ESPAM2.1

Model Validation

Idaho Department of Water Resources

Allan Wylie

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Contents

Abstract

The Idaho Department of Water Resources (IDWR) recently developed a new version of the Enhanced Snake Plain Aquifer Model (ESPAM) under the guidance of the Eastern Snake Hydrologic Modeling Committee (ESHMC). After calibration, ESPAM2.0 was validated using observations from two time periods: 1900 and 2009-2010. The 2009-2010 scenario took advantage of data that became available during calibration, and the 1900 scenario used data from reports published by the State Engineer and historical USGS documents. Subsequent to the model validation, mistakes in the water budget for the Mud Lake area were discovered repaired and the model was then recalibrated. The resulting model is referred to as ESPAM2.1. After recalibration, the IDWR reran the validation scenarios, but it was later determined that the 2009-2010 scenario was run with the ESPAM2.0 specific yield array and the 1900 scenario was run with the ESPAM2.0 transmissivity array. This report documents findings for the revised ESPAM2.1 validation scenarios. To evaluate the 2009-2010 Validation Scenario, the 1985-2008 calibration period was divided into 12 roughly two-year periods. The Root Mean Squared Error (RMSE) and the Median Absolute Deviation (MAD) were computed for each of the 12 periods for four model output categories (i.e. aquifer water levels, river gains, spring reach gains, and spring discharges) and compared with RMSE and MAD for the 2009-2010 validation period. The unweighted RMSE and MAD for the 2009-2010 validation period fell within the bounds generated from the calibration period. The weighted RMSE and MAD also fell within the bounds generated from the calibration period for every category except spring discharges.

The 1900 scenario took advantage of data located in Biennial Reports of the State Engineer (Mills, 1896; Ross, 1900; and Ross, 1902), USGS documents (Russell,1902; and Nace, 1958), and the Parameter-elevation Regression on Independent Slopes Model (PRISM) data sets. These sources provided crop mix, crop yield, acres irrigated, some water level observations collected in wells, spring discharge measurements and estimates, and precipitation data from around 1900. This allowed creation of model input data sets to simulate aquifer water levels and spring discharge from around 1900. Given the quantity and quality of available data, model output and field observations also match reasonably well for the 1900 Validation Scenario.

Neither the 2009-2010 nor the 1900 Validation Scenarios generated significant concerns or limitations regarding the use of the ESPAM2.1.

Introduction

The eastern Snake Plain extends from Ashton, Idaho in the northeast to King Hill, Idaho in the southwest (Figure 1). The population is generally sparse, with most people residing near the Snake River. Much of the land is federal, managed by the U.S. Bureau of Land Management. Extensive portions of the federal land are covered by rugged basalt outcrops.

The climate is arid to semi-arid with precipitation ranging from 8 to 14 inches per year, and irrigation is required to grow most agricultural crops. Irrigation began in the late 1800s using water from the Snake River and its tributaries (Garabedian, 1992). The number of acres irrigated with surface water increased until about the mid-1940s, and has since been declining as the number of ground water irrigated acres increased beginning in the 1950s (Cosgrove and others, 2006). Irrigation practices continue to change in response to technology and economic factors (Cosgrove and others, 2006).

Ground water and surface water are interconnected on the eastern Snake Plain. This interconnection prompted the Idaho Department of Water Resources (IDWR) to develop an aquifer model under the supervision of the Eastern Snake Hydrologic Modeling Committee (ESHMC) to help administer surface water and ground water conjunctively. The ESHMC is composed of hydrologists and modelers from state and federal agencies, representatives of private industry and their consultants, and the University of Idaho.

IDWR recently developed a new version of the Enhanced Snake Plain Aquifer Model (ESPAM) under the guidance of the ESHMC. After calibration, ESPAM2.0 was validated using observations from two time periods: 1900 and 2009-2010. The 2009-2010 scenario took advantage of data that became available during calibration, and the 1900 scenario used data from reports published by the State Engineer and historical USGS documents.

Subsequent to the model validation, mistakes in the water budget for the Mud Lake area were discovered repaired and the model was then recalibrated. The resulting model is referred to as ESPAM2.1. After recalibration, the IDWR reran the validation scenarios but it was later determined that the 2009-2010 scenario was run with the ESPAM2.0 specific yield array and the 1900 scenario was run with the ESPAM2.0 transmissivity array. This report documents findings for the revised ESPAM2.1 validation scenarios.

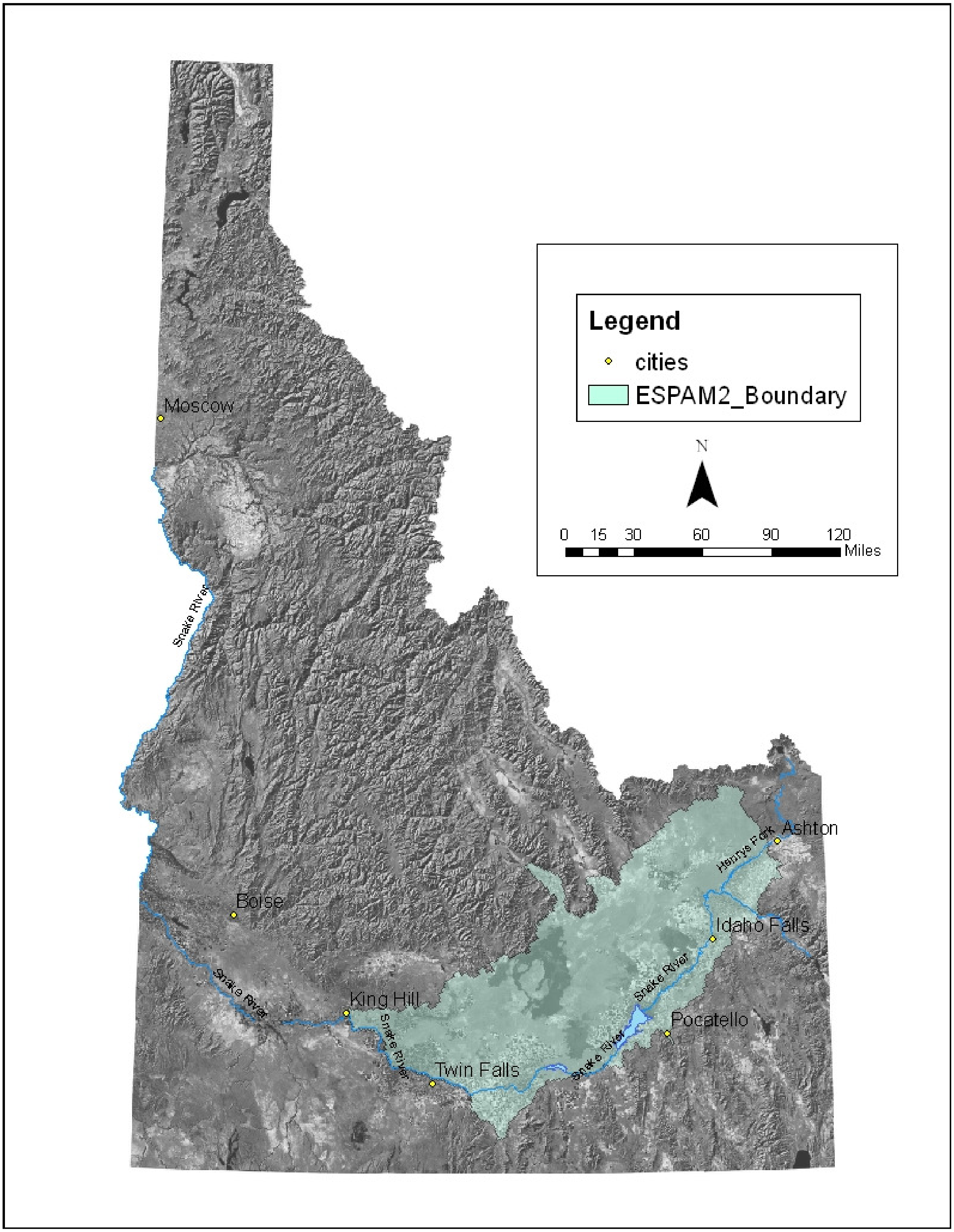


Figure 1. Boundaries of the Enhanced Snake Plain Aquifer Model version 2.1.

Hydrogeologic Setting

The surface of the eastern Snake Plain consists primarily of basalt, commonly with a thin covering of sediments. The subsurface consists of a series of thin basalt flows with occasional intercalated sediments. Flows range in thickness from a few feet to tens of feet (Welhan and Funderberg, 1997), with the collective thickness of basalt flows exceeding several thousand feet in places (Whitehead, 1986).

The Snake River flows along the southern margin of the eastern Snake Plain and is the exclusive surface-water discharge for the eastern Snake Plain. Groundwater outflow from the eastern Snake Plain is assumed to be minimal due to the low hydraulic conductivity deposits of the Glens Ferry Formation at the interface between the eastern and western Snake Plain aquifers. The discharge of the ESPA occurs primarily as Snake River gains and spring discharge; therefore, the flow of the Snake River at King Hill is considered to be the basin discharge, excluding evaporation (Garabedian, 1992).

Flow Model

The IDWR improved ESPAM1.1 (Cosgrove and others, 2006) by extending the dataset to 2008 and refining components of the water budget. ESPAM2.1 was developed by the IDWR and reviewed by the ESHMC. The ESPAM2.1 was created using the finite-difference ground water modeling program MODLFOW2000 (Harbaugh and others, 2000) and calibrated using PEST version 12.0 (Doherty, 2004). In MODFLOW, time is broken into small segments called stress periods, and the model domain is broken into grid cells. ESPAM2.1 has a uniform 1mi x 1mi grid. The 23.5-year calibration period is broken into 282 one-month stress periods preceded by a five-year warm up period consisting of 60 one-month stress periods for a total of 342 stress periods.

During calibration, model parameters such as transmissivity, aquifer storage, riverbed conductance, drain conductance, general head boundary conductance, and certain components of the water budget, were adjusted until model generated aquifer water levels and discharges matched observed values. PEST was only allowed to adjust the components of the water budget between assumed uncertainty bounds. For example, PEST could only adjust evapotranspiration (ET) ± 5 % because the ESHMC felt that ET was well known.

Model calibration targets include 43,165 aquifer water levels collected in 1,121 different wells, 1,405 river gain/loss observations, 2,485 spring discharge observations, and 1,124 spring reach targets.

