Memo

Adaptive Resources, Inc.

To: Western Water Use Management Modeling Joint Board

From: Thad Kuntz, P.G., and Joe Reedy

Date: 5/21/2016

Re: Western Water Use Management Ground Water Model Update through April 2014

INTRODUCTION

The Western Water Use Management (WWUM) ground water model, as documented in the report *Ground Water Flow Model for the Southern Half of the Nebraska Panhandle* (Luckey, 2013) and associated WWUM Modeling documentation, represents a comprehensive effort to understand and simulate the ground water system in the southern panhandle of Nebraska. The Luckey (2013) report describes the process of creating and calibrating the model to represent the system from May 1, 1953, through April 30, 2011. This document details the process of extending the model through April 30, 2014, including the extension of existing model properties, parameters, and calibration tools, as well as verification that the model's calibration reasonably represents the system.

This document provides details on the extension of the ground water model portion of the overall WWUM Modeling suite. Updates to the land use and acreage datasets, surface water operations (SWO) model and the Regionalized Soil Water Balance (RSWB) model are detailed in separate documentation. Updates to the ground water model that rely on information from other models or datasets created for the WWUM Model suite are discussed briefly, with references to sources. Additional information on each model and dataset may also be found in the *WWUM Modeling Chronological Index of Documentation* (Kuntz, 2016) and the original Luckey (2013) ground water model report.

MODEL PROPERTIES AND PARAMETERS EXTENSION

The Groundwater Vistas (GWV) software licensed by Environmental Simulations, Inc., was used for most of the ground water model extension, including editing the modeling packages and files. The software was developed as a graphical user interface for the MODFLOW modeling program with additional utilities available. Some package and dataset extensions were accomplished entirely within GWV, while others required creating or extending datasets in Microsoft Excel or Access and then importing into GWV.

The previous calibrated model, *model_1953-2011_130621.gwv*, was retitled with the new model name and date, *model_1953-2014_150707.gwv*. The original evapotranspiration (ET) surface file, *et_surface_120719.dat*, has been maintained. All file paths and root file names were updated to reflect the updated model name and directory.

The ground water model uses historical calendar months to represent stress periods for modeling calculations. The stress period dataset was expanded from 696 stress periods to 732 stress periods, maintaining the number of days in the month it represents, from May 1953 through April 2014. Each stress period uses six time steps with a time step multiplier of one. All stress periods are transient. To create the new dataset, the previous stress period dataset was exported from GWV, expanded in Excel, and reimported to GWV.

Boundary conditions, including specified head and head-dependent flux boundaries, were copied from stress period 696 to stress periods 697 through 732 using the GWV “copy stress period” tool. These include constant head cells, drain cells, general head cells, stream cells, and no-flow cells.

Non-variable model properties were copied automatically during the stress period extension, including hydraulic conductivity, storage, porosity, specific yield, top of layer 1 elevation, bottom of layer 1 elevation, and initial heads. Recharge and ET are treated as properties in GWV because they extend over extensive areas of the model and are represented zonally in the form of constant flux and head-dependent flux boundaries, respectively. ET was extended in GWV using the “copy transient cycle” tool for boundary conditions using the stress periods from 684 to 696, representing one annual cycle, to the range of stress periods from 697 to 732.

To complete the extension of the WWUM Modeling suite, the land use dataset was updated using aerial photography to determine the irrigation type on each parcel, which was then attributed with land-use and crop information. North Platte Natural Resources District (NPNRD) and South Platte Natural Resources District (SPNRD), sometimes referred to as Districts, provided irrigation well flow meter and crop history information for each certification to attribute the updated land use datasets. To extend the land use, crop types, and pumping estimates for lands not included in either District but which are within the model area, data for these lands were synthesized from recent past years of similar climatic conditions. This dataset was utilized in the SWO and RSWB models to provide extended pumping and recharge datasets for use in the ground water model.

The RSWB model was updated and extended by The Flatwater Group (TFG) to create several datasets that include the net irrigation requirement dataset utilized by the SWO model and the recharge dataset used in the ground water model. Calibration of the RSWB model’s consumptive use for winter wheat, alfalfa, and grass pasture resulted in changes to irrigation pumping and recharge for the period of time in the model before irrigation well flow meters were required by the Districts (also referred to as the pre-metered pumping). These changes are documented in the *Quality Assessment and Calibration of the Regionalized Soil Water Balance Model* (Kuntz, 2016). The RSWB modeling is documented in the report, *The Western Water Use Model: Regionalized Soil Water Balance Model* (The Flatwater Group, 2016).

The update and extension of the SWO model were completed by Wilson Water Group (WWG) and provided canal seepage from all canals and farm headgate deliveries for surface water only and commingled lands within NPNRD to the RSWB model over the entire model period. The pre-metered commingled pumping was provided to Adaptive Resources, Inc. (ARI), for further processing and incorporation into the RSWB and ground water models. The SWO modeling is documented in the *Western Water Use Management Model Historical Crop Consumptive Use* (Wilson Water Group, June 2013), *WWUM Historical Calibrated Surface Water Allocation Model* (Wilson Water Group, 11/4/2014), and *Western Water Use Management Model Water Resources Model User’s Manual* (Wilson Water Group, February 2015).

Figure 1 presents the average model recharge for the modeling timeframe as provided by the SWO and RSWB models.

