Idaho Water Resources Research Institute
Annual Technical Report
FY 2010

Introduction

The Idaho Water Resources Research Institute (IWRRI) is housed at the University of Idaho. IWRRI is dedicated to supporting and promoting water and water–related research, education, and information transfer throughout Idaho. IWRRI collaborates with researchers and educators from all Idaho state universities; staff of local, state, and federal agencies; and private water interests.

The IWRRI is the only mechanism in the state that provides an autonomous statewide source of support for water research and training without regard to specific topic or discipline area. This is important because Idaho's water problems cross multiple topics and disciplines and compartmental approaches to these problems are less effective. IWRRI is relied upon by state and federal agencies and private water interests to provide the objective expertise to address the needs of the state and region.

The Institute has been a strong proponent of education and outreach for both youth and adult audiences. It is through education that the public can make informed public policy decisions concerning water. It is also through education that individual citizens become engaged in the process through adjustments of their own attitudes and lifestyles.

Research Program Introduction

The Idaho Water Resources Research Institutes research program is comprised of the following objectives: (1) To work with state and federal agencies and non−government organizations to identify water research needs of the state and region; (2) To promote water−related research relevant to state and regional needs; (3) To stimulate, coordinate, and provide leadership for water resources research within Idaho universities and collaborate with sister institutions in adjoining states; (4) To cooperate with and assist state and federal agencies and non−governmental organizations for the benefit of the citizens of Idaho and the region; (5) To encourage and facilitate public involvement in water resource programs within the state; (6) To promote water education within the state at the K−12, undergraduate and graduate levels; and (7) To develop funding for needed research and encourage cooperation with other research organizations.

The projects funded during the 2010 104B Program Fiscal Year spanned the range of water issues facing the State of Idaho. This includes projects that investigate: the potential for managed recharge in the Treasure Valley of Idaho; the significance of groundwater underflow from the tributary drainages to the water balance of the East Snake Plain aquifer; and identifying the causes of elevated uranium in the Treasure Valley aquifer.

Wetlands as Sinks for Metal(loid)s in Mining-contaminated Coeur d'lene Basin Soils

Basic Information

Title:	Wetlands as Sinks for Metal(loid)s in Mining-contaminated Coeur d'lene Basin Soils
Project Number:	2007ID72B
Start Date:	3/1/2007
End Date:	9/30/2010
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Geochemical Processes, Wetlands, Water Quality
Descriptors:	
Principal Investigators:	Matthew Morra

Publications

There are no publications.

Title: Wetlands as Sinks for Metal(loid)s in Mining-contaminated Coeur d'Alene Basin Soils

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Project Summary

Mining activities within the Coeur d'Alene (CDA) Basin have resulted in large areas of metal contamination far beyond the designated Bunker Hill Mining and Metallurgical Superfund Site, contaminating the CDA River and CDA Lake. It will be impossible to remove and dispose of contaminated sediments within the CDA Basin and Lake CDA, and thus management decisions that protect the environment and human health are required. Our recent investigations indicate that continuously reduced sediments of ponds located in CDA River flooplain tailings contain soluble metal(loid) concentrations far less than similarly contaminated lake sediments experiencing active redox cycling. Analyses of plant tissues obtained from aquatic macrophytes within these ponds have confirmed that this stable redox environment decreases metal(loid) bioavailability. However, in preliminary investigations we observed that seasonal redox changes occurring in surrounding agricultural fields appear to mobilize metal(loid)s such that pond waters experience severe contaminant inputs during the spring. We propose that ponds strategically placed with respect to hydrologic gradients might be used as sinks to sequester metal(loid)s released from contiguous agricultural fields, thus decreasing contaminant mobility and bioavailability. Our objective is to determine the potential for ponds located within the floodplain of the CDA River to act as a sink for Cd, Zn, As, Cu, and Pb mobilized during seasonal changes in soil redox. We will achieve this goal by characterizing changes in soluble metal concentrations in ponds located in the contaminated floodplain during the course of one calendar year.

Our overall goal is to suggest management strategies for contaminated floodplain soils that will decrease the mobility and bioavailability of harmful metal(loid)s. We ultimately wish to 1) determine if wetlands in metal(loid)-contaminated areas can be used as contaminant sinks, 2) delineate spatial and temporal variables that control the extent of metal(loid) sequestration, and 3) elucidate the responsible biogeochemical processes. Our studies will help in determining if the creation of wetlands might be used to sequester metals, thereby preventing their further dispersal in the environment.

Total metal(loid) concentrations in the sediment of two contaminated ponds within the Coeur d'Alene Basin were determined on sediment digests using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). We confirmed that pond sediments are similar in contamination levels as those in Lake CDA and elevated substantially relative to an uncontaminated control pond (Table 1).

Table 1. Elemental sediment concentrations of Lake Coeur d'Alene and an uncontaminated pond in the Coeur d'Alene Basin.

	Element (µmol g^{-1} sediment)						
	As	Cd	Fe	Mn	Pb	S	Zn
	Lake Coeur d'Alene contaminated sites (Toevs et al., 2006)						
Range	1.2-6.0	0.13-0.39	652-2077	148-436	7.8-31.3	3.5-201	35.0-62.4
Median	2.1	0.23	1441	269	19.9	115	51.5
Mean	2.6	0.24	1473	283	19.4	107	50.5
	Uncontaminated control pond						
Range	0.21-0.29	0.022-0.033	285-344	2.9-4.5	0.072-0.63	2.3-5.8	0.88-2.2
Median	0.25	0.024	326	3.0	0.18	2.6	1.2
Mean	0.25	0.025	320	3.0	0.22	2.9	1.3

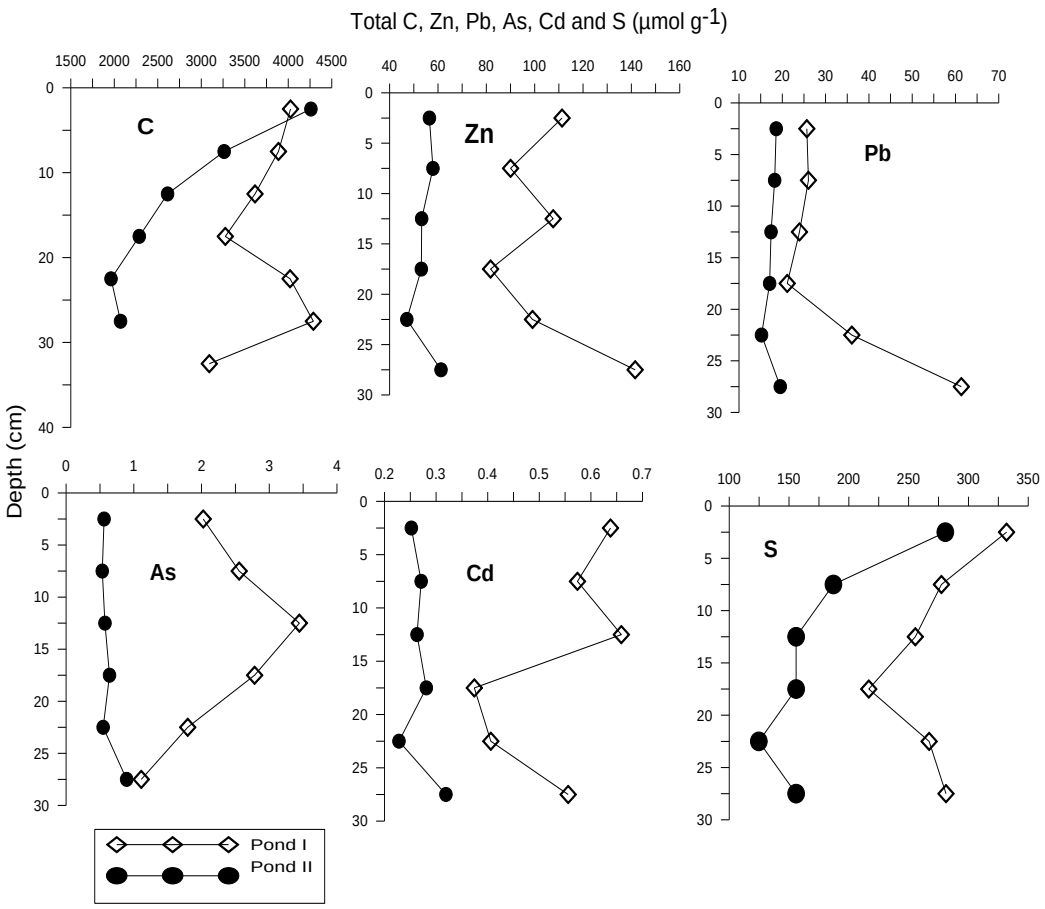

Fig. 1. Elemental concentrations in sediments of two contaminated ponds sampled in the Coeur d'Alene Basin.

Pond waters from two contaminated ponds were obtained at time intervals spanning one year and analyzed for common anions including SO_4^{2-}, PO_4^{3-}, and NO_3^- using ion chromatography (IC). Total dissolved metal(loid)s including As, Cd, Cu, Hg, Ni, Pb, and Zn in the waters were quantified using ICP-AES (Fig. 2). Obvious from Fig. 1 is the huge range in soluble Zn concentrations. The trend is for a very large release of Zn during the least biologically active time of the year, with minimums occurring during the warmest and most biologically active months. The observed release of Zn in February and March most likely results from oxidation of sulfidic precipitates as occurs with decreased microbial activity. This is confirmed by data for SO_4^{2-} that show a corresponding increase during that same time period (Fig. 3).

Shown in Fig. 2 are changes in soluble Pb concentrations in both of the sampled ponds. The trends are similar to those for Zn, but the relative changes in Pb concentration are not as extreme. The formation and oxidation of sulfidic Pb precipitates as with Zn, is the most likely explanation. The data also show the difference in concentration between the bottom and top waters of the ponds indicated, with the highest Pb concentrations measured in the bottom waters (Fig. 2). This indicates a sediment origin for the Pb in contrast to Zn that displays equivalent or higher concentrations in the surface waters.

Our conclusions from the data collected to this point indicate that ponds may be used to reduce soluble metal concentrations in these contaminated environments, but that seasonal changes greatly influence the stability of insoluble complexes responsible for metal(loid) sequestration. Management plans incorporating reduced aquatic environments such as ponds must ensure that seasonal redox changes are minimized in order to maintain low soluble metal(loid) concentrations.

Undergraduate and Graduate Student Researchers supported on the project

Meghan Carter is an M.S. student in the new Water Resources degree program working on the project concurrently as she pursues a J.D. degree. Abu Mansaray is a Fulbright Fellow from Sierra Leone who is also working on the project. He is completely supported by Fulbright funds. An undergraduate student named Kevin Ryan will also start working on the project in June of 2010. Kevin is participating in the NSF program entitled “Environmental Research Experiences for Students from Groups Underrepresented in Science and Engineering”.

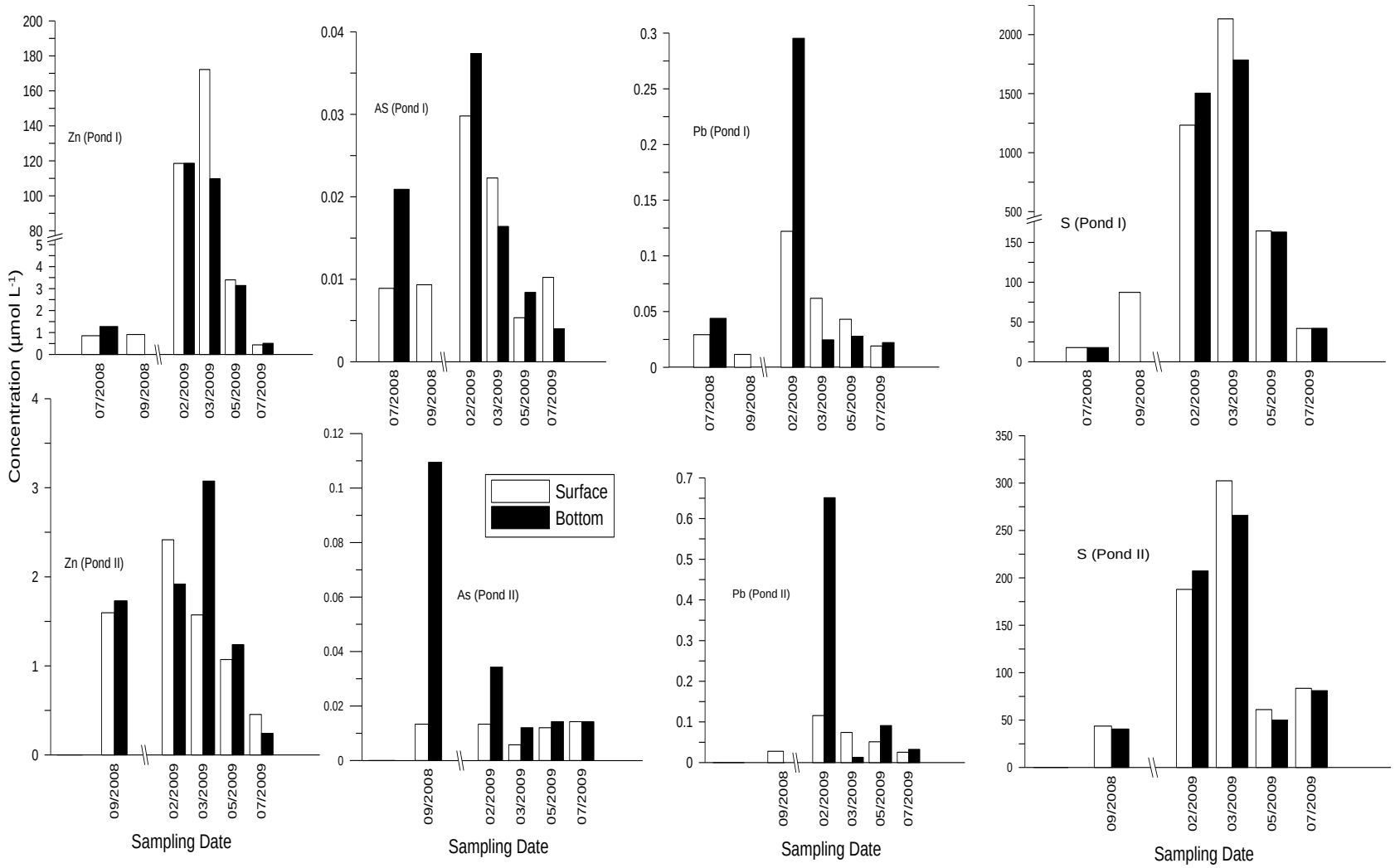

Fig. 2. Total dissolved metal(loid)s in surface and bottom water samples of two contaminated ponds sampled in the Coeur d'Alene Basin.

