Groundwater-Flow Model for the Wood River Valley Aquifer System, Version 1.1
Simulated Curtailment of Groundwater Use

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Introduction

The recently recalibrated Groundwater-Flow Model for the Wood River Valley Aquifer System, Version 1.1 (Wylie et al., 2019) was used to simulate curtailment of groundwater irrigation in the Wood River Valley. The recalibrated model incorporates additional head and flux data collected between 2011 and 2014, and extends the simulation period to 20 years (January 1995 through December 2014). The purpose of the curtailment simulation is to provide general information regarding the impacts of the consumptive use of groundwater in the Wood River Valley on surface water flow in the Big Wood River and Silver Creek. Similar simulations run using the previous version of the groundwater-flow model (Version 1.0, Fisher, et al., 2016) were presented in Sukow (2016).

The groundwater-flow model was used to simulate curtailment of non-exempt groundwater irrigation in the Wood River Valley. Agricultural irrigation, irrigation within municipal service areas and subdivisions with centralized water systems, and residential irrigation greater than ½ acre, were included in the curtailment simulation. Exempt domestic irrigation, where a domestic well is used to irrigate less than ½ acre, was excluded from the curtailment simulation. Irrigation covered by groundwater rights mitigated with non-use of surface water rights was also excluded from the curtailment simulation. The exempt and mitigated groundwater use excluded from the simulation comprises approximately 10% of the total consumptive use of groundwater within the model area during dry years and approximately 15% of the total consumptive use of groundwater during wet years.

Because a portion of the Big Wood River is perched and the extent of the perched reach varies with time, there is significant non-linearity in the groundwater-flow model. Because of the non-linearity, the use of superposition is not recommended with this model. Therefore, the curtailment simulations were run using 1995-2014 conditions as a baseline. The baseline conditions are equivalent to conditions simulated in the calibrated model (Wylie et al., 2019). Three curtailment simulations were performed. The first simulates curtailment of non-exempt groundwater irrigation during every year of the 1995-2014 period. The second simulates curtailment of non-exempt groundwater irrigation only during 2007, for comparison with results from the previous version of the model presented in Sukow (2016). The third simulates curtailment of non-exempt groundwater irrigation only during 2012, the year with the highest estimated consumptive use of groundwater.

The curtailment simulations were performed by adjusting the baseline MODFLOW well file to reduce non-exempt groundwater pumping and associated incidental recharge. The spatial distribution of adjustments to groundwater pumping and incidental recharge is illustrated in Figure 1 through Figure 4, using August 2007 stresses as an example. The modified well file for each scenario was generated using the "Wood River Valley Junior Groundwater Tool," with a priority date of January 1, 1890. A copy of the tool is included with the model simulation files[1]. Version 1.1 of the groundwater flow model was used to perform the baseline and curtailment simulations. Hydrologic responses to the simulated curtailment were calculated by differencing the results of the curtailment simulations from the results of the baseline simulation.

[1] https://idwr.idaho.gov/water-data/projects/wood-river-valley/model.html

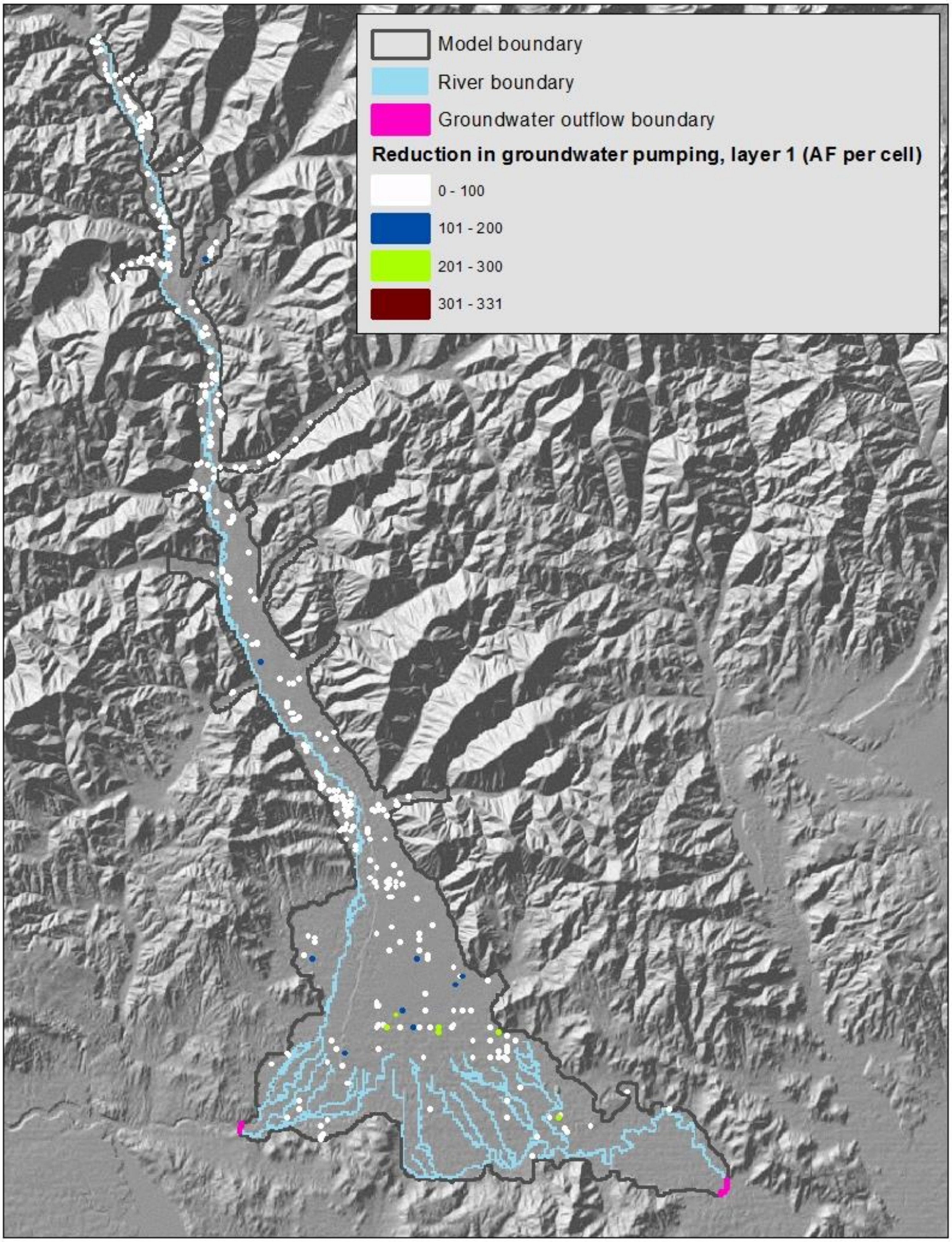

Figure 1. Spatial distribution of simulated reduction in groundwater pumping within model layer 1 (monthly stress from August 2007 shown as an example)