The RSWB model provides a ground water exchange file to ARI that is combined with the commingled pumping from the SWO model and the District’s irrigation well meter records. This information is processed to create a well file for the ground water model. The well file is imported into the ground water model using GWV, and the domestic, municipal, and industrial pumping is then distributed as steady-state wells having non-variable pumping rates, which is carried over from the previous model.

MODEL CALIBRATION EXTENSION AND MODEL RESULTS

Stream baseflow and ground water level targets were extended for the ground water model update and used to verify the model calibration. The process for extending the baseflow and water level targets are described in *Technical Documentation: Update of Stream Baseflow Calibration Targets* (Kuntz and Reedy, 2016) and *Technical Documentation: Development of Water Level Calibration Targets* (Kuntz and Reedy, 2015), respectively.

The ground water model was run following the extension of aquifer properties and model calibration targets to ensure the effectiveness of the model extension and update as well as to verify its calibration. Figure 2 shows the simulated 2014 potentiometric surface. Similar to the previous model, the potentiometric surface is highest in the southwest model area and locally high in the Wildcat Hills south of the North Platte River basin. The surface has declined slightly in the northeast portion of the model area, mostly in Box Butte and northern Garden Counties, and locally near the South Platte River basin in the southeastern model area; as a result, the ground water level contours have migrated slightly west and northwest.

There were 81 sites where water levels were measured between May 1, 2013, and April 30, 2014. Some sites had multiple measurements in this period, and their residuals were averaged to provide a single representative residual. Residuals range from -78 feet in southern Cheyenne County, to +83 feet in southwestern Garden County. There are six residuals of less than -50 feet, with four located in western Cheyenne County. There are eight residuals greater than +50 feet, with five in Box Butte County and one each in Cheyenne, Garden, and Kimball Counties. The mean water level residual for the 81 sites was +1.9 feet; the median residual was -0.5 feet. Relative residuals for the 81 updated sites are shown in Figure 3. Residuals were also calculated for the entire model period, from May 1, 1953 through April 30, 2014 for all 131 sites in the model domain. The mean residual for each site was computed, and range from -99 feet in Laramie County to +85 feet in southwestern Garden County. There are seven mean residuals of -50 feet or less, including three in Cheyenne County, one in Banner County, one in Scotts Bluff County, and one in southern Sioux County. There are three sites with residuals greater than +50 feet, including one in eastern Cheyenne County, and one in Kimball County. The mean water-level residual for all sites was -4.2 feet and the median residual was -1.8 ft.

Hydrographs demonstrating the simulated and observed changes in water level over the model period are shown for select targets in Figure 4. The hydrographs for all head targets are documented in the memo report *Technical Documentation: Water Level Calibration Target Results* (Kuntz et al., 1/26/2016). Site 413545103101301 is located near Pumpkin Creek in southwestern Morrill County. The observed and computed values track fairly well before beginning to diverge in 1997. Though the values diverge slightly, the observed trends are still matched well by the simulated model head. Site 413216102520201 is located near the North Platte River in southeastern Morrill County. The observed and simulated values match relatively poorly in early time but converge and match both trends and absolute values well from 2000 on. Site 411349103455201 is located along Lodgepole Creek in central Kimball County. The observed and simulated values match fairly well for the first half of the model simulation and begin to diverge in 1985, though major trends in ground water level changes still track consistently between the observed and simulated values. Site 41440102272201 is located near the head of Blue Creek in northern Garden County. The simulated values track the observed ground water level trends well, though the absolute values are consistently lower for the model period.

Figure 5 shows the simulated drawdown for the model period from May 1953 through April 2014. Simulated water-level declines are as large as 153 feet in central Box Butte County. Water-level declines of greater than 50 feet occur in southern Morrill and Keith Counties. Declines greater than 25 feet occur throughout the model but are concentrated largely in the “Good Streak” area in central Morrill and Garden Counties, as well as along Lodgepole Creek in Kimball and western Cheyenne Counties. Simulated increases in water levels of at least 25 feet occur in southern

Kimball County as well as southern Garden and northern Deuel Counties. Figure 6 displays the simulated saturated thickness at the end of the model simulation.

Simulated and observed baseflow for selected streams is charted in Figure 7. Objective methods for estimating the baseflow component of total streamflow, such as the filters described in the baseflow documentation for this model, are most accurate when applied to baseflow-dominated systems with little to no development. The North Platte River represents a highly developed system with multiple diversions and large canal districts. This development introduces rapid increases and decreases in total flow, as well as extensive contributions to stream baseflow from canal losses that may affect the duration of maximum and minimum flow events in ways that would not be expected in a less developed system. Though this is most apparent in mainstem stream targets, the distribution of canals also introduces this kind of complexity to some tributaries and smaller streams. The stream baseflow targets were adjusted using the estimated baseflow values previously determined by Bradley et al., October 2013, with a more involved estimation method (pilot point method). The updated stream baseflow estimates used the maximum rate of change, or the maximum percent difference between two consecutive values, from the previous calibration as a limiter. These limited values were then restricted further in cases where they exceeded the maximum previous baseflow estimate; values exceeding the maximum from the first 50 years of the model period were decreased by 85% of the difference between the current and previous maximum. For further information, see the additional documentation *Technical Documentation: Update of Stream Baseflow Calibration Targets* (Kuntz and Reedy, 12/14/2015) and *Technical Documentation: Stream Baseflow Calibration Target Results* (Kuntz and Reedy, 1/26/2016).

