Appendix H. Calibration of the Wood River Valley Groundwater-Flow Model

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Introduction

Model calibration refers to the process of assuring that the Wood River Valley (WRV) groundwater-flow model reproduces real-world flow conditions reasonably well. An estimator attempts to adjust model parameters so that the differences between simulated and measured values are minimized. Multiple model parameters were estimated using a nonlinear regression method.

Model Calibration

Model calibration is the task of adjusting model parameter estimates (such as hydraulic conductivity) until model results are consistent with measured data (such as groundwater levels in wells). The effectiveness of model calibration cannot be solely assessed by the agreement between field measurements and corresponding model results (misfit). Unreasonable parameter values may be estimated that adopt roles for which they were not designed in order for the model to provide an acceptable fit with field measurements (this is referred to as overfitting) (Doherty, 2005, p. 180). The problem with an overfit model is that it will typically have poor predictive performance, as it can exaggerate minor fluctuations in the data. Therefore, model calibration may necessitate a larger misfit in order to determine a parameter set that reflects a geologically and physically realistic conceptualization of the aquifer system (Fienen, Muffels, and Hunt, 2009, p. 842). Regularization is the process of supplementing field measurements with prior information that pertain directly to model parameters (also known as “regularization observations”) in order to prevent overfitting. For example, regularization may take the form of a penalty for increased spatial heterogeneity of horizontal hydraulic conductivity.

The parameter estimation program PEST version 13 (Doherty, 2005) is used in regularization mode to calibrate the WRV groundwater-flow model. PEST implements a nonlinear regression method to estimate model parameters by keeping model-to-measurement misfit below a certain user-defined threshold (PHIMLIM), while minimizing the deviation of parameter estimates from their preferred conditions. Parameter estimation is formulated as a constrained minimization problem and mathematically expressed as:

$$
\begin{aligned}
\underset{\boldsymbol{b}\,\varepsilon\,\mathbb{R}}{\text{minimize}} \quad & \sum_i \left(w_i \left[X_i - \widehat{X}_i \right] \right)^2 \\
\text{subject to} \quad & \sum_j \left(w_j \left[Y_j - \widehat{Y}_j \right] \right)^2 \leq \text{PHIMLIM} \\
& b_{min,k} \leq b_k \leq b_{max,k}
\end{aligned} \tag{1}
$$

where

$\boldsymbol{b}$ is a vector of adjustable model parameters;

$\mathbb{R}$ is the set of all real values;

w_i is the weight placed on regularization observation i;

X_i is the preferred model parameter of regularization observation i;

$\widehat{X}_i$ is the estimated model parameter of regularization observation i;

w_j is the weight placed on observation j;

Y_j is the field measurement quantity of observation j;

$\widehat{Y}_j$ is the model-simulated result of observation j;

PHIMLIM is a control variable for regularization that is used to avoid overfitting;

$b_{min,k}$ is the lower bound for adjustable model parameter k; and

$b_{max,k}$ is the upper bound for adjustable model parameter k.

The algorithm PEST uses to solve equation (1) is a modified Gauss-Newton method, assisted by a Levenberg-Marquardt formulation (Doherty, 2005, chapter 2).

Model-simulation results are output from MODFLOW-USG, a numerical model that simulates three-dimensional, steady-state and transient groundwater flow using a control volume finite-difference formulation (Panday and others, 2013). Because PEST runs the model many times during the parameter estimation process it was necessary to keep model run times reasonably short. Substantial time savings in model runs were achieved by simulating transient flow in the WRV aquifer system using a specified saturated thickness. In reality, the saturated thickness changes as model-simulated hydraulic heads change. Accounting for such changes during the simulation is possible with MODFLOW-USG; however, run times for these simulations can be very long—on the order of hours for simulating flow in WRV aquifer system. In comparison, run times are on the order of tens-of-minutes when the saturated thickness is held constant.

Field Measurements

Field measurements used in the parameter estimation process include groundwater levels in wells, stream-aquifer flow exchange in river reaches, and groundwater flow at outlet boundaries. A 3-year 'warm-up' period is included in the model simulation to recover from inaccuracies in the initial groundwater head distribution and account for potential transient responses to stresses occurring prior to January 1995. Therefore, field measurements during the first 3 years of the simulation (1995–1997) were not used when evaluating model-to-measurement misfit during model calibration.

Groundwater Levels in Wells

The groundwater-flow model was calibrated using 3,208 hydraulic-head observations (groundwater levels) from 615 well locations. During the 16-year model simulation period (1995–2010), both the period-of-record and frequency of monitoring varied by well (table H1). The historic variability of groundwater levels in a well over the period-of-record is described with the standard deviation (table H1). All relevant sources of groundwater-level data were considered during model calibration and described below.

The U.S. Geological Survey (USGS) groundwater-monitoring network described by Skinner, Bartolino, and Tranmer (2007) and Bartolino (2014) consists of 94 wells, with 387 groundwater-level observations recorded in these wells during the 1995 through 2010 time period (table H1, fig. H1); of these observations, 331 were recorded during the model-calibration period (1998–2010). Groundwater-level elevations were obtained by subtracting the depth to water from the elevation of a land-surface measurement point. The depth to water was measured by USGS and Idaho Department of Water Resources (IDWR) employees using an electric measuring tape accurate to about plus-or-minus (±) 0.01 meters (m) (±0.02 feet [ft]). Well locations were surveyed using real-time kinematic (RTK) and fast-static differential Global Positioning System (GPS) surveying techniques with a horizontal accuracy of about ±0.08 m (±0.26 ft) and a vertical accuracy of about ±0.16 m (±0.52 ft). Wells in this monitoring network are hereafter referred to as "USGS wells".

All available well driller reports (well logs) were examined for groundwater-level data recorded during the 1995 through 2010 time period. There were 670 groundwater-level observations (one observation per well log collected at the time of well construction) recorded by drillers onto well logs; of these observations, 509 were recorded during the model-calibration period. The location of driller wells in the model area is shown in figure H2. Methods used to determine the geographic coordinate (longitude and latitude) of a driller well varied. For 62 percent of the driller wells, either a hand-held GPS measurement or street address was recorded by the driller onto the well log and used to determine (either directly or indirectly) its geographic coordinate. Geolocation software was used to convert street addresses to geographic coordinates; their locations typically adjusted to coincide with the center of the land-owner's property (these land parcels are typically less than 0.004 square-kilometers [km^2] or 1 acre, although, some are as large as 0.04 km^2 [10 acres]). Driller wells of this type are hereafter referred to as "Geolocated driller wells". The remaining 38 percent of the driller wells were located using the Public Land Survey System (PLSS) township, range, section, quarter-section, quarter-quarter section division of the state (TRSQQ) recorded by the driller onto the well log. The PLSS records were converted to geographic coordinates using assumed site locations at the center of their quarter-quarter section (0.16 km^2 or 40 acres). Driller wells of this type are hereafter referred to as "PLSS-located driller wells".

For all driller wells, the elevation of the land-surface measurement point was determined from a digital elevation model at a horizontal grid resolution of about 10 m (33 ft) and vertical accuracy of about ±1.5 m (±5 ft) (10-m DEM). The method used for the driller-reported depth-to-water measurement was never reported. The accuracy of driller-reported groundwater-level measurements could not be quantified, although groundwater levels for the geolocated driller wells are assumed less accurate (at least horizontally) for the PLSS-located driller wells because a TRSQQ is 0.16 km^2 and most land parcels are less than 0.004 km^2 in area.

Groundater-levels in two of the Sun Valley Water and Sewer District (SVWSD) production wells were recorded during the 1995 through 2010 time period under non-pumping conditions. Figure H3 shows the location of the SVWSD production wells in the model area. There were 393 groundwater-level observations recorded in these wells during the 16-year simulation; of these observations, 341 were recorded during the model-calibration period. Depth-to-water measurements were made by a SVWSD employee using a submerged air line method. Of the two SVWSD production wells, one (well No. 765) was located using a hand-held GPS unit (horizontal accuracy of about ±3 m [±10 ft]) and 10-m DEM, and the other (433936114210701, well No. 766) was surveyed as part of the USGS groundwater-monitoring network. Wells of this type are hereafter referred to as “SVWSD wells”.

The Nature Conservancy (TNC) groundwater-monitoring network consists of 10 wells, with 2,027 groundwater-level observations (average daily values) recorded for these wells during the 16-year simulation (fig. H3), and all within the model-calibration period. The period-of-record for groundwater-level observations is relatively short in duration, spanning the last 9 months of the model-calibration period. In each of the wells, a submerged pressure transducer installed at a fixed depth in the well, collected nearly continuous measurements of the height of the water column above the transducer. Groundwater-level elevations were obtained by adding the height of water column to the elevation of the submerged pressure transducer, where transducer elevation is determined by subtracting the depth to the pressure transducer from the elevation of a land-surface measurement point. Groundwater-level data provided by these transducers is not adequately supported by quality-assurance procedures and documentation; therefore, the vertical accuracy of groundwater-level observations in these wells could not be quantified. The location of wells in this network were either surveyed as part of the USGS groundwater-monitoring network or located with a hand-held GPS unit and 10-m DEM. Wells in this monitoring network hereafter referred to as “TNC wells”.

Table H1. Observation wells in the Wood River Valley aquifer system. [**Well type**: "USGS well" is monitored by the U.S. Geological Survey and (or) the Idaho Department of Water Resources; "Geolocated driller well" is a driller recorded groundwater level in a geolocated well; "PLSS-located driller well" is a driller recorded groundwater level in a well located using the Public Land Survey System (PLSS); "SVWSD well" is a production well in the Sun Valley Water and Sewer District (SVWSD); and "TNC well" is monitored by The Nature Conservancy and installed with a pressure transducer. **Well No.**: identifier used to locate wells in figures H1, H2, and H3. **Site identifier**: unique numerical identifiers used to access well data (https://waterdata.usgs.gov/nwis). **Name**: local well name used in this study. **SD**: standard deviation of groundwater levels. **Abbreviations**: m, meters; –, not available; NA, not applicable]