2009-2010 Validation Scenario

After model calibration, additional agricultural diversions, Snake River gain and loss data, aquifer water levels, spring discharge data, and other water budget data became available allowing the IDWR to use November 2008 through September 2010 as a validation period. The water budget data were compiled and formatted for use in the model and the model was run to generate predictions of river gains, aquifer head and spring discharge. Model outputs were then compared with field observations. Field observations during the validation period included 4,600 aquifer water levels collected from 355 different wells, 120 river gain/loss observations, 321 spring discharge observations, and 96 spring reach observations.

The IDWR requested advice from Dr. Maxine Dakins, a University of Idaho professor, on statistical methods for evaluating model performance. Dr. Dakins (2012) suggested dividing the 23.5-year calibration period into 11 two-year and one 1.5-year period and comparing the single two-year validation period to the distribution of values from the calibration period. Dr. Dakins (2012) also suggested using RMSE and MAD as comparison metrics.

The RMSE (Hill and Tiedaman, 2007) is calculated from the Sum of the Squared Errors (SSE).

Where: $RMSE = \sqrt{\frac{SSE}{df}}$

SSE= Sum of the Squared Errors

df = degrees of freedom = n-p

n = number of values used as calibration targets

p = number of calibration parameters

Hill and Tiedaman (2007) recommend using the same weighting scheme as during calibration. This changes the units of the observations, so this report will show RMSE and MAD both weighted and unweighted. Regardless, each aquifer water level observation was weighted the same during calibration, so weighting will have no impact on the RMSE or MAD for aquifer head data. River reach gains, spring reach gains, and spring discharges had different weights during calibration to account for variation in the magnitudes of discharge and the number of observations available at each spring. Statistics for these groups were calculated using both weighted and unweighted values.

MAD is the median of the absolute values of the deviation from the median of the dataset.

$$MAD = median(|X_i - medianX_j|)$$

Where:

X_i = the ith data point in the dataset

median X_j = the median of all of the data values in the dataset

| | = the absolute value

Aquifer head

A total of 43,165 water-level measurements collected in 1,121 different wells were used during model calibration. Of those wells, 354 were measured during the validation period. A total of 4,600 aquifer water level observations were available during the validation period for comparison with model output. Figure 2 shows the location of the 1,121 wells used for calibration and the 354 wells used for both calibration and validation.

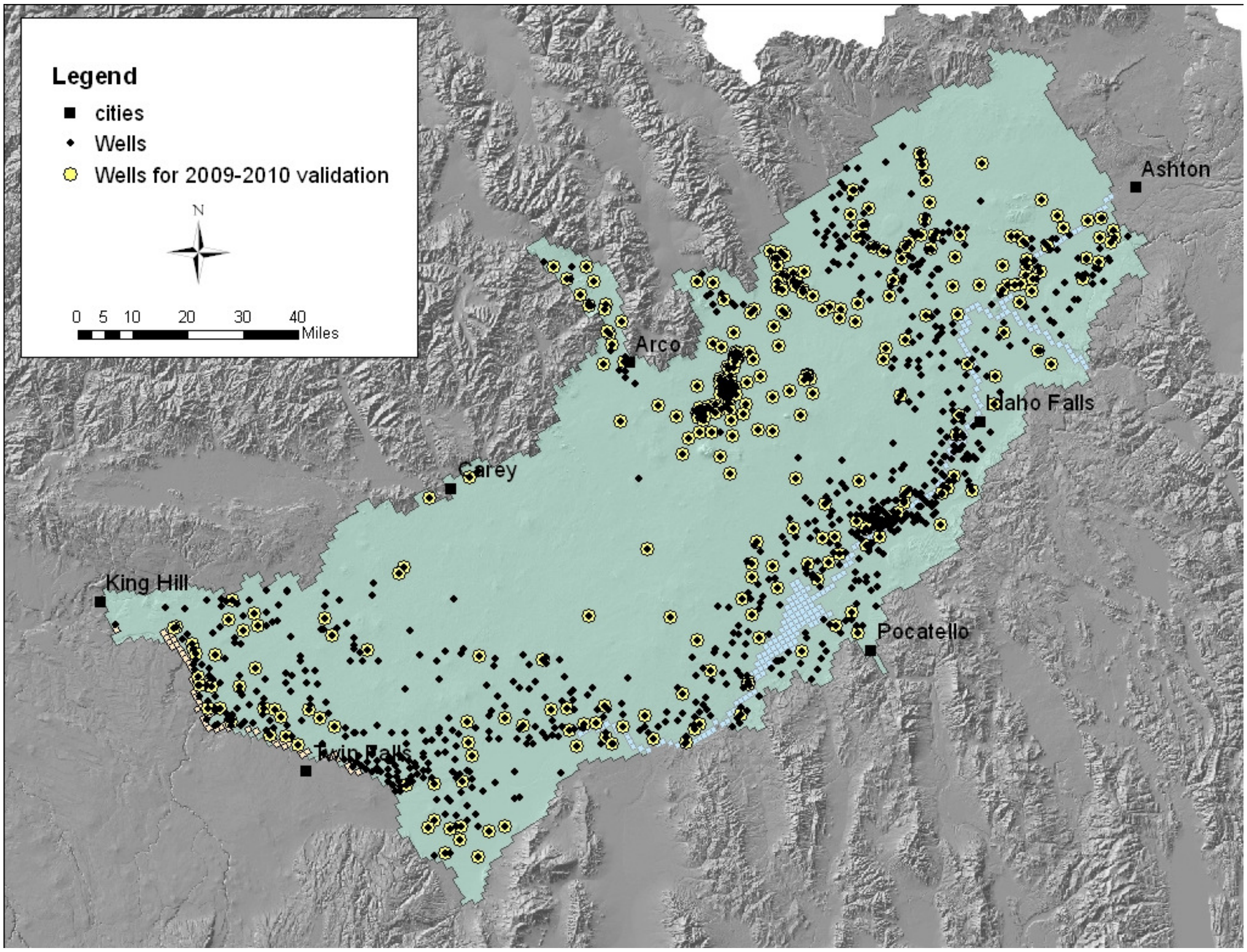


Figure 2. Location of wells used to collect aquifer head observations.

Aquifer head RMSE and MAD from the validation period were compared with the distributions of RMSE and MAD from the calibration period. During calibration, the RMSE for the 11 two-year periods and the 1.5-year period ranged from 25.1 to 31.7 ft, and the RMSE from the validation period was 26.5 ft (Figure 3). The MAD for the 11 two-year periods and the 1.5-year calibration period ranged from 12.8 to 8.2 ft, and the MAD for the validation period is 9.9 ft. Both the validation RMSE and the MAD are within the ranges computed from the calibration data (Figure 3).

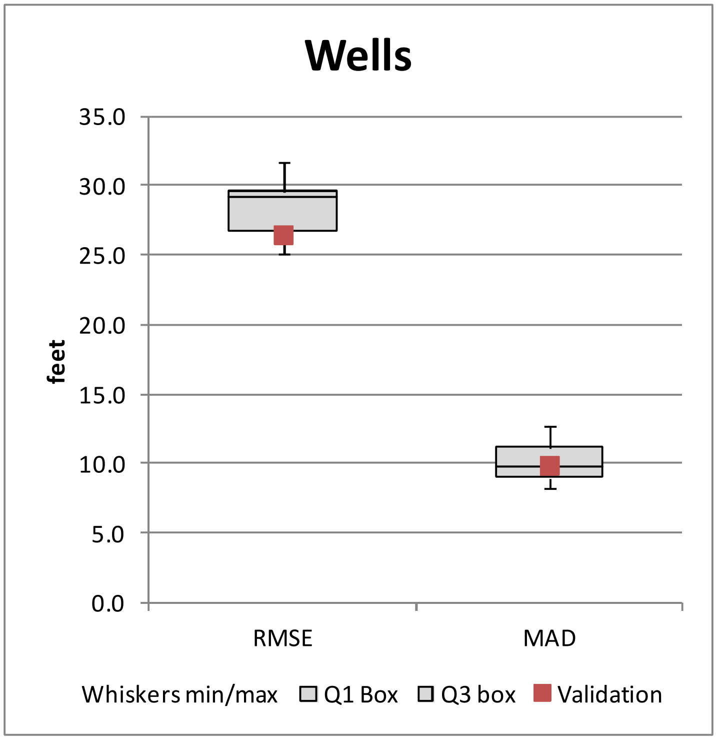


Figure 3. RMSE and MAD box and whisker plots for water levels from the 2009-2010 Validation Scenario.

River reach gains

The Snake River was divided into five river reaches defined by river gages operated by the United States Geological Survey (USGS). The river reach gain/loss calibration targets were computed by differencing the upstream and downstream gages while accounting for diversions, returns, tributary inflow, and changes in reservoir storage. Model calibration targets included a total of 1,405 river gain/loss observations. One-hundred and twenty observations were available during the validation period for comparison with model output. Figure 4 shows the locations of the five river reaches.