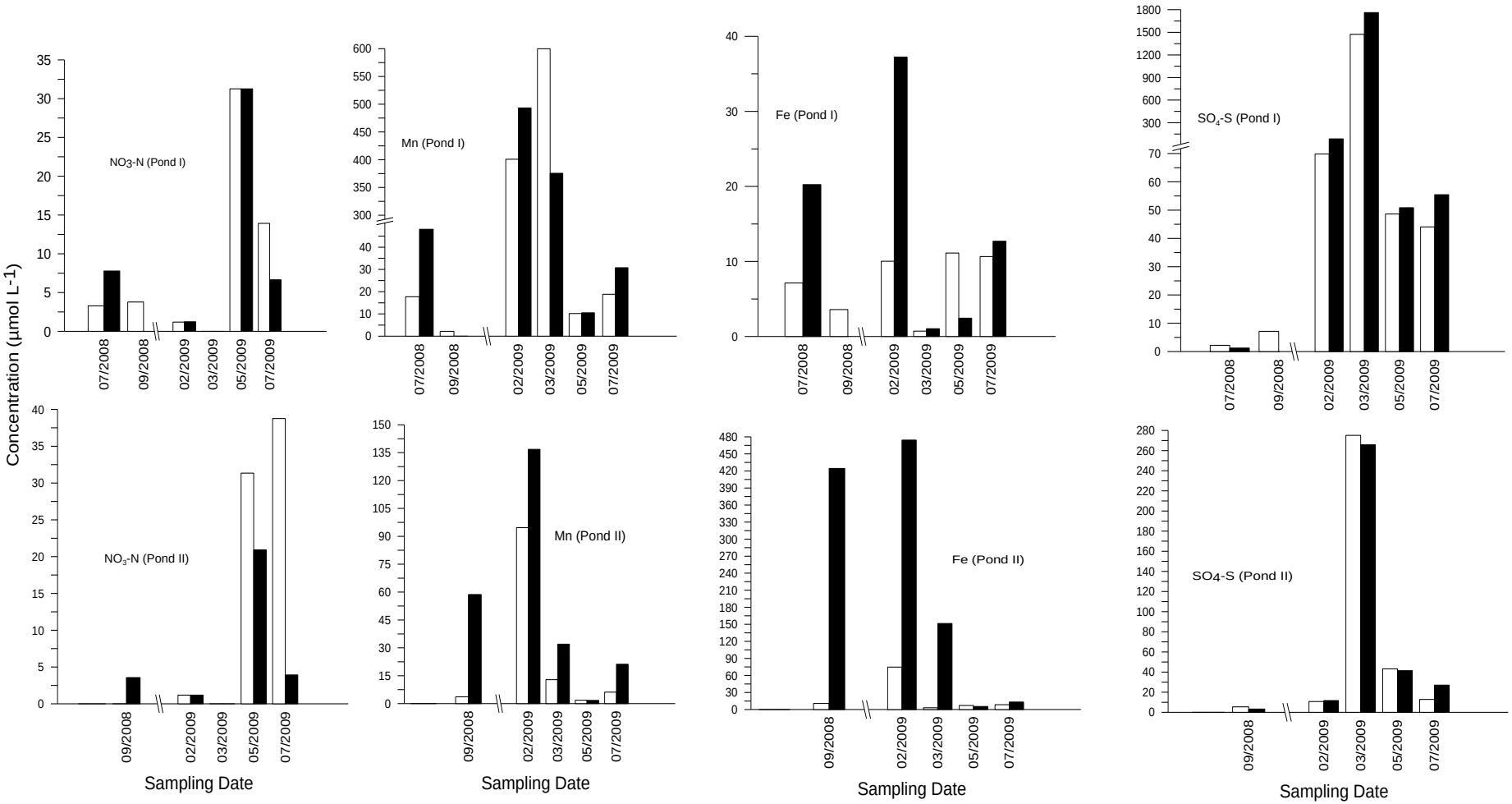

Fig. 3. Dissolved constituents in surface and bottom water samples of two contaminated ponds sampled in the Coeur d'Alene Basin.

Development of a Hydrologic Frame Work and Estimation of the Water Balance in the Mountainous Watersheds of Idaho

Basic Information

Title:	Development of a Hydrologic Frame Work and Estimation of the Water Balance in the Mountainous Watersheds of Idaho
Project Number:	2009ID139B
Start Date:	3/1/2009
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Funding Source:	104B
Congressional District:	2
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Water Quantity, Surface Water
Descriptors:	
Principal Investigators:	Venkataramana Sridhar

Publications

1. Sridhar, V., Sinnathamby, S., Muche, M., Assessment of Water Availability in the Mountainous Watersheds of Idaho, American Water Resources Association 2010 Summer Specialty Conference, GIS& Water Resources VI, Orlando, Florida, March 29-31, 2010.
2. Jin, X., V. Sridhar (2010). Impacts of climate change on hydrology and water resources in the Boise and Spokane River Basins, Journal of American Water Resources Association (in review)
3. Sridhar, V., Jin, X (2010). Climate change impacts: Streamflow conditioning for useful water resources planning and management, Journal of Hydrology (in preparation)

Development of a Hydrologic Frame work and Estimation of the water balance in the mountainous watersheds of Idaho

Final Report submitted on 12/03/2010
To
Idaho Water Resources Research Institute (IWRRI)
University of Idaho

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Executive Summary

- We identified five climate models that are relevant to capturing the future trends in precipitation and temperature. The models include CCSM3 (warmer and dry summer through 2020), HADCM3 (warmer and dry summer through 2040), IPSL CM4 (wetter winter), MIROC 3.2 (warmer and wetter winter) and PCM (cooler and dry summer). They represented a wide range of conditions and also change by time.
- After identifying the models, we downloaded the spatially downscaled climate model data from CMIP3 source developed by Bureau of Reclamation and other collaborators and subsequently temporally disaggregated them from monthly to daily to run the hydrology model.
- The precipitation forecast is less certain. In other words, some models predicted a slightly increased precipitation between 2010 and 2060 while other models predicted a decrease in precipitation. However, the temperature increase is found to be consistent.
- For the Treasure Valley region, changes in precipitation ranged between -3.8 % and 36%. Changes in temperature are expected to be between 0.02 and 3.9 °C. In the Rathdrum Prairie region, changes in precipitation are expected to be between -6.7% and 17.9 %.
- Changes in temperature will likely be ranging between 0.1 and 3.5 °C. Overall, the chosen climate models showed a rise in temperature (0.31 °C to 0.42 °C/decade for Rathdrum Prairie and 0.34 °C to 0.46 °C/decade) and an increase in annual precipitation (4.7% to 5.8% for Rathdrum Prairie and 5.3% to 8.5% for Treasure Valley) over a period of next five decades between 2010-2060.
- In order to study the response of the hydrology model due to changes in precipitation, we implemented the Soil Water Assessment Tool (SWAT) hydrology model to simulate the basin scale hydrologic response to changing climate. However, it is critical to calibrate the model based on the observed flow for multiple sub-basins in each basin. Therefore, we first calibrated the SWAT model for the Spokane River basin using the flows from Post Falls and Spokane. Similarly, we calibrated the model for the Boise River basin using the flows from Parma, Lucky Peak, Arrowrock, Twin Springs and Anderson Ranch. This calibration exercise resulted in 16 parameters adjusted for various processes within the basin including snowmelt, vegetation, groundwater and surface runoff. In both basins the model performance was evaluated using the R^2 values and we obtained a value of 0.6 or higher and that is considered to be good in the modeling environment for extending the simulation framework with selected parameters to another period.
- The SWAT hydrology model was implemented under future climate conditions using the newly calibrated parameters. Considering a wide range of precipitation and temperature outlook, we expected that predictions on the basin hydrology to express a

- We calculated the increase or decrease in flows from historic average flow. Therefore, when we state a decrease or an increase by certain flow rate, it is the difference in flows when compared with historic flows. Based on the average of eight sites (Twin Springs, Anderson Ranch, Arrowrock, Lucky Peak, Glenwood, Middleton, Caldwell and Parma) in the Boise River basin, the peak flows (March through June) appear to increase by 4117 cfs (A2), 3285 cfs (A1B) and 3917 cfs (B1). An eight site average of decrease in peak flows for the Boise River basin revealed the flows as 1223 cfs (A2), 1693 cfs (A1B) and 1366 cfs (B1) due to some scenarios where precipitation is predicted to be decreasing. Overall, the peak flow averages expected to increase by 621 cfs (A2), 300 cfs (A1B) and 436 cfs (B1). Thus, the high flows in the future will probably be higher than the historic high flows.
- We averaged the two site predictions (Post Falls and Spokane) in the Rathdrum Prairie basin to understand the peak flow trends. It was found that increases are expected to be about 2525 cfs (A2), 610 cfs (A1B) and 1899 cfs (B1) based on the two site average flows predicted by the model. The decreases in peakflows were higher than the flows predicted in the Boise River Basin. For example, a decrease in peak flows by 7303 cfs (A2), 7590 cfs (A1B) and 6029 cfs (B1) are also simulated by some scenarios that predict a decrease in precipitation. Again, the high flows in the future will probably be higher than the historic high flows.
- The low flows (July-Oct) predicted by the model have projected an average increase in the summertime flows by 195 cfs (A2), 77 cfs (A1B) and 336 cfs (B1) scenarios. The minimum low flows predicted by the model have projected decreasing flows by 622 cfs (A2), 662 cfs (A1B) and 607 cfs (B1).Overall, the low flow averages declined in the future by 281 cfs (A2), 303 cfs (A1B) and 328 cfs (B1). In the Rathdrum Prairie basin, for instance, a decrease in flow by 1037 cfs (A2), 903 cfs (A1B) and 6029 cfs (B1) is predicted. The maximum low flows are increasing by 1848 cfs (A2), 954 cfs (A1B) and 1635 cfs (B1). A minimal increase in the average low flows, rather than a decrease as in the Treasure Valley region, by 98 cfs (A2), 56 cfs (A1B) and 95cfs (B2) is simulated by these models. For both basins, the low flows are lower than (Treasure Valley) or about the same as that of the historic low flows.
- We computed the volume of flow changes in the Boise River basin at Lucky Peak by integrating the area under the hydrograph. The expected increase in flow volumes are 201896 ac-ft (A2), 120547 ac-ft (A1B) and 265384 ac-ft (B1). The overall average when combining all of these flow volumes results in the flow volume increase by 195942 ac-ft.
- We also anticipate a shift in the timing of snowmelt and this shift is advancing from the current peak melt period of May to April, by about 3-4 weeks. This has been

- In the Boise River basin, depending on the climate scenario, a range in precipitation between 23 and 35 inches is probable and it has the cascading effect on the hydrological water balance components. This precipitation is subsequently partitioned into different water balance components, such as streamflow, evapotranspiration, soil moisture and recharge. For instance, streamflows predicted by the model were between 10 and 19 inches and recharge from 4 to 8 inches. The other two components, evapotranspiration and soil water storage although are expected to change, under natural condition (without any human influence) as predicted by these models have shown lesser variability.
- In the Rathdrum Prairie basin, precipitation is expected to range between 32 and 40 inches over the next decades, which in turn appeared to cause a range in streamflow (14-20 inches) and recharge (2-4 inches) estimates. Evapotranspiration varied between 15 and 19 inches under natural vegetation conditions. Soil water projections are between 6-8 inches.
- It is also important to recognize that there are some uncertainties in our estimates and that can be attributed to GCM-produced precipitation and temperature, model parameters and structure (for instance reach gain or loss, residence time of aquifer recharge) and measured regulated flow, computed natural flow and its year-to-year variability.

1. The Pacific Northwest Climate Change Literature

We reviewed the literature on climate change and the potential impacts on the regional hydrology and water supply including the Treasure Valley and Rathdrum Prairie regions. There is no climate change impact study performed and/or documented for these basins, however, the regional hydroclimatology studies have been reported widely and the following description provides a summary of them.

In general, climate in the Pacific Northwest is changing. A study by Mote (2003) indicates that annual average temperatures in the Northwest rose faster than the global average during the 20th century. At the time of the study, temperatures in the Northwest had risen 0.8°C in comparison to the global increase of 0.6°C (Folland et al., 2001). This warming occurred mostly during the winter and spring. The predominance of winter and spring warming, especially in regard to extreme minimum temperatures, was confirmed more recently in a smaller study at two locations: one in Western Montana and the other in British Columbia (Caprio et al., 2009). The warming climate has resulted in a lengthened growing season (Kunkel et al., 2004), decline of snowpack (Mote, 2006), and earlier timing of the spring runoff (Stewart et al., 2005; Hamlet and Lettenmaier, 1999). Water supply in the West is vulnerable to climatic change, mainly because it relies heavily upon the capture of the spring runoff. Precipitation typically accumulates in the mountains as snowpack and is released during the spring melt, which may continue at high elevations into July. Warmer temperatures are likely to lead to more rain and less snow in the winter, causing an increase in the wintertime streamflow and decrease in spring runoff. Warmer weather is also likely to cause snowpack to retreat to higher elevations and experience earlier melt (Hamlet and Lettenmaier, 1999).

The Pacific Northwest is expected to have increases in annual temperature of about 1.1°C (2.0°F) by the 2020s, 1.8°C (3.2°F) by the 2040s, and 3.0°C (5.3°F) by the 2080s, compared with the average from 1970 to 1999, averaged across all of the climate models (Mote and Salathe, 2009). In the case of projected precipitation, modest changes (+1 to +2%) are expected with an increased winter precipitation and decreased summer precipitation. It is possible that an increase in future precipitation, which some Global Climate Models (GCMs) predict (Mote and Salathe, 2009), could offset the impacts of warming temperatures and it could have direct implications on the regional water supply. However, it should be noted that a 13%-38% increase in precipitation during the 20th century (Mote, 2003) did not reverse the observed impacts of warmer climate in the trend analysis (Kunkel et al., 2004; Mote, 2006; Stewart et al., 2005). Studies indicated that historic climatic change in the Northwest is not due to natural fluctuation of climate caused by the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) which are thought to govern natural climate variability in the Northwest. More recent investigation using the detection and attribution (D-A) analysis have linked the change in the growing season (Christidis et al., 2007), decline in snowpack (Pierce et al., 2008), and earlier spring runoff (Barnett et al., 2008; Hidalgo et al., 2009) to anthropogenic factors, namely greenhouse gas emissions. A similar D-A analysis on all three variables by Barnett et al. (2008) found that 60% of the change in hydrology in the West over the last half century is the result of human-induced climate change.