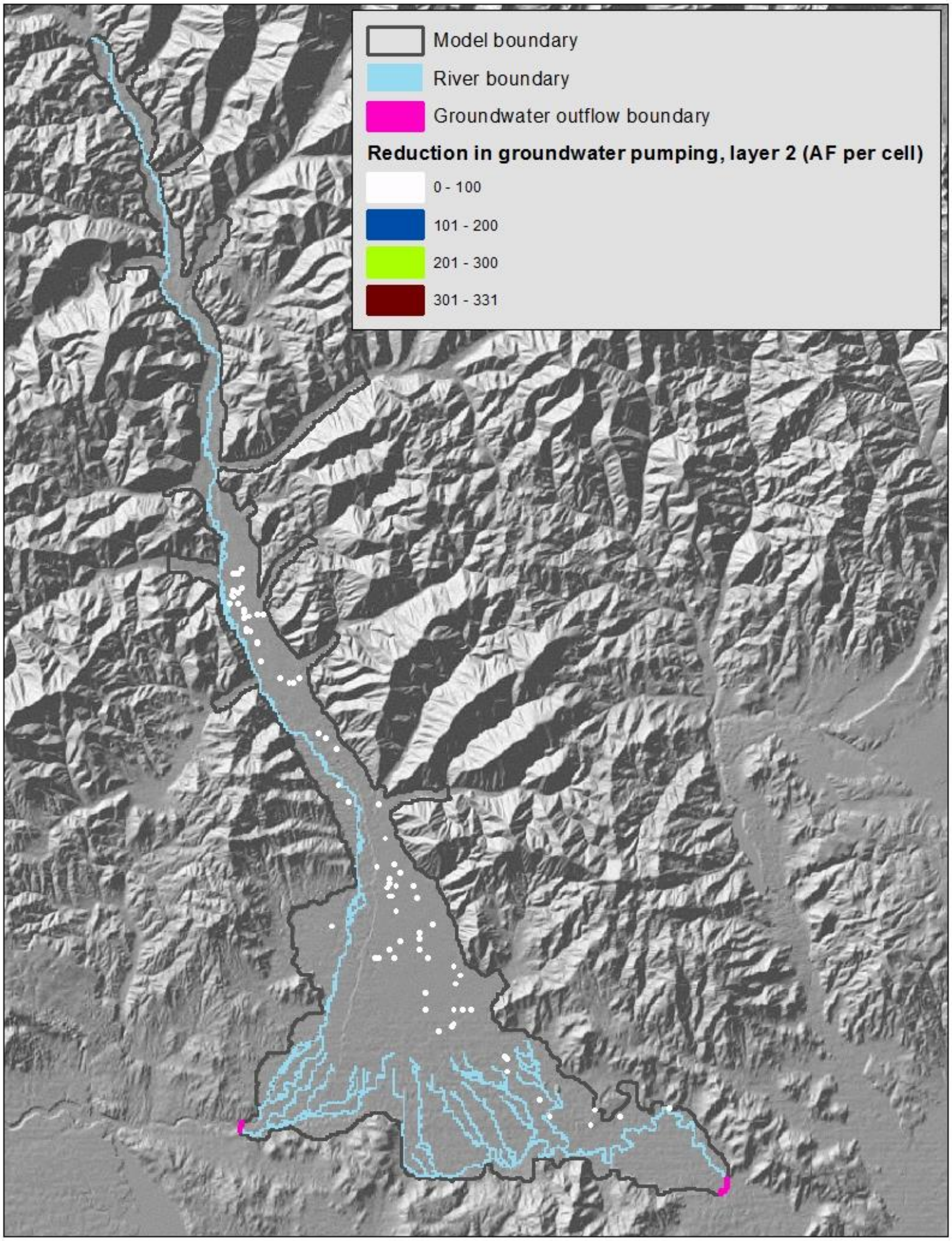

Figure 2. Spatial distribution of simulated reduction in groundwater pumping within model layer 2 (monthly stress from August 2007 shown as an example)

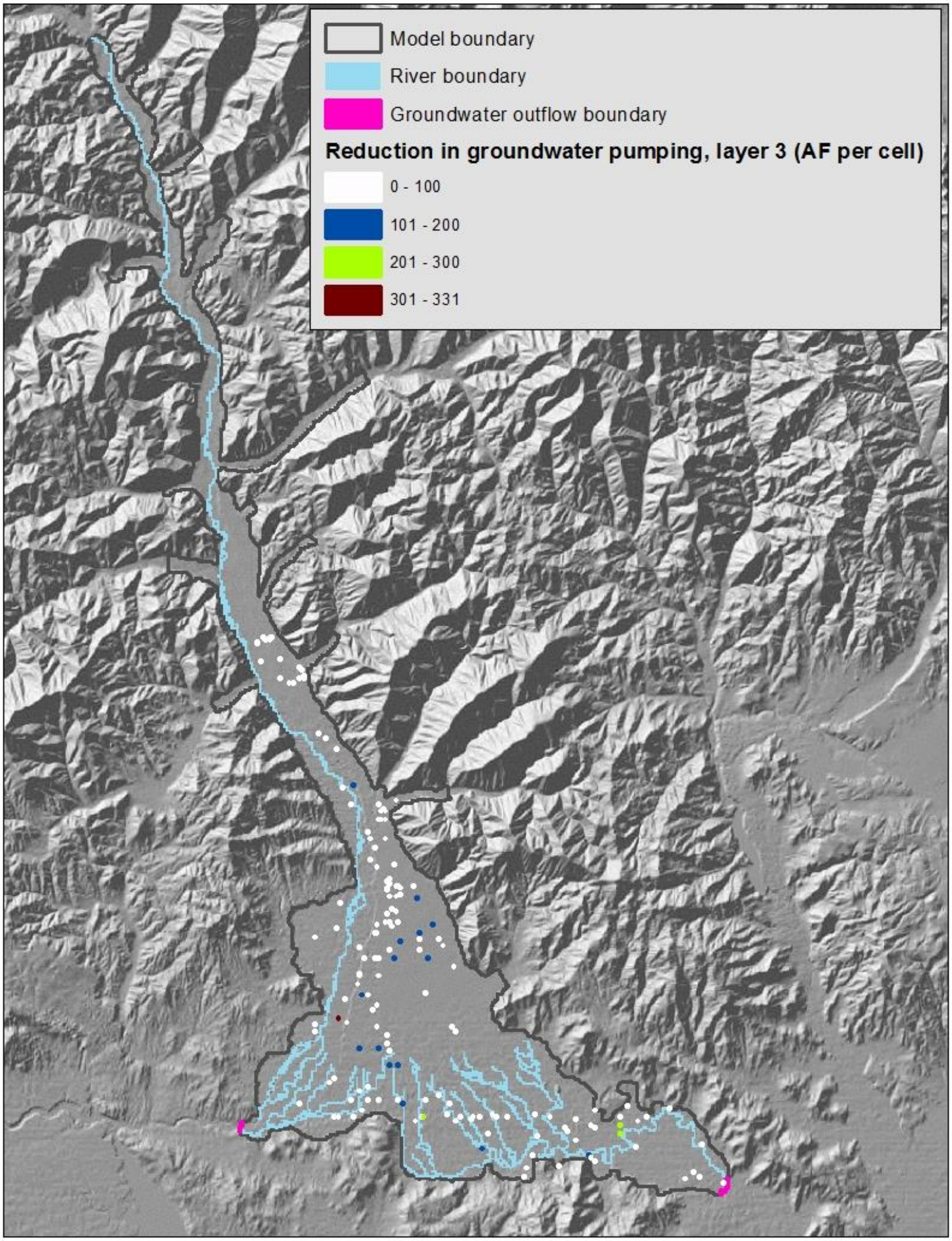

Figure 3. Spatial distribution of simulated reduction in groundwater pumping within model layer 3 (monthly stress from August 2007 shown as an example)