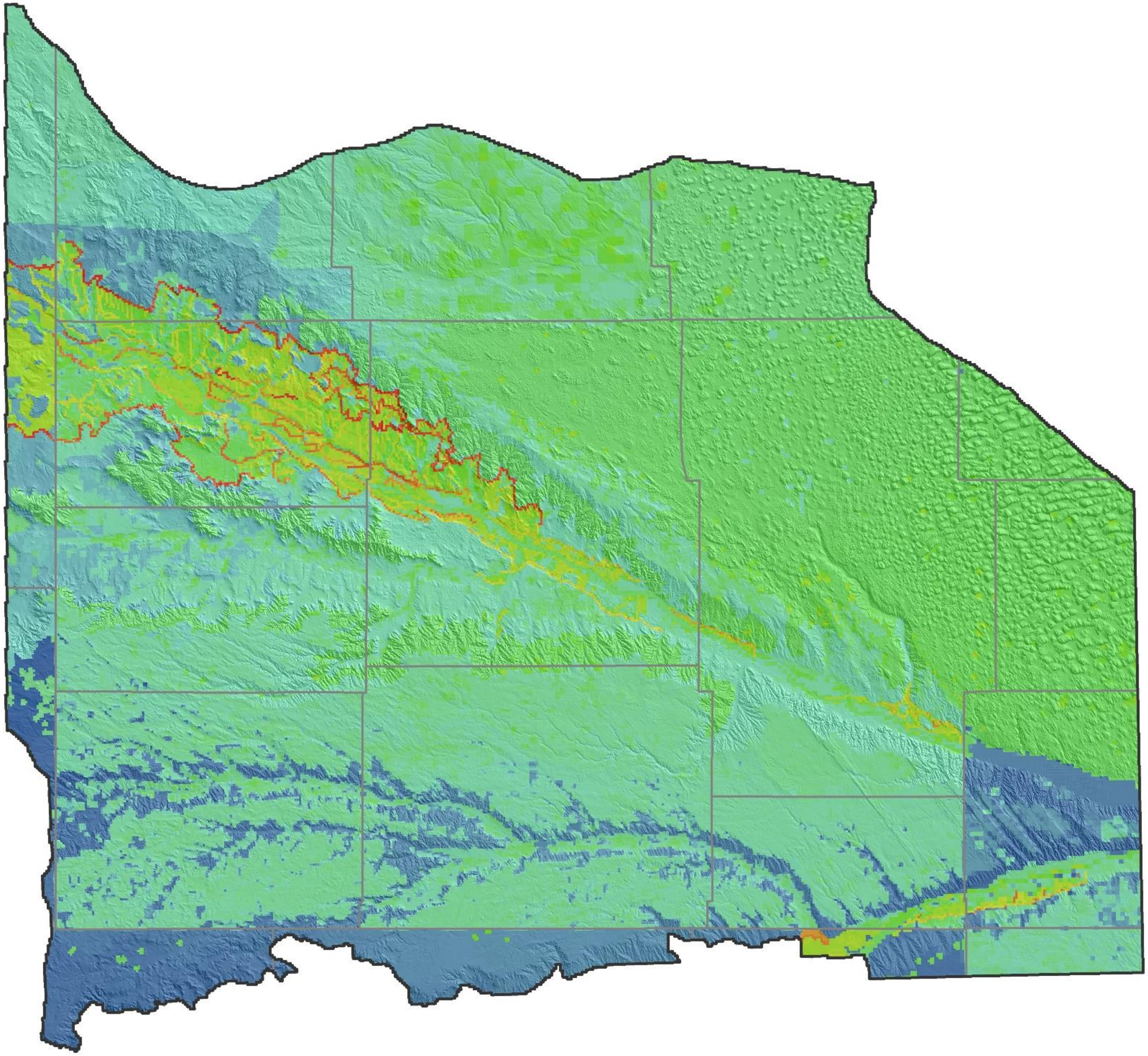

Figure 1. Average simulated recharge for the model period. Values range from 0.0000253 ft/d (blue) to 0.0692 ft/d (red).