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
USGS well	1	432659114151201	01N 18E 01ACA2	1	Oct 2006	NA
	2	432650114144701	01N 18E 01DAA2	66	Mar 1995 – Dec 2010	0.84
	3	432547114151001	01N 18E 12DCA2	1	Oct 2006	NA
	4	432514114162101	01N 18E 14ACD1	1	Oct 2006	NA
	5	432428114150202	01N 18E 24ADB2	1	Oct 2006	NA
	6	432347114171301	01N 18E 27AAA2	2	Oct 2006 – Jul 2007	0.20
	7	432244114163201	01N 18E 35ACB1	1	Oct 2006	NA
	8	432616114143801	01N 19E 07BAC1	3	Aug 1998 – Jul 2007	1.11
	9	432521114133601	01N 19E 18ADA1	1	Oct 2006	NA
	10	432415114133401	01N 19E 20CBB1	1	Oct 2006	NA
	11	432224114141901	01N 19E 31CAD1	1	Oct 2006	NA
	12	432233114132001	01N 19E 32CBA1	1	Oct 2006	NA
	13	432140114160901	01S 18E 01CDC2	1	Oct 2006	NA
	14	432134114162701	01S 18E 12BBB1	1	Oct 2006	NA
	15	431955114162901	01S 18E 13CCC1	1	Oct 2006	NA
	16	432042114163801	01S 18E 14AAB1	64	Mar 1995 – Oct 2010	1.76
	17	431954114181001	01S 18E 15DCC2	1	Oct 2006	NA
	18	–	01S 19E 03CCB3	66	Mar 1995 – Dec 2010	1.13
	19	432139114104501	01S 19E 03DDC3	2	Oct 2006 – Jul 2007	0.81
	20	432133114144302	01S 19E 07BAA2	1	Oct 2006	NA
	21	432108114143301	01S 19E 07DBB2	1	Oct 2006	NA
	22	432136114102901	01S 19E 11BBB1-DESTROYED	3	Mar 2001 – Mar 2002	0.55
	23	432017114102801	01S 19E 14CBB1	1	Oct 2006	NA
	24	431958114095101	01S 19E 14DCC1	1	Oct 2006	NA
	25	432041114125801	01S 19E 17AAA2	1	Oct 2006	NA
	26	431948114114401	01S 19E 21AAA1	1	Oct 2006	NA
	27	431950114102901	01S 19E 22AAA1	6	Mar 2001 – Oct 2008	0.39
	28	431925114110501	01S 19E 22CAA1	1	Oct 2006	NA
	29	431852114093501	01S 19E 26AAC1	1	Oct 2006	NA
	30	431938114073401	01S 20E 19BDA1	1	Oct 2006	NA
	31	431900114063001	01S 20E 20CDD1	1	Oct 2006	NA
	32	431810114025901	01S 20E 26CDC1	3	Sep 2001 – Oct 2006	0.69
	33	431836114040101	01S 20E 27BDA1	5	Mar 2001 – Oct 2008	0.83
	34	431850114073601	01S 20E 30BAD1	1	Oct 2006	NA
	35	433204114192701	02N 18E 04CBB1	1	Oct 2006	NA
	36	433159114185401	02N 18E 04DBB1	1	Oct 2006	NA
	37	433232114193402	02N 18E 05AAA3	1	Oct 2006	NA
	38	433117114190301	02N 18E 09BDC1	1	Oct 2006	NA
	39	433103114191201	02N 18E 09CAC1	1	Oct 2006	NA
	40	433055114182201	02N 18E 09DDA1	1	Oct 2006	NA
	41	433107114174201	02N 18E 10DBC1	1	Oct 2006	NA
	42	433055114174201	02N 18E 10DCB1	1	Oct 2006	NA
	43	433028114182101	02N 18E 15BCC1	1	Oct 2006	NA
	44	433017114181601	02N 18E 15CBB1	1	Oct 2006	NA
	45	433003114180701	02N 18E 15CCA1	3	Jul 1996 – Aug 2010	0.17
	46	433033114201701	02N 18E 17BDA1	1	Oct 2006	NA
	47	432912114173201	02N 18E 22DDB1	1	Oct 2006	NA
	48	432907114163201	02N 18E 23DCC1	1	Oct 2006	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
USGS well	49	432832114171001	02N 18E 26CBB1	1	Oct 2006	NA
	50	432813114160201	02N 18E 26DDD1	2	Jul 2002 – Oct 2006	0.36
	51	432721114161901	02N 18E 35DCD1	1	Oct 2006	NA
	52	432725114151001	02N 18E 36DCA1	1	Oct 2006	NA
	53	432741114143701	02N 19E 31CCD1	1	Oct 2006	NA
	54	433357114221001	03N 17E 25ADC1	1	Oct 2006	NA
	55	433712114175701	03N 18E 03CAB1	1	Oct 2006	NA
	56	433734114203501	03N 18E 05BBC1	1	Oct 2006	NA
	57	433623114210701	03N 18E 07DBA1	1	Oct 2006	NA
	58	433643114203501	03N 18E 08BCC1	1	Oct 2006	NA
	59	433616114203301	03N 18E 08CBC4	1	Oct 2006	NA
	60	433633114184101	03N 18E 09ADB1	1	Oct 2006	NA
	61	433558114204701	03N 18E 18AAA1	2	Jul 1999 – Oct 2006	0.95
	62	433556114210301	03N 18E 18AAB1	1	Oct 2006	NA
	63	433536114205701	03N 18E 18ADD1	1	Oct 2006	NA
	64	433451114201101	03N 18E 20BDA1	1	Oct 2006	NA
	65	433415114200201	03N 18E 20DCC1	1	Oct 2006	NA
	66	433334114184601	03N 18E 28DCA1	1	Oct 2006	NA
	67	433359114200901	03N 18E 29BDA1	1	Oct 2006	NA
	68	433328114203201	03N 18E 29CCD1	1	Oct 2006	NA
	69	433328114201001	03N 18E 29DCC2	1	Oct 2006	NA
	70	433322114195701	03N 18E 32ABA1	1	Oct 2006	NA
	71	433258114195701	03N 18E 32DBA1	1	Oct 2006	NA
	72	433254114191001	03N 18E 33CAB1	1	Oct 2006	NA
	73	434216114224801	04N 17E 01CCA1	1	Oct 2006	NA
	74	434212114222001	04N 17E 01DCD1	1	Oct 2006	NA
	75	434127114232301	04N 17E 11DAC1	1	Oct 2006	NA
	76	434150114221201	04N 17E 12ADB1	4	Jul 1996 – Oct 2006	0.10
	77	434122114223701	04N 17E 12CDD1	1	Oct 2006	NA
	78	434059114222001	04N 17E 13ACA1	1	Oct 2006	NA
	79	434104114241301	04N 17E 14BBC1	75	Feb 1995 – Dec 2010	0.46
	80	434128114210202	04N 18E 07DCA2	1	Oct 2006	NA
	81	434015114215201	04N 18E 19BBC1	1	Oct 2006	NA
	82	433955114211301	04N 18E 19DBB1	1	Oct 2006	NA
	83	433936114210701	04N 18E 19DCDC1	1	Oct 2006	NA
	84	433914114205401	04N 18E 30ADB3	1	Oct 2006	NA
	85	433748114205701	04N 18E 31DDC1	1	Oct 2006	NA
	86	434646114244901	05N 17E 10DBD1	1	Oct 2006	NA
	87	434620114231601	05N 17E 14AAA1	1	Oct 2006	NA
	88	434605114234901	05N 17E 14ADD1	1	Oct 2006	NA
	89	434554114241701	05N 17E 14CBC1	3	Jul 1996 – Oct 2006	0.42
	90	434511114234601	05N 17E 23ACC2	1	Oct 2006	NA
	91	434426114225801	05N 17E 25BCA1	1	Oct 2006	NA
	92	434346114220601	05N 17E 36AAA1	1	Oct 2006	NA
	93	434350114223201	05N 17E 36ABB1	1	Oct 2006	NA
	94	434338114224801	05N 17E 36BDB1	1	Oct 2006	NA
Geo-located driller well	95	–	1000001	1	Sep 1995	NA
	96	–	1000003	1	Jan 1995	NA
	97	–	1000004	1	Mar 1995	NA
	98	–	1000005	1	Sep 1995	NA
	99	–	1000006	1	Oct 1995	NA
	100	–	1000008	1	May 1995	NA
	101	–	1000009	1	May 1995	NA
	102	–	1000010	1	Jul 1995	NA
	103	–	1000012	1	Mar 1995	NA
	104	–	1000013	1	Jul 1995	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
Geo-located driller well	105	–	1000014	1	Apr 1995	NA
	106	–	1000015	1	Mar 1995	NA
	107	–	1000017	1	Jul 1995	NA
	108	–	1000018	1	Aug 1995	NA
	109	–	1000019	1	Sep 1995	NA
	110	–	1000020	1	Mar 1995	NA
	111	–	1000021	1	Sep 1995	NA
	112	–	1000022	1	Jan 1995	NA
	113	–	1000023	1	Oct 1995	NA
	114	–	1000024	1	May 1995	NA
	115	–	1000025	1	Oct 1995	NA
	116	–	1000026	1	Sep 1995	NA
	117	–	1000027	1	Jul 1995	NA
	118	–	1000029	1	Oct 1995	NA
	119	–	1000030	1	Jun 1995	NA
	120	–	1000031	1	Sep 1995	NA
	121	–	1000032	1	Jul 1995	NA
	122	–	1000033	1	Nov 1995	NA
	123	–	1000034	1	Jul 1995	NA
	124	–	1000035	1	Nov 1995	NA
	125	–	1000036	1	Jul 1995	NA
	126	–	1000038	1	Jan 1995	NA
	127	–	1000039	1	May 1995	NA
	128	–	1000040	1	Oct 1995	NA
	129	–	1000043	1	May 1995	NA
	130	–	1000044	1	May 1995	NA
	131	–	1000045	1	Jun 1996	NA
	132	–	1000046	1	Nov 1996	NA
	133	–	1000047	1	Apr 1996	NA
	134	–	1000048	1	Jul 1996	NA
	135	–	1000049	1	Jul 1996	NA
	136	–	1000050	1	Aug 1996	NA
	137	–	1000051	1	Sep 1996	NA
	138	–	1000052	1	Oct 1996	NA
	139	–	1000054	1	Sep 1996	NA
	140	–	1000055	1	May 1996	NA
	141	–	1000057	1	Jun 1996	NA
	142	–	1000058	1	Oct 1996	NA
	143	–	1000059	1	Nov 1996	NA
	144	–	1000060	1	Apr 1996	NA
	145	–	1000061	1	Oct 1996	NA
	146	–	1000062	1	Aug 1996	NA
	147	–	1000063	1	Nov 1996	NA
	148	–	1000064	1	Aug 1996	NA
	149	–	1000065	1	Jun 1996	NA
	150	–	1000066	1	Nov 1996	NA
	151	–	1000067	1	Jul 1996	NA
	152	–	1000068	1	Jul 1996	NA
	153	–	1000069	1	Apr 1996	NA
	154	–	1000070	1	May 1996	NA
	155	–	1000071	1	Dec 1996	NA
	156	–	1000072	1	Aug 1996	NA
	157	–	1000073	1	Jul 1996	NA
	158	–	1000075	1	Nov 1996	NA
	159	–	1000076	1	Aug 1996	NA
	160	–	1000077	1	Nov 1996	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
Geo-located driller well	161	–	1000078	1	Feb 1996	NA
	162	–	1000079	1	Jun 1996	NA
	163	–	1000080	1	Jun 1996	NA
	164	–	1000081	1	May 1996	NA
	165	–	1000083	1	Oct 1996	NA
	166	–	1000084	1	Aug 1996	NA
	167	–	1000085	1	Aug 1996	NA
	168	–	1000087	1	Aug 1997	NA
	169	–	1000088	1	Sep 1997	NA
	170	–	1000089	1	Jun 1997	NA
	171	–	1000090	1	May 1997	NA
	172	–	1000091	1	Oct 1997	NA
	173	–	1000092	1	Sep 1997	NA
	174	–	1000094	1	Jul 1997	NA
	175	–	1000095	1	Jun 1997	NA
	176	–	1000096	1	Nov 1997	NA
	177	–	1000097	1	Apr 1997	NA
	178	–	1000098	1	Sep 1997	NA
	179	–	1000099	1	May 1997	NA
	180	–	1000100	1	May 1997	NA
	181	–	1000101	1	Nov 1997	NA
	182	–	1000102	1	Jul 1997	NA
	183	–	1000103	1	Apr 1997	NA
	184	–	1000104	1	May 1997	NA
	185	–	1000105	1	Oct 1997	NA
	186	–	1000106	1	Aug 1997	NA
	187	–	1000107	1	Sep 1997	NA
	188	–	1000109	1	Sep 1997	NA
	189	–	1000110	1	Apr 1997	NA
	190	–	1000111	1	Apr 1997	NA
	191	–	1000112	1	Oct 1997	NA
	192	–	1000113	1	Aug 1998	NA
	193	–	1000114	1	Jul 1998	NA
	194	–	1000115	1	Sep 1998	NA
	195	–	1000116	1	Dec 1998	NA
	196	–	1000117	1	Aug 1998	NA
	197	–	1000118	1	Sep 1998	NA
	198	–	1000119	1	Apr 1998	NA
	199	–	1000120	1	Aug 1998	NA
	200	–	1000121	1	Nov 1998	NA
	201	–	1000123	1	Nov 1998	NA
	202	–	1000124	1	Apr 1998	NA
	203	–	1000125	1	Apr 1998	NA
	204	–	1000126	1	Nov 1998	NA
	205	–	1000127	1	May 1998	NA
	206	–	1000129	1	Aug 1998	NA
	207	–	1000130	1	Apr 1998	NA
	208	–	1000131	1	Sep 1998	NA
	209	–	1000132	1	Jan 1998	NA
	210	–	1000133	1	Sep 1998	NA
	211	–	1000134	1	Nov 1998	NA
	212	–	1000135	1	Aug 1998	NA
	213	–	1000136	1	Apr 1998	NA
	214	–	1000137	1	Dec 1998	NA
	215	–	1000138	1	Aug 1998	NA
	216	–	1000139	1	Nov 1998	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
Geo-located driller well	217	–	1000140	1	Apr 1998	NA
	218	–	1000141	1	Jul 1998	NA
	219	–	1000142	1	Jul 1998	NA
	220	–	1000143	1	Sep 1998	NA
	221	–	1000144	1	Oct 1998	NA
	222	–	1000145	1	Jun 1998	NA
	223	–	1000146	1	Sep 1998	NA
	224	–	1000147	1	Aug 1998	NA
	225	–	1000148	1	Oct 1998	NA
	226	–	1000149	1	Dec 1998	NA
	227	–	1000150	1	Sep 1998	NA
	228	–	1000151	1	Oct 1999	NA
	229	–	1000152	1	Nov 1999	NA
	230	–	1000153	1	Aug 1999	NA
	231	–	1000154	1	Sep 1999	NA
	232	–	1000155	1	Apr 1999	NA
	233	–	1000156	1	Sep 1999	NA
	234	–	1000157	1	Sep 1999	NA
	235	–	1000158	1	Oct 1999	NA
	236	–	1000159	1	Oct 1999	NA
	237	–	1000160	1	Oct 1999	NA
	238	–	1000161	1	Jun 1999	NA
	239	–	1000162	1	Aug 1999	NA
	240	–	1000163	1	Apr 1999	NA
	241	–	1000164	1	Oct 1999	NA
	242	–	1000166	1	May 1999	NA
	243	–	1000167	1	Jul 1999	NA
	244	–	1000168	1	Oct 1999	NA
	245	–	1000169	1	Aug 1999	NA
	246	–	1000170	1	Sep 1999	NA
	247	–	1000173	1	Dec 1999	NA
	248	–	1000174	1	Jun 1999	NA
	249	–	1000175	1	Jun 1999	NA
	250	–	1000176	1	Jul 1999	NA
	251	–	1000177	1	Aug 1999	NA
	252	–	1000178	1	Oct 1999	NA
	253	–	1000179	1	Jun 2000	NA
	254	–	1000180	1	Jun 2000	NA
	255	–	1000181	1	Aug 2000	NA
	256	–	1000182	1	May 2000	NA
	257	–	1000183	1	Jul 2000	NA
	258	–	1000184	1	Nov 2000	NA
	259	–	1000185	1	Sep 2000	NA
	260	–	1000186	1	Jul 2000	NA
	261	–	1000187	1	Sep 2000	NA
	262	–	1000189	1	Sep 2000	NA
	263	–	1000190	1	May 2000	NA
	264	–	1000192	1	Jun 2000	NA
	265	–	1000193	1	Nov 2000	NA
	266	–	1000195	1	Jul 2000	NA
	267	–	1000196	1	Jul 2000	NA
	268	–	1000197	1	May 2000	NA
	269	–	1000198	1	Nov 2000	NA
	270	–	1000199	1	Jun 2000	NA
	271	–	1000200	1	Oct 2000	NA
	272	–	1000201	1	Jun 2000	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
Geo-located driller well	273	–	1000202	1	Jul 2000	NA
	274	–	1000203	1	Apr 2000	NA
	275	–	1000204	1	Oct 2000	NA
	276	–	1000206	1	Jul 2000	NA
	277	–	1000207	1	Aug 2000	NA
	278	–	1000209	1	May 2000	NA
	279	–	1000211	1	May 2001	NA
	280	–	1000213	1	May 2001	NA
	281	–	1000214	1	May 2001	NA
	282	–	1000216	1	Apr 2001	NA
	283	–	1000217	1	Aug 2001	NA
	284	–	1000218	1	Jul 2001	NA
	285	–	1000220	1	Nov 2001	NA
	286	–	1000221	1	Sep 2001	NA
	287	–	1000222	1	Oct 2001	NA
	288	–	1000223	1	Aug 2001	NA
	289	–	1000224	1	Jun 2001	NA
	290	–	1000225	1	Sep 2001	NA
	291	–	1000226	1	Sep 2001	NA
	292	–	1000227	1	Apr 2001	NA
	293	–	1000228	1	Apr 2001	NA
	294	–	1000229	1	Sep 2001	NA
	295	–	1000230	1	Nov 2001	NA
	296	–	1000231	1	Oct 2001	NA
	297	–	1000232	1	May 2001	NA
	298	–	1000233	1	May 2001	NA
	299	–	1000234	1	Nov 2001	NA
	300	–	1000236	1	Nov 2001	NA
	301	–	1000238	1	Nov 2001	NA
	302	–	1000239	1	May 2001	NA
	303	–	1000240	1	Jun 2001	NA
	304	–	1000241	1	Apr 2001	NA
	305	–	1000243	1	Jun 2001	NA
	306	–	1000244	1	May 2001	NA
	307	–	1000246	1	May 2001	NA
	308	–	1000247	1	Sep 2001	NA
	309	–	1000248	1	Sep 2001	NA
	310	–	1000250	1	May 2001	NA
	311	–	1000251	1	Jul 2002	NA
	312	–	1000252	1	Aug 2002	NA
	313	–	1000253	1	May 2002	NA
	314	–	1000254	1	Apr 2002	NA
	315	–	1000255	1	Jun 2002	NA
	316	–	1000256	1	Jul 2002	NA
	317	–	1000257	1	Jul 2002	NA
	318	–	1000258	1	Aug 2002	NA
	319	–	1000259	1	Oct 2002	NA
	320	–	1000260	1	Jul 2002	NA
	321	–	1000261	1	Oct 2002	NA
	322	–	1000262	1	Jul 2002	NA
	323	–	1000263	1	Jun 2002	NA
	324	–	1000264	1	May 2002	NA
	325	–	1000265	1	Jun 2003	NA
	326	–	1000266	1	Aug 2003	NA
	327	–	1000267	1	Mar 2003	NA
	328	–	1000268	1	Jun 2004	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
Geo-located driller well	329	–	1000269	1	Dec 2004	NA
	330	–	1000271	1	May 2004	NA
	331	–	1000272	1	Dec 2004	NA
	332	–	1000273	1	Mar 2004	NA
	333	–	1000274	1	May 2004	NA
	334	–	1000275	1	Dec 2004	NA
	335	–	1000276	1	Aug 2004	NA
	336	–	1000277	1	Jul 2004	NA
	337	–	1000278	1	Jul 2004	NA
	338	–	1000279	1	Jul 2004	NA
	339	–	1000280	1	May 2004	NA
	340	–	1000281	1	Jul 2005	NA
	341	–	1000282	1	Oct 2005	NA
	342	–	1000283	1	Nov 2005	NA
	343	–	1000284	1	Nov 2005	NA
	344	–	1000285	1	May 2005	NA
	345	–	1000286	1	Jun 2005	NA
	346	–	1000288	1	Jan 2006	NA
	347	–	1000289	1	Jan 2006	NA
	348	–	1000290	1	Sep 2006	NA
PLSS-located driller well	349	–	5000001	1	Jan 1995	NA
	350	–	5000002	1	Jan 1995	NA
	351	–	5000004	1	May 1995	NA
	352	–	5000005	1	May 1995	NA
	353	–	5000006	1	May 1995	NA
	354	–	5000007	1	May 1995	NA
	355	–	5000008	1	May 1995	NA
	356	–	5000009	1	May 1995	NA
	357	–	5000010	1	May 1995	NA
	358	–	5000011	1	Jun 1995	NA
	359	–	5000012	1	Jun 1995	NA
	360	–	5000013	1	Jun 1995	NA
	361	–	5000014	1	Jun 1995	NA
	362	–	5000015	1	Jul 1995	NA
	363	–	5000016	1	Aug 1995	NA
	364	–	5000017	1	Aug 1995	NA
	365	–	5000019	1	Aug 1995	NA
	366	–	5000022	1	Aug 1995	NA
	367	–	5000023	1	Aug 1995	NA
	368	–	5000025	1	Aug 1995	NA
	369	–	5000027	1	Sep 1995	NA
	370	–	5000028	1	Oct 1995	NA
	371	–	5000029	1	Oct 1995	NA
	372	–	5000030	1	Oct 1995	NA
	373	–	5000031	1	Oct 1995	NA
	374	–	5000032	1	Oct 1995	NA
	375	–	5000033	1	Nov 1995	NA
	376	–	5000034	1	Nov 1995	NA
	377	–	5000035	1	Dec 1995	NA
	378	–	5000036	1	Mar 1996	NA
	379	–	5000037	1	Mar 1996	NA
	380	–	5000038	1	Apr 1996	NA
	381	–	5000039	1	Apr 1996	NA
	382	–	5000040	1	May 1996	NA
	383	–	5000041	1	May 1996	NA
	384	–	5000042	1	May 1996	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
PLSS-located driller well	385	–	5000043	1	Jun 1996	NA
	386	–	5000045	1	Jun 1996	NA
	387	–	5000046	1	Jun 1996	NA
	388	–	5000047	1	Jun 1996	NA
	389	–	5000048	1	Jun 1996	NA
	390	–	5000049	1	Jul 1996	NA
	391	–	5000050	1	Jul 1996	NA
	392	–	5000054	1	Oct 1996	NA
	393	–	5000055	1	Oct 1996	NA
	394	–	5000058	1	Apr 1997	NA
	395	–	5000059	1	May 1997	NA
	396	–	5000060	1	May 1997	NA
	397	–	5000061	1	May 1997	NA
	398	–	5000062	1	Jun 1997	NA
	399	–	5000063	1	Jun 1997	NA
	400	–	5000064	1	Jun 1997	NA
	401	–	5000065	1	Jun 1997	NA
	402	–	5000066	1	Jul 1997	NA
	403	–	5000067	1	Jul 1997	NA
	404	–	5000068	1	Aug 1997	NA
	405	–	5000069	1	Aug 1997	NA
	406	–	5000071	1	Sep 1997	NA
	407	–	5000073	1	Sep 1997	NA
	408	–	5000075	1	Oct 1997	NA
	409	–	5000076	1	Oct 1997	NA
	410	–	5000081	1	Nov 1997	NA
	411	–	5000082	1	Dec 1997	NA
	412	–	5000083	1	Dec 1997	NA
	413	–	5000084	1	Jan 1998	NA
	414	–	5000085	1	Apr 1998	NA
	415	–	5000086	1	Apr 1998	NA
	416	–	5000087	1	May 1998	NA
	417	–	5000088	1	May 1998	NA
	418	–	5000089	1	May 1998	NA
	419	–	5000090	1	Jun 1998	NA
	420	–	5000091	1	Jun 1998	NA
	421	–	5000093	1	Jun 1998	NA
	422	–	5000094	1	Jul 1998	NA
	423	–	5000095	1	Jul 1998	NA
	424	–	5000096	1	Jul 1998	NA
	425	–	5000097	1	Aug 1998	NA
	426	–	5000100	1	Oct 1998	NA
	427	–	5000101	1	Oct 1998	NA
	428	–	5000102	1	Nov 1998	NA
	429	–	5000104	1	Dec 1998	NA
	430	–	5000105	1	Dec 1998	NA
	431	–	5000106	1	Dec 1998	NA
	432	–	5000108	1	Apr 1999	NA
	433	–	5000110	1	Apr 1999	NA
	434	–	5000111	1	May 1999	NA
	435	–	5000112	1	Jun 1999	NA
	436	–	5000114	1	Jul 1999	NA
	437	–	5000115	1	Jul 1999	NA
	438	–	5000117	1	Aug 1999	NA
	439	–	5000118	1	Sep 1999	NA
	440	–	5000120	1	Oct 1999	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
PLSS-located driller well	441	–	5000123	1	Nov 1999	NA
	442	–	5000126	1	May 2000	NA
	443	–	5000127	1	May 2000	NA
	444	–	5000128	1	May 2000	NA
	445	–	5000129	1	May 2000	NA
	446	–	5000131	1	May 2000	NA
	447	–	5000132	1	Jun 2000	NA
	448	–	5000133	1	Jun 2000	NA
	449	–	5000134	1	Jun 2000	NA
	450	–	5000135	1	Jun 2000	NA
	451	–	5000136	1	Jul 2000	NA
	452	–	5000137	1	Jul 2000	NA
	453	–	5000138	1	Jul 2000	NA
	454	–	5000139	1	Jul 2000	NA
	455	–	5000140	1	Jul 2000	NA
	456	–	5000142	1	Aug 2000	NA
	457	–	5000143	1	Sep 2000	NA
	458	–	5000144	1	Sep 2000	NA
	459	–	5000145	1	Oct 2000	NA
	460	–	5000146	1	Oct 2000	NA
	461	–	5000147	1	Oct 2000	NA
	462	–	5000148	1	Oct 2000	NA
	463	–	5000149	1	Oct 2000	NA
	464	–	5000150	1	Nov 2000	NA
	465	–	5000151	1	Dec 2000	NA
	466	–	5000153	1	Apr 2001	NA
	467	–	5000154	1	Apr 2001	NA
	468	–	5000155	1	May 2001	NA
	469	–	5000156	1	May 2001	NA
	470	–	5000157	1	Jun 2001	NA
	471	–	5000159	1	Jun 2001	NA
	472	–	5000161	1	Jul 2001	NA
	473	–	5000162	1	Aug 2001	NA
	474	–	5000163	1	Aug 2001	NA
	475	–	5000164	1	Aug 2001	NA
	476	–	5000165	1	Aug 2001	NA
	477	–	5000166	1	Aug 2001	NA
	478	–	5000167	1	Sep 2001	NA
	479	–	5000168	1	Oct 2001	NA
	480	–	5000169	1	Oct 2001	NA
	481	–	5000171	1	Oct 2001	NA
	482	–	5000172	1	Nov 2001	NA
	483	–	5000173	1	Nov 2001	NA
	484	–	5000174	1	Nov 2001	NA
	485	–	5000175	1	Dec 2001	NA
	486	–	5000177	1	Apr 2002	NA
	487	–	5000178	1	Apr 2002	NA
	488	–	5000179	1	Apr 2002	NA
	489	–	5000180	1	Apr 2002	NA
	490	–	5000181	1	Apr 2002	NA
	491	–	5000182	1	Apr 2002	NA
	492	–	5000183	1	May 2002	NA
	493	–	5000184	1	May 2002	NA
	494	–	5000185	1	May 2002	NA
	495	–	5000186	1	Jun 2002	NA
	496	–	5000187	1	Jul 2002	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
PLSS-located driller well	497	–	5000188	1	Jul 2002	NA
	498	–	5000189	1	Jul 2002	NA
	499	–	5000190	1	Jul 2002	NA
	500	–	5000191	1	Aug 2002	NA
	501	–	5000192	1	Aug 2002	NA
	502	–	5000193	1	Aug 2002	NA
	503	–	5000194	1	Aug 2002	NA
	504	–	5000195	1	Aug 2002	NA
	505	–	5000197	1	Sep 2002	NA
	506	–	5000198	1	Sep 2002	NA
	507	–	5000199	1	Sep 2002	NA
	508	–	5000200	1	Sep 2002	NA
	509	–	5000201	1	Sep 2002	NA
	510	–	5000202	1	Sep 2002	NA
	511	–	5000204	1	Sep 2002	NA
	512	–	5000205	1	Sep 2002	NA
	513	–	5000206	1	Sep 2002	NA
	514	–	5000207	1	Sep 2002	NA
	515	–	5000208	1	Oct 2002	NA
	516	–	5000209	1	Oct 2002	NA
	517	–	5000210	1	Oct 2002	NA
	518	–	5000211	1	Oct 2002	NA
	519	–	5000212	1	Oct 2002	NA
	520	–	5000214	1	Oct 2002	NA
	521	–	5000215	1	Oct 2002	NA
	522	–	5000216	1	Nov 2002	NA
	523	–	5000217	1	Nov 2002	NA
	524	–	5000218	1	Nov 2002	NA
	525	–	5000219	1	Jan 2003	NA
	526	–	5000220	1	Apr 2003	NA
	527	–	5000221	1	Apr 2003	NA
	528	–	5000222	1	Apr 2003	NA
	529	–	5000223	1	Apr 2003	NA
	530	–	5000224	1	Apr 2003	NA
	531	–	5000225	1	Apr 2003	NA
	532	–	5000226	1	May 2003	NA
	533	–	5000227	1	Jun 2003	NA
	534	–	5000228	1	Jun 2003	NA
	535	–	5000229	1	Jun 2003	NA
	536	–	5000230	1	Jun 2003	NA
	537	–	5000231	1	Jun 2003	NA
	538	–	5000232	1	Jun 2003	NA
	539	–	5000233	1	Jun 2003	NA
	540	–	5000234	1	Jun 2003	NA
	541	–	5000235	1	Jun 2003	NA
	542	–	5000236	1	Jun 2003	NA
	543	–	5000237	1	Jun 2003	NA
	544	–	5000238	1	Jun 2003	NA
	545	–	5000239	1	Jun 2003	NA
	546	–	5000240	1	Jul 2003	NA
	547	–	5000241	1	Jul 2003	NA
	548	–	5000242	1	Jul 2003	NA
	549	–	5000244	1	Aug 2003	NA
	550	–	5000245	1	Aug 2003	NA
	551	–	5000246	1	Aug 2003	NA
	552	–	5000247	1	Aug 2003	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
PLSS-located driller well	553	–	5000248	1	Aug 2003	NA
	554	–	5000249	1	Aug 2003	NA
	555	–	5000250	1	Sep 2003	NA
	556	–	5000251	1	Oct 2003	NA
	557	–	5000252	1	Oct 2003	NA
	558	–	5000254	1	Oct 2003	NA
	559	–	5000255	1	Oct 2003	NA
	560	–	5000256	1	Oct 2003	NA
	561	–	5000257	1	Oct 2003	NA
	562	–	5000258	1	Oct 2003	NA
	563	–	5000259	1	Oct 2003	NA
	564	–	5000260	1	Oct 2003	NA
	565	–	5000261	1	Oct 2003	NA
	566	–	5000262	1	Oct 2003	NA
	567	–	5000263	1	Oct 2003	NA
	568	–	5000264	1	Oct 2003	NA
	569	–	5000265	1	Oct 2003	NA
	570	–	5000266	1	Oct 2003	NA
	571	–	5000267	1	Oct 2003	NA
	572	–	5000269	1	Oct 2003	NA
	573	–	5000270	1	Oct 2003	NA
	574	–	5000271	1	Oct 2003	NA
	575	–	5000272	1	Oct 2003	NA
	576	–	5000273	1	Oct 2003	NA
	577	–	5000274	1	Oct 2003	NA
	578	–	5000275	1	Oct 2003	NA
	579	–	5000276	1	Oct 2003	NA
	580	–	5000277	1	Oct 2003	NA
	581	–	5000278	1	Oct 2003	NA
	582	–	5000279	1	Oct 2003	NA
	583	–	5000280	1	Oct 2003	NA
	584	–	5000281	1	Oct 2003	NA
	585	–	5000282	1	Nov 2003	NA
	586	–	5000283	1	Nov 2003	NA
	587	–	5000284	1	Nov 2003	NA
	588	–	5000285	1	Nov 2003	NA
	589	–	5000286	1	Nov 2003	NA
	590	–	5000287	1	Nov 2003	NA
	591	–	5000288	1	Nov 2003	NA
	592	–	5000289	1	Nov 2003	NA
	593	–	5000290	1	Nov 2003	NA
	594	–	5000291	1	Nov 2003	NA
	595	–	5000292	1	Nov 2003	NA
	596	–	5000293	1	Nov 2003	NA
	597	–	5000295	1	Nov 2003	NA
	598	–	5000296	1	Nov 2003	NA
	599	–	5000298	1	Nov 2003	NA
	600	–	5000299	1	Nov 2003	NA
	601	–	5000300	1	Nov 2003	NA
	602	–	5000301	1	Nov 2003	NA
	603	–	5000302	1	Nov 2003	NA
	604	–	5000305	1	Dec 2003	NA
	605	–	5000306	1	Dec 2003	NA
	606	–	5000309	1	Dec 2003	NA
	607	–	5000310	1	Jan 2004	NA
	608	–	5000311	1	Jan 2004	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
PLSS-located driller well	609	–	5000312	1	Jan 2004	NA
	610	–	5000313	1	Mar 2004	NA
	611	–	5000314	1	Mar 2004	NA
	612	–	5000315	1	Apr 2004	NA
	613	–	5000316	1	Apr 2004	NA
	614	–	5000318	1	Apr 2004	NA
	615	–	5000319	1	Apr 2004	NA
	616	–	5000320	1	May 2004	NA
	617	–	5000322	1	May 2004	NA
	618	–	5000323	1	May 2004	NA
	619	–	5000324	1	Jun 2004	NA
	620	–	5000325	1	Jun 2004	NA
	621	–	5000326	1	Jun 2004	NA
	622	–	5000327	1	Jun 2004	NA
	623	–	5000328	1	Jun 2004	NA
	624	–	5000329	1	Jul 2004	NA
	625	–	5000330	1	Jul 2004	NA
	626	–	5000331	1	Jul 2004	NA
	627	–	5000332	1	Jul 2004	NA
	628	–	5000335	1	Aug 2004	NA
	629	–	5000336	1	Aug 2004	NA
	630	–	5000337	1	Aug 2004	NA
	631	–	5000338	1	Aug 2004	NA
	632	–	5000339	1	Aug 2004	NA
	633	–	5000340	1	Aug 2004	NA
	634	–	5000342	1	Sep 2004	NA
	635	–	5000343	1	Sep 2004	NA
	636	–	5000344	1	Sep 2004	NA
	637	–	5000345	1	Sep 2004	NA
	638	–	5000346	1	Sep 2004	NA
	639	–	5000347	1	Sep 2004	NA
	640	–	5000348	1	Sep 2004	NA
	641	–	5000349	1	Sep 2004	NA
	642	–	5000350	1	Oct 2004	NA
	643	–	5000351	1	Oct 2004	NA
	644	–	5000352	1	Oct 2004	NA
	645	–	5000354	1	Nov 2004	NA
	646	–	5000355	1	Nov 2004	NA
	647	–	5000356	1	Nov 2004	NA
	648	–	5000357	1	Nov 2004	NA
	649	–	5000358	1	Nov 2004	NA
	650	–	5000359	1	Nov 2004	NA
	651	–	5000360	1	Nov 2004	NA
	652	–	5000362	1	Nov 2004	NA
	653	–	5000363	1	Nov 2004	NA
	654	–	5000364	1	Dec 2004	NA
	655	–	5000365	1	Mar 2005	NA
	656	–	5000366	1	Apr 2005	NA
	657	–	5000367	1	May 2005	NA
	658	–	5000368	1	May 2005	NA
	659	–	5000369	1	Jun 2005	NA
	660	–	5000370	1	Jul 2005	NA
	661	–	5000371	1	Jul 2005	NA
	662	–	5000372	1	Aug 2005	NA
	663	–	5000373	1	Aug 2005	NA
	664	–	5000374	1	Aug 2005	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
PLSS-located driller well	665	–	5000376	1	Aug 2005	NA
	666	–	5000377	1	Aug 2005	NA
	667	–	5000378	1	Sep 2005	NA
	668	–	5000379	1	Sep 2005	NA
	669	–	5000381	1	Oct 2005	NA
	670	–	5000382	1	Oct 2005	NA
	671	–	5000383	1	Oct 2005	NA
	672	–	5000384	1	Oct 2005	NA
	673	–	5000385	1	Oct 2005	NA
	674	–	5000386	1	Nov 2005	NA
	675	–	5000390	1	Nov 2005	NA
	676	–	5000392	1	Apr 2006	NA
	677	–	5000394	1	May 2006	NA
	678	–	5000395	1	May 2006	NA
	679	–	5000396	1	May 2006	NA
	680	–	5000397	1	May 2006	NA
	681	–	5000398	1	May 2006	NA
	682	–	5000399	1	May 2006	NA
	683	–	5000400	1	May 2006	NA
	684	–	5000401	1	May 2006	NA
	685	–	5000402	1	May 2006	NA
	686	–	5000403	1	May 2006	NA
	687	–	5000404	1	May 2006	NA
	688	–	5000405	1	Jun 2006	NA
	689	–	5000406	1	Jun 2006	NA
	690	–	5000407	1	Jun 2006	NA
	691	–	5000408	1	Jun 2006	NA
	692	–	5000410	1	Jun 2006	NA
	693	–	5000412	1	Jul 2006	NA
	694	–	5000413	1	Jul 2006	NA
	695	–	5000415	1	Aug 2006	NA
	696	–	5000416	1	Aug 2006	NA
	697	–	5000417	1	Aug 2006	NA
	698	–	5000418	1	Aug 2006	NA
	699	–	5000419	1	Aug 2006	NA
	700	–	5000420	1	Aug 2006	NA
	701	–	5000421	1	Aug 2006	NA
	702	–	5000422	1	Aug 2006	NA
	703	–	5000423	1	Aug 2006	NA
	704	–	5000424	1	Aug 2006	NA
	705	–	5000425	1	Aug 2006	NA
	706	–	5000426	1	Sep 2006	NA
	707	–	5000427	1	Sep 2006	NA
	708	–	5000428	1	Sep 2006	NA
	709	–	5000429	1	Sep 2006	NA
	710	–	5000430	1	Oct 2006	NA
	711	–	5000431	1	Oct 2006	NA
	712	–	5000433	1	Oct 2006	NA
	713	–	5000434	1	Oct 2006	NA
	714	–	5000435	1	Oct 2006	NA
	715	–	5000437	1	Nov 2006	NA
	716	–	5000438	1	Nov 2006	NA
	717	–	5000439	1	Mar 2007	NA
	718	–	5000443	1	Mar 2007	NA
	719	–	5000445	1	Apr 2007	NA
	720	–	5000446	1	May 2007	NA