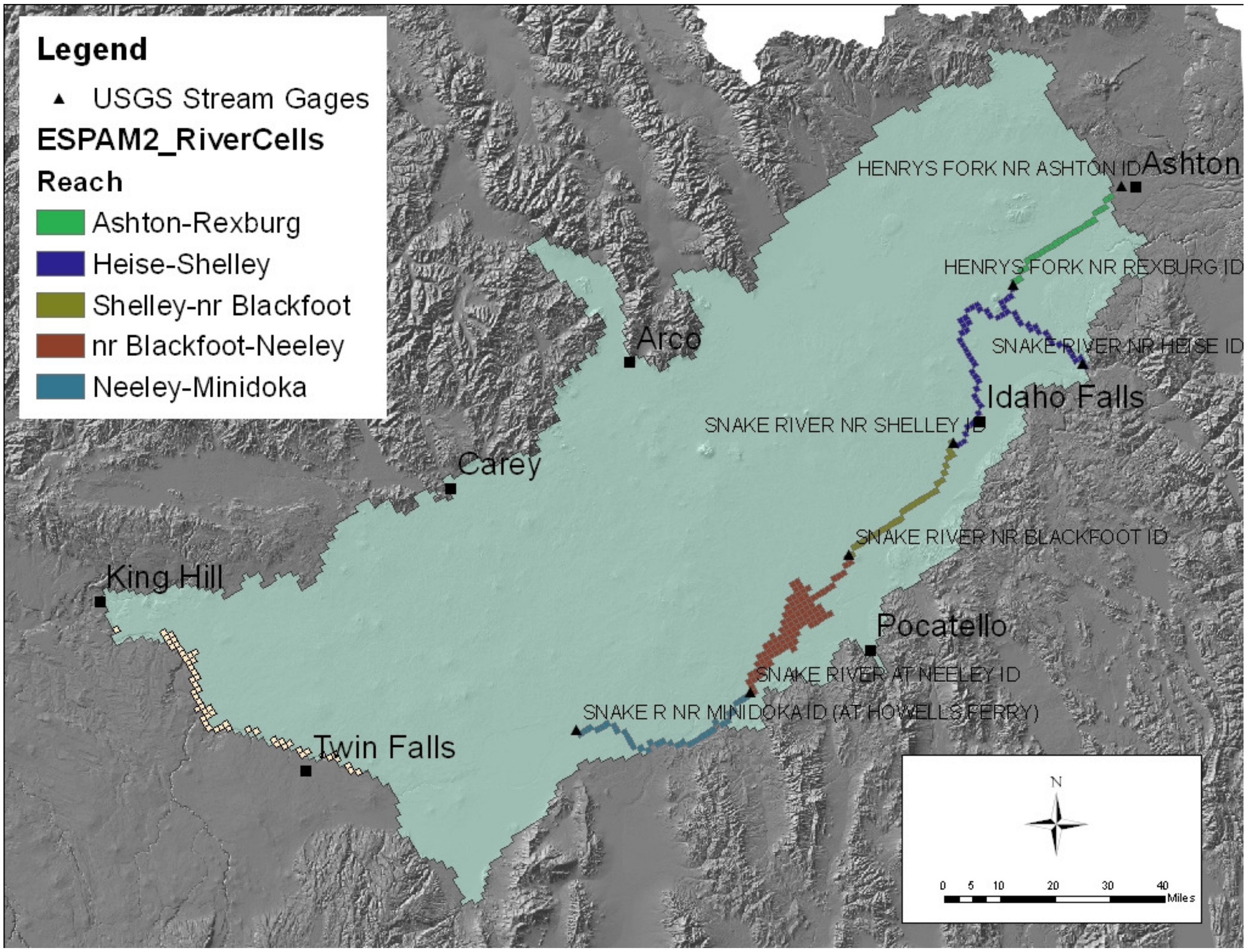


Figure 4. Location of gages used to establish river reaches.

River reach gain RMSE and MAD from the 2009-2010 validation period were compared with the distributions of RMSE and MAD from the calibration period. These comparisons were made using both unweighted and weighted residuals. The unweighted RMSE for the 12 periods during calibration ranged from 38.0 to 82.6 cfs, and the unweighted RMSE from the validation period was 63.6 cfs. The unweighted MAD for the 12 periods during calibration ranged from 117.4 to 215.1 cfs, and the unweighted MAD for the validation period is 179.3 cfs.

The weighted RMSE for the 12 periods during calibration ranged from 3.4e-6 to 7.6e-6, and the weighted RMSE from the validation period was 5.3e-6. The weighted MAD for the 12 periods during calibration ranged from 1.1e-5 to 2.2e-5, and the weighted MAD for the validation period is 1.6e-5. Both the weighted and unweighted validation RMSE and the MAD are within the ranges computed from the calibration data (Figure 5).

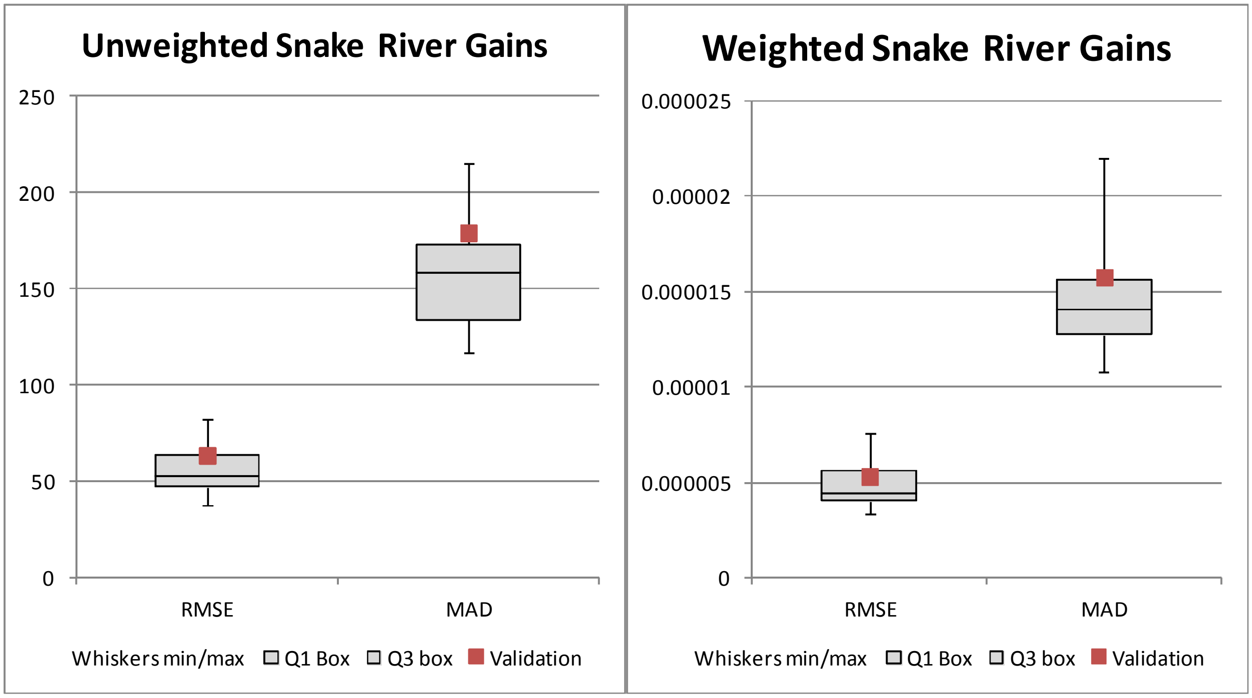


Figure 5. RMSE and MAD box and whisker plots for Snake River gains from the 2009-2010 Validation Scenario.

Spring reach gains

The ESPA discharges from springs in the Magic Valley which extend from east of Twin Falls to King Hill. The springs are grouped into three spring reaches defined by gages on the Snake River: Kimberly to Buhl, Buhl to Lower Salmon Falls, and Lower Salmon Falls to King Hill (Figure 6). Model calibration targets included 1,124 spring reach observations. Ninety-six observations are available during the validation period for comparison with model output.

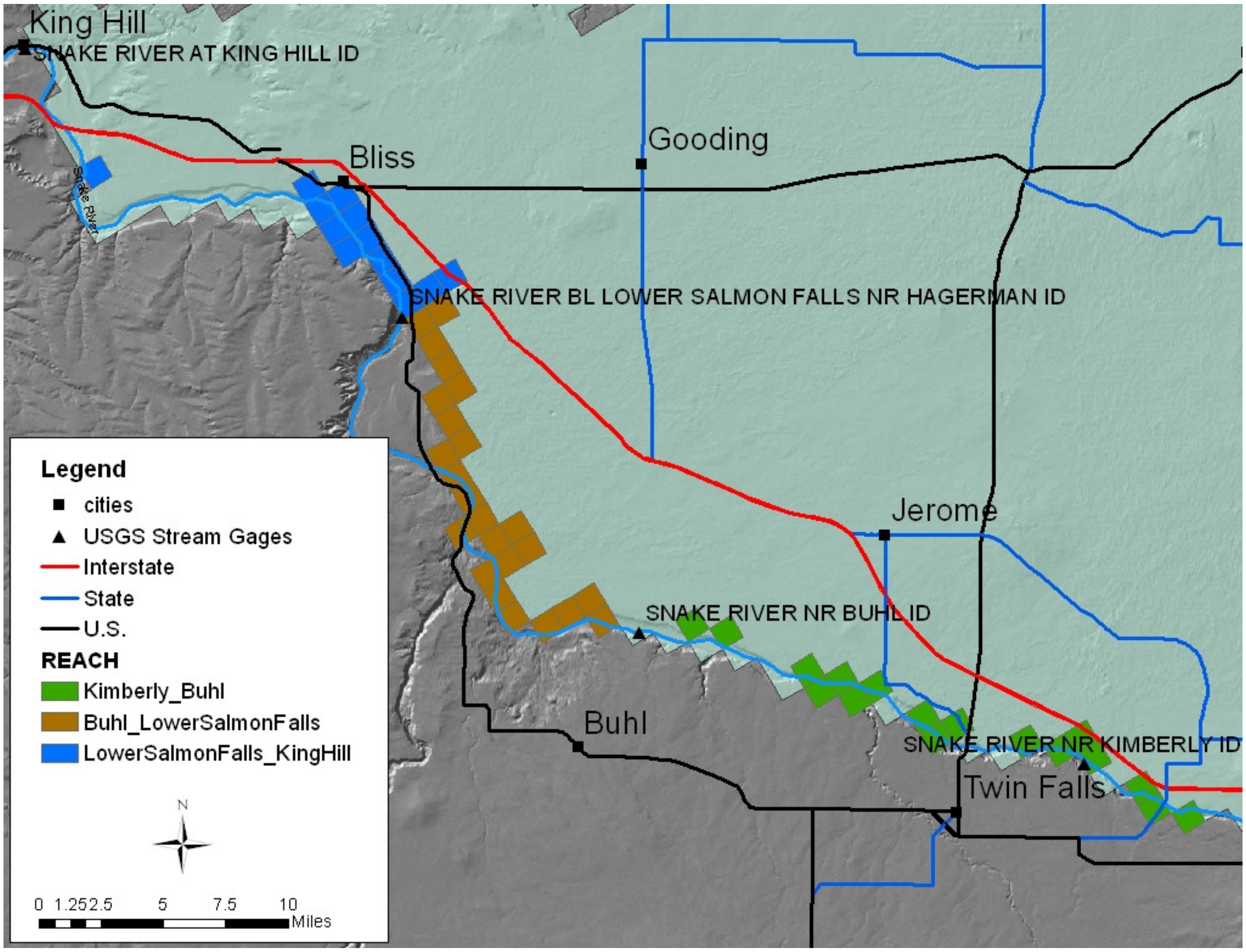


Figure 6. ESPAM2.1 spring reaches.