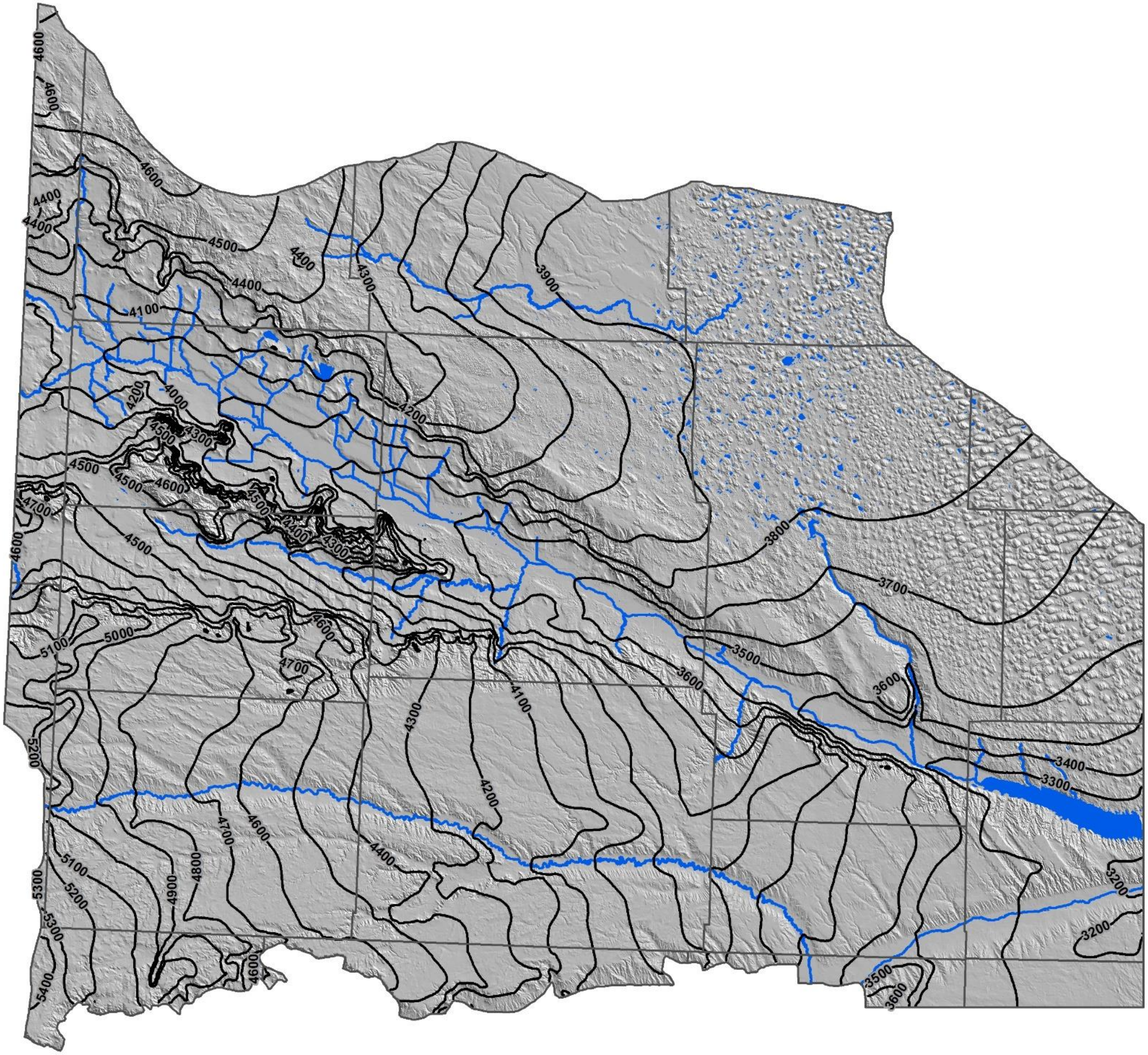

Figure 2. Simulated 2014 potentiometric surface from the updated model. Contour interval is 100 ft. Datum is sea level.