Table H1. Observation wells in the Wood River Valley aquifer system.—Continued

Well type	Well No.	Site identifier	Name	No. of records	Period of record	SD (m)
PLSS-located driller well	721	–	5000447	1	May 2007	NA
	722	–	5000448	1	May 2007	NA
	723	–	5000449	1	May 2007	NA
	724	–	5000450	1	May 2007	NA
	725	–	5000451	1	May 2007	NA
	726	–	5000453	1	Jun 2007	NA
	727	–	5000454	1	Jun 2007	NA
	728	–	5000455	1	Jul 2007	NA
	729	–	5000456	1	Jul 2007	NA
	730	–	5000457	1	Aug 2007	NA
	731	–	5000458	1	Aug 2007	NA
	732	–	5000459	1	Aug 2007	NA
	733	–	5000460	1	Aug 2007	NA
	734	–	5000461	1	Aug 2007	NA
	735	–	5000462	1	Aug 2007	NA
	736	–	5000463	1	Aug 2007	NA
	737	–	5000465	1	Aug 2007	NA
	738	–	5000468	1	Oct 2007	NA
	739	–	5000469	1	Nov 2007	NA
	740	–	5000470	1	Nov 2007	NA
	741	–	5000471	1	Nov 2007	NA
	742	–	5000472	1	Nov 2007	NA
	743	–	5000474	1	Apr 2008	NA
	744	–	5000475	1	May 2008	NA
	745	–	5000476	1	May 2008	NA
	746	–	5000477	1	Jun 2008	NA
	747	–	5000478	1	Jun 2008	NA
	748	–	5000479	1	Jul 2008	NA
	749	–	5000480	1	Jul 2008	NA
	750	–	5000481	1	Jul 2008	NA
	751	–	5000482	1	Jul 2008	NA
	752	–	5000484	1	Aug 2008	NA
	753	–	5000487	1	Sep 2008	NA
	754	–	5000488	1	Oct 2008	NA
	755	–	5000489	1	Oct 2008	NA
	756	–	5000490	1	Oct 2008	NA
	757	–	5000491	1	Oct 2008	NA
	758	–	5000492	1	Oct 2008	NA
	759	–	5000493	1	Oct 2008	NA
	760	–	5000494	1	Nov 2008	NA
	761	–	5000495	1	Nov 2008	NA
	762	–	5000496	1	Nov 2008	NA
	763	–	5000497	1	Nov 2008	NA
	764	–	5000501	1	Mar 2009	NA
SVWSD well	765	–	04N 18E 07ADD	107	Jan 1995 – Jan 2004	2.33
	766	433936114210701	04N 18E 19DCDC1	286	Jan 1995 – Oct 2010	0.42
TNC well	767	–	01N 19E 29CCC1	251	Apr–Dec 2010	1.16
	768	–	01S 20E 20CDD2	239	Apr–Dec 2010	0.95
	769	–	01S 18E 15ABB1	144	Aug–Dec 2010	0.28
	770	–	02N 18E 09BCD1	150	Aug–Dec 2010	0.04
	771	–	01N 18E 36DDC1	146	Aug–Dec 2010	0.69
	772	–	01S 19E 08 BBD1	252	Apr–Dec 2010	0.93
	773	–	01N 19E 19CAA1	201	Apr–Dec 2010	1.19
	774	432657114144801	01N 18E 01DAA1	142	Aug–Dec 2010	0.47
	775	432143114114301	01S 19E 03CCB2	254	Apr–Dec 2010	0.61
	776	–	02N 18E 35ACC1	248	Apr–Dec 2010	0.31

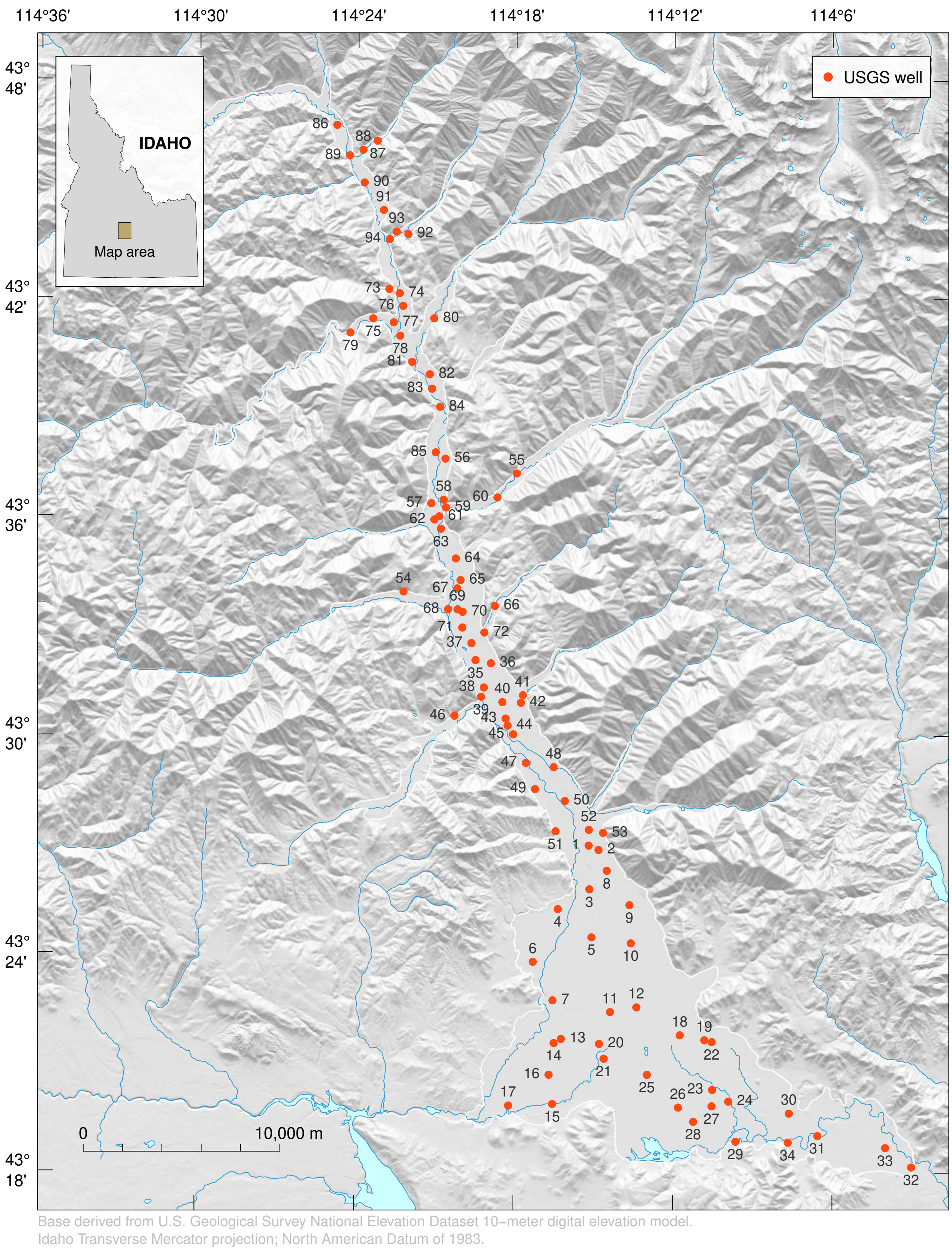


Figure H1. Location of wells in the U.S. Geological Survey (USGS) groundwater monitoring network, Wood River Valley, Idaho.

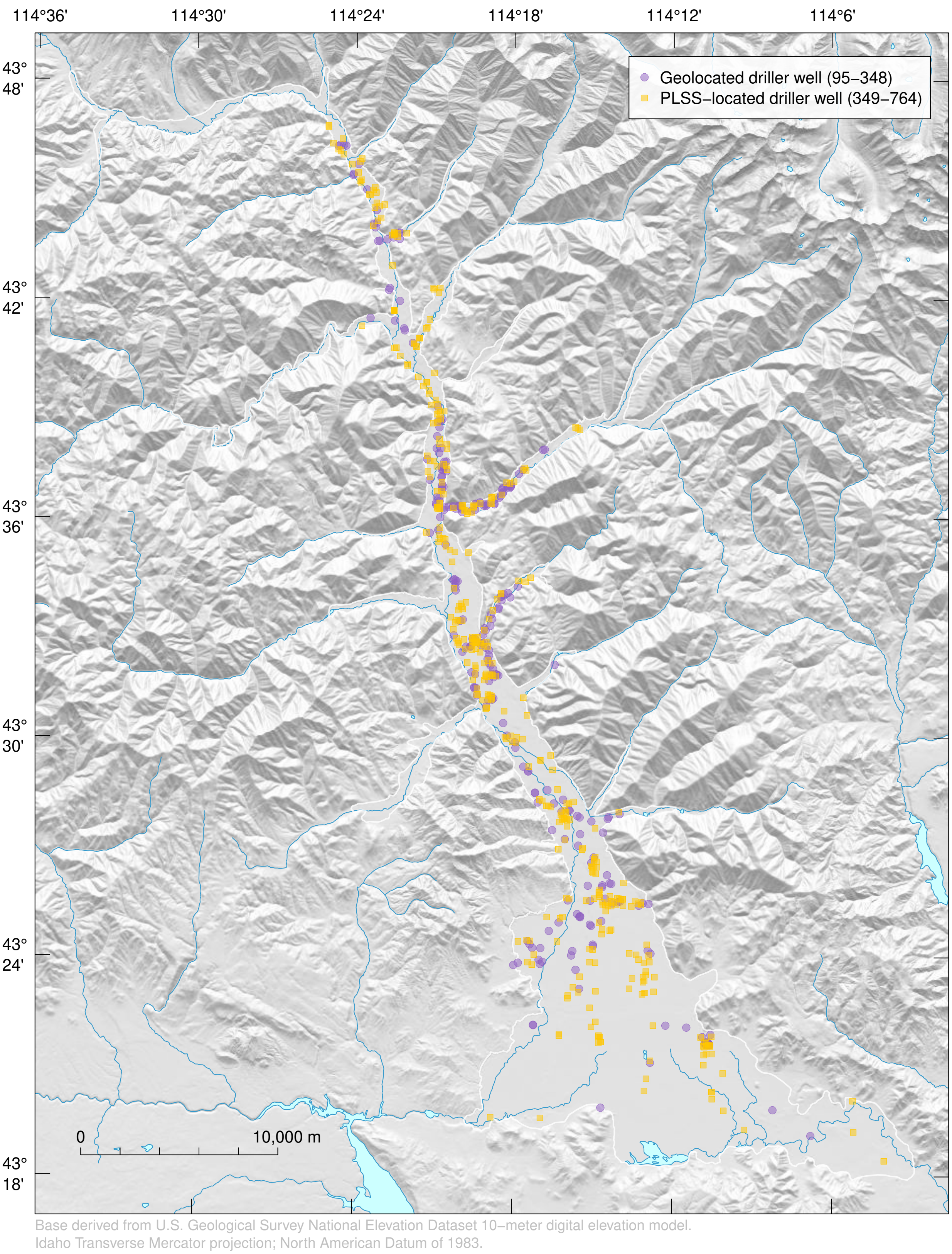


Figure H2. Location of geolocated driller wells and Public Land Survey System (PLSS)-located driller wells in the Wood River Valley, Idaho.

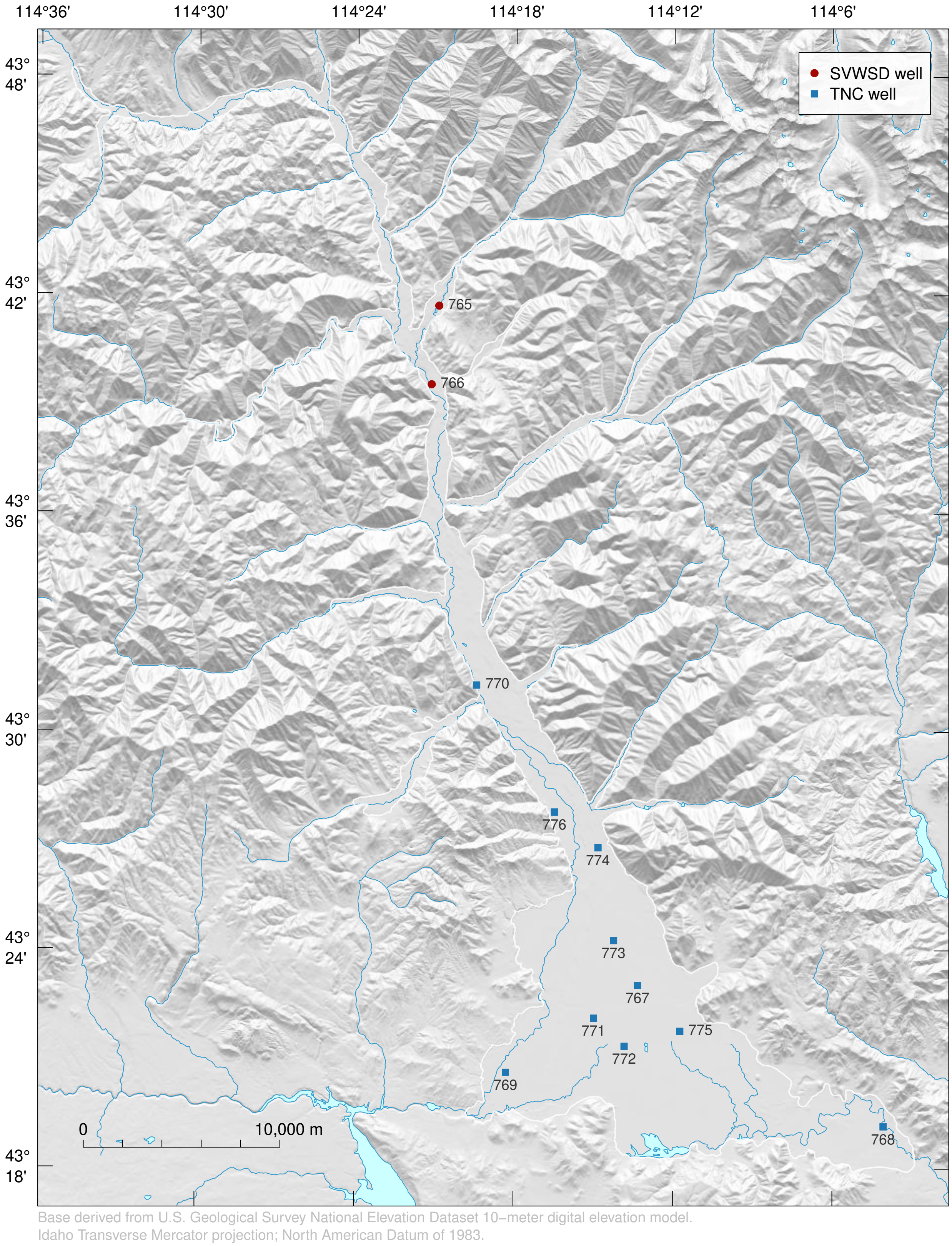


Figure H3. Location of two Sun Valley Water and Sewer District (SVWSD) production wells, and wells in The Nature Conservancy (TNC) groundwater monitoring network, Wood River Valley, Idaho.

Stream-Aquifer Flow Exchange in River Reaches

Stream-aquifer flow exchange is simulated along the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributary streams (fig. H4). Whether a river or stream loses or gains water as it flows downstream is dependent on the head difference between the stream and the aquifer, and the hydraulic conductance of the riverbed. The model-simulated flow-exchange between the stream and aquifer was assessed using field measurements.

Streamflows

Continuous streamflow measurements are available from nine streamgages (8 gages operated by the USGS and one by the Idaho Power Company) in the Wood River Valley, Idaho (table H2, fig. H4). The Big Wood River near Ketchum (13135500, site No. 1) and the North Fork Big Wood River near Sawtooth NRA Headquarters near Ketchum (13135520, site No. 2) streamgage measure surface-water inflow at the northern boundary of the model. The Big Wood River at Hailey (13139510, site No. 14) streamgage lies at about the midpoint of the river within the model domain, and the Big Wood River at Stanton Crossing near Bellevue (13140800, site No. 20) is at the southern boundary where the river exits the model domain. Three tributaries to the Big Wood River have streamgages; these are, Warm Springs Creek near Ketchum (13137000, site No. 9), Trail Creek at Ketchum (13137500, site No. 10), and East Fork Big Wood River at Gimlet (13138000, site No. 12). The Willow Creek near Bellevue (13140900, site No. 21) streamgage is operated by Idaho Power Company and measures spring-fed stream tributaries that enter the Big Wood River downstream of the model boundary near the southwest boundary of the model. The Silver Creek at Sportsman Access (13150430, site No. 31) streamgage measures spring-fed stream tributaries that enter Silver Creek about 11 river kilometers (7 miles) upstream of the southeast model boundary.

The period of record for streamgages with continuous records are given in table H2. Streamgages not in operation during the model simulation period (1995–2010) include: the Big Wood River near Ketchum (site No. 1), the North Fork Big Wood River near Sawtooth NRA Headquarters near Ketchum (site No. 2), Warm Springs Creek near Ketchum (site No. 9), Trail Creek at Ketchum (site No. 10), and East Fork Big Wood River at Gimlet (site No. 12). All of these streamgages are located upstream of the Big Wood River at Hailey streamgage (site No. 14), and are either on the Big Wood River or on one of its tributary streams. Furthermore, the periods of record for these streamgages all coincide with the period of record for the Hailey streamgage (1915–present). Using the coinciding streamflow data, linear regression models were developed for predicting the missing streamflow records (table H3).