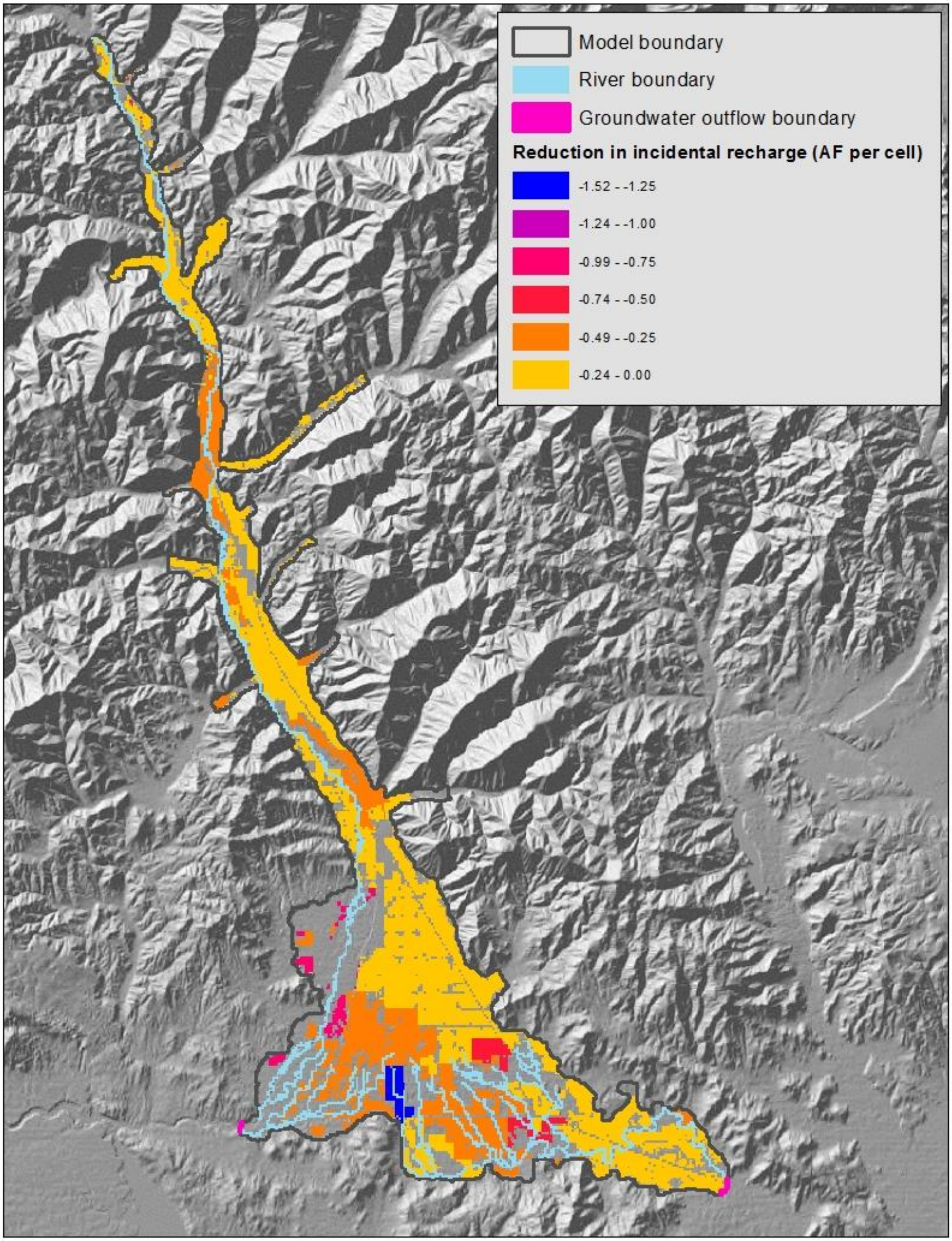

Figure 4. Spatial distribution of simulated reduction in incidental recharge within model layer 1 (monthly stress from August 2007 shown as an example)

Simulated curtailment of groundwater irrigation during 1995 through 2014

The curtailment of groundwater irrigation was simulated by reducing groundwater pumping and incidental recharge. The net change in simulated aquifer stress is equivalent to the consumptive use associated with the curtailed groundwater rights. During 1995-2014, the net annual change in aquifer stress ranged from 12,700 acre-feet (AF) in 1998 to 48,200 AF in 2012, averaging 30,200 AF. The total volume of curtailed consumptive use was 604,000 AF over the 20 year period. The net change in aquifer stress varies monthly, as shown in Figure 5. The peak monthly rate was 250 cubic feet per second (cfs) during August 2014. The average rate for 1995-2014 was 41 cfs.

Hydrologic responses to curtailment include changes in aquifer storage, streamflow, and groundwater underflow from the Wood River Valley to the Eastern Snake Plain aquifer (ESPA). Aggregate hydrologic responses to curtailment are shown in Figure 5 and Figure 6. The cumulative increase in aquifer storage at the end of the simulation was 23,400 AF, approximately 4% of the curtailed consumptive use. The peak increase in streamflow was 91 cfs in August 2012 and August 2013. The average increase in streamflow for 1995-2014 was 37 cfs, approximately 90% of the curtailed consumptive use. The peak increase in groundwater underflow to the ESPA was 6 cfs in October 2014. The average increase in groundwater underflow to the ESPA for 1995-2014 was 2.6 cfs, approximately 6% of the curtailed consumptive use.

Hydrologic responses by river reach are shown in Figure 7. Aquifer discharge to the Big Wood River above Hailey is predicted to increase by up to 16 cfs, with an average predicted increase of 5 cfs. Net stream losses to the aquifer from the Big Wood River between Hailey and Heart Rock Ranch are predicted to decrease by as much as 17 cfs, with an average predicted decrease of 6 cfs. Aquifer discharge to Willow Creek and the Big Wood River below Heart Rock Ranch is predicted to increase by up to 14 cfs, with an average predicted increase of 5 cfs. Aquifer discharge to Silver Creek is predicted to increase by up to 57 cfs, with an average predicted increase of 21 cfs. Approximately 72% of the increase in river reach gains is predicted to occur during the irrigation season (April through October) and approximately 28% of the increase is predicted to occur during the non-irrigation season (November through March).

Hydrologic responses at outlet boundaries are shown in Figure 8. Groundwater underflow at the model boundary near Picabo is predicted to increase by up to 6 cfs, with an average predicted increase of 2.6 cfs. The predicted change in groundwater underflow at the model boundary near Stanton Crossing is negligible.

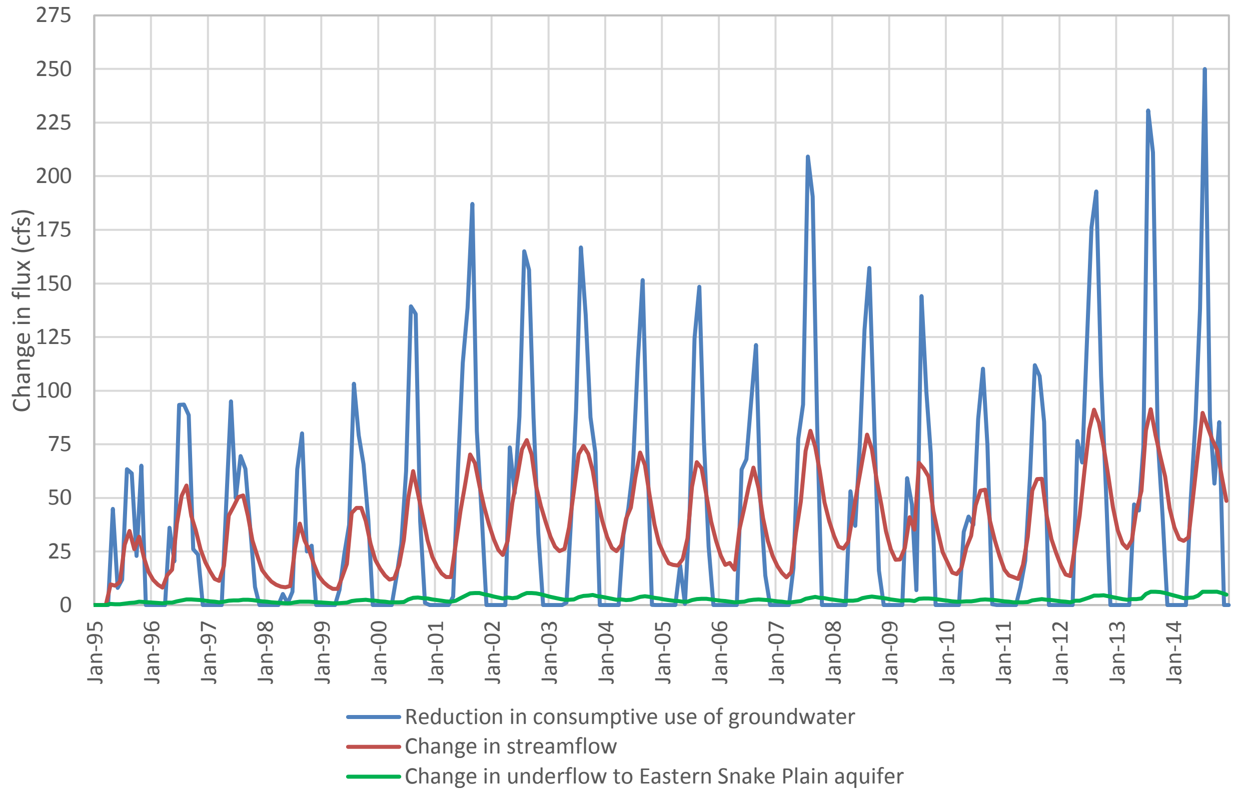

Figure 5. Hydrologic response to simulated curtailment of non-exempt groundwater irrigation (1995-2014)