Spring reach gain RMSE and MAD from the validation period were compared with the distributions of RMSE and MAD from the calibration period. These comparisons were made using both unweighted and weighted residuals. The unweighted RMSE for the 12 calibration periods ranged from 38.7 to 77.6 cfs, and the unweighted RMSE from the validation period was 46.5 cfs. The unweighted MAD for the 12 calibration periods ranged from 141.2 to 273.3 cfs, and the unweighted MAD for the validation period is 159.7 cfs.

The weighted RMSE for the 12 calibration periods ranged from 3.8e-6 to 8.4e-6, and the weighted RMSE from the validation period was 4.4e-6. The weighted MAD for the 12 calibration periods ranged from 1.5e-5 to 3.1e-5, and the weighted MAD for the validation period is 1.4e-5. The weighted and unweighted validation RMSE and the unweighted validation MAD are within the ranges computed from the calibration data. The weighted MAD is below the range for the range computed from the calibration data (Figure 7) indicating a better fit than during the calibration period.

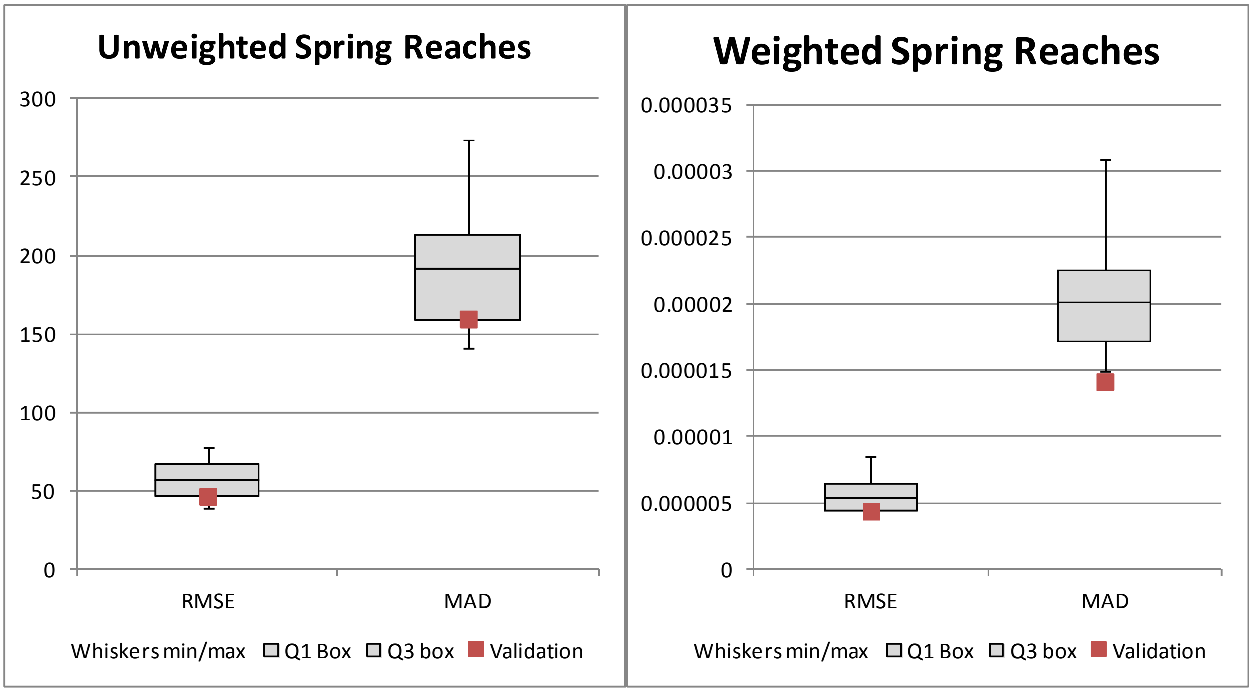


Figure 7. RMSE and MAD box and whisker plots for spring reach gains from the 2009-2010 Validation Scenario.

Discharge for individual springs

Fourteen springs in the Magic Valley were used as transient calibration targets for the 2009-2010 validation: Devils Washbowl, Devils Coral, Blue Lake, Crystal Spring, Niagara Springs, Clear Lakes, Briggs Springs, Box Canyon Springs, Sand Springs, Thousand Springs, National Fish Hatchery, Rangen Springs, Three Springs, and Malad Springs. These springs were referred to as A&B springs during model calibration. Model calibration targets included 2,485 spring discharge observations. A total of 321 observations were available during the validation period for comparison with model output. Figure 8 shows the locations of the springs used as transient calibration targets.

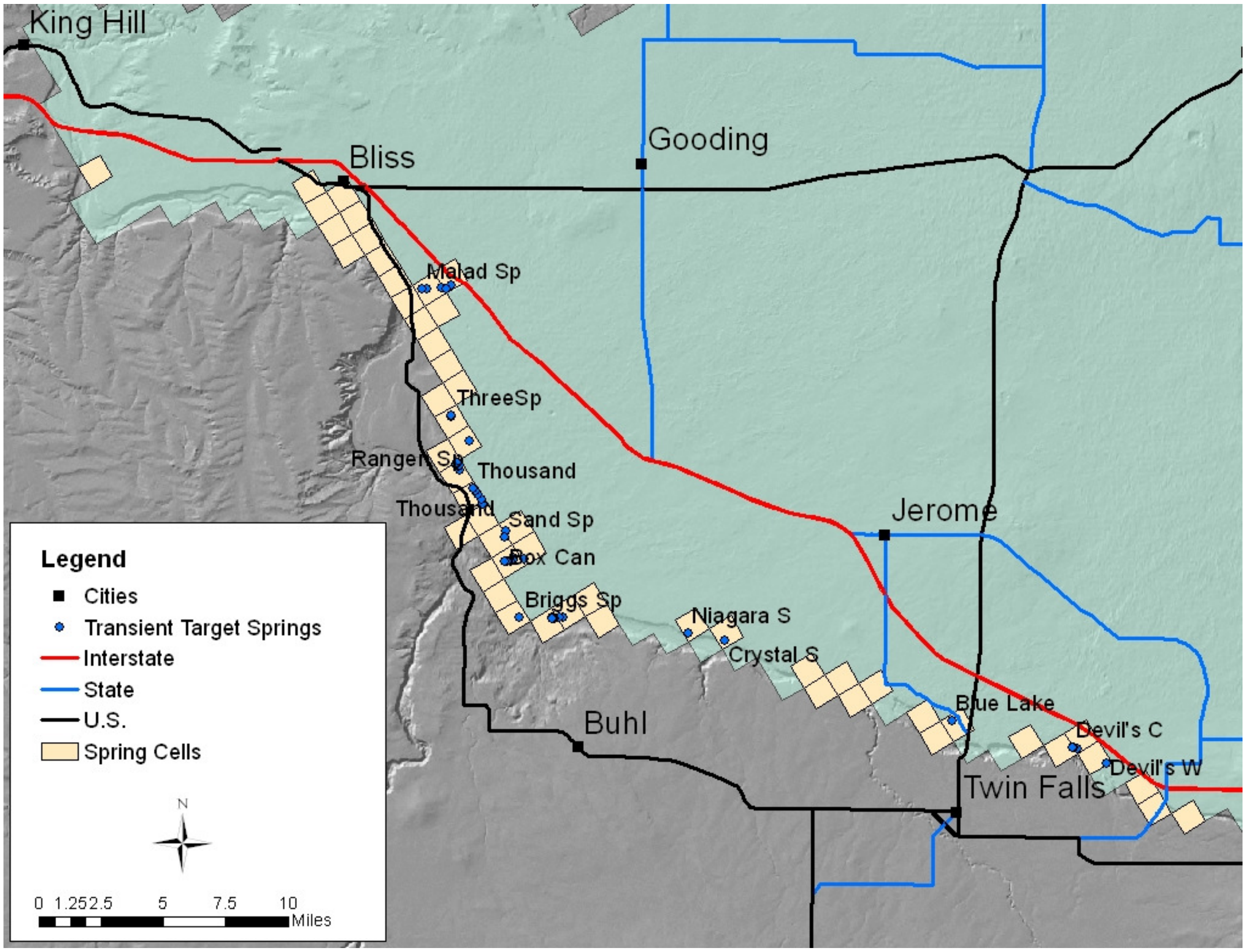


Figure 8. Location of the 14 springs used as transient calibration targets for the 2009-2010 validation.

Spring discharge RMSE and MAD from the validation period were compared with the distributions of RMSE and MAD from the calibration period. These comparisons were made using both unweighted and weighted residuals. The unweighted RMSE for the 12 calibration periods ranged from 1.9 to 5.4 cfs, and the unweighted RMSE from the validation period was 5.2 cfs. The unweighted MAD for the 12 calibration periods ranged from 2.8 to 8.2 cfs, and the unweighted MAD for the validation period is 7.2 cfs.

The weighted RMSE for the 12 calibration periods ranged from 3.1e-6 to 5.9e-6, and the weighted RMSE from the validation period was 8.4e-6. The weighted MAD for the 12 calibration periods ranged from 7.1e-6 to 1.1e-5, and the weighted MAD for the validation period is 1.2e-5. The unweighted validation RMSE and the MAD are within the ranges computed from the calibration data, however, the weighted RMSE and MAD are higher than the ranges computed from the calibration data (Figure 9).

