EXHIBIT

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Groundwater-Flow Model for the Wood River Valley Aquifer System, Version 1.1

Idaho Department of Water Resources
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Abstract

This report documents the design, development, and calibration of the Wood River Valley (WRV) Aquifer Model Version 1.1. The objective of this update to WRV Aquifer Model 1.0 was to include data collected between 1/1/2011 and 12/31/2014 while preserving the basic design of the groundwater model developed by Fisher and others (2016). The geologic interpretations, groundwater-flow system understanding, and model layering and grid remain as described by Fisher. The model boundary was adjusted to include three additional irrigation wells.

The calibration data include river gain and loss records calculated using nine continuous gages. Three of the gages are on the Big Wood River, four of the gages measure tributary inflow to the Big Wood River and two measure discharge from springs that arise within the model boundary. Aquifer water-level data include 1,314 water-levels collected in 332 wells.

Adjustable parameters for the WRV Aquifer Model calibration include aquifer transmissivity, storage coefficient, riverbed conductance, drain conductance, irrigation efficiency, and tributary-aquifer underflow.

The calibration period (1/1/1998 through 12/31/2014) includes some of the wettest and driest years on record, indicating that the stresses the model is calibrated to include the range of stresses that can realistically be expected for most analyses. The fit between field observations and model output is good, suggesting that the model reasonably represents the hydrogeologic system.

Along with adding four additional years of data to the model period, the recalibration resulted in an improved representation of the length of the Big Wood River that becomes dry during the summer and the length of time it remains dry annually.

The length of the Big Wood River in hydrologic communication with the aquifer varies substantially during most years, making development of a numerical-superposition model inadvisable.

Keywords:

Aquifer river interaction, MODFLOW-USG, PEST, METRIC

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Introduction

This report documents the design, development, and calibration of Wood River Valley (WRV) Aquifer Model Version 1.1. The objective of the WRV Aquifer Model Version 1.1 project was to include data collected between 1/1/2011 and 12/31/2014 with the original calibration period of 1/1/1998 through 12/31/2010 while updating the Wood River Valley aquifer model developed by Fisher and others (2016). Adding the years between 1/1/2011 and 12/31/2014 incorporates years during which more groundwater level and streamflow data were collected in the WRV than in any other four-year span in the calibration period. During this period the U.S. Geological Survey (USGS) conducted a mass measurement of wells in the WRV, conducted three seepage surveys on the Big Wood River and Silver Creek, and installed stream gages on the Big Wood River and four tributary streams. In addition, The IDWR installed pressure transducers in several wells, and significantly increased the number of wells routinely measured in the valley.

Descriptions of the study area, groundwater-flow system, and groundwater-flow model can be found in Fisher and others (2016). The geologic interpretations, the groundwater-flow system understanding, and the model layering and grid size used in WRV Aquifer Model Version 1.0 remain unchanged.

The boundary of the model was adjusted to include three irrigation wells near the Sportsman's Access Gage on Silver Creek. The added areas are within the circles in Figure 1.

The intent of this project is to update and improve upon the WRV Aquifer Model Version 1.0 calibration by including more years with higher data density while preserving the basic design of the model developed by Fisher and others (2016).

Model Development

WRV Aquifer Model Version 1.1 was calibrated using PEST (Doherty, 2016), an automated parameter estimation program. The goal of WRV model calibration is to adjust aquifer parameters within reasonable ranges until model-generated aquifer head, and gains to the Big Wood River, Willow Creek and Silver Creek match observed values. The adjustable parameters included riverbed conductance, drain conductance, irrigation-entity efficiency, tributary underflow, aquifer transmissivity, and aquifer storage. Transmissivity and aquifer storage were estimated using the PEST pilot points system (Doherty, 2003). PEST was only allowed to adjust parameters between assumed uncertainty bounds. For example, PEST could only adjust layer-one storage coefficients between 0.10 and 0.30 because those were assumed to be reasonable bounds based on available geologic information. Groundwater flow was simulated using MODFLOW-USG (Panday and others, 2013), a numerical model for simulating three-dimensional, steady-state and transient groundwater flow. Because the model is run many times during the parameter-estimation process, it was necessary to limit model run times. Substantial savings in model run times were achieved by simulating transient flow in the WRV aquifer system using a specified saturated thickness.