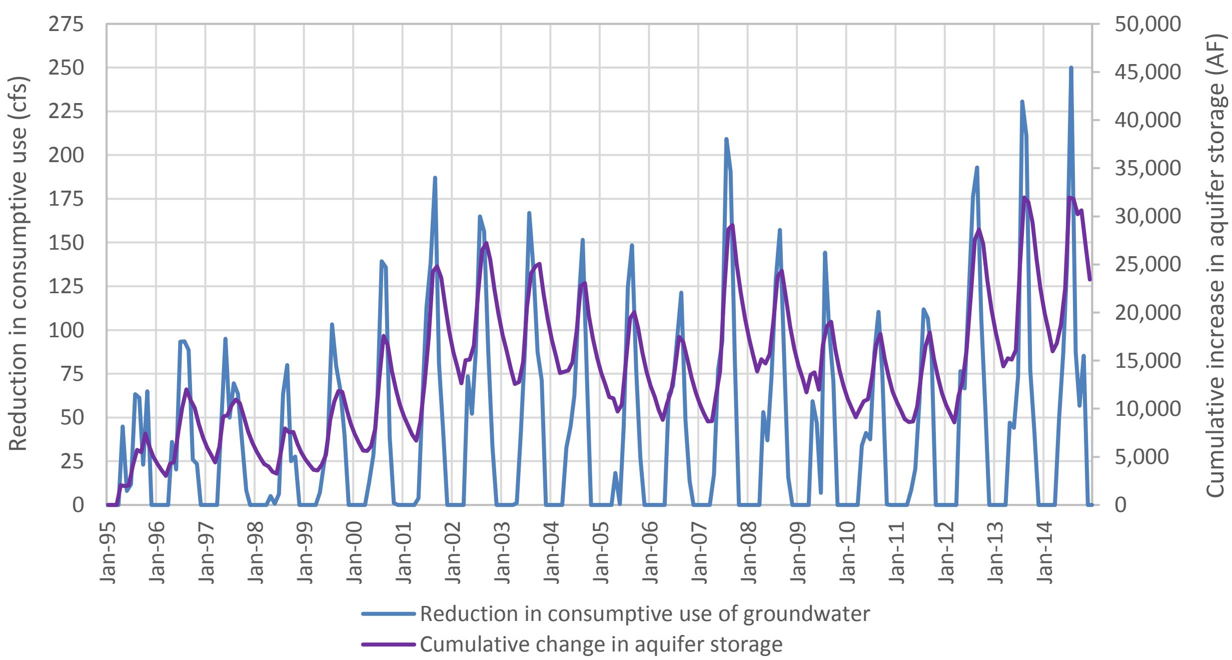

Figure 6. Change in aquifer storage resulting from simulated curtailment of non-exempt groundwater irrigation (1995-2014)

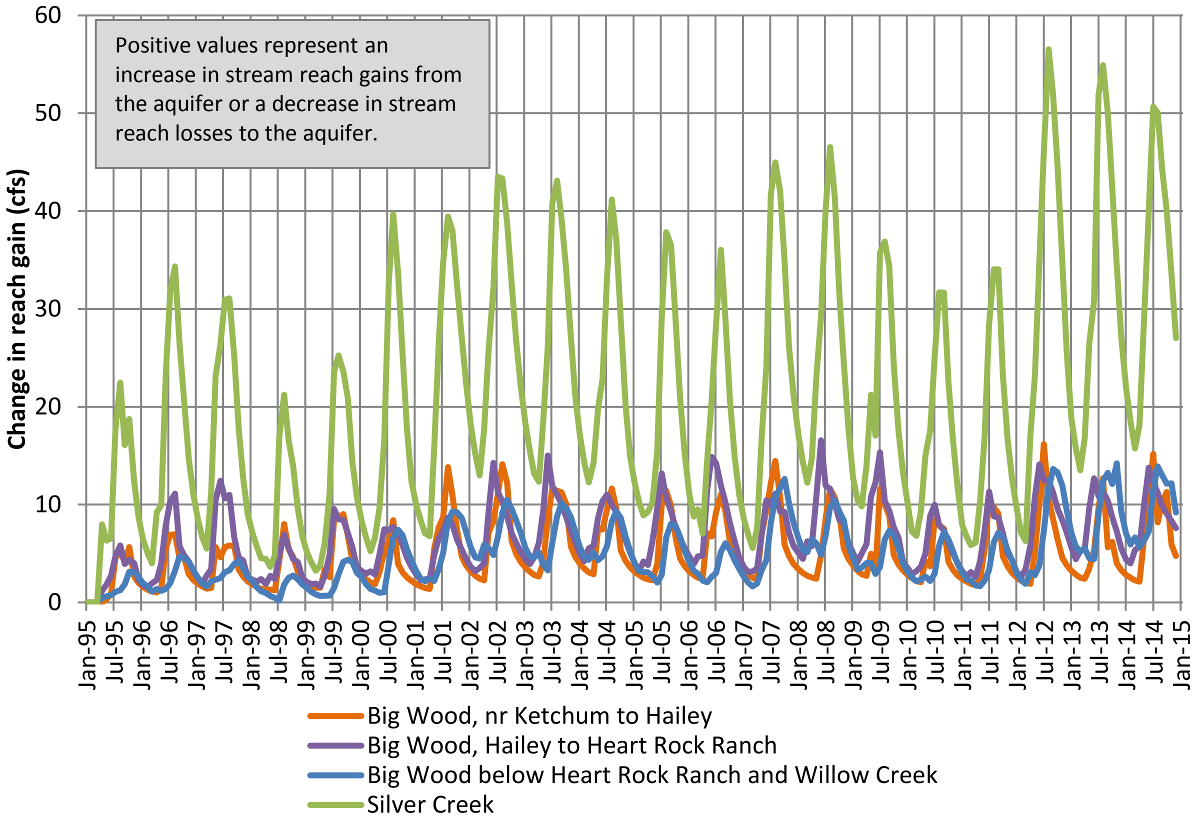

Figure 7. Predicted increase in streamflow in response to curtailment of non-exempt groundwater irrigation (1995-2014)

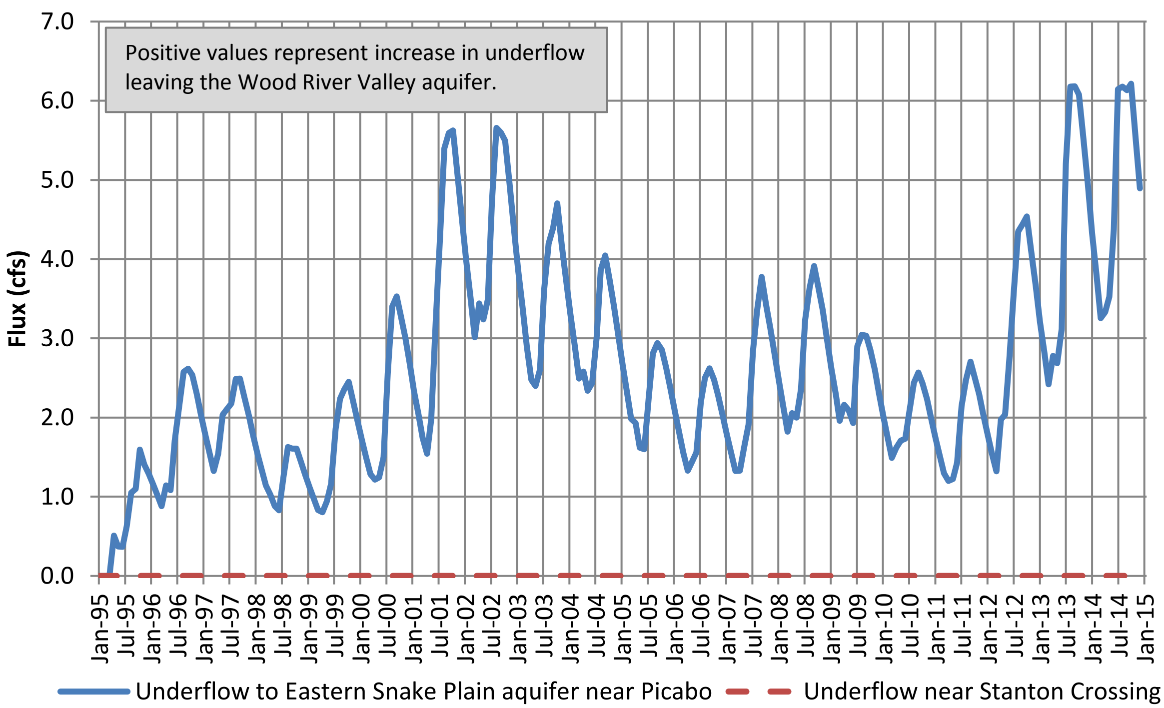

Figure 8. Predicted increase in groundwater outflow in response to curtailment of non-exempt groundwater irrigation (1995-2014)

Simulated curtailment of groundwater irrigation during 2007

Curtailment of non-exempt groundwater during only the year of 2007 was simulated to illustrate the predicted impact of a single year of curtailment during a dry year. During 2007, the net change in aquifer stress was 41,000 AF. The net change in aquifer stress varies monthly, as shown in Figure 9. The peak monthly rate was 209 cfs during July 2007. The average rate for the 2007 irrigation season was 96 cfs.

Hydrologic responses to curtailment include changes in aquifer storage, streamflow, and groundwater underflow from the Wood River Valley to the ESPA. Aggregate hydrologic responses to curtailment are shown in Figure 9 and Figure 10. The peak increase in streamflow was 76 cfs in August 2007. The peak increase in groundwater underflow to the ESPA was 3 cfs in September 2007. During the 2007 irrigation season (April through October), the average increase in streamflow was 48 cfs (approximately 50% of the curtailed consumptive use) and the change in underflow to the ESPA was negligible. During the 2008 irrigation season, the average increase in streamflow was 13 cfs (approximately 14% of the curtailed consumptive use) and the average increase in underflow to the ESPA was approximately 1 cfs. During the 2009 irrigation season, the average increase in streamflow was 2 cfs (approximately 2% of the curtailed consumptive use) and the average increase in underflow to the ESPA was approximately 1 cfs. The cumulative increase in aquifer storage at the end of the 2007, 2008, and 2009 irrigation seasons was 48%, 8%, and 3% of the curtailed consumptive use, respectively.