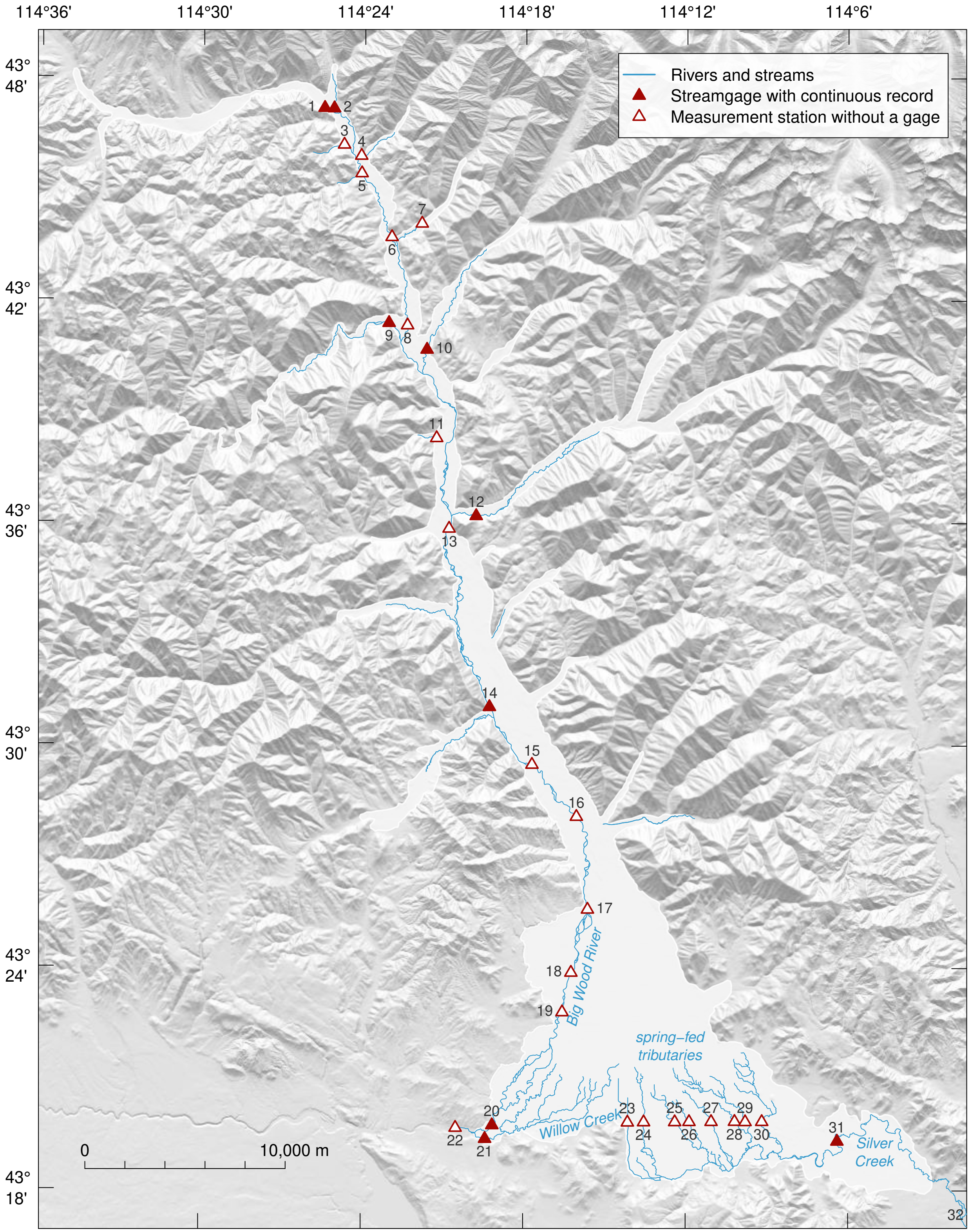
The USGS made three seepage runs: August 2012, October 2012, and March 2013 (table H2, fig. H4) (Bartolino, 2014). Based on these measurements, the August streamflow from ungaged tributaries to the Big Wood River upstream of the Big Wood River at Hailey streamgage (site No. 14) was estimated to be 9,542 cubic meters per day (m^3/d) (3.9 cubic feet per second [cfs]). Contributions from ungaged tributaries to the Big Wood River downstream of the Big Wood River at Hailey (site No. 14) streamgage were estimated to be zero during the October and March seepage runs.

Returns

There are three water-source types for streamflow returns to the Big Wood River, Silver Creek, and spring-fed tributary streams. These water-source types are: (1) effluent from wastewater treatment plants (WWTP), (2) surface water from canals, and (3) pumped groundwater from exchange wells. Effluent flows into the Big Wood River from three municipal WWTP's (table H4, fig. H5). The Ketchum Sun Valley (which includes the City of Ketchum and the Sun Valley Water and Sewer District) WWTP (return No. 3) and The Meadows WWTP (return No. 4) outfalls are into the river between the Near Ketchum (13135500) and Hailey (13139510) streamgages. The City of Hailey WWTP outfall (return No. 5) is into the river between the Hailey (13139510) and the Stanton Crossing near Bellevue (13140800) streamgages. Records of wastewater treatment plant return flows are available for various years (1995–2012 for the Ketchum Sun Valley WWTP, 1996–2012 for the City of Hailey WWTP, and 2000–2012 for The Meadows WWTP). Effluent return flows during periods of missing data (1995 for the City of Hailey WWTP and 1995–1999 for The Meadows WWTP) were assumed to be similar to the first year for which data were available.

There are few measured returns from canals to rivers or streams in the study area (table H4, fig. H5). Water District 37 has recorded streamflow returns from the District 45 canal system to the Loving Creek area (return No. 6). In recent years, Water District 37 began recording returns to the Big Wood River from canals that primarily deliver water for aesthetic, non-consumptive uses; such as the Gimlet and Rinker irrigation systems (return No. 1, 2). Unmeasured returns from irrigation canals to streams are thought to be negligible in the study area (Kevin Lakey, Watermaster Water District 37, written commun., August 27, 2013).

Exchange wells pump water into a river or stream so that an equivalent amount of water can be diverted at a downstream location. There are 9 exchange wells in the study area and diversion amounts are recorded by Water District 37. Eight of these wells discharge into Silver Creek or its tributaries above the Silver Creek at Sportsman Access streamgage (13150430, site No. 31). The other well (return No. 19) discharges into Silver Creek downstream of the Silver Creek at Sportsman Access streamgage (13150430).



Base derived from U.S. Geological Survey National Elevation Dataset 10–meter digital elevation model.
Idaho Transverse Mercator projection; North American Datum of 1983.

Figure H4. River network and streamflow measurement sites in the Wood River Valley, Idaho.

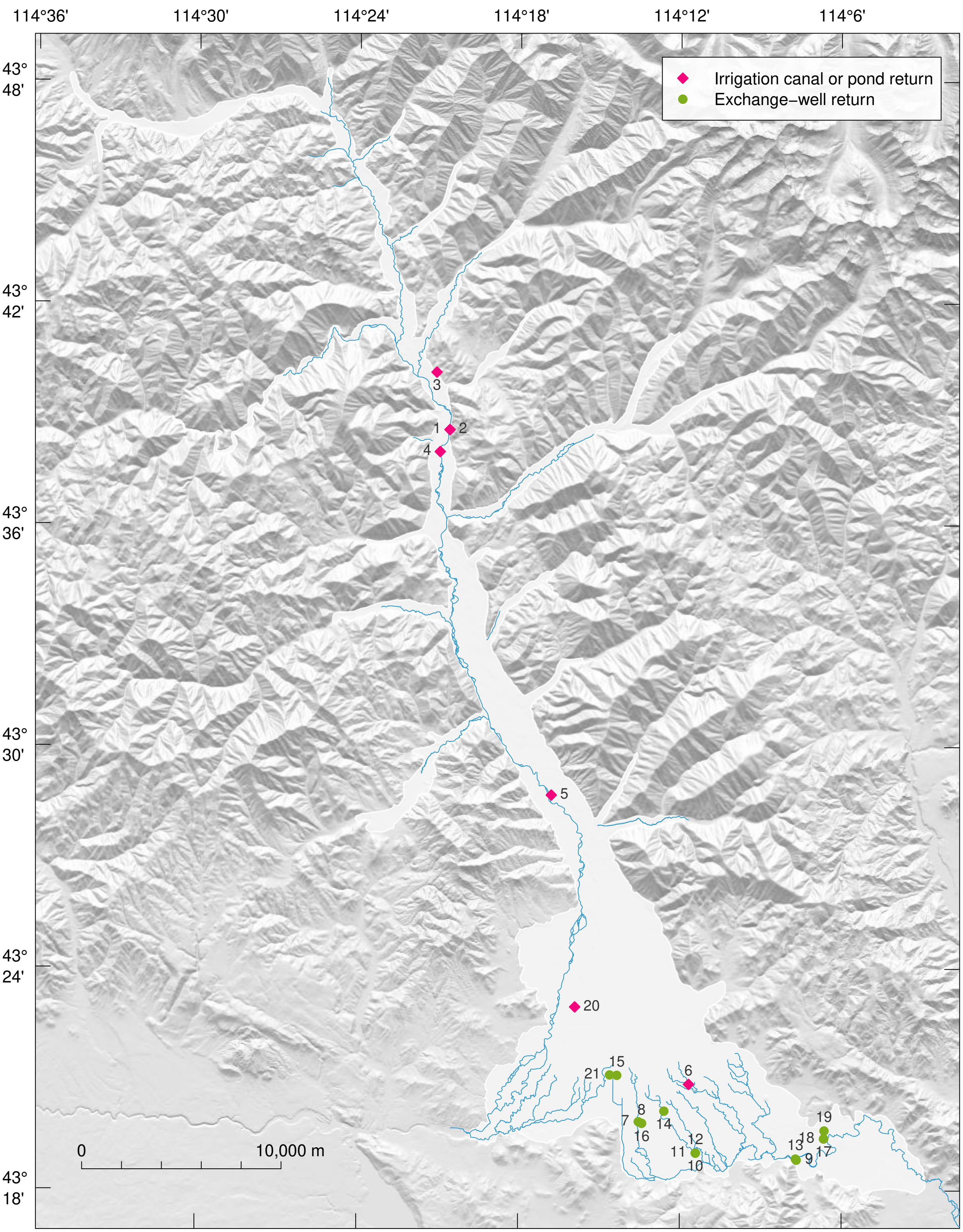


Figure H5. Streamflow returns from irrigation canals or ponds, and exchange wells located on the Big Wood River, Silver Creek, and spring-fed tributaries.

Table H2. Streamflow measurement sites located on the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributaries. [**Site No.**: identifier used to locate measurement sites on maps located in figures and as a cross reference with data in other tables. **Site identifier**: unique numerical identifiers used to access streamflow data (https://waterdata.usgs.gov/nwis). **Name**: local measurement site name used in this study.]

Site No.	Site identifier	Name	Period of record
1	13135500	BIG WOOD RIVER NEAR KETCHUM	1948–1972, 2011–present
2	13135520	NF BIG WOOD RIVER NR SAWTOOTH NRA HQ NR KETCHUM, ID	2011–present
3	434611114244600	CHOCOLATE GULCH CREEK NR KETCHUM, ID	Aug, Oct 2012; Mar 2013
4	13135600	EAGLE CREEK AT US HWY 75 NR KETCHUM, ID	Aug, Oct 2012; Mar 2013
5	13135700	FOX CREEK AT MOUTH NR KETCHUM, ID	Aug, Oct 2012; Mar 2013
6	13135840	BIG WOOD RIVER AT HULEN ROAD BRIDGE NR KETCHUM, ID	Aug, Oct 2012; Mar 2013
7	434404114215200	LAKE CREEK ABOVE MOUTH NR KETCHUM, ID	Aug, Oct 2012
8	13136000	BIG WOOD RIVER AT KETCHUM, ID	Aug, Oct 2012; Mar 2013
9	13137000	WARM SPRINGS CREEK NEAR KETCHUM, ID	1920–1921, 2011–present
10	13137500	TRAIL CREEK AT KETCHUM, ID	1920–1921, 2011–present
11	433817114211800	CLEAR CREEK AT US HWY 75 NR KETCHUM, ID	Aug, Oct 2012; Mar 2013
12	13138000	EAST FORK BIG WOOD RIVER AT GIMLET, ID	1920–1921, 2011–present
13	13138500	BIG WOOD RIVER AT GIMLET, ID	Aug, Oct 2012; Mar 2013
14	13139510	BIG WOOD RIVER AT HAILEY, ID TOTAL FLOW	1915–present
15	432929114174300	BIG WOOD RIVER BLW N BROADFORD BRIDGE NR HAILEY,ID	Aug, Oct 2012; Mar 2013
16	432805114160400	BIG WOOD RIVER AT S BROADFORD CROSSING BELLVUE, ID	Aug, Oct 2012; Mar 2013
17	13140500	BIG WOOD RIVER AT GLENDALE BRIDGE NR BELLEVUE, ID	Aug, Oct 2012; Mar 2013
18	432352114161500	BIG WOOD RIVER AT SLUDER DR NR BELLEVUE, ID	March 2013
19	432248114163400	BIG WOOD RIVER AT WOOD RIVER RANCH NR BELLEVUE, ID	March 2013
20	13140800	BIG WOOD RIVER AT STANTON CROSSING NR BELLEVUE, ID	1996–present
21	13140900	WILLOW CREEK NR SPRING CR RANCH NR BELLEVUE, ID	1999–present
22	13141000	BIG WOOD RIVER NR BELLEVUE, ID	Aug, Oct 2012; Mar 2013
23	13150010	BUTLER DRAIN AT US HWY 20 NR GANNETT, ID	Aug, Oct 2012; Mar 2013
24	431947114133300	PATTON CREEK	Aug, Oct 2012; Mar 2013
25	13150140	CAIN CREEK AT US HWY 20 NR GANNETT, ID	Aug, Oct 2012; Mar 2013
26	13150150	CHANEY CREEK AT US HWY 20 NR GANNETT, ID	Aug, Oct 2012; Mar 2013
27	13150300	MUD CREEK AT US HWY 20 NR GANNETT, ID	Aug, Oct 2012; Mar 2013
28	13150350	WILSON CREEK AT US HWY 20 NR GANNETT, ID	Aug, Oct 2012; Mar 2013
29	13150360	GROVE CREEK AT US HWY 20 NR GANNETT, ID	Aug, Oct 2012; Mar 2013
30	13150400	LOVING CREEK AT US HWY 20 NR GANNETT, ID	Aug, Oct 2012; Mar 2013
31	13150430	SILVER CREEK AT SPORTSMAN ACCESS NR PICABO, ID	1974–present
32	13150500	SILVER CREEK NEAR HWY 20 NEAR PICABO, ID	Aug, Oct 2012; Mar 2013

Diversions

Surface-water irrigation diversions from the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributary streams have been recorded by Water District 37 and Water District 37M since 1920 (table H5, fig. H6). IDWR employees compiled monthly diversion data for the simulation period (1995–2010) that are available from April through September each year. The irrigation season extends through October 31, and the Water Districts do not record diversions that occur between September 30 and April 1 of the following year. Diversions recorded during the month of October were estimated to be 25 percent of September diversions.

River reaches

To simplify the structural complexity of the WRV river system, five river reaches were delineated based on the locations of streamgages with continuous streamflow records (fig. H7, table H6). A river reach is defined as a continuous run of surface water with similar hydrologic characteristics. The upstream and downstream boundaries of a river reach typically coincide with the location of a streamgage with continuous records (table H6). The exception is Willow Creek (reach No. 3) and Silver Creek above Sportsman Access (reach No. 4) which begin as spring-fed streams and there are no upstream streamgages for these reaches.

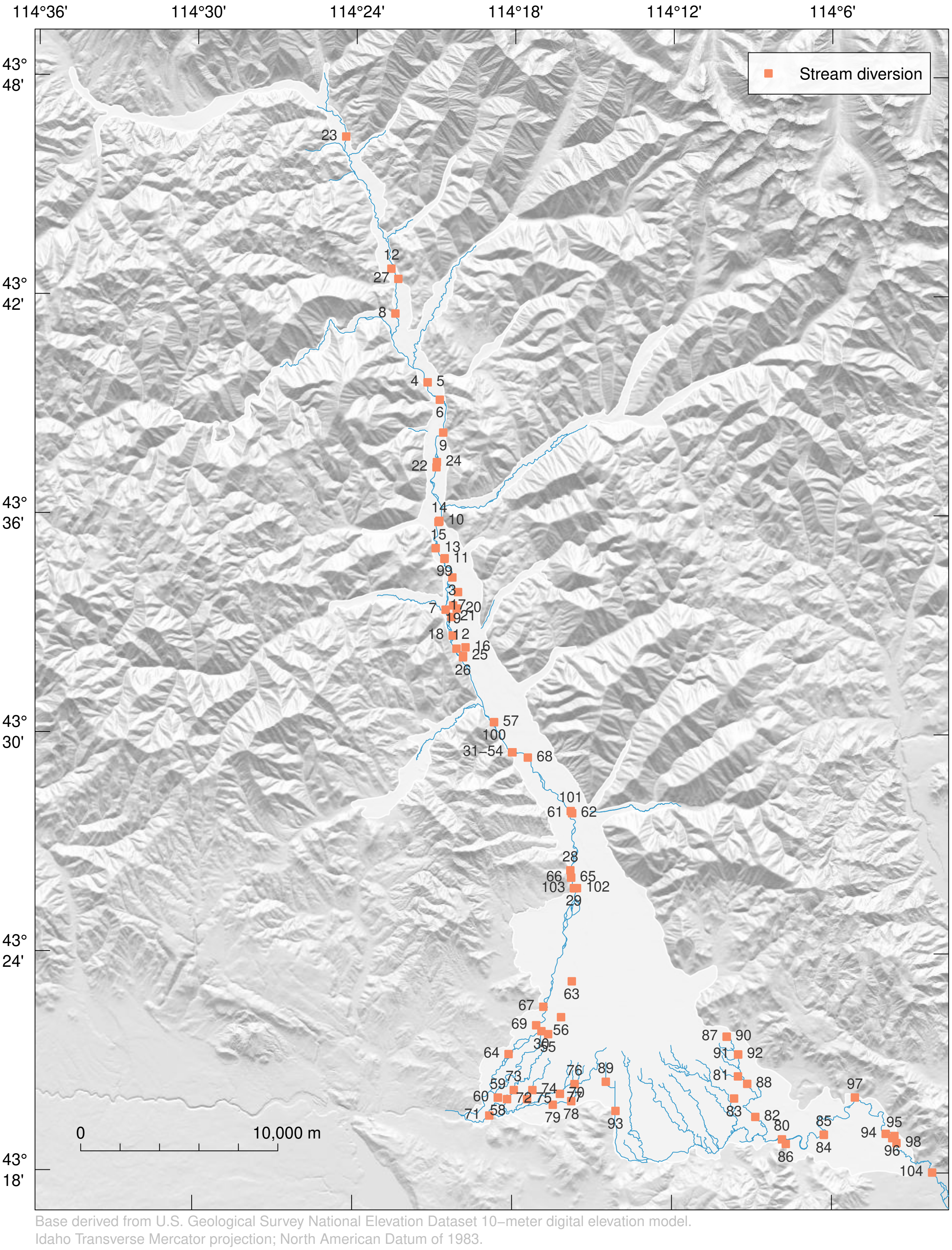


Figure H6. Streamflow diversions along on the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributary streams.

Table H3. Characteristics of the linear regression models used to estimate streamflow at various streamgages during periods of missing data. The independent variable of the linear regression models is streamflow measured at the Big Wood River, Hailey streamgage (13139510), in cubic meters per day. [**Station name**: local streamgage name used in this study. **Site No.**: identifier used to locate streamflow measurement sites in figure H4 and table H2. **Coinciding time period**: when streamflow data were available at both streamgages. **Slope** and **Intercept**: of the linear regression model. $\mathbf{R^2}$: the coefficient of determination. **Abbreviations**: m^3/d, cubic meters per day]

Station name	Site No.	Coinciding time period	Slope (1)	Intercept (m^3/d)	R^2 (1)
BIG WOOD RIVER NEAR KETCHUM	1	Jun 1948 – Sep 1971, May 2011 – Sep 2013	0.34	122	0.975
NF BIG WOOD RIVER NR SAWTOOTH NRA HQ NR KETCHUM, ID	2	May 2011 – Sep 2013	0.16	-14,043	0.863
WARM SPRINGS CREEK NEAR KETCHUM, ID	9	Feb 2011 – Mar 2014	0.17	16,123	0.885
TRAIL CREEK AT KETCHUM, ID	10	Dec 2010 – Mar 2014	0.12	-29,114	0.865
EAST FORK BIG WOOD RIVER AT GIMLET, ID	12	Nov 2011 – Sep 2013	0.12	-17,640	0.877

A flow-difference method was used to estimate the stream-aquifer flow exchange along a river reach (table H6). This method assumes that the changes in flow along a reach are solely attributed to groundwater inflows and outflows, all other surface-water inflows (such as returns) and outflows (such as diversions) are either negligible or have been quantified. Streamflow gain (or loss) for a reach was determined by subtracting inflow measurements from outflow measurements, and expressed as,

$$\Delta S = RIV_{out} - \sum RIV_{in} - \sum TRIB - \sum RET + \sum DIV \tag{2}$$

where

ΔS is the difference in surface-water flow within a river reach for a given time, a positive value is a stream gain (gaining reach) and a negative value is a stream loss (losing reach), in cubic meters per day;

RIV_{out} is the volumetric outflow at the downstream end of the river reach, in cubic meters per day;

RIV_{in} is the volumetric inflow at the upstream end of the river reach, in cubic meters per day;

$TRIB$ is the volumetric inflow from a tributary of the river reach, in cubic meters per day;

RET is the volumetric return flow from an irrigation canal, pond, wastewater-treatment plant, and (or) exchange-well return flow to the river reach, in cubic meters per day; and

DIV is the volumetric outflow from a stream diversion on the river reach, in cubic meters per day.

To facilitate a comparison with model-simulated results, equation (2) is expressed in terms of aquifer recharge as,

$$Q = \sum RIV_{in} - RIV_{out} + \sum TRIB + \sum RET - \sum DIV \tag{3}$$

where

Q is the estimated stream-aquifer flow exchange in a river reach, a positive value is flow into the aquifer and a negative value is flow out of the aquifer, in cubic meters per day.

For each iteration of PEST, a model-simulated stream-aquifer flow exchange is calculated for each river reach and compared to its corresponding field-based estimate. The differences between simulated and measured values is minimized during model calibration (equation 1) (1998–2010).