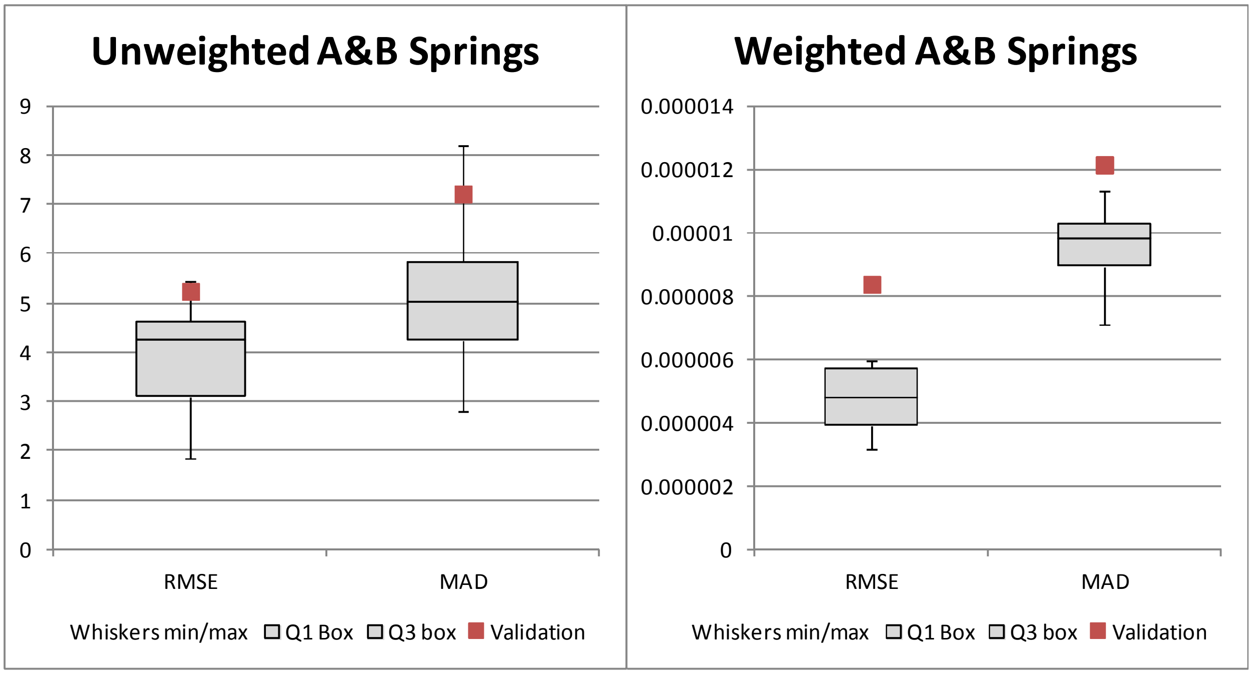


Figure 9. RMSE and MAD box and whisker plots for discharge from A&B Springs from the 2009-2010 Validation Scenario.

Much of the misfit appears to be with Blue Lakes. When Blue Lakes is removed from the validation set, the weighted statistical comparison for the A&B Springs is improved (Figure 10).

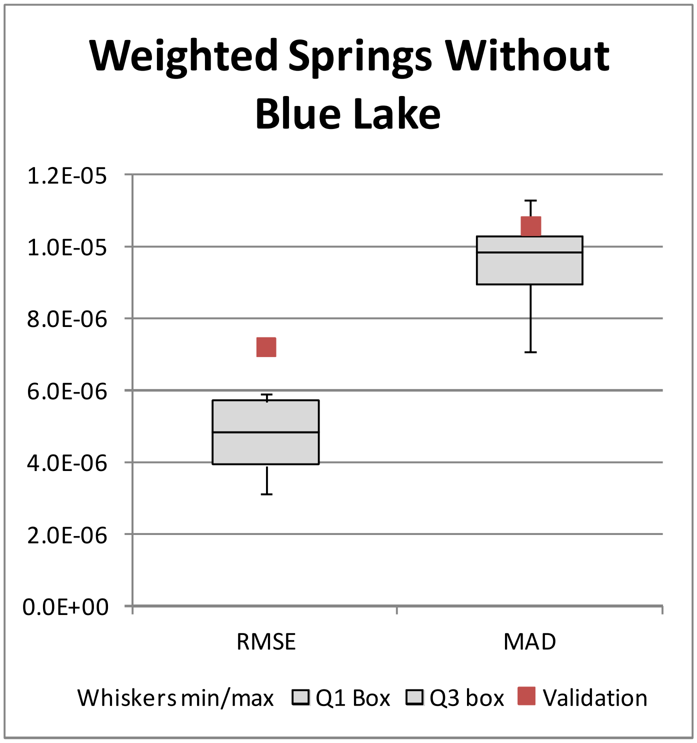
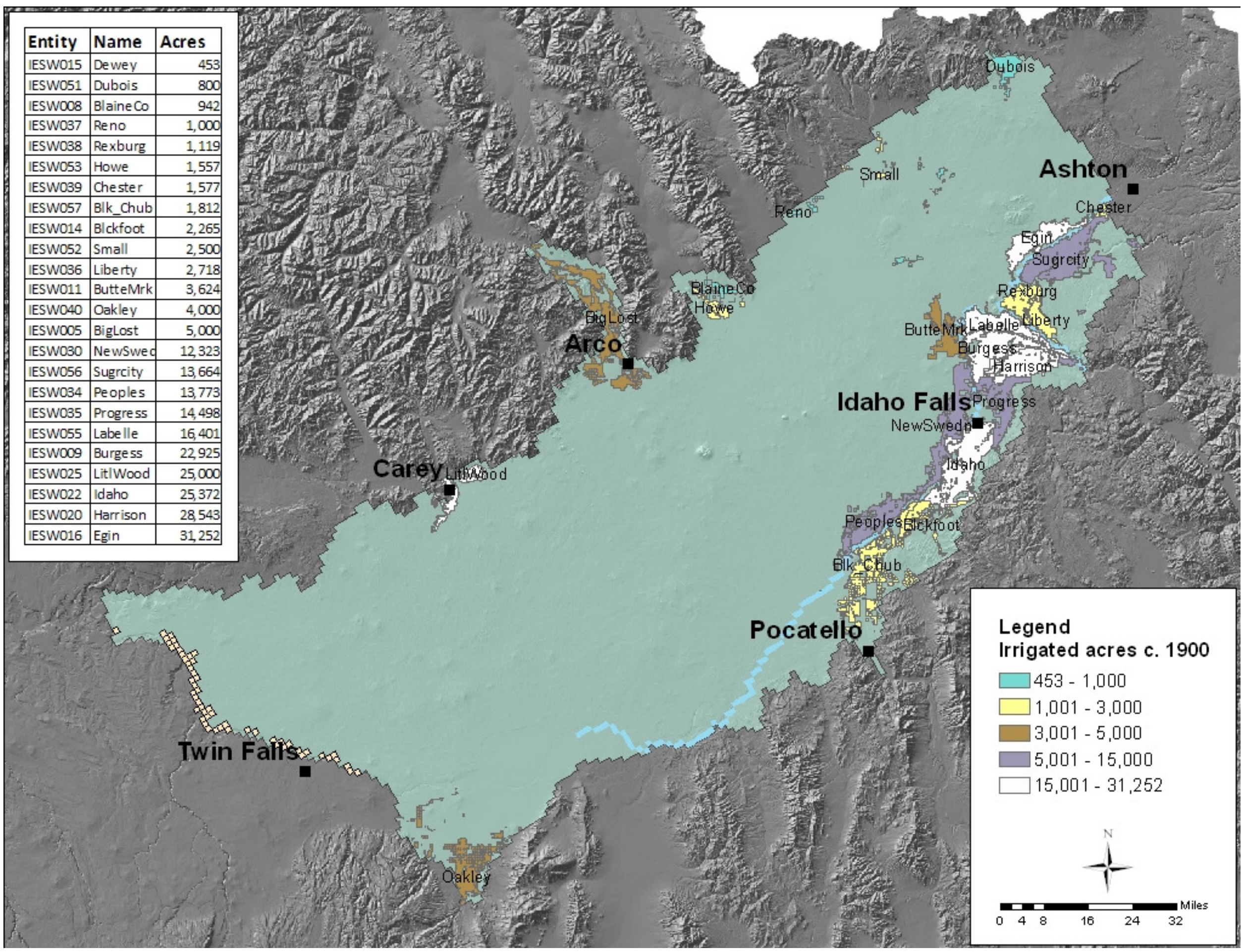


Figure 10. RMSE and MAD box and whisker plots for weighted discharge from A&B springs from the 2009-2010 Validation Scenario with Blue Lakes removed.

1900 Model Validation

The IDWR also sought to compare model output with ESPA observations collected around 1900 by the USGS (Russell, 1902) and data recorded in the 1895-1896, 1899-1900, and 1901-1902 Biennial Reports of the Idaho State Engineer (Mills, 1896; Ross, 1900; Ross, 1902). The data are not rich enough to populate a transient model, so the IDWR produced a steady state model representing average conditions around 1900. This required some modifications to the original model because fewer acres were irrigated and American Falls Reservoir had not been built. Russell (1902) recorded conditions on the ESPA such as where irrigation was taking place, and noted that spring discharges did not vary seasonally. Russell (1902) also provided depth to water measurements collected in a few wells. He indicated that most of the well measurements were collected by the Oregon Short Line railroad (OSL), but he did not indicate when the measurements were collected and wells were only located by town name.

The Biennial Reports of the State Engineer (Mills, 1896; Ross, 1900; Ross 1902) record details such as crop mix, crop yield, acres irrigated, and spring discharge. The spring discharges reported in Ross (1902) were measured or estimated by Jay D. Stannard between April 15 and April 28, 1902. Ross (1902) reported irrigated acres by canal along the upper Snake River. Irrigated acres in non-Snake basins overlying the ESPA were reported in Ross (1900). Irrigated acres were assigned to ESPAM2.1 irrigation entities based on these reports (Figure 11).



Entity	Name	Acres
IESW015	Dewey	453
IESW051	Dubois	800
IESW008	BlaineCo	942
IESW037	Reno	1,000
IESW038	Rexburg	1,119
IESW053	Howe	1,557
IESW039	Chester	1,577
IESW057	Blk_Chub	1,812
IESW014	Blckfoot	2,265
IESW052	Small	2,500
IESW036	Liberty	2,718
IESW011	ButteMrk	3,624
IESW040	Oakley	4,000
IESW005	BigLost	5,000
IESW030	NewSwed	12,323
IESW056	Sugrcity	13,664
IESW034	Peoples	13,773
IESW035	Progress	14,498
IESW055	Labelle	16,401
IESW009	Burgess	22,925
IESW025	LitlWood	25,000
IESW022	Idaho	25,372
IESW020	Harrison	28,543
IESW016	Egin	31,252

Figure 11. Irrigated acres by ESPAM2 irrigation entity based on Ross (1900) and Ross (1902).

Precipitation data for 1895-1902 were obtained from the PRISM Climate Group with Oregon State University. With these data, IDWR determined that the average precipitation for 1895-1902 was similar to the average for 1988-1992. IDWR then set the values for non-irrigated recharge, tributary underflow, perched river seepage, and the average annual ET to the average for 1988-1992.