How will the climate change impact water resource management in the Pacific Northwest, in particular the Treasure Valley and the Rathdrum Prairie watersheds? Although the Climate Impacts Group (CIG) of the University of Washington has carried out multiple studies of climate impacts on the Columbia River basin, their assessment of water resource impacts in the Treasure Valley and Rathdrum Prairie watersheds has been limited. An early study simulating natural flows in the Columbia River basin using the VIC hydrologic model concluded that the model failed to accurately represent the flows at Oxbow Dam (near the outlet of the Snake River Basin in Hells Canyon). The explanation for a large underprediction of flow was due to the inability of the VIC model to simulate gains to the Snake River reaches occurring from the Eastern Snake River Plains Aquifer (ESPA) (Nijssen et al., 1997; Nijssen et al., 2001). The limitation with the VIC model in simulating the groundwater/surface water interaction in the middle reaches of the Snake River was also reported by Hamlet and Lettenmaier (1999) in their assessment of climate impacts on the water resources in the Columbia River Basin. It is likely that the quantile mapping, a technique commonly used in applying hydrologically modeled natural flow to a water resources model, may have been applied to evaluate the natural flow predictions. This technique removes the systematic bias both in the variability and quantity of modeled flows by applying the difference between simulated historic cumulative distribution function (cdf) and modeled future flow cdf. Because of the changes in flow due to aquifer interaction may not be a natural phenomenon, bias correction using the cdf technique based on these flows may lead to an inaccurate prediction of future flows. Future flows are not likely to follow the *artificial* historic bias caused by irrigation.

The assessment by Hamlet and Lettenmaier (1999) on the climate impacts had limitations due to the scope of the water resource model, ColSim, employed in their study. For instance, ColSim included only two reservoirs within the Snake River basin, an aggregate storage reservoir near Brownlee Dam with a run-of-the-river dam at Oxbow. A further study by Payne et al. (2004) addressing techniques to mitigate negative climate impacts within the Columbia River Basin used a more refined version of ColSim, which included five reservoirs within the Snake River basin namely, Hell's Canyon Dam, Oxbow Dam, Brownlee Dam, as well as an aggregate Middle Snake and Upper Snake Dams. The Brownlee, Middle Snake, and Upper Snake Dams were modeled as storage reservoirs for flood and irrigation analysis. The projected change in reliability of irrigation supply was of a similar magnitude to that found by Hamlet and Lettenmaier (1999). Again the VIC model used for the hydrologic analysis did not have the capacity to model groundwater/surface water exchanges occurring in the middle reaches of the Snake River. These studies did not extend to the Rathdrum Prairie basin. However, regional hydrologic studies have shown that a strong surface water-ground water interaction existed in the Rathdrum Prairie watershed and the contribution of flow from the Spokane Valley-Rathdrum Prairie basin as return flow to the Spokane and Little Spokane Rivers during critical low-flow periods is evident (Hseih et al., 2007; Barber et al., 2009). Furthermore, Hseih et al. (2007) also found that the future summer groundwater withdrawals would adversely decrease the return flows in the Spokane River and the Little Spokane River. Alternately, the low flows in the Spokane Valley-Rathdrum Prairie region were somewhat enhanced by augmenting infiltration basins and injection wells with winter surface water diversions (Barber et al., 2009). Climate change impacts via hydrological water balance assessment would therefore provide a basis for the region's water resources availability under current and future climate conditions.

2. Chosen Climate models for Treasure Valley and Rathdrum Prairie Watersheds

In our study, we chose the following five models based on the discussion above, which includes all three scenarios, A1b, A2 and B1 for five global circulation models. The models are listed below.

A) Wet and warmer winter Projections

1) MIROC 3.2 (medres) developed by CCSR/NIES/FRCGC, Japan
   CCSR = Center for Climate System Research, University of Tokyo, NIES = National Institute for Environmental Studies, FRCGC = Frontier Research Center for Global Chance, Japan Agency for Marine-Earth Science and Technology (JAMSTEC); Resolution: ~2.8º x 2.8º

2) CCSM3-- Community Climate System Model developed by National Center for Atmospheric Research (NCAR), USA; Resolution: 1.4º x 1.4º

B) Wetter winter Projection

IPSL-CM4, Institut Pierre Simon Laplace (IPSL), CNRS, CEA, France ; Resolution: 2.5º x 3.75º

C) Warmer and Drier Summer

3) UKMO-HadCM3, Hadley Centre for Climate Prediction and Research, Met Office, United Kingdom; Resolution: 2.5º x 3.75º

D) Cooler and Drier Summer Projection

PCM (Parallel Climate Model), National Center for Atmospheric Research (NCAR); Resolution: ~2.8º x 2.8º

3. Hydrological Modeling: The Boise River Basin

The Soil Water Assessment Tool (SWAT) model has been implemented. This is one of the watershed scale models that is well-tested, widely used and runs with readily available inputs in Geographic Information System (GIS). For data-limited region such as ours, this model can simulate the hydrological processes relatively easily. Furthermore, we have customized this model for other Idaho watersheds earlier (Stratton et al., 2009, Sridhar and Nayak, 2010) and currently we have been implementing the SWAT model for other regions in Idaho. As this effectively reduces the time to customize the model for this project, we were able to start the climate model impact assessment in a relatively short time.

The basic drivers for this model are the USGS-derived Digital Elevation Model, STATSGO soil layer, National Land Cover Data (NLCD) 2001 to extract the vegetation and

weather data. Basin boundaries and sub-basins are shown in Figure 1. We divided the entire basin into 140 individual sub-basins to represent the spatial heterogeneity of the basin in the model. We also used 74 grids at the 1/8th degree resolution to drive the hydrology model with GCM-produced precipitation and temperature after downscaling them as explained previously.

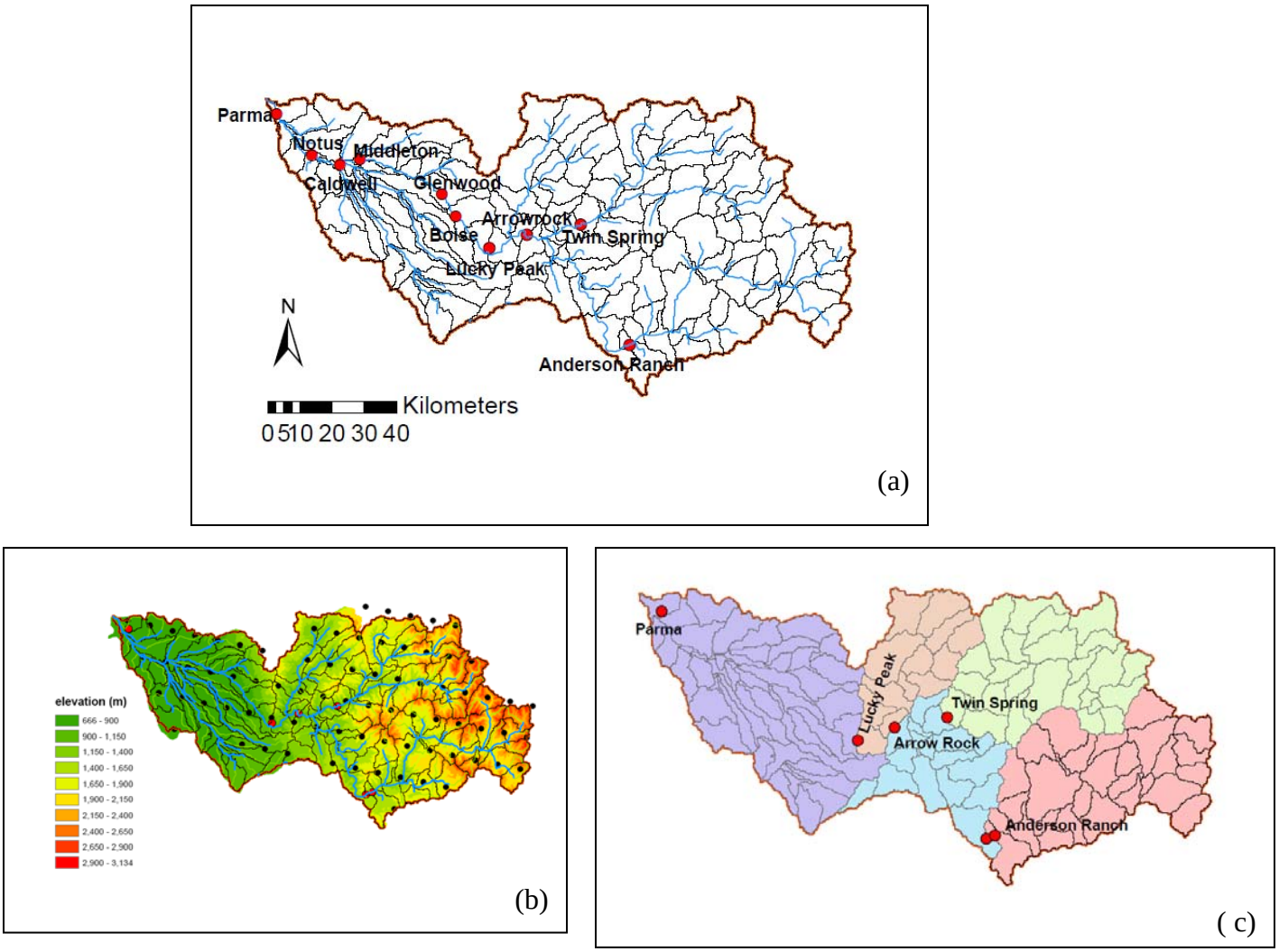


Figure 1. (a) The Boise River basin with sub-basins and calibration/validation streamflow sites (b) the climate model grids (c) delineation of sub-basins for calibration

Based on a sensitivity analysis using one-at-a time method and manual verification, we identified 16 parameters of interest for this basin. We started with all 27 hydrological flow-related parameters and ranked them by their order of sensitivity in simulating the basin hydrology. We selected the 10 most sensitive parameters from this list and manually added

additional parameters that we considered to be important for capturing the basin scale hydrological processes. For instance, even if model sensitivity analysis did not consider melt factor as an important one to be calibrated, we included it manually. Likewise, both based on sensitivity analysis and manual process, we included 16 parameters for our next calibration procedure.

The final parameters are SCS curve number, maximum canopy storage, soil depth, threshold water depth in the shallow aquifer for revap, available soil water capacity, saturated hydraulic conductivity, channel effective hydraulic conductivity, soil evaporation compensation factor, plant uptake compensation factor, ground water delay, groundwater revap coefficient, threshold water depth for flow, deep aquifer percolation fraction, surface runoff lag time, snow pack temperature lag factor and snow melt base temperature. These parameters with their optimal values are shown in Table 1 (a&b). These are considered optimal based on the objective functions, correlation coefficient (R^2) and Nash-Sutcliff Efficiency (NSE). For monthly calibration, as performed in this study, Stratton et al. (2009) suggested that an R^2 of 0.6 is desirable. We additionally considered NSE as another metric for calibration. It can be inferred from our statistical analysis that these metrics rely on the quality of the observed streamflow data, spatial and temporal distribution of streamflow gages. Therefore, after identifying the sensitive parameters for both Treasure Valley and Rathdrum Prairie regions, we generated the optimum parameters based on the autocalibration function, Sequential Uncertainty Fitting Version 2 (SUFI2) calibration algorithm. The lower bound and upper bound columns indicate the range a given parameter can move in space while calibrating it. Also, there are options for the parameter estimation within this algorithm, known as IMET options, for replacement, multiplication and addition/subtraction and here we used replacement or multiplication options. For example, in case of replacement, we replace the old parameter value with a new value to check if the model does better. For the multiplication option, the parameter value is multiplied by the factor at every parameter space.

SUFI2 (Sequential Uncertainty Fitting Version2) is a program that is linked with SWAT for its calibration. This optimization method calibrates the parameter to achieve best fitness and also to the maximum degree to account for the uncertainty between simulated and measured data. The metric used in this calibration procedure is R-factor and P-factor (Abbaspour, 2008). The calibration process is to adjust the parameter values to make the R-factor close to 1 and the P-factor close to 0.

This program includes several steps: 1. Define objective function; 2. Define the initial range of the parameters; 3. Sensitivity analysis (optional, but highly recommended which we performed in this project); 4. Latin Hypercube Sampling (LHS) of the parameters. The common number of combinations of parameters is n=500-1000; 5. Run the simulation n

times and save the simulated output variables of interest, corresponding to the measurement; 6. Calculate the objective function; 7. Calculate the metrics for fitness and uncertainty; 8. Adjust the range of parameters and repeat “1”. By this way, the optimal set of parameters is obtained for the subsequent simulation.

SWAT is a HRU-based model that makes parameters distributed for each HRU. This may be tedious to collect or estimate a large number of parameters for a simulation of even a small watershed. In order to facilitate the calibration of such distributed parameters, SUFI2 has been improved to accommodate the aggregate of parameters. This is implemented by encoding extended parameters to include the information on what locations to apply a parameter value and hence to aggregate the parameters. This format is adopted in our research.

Table 1(a&b) shows the list of calibrated parameters. The historic period was divided into calibration (1958-1963) and validation (1964-2004) windows for this analysis. This splitting of calibration and validation is essential so that the performance of the model is evaluated independent of the calibration effects. The SWAT model was calibrated and verified at five locations (Twin Springs, Anderson Ranch Reservoir, Arrowrock Reservoir, Lucky Peak Reservoir and Parma) in the Treasure Valley region and two locations (Post Falls and Spokane) in the Rathdrum Prairie region, thus covering large areas in the Boise River basin and the Spokane River basin, respectively. The locations are chosen based on the availability of data from U.S Geological Survey (USGS) and the outflow points identified after delineating basins into subbasins in the model. Also, it is clear that the basins highly heterogeneous. Hence, calibrating them with more number of subbasins helps to characterize the watershed in a more realistic way. Therefore, it is preferred to distribute the locations from upstream to downstream sections at multiple gaging locations in order to study the impacts and variability of watershed hydrology due to environmental conditions, specifically climate change. Note that some parameters are calibrated at the finest scale, which is known as, the Hydrological Response Unit (HRU). These HRUs are based on the unique combination of soil, vegetation and slope and are derived from the GIS layers by overlaying them. The total number of HRUs in the Treasure Valley Basin is over 5500. Some other parameters are calibrated at the subbasin level while the remaining parameters are at the basin level.