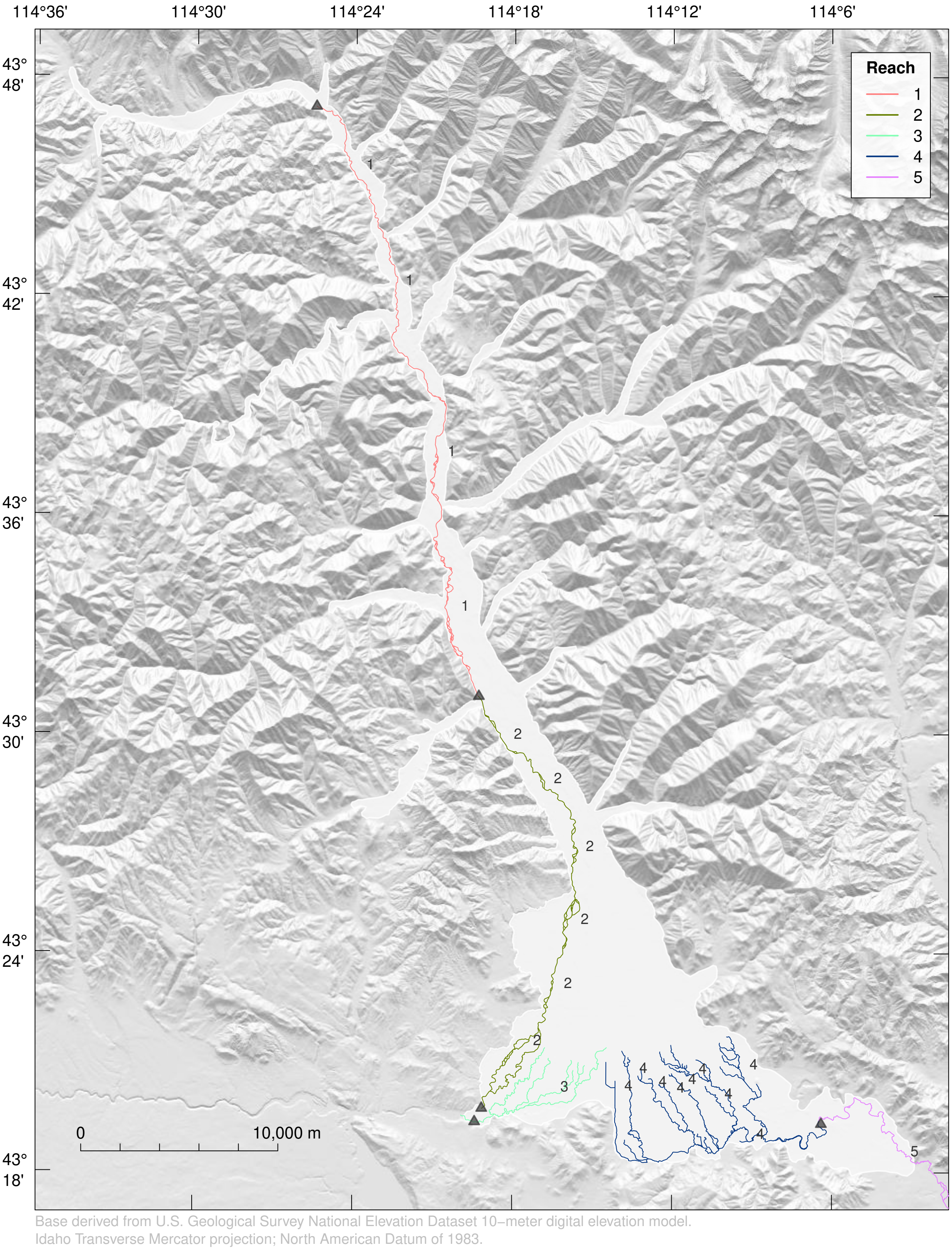


Figure H7. Assigned river reaches in the Wood River Valley, Idaho.

Table H4. Streamflow returns located on the Big Wood River, Silver Creek, and spring-fed tributaries. [**Return No.**: identifier used to locate returns in figure H5. **Name**: local name used to identify the return-flow location in this study. **Water-source**: the water type for return flows.]

Return No.	Name	Water-source
1	Comstock 10 Outflow	Irrigation canal or pond
2	Comstock 10A Outflow	Irrigation canal or pond
3	Ketchum Sun Valley WWTP	Irrigation canal or pond
4	The Meadows WWTP	Irrigation canal or pond
5	Hailey WWTP	Irrigation canal or pond
6	District 45 Legacy Project	Irrigation canal or pond
7	Bickett Well 00P1	Exchange well
8	Lucke Well 00P4 Flood	Exchange well
9	Meadow Well 18P1	Exchange well
10	Prinz 0P6	Exchange well
11	Prinz Well 0P6	Exchange well
12	Prinz Well 0P6A	Exchange well
13	Rinker Well 18P	Exchange well
14	Stalker 0P7	Exchange well
15	Steve 0P	Exchange well
16	Teeter Canyon 00-P5	Exchange well
17	Tick Tock 16P1	Exchange well
18	Tick Tock 16P1A	Exchange well
19	Mill In 16P	Exchange well
20	BYPASS CANAL ABV AND BLW DIVERSION NR BELLEVUE, ID	Irrigation canal or pond
21	A well into Buhler Drain	Exchange well

During the simulation period (1995–2010) the October through April stream-aquifer flow exchange along the Big Wood River, near Ketchum to Hailey reach (reach No. 1) was estimated using equation (3). Because of probable ungaged tributary stream contributions in this reach, the May through September flow exchange could not be estimated. Outflows from the reach are measured streamflow at the Big Wood River at Hailey streamgage (13139510, site No. 14) and recorded irrigation diversions. Inflows to the reach are correlated streamflows at the Big Wood River near Ketchum (13135500, site No. 1), North Fork Big Wood River near Sawtooth NRA Headquarters near Ketchum (13135520, site No. 2), Warm Springs Creek near Ketchum (13137000, site No. 9), Trail Creek at Ketchum (13137500, site No. 10), and East Fork Big Wood River at Gimlet (13138000, site No. 12) streamgages; streamflow from ungaged tributaries; and recorded wastewater treatment plant return flows (table H6). The resultant stream-aquifer flow exchange is shown in figure H8; aquifer discharges are typically smallest in February and largest in April. Estimates range from -244,535 m^3/d (-99 cfs) to -56,638 m^3/d (-23 cfs); with a mean and standard deviation of -88,362 m^3/d (-36 cfs) and 37,507 m^3/d (15 cfs), respectively.

The stream-aquifer flow exchange along the Big Wood River, Hailey to Stanton Crossing reach (reach No. 2) was estimated using equation (3). Outflows from the reach are the measured streamflow at the Big Wood River at Stanton Crossing near Bellevue streamgage (13140800, site No. 20) and recorded irrigation diversions. Inflow to the reach is the measured streamflow at the Big Wood River at Hailey streamgage (site No. 14); streamflow contributions from ungaged tributaries along this reach were assumed negligible. The resultant stream-aquifer flow exchange is shown in figure H9. Estimates range from -1,542,590 m^3/d (-630 cfs) to 614,432 m^3/d (251 cfs); with a mean and standard deviation of 163,786 m^3/d (66 cfs) and 302,651 m^3/d (123 cfs), respectively. Most months have positive values (aquifer recharge) indicating that it is a losing reach during most of the simulation period. There was insufficient measurement data to estimate flow exchange prior to October 1996.

The stream-aquifer flow exchange along the Willow Creek reach (reach No. 3) was estimated using equation (3). Outflows from the reach are measured streamflow at the Willow Creek near Bellevue streamgage (13140900, site No. 21) and recorded irrigation diversions. Because the upstream end of the reach is defined as the spring-fed origins of Willow Creek and its tributaries, total inflows to the reach are assumed to be zero. Note that minor and unmeasured inflows from uncontrolled flowing wells may contribute to reach gains. The resultant stream-aquifer flow exchange is shown in figure H10. Estimates range from -149,803 m^3/d (-61 cfs) to -18,789 m^3/d (-7 cfs); with a mean and standard deviation of -66,876 m^3/d (-27 cfs) and 32,282 m^3/d (13 cfs), respectively. All values are negative (aquifer discharge) which indicates that it is a gaining reach during the period from July 2000 through December 2010. Aquifer discharges are typically smallest in January and largest in July. There was insufficient measurement data to estimate flow exchange prior to July 2000.

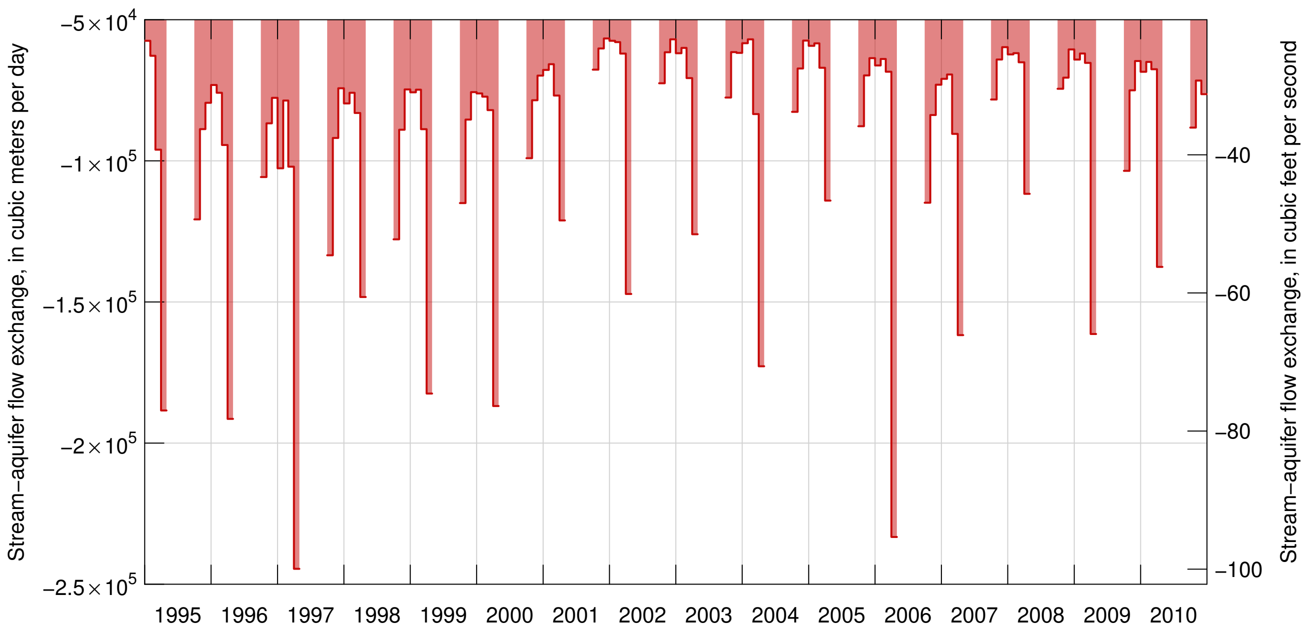


Figure H8. Stream-aquifer flow exchange in the Big Wood River, near Ketchum to Hailey river reach.

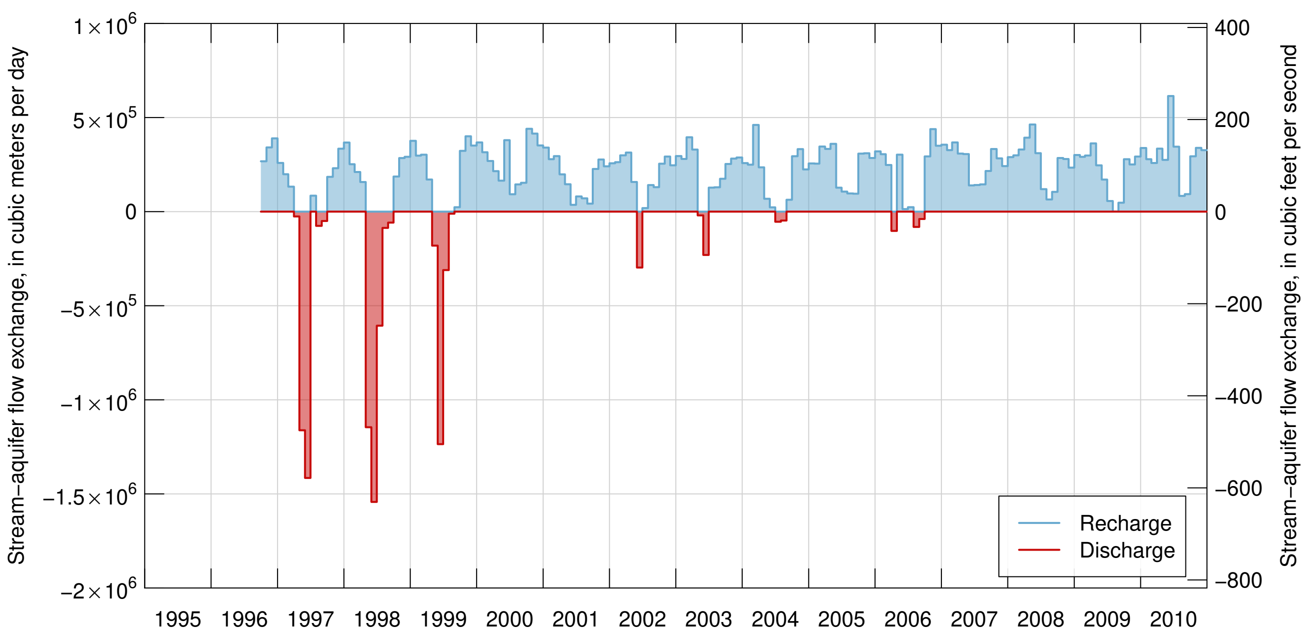


Figure H9. Stream-aquifer flow exchange in the Big Wood River, Hailey to Stanton Crossing river reach.

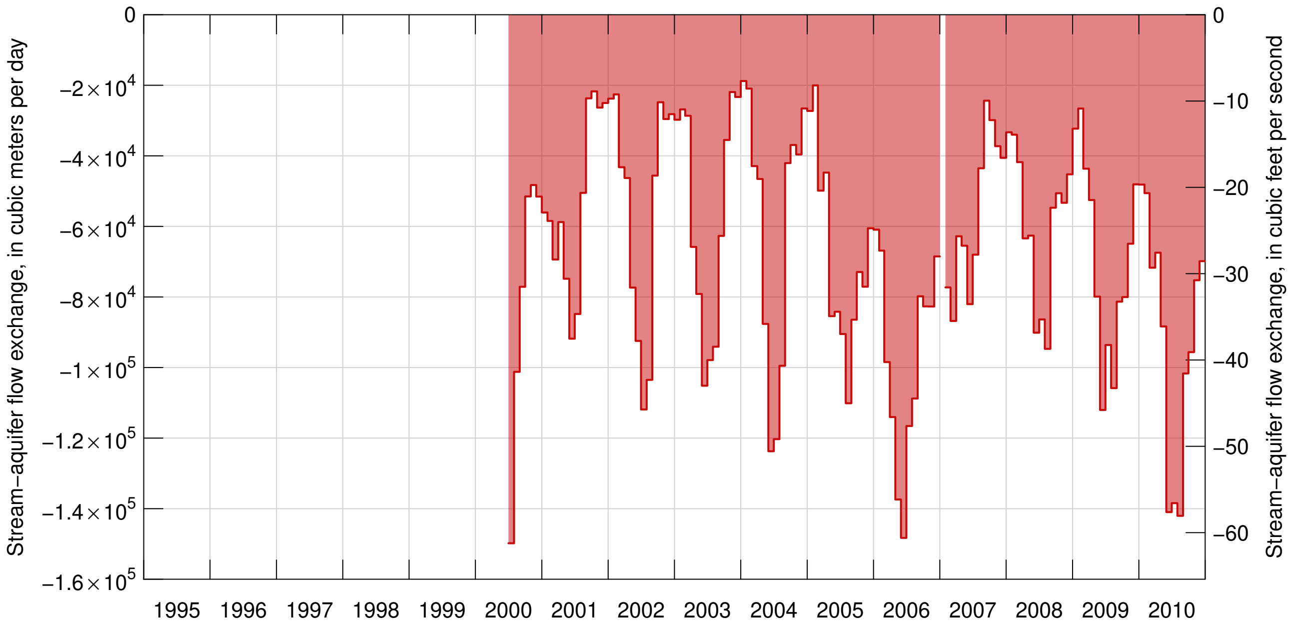


Figure H10. Stream-aquifer flow exchange in the Willow Creek river reach.

The stream-aquifer flow exchange along Silver Creek, above Sportsman Access river reach (reach No. 4) was estimated using equation (3). This reach includes Buhler Drain and Stalker, Patton, Cain, Chaney, Mud, Wilson, Grove, and Loving Creeks. Outflows from the reach are measured streamflow at the Silver Creek at Sportsman Access near Picabo streamgage (13150430, site No. 31) and recorded irrigation diversions. As with the Willow Creek reach (reach No. 3), because the upstream end of the reach is defined as the spring-fed origins of Silver Creek and its tributaries, total inflows to the reach are assumed to be zero. Recorded inflows to the reach are primarily spring and seep discharge but include exchange wells and returns from the District 45 Legacy Project. The resultant stream-aquifer flow exchange is shown in figure H11; all estimated values are negative (aquifer discharge) which indicates that it is a gaining reach through the entire simulation period. Estimates range from -645,602 m^3/d (-263 cfs) to -173,021 m^3/d (-70 cfs); with a mean and standard deviation of -377,531 m^3/d (-154 cfs) and 95,289 m^3/d (38 cfs), respectively. Aquifer discharges are typically smallest in October and largest in March.

Estimates of stream-aquifer flow exchange along the Silver Creek, Sportsman Access to near Picabo reach (reach No. 5) were first made by Moreland (1977) using a flow difference approach. He reports a reach loss (aquifer recharge) of 9,786 m^3/d (4 cfs) in May 1975, and reach gains (aquifer discharge) of 61,164 m^3/d (25 cfs) in June 1975 and 22,019 m^3/d (9 cfs) in October 1975. For comparison, the flow exchange reported by Bartolino (2014) (and adjusted to account for diversions and exchange wells reported by Water District 37M; also using a flow difference approach) were reach gains of 13,211 m^3/d (5.4 cfs) in August 2012, 29,359 m^3/d (12 cfs) in October 2012, and zero in March 2013. Because Water District 37M does not record diversion rates during October, it is possible that the estimated reach gain in October 2012 was affected by unmeasured diversions or exchange well inflows. The 2012 through 2013 estimates did not account for irrigation returns from the O Drain, which enters Silver Creek downstream of the model boundary. It is unclear whether Moreland (1977) accounted for inflow from this drainage ditch.

Moreland (1977) noted that the Silver Creek at Sportsman Access near Picabo streamgage (13150430, site No. 31) was installed in 1974 as part of his investigation. The site was selected near the area of assumed maximum flow. Moreland indicates that Silver Creek generally gains water (aquifer discharge) upstream of Point of Rocks (about 3.2 river kilometers [2 miles] downstream of Sportsman Access), and may seasonally gain or lose water in the 3.2-km (2-mi) reach downstream of Point of Rocks where groundwater levels may be relatively close to land surface during the irrigation season. Approximately 6.4 river kilometers (4 mi) downstream of Silver Creek at Sportsman Access near Picabo streamgage (site No. 31), the water table in the basalt portion of the WRV aquifer system becomes deeper and slopes steeply toward the Snake River Plain and Silver Creek becomes perched above the aquifer. A shallow perched aquifer apparently interacts with the creek in this area and contributes to measured gains and losses (Moreland, 1977).

October 2012 groundwater-level measurements and maps (Bartolino, 2014) indicate that Silver Creek is perched above the aquifer between about Point of Rocks and the model boundary. In October 2012, the depth below land surface to the water table was 20 m (65 ft) about 0.4 km (0.25 mi) north of Picabo, and 38 m (126 ft) about 0.25 mi south of where Silver Creek crosses the model boundary.

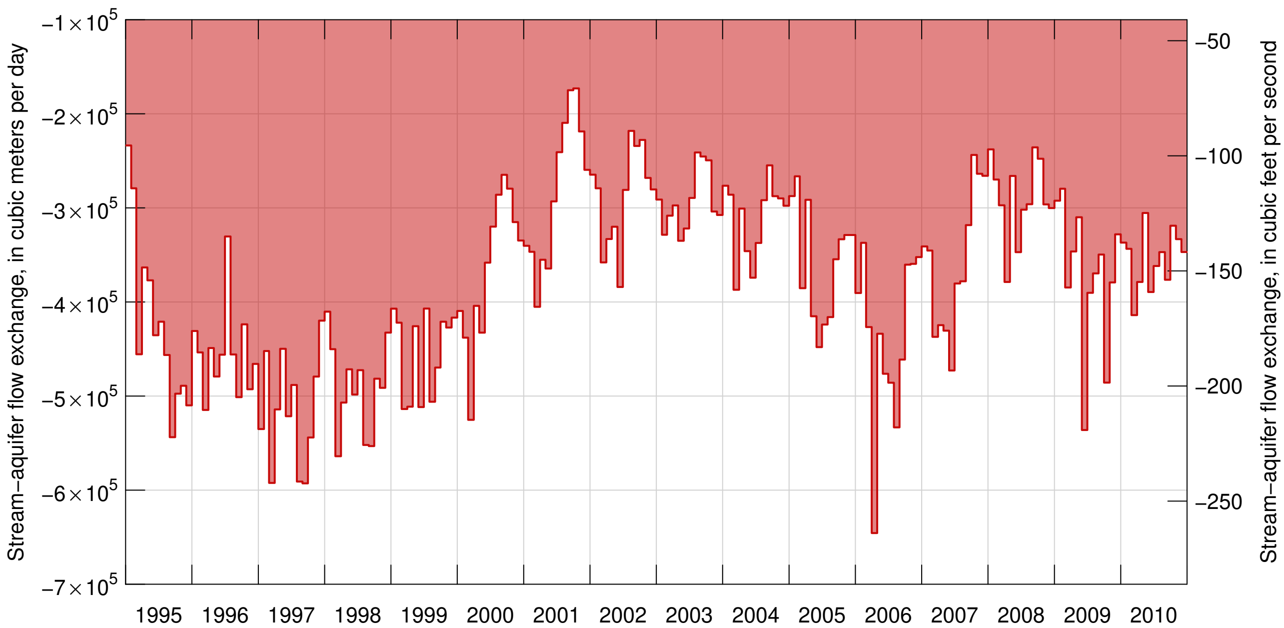


Figure H11. Stream-aquifer flow exchange in Silver Creek, above Sportsman Access river reach.