Hydrologic responses by river reach are shown in Figure 11. Aquifer discharge to the Big Wood River above Hailey is predicted to increase by 13 cfs in August 2007. Net stream losses to the aquifer from the Big Wood River between Hailey and Heart Rock Ranch are predicted to decrease by 10 cfs in August 2007. Aquifer discharge to Willow Creek and the Big Wood River below Heart Rock Ranch is predicted to increase by 10 cfs in August 2007. Aquifer discharge to Silver Creek is predicted to increase by 43 cfs in August 2007.

Hydrologic responses at outlet boundaries are shown in Figure 12. The predicted increase in groundwater underflow near Picabo peaks at 3 cfs in September 2007. The predicted change in groundwater underflow at the model boundary near Stanton Crossing is negligible.

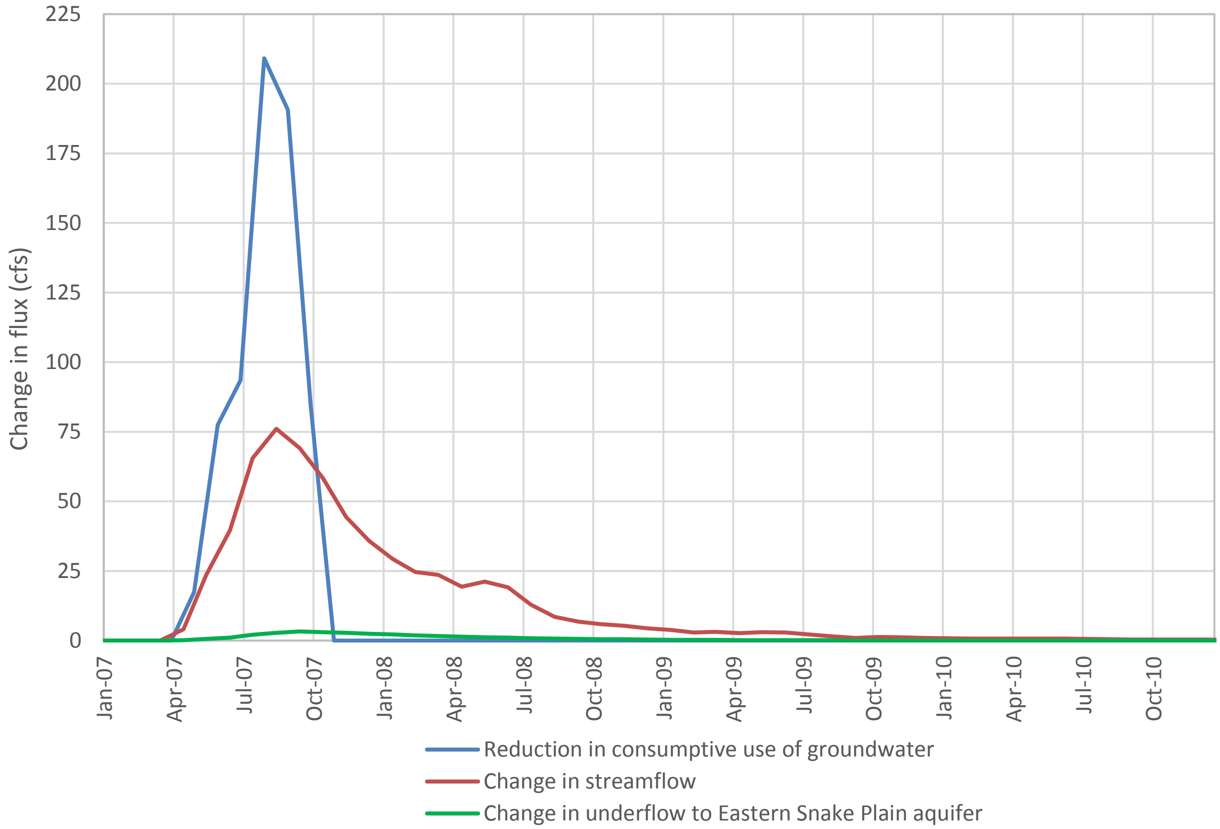

Figure 9. Hydrologic responses to simulated curtailment of non-exempt groundwater irrigation (2007)

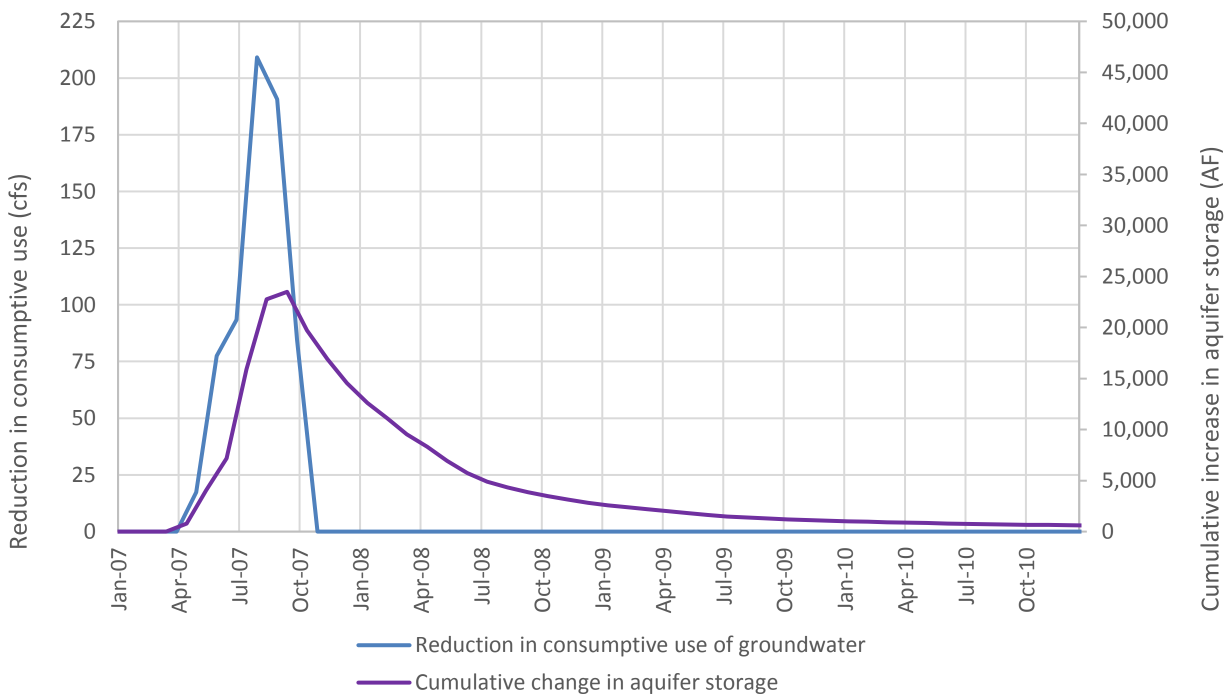

Figure 10. Change in aquifer storage resulting from simulated curtailment of non-exempt groundwater irrigation (2007)