The following sections describe the parameter-estimation tools used for the WRV Aquifer Model calibration, as well as the observation data. Final model parameters and a comparison between model-predicted values and observed values are discussed in the subsequent "Model Calibration" section.

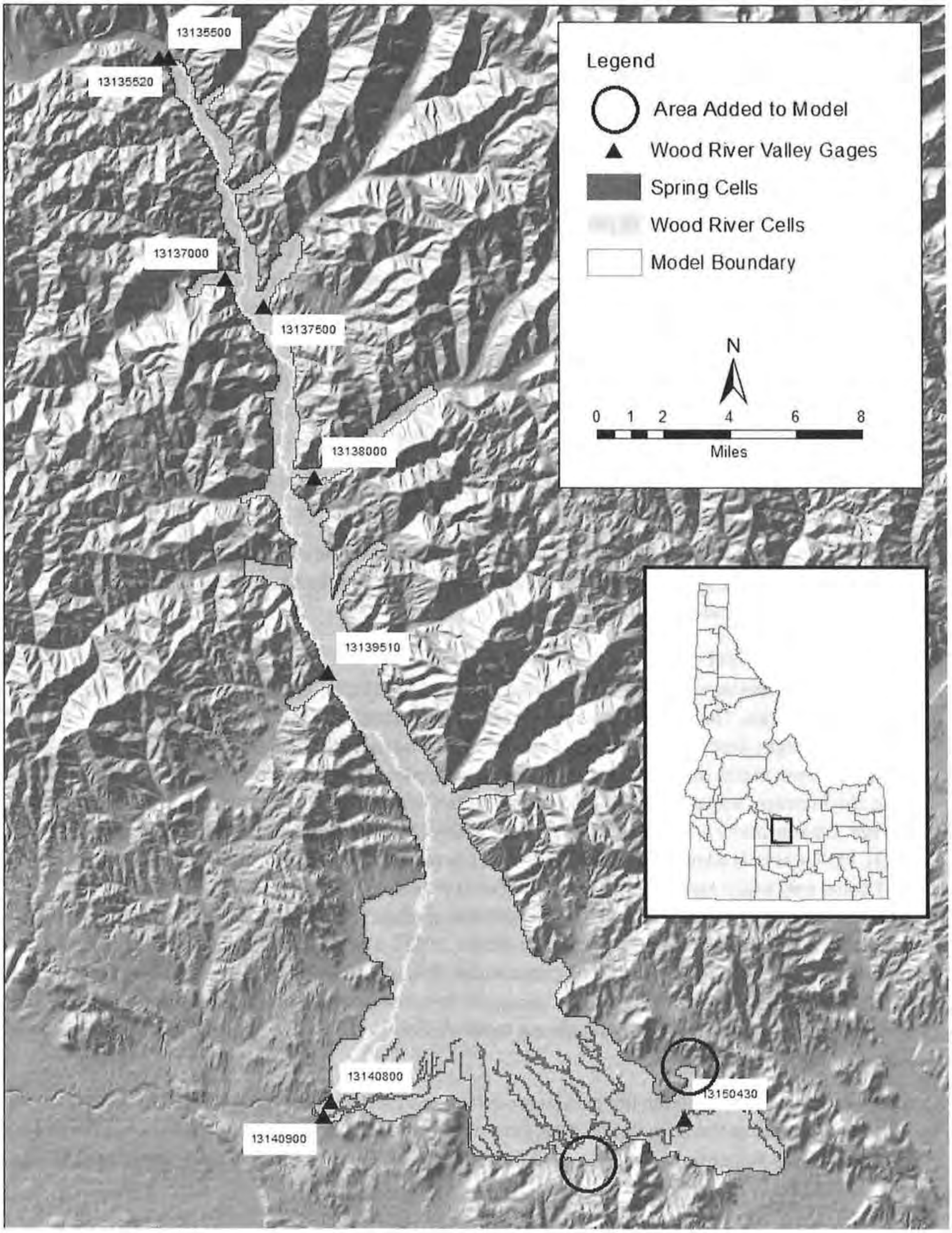

Figure 1. Location map and continuous river gages.

Parameter estimation tools

PEST, a nonlinear, least-squares inverse modeling program (Doherty, 2016) was used to calibrate the WRV Aquifer Model Version 1.1. During calibration, PEST runs MODFLOW-USG thousands of times, comparing model-generated values with field observations. The goal is to minimize the weighted, sum of the squared residuals, or difference between the model-generated values and the field observations.