Parameter name	Parameter definition:Parma	low bound	up bound	imet	Calibration Sites				scale level
					Lucky Peak	Arrowrock	Twin Springs	Anderson Ranch	
Canmx	Maximum canopy storage (mm)	0.816	9.802	v	4.344	3.109	2.508	8.351	hru
Cn2	Initial SCS CN II value	-34.77	37.44	r	-32.5	-21	-32.9	-21.68	hru
Alpha_Bf	baseflow alpha factor (days)	0	1	v					hru
Epco	Plant uptake compensation factor	-50	50	r					hru
Esco	Soil evaporation compensation factor	0.95	1	v					hru
Gw_Delay	Groundwater delay (days)	0	192.3	v					hru
Gw_Revap	Groundwater revap coefficient	0.02	0.2	v					hru
Revapmn	Threshold water depth in the shallow aquifer for "revap" (mm)	0.01	500	v					hru
Gwqmn	Threshold water depth in the shallow aquifer for flow (mm)	0	673	v	572.2	422.3	535.5	75.5	hru
Rchrg_Dp	Deep aquifer percolation fraction	0	1	v	0.488	0.89	0.364	0.272	hru
Ch_K2	channel effective hydraulic conductivity (mm/hr)	3.8	80.8	v	19.8	72.3	51.01	34.2	subbasin
Sol_Awc	Available water capacity (mm H2O/mm soil)	-50	50	r	8.9	16.9	12.38	13.9	hru
Sol_K	Saturated hydraulic conductivity (mm/hr)	12.5	37.5	r					hru
Surlag	surface runoff lag time (days)	0	10	v	1.446				basin
Timp	Snow pack temperature lag factor	0.001	1	v	0.0063				basin
Smtmp	snow melt base temperature (C)	1.8	5.5	v	4.1				basin
	note: for imet, v - replacement, r - multiplying initial value by value (in percentage)								

Table 1 (a). Calibration of the SWAT model using Sequential Uncertainty Fitting algorithm to obtain the optimum parameters representing the basin characteristics for four calibration sites (Lucky Peak, Arrowrock, Anderson Ranch, Twin Springs) in the Treasure Valley Region.

Parameter name	Parameter definition	low bound	up bound	imet	Parma Calibration values	scale level
Canmx	Maximum canopy storage (mm)	0.816	9.802	v	1.705	hru
Cn2	Initial SCS CN II value	-34.77	37.44	r	23.6	hru
Alpha_Bf	baseflow alpha factor (days)	0	1	v	0.0601	hru
Epco	Plant uptake compensation factor	-50	50	r	9.46	hru
Esco	Soil evaporation compensation factor	0.95	1	v	0.962	hru
Gw_Delay	Groundwater delay (days)	0	192.3	v	173.2	hru
Gw_Revap	Groundwater revap coefficient	0.02	0.2	v	0.191	hru
Revapmn	Threshold water depth in the shallow aquifer for "revap" (mm)	0.01	500	v	3.66	hru
Gwqmn	Threshold water depth in the shallow aquifer for flow (mm)	0	673	v	643.9	hru
Rchrg_Dp	Deep aquifer percolation fraction	0	1	v	0.252	hru
Ch_K2	channel effective hydraulic conductivity (mm/hr)	3.8	80.8	v	13.36	subbasin
Sol_Awc	Available water capacity (mm H2O/mm soil)	-50	50	r	-28.88	hru
Sol_K	Saturated hydraulic conductivity (mm/hr)	12.5	37.5	r	36.73	hru
Surlag	surface runoff lag time (days)	0	10	v	1.446	basin
Timp	Snow pack temperature lag factor	0.001	1	v	0.0063	basin
Smtmp	snow melt base temperature (C)	1.8	5.5	v	4.1	basin
	note: for imet, v - replacement, r - multiplying initial value by value (in percentage)					

Table 1 (b). Calibration of the SWAT model using Sequential Uncertainty Fitting algorithm to obtain the optimum parameters representing the basin characteristics for Parma in the Treasure Valley Region.

The selected parameter values were subsequently employed for historical hydrological simulations. Statistical results (R^2 >0.7 and Nash-Sutcliff Efficiency >0.7) for the calibration and historical validation of streamflows are shown in Table 2. Validation of Twin Springs and Anderson Ranch were slightly less when compared with other sites demonstrating an NSE of about 0.65. However, both the sites have an R^2 greater than 0.8 for the validation period. It is generally expected that the validation period statistics will be similar or slightly inferior to that of the calibration period statistics. Stream flow data used for calibration could be attributed to this decreased NSE in addition to the parameters related to snow-melt induced runoff in these forested upstream locations.

Subbasin		r^2	NSE
Parma	calibrated (1959 - 1963)	0.81	0.75
	validated (1964 - 2004)	0.82	0.80
Lucky Peak	calibrated (1959 - 1963)	0.79	0.78
	validated (1964 - 2004)	0.78	0.73
Arrow Rock	calibrated (1959 - 1963)	0.75	0.75
	validated (1964 - 2004)	0.77	0.70
Twin Spring	calibrated (1959 - 1963)	0.87	0.85
	validated (1964 - 2004)	0.81	0.65
Anderson Ranch	calibrated (1959 - 1963)	0.87	0.70
	validated (1964 - 2004)	0.83	0.64

Table 2. Calibration and Validation statistics for various gaging locations in the Boise River - Basin.

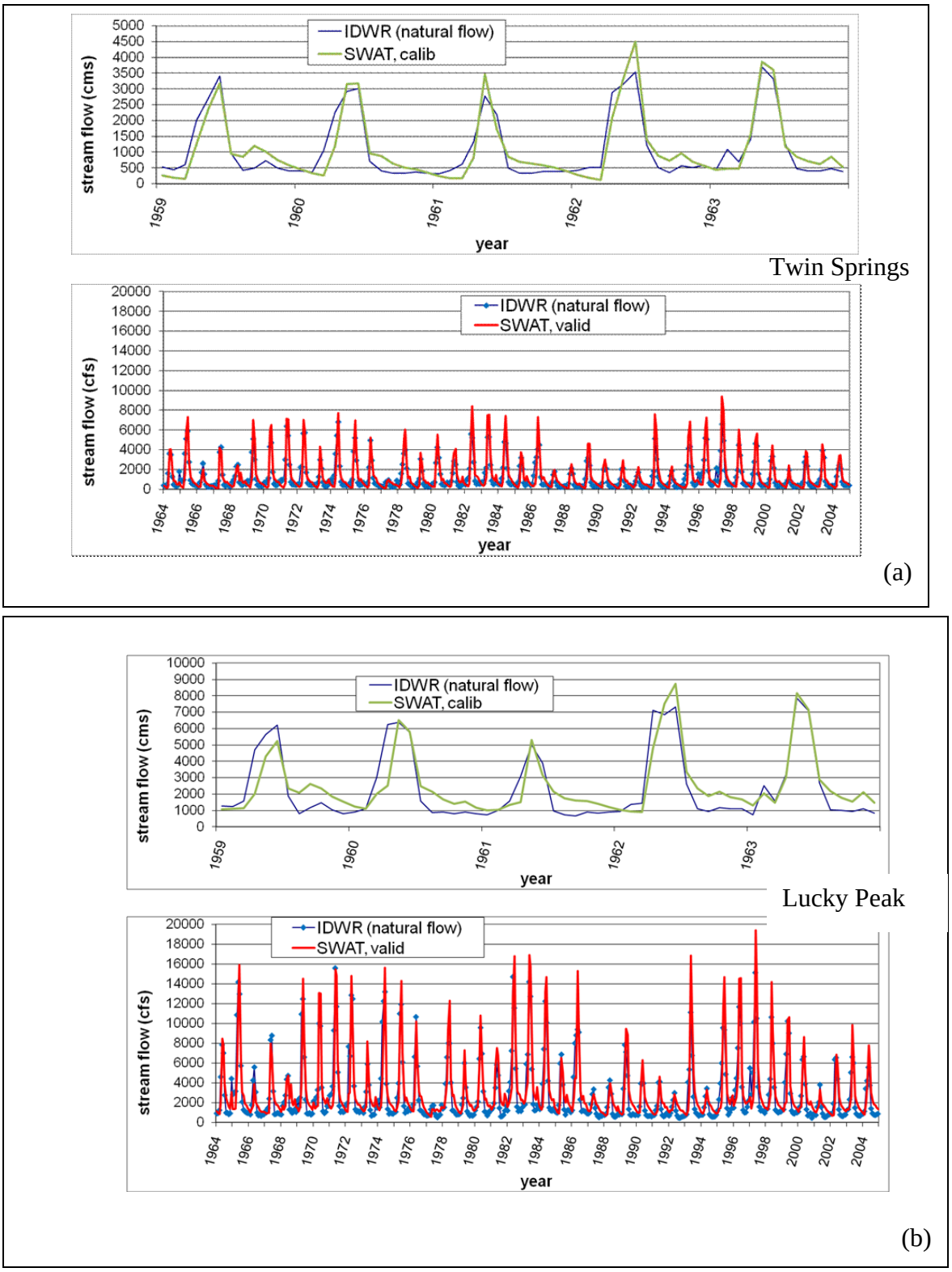


Figure 2. Streamflows for (a) Twin Springs and (b) Lucky Peak simulated by the SWAT model during the calibration (1959-1963) and validation period (1964-2004).

Capturing both low flows and high flows is considered as a prerequisite for our implementation of the model with the calibrated parameters under the climate change scenarios. As changes to the hydrologic conditions are expected to occur rapidly in the future, knowing the historic behavior of flows and hydrology as the baseline reference is critical. Streamflows simulated for historical conditions showed good correlation both in terms of peak flow magnitudes and the timing of snowmelt for the historic climate conditions. Figure 2 shows the time series plot of model-simulated streamflow and observed natural flow for Twin Springs and Lucky Peak. Their performance metrics are mentioned in Table 2. Natural or unmanaged high flows ranged between 4000-6000 cfs for the upstream locations and 12000-16000 cfs for the downstream gaging stations and the low flows were between 1000-2000 cfs in the Boise River basin. Our simulation also showed that interannual variability in streamflows was relatively high for the Treasure Valley region for the historic climatic conditions. Other water balance components (evapotranspiration, soil moisture, recharge) were analyzed. Evapotranspiration accounts for 50-60% of total precipitation annually. Soil moisture and recharge accounts for about 10-15% of annual precipitation.

4. *Hydrological Modeling: The Spokane River Basin*

The SWAT model has been configured to run for the whole of the Spokane River basin in order to establish the hydrologic connectivity and watershed characterization including the aquifer. In other words, to understand the flow pattern in the upstream portion of the Spokane River basin which lies in Idaho (the Rathdrum Prairie region), it is essential to consider the entire watershed beyond Idaho borders. Therefore, our delineation of the basin includes both the regions in Idaho and Washington. Figure 3 shows the basin boundary and sub-basins for this basin. There are 226 sub-basins and over 5700 HRUs (derived from a combination of DEMs, slope and soil layers) and 144 weather points within this basin to drive the model with the GCM data.

We identified 15 sensitive parameters for this basin and they include surface flow, groundwater, soil and snow parameters similar to those of the Treasure Valley region. The initial calibration was performed by delineating the region above Post Falls and the region below Post Falls. A combination approach of autocalibration using SUFI algorithm followed by manual calibration for the Post Falls and Spokane streamflow stations shows good correlation for the historic period. Optimum values of the parameters are shown in Table 3. The parameters that we calibrated include baseflow factor, maximum canopy storage, SCS curve number, deep aquifer percolation fraction, soil evaporation compensation factor, plant uptake compensation factor, ground water delay, deep aquifer percolation fraction, threshold water depth in the shallow aquifer, available soil water capacity, saturated hydraulic conductivity, channel effective hydraulic conductivity, surface runoff lag time, snow pack temperature lag factor and snow melt base temperature.

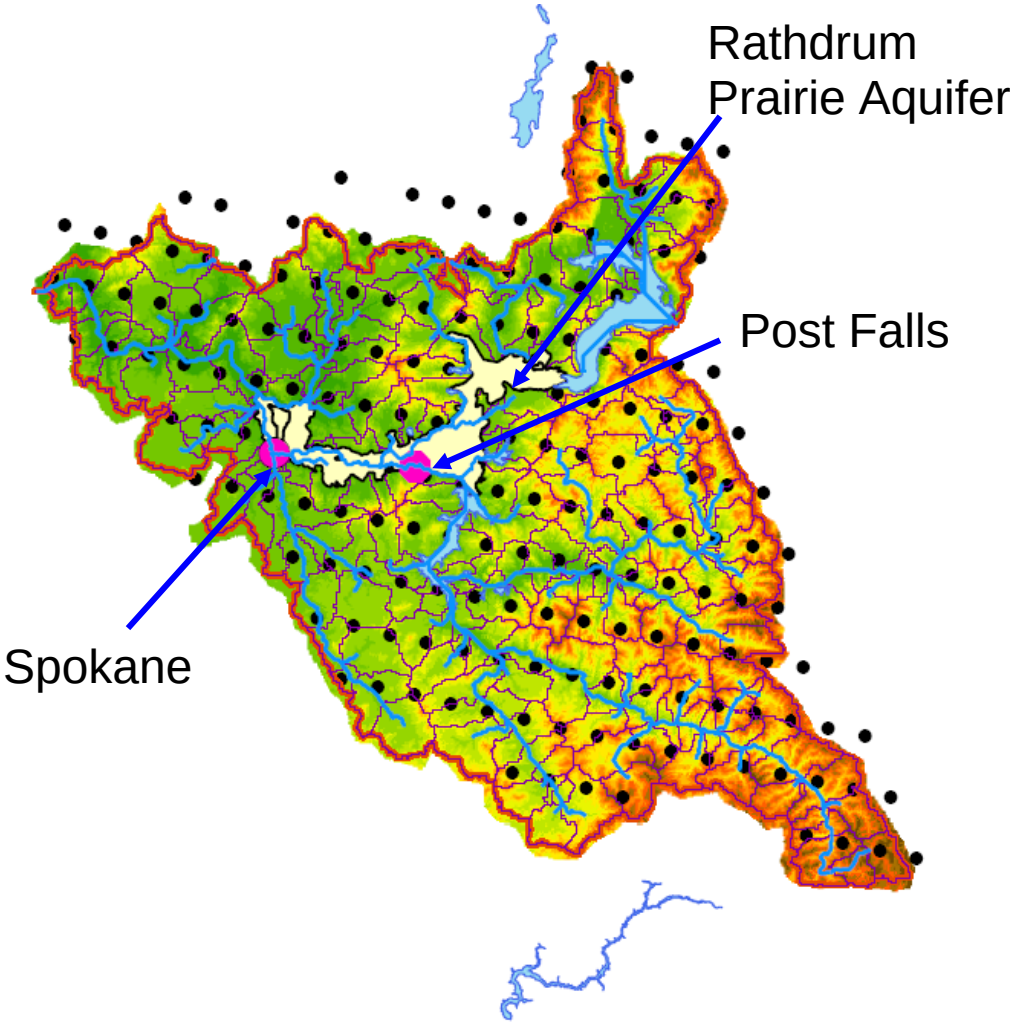


Figure 3. The Rathdrum Prairie aquifer region with the Spokane River basin, sub-basins and weather grids.