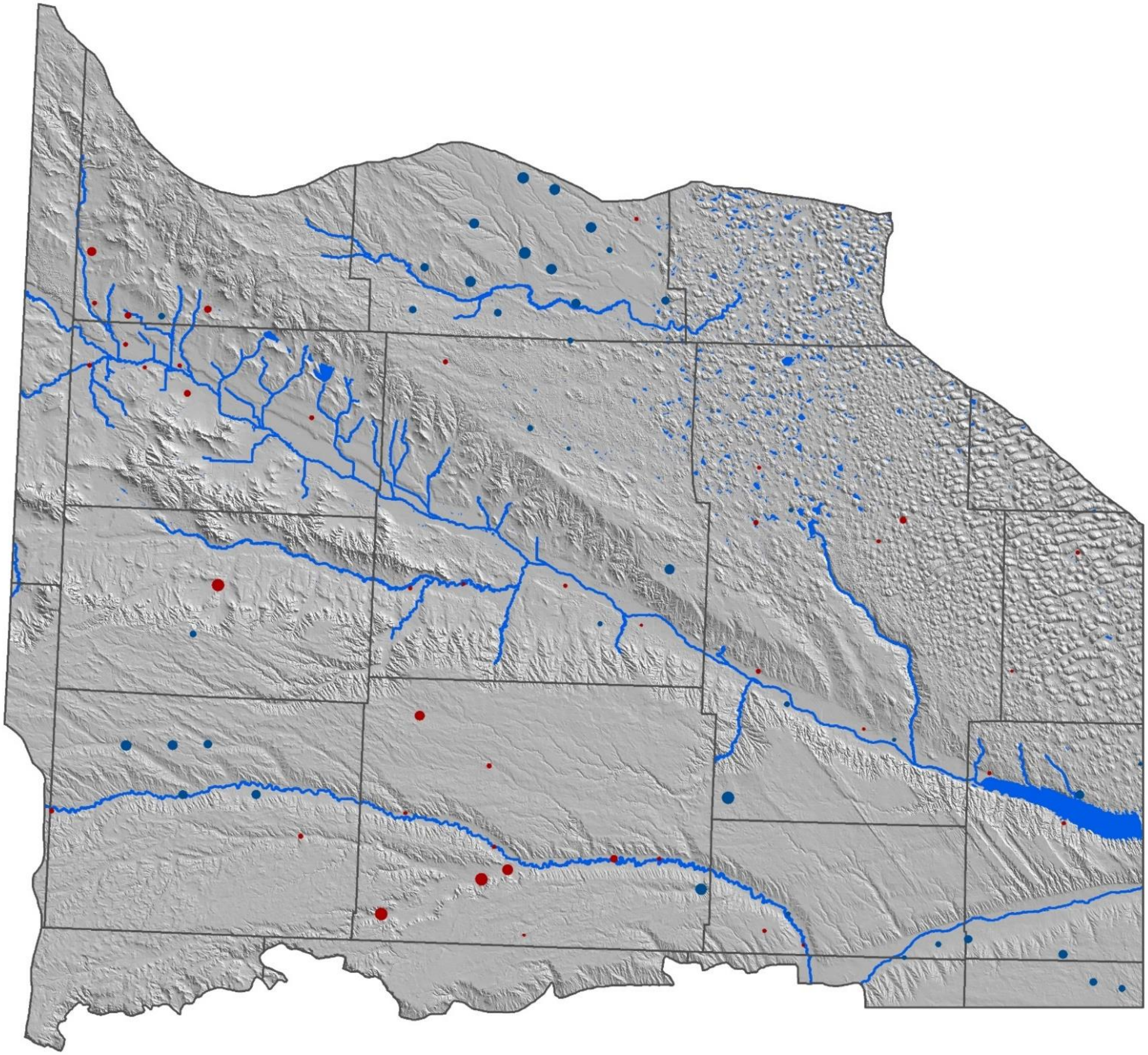

Figure 3. Residuals at 2014 water-level targets. Residuals range from -78 to +83 feet. Negative residuals are shown in red and positive residuals in blue. The diameter of the circle is proportional to the absolute value of residual, except that a minimum diameter is maintained to aid in visibility.

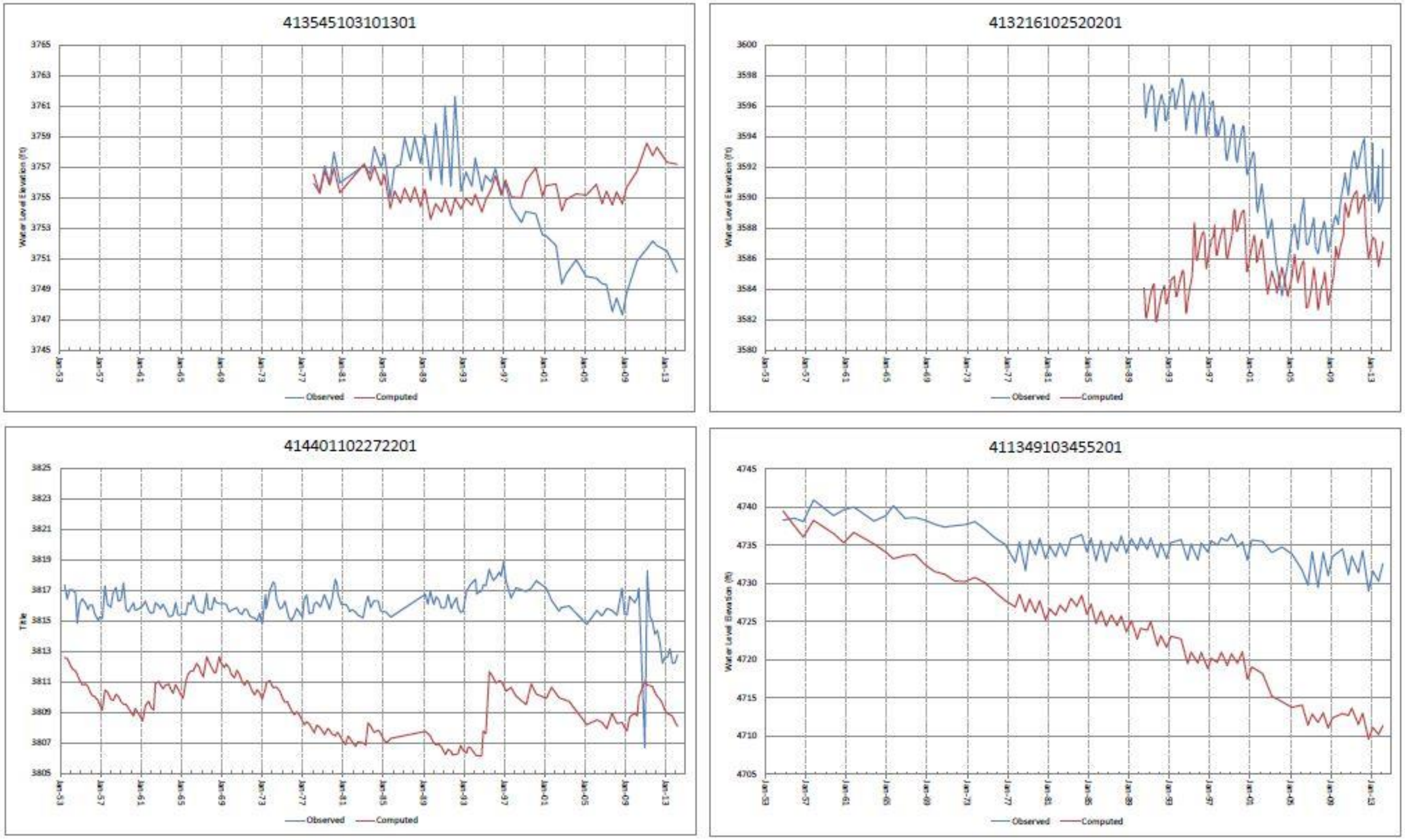

Figure 4. Hydrographs of selected targets for the model period of May 1953 to April 2014.