Data obtained from the Biennial Reports of the State Engineers (Mills, 1896; Ross, 1900; Ross 1902) indicate that crop yields were lower in 1900. Lower crop yields may have resulted from moisture stress, lower plant density, lower ratio of harvestable material, lower resistance to disease, and other factors. ET likely was also lower in 1900, but there is not sufficient information to accurately quantify the relationship between the difference in crop yields and differences in ET. An estimated ET adjustment factor of 0.7 was applied for the 1900 validation.

The MODLFOW river file used during calibration contains American Falls Reservoir, which was not constructed until 1927, and requires river stage as an input. While river stage is available at various gages during the calibration period, it is not available at a sufficient number of locations during the 1900 validation period. Thus, the MODFLOW Streamflow-routing (SFR) package (Prudic and others, 2004) is used for the 1900 validation simulation. American Falls Reservoir was eliminated by extending a line of SFR cells down the middle of the reservoir (Figure 12). Required input for SFR package includes river width and flux at the upriver end, but not stage. The average unregulated flow for 1988-1992 is used as an estimate for the flux into the model at the Snake River upstream from Heise and for the Henry's Fork downstream from Ashton.

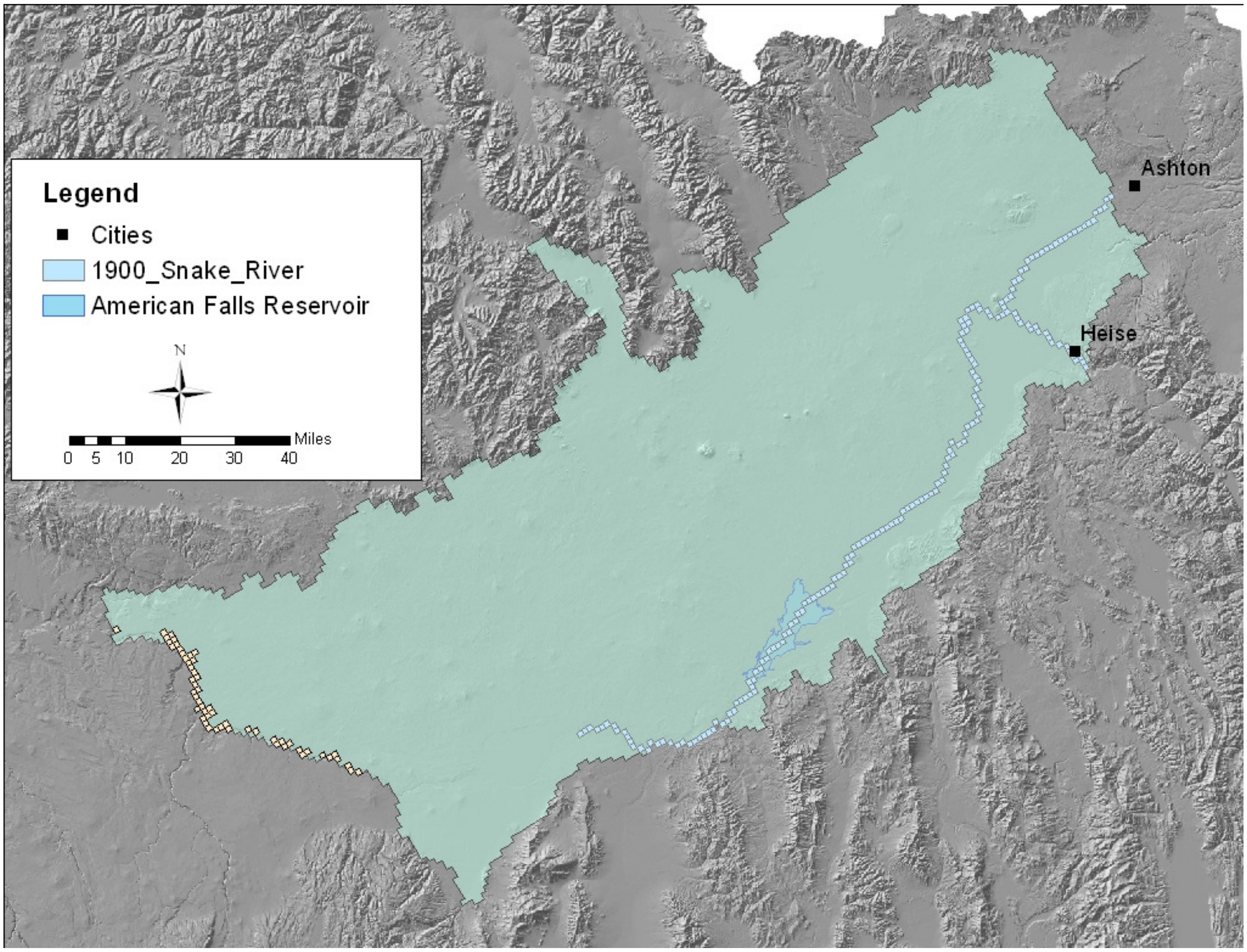


Figure 12. Location of Stream Flow Routing Package cells used to represent the Snake River for the 1900 Validation Scenario.

Aquifer head

All but one of the 1900 aquifer head observations reported by Russell (1902) are credited to the OSL railroad (Table 1, Figure 14). The data associated with the wells provided by Russell are simply town names and depth to water; no date is provided with the railroad wells to indicate when the measurement was collected. Perhaps the depth to water measurements from the OSL wells were collected by drillers upon completion of wells used to supply water for railroad stations. Wikipedia indicates that the railroad line between Pocatello, Idaho and Huntington, Oregon was completed in 1884, so the wells were probably drilled and measured before 1884. Along with the railroad wells, Russell (1902) mentions a well drilled in 1890 at Gooding, Idaho in which water rose to within 110 ft of land surface. Using approximate well locations and land surface elevations, Table 1 shows the observed aquifer head prior to or at 1900, the modeled head, and the residual difference between the observed and modeled heads. It is interesting to note that the water elevation at Bliss is lower than most of the springs in the model cell containing Bliss (Figure 13). Perhaps landslides in the Bliss area have changed the local hydrogeology. Gillerman (2001) indicates that there have been several landslides in the area, the most recent being in 1993. If landslides since 1900 have altered the local hydrogeology and the model uses modern spring elevations, the model cannot be expected to replicate the 1900 water table in the vicinity of Bliss.

Table 1. Head observations from Russell (1902).

Well	Source	Measured (ftamsl)	Modeled (ftamsl)	Residual (ft)
GOODING	Russell	3463	3285	178
OWINZA	OSL	3865	3882	-17
KIMAMA	OSL	4007	3952	55
MINIDOKA	OSL	3906	3955	-49
BLISS	OSL	2841	3063	-222

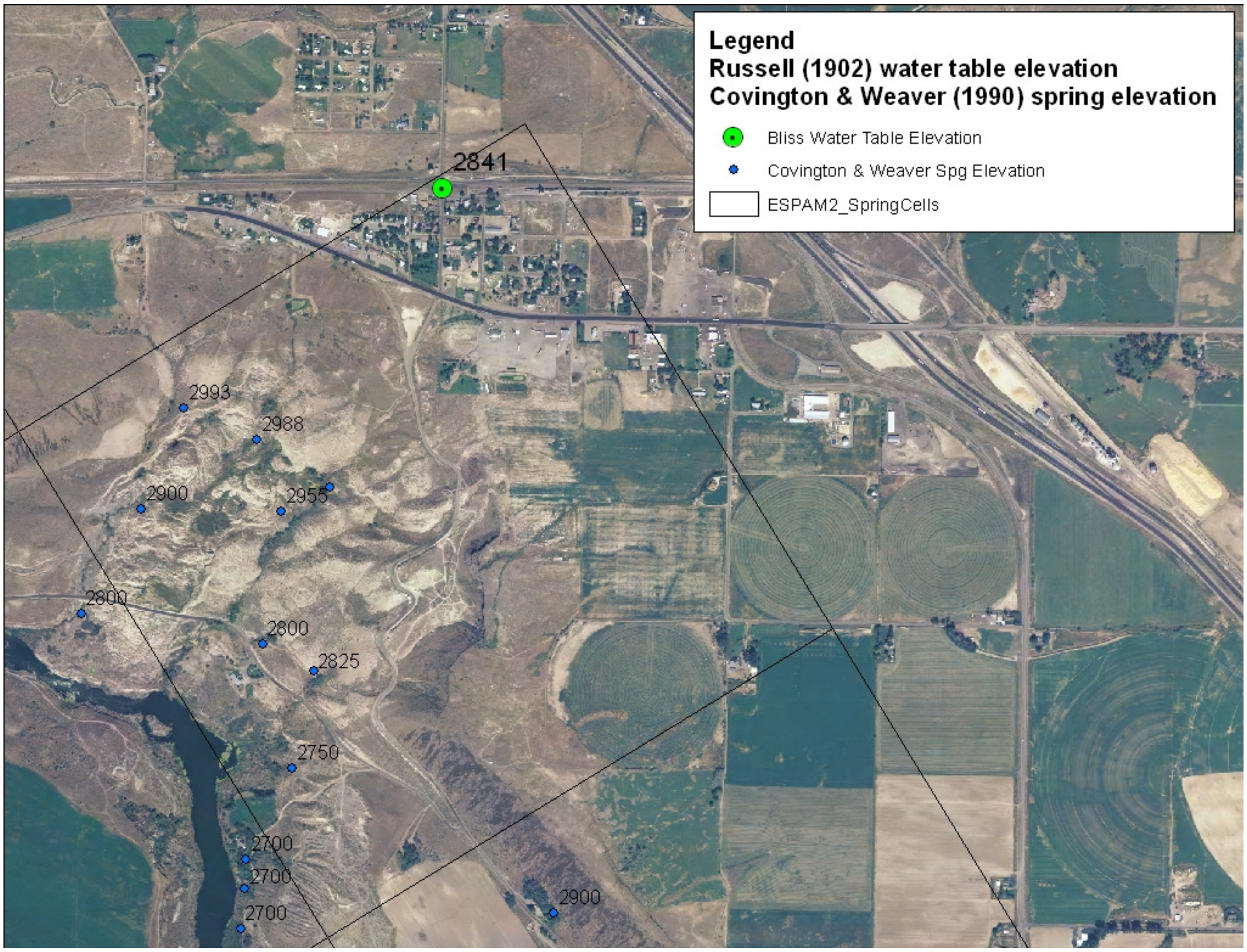


Figure 13. Water table elevation at Bliss (Russell, 1902) and spring elevations (Covington & Weaver, 1990).