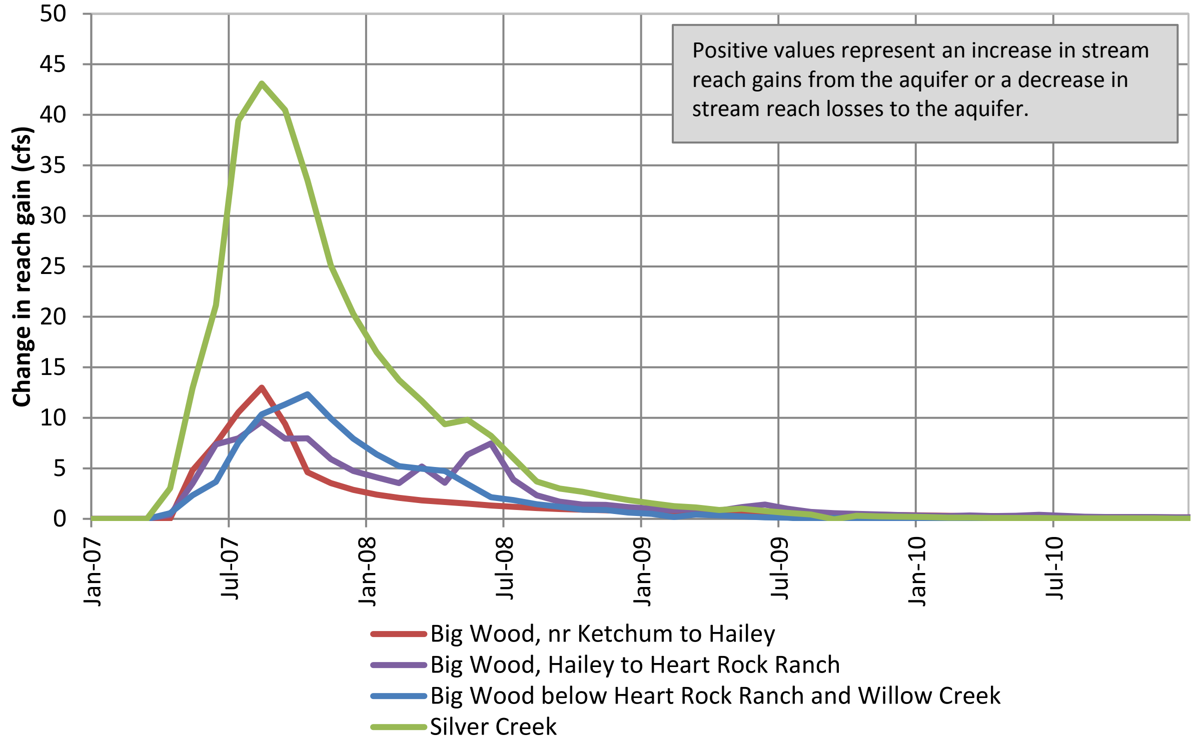

Figure 11. Predicted increase in streamflow in response to curtailment of non-exempt groundwater irrigation (2007)

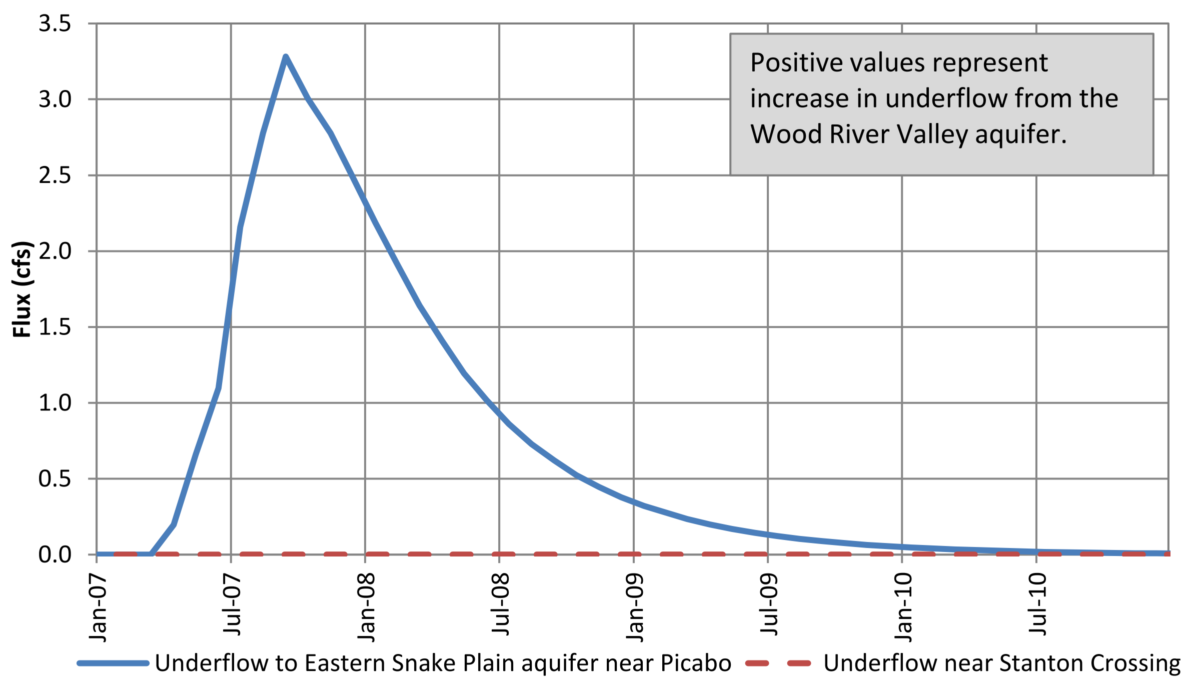

Figure 12. Predicted increase in groundwater outflow in response to curtailment of non-exempt groundwater irrigation (2007)

Simulated curtailment of groundwater irrigation during 2012

In Version 1.0 of the model, the 2007 irrigation season had the highest groundwater consumptive use within the model calibration period. With the extension of the model calibration period through 2014 for Version 1.1, the 2012 irrigation season had the highest groundwater consumptive use within the model calibration period. Curtailment of non-exempt groundwater during only the year of 2012 was simulated to illustrate the predicted impact of a single year of curtailment during the year with the highest groundwater use. During 2012, the net change in aquifer stress was 48,100 AF. The net change in aquifer stress varies monthly, as shown in Figure 13. The peak monthly rate was 192 cfs during August 2012. The average rate for the 2012 irrigation season was 113 cfs.

Hydrologic responses to curtailment include changes in aquifer storage, streamflow, and groundwater underflow from the Wood River Valley to the ESPA. Aggregate hydrologic responses to curtailment are shown in Figure 13 and Figure 14. The peak increase in streamflow was 86 cfs in August 2012. The peak increase in groundwater underflow to the ESPA was 4 cfs in October 2012. During the 2012 irrigation season (April through October), the average increase in streamflow was 59 cfs (approximately 52% of the curtailed consumptive use) and the average change in underflow to the ESPA was 3 cfs (approximately 2% of the curtailed consumptive use. During the 2013 irrigation season, the average increase in streamflow was 13 cfs (approximately 12% of the curtailed consumptive use) and the average increase in underflow to the ESPA was approximately 1 cfs. During the 2014 irrigation season, the average increase in streamflow was 2 cfs (approximately 2% of the curtailed consumptive use) and the increase in underflow to the ESPA was negligible. The cumulative increase in aquifer storage at the end of the 2012, 2013, and 2014 irrigation seasons was 45%, 8%, and 3% of the curtailed consumptive use, respectively.

Hydrologic responses by river reach are shown in Figure 15. Aquifer discharge to the Big Wood River above Hailey is predicted to increase by 10 cfs in August 2012. Net stream losses to the aquifer from the Big Wood River between Hailey and Heart Rock Ranch are predicted to decrease by 11 cfs in August 2012. Aquifer discharge to Willow Creek and the Big Wood River below Heart Rock Ranch is predicted to increase by 11 cfs in August 2012. Aquifer discharge to Silver Creek is predicted to increase by 55 cfs in August 2012.

Hydrologic responses at outlet boundaries are shown in Figure 16. The predicted increase in groundwater underflow near Picabo peaks at 3 cfs in September 2007. The predicted change in groundwater underflow at the model boundary near Stanton Crossing is negligible.