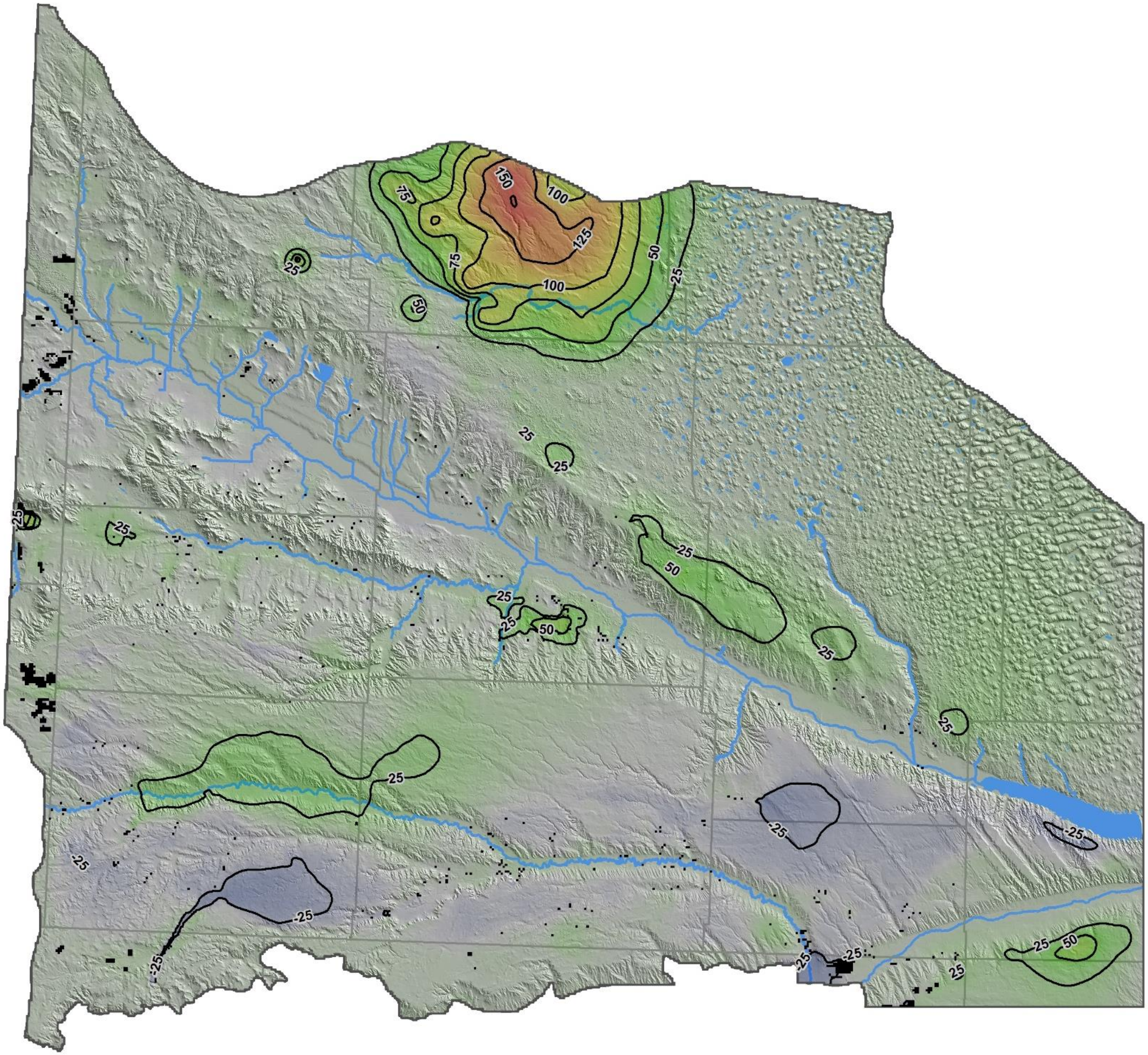

Figure 5. 1953-2014 simulated water-level change. Black squares represent simulated dry cells in the model.