A discharge of 206,980 m^3/d (84.6 cfs) in Silver Creek at the Picabo Road bridge, about 0.8 km (0.5 mi) north of Picabo was measured on October 16, 2014 (Allan H. Wylie and Dennis Owsley, Idaho Department of Water Resources, oral commun., 2014). On that date, mean daily discharge measured at the Silver Creek at Sportsman Access near Picabo streamgage (site No. 31) was 200,619 m^3/d (82 cfs). Because Water District 37 does not record diversions during October, it is not known if the Mill In 16P exchange well (return No. 19) was injecting water into the creek or if there were diversions from the creek that day. It is also not known if perched irrigation returns contributed to the calculated reach gain. There also may be diversions and returns along this river reach (reach No. 5) that are not represented by the model because they could not be located. The calculated reach gain of about 7,340 m^3/d (3 cfs) is also within the error of the downstream measurement. Based on available information, the gain to (aquifer discharge) or loss from (aquifer recharge) the Silver Creek at Sportsman Access near Picabo streamgage (site No. 31) and the model boundary does not appear to be significantly different from zero with respect to the WRV aquifer, and a stream-aquifer flow exchange of zero was assumed.

River subreaches

Greater spatial resolution of stream-aquifer groundwater exchange on the Big Wood River, Silver Creek, and spring-fed tributaries was possible using field measurements (streamflows, diversions, and returns) recorded in August 2012, October 2012, and March 2013 (Bartolino, 2014). Not unlike the larger river reaches, river subreaches were typically defined between upstream and downstream measurement stations; many of these stations have non-continuous streamflow records and were ungaged. Figure H12 shows the location of the 19 subreaches within the WRV. A flow difference method (equation 3) was used to estimate groundwater inflows and outflows along a river subreach (tables H7 and H8).

Subreach estimates of stream-aquifer flow exchange values aggregated by river reach were compared to reach estimates based on streamflow measurements recorded during August, October, and March of 2000 through 2010. The 2000 through 2010 streamflow conditions (relatively dry) were similar to the 2012 through 2013 conditions and thus suitable for comparison. The percent difference between these two datasets is provided in table H9. Percent difference is largest (greater than 100 percent) for August estimates in the Big Wood River, Hailey to Stanton Crossing river reach (reach No. 2), and attributed to gage measurement error at the Hailey and Stanton Crossing streamgages and diversion measurement error. Moderate values of percent difference (about 50 percent) were measured for August and March in the Big Wood River near Ketchum to Hailey river reach (reach No. 1). With the exception of August 2012, all 2012 through 2013 stream-aquifer flow-exchange estimates are within the range of estimates made during the simulation period ($-1,542,590$ to $614,432$ m^3/d) (figs. H8–H11). The August 2012 estimates of stream-aquifer flow exchange along the Big Wood River, near Ketchum to Hailey river reach were well outside the range of flow exchange values estimated for this reach during the transient simulation period (1995–2010); therefore these measurements were not used in the calibration process. The stream-aquifer flow exchange for August 2012 was 36,698 m^3/d (15 cfs), and the minimum flow exchange value during the transient simulation period was 66,057 m^3/d (27 cfs).

The objective of the subreach analysis is to refine the spatial resolution of seepage rates within a river reach. Using the 2012 through 2013 subreach data, the stream-aquifer flow-exchange ratio between river subreaches and their corresponding river reach were estimated and are given in table H10. Ratio estimates for a single measurement period (such as, August 2012) are mathematically expressed as:

$$r_i = \frac{Q_i}{Q_j} \tag{4}$$

where

r_i is the stream-aquifer flow-exchange ratio between river subreach i and its corresponding river reach, a dimensionless quantity;

Q_i is the average stream-aquifer flow exchange of river subreach i, in cubic meters per day; and

Q_j is the average stream-aquifer flow exchange of river reach j determined from continuous streamflow records, in cubic meters per day.

Note that river subreach i is a component of river reach j. For each iteration of PEST, the model-simulated ratio is calculated every August, October, and March of the 2000 through 2010 time period and compared to its corresponding 2012 through 2013 monthly estimate. The differences between simulated and measured ratios are minimized during model calibration (equation 1).

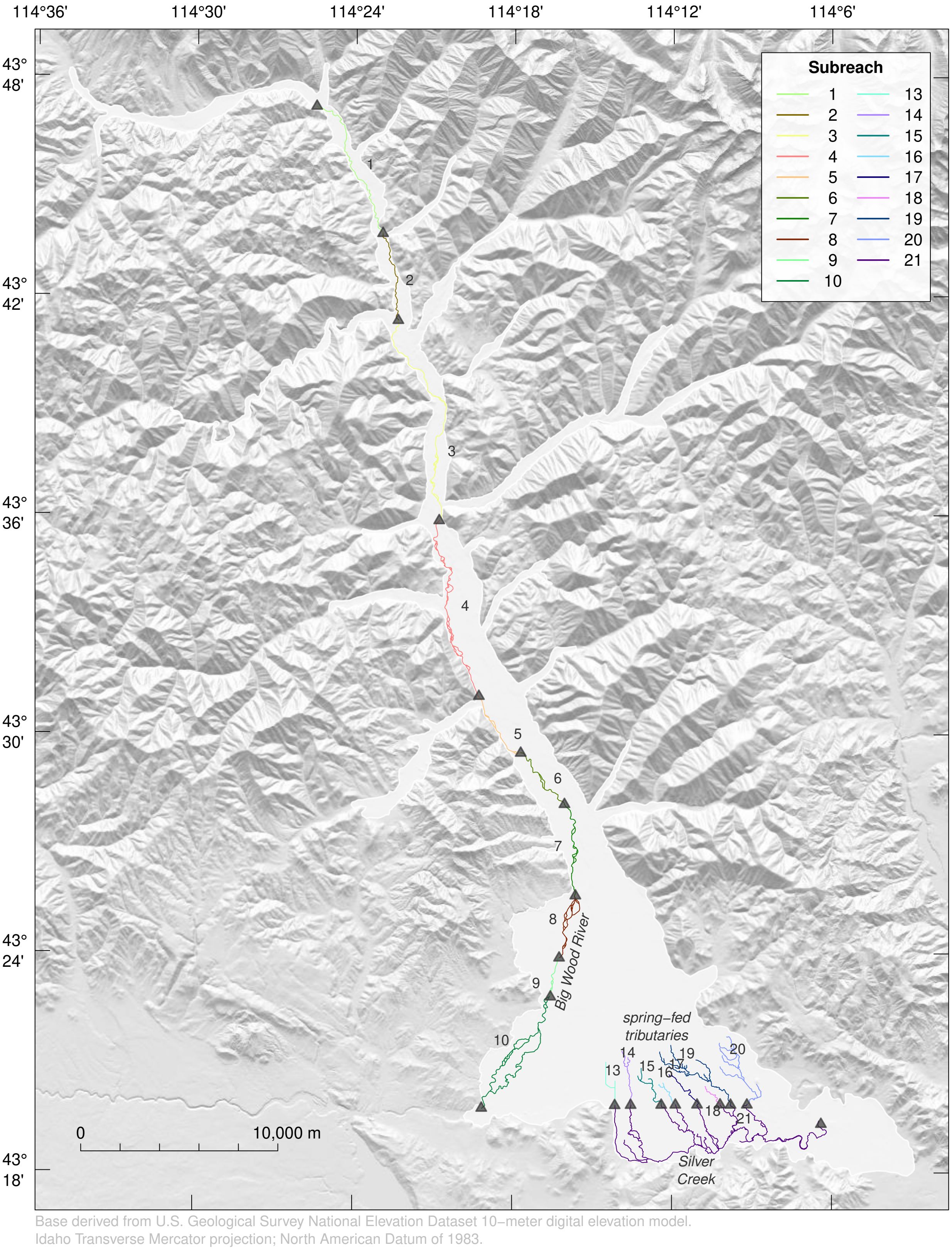


Figure H12. Assigned river subreaches in the Wood River Valley, Idaho.

Table H5. Streamflow diversions located on the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributaries. [**Div. No.**: identifier used to locate diversions in figure H6. **Site identifier**: unique numerical identifiers used to access streamflow measurement data (https://waterdata.usgs.gov/nwis). **Name**: local diversion name used in this study. **Abbreviations**: –, not available]

Div. No.	Site identifier	Name
1	–	Aspen 27
2	–	Aspen 27P
3	–	Berlow estimated
4	–	Bonning 7P
5	–	Bonning 7P & 7P1
6	–	Comstock 10
7	–	Deer 22 P2
8	–	Don P3
9	–	Gimlet 9 estimated consumptive
10	–	Golden 21P
11	–	Hiawatha 22
12	–	Huf 0P1A
13	–	Lufkin 21 P2
14	–	Mizer 20
15	–	Moore 21
16	–	Ogara 29A
17	–	Osborn 24
18	–	Palmer 27P
19	–	Purd 22-P1
20	–	Purdum 25
21	–	Purdum 25A
22	–	Rinker 11 estimated consumptive
23	–	River 0P
24	–	Simon 11B
25	–	Thomas 30
26	–	Thomas 30A
27	–	Tom P2
28	–	Bannon 49
29	–	Baseline 55C
30	–	Black 61
31	–	Broadford 34
32	–	Broadford 34P
33	–	Broadford 35
34	–	Broadford 36
35	–	Broadford 37
36	–	Broadford 38
37	–	Broadford 38P
38	–	Broadford 38P1
39	–	Broadford 39
40	–	Broadford 39A
41	–	Broadford 40P
42	–	Broadford 40P1
43	–	Broadford 40P11
44	–	Broadford 40P2
45	–	Broadford 40P9
46	–	Broadford 41
47	–	Broadford 41P1
48	–	Broadford 41P2
49	–	Broadford 42 & 42P
50	–	Broadford 42A
51	–	Broadford 42P1
52	–	Broadford 42P1A

Table H5. Streamflow diversions located on the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributaries.—Continued

Div. No.	Site identifier	Name
53	–	Broadford 42P2
54	–	Broadford 42P3
55	–	Brown 57F
56	–	Brown 57F1
57	–	Cove 33
58	–	Davis 76
59	–	Davis 76A
60	–	Davis 76P
61	–	District 45
62	–	District 45 Legacy Project
63	–	Dittoe 56D
64	–	Flood 64
65	–	Glendale 50
66	–	Glendale 50 Cameron Rockwell Water
67	–	Graff 62
68	–	Kohler 44
69	–	Uhrig 63
70	–	Cloud 74
71	–	Davis 77P
72	–	Hice 71
73	–	Hice 71-A
74	–	Martin 72
75	–	Martin 72A
76	–	Pugel 75
77	–	Pugel 75B
78	–	Pugel 75P
79	–	Salisbury 68
80	–	Albretheson 17
81	–	Bill 9
82	–	Gillihan 11
83	–	Heath 10
84	–	Iden 19
85	–	Iden 19B
86	–	Kilpatrick 18
87	–	Loving 12B
88	–	Patterson 15
89	–	Rogers 0P1
90	–	Stanfield 12P
91	–	Stanfield 13
92	–	Stanfield 13A
93	–	Willis 1
94	–	Iden 19P
95	–	Man 19P1
96	–	Man 19P2
97	–	Mantey 14P
98	–	Tick Tock 19TT
99	13138600	HIAWATHA CANAL AT POINT OF DIVERSON NR GIMLET, ID
100	433020114184400	COVE CANAL AT POINT OF DIVERSON NR HAILEY, ID
101	432754114155000	DISTRICT 45 CANAL AT POINT OF DIVERSON BELLVUE, ID
102	432547114153500	GLENDALE CANAL AT POINT OF DIVERSON NR BELLVUE, ID
103	13140495	BYPASS CANAL AT POINT OF DIVERSION NR BELLEVUE, ID
104	–	Div 21-23 and 27-29

Table H6. Assigned river reaches of the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributaries. [**Reach No.**: identifier used to locate river reaches in figure H7. **Name**: local reach name used in this study. **Site No.**: identifier used to locate streamflow measurement sites in figure H4 and table H2. Entry in **bold** indicates a streamgage with continuous record. No upstream site number indicates that the reach is spring-fed. **Return No.**: identifier used to locate return flows in figure H5 and table H4. **Diversion No.**: identifier used to locate stream diversions in figure H6 and table H5. **Abbreviations**: –, not present.]

Reach No.	Name	Upstream Site No.	Down-stream Site No.	Tributary Site No.	Return No.	Diversion No.
1	Big Wood, Nr Ketchum to Hailey	**1**	**14**	2, 9, 10, 12	1–27	1–4
2	Big Wood, Hailey to Stanton Crossing	**14**	**20**	–	28–69	5
3	Willow Creek	–	**21**	–	70–79	–
4	Silver Creek, above Sportsman Access	–	**31**	–	80–93	6–18
5	Silver Creek, Sportsman Access to Nr Picabo	**31**	32	–	94–98	19

Table H7. Assigned river subreaches of the Big Wood River, Silver Creek, and spring-fed tributaries. [**Reach No.**: identifier used to locate river reaches in figure H7. **Subreach No.**: identifier used to locate river subreaches in figure H12. **Name**: local subreach name used in this study. **Site No.**: identifier used to locate streamflow measurement sites in figure H4 and table H2. No upstream site number indicates that the reach is spring-fed. **Return No.**: identifier used to locate return flows in figure H5 and table H4. **Diversion No.**: identifier used to locate stream diversions in figure H6 and table H5. **Abbreviations**: –, not present]

Reach No.	Sub-reach No.	Name	Upstream Site No.	Down-stream Site No.	Tributary Site No.	Return No.	Diversion No.
1	1	Big Wood, Nr Ketchum to Hulen Rd	**1**	6	2–5	–	–
	2	Big Wood, Hulen Rd to Ketchum	6	8	7	–	8, 27
	3	Big Wood, Ketchum to Gimlet	8	13	9–12	–	–
	4	Big Wood, Gimlet to Hailey	13	14	–	–	1, 99
2	5	Big Wood, Hailey to N Broadford	14	15	–	–	100
	6	Big Wood, N Broadford to S Broadford	15	16	–	–	–
	7	Big Wood, S Broadford to Glendale	16	17	–	–	28, 101–103
	8	Big Wood, Glendale to Sluder	17	18	–	–	–
	9	Big Wood, Sluder to Wood River Ranch	18	–	–	–	–
	10	Big Wood, Wood River Ranch to Stanton Crossing	–	20	–	20	64, 67, 69
4	13	Buhler Drain abv Hwy 20	–	23	–	21	89
	14	Patton Creek abv Hwy 20	–	24	–	7	–
	15	Cain Creek abv Hwy 20	–	25	–	–	–
	16	Chaney Creek abv Hwy 20	–	26	–	–	–
	17	Mud Creek abv Hwy 20	–	27	–	–	–
	18	Wilson Creek abv Hwy 20	–	28	–	–	–
	19	Grove Creek abv Hwy 20	–	29	–	–	–
	20	Loving Creek abv Hwy 20	–	30	–	–	81, 87, 90–92
	21	spring creeks blw Hwy 20	23–30	31	–	8–10, 13–17	80, 82–86, 88, 93

Table H8. Estimated stream-aquifer flow exchange in river subreaches for August 2012, October 2012, and March 2013; modified from Bartolino (2014). [**Subreach No.**: identifier used to locate river subreaches in figure H12. **Name**: local subreach name used in this study. **Abbreviations**: m^3/d, cubic meters per day; cfs, cubic-feet per second; –, not available because of missing tributary inflows to the Big Wood River above Hailey]

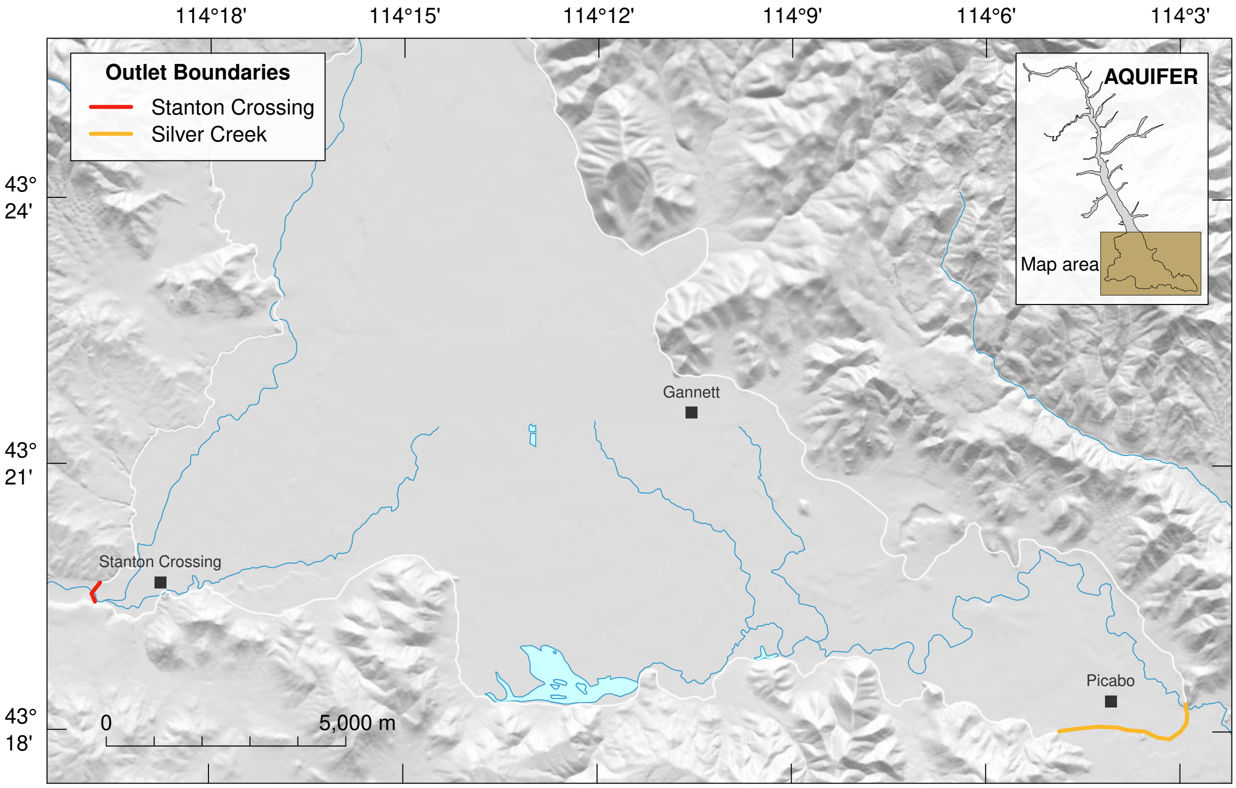
Subreach No.	Name	Aug 2012 (m^3/d)	Oct 2012 (m^3/d)	Mar 2013 (m^3/d)	Aug 2012 (cfs)	Oct 2012 (cfs)	Mar 2013 (cfs)
1	Big Wood, Nr Ketchum to Hulen Rd	–	-32,417	-52,161	–	-13	-21
2	Big Wood, Hulen Rd to Ketchum	–	3,572	8,074	–	1	3
3	Big Wood, Ketchum to Gimlet	–	-48,124	-28,478	–	-20	-12
4	Big Wood, Gimlet to Hailey	–	-18,447	-61,164	–	-8	-25
5	Big Wood, Hailey to N Broadford	49,910	54,094	53,825	20	22	22
6	Big Wood, N Broadford to S Broadford	48,932	41,592	73,397	20	17	30
7	Big Wood, S Broadford to Glendale	56,418	49,837	53,335	23	20	22
8	Big Wood, Glendale to Sluder	0	2,447	63,856	0	1	26
9	Big Wood, Sluder to Wood River Ranch	0	0	40,368	0	0	16
10	Big Wood, Wood River Ranch to Stanton Crossing	-77,067	100,065	26,912	-32	41	11
13	Buhler Drain abv Hwy 20	-10,838	-3,156	-2,544	-4	-1	-1
14	Patton Creek abv Hwy 20	-6,239	-2,006	-2,447	-3	-1	-1
15	Cain Creek abv Hwy 20	-9,982	-4,282	-4,330	-4	-2	-2
16	Chaney Creek abv Hwy 20	-27,133	-26,423	-34,252	-11	-11	-14
17	Mud Creek abv Hwy 20	-11,034	-11,059	-12,208	-5	-5	-5
18	Wilson Creek abv Hwy 20	-24,710	-25,689	-29,604	-10	-10	-12
19	Grove Creek abv Hwy 20	-105,447	-85,630	-89,300	-43	-35	-36
20	Loving Creek abv Hwy 20	-76,529	-73,153	-76,822	-31	-30	-31
21	spring creeks blw Hwy 20	-80,810	-64,639	-71,171	-33	-26	-29

Table H9. Percent difference between stream-aquifer flow exchange values estimated in river reaches during August, October, and March of 2000 through 2010; and in river subreaches aggregated by reach during August 2012, October 2012, and March 2013. [**Subreach No.**: identifier used to locate river subreaches in figure H12. **Name**: local reach name used in this study. **Year**: the measurement year. **Abbreviations**: –, not available]

Reach No.	Name	Year	August (1)	October (1)	March (1)
1	Big Wood, Nr Ketchum to Hailey	2000	–	2	35
		2001	–	24	40
		2002	–	19	56
		2003	–	14	46
		2004	–	10	33
		2005	–	6	50
		2006	–	12	48
		2007	–	14	28
		2008	–	17	52
		2009	–	5	52
		2010	–	5	49
2	Big Wood, Hailey to Stanton Crossing	2000	36	34	10
		2001	7	6	4
		2002	35	2	3
		2003	30	1	15
		2004	145	11	24
		2005	14	14	7
		2006	132	11	16
		2007	36	19	11
		2008	13	9	4
		2009	193	8	3
		2010	4	11	13
4	Spring creeks abv Sportsman	2000	14	4	30
		2001	37	38	15
		2002	34	18	7
		2003	27	12	3
		2004	13	2	12
		2005	11	8	11
		2006	25	13	18
		2007	5	13	19
		2008	12	12	6
		2009	3	30	11
		2010	1	5	16

Table H10. Stream-aquifer flow-exchange ratio between river subreaches and their corresponding reach, for August 2012, October 2012, and March 2013. [**Subreach No.**: identifier used to locate river subreaches in figure H12. **Name**: local subreach name used in this study. **Abbreviations**: –, not available]

Subreach No.	Name	Aug 2012 (1)	Oct 2012 (1)	Mar 2013 (1)
1	Big Wood, Nr Ketchum to Hulen Rd	–	0.34	0.39
2	Big Wood, Hulen Rd to Ketchum	–	-0.04	-0.06
3	Big Wood, Ketchum to Gimlet	–	0.50	0.21
4	Big Wood, Gimlet to Hailey	–	0.19	0.46
5	Big Wood, Hailey to N Broadford	0.64	0.22	0.17
6	Big Wood, N Broadford to S Broadford	0.63	0.17	0.24
7	Big Wood, S Broadford to Glendale	0.72	0.20	0.17
8	Big Wood, Glendale to Sluder	0.00	0.01	0.20
9	Big Wood, Sluder to Wood River Ranch	0.00	0.00	0.13
10	Big Wood, Wood River Ranch to Stanton Crossing	-0.99	0.40	0.09
13	Buhler Drain abv Hwy 20	0.03	0.01	0.01
14	Patton Creek abv Hwy 20	0.02	0.01	0.01
15	Cain Creek abv Hwy 20	0.03	0.01	0.01
16	Chaney Creek abv Hwy 20	0.08	0.09	0.11
17	Mud Creek abv Hwy 20	0.03	0.04	0.04
18	Wilson Creek abv Hwy 20	0.07	0.09	0.09
19	Grove Creek abv Hwy 20	0.30	0.29	0.28
20	Loving Creek abv Hwy 20	0.22	0.25	0.24
21	spring creeks blw Hwy 20	0.23	0.22	0.22



Base derived from U.S. Geological Survey National Elevation Dataset 10–meter digital elevation model.
Idaho Transverse Mercator projection; North American Datum of 1983.