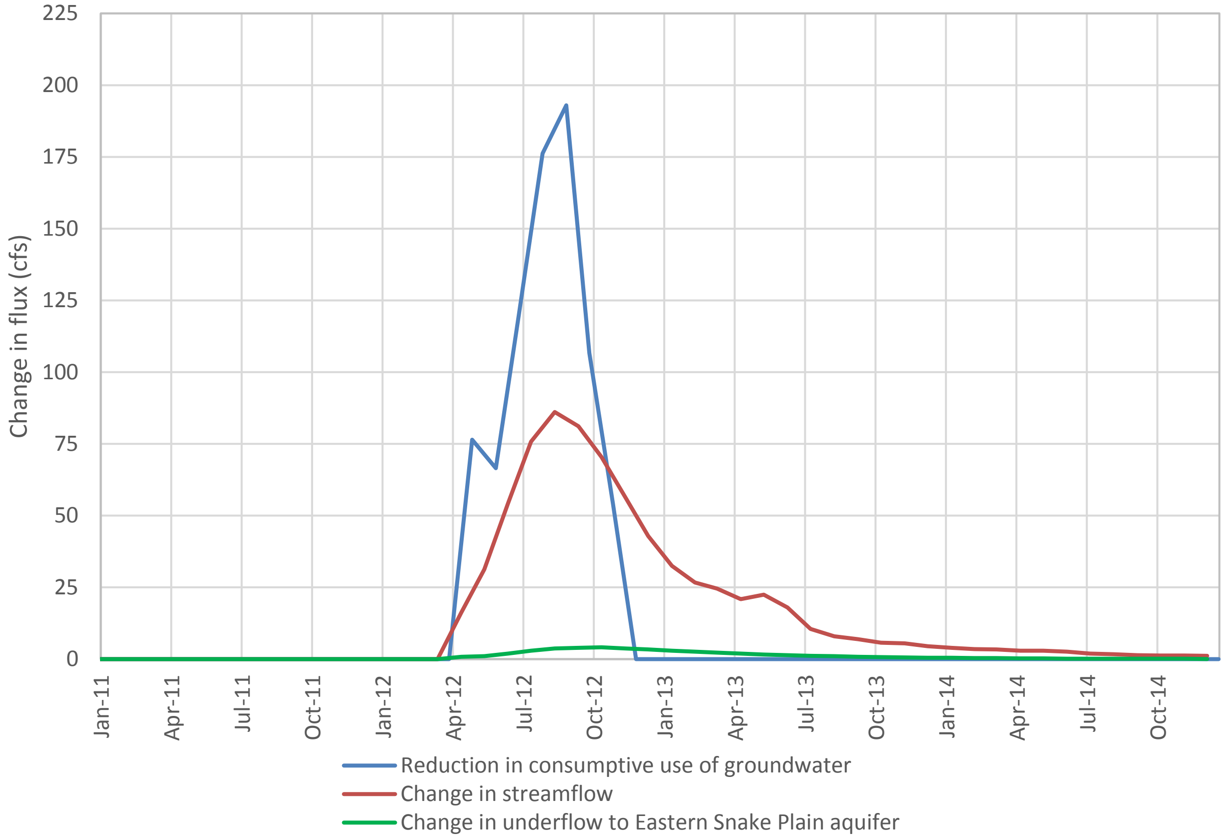

Figure 13. Hydrologic responses to simulated curtailment of non-exempt groundwater irrigation (2012)

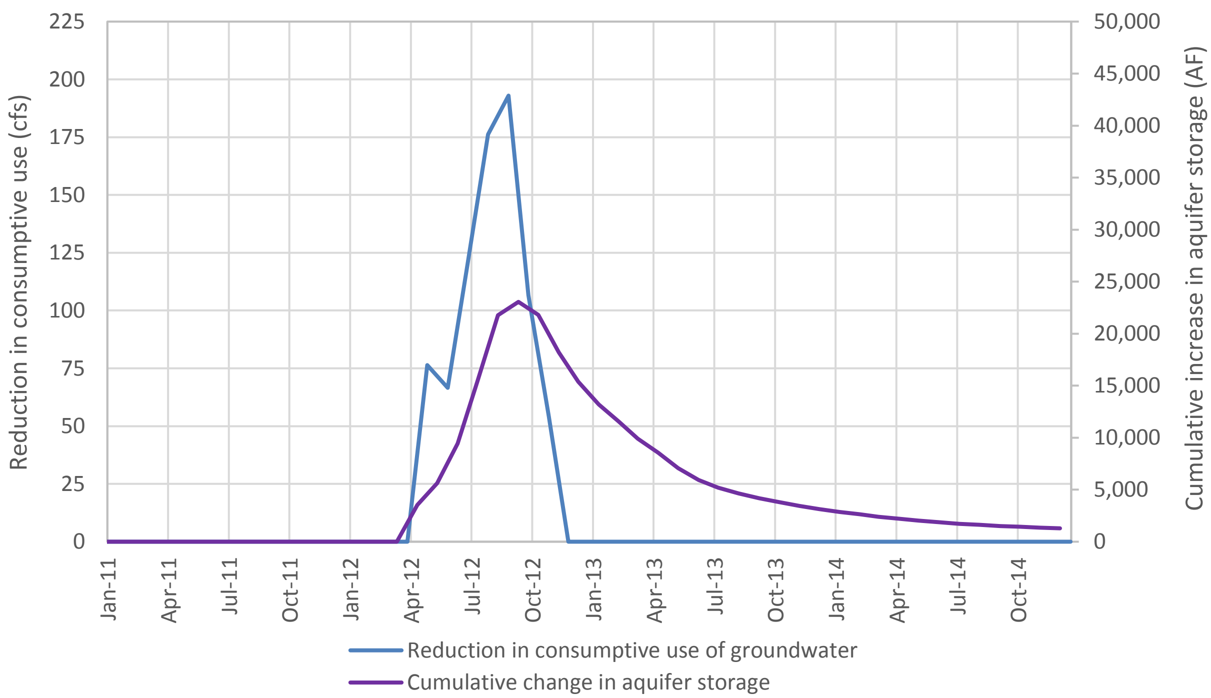

Figure 14. Change in aquifer storage resulting from simulated curtailment of non-exempt groundwater irrigation (2012)

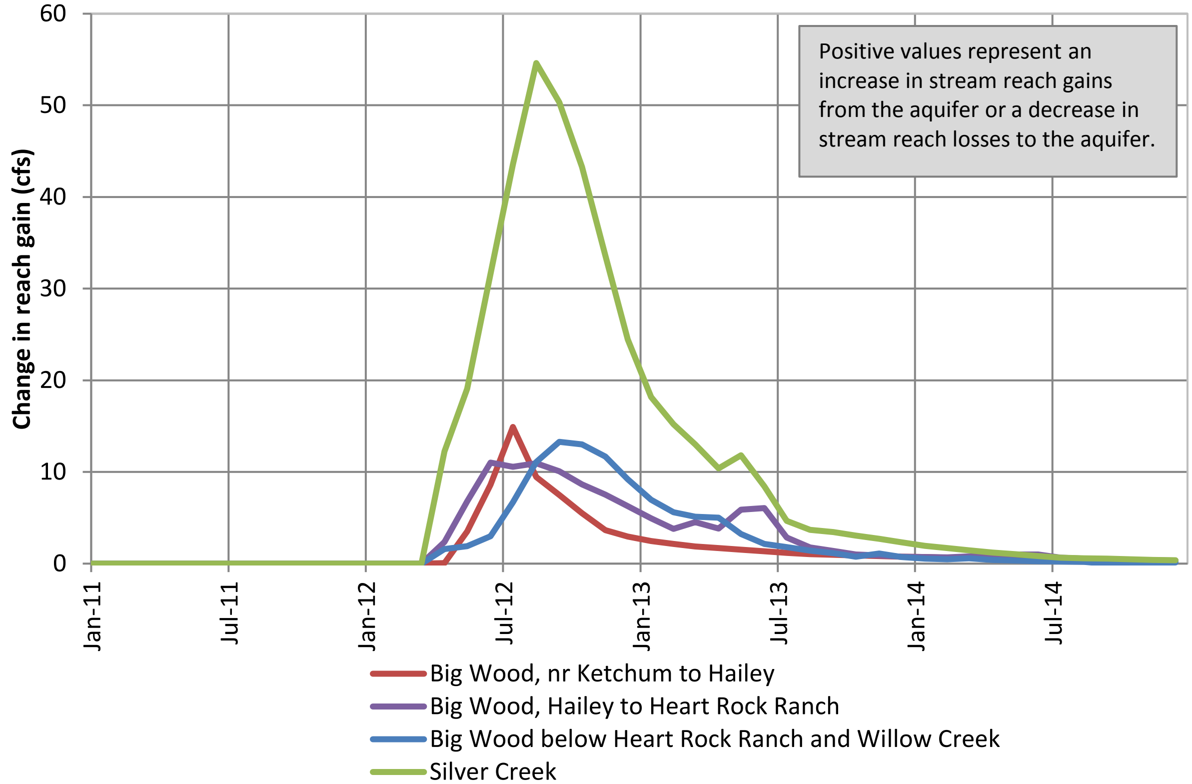

Figure 15. Predicted increase in streamflow in response to curtailment of non-exempt groundwater irrigation (2012)