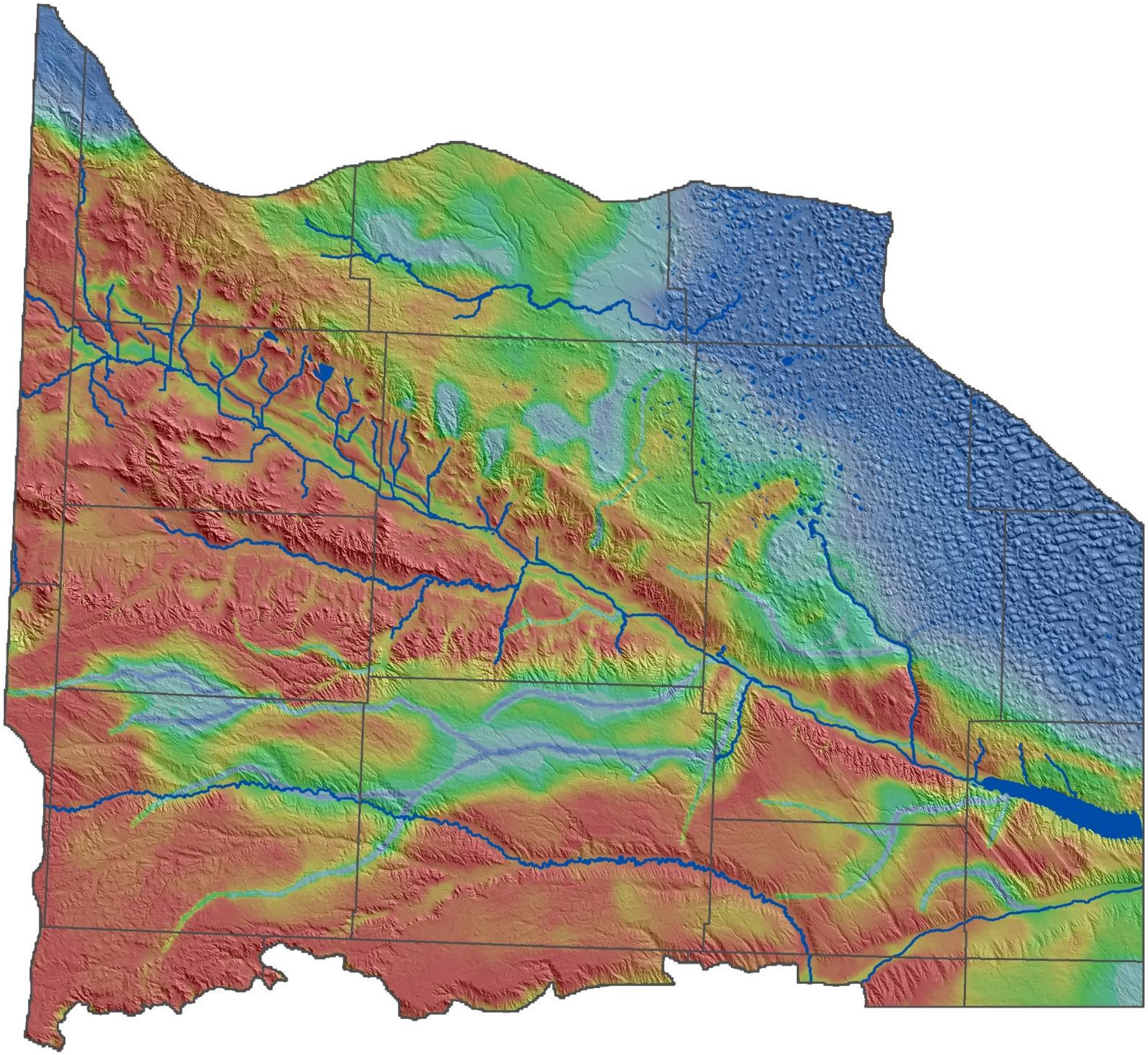

Figure 6. Saturated thickness of the High Plains aquifer. Values range from 0 feet (red) to 1070 feet (blue).