Figure H13. Location of the Silver Creek and Stanton Crossing groundwater outlet boundaries.

Groundwater Flow Across the Outlet Boundaries

The average rate of groundwater discharge across the Stanton Crossing and Silver Creek outlet boundaries (fig. H13) has been reported by various studies. The previous estimates of groundwater discharge from the WRV aquifer system beneath Stanton Crossing towards Magic Reservoir range from 0 to 1,000 m^3/d (300 acre-feet per year [acre-ft/yr]). Smith (1959) estimated that groundwater discharge beneath Stanton Crossing was "relatively small" while Brockway and Grover (1978), Brockway and Kahlown (1994), and Wetzstein, Robinson, and Brockway (2000) considered it "negligible". Bartolino (2009) and Loinaz (2012) assumed that there was no outflow beneath Stanton Crossing. Bartolino and Adkins (2012) estimated an underflow rate of 1,000 m^3/d (300 acre-ft/yr).

Previous estimates of the average groundwater discharge beneath Silver Creek towards the eastern Snake River Plain aquifer range from 13,500 to 178,000 m^3/d (4,000 to 53,000 acre-ft/yr). Smith (1959) estimated 128,000 m^3/d (38,000 acre-ft/yr), Garabedian (1992) 179,000 m^3/d (53,000 acre-ft/yr), Brockway and Kahlown (1994) 40,000 m^3/d (11,800 acre-ft/yr), Cosgrove, Contor, and Johnson (2006) 159,000 m^3/d (47,000 acre-ft/yr), Bartolino (2009) 68,000 m^3/d (20,000 acre-ft/yr), Loinaz (2012) 131,000 m^3/d (38,900 acre-ft/yr), and Bartolino and Adkins (2012) 13,500 m^3/d (4,000 acre-ft/yr).

The method used to estimate average flow rates across the outlet boundaries was different for each study. For example, Garabedian (1992) relied on basin yield estimates, Brockway and Kahlown (1994) model residuals, and Bartolino and Adkins (2012) Darcian estimates. Furthermore, the accuracy of outflow estimates was never reported. Given the uncertainties associated with these estimates, the choice of which groundwater discharge estimate to use in the calibration process was based on the perceived robustness of the estimation method and the ease-of-reproducibility of estimated values. Considering this, the WRV groundwater-flow model was calibrated using the Bartolino and Adkins (2012) average outflow estimates of 1,000 m^3/d for Stanton Crossing and 13,500 m^3/d for Silver Creek. A measurement weighting scheme was applied that allowed the complete range of published outflow estimates to be considered during model calibration.

The model-simulated observation of groundwater flow across an outlet boundary was calculated by summing the simulated flow rates in drain cells composing an outlet boundary and averaged over time.

Adjustable Model Parameters

Adjustable model parameters calibrated during parameter estimation ($\boldsymbol{b}$ in equation 1) include: (1) the spatial distributions of hydraulic conductivity and storage coefficient in the model domain; (2) riverbed conductance along reaches and subreaches of the Big Wood River, Willow Creek, Silver Creek, and spring-fed tributaries; (3) drain conductance for the Stanton Crossing and Silver Creek groundwater outlet boundaries; (4) control parameters describing groundwater flow into the model domain that originates as precipitation in a tributary basin; and (5) irrigation efficiency on irrigated lands. Lower and upper bounds on the adjustable model parameters (b_{min} and b_{max} in equation 1) define the maximum and minimum values which a parameter is allowed to assume during parameter estimation (Doherty, 2005, pgs. 2-19–20). Initial estimates (or starting values) for the adjustable model parameters were either assigned from the groundwater literature and based on assumed average values, or derived from field measurements.

Hydraulic Conductivity and Storage Coefficient

A pilot-points parameterization method is used by PEST to estimate the spatial distribution of horizontal hydraulic conductivity and storage coefficient in the model domain. The parameter values are estimated for 106 points (also known as "pilot points") lying within the model domain (fig. H14) and spatially interpolated to the midpoint of each cell in the model grid. The distribution and density of pilot points was chosen to provide adequate spatial coverage of the model domain. Note that an increase in the number of pilot points is accompanied by an increase in the computational time required by PEST. The model domain is subdivided into numerous zones (table H11, fig. H14) and a kriging interpolation method used to predict parameter values within a zone from parameter estimates of pilot points lying within the current zone (table H11).

Allocation of zones primarily is based on the spatial distribution of hydrogeologic units in the model domain (table H12), in which zones A through M, and P represent parts of the unconfined aquifer that are composed of coarse-grained sand and gravel; zones N and Q represent the part of the unconfined aquifer that is composed of basalt; zone O represents the confining unit, an aquitard composed of fine-grained silt and clay; and zone R represents the part of the confined aquifer that is composed of coarse-grained sand and gravel. Zones B through L are located in the major tributary canyons of the WRV, whereas all other zones are located beneath the main part of the valley.

With the exception of zone O, the lower and upper bounds on horizontal hydraulic conductivity were specified at 1×10^{-10} and 1×10^{10} m/d, respectively; thus allowing for a very wide range of geological materials to be considered during model calibration. Recall that zone O represents the low-permeability aquitard and as such necessitates a much smaller upper bound of 1 m/d; its lower bound was 1×10^{-10} m/d.

The WRV aquifer system is assumed anisotropic with respect to hydraulic conductivity. Vertical hydraulic conductivity is determined by dividing the horizontal hydraulic conductivity by the vertical anisotropy, the ratio of horizontal to vertical hydraulic conductivity. A single adjustable value of vertical anisotropy is assigned to all cells in the model grid. Lower and upper bounds on the vertical anisotropy were specified at 1×10^{-10} and 1×10^{10}.

Lower and upper bounds on the storage coefficient were specified at 0.095 and 0.35 in the partially-saturated conditions of model layer 1 (zones A–L), and 1×10^{-10} and 0.001 in the primarily saturated conditions of model layers 2 and 3 (zones M–R)–with the exception of pilot-points 77 (in zone N) and 99 (in zone Q) which were specified with a lower and upper bound of 1×10^{-10} and 0.35 because they are located in an area of the aquifer where the water table is known to reside in either model layers 2 or 3. The storage coefficient for partially-saturated conditions is virtually equal to the specific yield (also known as the drainable porosity) and indicates that larger storage coefficient values would be expected. For all cell values not coinciding with pilot-point locations, storage coefficient values are interpolated with lower and upper bounds specified at 1×10^{-6} to 0.35, respectively. These interpolation limits are used to eliminate unreasonable estimates of storage coefficient.

Starting values of horizontal hydraulic conductivity, vertical anisotropy, and storage coefficient are given in table H12 and based on previous estimates by Bartolino and Adkins (2012, table 2, p. 25-26).

Riverbed Conductance

The hydraulic conductance of the riverbed sediment was adjusted along the Willow Creek (reach No. 3) and Silver Creek (reach No. 5) river reaches (fig. H7), along each of the 19 subreaches of the Big Wood River, Silver Creek, and spring-fed tributaries (fig. H12). The lower and upper bounds on riverbed conductance were specified at 1×10^{-10} and 1×10^{10} square meters per day (m^2/d), respectively; thus allowing for a very wide range of riverbed materials to be considered during model calibration. The starting value for riverbed conductance was the same for all subreaches on the Big Wood River at 5,669 m^2/d, and 1,890 m^2/d on all other reaches and subreaches in the WRV.

(A) Model layer 1

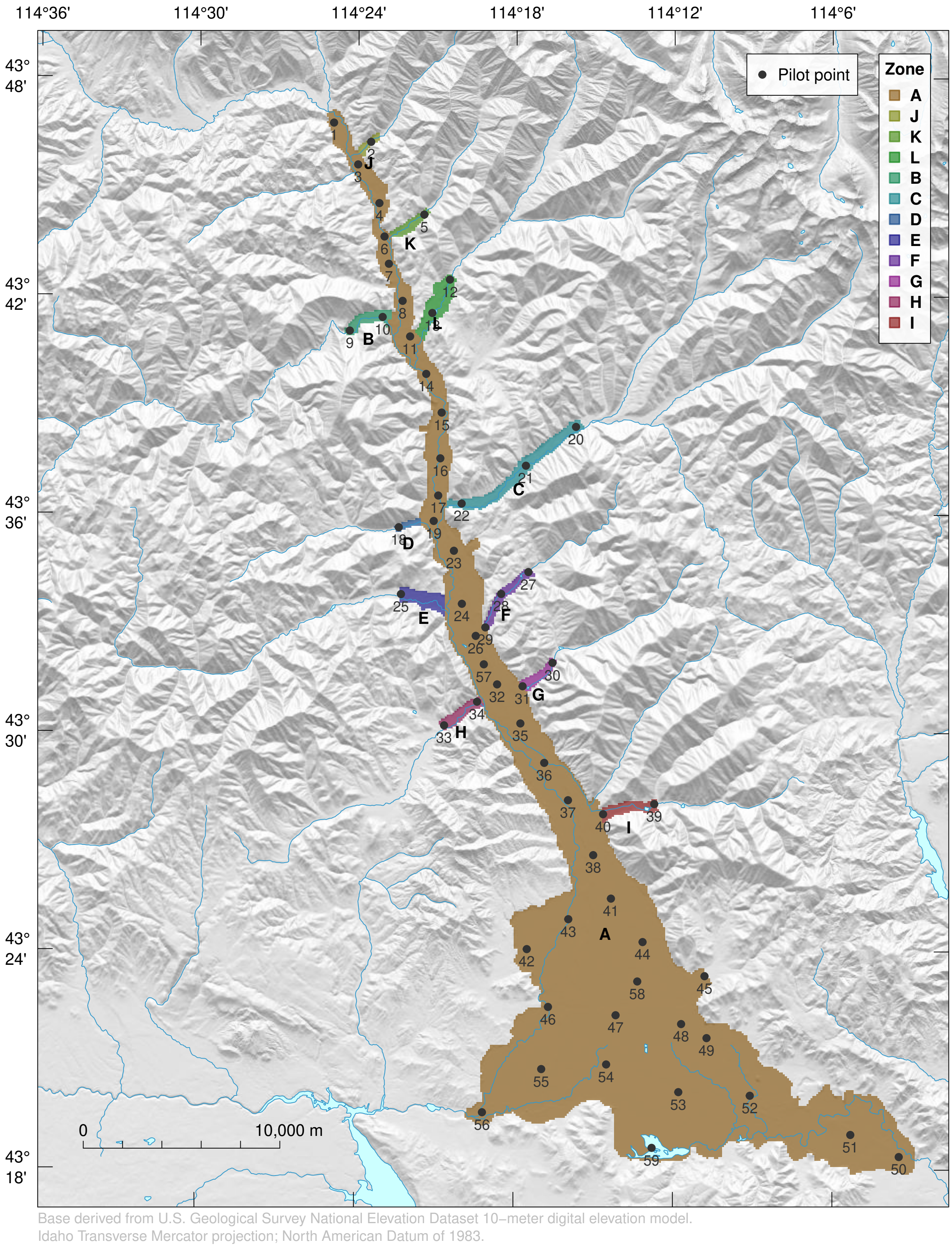
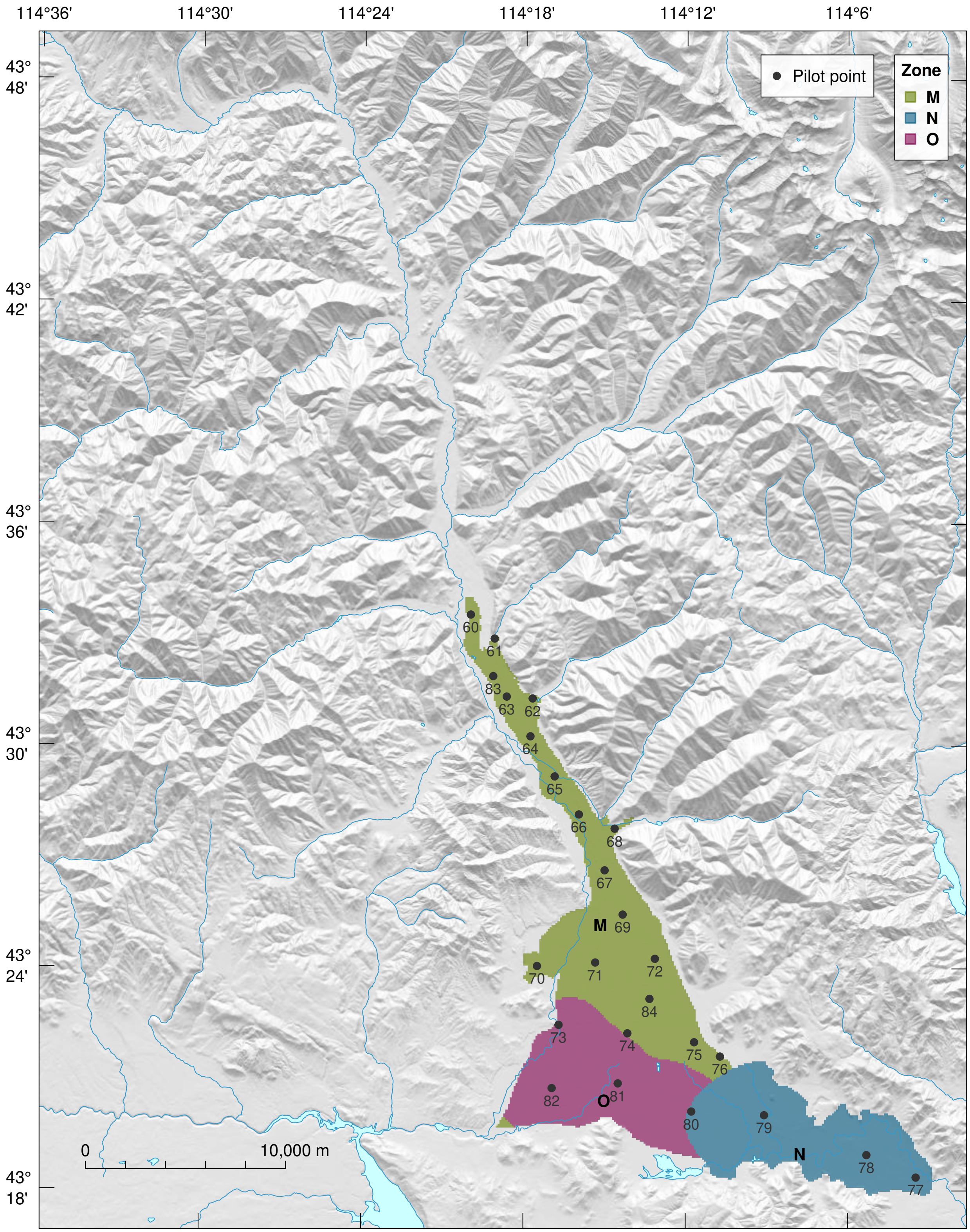


Figure H14. Spatial distribution of the pilot points and zones in (***A***) model layer 1, (***B***) model layer 2, and (***C***) model layer 3.

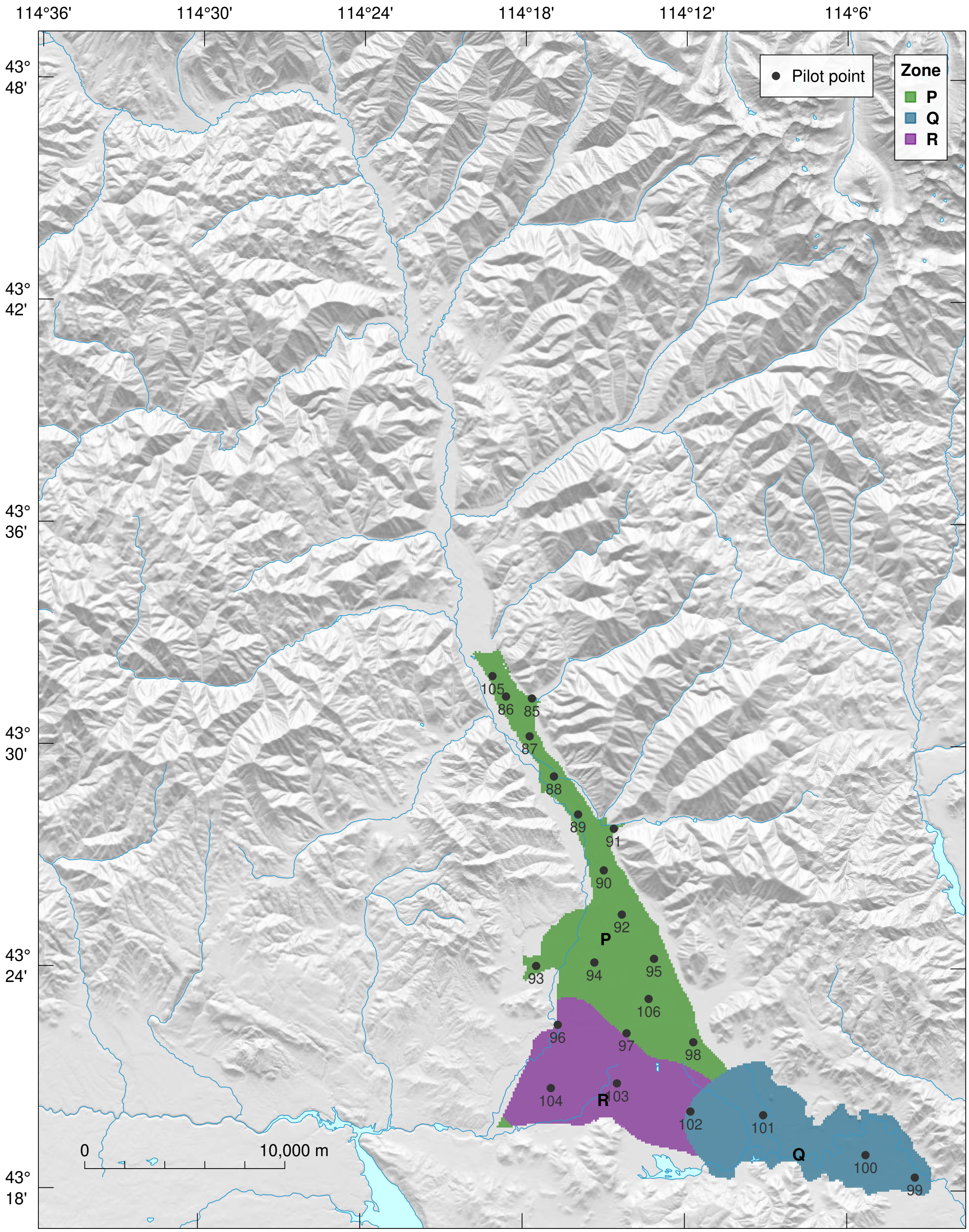
(B) Model layer 2



Base derived from U.S. Geological Survey National Elevation Dataset 10–meter digital elevation model.
Idaho Transverse Mercator projection; North American Datum of 1983.

Figure H14. —Continued

(C) Model layer 3



Base derived from U.S. Geological Survey National Elevation Dataset 10–meter digital elevation model.
Idaho Transverse Mercator projection; North American Datum of 1983.

Figure H14. —Continued

Table H11. Zones and pilot-points within the model domain. [**Zone**: identifier used to locate a zone in figure H14. **Name**: local zone name used in this study. **No. of points**: contained within a zone. **Point No.**: identifier used to locate pilot points in figure H14.]

Model layer	Zone	Name	No. of points	Point No.
1	A	WRV, unconfined alluvium unit	39	1, 3, 4, 6–8, 11, 14–17, 19, 23, 24, 26, 32, 35–38, 41–59
	J	Eagle Creek, unconfined alluvium unit	2	30, 31
	K	Lake Creek, unconfined alluvium unit	2	33, 34
	L	Trail Creek, unconfined alluvium unit	2	39, 40
	B	Warm Springs Creek, unconfined alluvium unit	1	2
	C	East Fork, unconfined alluvium unit	1	5
	D	Greenhorn Gulch, unconfined alluvium unit	2	12, 13
	E	Deer Creek, unconfined alluvium unit	2	9, 10
	F	Indian Creek, unconfined alluvium unit	3	20–22
	G	Quigley Creek, unconfined alluvium unit	1	18
	H	Croy Creek, unconfined alluvium unit	1	25
	I	Seamans Gulch, unconfined alluvium unit	3	27–29
2	M	WRV, unconfined alluvium unit	18	60–72, 74–76, 83, 84
	N	WRV, unconfined basalt unit	4	77–80
	O	WRV, confining clay unit (aquitard)	3	73, 81, 82
3	P	WRV, unconfined alluvium unit	15	85–95, 97, 98, 105, 106
	Q	WRV, unconfined basalt unit	4	99–102
	R	WRV, confined alluvium unit	3	96, 103, 104

Table H12. Starting values of horizontal hydraulic conductivity, vertical anisotropy, and storage coefficient; values assigned to each zone in the model domain. [**Hydraulic conductivity**: is the horizontal hydraulic conductivity. **Vertical anisotropy**: is the ratio of horizontal to vertical hydraulic conductivity. **Storage coefficient**: for saturated conditions it is the product of specific storage and the saturated thickness of the aquifer; for partially-saturated conditions it is virtually equal to the specific yield. **Abbreviations**: m/d, meters per day]

Zone	Hydrogeologic unit	Hydraulic conductivity (m/d)	Vertical anisotropy (1)	Storage coefficient (1)
A–M, P	Alluvium (unconfined)	2.1×10^{1}	50	1.0×10^{-1}
N, Q	Basalt	1.5×10^{1}	50	3.6×10^{-5}
O	Clay	8.5×10^{-7}	50	1.1×10^{-2}
R	Alluvium (confined)	1.3×10^{1}	50	7.5×10^{-5}

Drain Conductance

Drain conductances of the Stanton Crossing and Silver Creek outlet boundaries (fig. H13) were adjusted during model calibration. A drain conductance was assigned to each model layer of the outlet boundary (model layer 1 at Stanton Crossing and layers 1 through 3 at Silver Creek). The lower and upper bounds on drain conductance were specified at 1×10^{-10} and 1×10^{10} m^2/d, respectively; thus allowing for a very wide range of outflow conditions to be considered during model calibration. The starting values for drain conductance were 210 m^2/d at the Stanton Crossing outlet boundary and 152 m^2/d (identical in all 3 model layers) at the Silver Creek boundary.

