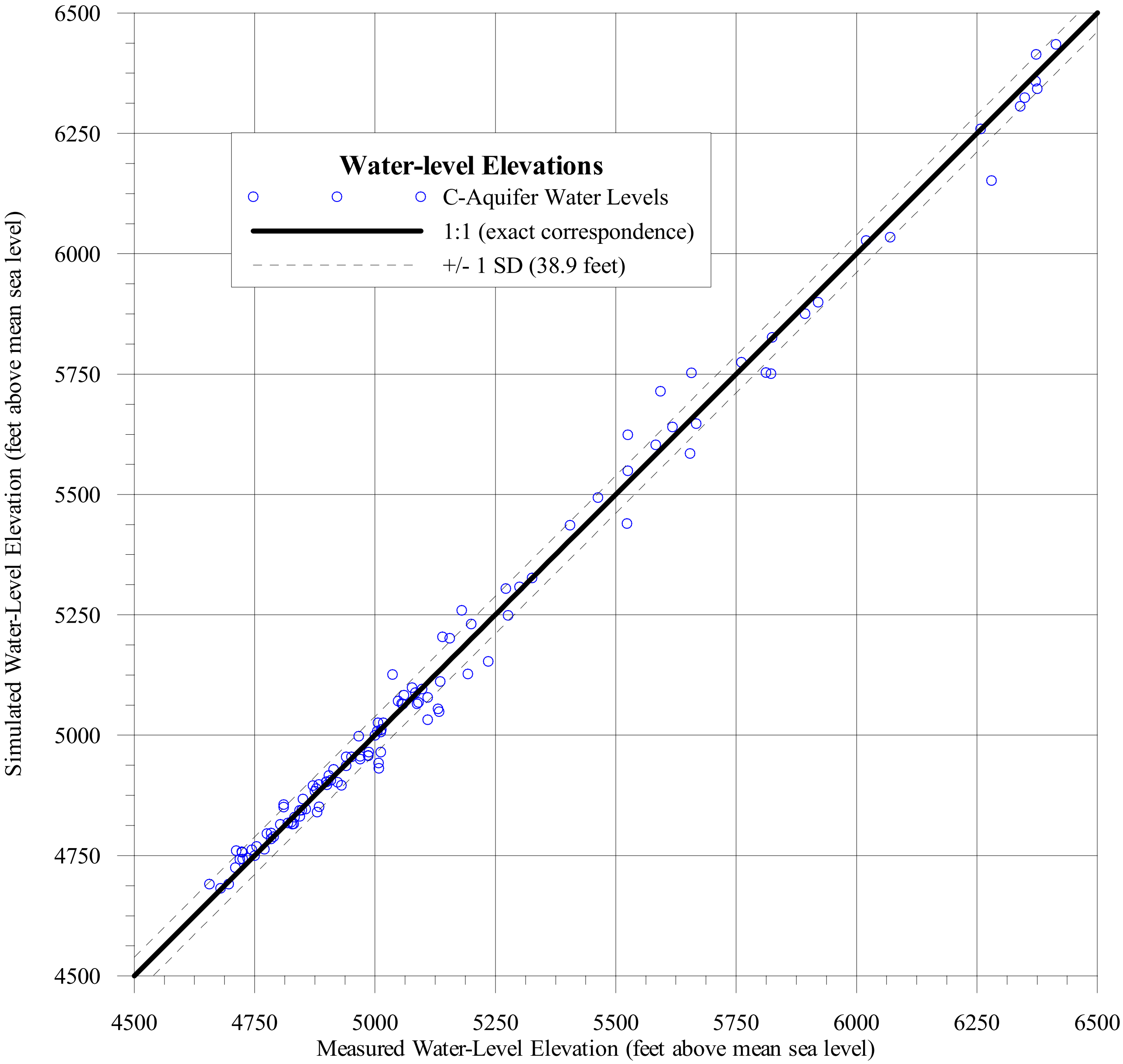


Figure 4 Water-Level Elevations WNH Three Canyons Model Area



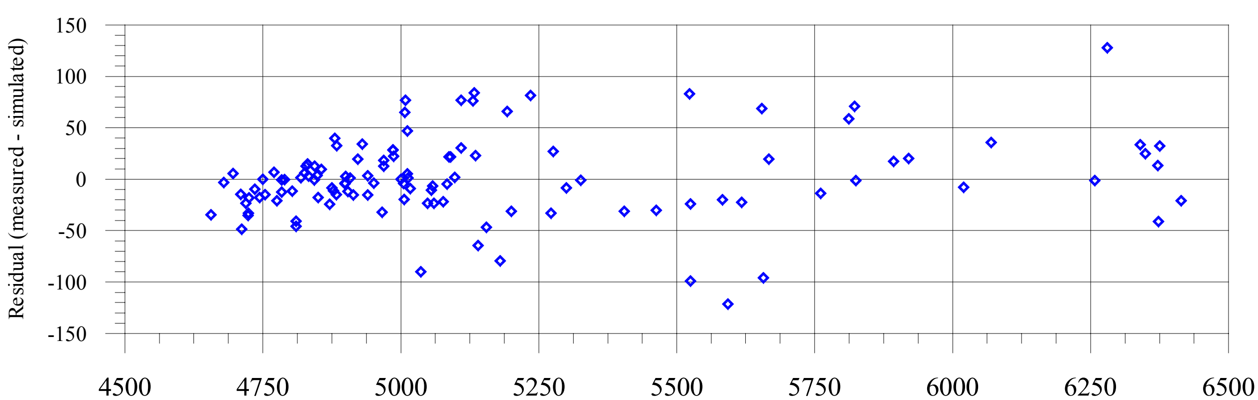


Figure 5 Cross Plot and