Parameter name	Parameter definition:Parma	low bound	up bound	imet	Calibration Sites		scale level
					Post Falls	Spokane to Post Falls	
Alpha_Bf	baseflow alpha factor (days)	0.05	0.15	v	0.077	0.079	hru
Canmx	Maximum canopy storage (mm)	1.28	3.84	v	2.7	1.8	hru
Ch_K2	channel effective hydraulic conductivity (mm/hr)	10	30	v	31.5	19.9	subbasin
Cn2	Initial SCS CN II value	6.38	19.14	r	7.78	12.9	hru
Epco	Plant uptake compensation factor	-50	50	r	16.1	-37.4	hru
Esco	Soil evaporation compensation factor	0.33	1	v	0.55	0.9	hru
Gw_Delay	Groundwater delay (days)	101	303	v	188.4	146.7	hru
Gw_Revap	Groundwater revap coefficient	0.047	0.141	v	0.093	0.133	hru
Gwqmn	Threshold water depth in the shallow aquifer for flow (mm)	219	656	v	333.8	299.2	hru
Revapmn	Threshold water depth in the shallow aquifer for "revap" (mm)	0.01	500	v	299.1	146.9	hru
Sol_Awc	Available water capacity (mm H20/mm soil)	12.5	37.5	r	18.6	33.3	hru
Sol_K	Saturated hydraulic conductivity (mm/hr)	4.27	12.8	r	5.7	13.2	hru
Surlag	surface runoff lag time (days)	2.27	6.81	v	6.3		basin
Timp	Snow pack temperature lag factor	0.01	1	v	0.0035		basin
Smtmp	snow melt base temperature (C)	1.61	4.83	v	3.39		basin
	note: for imet, v - replacement, r - multiplying initial value by value (in percentage)						

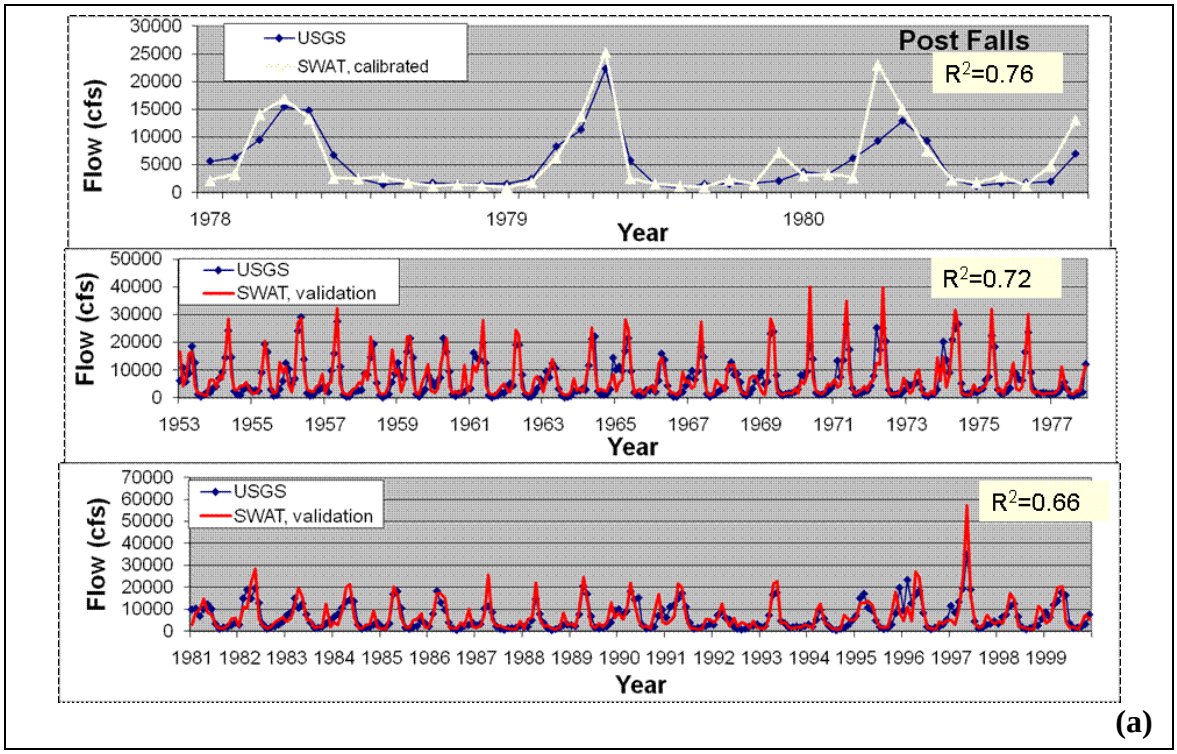
Table 3. Calibration of the SWAT model using Sequential Uncertainty Fitting algorithm to obtain the optimum parameters representing the basin characteristics in the Rathdrum Prairie Aquifer Region.

The calibrated SWAT model was verified at two locations (Post Falls and Spokane) in the Rathdrum Prairie region, thus covering the large areas of Spokane River basin. Both the seasonality and peakflows were captured by the model under historic climate conditions. Statistical results with R^2 >0.65 and Nash-Sutcliff Efficiency >0.55 for the calibration and historical validation with R^2 >0.66 for the model performance in predicting streamflows are shown in Table 4. However, for the second validation period, 1981-99, both R^2 (0.66) and NSE (0.41) have shown a slightly inferior performance of the model. Normally, validation period statistics is somewhat lower when compared against the calibration period and we found in this case as well. However, the correlation coefficient of 0.6 is reliable in order for us to use this as a predictive tool in our hydrological impact analysis.

Subbasin	Gage station		r^2	NSE
Post Falls	Post Falls, ID, 12419000	calibrated (1978 - 1980)	0.76	0.58
		validated (1953 -1977)	**0.72**	**0.65**
		validated (1981 -1999)	**0.66**	**0.48**
Spokane	Spokane, WA, 12422500	calibrated (1978 - 1980)	0.75	0.55
		validated (1953 -1977)	**0.71**	**0.62**
		validated (1981 -1999)	**0.66**	**0.41**

Table 4. Calibration and Validation statistics for various gaging locations in the Rathdrum Prairie Basin.

For the Spokane River basin, the high flows ranged between 20,000-30,000 cfs. The historic streamflow analysis showed that the interannual variability in streamflow was relatively high for the Treasure Valley region. However, this was slightly less in the Rathdrum Prairie aquifer region which can be attributed to a lesser precipitation variability in the historic climatic conditions. There was an earlier snowmelt for both regions as a result of increasing temperature trends, especially at lower elevations. Streamflows simulated by the model is verified against the observations. Figure 4 shows the time series of streamflows captured by the model for the Post Falls and Spokane gaging stations.



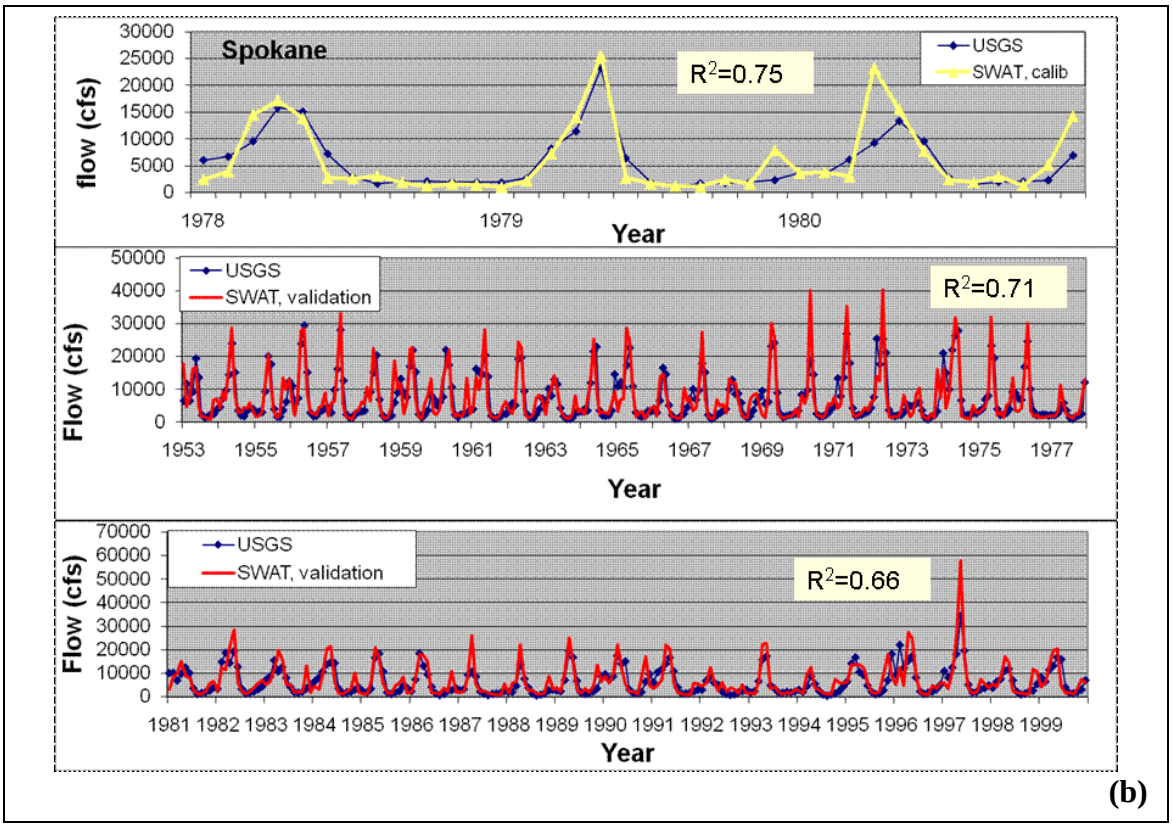


Figure 4. Streamflows for Post Falls and Spokane from SWAT model during the calibration (1978-1981) and validation period (1953-1977; 1981-2000)

5. Results

5.1 Impacts of Climate Variability on the Rathdrum Prairie and Treasure Valley Basins

We have assessed the climate change impacts using the GCM-produced, downscaled precipitation and temperature for the Treasure Valley and Rathdrum Prairie basins' hydrology and water resources.

A Table showing all of the ensemble members, comprising of all 5 models for 3 scenarios (a total of 15 members) are shown for each decade between 2010 and 2060 in Table 5. For the Treasure Valley region, changes in precipitation ranged between -3.8 % to 36% (A2), -9% to 35% (A1B) and -6.7% to 30.5% (B1). Changes in temperature are expected to be between 0.02-3.6 °C (A2), 0.8-3.9 °C (A1B) and 0.5-3.1 °C (B1). In the Rathdrum Prairie region, changes in precipitation are expected to be between -3.8 % to14% (A2), -6.7% to 17.9 % (A1B) and -7.4 % to 14.3 % (B1). Changes in temperature will likely be 0.1-3.2 °C (A2), 0.8-3.5 °C (A1B) and 0.3-2.7 °C (B1). Overall, the chosen climate models showed a rise in temperature (0.31 °C to 0.42 °C/decade for Rathdrum Prairie and 0.34 °C to 0.46 °C/decade) and an increase in annual precipitation (4.7% to 5.8% for Rathdrum Prairie and 5.3% to 8.5% for Treasure Valley) over a period of next five decades between 2010-2060 (Figure 5 and Figure 6) . The precipitation forecast is less certain than the temperature trends as there is less agreement among the models. This is generally the case even at the global scale. However, the temperature increase is found to be consistent among the models considered in this study. In general, both the regions are expected to see increased annual precipitation (4-8%) and temperature (0.31-0.45 ºC/decade) when averaged over all the GCMs.

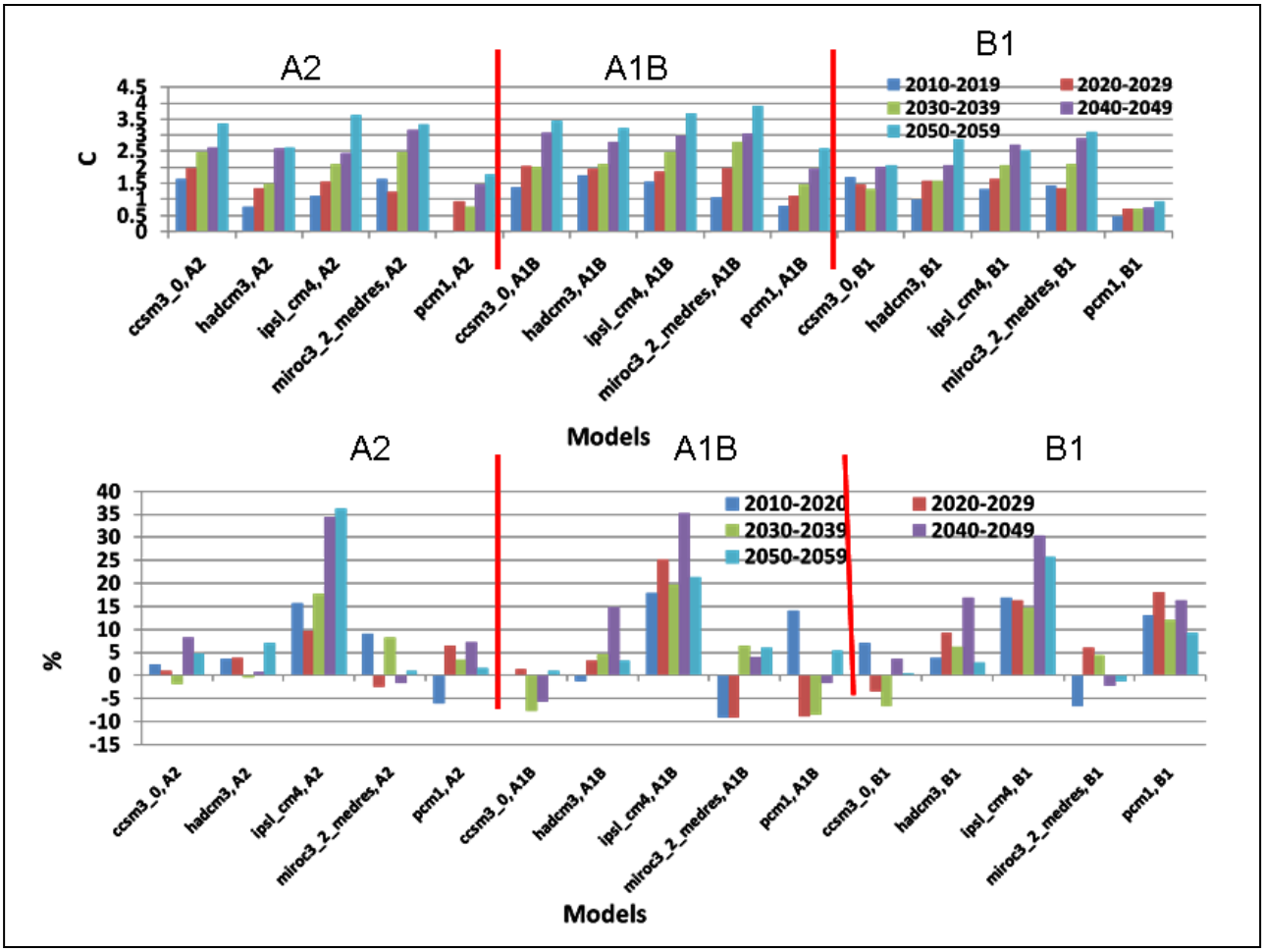


Figure 5. Precipitation and Temperature trends under climate change conditions for the Treasure Valley region between 2010 and 2060. The models used are CCSM3, HADCM3, IPSL CM4, MIROC 3.2 and PCM.