Another check on the 1900 water table elevation is to compare the modeled water table with land surface elevation. Where 1900 wetlands existed, the water table should be near or above land surface; where sagebrush steppe existed, the water table should be below land surface. Wetlands existed at Market Lake near the confluence of the Henrys Fork and Snake River, Carey Lake, in the Fort Hall Bottoms north of Pocatello, and at the springs along the Snake River Canyon between King Hill, and east of Twin Falls. Figure 14 shows a comparison of the modeled wetlands and observed wetlands. Sterns and others (1939) note that Mud Lake and the shallow ground water in the area is perched and it lies a few hundred feet above the regional aquifer, thus the water level shown near Mud Lake is reasonable.

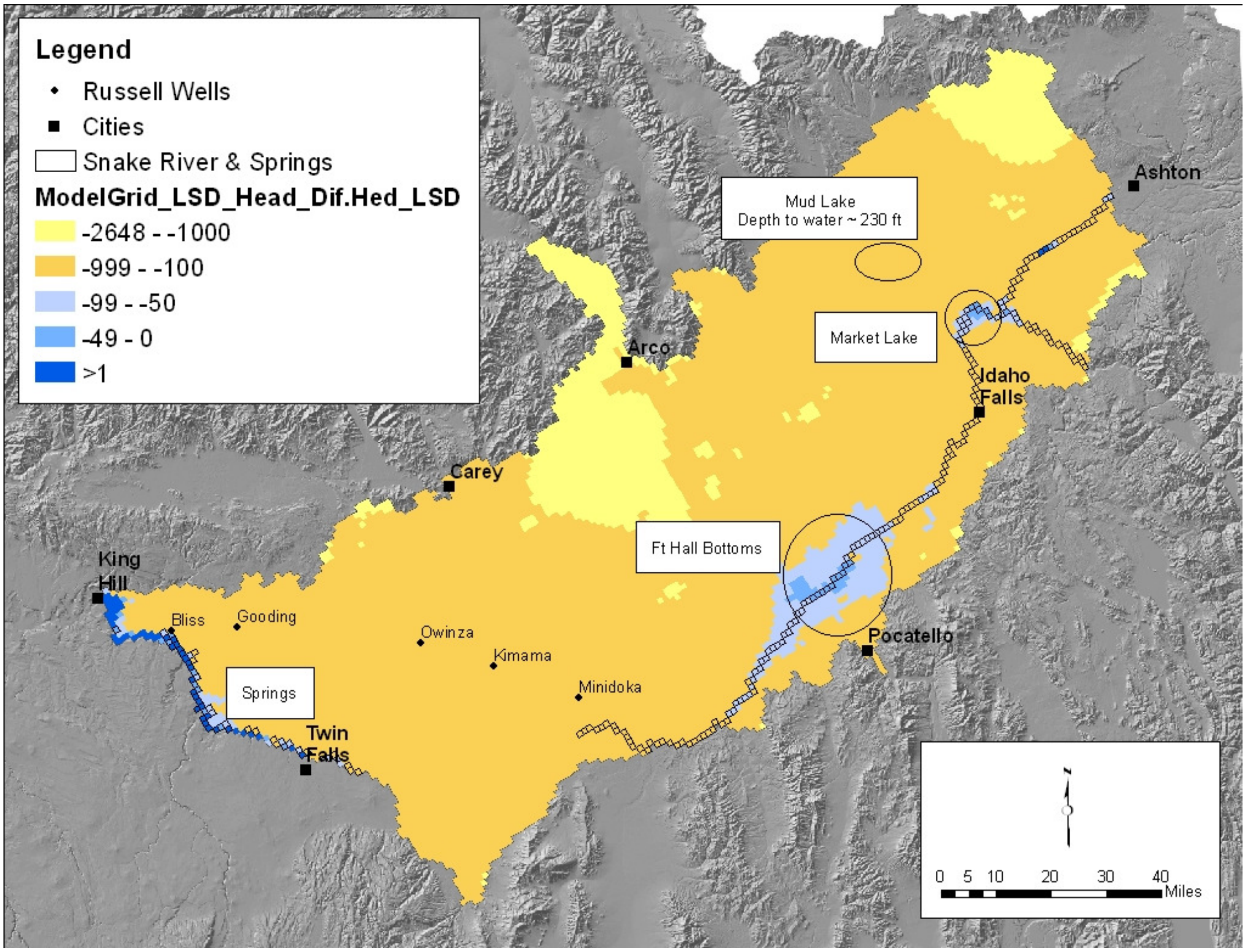


Figure 14. Modeled and observed wells, springs, and wetlands c. 1900.

Individual spring discharge

Spring discharge measurements collected by Jay D. Stannard in the Magic Valley in 1902 are recorded in the Biennial Report of the State Engineer (Ross, 1902). These measurements are compiled by spring or spring reach in Table 2.

Table 2. Spring discharge measurements/estimates from Stannard recorded in Ross (1902).

Spring(s)	Discharge (cfs)	Comments
3 to 2.25 miles above Twin Falls	36.22	Sum of 14 springs (one measured, 13 estimated), some may be on south side
Devils Washbowl	1.15	Sum of two measurements
Devils Corral	18.4	Sum of three measurements
1065027	8.83	Sum of five measurements and one estimated flow
1064026	2.43	Sum of two measurements
Blue Lakes	86.37	Measured
Trail Springs (Ellison Springs, Cells 1059022 & 1058021)	13.93	Springs below Auger Falls for 1.5 miles (27 estimated and one measured)
Crystal Springs	306.7	Sum of two measurements and one estimated flow (2.5 cfs)
Smalley's Spring (Niagara)	106.75	Measured
1051014	0.25	Estimated
1050014	0.5	Estimated
Clear Lakes	150.1	Sum of two estimated flows
Briggs Spring	77.15	Measured
Banbury Cold Springs	65.91	Measured
Blind Canyon	1.5	Estimated
Box Canyon	450	Estimated
Springs at or below river level between Box Canyon & Blue Springs	94.1	Sum of 10 estimates
Blue Springs	48.47	Measured
Sand Springs	28.51	Measured
3/4 mile below Lewis Ferry, 1045012	17.47	Measured
Thousand Springs & Magic Springs	797.44	Sum of eight measurements and four estimates
Vaders Creek (Bickel Springs)	10.29	Measured, part of National Fish Hatchery
Riley Creek	137.13	Measured, part of National Fish Hatchery
1/4 mile below Riley Creek	31.88	Measured, appears to be Tucker (cell 1042012)
Hagerman Valley springs	87.5	Sum of six estimates
Billingsley Creek	54.35	Measured, but location of section is unknown.
Between Billingsley and Malad (exclusive)	23.84	Sum of two measurements and six estimates
Malad Springs	1090	Measured
Springs below Malad	10	Estimated

Figure 15 shows the springs used as transient targets for calibration of ESPAM2.1 for which observations were also collected in the 1900 timeframe. Stannard (Ross, 1902) collected discharge measurements in a manner that allowed most of the ESPAM2.1 transient target springs to be compared with observations from 1902. Stannard estimated Clear Lake, Box Canyon Spring, and Thousand Springs and all three were ESPAM2.1 transient targets. Stannard also measured Billingsley Creek, which drains much of the Hagerman Valley, but it does not appear that either Rangen or Three-Weatherby Spring, which were used as calibration targets in ESPAM2.1, were measured or estimated individually.

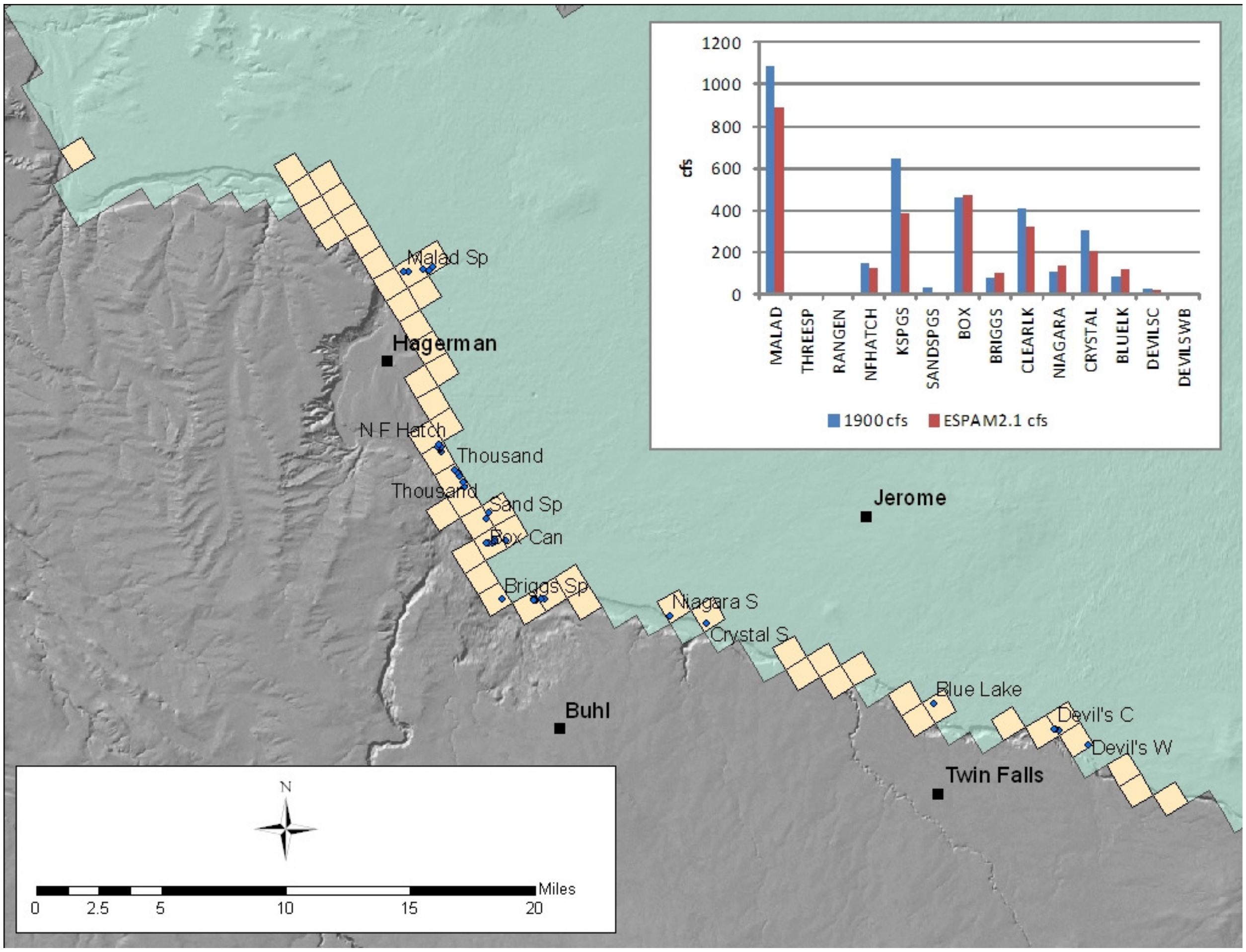


Figure 15. Location of springs used as transient calibration targets and measured or estimated by Stannard (Ross, 1902).