Tributary Basin Underflow Control Parameters

Control parameters for describing the volumetric flow rate of groundwater entering the model domain that originates as precipitation in a tributary basin were adjusted during the parameter estimation process; this flow rate is referred to as tributary basin underflow. Figure H15 shows the location of underflow boundaries in the major tributary canyons and the upper part of the WRV. A detailed description of these model boundary conditions is provided in appendix E. For each underflow boundary, the temporal distribution of groundwater flow (hydrograph) during the simulation period (1995–2010) was adjusted using the following three control parameters: (1) a long-term mean tributary basin underflow, (2) the duration of the moving average, and (3) an amplitude reduction factor. The long-term mean tributary basin underflow controls the overall magnitude of tributary basin underflows, with the duration of the moving average and amplitude reduction factor controlling the timing and duration of underflows (that is, the shape of the hydrograph). A unique long-term mean tributary basin underflow was assigned to each of the tributary boundaries (23 parameters), whereas the duration of the moving average and amplitude reduction factor were the same for all underflow boundaries (2 parameters). Assigning the same shape to all hydrographs is a simplification of reality—timing and duration of tributary basin underflow can substantially vary among tributaries as a result of large variations in land-surface topography, climatic differences over small distances, and heterogeneities in rock permeability. Parameter simplification was deemed necessary for the purpose of attaining inverse problem uniqueness where the calibration dataset is information-poor.

Simulated long-term mean tributary basin underflow was not directly adjusted during parameter estimation; rather, a scalar component of the empirically derived estimate of long-term mean underflow was calibrated. The functional dependency between the simulated tributary basin underflow and the scalar quantity is expressed as:

$$\overline{Q}_{sim,i} = \overline{Q}_i s_i \tag{5}$$

where

$\overline{Q}_{sim,i}$ is the simulated long-term mean tributary basin underflow entering the model domain from tributary i, in cubic meters per day;

$\overline{Q}_i$ is the estimated long-term mean underflow entering the model domain from tributary i (table H13), in cubic meters per day; and

s_i is the scalar component of the mean underflow entering the model domain from tributary i, a dimensionless quantity.

Scalars were originally intended to facilitate regularization. However, inclusion of these parameters in the regularization process resulted in problems with the PEST regularization scheme, because of this, scalars were omitted from the regularized inversion process. Therefore, the use of scalars was not done for parameter estimation but the use was preserved for future implementations of regularization schemes.

The lower bound on the scalar was specified at 0.01; that is, one-hundredth of the estimated long-term mean tributary basin underflow. And its upper bound specified at 20 percent of the precipitation estimate of mean underflow (the product of a tributary basin's mean precipitation rate and area), that is:

$$s_{up,i} = 0.2 \left(\frac{\overline{Q}_{p,i}}{\overline{Q}_i} \right) \tag{6}$$

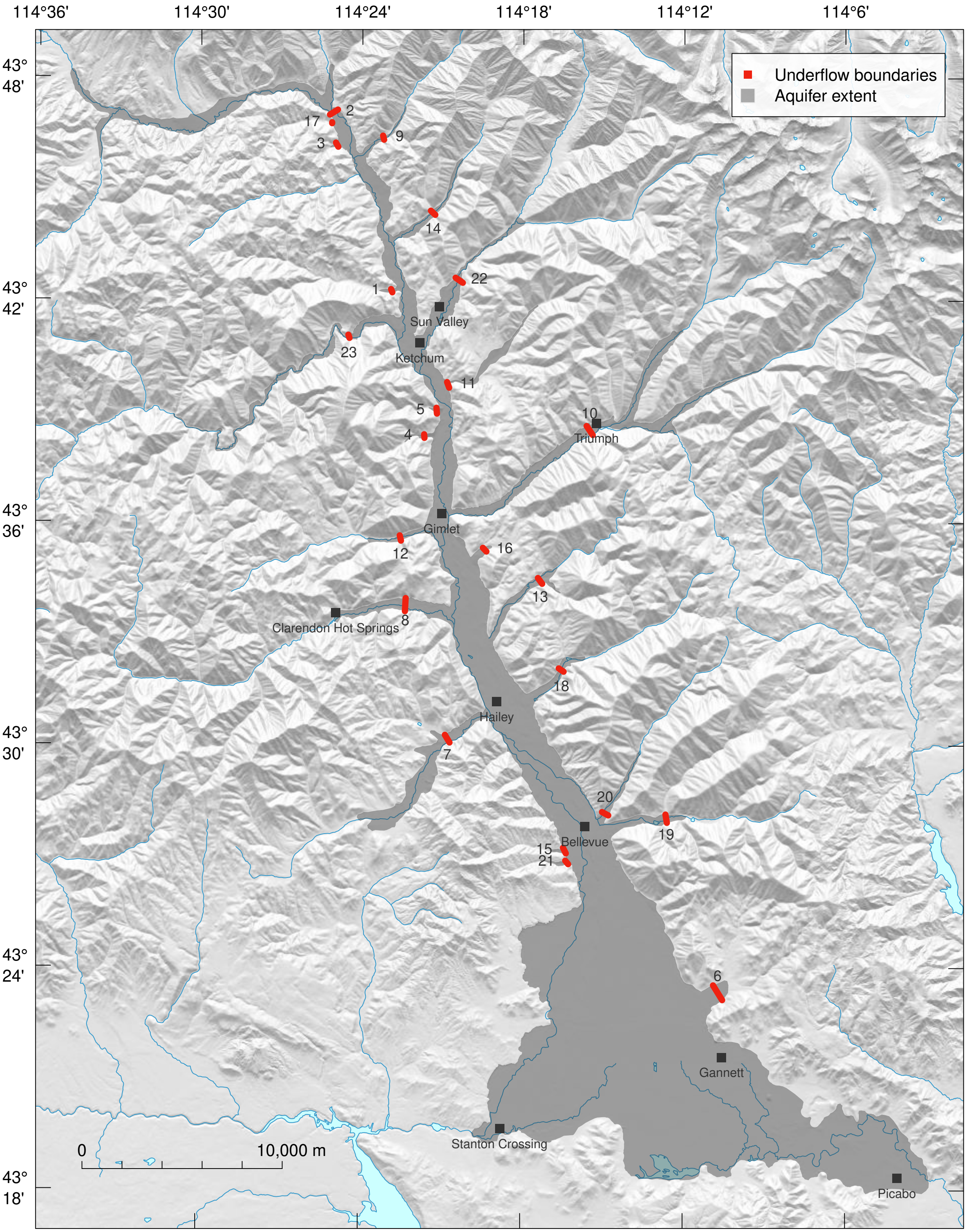
where

$s_{up,i}$ is the upper bound on the scalar component of the estimated long-term mean tributary basin underflow entering the model domain from tributary i, a dimensionless quantity; and

$\overline{Q}_{p,i}$ is the precipitation estimate of mean underflow entering from tributary i, in cubic meters per day (table H13).

Scalar starting values were specified at 1 for all tributary basins; thus corresponding to their estimated long-term mean tributary basin underflow ($\overline{Q}$ in equation 5).

Lower and upper and lower bounds on the duration of the moving average were specified at 1 day and 730.5 days (2 years), respectively; and the lower and upper bounds on the amplitude reduction factor specified at 0.001 and 10, respectively. These bounds allow for a wide variety of hydrograph shapes to be considered during model calibration. Starting values for the duration of the moving average and the amplitude reduction factor were 275 days (9 months) and 2, respectively.



Base derived from U.S. Geological Survey National Elevation Dataset 10–meter digital elevation model.
Idaho Transverse Mercator projection; North American Datum of 1983.

Figure H15. Location of underflow boundaries in the major tributary canyons and the upper part of the Wood River Valley.

Table H13. Upper bound placed on scalar components of the mean tributary basin underflow. [**Trib No.**: is an identifier used to locate the tributary model boundaries on the map in figure H15. **Flow rate**: is the empirically derived estimate of the mean tributary basin underflow. **Precip. flow**: is the precipitation estimate of mean tributary basin underflow. **Abbreviations**: m^3/d, cubic meters per day]

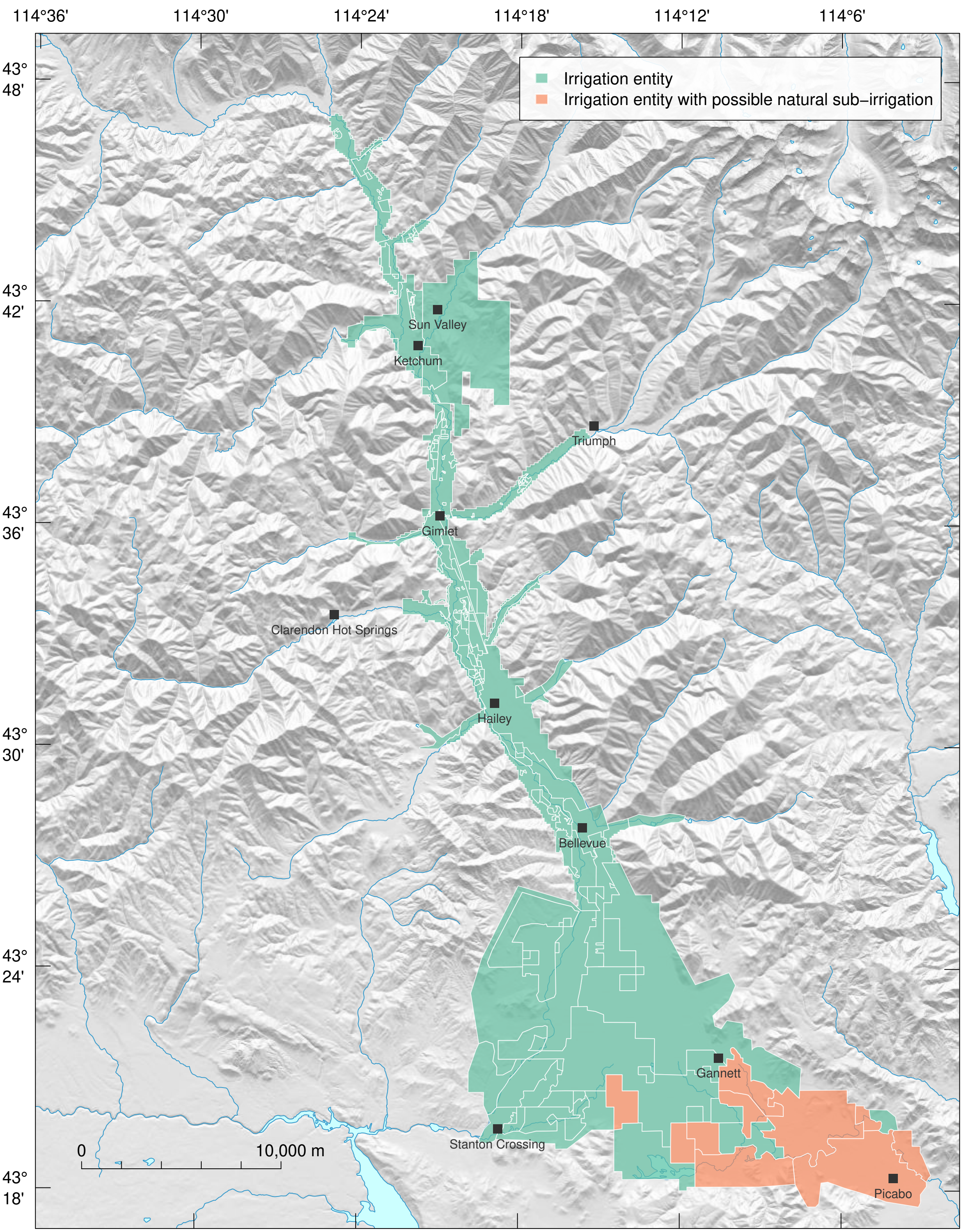
Name	Trib No.	Flow rate $\overline{Q}$ (m^3/d)	Precip. flow $\overline{Q}_p$ (m^3/d)	Upper bound on scalar s_{up} (1)
Adams Gulch	1	2,874	59,438	4.1
BWR Upper	2	2,063	1,057,998	102.6
Chocolate Gulch	3	197	3,963	4.0
Clear Creek	4	358	7,205	4.0
Cold Springs Gulch	5	591	11,888	4.0
Cove Canyon	6	482	37,824	15.7
Croy Creek	7	2,379	80,692	6.8
Deer Creek	8	4,925	247,659	10.1
Eagle Creek	9	3,423	57,457	3.4
East Fork	10	1,586	402,738	50.8
Elkhorn Gulch	11	173	42,147	48.6
Greenhorn Gulch	12	2,300	102,125	8.9
Indian Creek	13	8,107	33,682	0.8
Lake Creek	14	8,092	58,357	1.4
Lees Gulch	15	403	8,105	4.0
Ohio Gulch	16	716	14,409	4.0
Oregon Gulch	17	1,163	23,415	4.0
Quigley Creek	18	1,896	52,053	5.5
Seamans Gulch	19	6,557	62,140	1.9
Slaughterhouse Gulch	20	1,700	39,806	4.7
Townshead Gulch	21	134	2,702	4.0
Trail Creek	22	9,739	380,404	7.8
Warm Springs Creek	23	1,631	605,188	74.2

Irrigation efficiency

An irrigation efficiency was assigned to each of the 88 irrigation entities in the WRV (fig. H16). Irrigation efficiency is defined as the ratio between irrigation water actually utilized by growing plants and the total water diverted from sources in order to supply such irrigation water. The lower bound on irrigation efficiency was specified at 0.50 (50 percent) for all irrigation entities; the upper bound on irrigation efficiency was 0.95 (95 percent) for irrigation entities located in areas where conditions for natural sub-irrigation may exist (fig. H16), and 0.90 (90 percent) otherwise. Recall that natural sub-irrigation occurs in areas where the water table is high and the capillary fringe is within the reach of root zone crops; therefore, there is potentially less irrigation water delivered to these areas. The starting values for irrigation efficiency were 0.75 (75 percent). The irrigation efficiencies of the 73 irrigation entities with groundwater irrigation sources were adjusted during model calibration.

Prior Information

Prior information on estimated model parameters (X in equation 1) was used to supplement field measurements. These supplementary observations are based on expert knowledge and specified as a preferred value for estimated parameters. For the horizontal hydraulic conductivity and storage coefficient, homogeneity is assumed to prevail within each zone (fig. H14 and table H11), thus supporting the hydrogeologic conceptualization for the study area. PEST implements the homogeneity condition by minimizing the difference in parameter values between adjacent pilot points located in the same zone. In parts of the unconfined aquifer that are composed of basalt (zone's N and Q), the homogeneity condition for horizontal hydraulic conductivity was expanded to include a preference for near equal parameter values between pilot points in adjacent model layers.



Base derived from U.S. Geological Survey National Elevation Dataset 10−meter digital elevation model.
Idaho Transverse Mercator projection; North American Datum of 1983.

Figure H16. Irrigation entities in the Wood River Valley, Idaho.

As a general rule, it is unlikely that there exists large differences between subreach estimates of riverbed conductance in the study area. This “observation” is included as prior information in the parameter estimation process by imposing a homogeneity condition on riverbed conductance within each river reach. That is, river subreach estimates of riverbed conductance should be near equal to one another within a river reach.

Expert knowledge of the specific practices in the WRV and the prevailing geologic conditions indicate that a 75-percent irrigation efficiency is a reasonable value for all irrigation entities in the WRV (fig. H16). This prior information is included in the parameter estimation processes as a preferred value. PEST implements the preferred value condition by minimizing the difference between the parameter estimate and its starting value; recall that the starting value for irrigation efficiency is 75 percent. PEST will only deviate from the starting value in order to calibrate the model. While there is considerable uncertainty in the actual value of irrigation efficiency within each irrigation entity, the preferred value was included as prior information to discourage PEST from influencing flux between model layers by adjusting irrigation efficiency in lieu of adjusting hydraulic properties.

Observation Weights

Weights (w in equation 1) indicate the importance of an observation on the regression (equation 1). An observation with a large weight asserts a large influence on the regression and, therefore, the estimated parameter values. Conversely, an observation with a small weight asserts less influence on the regression and estimated parameter values. Weights should ideally be inversely proportional to the "error" associated with the measured quantity of the observation. In the case of prior information this "error" is the uncertainty of that information (Doherty, 2015, p. 97). The difficulties with assigning weights using this approach are as follows:

- Errors associated with field measurements and prior expert knowledge are not easily quantifiable. For example, the accuracy of groundwater-level measurements recorded by drillers onto well logs is unknown and most-likely highly variable between wells. Also unknown are the uncertainties associated with prior expert knowledge; that is, the propensity of riverbed conductance to be equal among river reaches and an irrigation efficiency equal to 75 percent.

- The relative importance of each observation type in the overall parameter estimation process is dependent on the weights. For example, both groundwater-level and stream-aquifer flow-exchange measurements are used in model calibration. Groundwater levels are expressed in meters above the North American Vertical Datum of 1988 (NAVD 88) and stream-aquifer flow exchanges are expressed in cubic meters per day (m^3/d). For groundwater levels, model-to-measurement discrepancies ($Y - \widehat{Y}$ in equation 1) of as much as 1 m are tolerable; whereas, the model-to-measurement discrepancies for stream-aquifer flow exchange are typically much larger with a discrepancy of 100,000 m^3/d being tolerable. Using these model-to-measurement discrepancy values, stream-aquifer flow-exchange measurements would need to be decreased by a factor of 100,000 so that both measurement sets are equally effective in determining model parameters; that is, neither observation dominates the parameter estimation process.

Unquantifiable observation errors and differing observation types necessitated the use of a subjective weighting scheme for calibrating the WRV groundwater-flow model. Weights were assigned to observation groups so that weighted residuals were roughly of the same order of magnitude (table H14). Further adjustments were made to weights placed on the groundwater-level observation groups in order to reflect the credibility of measurements in each group. For example, groundwater levels measured in the USGS monitoring network wells were assigned the largest weight (with respect to groundwater-level observation groups) at 1 inverse meter (1/m) because this was the only one of these groups where measurement accuracy was quantified. For the remaining groundwater-level observation groups, weights were assigned based on a qualitative assessment of their measurement accuracy, and a quantitative assessment of each group's sample size and temporal distribution. The groundwater-level observation groups in order of decreasing measurement accuracy are roughly as follows: USGS wells, SVSWD wells, TNC wells, geolocated driller wells, and PLSS-located driller wells. Because some observation groups are composed of many measurements recorded over a short period-of-record (such as TNC wells with 2,027 measurements all recorded over the last 8-months of the model-calibration period) it was necessary to decrease the observation weight of these groups to prevent their measurements from dominating the model-calibration process.

Weights on the regularized prior information (that is, the horizontal hydraulic conductivity and storage coefficient), vertical anisotropy, and tributary basin underflow parameters were automatically adjusted by PEST during the parameter estimation process.

PHIMLIM

The user-specified PEST variable PHIMLIM in equation 1 is the upper limit on the sum of squared weighted differences between model results and corresponding field measurements (Doherty, 2005, p. 7-6). Its purpose is to control the tradeoff between model-to-measurement fit and the level of adherence to preferred parameter value conditions. For example, a decrease in the PHIMLIM value can dramatically reduce the model-to-measurement fit, while at the same time, increasing the likelihood of overfitting model results to measurements (that is, estimating an unrealistic parameter set). Adhering to the general guidelines provided by Fienen, Muffels, and Hunt (2009, p. 842), a PHIMLIM of 54,150 was selected for the WRV model-calibration process; this value is thought to provide a good compromise between model-to-measurement fit and model-parameter believability.

Table H14. Observation weights assigned to field measurements and prior-information. [**Abbreviations**: ADJ, automatically adjusted during the parameter estimation process; 1/m, inverse meters; d/m^3, days per cubic meter; d/m^2, days per square meter; 1/d, inverse days]

Observation type	Observation group	Weight	Units
Groundwater level	U.S. Geologic Survey monitoring network wells	1.0×10^{0}	1/m
	Geolocated driller wells	7.5×10^{-1}	1/m
	Public Land Survey System-located driller wells	2.3×10^{-1}	1/m
	Sun Valley Water and Sewer production well	5.0×10^{-1}	1/m
	The Nature Conservancy monitoring network well	2.1×10^{-1}	1/m
Stream-aquifer flow exchange	Big Wood River, Near Ketchum to Hailey reach	3.2×10^{-4}	d/m^3
	Big Wood River, Hailey to Stanton Crossing reach	5.5×10^{-5}	d/m^3
	Willow Creek reach	4.6×10^{-4}	d/m^3
	Silver Creek, above Sportsman Access reach	9.9×10^{-5}	d/m^3
	Silver Creek, Sportsman Access to near Picabo reach	9.9×10^{-5}	d/m^3
Stream-aquifer flow-exchange ratio	Subreaches of the Big Wood River, Silver Creek, and spring-fed tributaries	1.1×10^{1}	1
Groundwater discharge	Stanton Crossing outlet boundary	1.0×10^{-2}	d/m^3
	Silver Creek outlet boundary	1.0×10^{-4}	d/m^3
Horizontal hydraulic conductivity	Pilot points in each zone (fig. H14)	ADJ	d/m
	Pilot points in zones A, M, and P	ADJ	d/m
Vertical anisotropy	Global value	ADJ	1
Storage coefficient	Pilot points in each zone	ADJ	1
Riverbed conductance	Willow Creek reach and Silver Creek, Sportsman Access to Near Picabo reach; subreaches of the Big Wood River, Silver Creek, and spring-fed tributaries	1.0×10^{0}	d/m^2
Irrigation efficiency	Irrigated lands	1.0×10^{1}	1
Scalar component	Tributary boundaries	ADJ	1
Moving average duration	Global value for all tributary boundaries	ADJ	1/d
Amplitude-reduction factor	Global value for all tributary boundaries	ADJ	1

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