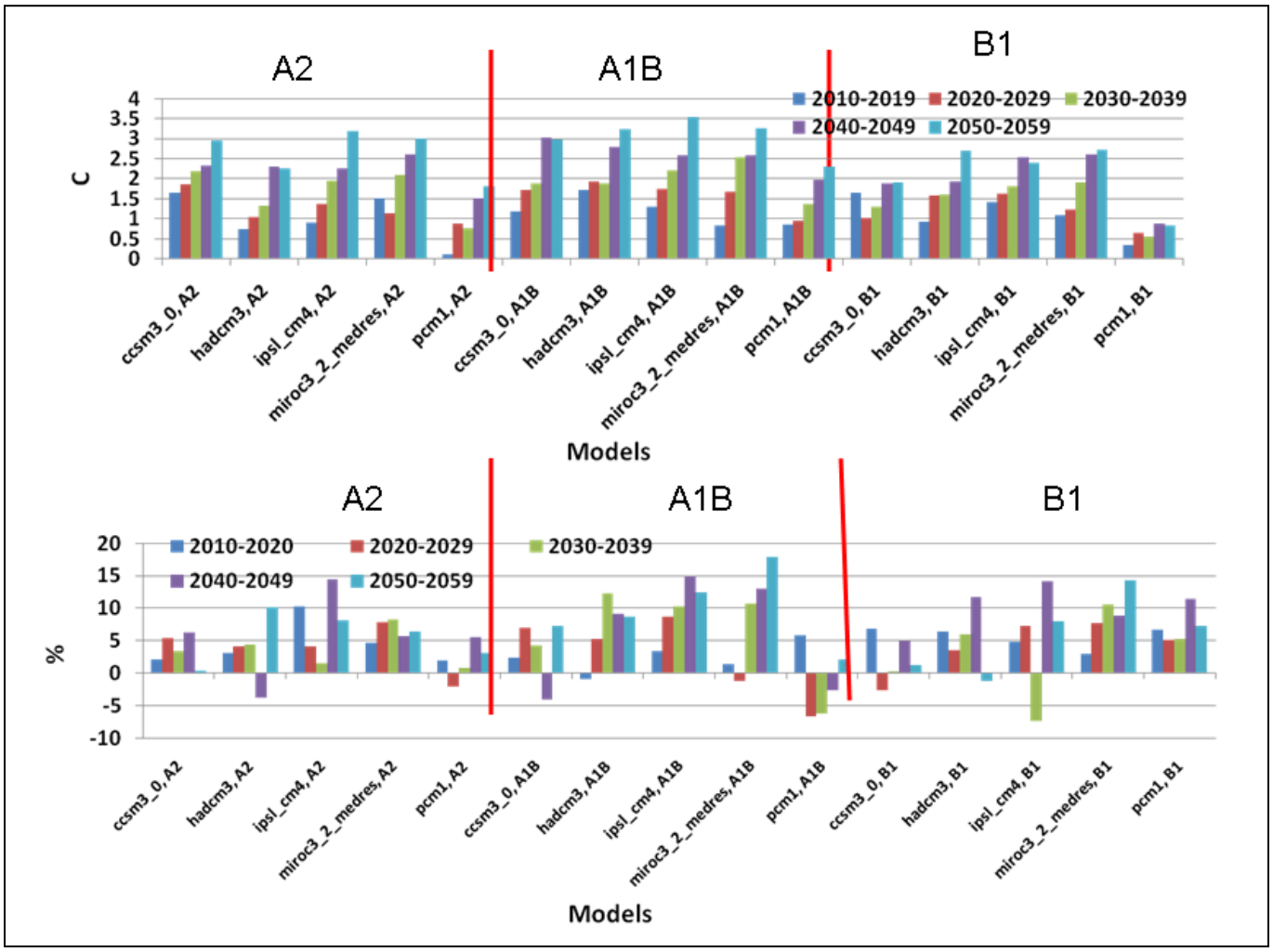


Figure 6. Precipitation and Temperature trends under climate change conditions for the Treasure Valley region between 2010 and 2060. The models used are CCSM3, HADCM3, IPSL CM4, MIROC 3.2 and PCM.

A2			
		P (%)	T (C°)
2010-2019	ccsm3_0	2.49	1.63
	hadcm3	3.60	0.76
	ipsl_cm4	15.71	1.11
	miroc3_2_medres	9.09	1.64
	pcm1	-6.02	0.02
2020-2029	ccsm3_0	0.93	1.98
	hadcm3	3.76	1.35
	ipsl_cm4	9.72	1.53
	miroc3_2_medres	-2.33	1.24
	pcm1	6.36	0.93
2030-2039	ccsm3_0	-1.82	2.47
	hadcm3	-0.47	1.48
	ipsl_cm4	17.66	2.11
	miroc3_2_medres	8.23	2.47
	pcm1	3.33	0.77
2040-2049	ccsm3_0	8.22	2.63
	hadcm3	0.85	2.59
	ipsl_cm4	34.37	2.43
	miroc3_2_medres	-1.64	3.17
	pcm1	7.15	1.47
2050-2059	ccsm3_0	4.89	3.37
	hadcm3	7.00	2.61
	ipsl_cm4	36.28	3.61
	miroc3_2_medres	1.00	3.34
	pcm1	1.69	1.77

A1B			
		P (%)	T (C°)
2010-2019	ccsm3_0	0.18	1.38
	hadcm3	-1.19	1.76
	ipsl_cm4	17.89	1.56
	miroc3_2_medres	-9.11	1.07
	pcm1	14.12	0.79
2020-2029	ccsm3_0	1.45	2.05
	hadcm3	3.20	1.96
	ipsl_cm4	25.16	1.85
	miroc3_2_medres	-9.06	1.98
	pcm1	-8.81	1.10
2030-2039	ccsm3_0	-7.66	2.02
	hadcm3	4.58	2.10
	ipsl_cm4	19.82	2.48
	miroc3_2_medres	6.40	2.78
	pcm1	-8.50	1.45
2040-2049	ccsm3_0	-5.62	3.08
	hadcm3	14.86	2.80
	ipsl_cm4	35.15	2.99
	miroc3_2_medres	4.06	3.06
	pcm1	-1.59	1.95
2050-2059	ccsm3_0	1.06	3.44
	hadcm3	3.15	3.22
	ipsl_cm4	21.28	3.70
	miroc3_2_medres	6.05	3.91
	pcm1	5.49	2.59

B1			
		P (%)	T (C°)
2010-2019	ccsm3_0	7.02	1.690
	hadcm3	3.79	1.005
	ipsl_cm4	16.97	1.321
	miroc3_2_medres	-6.58	1.418
	pcm1	13.15	0.484
2020-2029	ccsm3_0	-3.45	1.470
	hadcm3	9.17	1.567
	ipsl_cm4	16.28	1.645
	miroc3_2_medres	6.10	1.345
	pcm1	18.17	0.699
2030-2039	ccsm3_0	-6.72	1.302
	hadcm3	6.21	1.587
	ipsl_cm4	14.66	2.063
	miroc3_2_medres	4.37	2.101
	pcm1	12.15	0.696
2040-2049	ccsm3_0	3.62	2.003
	hadcm3	16.88	2.067
	ipsl_cm4	30.49	2.702
	miroc3_2_medres	-2.24	2.907
	pcm1	16.28	0.747
2050-2059	ccsm3_0	0.46	2.068
	hadcm3	2.89	2.865
	ipsl_cm4	25.75	2.542
	miroc3_2_medres	-1.17	3.092
	pcm1	9.28	0.949

(a)

A2			
		P (%)	T (C°)
2010-2019	ccsm3_0	2.10	1.654
	hadcm3	3.18	0.727
	ipsl_cm4	10.28	0.896
	miroc3_2_medres	4.62	1.512
	pcm1	1.97	0.100
2020-2029	ccsm3_0	5.45	1.849
	hadcm3	4.12	1.034
	ipsl_cm4	4.18	1.377
	miroc3_2_medres	7.80	1.128
	pcm1	-2.02	0.888
2030-2039	ccsm3_0	3.37	2.187
	hadcm3	4.45	1.327
	ipsl_cm4	1.52	1.947
	miroc3_2_medres	8.32	2.101
	pcm1	0.76	0.749
2040-2049	ccsm3_0	6.32	2.332
	hadcm3	-3.80	2.300
	ipsl_cm4	14.46	2.248
	miroc3_2_medres	5.66	2.607
	pcm1	5.58	1.499
2050-2059	ccsm3_0	0.39	2.961
	hadcm3	10.09	2.265
	ipsl_cm4	8.17	3.189
	miroc3_2_medres	6.37	3.002
	pcm1	3.15	1.809

A1B			
		P (%)	T (C°)
2010-2019	ccsm3_0	2.40	1.180
	hadcm3	-0.97	1.714
	ipsl_cm4	3.46	1.301
	miroc3_2_	1.36	0.829
	pcm1	5.80	0.844
2020-2029	ccsm3_0	6.94	1.713
	hadcm3	5.26	1.924
	ipsl_cm4	8.71	1.736
	miroc3_2_	-1.21	1.681
	pcm1	-6.69	0.951
2030-2039	ccsm3_0	4.31	1.879
	hadcm3	12.36	1.893
	ipsl_cm4	10.25	2.214
	miroc3_2_	10.64	2.529
	pcm1	-6.15	1.364
2040-2049	ccsm3_0	-4.00	3.025
	hadcm3	9.15	2.786
	ipsl_cm4	14.84	2.582
	miroc3_2_	13.02	2.592
	pcm1	-2.57	1.986
2050-2059	ccsm3_0	7.21	2.984
	hadcm3	8.73	3.241
	ipsl_cm4	12.45	3.530
	miroc3_2_	17.89	3.253
	pcm1	2.15	2.305

B1			
B1		P (%)	T (C°)
2010-2019	ccsm3_0	6.86	1.650
	hadcm3	6.48	0.914
	ipsl_cm4	4.78	1.413
	miroc3_2_	3.00	1.087
	pcm1	6.75	0.335
2020-2029	ccsm3_0	-2.59	1.017
	hadcm3	3.60	1.587
	ipsl_cm4	7.26	1.621
	miroc3_2_	7.75	1.218
	pcm1	5.18	0.635
2030-2039	ccsm3_0	0.28	1.295
	hadcm3	6.05	1.600
	ipsl_cm4	-7.39	1.822
	miroc3_2_	10.58	1.913
	pcm1	5.29	0.542
2040-2049	ccsm3_0	5.00	1.874
	hadcm3	11.68	1.923
	ipsl_cm4	14.16	2.542
	miroc3_2_	8.90	2.606
	pcm1	11.41	0.877
2050-2059	ccsm3_0	1.27	1.915
	hadcm3	-1.25	2.699
	ipsl_cm4	8.00	2.392
	miroc3_2_	14.31	2.722
	pcm1	7.34	0.840

(b)

Table 5. (a) Boise River Basin Future Temperature and Precipitation changes for each decade between 2010-2060 for each scenario (A2, A1b and B1) (b) Spokane River Basin Future Temperature and Precipitation changes for each decade between 2010-2060 for each scenario (A2, A1B and B1)

5.2 High Flows and Low Flows Assessment in a Changing Climate

As a result of the increased precipitation and temperature, generally both the regions are expected to have increased streamflows during the peak flow season (Figure 7) and decreased flows in the summer. In order to make sure that flows are realistic, we bias-corrected the predicted flows by comparing with the long-term flow data. With all the climate scenarios that have been analyzed in the study, a wide range of predictions is probable for the entire 50 year period between 2010 and 2060. The choice of the model in understanding the flow pattern becomes critical. This was observed for all the emission scenarios, A1B, A2 and B1 where we have projected mostly increased precipitation possibilities and the range of peak flows (March through June) is expected to increase by 4117 cfs (A2), 3285 cfs (A1B) and 3917 cfs (B1). This is based on the average of the eight sites in the Boise River basin where flows are predicted by the model. However, there are uncertainties in these predictions as evidenced from decreases in peak flows predicted in some scenarios. An eight site average of decrease in peak flows for the Boise River basin revealed the flows as 1223 cfs (A2), 1693 cfs (A1B) and 1366 cfs (B1). These are due to some scenarios where precipitation is predicted to be decreasing. In general, the peak flow averages expected to increase by 621 cfs (A2), 300 cfs (A1B) and 436 cfs (B1). Thus, the high flows in the future will probably be higher than the historic high flows. Table 8 shows the flows based on the averages from eight sites.

	Change in flows (cfs)		
Scenario	Peak flow Min	Peak flow Max	Peak flow Avg
A2	-1223	4117	621
A1B	-1693	3285	300
B1	-1366	3917	436
	Low flow Min	Low flow Max	Low flow Avg
A2	-622	195	-281
A1B	-662	77	-303
B1	-607	336	-328

Table 8. The Boise River Basin flow changes in comparison with the historical flows.

As in Figure 8, in the Rathdrum Prairie basin the peak flow increases are expected to be about 2525 cfs (A2), 610 cfs (A1B) and 1899 cfs (B1) based on the two site average flows predicted by the model. However, the decreases in peakflows are also greater than that of the decreases in the Boise River Basin. For instance, a decrease in peak flows by 7303 cfs (A2), 7590 cfs (A1B) and 6029 cfs (B1) are also simulated by some scenarios that predict a decrease in precipitation. Precipitation uncertainty causing flow variations appears to be magnified in the higher latitudes such as the Rathdrum Prairie basin. However, nearly all scenarios agree that there will be a slight advancement in the timing of snow melt in the Treasure Valley and the Rathdrum Prairie basins. The peak flow averages are expected to be about 24 cfs (A2), 11 cfs (A1B) and 20 cfs (B1).