River gain and loss data

River-gain and loss data consist of river-gaging information used to calculate gains from the aquifer to the river or losses from the river to the aquifer along the Big Wood River, Willow Creek, and Silver Creek and its tributaries. Streamflow measurements are available from the following nine continuous recording stations (Figure 1):

1. Big Wood River near Ketchum (USGS 13135500),
2. North Fork Big Wood River near Sawtooth NRA Headquarters (USGS 13135520),
3. Warm Springs Creek near Ketchum (USGS 13137000),
4. Trail Creek at Ketchum (USGS 13137500),
5. East Fork Big Wood River at Gimlet (USGS 13138000),
6. Big Wood River at Hailey (USGS 13139510),
7. Big Wood River at Stanton Crossing (USGS 13140800),
8. Willow Creek near Spring Creek Ranch (IPCO 13140900), and
9. Silver Creek at Sportsman Access (USGS 13150430).

Although most of these gages were not in operation during the entire model period, correlations with the gage at Hailey allow calculation of streamflow for the entire model period for Big Wood River near Ketchum, North Fork Big Wood River at Sawtooth NRA Headquarters, Warm Springs Creek near Ketchum, Trail Creek at Ketchum, and East Fork Big Wood River at Gimlet (Sukow, 2014). Semi-annual gaging of Silver Creek near Picabo (Wylie, 2019) and historic seepage surveys (Moreland, 1977) indicates that the gains between Sportsman Access and the model boundary are negligible. Thus the gages allow calculation of average monthly reach gains for five river reaches:

1. Big Wood River near Ketchum to at Hailey (240 observations between 1995-2015),
2. Big Wood River at Hailey to Stanton Crossing (219 observations between 1996-2015),
3. Willow Creek (173 observations between 2000-2015),
4. Silver Creek above Sportsman Access (240 observations between 1995-2015), and
5. Silver Creek Sportsman Access to Model Boundary (negligible based on a few streamflow measurements.

The USGS conducted three seepage surveys of the Big Wood River and Silver Creek. Each survey consisted of a single measurement at 28 different streamflow and diversion sites within the model domain. The seepage surveys were conducted in August 2012, October 2012, and March 2013

(Bartolino, 2014). Although each of the seepage surveys represent a single moment in time, they were conducted during the model-calibration period, and can be used to calculate reach gains and losses for shorter subreaches of the Big Wood River and Silver Creek.

Aquifer water level data

The calibration targets include water-levels collected by the USGS, IDWR, other cooperators, and water-well drillers. These measurements include mass measurements collected during October 2006 and October 2012. A total of 1,314 water-level measurements collected in 332 different wells were used in the model calibration. These observations fall into two categories:

1) Observation Well measurements. Measurements collected in wells with multiple water-level measurements (1,101 water-levels in 119 wells) (Figure 2), and
2) Geolocated Well measurements. Measurements obtained from driller logs (213 water-level measurements). The corresponding wells either have a GPS location provided by the driller or were geolocated using an addresses provided for the well by the driller (Figure 2).

Evapotranspiration

Evapotranspiration (ET), the sum of evaporation and plant transpiration, is a significant component of aquifer discharge in the WRV. Traditional ET estimation methods such as the FAO Penman-Monteith method (Allen and others, 1998) proved unreliable in the WRV because the county crop mix was not representative of the crops grown in the WRV. Therefore, ET for the WRV model was estimated using remote sensing techniques. Using ET estimates based on the METRIC algorithm (Allen and others, 2010) circumvented most of the problem. Where METRIC estimates for ET were not available for a model irrigation season, ET was estimated using Normalized Difference Vegetative Index (NDVI) (Allen and others, 2010). NDVI is a normalized ratio of the difference between red and infrared wavelengths reflected from the earth's surface and serves as an indicator of viable plant cover. ET is strongly dependent on the presence of growing plants, enabling the development of strong correlations between NDVI and ET (McVay, 2014).

Model Calibration

Model calibration involves adjustment of model parameters to minimize the difference between model output and field observations. This section describes the adjustable parameters and the results. For the WRV Aquifer Model Version 1.1, the simulation period extends from 1/1/1995 through 12/31/2014 and the calibration period extends from 1/1/1998 through 12/31/2014. The period 1/1/1995 through 12/31/1997 provides the model with a three year warm-up before matching model output with field observations.