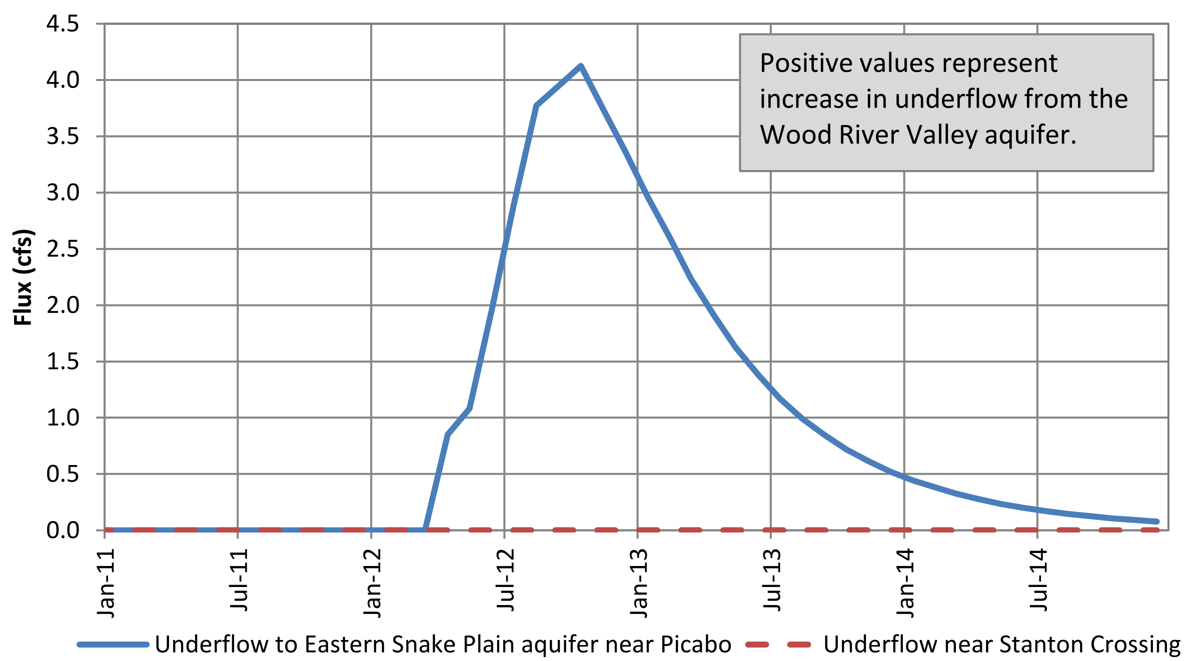

Figure 16. Predicted increase in groundwater outflow in response to curtailment of non-exempt groundwater irrigation (2012)

Comparison with Version 1.0

Recalibration of the groundwater-flow model resulted in different calibrated values for aquifer properties (transmissivity, storage coefficient), riverbed conductance, drain conductance at groundwater outflow boundaries, irrigation efficiency, and tributary underflow. Extension of the calibration period to include the years 2011 through 2014 facilitated the inclusion of transient head data and streamflow data that were collected to address data gaps identified during the development of the first version of the model.

Extension of the calibration period also facilitated inclusion of additional groundwater diversion data collected by Water District 37 in 2013 and 2014, which helped constrain estimates of irrigation efficiency for a few irrigation service areas. Irrigation efficiency is still poorly constrained in many areas. In service areas irrigated by both surface water and unmeasured groundwater diversions, the calibrated values of irrigation efficiency are used in conjunction with surface water diversion and evapotranspiration data to calculate the consumptive use of groundwater.

Other improvements in the recalibrated model include improved representation of the Big Wood River in the vicinity of the Dry Bed, addition of a calibration target for the gaining reach of the Big Wood River downstream of the Dry Bed, and improved representation of the extent of the confined aquifer (Wylie et al., 2019).

In the recalibrated model, significant increases in the calibrated value of irrigation efficiency for several large irrigation service areas resulted in a reduction in the calculated consumptive use of groundwater for agricultural irrigation during the 1995 through 2010 irrigation seasons. This resulted in lower applied stress in the curtailment scenario for these years. A lack of historic groundwater diversion data contributes to uncertainty in estimating the consumptive use of groundwater. Because totalizing flowmeters have been required on most irrigation wells in the Wood River Valley since 2014, and are read annually by Water District 37, additional data will hopefully be available to refine calculation of the consumptive use of groundwater for future years.

Extension of the simulation period added three years when consumptive use of groundwater was higher than any of the years in the 1995 to 2010 simulation period for Version 1.0 of the model. Relatively high evapotranspiration, low precipitation, and low surface water diversions resulted in relatively high consumptive use of groundwater in 2012 through 2014.

Streamflow responses to the simulated curtailments are generally similar to those predicted with Version 1.0 for the years 1995 through 2010. Streamflow responses are slightly faster, peaking about one month earlier. This results in more impact predicted during the irrigation season and less impact predicted during the non-irrigation season. Because of higher consumptive use in 2012 through 2014, the peak impacts on streamflow predicted with Version 1.1 occur in these years, and are higher than peak impacts predicted during the 1995 through 2010 period simulated with Version 1.0.

Predicted impacts on groundwater outflow to the ESPA near Picabo with Version 1.1 are approximately double those predicted with Version 1.0, but are still relatively small. The response at the outflow boundary is faster with Version 1.1, peaking approximately 6 months earlier than with Version 1.0.

Predicted impacts on aquifer storage are lower with Version 1.1. This is consistent with faster responses in streamflow and groundwater outflow, which result in shorter retention times for aquifer storage. Because of lower retention times, the prediction of the cumulative change in aquifer storage resulting from continual curtailment during 1995 through 2010 with Version 1.1 is less than half the cumulative change predicted with Version 1.0.

Limitations of model simulations

The simulations of groundwater curtailment are intended to improve the understanding of groundwater/surface-water interaction within the Wood River Valley on a regional scale. Because historic measurement of groundwater diversions was limited prior to 2014, the majority of groundwater diversions were estimated during development of the groundwater-flow model as described in Fisher et al. (2016) and Sukow (2014). Uncertainty regarding the efficiency of surface water delivery and irrigation efficiency contributes to uncertainty in estimates of unmeasured groundwater diversions. Surface water diversions and surface water priority dates were considered in the calculation of estimated groundwater diversions on mixed source lands, but the spatial resolution of surface water deliveries was generally limited to canal service areas. While the volume of estimated groundwater diversions and the simulated volume of curtailed consumptive use within irrigation entities (Fisher et al., 2016; Sukow, 2014) are reasonable estimates on a regional scale, volumes simulated at a specific well site may not be an accurate estimate of historic use at the local scale. Thus, these simulations are intended to be used to evaluate hydrologic responses to regional groundwater use. The spatial representation of groundwater pumping in these simulations should not be used to evaluate the impacts of a single well.

Prediction of the timing of hydrologic responses to curtailment of groundwater use is constrained to the extent time-series data were available to calibrate the transient groundwater-flow model. Monthly surface water diversion data and evapotranspiration data provided a reasonable estimate of the timing of incidental recharge during the 1995-2014 model calibration period. Monthly reach gains for most river reaches were available for a significant portion of the calibration period, and provide information on the timing of streamflow responses to aquifer recharge and groundwater pumping. Limited transient water level measurement data were available during the model calibration period for Version 1.0 (1995-2010). Tributary streamflow data were also lacking during this period. The Idaho Department of Water Resources began collecting additional data during development of Version 1.0, including additional transient water level data and additional reach gain data for the near Ketchum to Hailey reach of the Big Wood River and Trail Creek. Version 1.1 of the model was calibrated with an extended calibration period (adding the years 2011-2014) to incorporate these data and further constrain predictions of the timing of hydrologic responses to changes in aquifer stress. Ongoing collection of these data are recommended to provide transient data for a wider range of climatic conditions and facilitate further refinement of the groundwater-flow model in the future.

The groundwater-flow model does not predict the fate of increases in streamflow resulting from curtailment. Because increased streamflow in some reaches may be rediverted by surface water right holders prior to leaving the model area, and because of the complexity of water rights administration, the prediction of anthropogenic responses to increases in streamflow and the potential effects of those actions on the aquifer are beyond the scope of this scenario.

Predictive uncertainty of the groundwater-flow model was evaluated by Wylie (2019). The evaluation indicated the recalibration of the model with additional data lowered the predictive uncertainty for four example predictions previously evaluated with Version 1.0. The predictive uncertainty for a fifth example prediction was the same as with Version 1.0. Wylie (2019) concluded Version 1.1 is the best available scientific tool for predicting hydrologic responses to changes in aquifer stress in the Wood River Valley aquifer system, because Version 1.1 is an improvement over Version 1.0 and analytical solutions. Predictive uncertainty of the five example predictions evaluated by Wylie (2019) ranged from ±0.5% to ±22%.

Compared to Versions 1.0 and 1.1 of the Wood River Valley groundwater-flow model, previous groundwater-flow models of the Wood River Valley aquifer system were developed for smaller portions of the aquifer and were calibrated to fewer data collected over much shorter time periods (Fisher et al., 2016). Because the recently recalibrated model (Version 1.1) includes the majority of the Wood River Valley aquifer system and incorporates hydrologic and water use data from a 20-year period, which encompassed a variety of climatic conditions, the recently completed model is the best available scientific tool for predicting the hydrologic impacts of reducing the consumptive use of groundwater.

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