Streamflows in the low flow period (July through Oct) are decreasing in the Boise River basin. More specifically, the average increase in the summertime flows are 195 cfs (A2), 77 cfs (A1B) and 336 cfs (B1) scenarios. The minimum low flows predicted by the model have projected decreasing flows by 622 cfs (A2), 662 cfs (A1B) and 607 cfs (B1). In general, the low flow averages declined in the future by 281 cfs (A2), 303 cfs (A1B) and 328 cfs (B1). Notably, the low flows are expected to be lower than the historic low flows (Figure 9). The summertime minimum low flows in the Rathdrum Prairie appear to have decreased when compared against the historic conditions (Figure 10). For instance, a decrease in flow by 1037 cfs (A2), 903 cfs (A1B) and 6029 cfs (B1) is predicted. The maximum low flows are increasing by 1848 cfs (A2), 954 cfs (A1B) and 1635 cfs (B1). A minimal increase in the average low flows, rather than a decrease as in the Treasure Valley region, by 98 cfs (A2), 56 cfs (A1B) and 95 cfs (B2) is simulated by these models. The results are shown in Table 6. While most of the increase could be attributed to climate change, as can be noticed from our historic model validation approximately some 20% of the flows were unexplained by mode (r^2=0.8) and therefore uncertainty in the hydrological model predictions should be included when planning the water availability forecasts.

	Change in flows (cfs)		
Scenario	Peak flow Min	Peak flow Max	Peak flow Avg
A2	-7303	2525	24
A1B	-7590	610	11
B1	-6029	1899	20
	Low flow Min	Low flow Max	Low flow Avg
A2	-1037	1848	98
A1B	-903	954	56
B1	-6029	1635	95

Table 6. The Spokane River Basin flow changes in comparison with the historical flows.

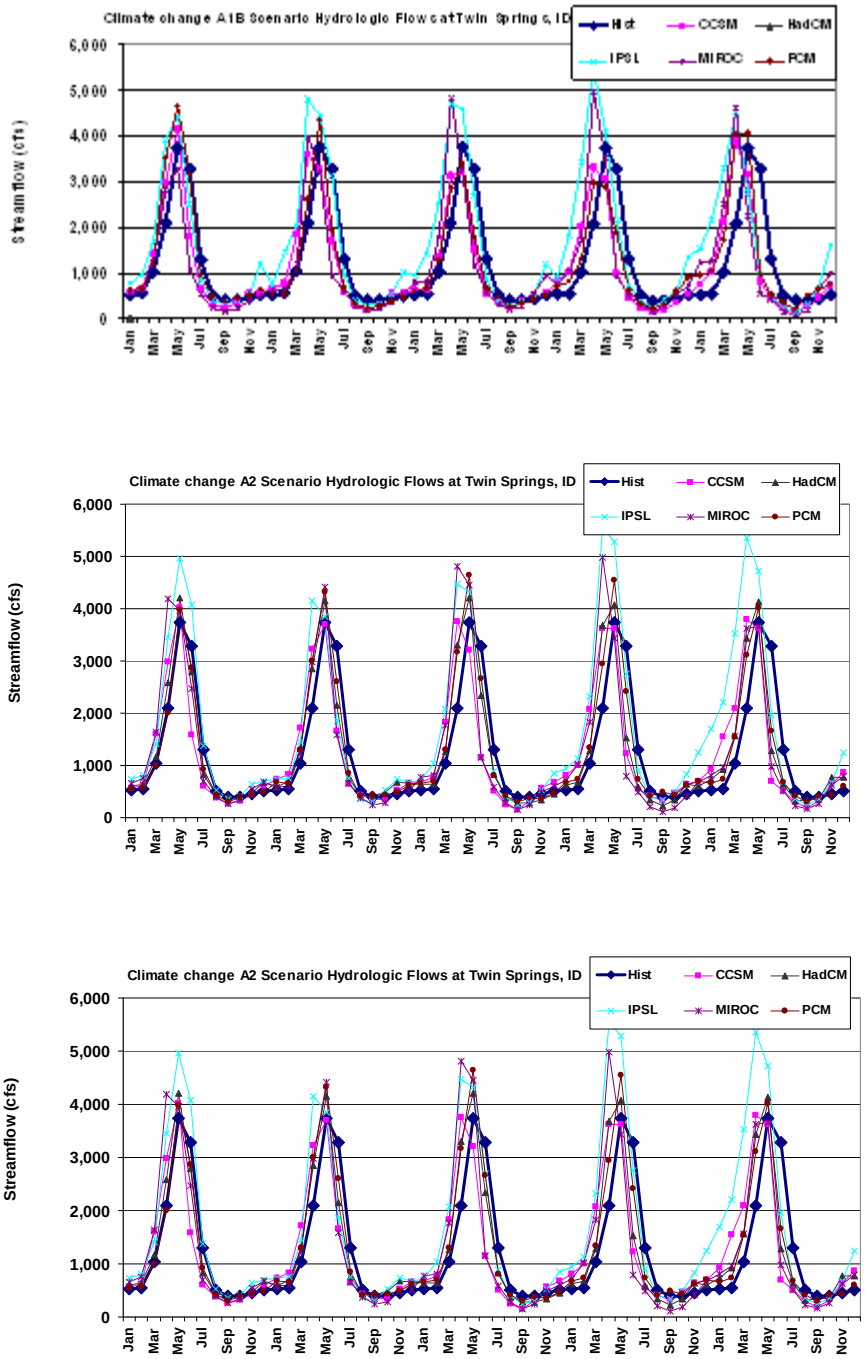
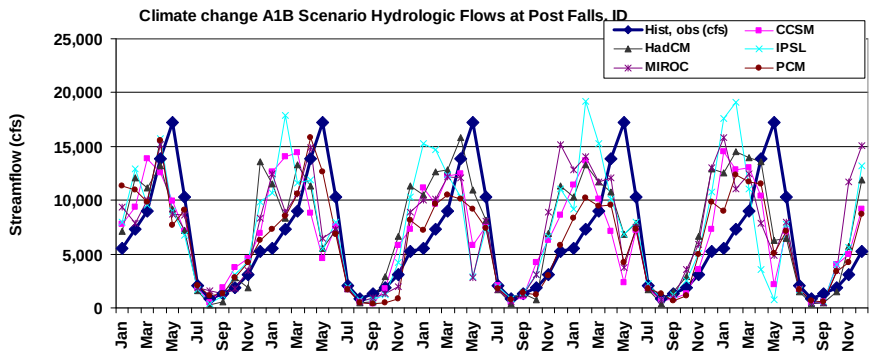
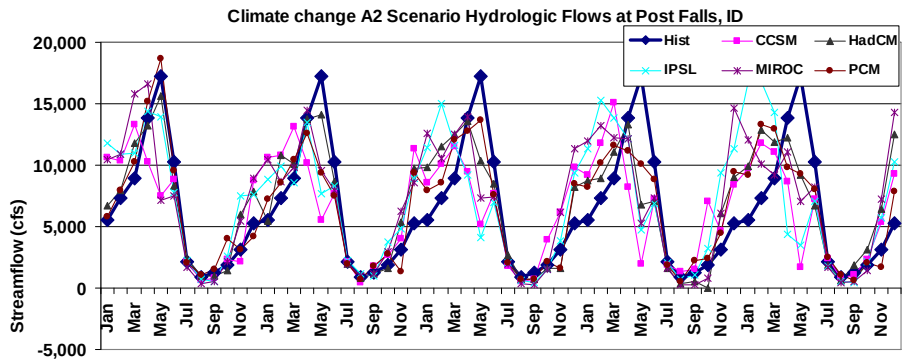


Figure 7. Seasonal streamflows for each decade between 2010 and 2060 at Twin Springs in the Upper Boise River basin for each scenario for A1B (top), A2 (middle) and B1 (bottom). Higher peak flows are expected to occur in May and low flows are about the same or slightly above when compared against the historic flows.





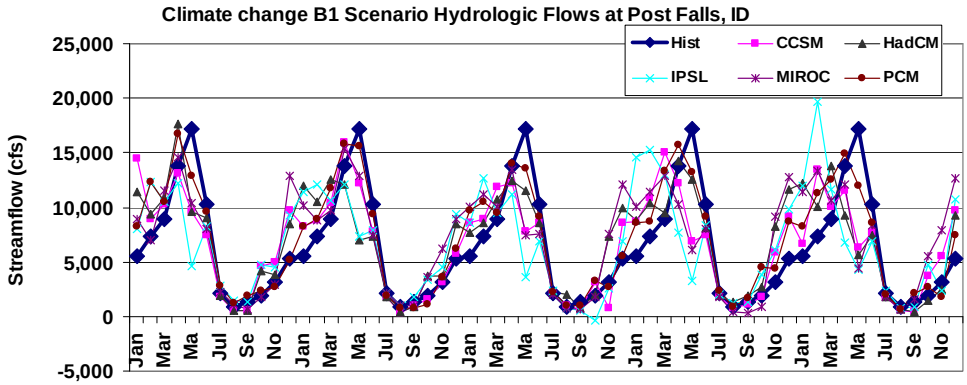


Figure 8. Seasonal streamflows for each decade between 2010 and 2060 at Post Falls in the Spokane River Basin for each scenario for A1B (top), A2 (middle) and B1 (bottom). Higher peak flows are expected to occur in May and low flows are about the same or slightly above when compared against the historic flows.

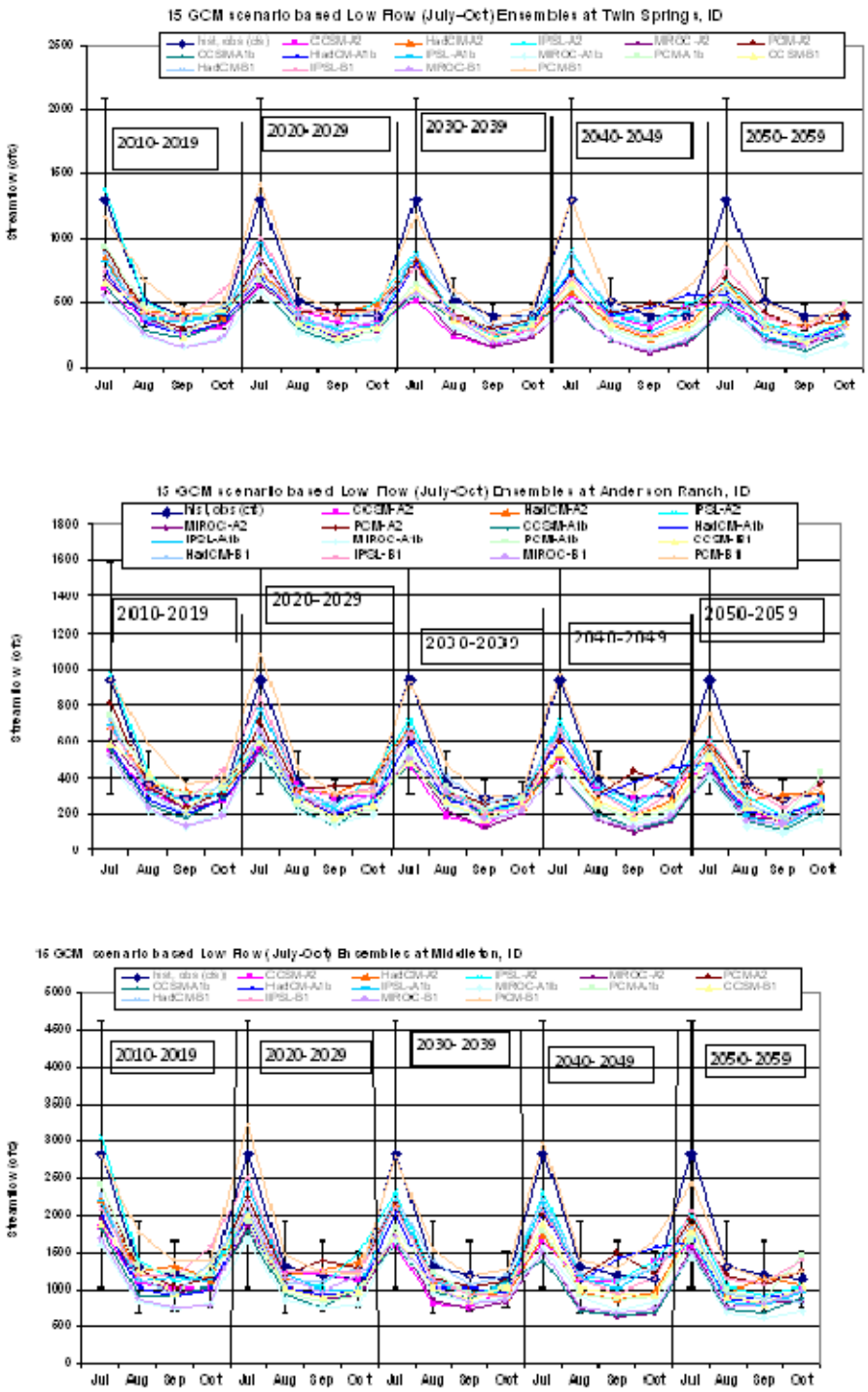
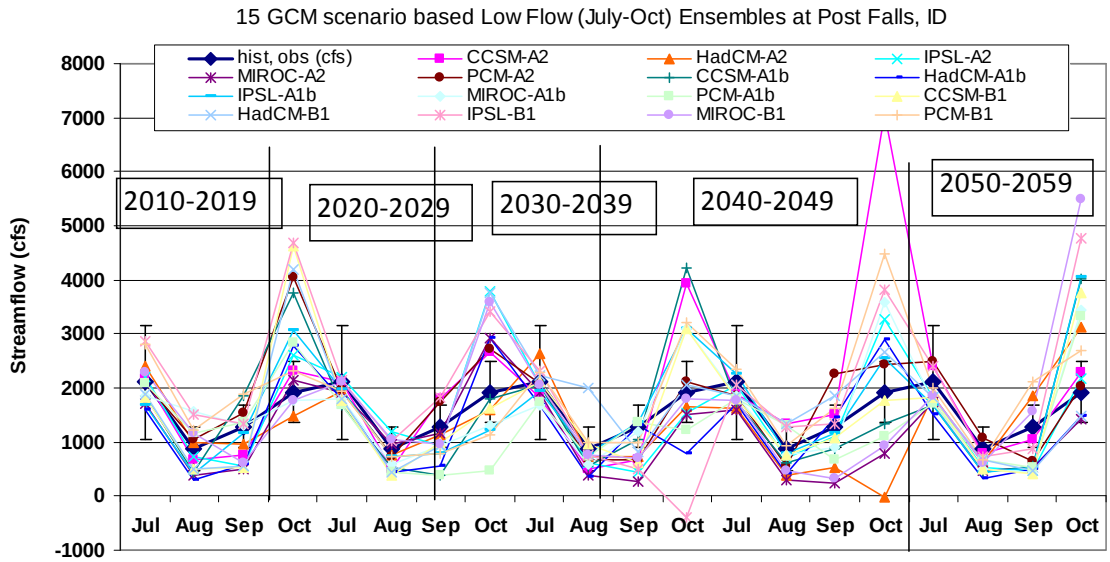


Figure 9. Low flows for each decade between 2010 and 2060 at Twin Springs, Anderson Ranch and Middleton in the Boise River Basin.