For comparison with ESPAM2.1, Stannard's estimate for Clear Lake was replaced by a 1913 measurement of 410 cfs (Nace, 1958) and Stannard's estimate for Box Canyon was replaced by a 1911 measurement of 465 cfs (Nace, 1958). Thousand Springs does not appear to have been measured until construction of the Thousand Springs Power Plant, so an average of the Russell (1902) and Stannard (Ross, 1902) estimates were used for comparison with the model results. Russell estimated 500 cfs, and Stannard estimated 797.4 cfs, the average of these is 648.5 cfs. Table 3 contains the resulting spring discharges recorded at or near 1900 used in the 1900 Validation Scenario. The modeled water table is less than eight ft from the drain elevation at Rangen and less than five ft below the upper drain at Sand Springs. The lower drain at Sand Springs lies below the modeled water table, but has a very low conductance (4.05 ft^2/d), hence the very low discharge shown in Table 3.

Table 3. Comparison of 1902 spring discharge observations and modeled spring discharges. 1902 values were collected by Stannard and recorded in Ross (1902) unless noted otherwise.

Spring	1900 cfs	ESPAM2.1 cfs	Residual
MALAD	1090	890	200.16
THREESP		7	
RANGEN		0	
NFHATCH	147.4	124	23.32
KSPGS[1]	648.7	389	259.36
SANDSPGS	28.5	1	27.63
BOX[2]	465	471	-5.92
BRIGGS	77.2	99	-21.56
CLEARLK[3]	410	317	93.48
NIAGARA	106.8	135	-27.98
CRYSTAL	306.7	206	100.51
BLUELK	83.2	121	-37.59
DEVILSC	21.5	16	5.62
DEVILSWB	1.15	0	1.15
no measurements			
estimates			
better targets			
[1]Average of Russell (1902) pg 27 & Stannard (1902) estimates			
[2]Nace and others (1958) pg 41 (measurement in 1911)			
[3]Nace and others (1958) pg 34 (measurement in 1913)			
Sum of 1900 spring discharges			3,883
Modeled spring discharges Kimberly-King Hill			3,157
Modeled base flow Kimberly-King Hill			1,460
		Mean residual	51.51
		standard dev	94.56

Spring reach gains

Assuming that Stannard (Ross, 1902) measured or estimated all of the springs between the Kimberly and the King Hill gages, then the sum of the reported values could be compared to the sum of the modeled spring discharges in that same reach. Table 4 shows the measured or estimated spring discharges with estimates for Clear Lakes and Box Canyon Spring replaced with the measured values found in Nace

(1958). The total for the spring discharges around 1900 is 3,883 cfs and the total modeled discharge is 3,157 cfs.

Table 4. Total discharge of springs from Ross (1902) unless noted otherwise.

Spring(s)	Discharge (cfs)	Comments
3 to 2.25 miles above Twin Falls	36.22	Sum of 14 springs (one measured, 13 estimated), some may be on south side
Devils Washbowl	1.15	Sum of two measurements
Devils Corral	18.4	Sum of three measurements
1065027	8.83	Sum of five measurements and one estimated flow
1064026	2.43	Sum of two measurements
Blue Lakes	86.37	Measured
Trail Springs (Ellison Springs, Cells 1059022 & 1058021)	13.93	Springs below Auger Falls for 1.5 miles (27 estimated and one measured)
Crystal Springs	306.7	Sum of two measurements and one estimated flow (2.5 cfs)
Smalley's Spring (Niagara)	106.75	Measured
1051014	0.25	Estimated
1050014	0.5	Estimated
Clear Lakes	410	Nace (1958) pg 34
Briggs Spring	77.15	Measured
Banbury Cold Springs	65.91	Measured
Blind Canyon	1.5	Estimated
Box Canyon	465	Nace (1958) pg 41
Springs at or below river level between Box Canyon & Blue Springs	94.1	Sum of 10 estimates
Blue Springs	48.47	Measured
Sand Springs	28.51	Measured
3/4 mile below Lewis Ferry, 1045012	17.47	Measured
Thousand Springs & Magic Springs	648.7	Average of Russell (1902) & Stannard (1902) estimates
Vaders Creek (Bickel Springs)	10.29	Measured, part of National Fish Hatchery
Riley Creek	137.13	Measured, part of National Fish Hatchery
1/4 mile below Riley Creek	31.88	Measured, appears to be Tucker (cell 1042012)
Hagerman Valley springs	87.5	Sum of six estimates
Billingsley Creek	54.35	Measured, but location of section is unknown.
Between Billingsley and Malad (exclusive)	23.84	Sum of two measurements and six estimates
Malad Springs	1090	Measured
Springs below Malad	10	Estimated
Total	3883.33	

Summary and Conclusions

The data used to extend the model for the 2009-2010 Validation Scenario are much richer than the data used to develop the 1900 Validation Scenario. The 1900 Validation Scenario required approximating tributary underflow, non-irrigated recharge, perched river seepage, and ET using the average of 1988-1992 based on the similarity of the average precipitation for the two time periods. No adjustments to the input data for either validation scenario were made to improve model fit with validation data.

Because the 2009-2010 validation data are comparable in quality to the calibration data, statistics can be used to facilitate scenario evaluation (Figures 2-10). The unweighted RMSE and MAD for the 2009-2010 validation period fell within the bounds generated from the calibration period for every catagory. The weighted RMSE and MAD fell within the bounds generated during the calibration period for wells, river gains, and spring reach discharge RMSE. The weighted MAD for spring reach discharges fell slightly below the range generated during calibration, indicating a better fit during validation, and the weighted

RMSE and MAD for A&B spring discharges fell above the range generated during the calibration period. When the Blue Lakes discharge is removed, only the weighted RMSE for spring discharge falls outside the bounds generated during the calibration period.

Because field data for the 1900 validation scenario are limited and of questionable quality, the evaluation is more qualitative. Table 1 shows the comparison between the head observations and Figure 15 shows the comparison with spring discharges. Recall that landslides may have altered the springs near Bliss, possibly changing the local hydrology and water levels. Also recall that the discharge from Thousand Springs (KSPGS in Figure 15) was not measured until after construction of the Thousand Springs Power Plant.

The model appears to fit the field observations adequately given the nature of the input data. Neither the 2009-2010 nor the 1900 Validation Scenarios generated significant concerns or limitations regarding the use of the ESPAM2.1.

References

Cosgrove, D.M., B.A. Contour, G.S. Johnson, 2006. Enhanced Eastern Snake Plain Aquifer Model Final Report. Idaho Water Resources Technical Report 06-002.

Covington, H.R. and J.N. Weaver, 1990. Geologic map and profile of the north wall of the Snake River Canyon. U.S. Geological Survey Miscellaneous Investigation Series, Maps I-1947A through I-1947E.

Dakins, M., 2012. The Statistical Evaluation of the ESPAM2 Model. White Paper Presented to the ESHMC June 22, 2012.

Doherty, J., 2004. PEST Model-Independent Parameter Estimation Users Manual, Watermark Numerical Computing, 336 Cliveden Avenue, Corinda 4075, Brisbane, Australia.

Garabedian, S.P., 1992. Hydrology and digital simulation of the regional aquifer system, eastern Snake River Plain, Idaho. USGS Professional Paper 1408. F.

Gillerman, V.S., 2001. Geologic Report on the 1993 Bliss Landslide, Gooding County, Idaho. Staff Report 01-1.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald, 2000. Modflow-2000, the U.S. Geological Survey modular ground-water model-user guide to modularization concepts and the ground-water flow process. USGS Open-File Report 00-92.

Hill, M.C. and C.R. Tiedeman, 2007. Effective Calibration of Environmental Models with Analysis of Data, Sensitivities, Prediction and Uncertainty.

Mills, F.J., 1896. Biennial Report of the State Engineer to the Governor of Idaho, December 1896. Arch Cunningham Printer, Boise, Idaho.

Nace, R.L., I.S. McQueen, A. Vant Hul, 1958. Records of Springs in the Snake River Valley Jerome and Gooding Counties, Idaho, 1899-1947. U.S. Geological Survey, Water-Supply Paper 1463.

PRISM Climate Group http://www.prism.oregonstate.edu/

Prudic, D.E., L.F. Konikow, and E.R. Banta, 2004. A new Streamflow-Routing (SFR1) Package to Simulate Stream-Aquifer Interaction with Modflow-2000. U.S. Geological Survey, Open-File Report 2004-1042.

Russell, I.C., 1902. Geology and Water Resources of the Snake River Plains of Idaho. U.S. Geological Survey, Bulletin No. 199.

Ross, D.W., 1900. Biennial Report of the State Engineer to the Governor of Idaho, 1899-1900. Capital Printing Office, Boise, Idaho.

Ross, D.W., 1902. Biennial Report of the State Engineer to the Governor of Idaho, 1901-1902. Statesman Print, Boise, Idaho.

Sterns, H.T., L.L. Bryan and L. Crandall, 1939. Geology and Water Resources of the Mud Lake Region, Idaho, Including the Island Park Area. U.S. Geological Survey, Water-Supply Paper 818.

Welhan, J. and T. Funderberg, 1997. Stochastic modeling of hydraulic conductivity in the Snake River Plain aquifer: 1. Hydrogeologic constraints and conceptual approach: Proceedings of the 32nd Symposium on Engineering Geology and Geotechnical engineering, Boise, ID, March 26-28. 1997, pp. 75-91.

Whitehead, R.L., 1986. Geohydrologic framework of the Snake River Plain, Idaho and Eastern Oregon. Atlas HA-681.

Wikipedia http://en.wikipedia.org/wiki/Oregon_Short_Line_Railroad