Transient calibration procedure

Each calibration iteration consisted of: first running the WRV water budget tool (Fisher and others, 2016), which calculates net recharge and writes a MODFLOW-USG well file, and then running MODFLOW-USG to calculate aquifer heads and aquifer-stream exchanges. Starting heads for each transient MODFLOW-USG simulation are calculated during an initial steady-state stress period. The well file for the initial steady-state stress period is generated using average water-budget data from April 2004 through March 2005. The steady-state stress period is used only to generate starting heads for the

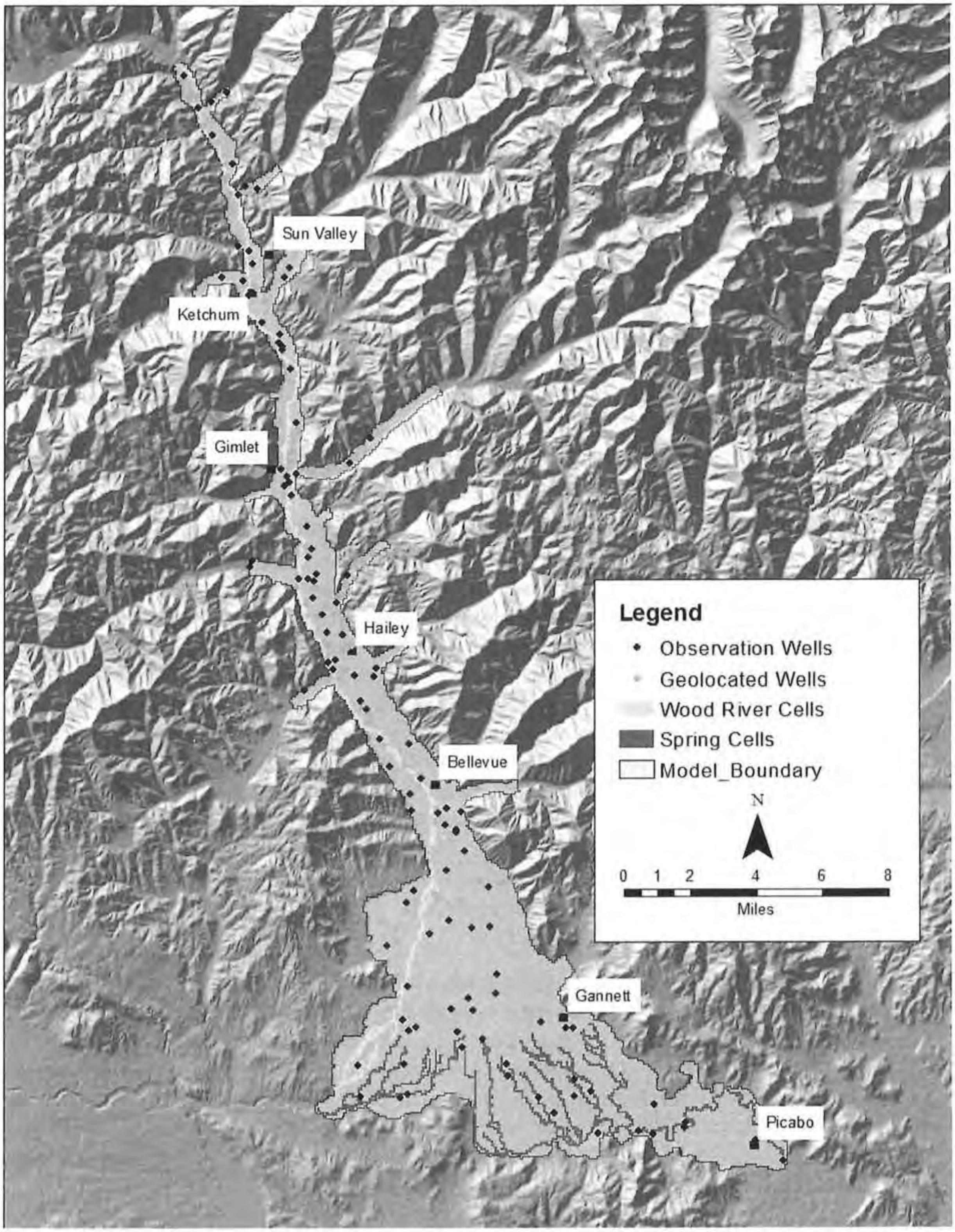

Figure 2. Observation and geolocated wells.