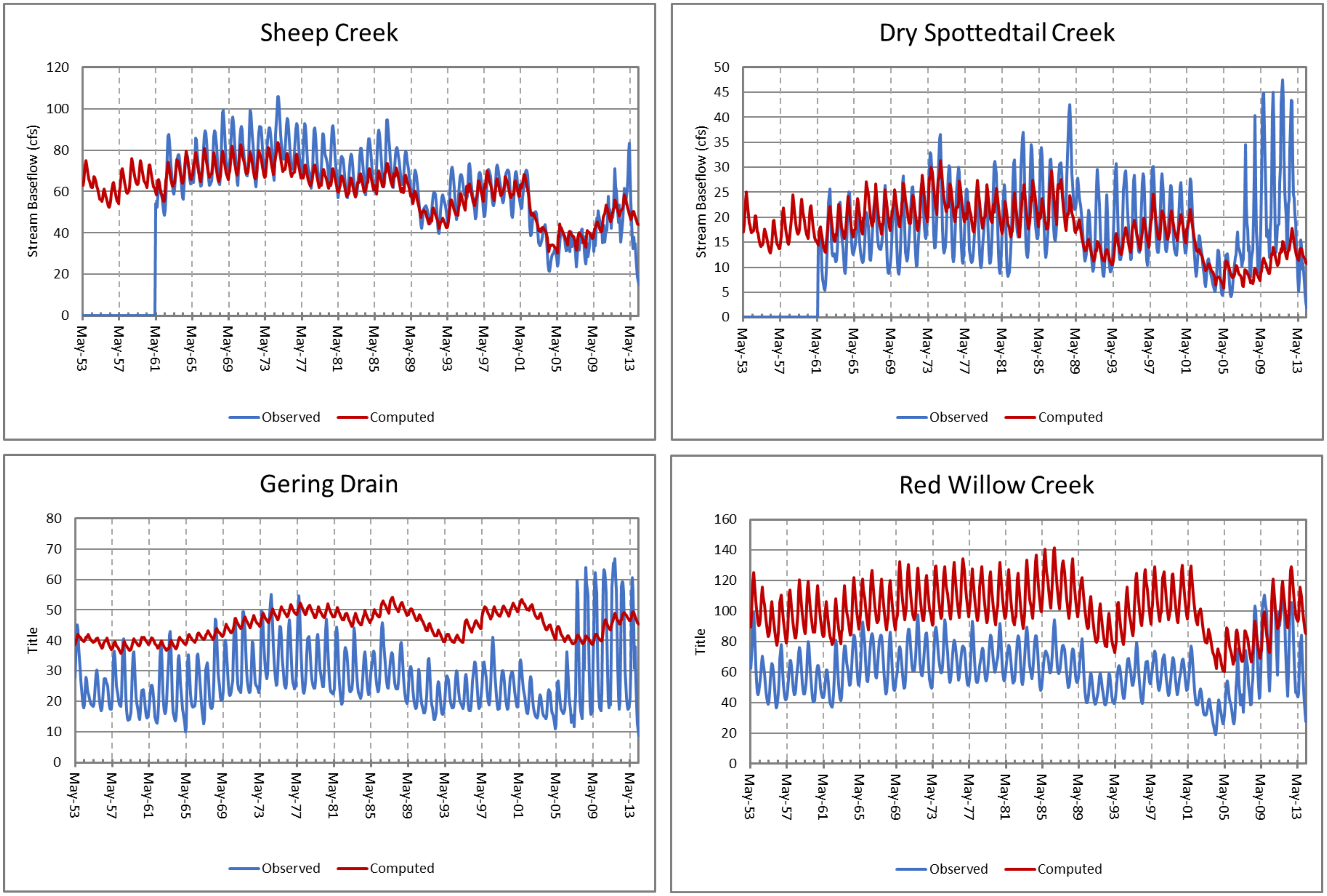

Figure 7. Computed and observed stream baseflow hydrographs for 1953-2014 at selected sites. Zero values in observed data at beginning and end of hydrographs are artifacts of the plotting routine.

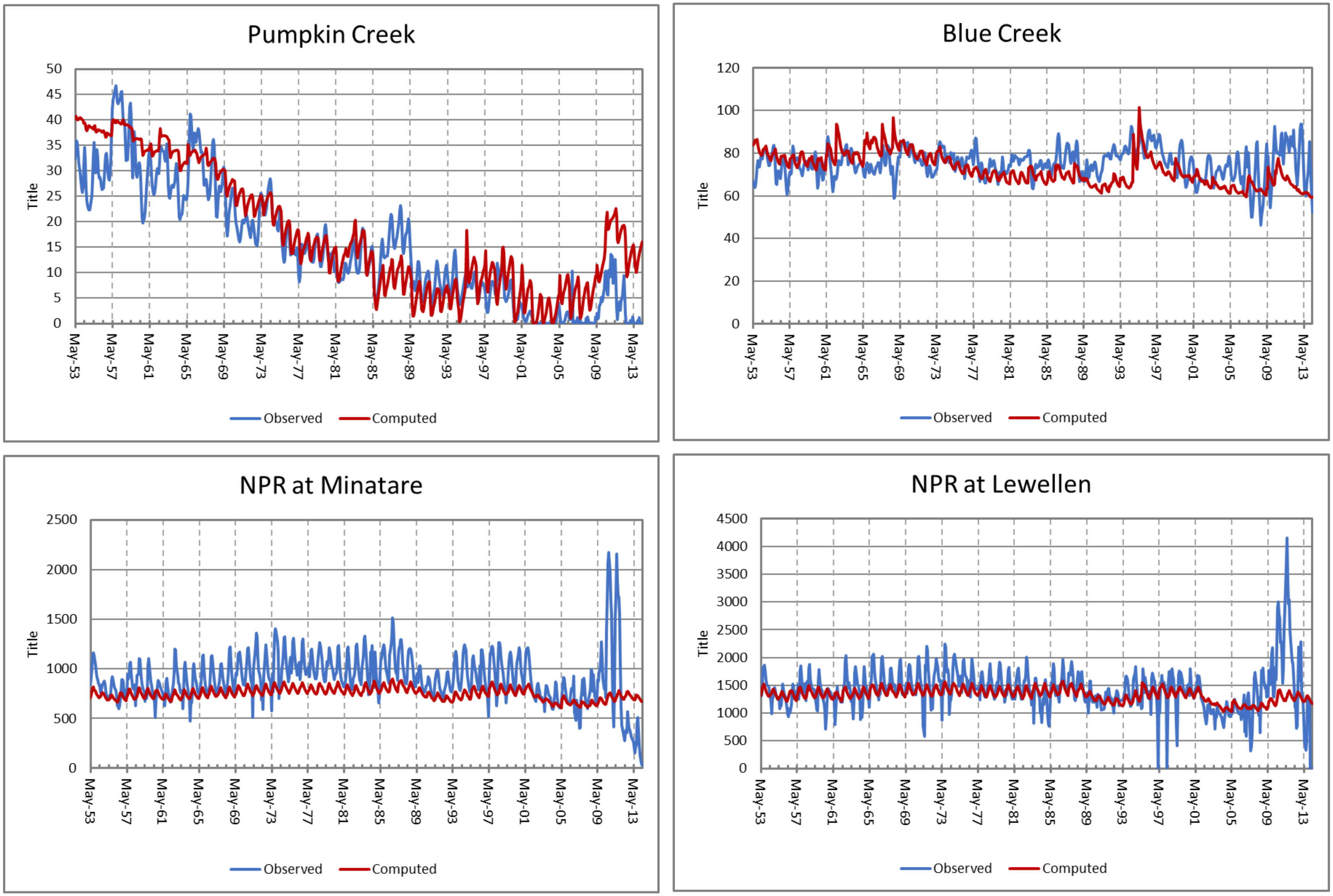

Figure 7 (continued). Computed and observed stream baseflow hydrographs for 19853-2014 at selected sites. Zero values in observed data at beginning and end of hydrographs are artifacts of the plotting routine.

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