Residuals Plots for Measured and Simulated Water-Levels, WNH Three Canyons Model

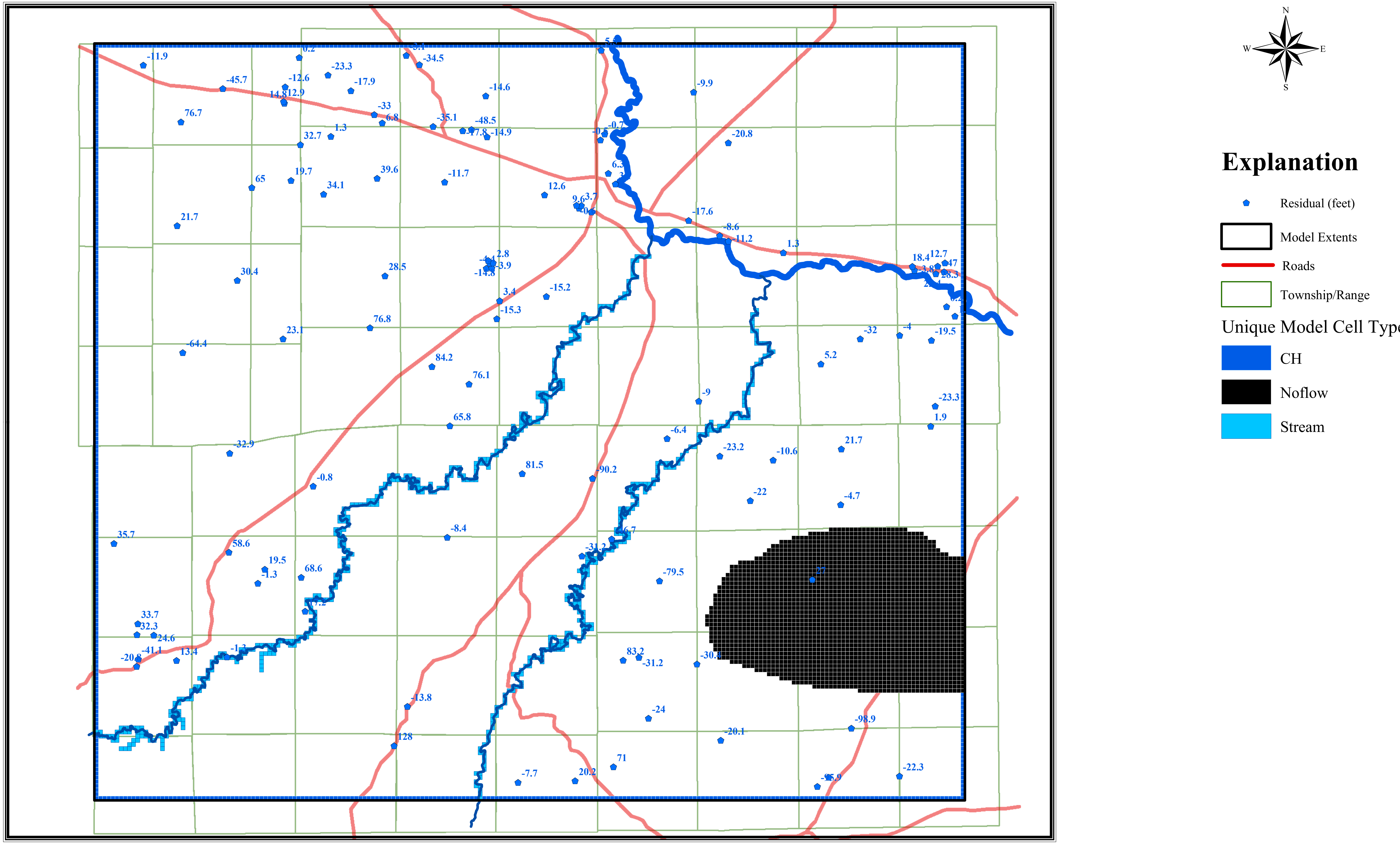


Figure 6 WHN Three Canyons Model Calibration Residuals