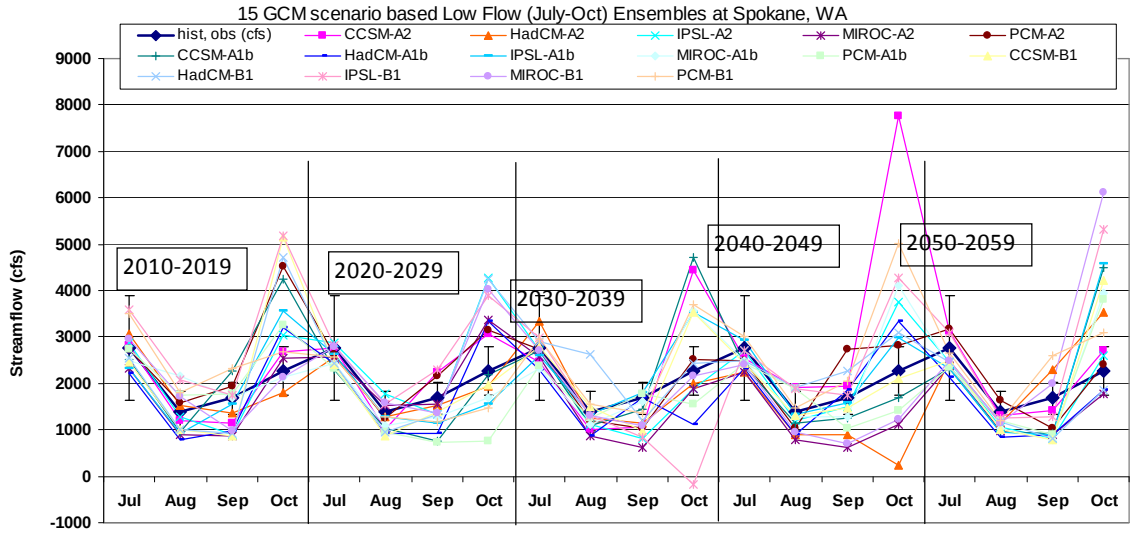


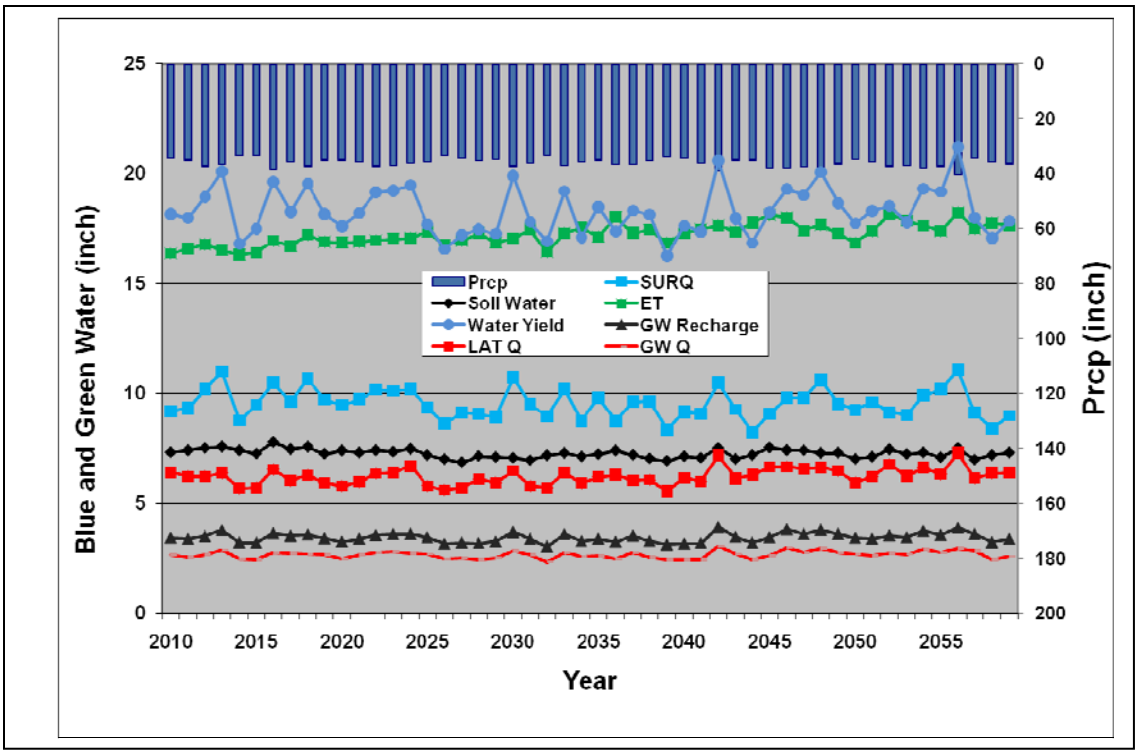
Figure 10. Low flows for each decade between 2010 and 2060 at Post Falls in the Spokane River Basin. Low flows are about the same or slightly below when compared against the historic flows.

6. Annual Hydrologic Mass Balance estimates under future climate

Precipitation being the main driver in the water balance computation, its variability both annually and seasonally has a direct impact on other water budget components. As shown in Figure 11, the Rathdrum Prairie region is expected to receive in the future about 36 inches of precipitation on average of which about 40-50% goes to evapotranspiration and 15-20% goes to recharge which is essentially 4-8 inches in a year. Streamflow referred as water yield (blue line with circles) ranging between 10-20 inches/year can be from Figure 16. Sridhar and Nayak (2010) and Stratton et al., (2009) reported that about 50-60% of annual precipitation was partitioned into evapotranspiration historically.

In the Rathdrum Prairie basin, precipitation is expected to range between 32-40 inches over the next decades, thereby causing a wide range in streamflow (14-20 inches) and moderate recharge between 2-4 inches. Evapotranspiration varied between 15 and 19 inches under natural vegetation conditions. Soil water projections are between 6-8 inches. Historic recharge was between 1-20 inches by various methods of recharge estimation over the Rathdrum Prairie basin (Bartolino, J.R., 2007). On average, evapotranspiration is expected to be about 15-17 inches in the Rathdrum Prairie region, which is about 40-50% of the annual expected precipitation. The range of variability is quite apparent for both the basins.

In the Boise River basin, precipitation ranged from 23 to 35 inches, which appears to cause significant ranges in streamflow between 10-19 inches and recharge from 4-8 inches among the models for the three emission scenarios. The other two components, evapotranspiration and soil water storage although are expected change, under natural condition (without any human influence) as predicted by these models have shown lesser variability. On average, evapotranspiration is expected to be between 9-11 inches in the Boise River basin.



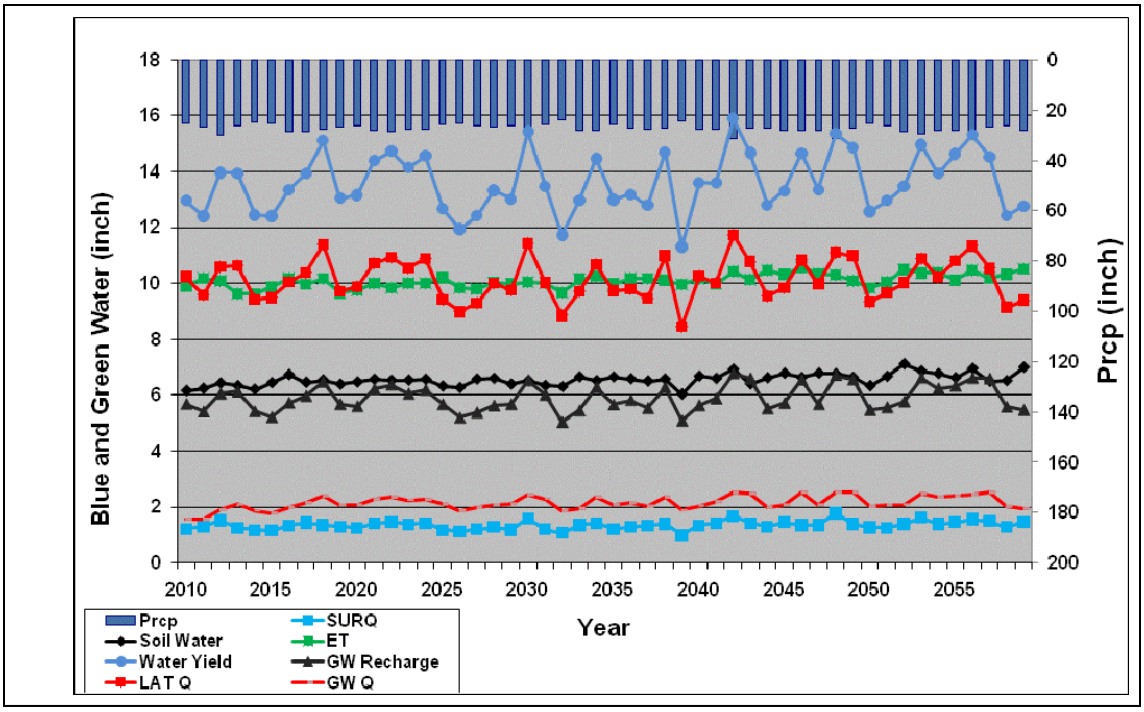


Figure 11. The annual Water balance estimates for the Spokane River basin (top) and the Boise River (bottom) basin and averaged over all GCMs and scenarios (15 members).

Conclusions

This project covered many tasks including the evaluation of climate models, climate model output downscaling, SWAT model calibration and validation, simulation of climate change in the basin's hydrology and assessment. We identified five climate models that are relevant to capturing the future trends in precipitation and temperature. The models include CCSM3 (warmer and dry summer through 2020), HADCM3 (warmer and dry summer through 2040), IPSL CM4 (wetter winter), MIROC 3.2 (warmer and wetter winter) and PCM (cooler and dry summer). They represented a wide range of conditions and also change by time. After identifying the models, we downloaded the spatially downscaled climate model data from CMIP3 source developed by Bureau of Reclamation and other collaborators and subsequently temporally disaggregated them from monthly to daily to run the hydrology model. The precipitation forecast is less certain. In other words, some models predicted increased precipitation between 2010 and 2060 while other models predicted a decrease in precipitation. However, temperature increase is found to be consistent. For the Treasure Valley region, changes in precipitation ranged between -3.8 % and 36%. Changes in temperature are expected to be between 0.02 and 3.9 °C. In the Rathdrum Prairie region, changes in precipitation are expected to be between -6.7% and 17.9 %. Changes in temperature will likely be ranging between 0.1 and 3.5 °C. Overall, the chosen climate models showed a rise in temperature (0.31 °C to 0.42 °C/decade for Rathdrum Prairie and 0.34 °C to 0.46 °C/decade) and an increase in annual precipitation (4.7% to 5.8% for Rathdrum Prairie and 5.3% to 8.5% for Treasure Valley) over a period of next five decades between 2010-2060

In order to study the response of the hydrology model due to changes in precipitation, we implemented the SWAT hydrology model to simulate the basin scale hydrologic response to changing climate. However, it is critical to calibrate the model based on the observed flow for multiple sub-basins in each basin. Therefore, we first calibrated the SWAT model for the Spokane River basin using the flows from Post Falls and Spokane. Similarly, we calibrated the model for the Boise River basin using the flows from Parma, Lucky Peak, Arrowrock, Twin Springs and Anderson Ranch. This calibration exercise resulted in 16 parameters adjusted for various processes within the basin including snowmelt, vegetation, groundwater and surface runoff. In both basins the model performance was evaluated using the R^2 values and we obtained a value of 0.6 or higher and that is considered to be good in the modeling environment for extending the simulation framework with selected parameters to another period.

The SWAT hydrology model was implemented under future climate conditions using the newly calibrated parameters. Considering a wide range of precipitation and temperature outlook, we expected predictions about the basin hydrology to express a broad range in streamflows, evapotranspiration and recharge during the simulation period of the entire 50 year period between 2010 and 2060. This was observed for all emission scenarios, A1B, A2 and B1 and based on the average of eight sites (Twin Springs, Anderson Ranch, Arrowrock, Lucky Peak, Glenwood, Middleton, Caldwell and Parma)

in the Boise River basin the peak flows (March through June) appear to increase by 4117 cfs (A2), 3285 cfs (A1B) and 3917 cfs (B1). Also, decreased peak flows of 1223 cfs (A2), 1693 cfs (A1B) and 1366 cfs (B1) are expected. These are due to some scenarios where precipitation is predicted to be decreasing. In general, the peak flow averages expected to increase by 621 cfs (A2), 300 cfs (A1B) and 436 cfs (B1). We averaged the two site predictions (Post Falls and Spokane) in the Rathdrum Prairie basin to understand the peak flow trends. It was found that increases are expected to be about 2525 cfs (A2), 610 cfs (A1B) and 1899 cfs (B1) based on the two site average flows predicted by the model. However, the decreases in peakflows are also greater than that of the Boise River Basin. For instance, a decrease in peak flows by 7303 cfs (A2), 7590 cfs (A1B) and 6029 cfs (B1) were simulated by some scenarios.

The low flows (July-Oct) predicted by the model have projected decreasing flows by 622 cfs (A2), 662 cfs (A1B) and 607 cfs (B1) in the Boise River basin. In the Rathdrum Prairie, a minimal increase in the average low flows, rather than a decrease as in the Treasure Valley region, by 98 cfs (A2), 56 cfs (A1B) and 95 cfs (B2) is simulated by these models. Thus, the low flows are expected to lower than the historic low flows and high flows are anticipated to be higher than the historic high flows and earlier.

We also anticipate a shift in the timing of snowmelt and this shift is advancing from current peak melt period of May to April. This has been consistent for both the basins. This is pretty typical of many regions in the Western U.S. which is expected to cause some management problems related to the water resources in the region. An earlier melt, if not stored, might cause some shortages in the system thereby possibly impacting various sectors including irrigated agriculture, hydro power and domestic as well as municipal water supply.

In the Boise River basin, depending on the climate scenario, a range in precipitation between 23 and 35 inches is probable and it has the cascading effect on the hydrological water balance components. For instance, streamflows predicted by the model were between 10 and 19 inches and recharge from 4 to 8 inches. The other two components, evapotranspiration and soil water storage although are expected change, under natural condition (without any human influence) as predicted by these models have shown lesser variability. In the Rathdrum Prairie basin, precipitation is expected to range between 32 and 40 inches over the next decades, which in turn appeared to cause a range in streamflow (14-20 inches) and recharge (2-4 inches) estimates. Evapotranspiration varied between 15 and 19 inches under natural vegetation conditions. Soil water projections are between 6-8 inches.

It is also important to recognize that there are some uncertainties in our estimates and that can be attributed to GCM-produced precipitation and temperature, model parameters and structure (for instance reach gain or loss, residence time of aquifer recharge) and measured regulated flow, computed natural flow and its year-to-year variability.

Publication/Conference Presentation:

Sridhar, V., Sinnathamby, S., Muche, M., Assessment of Water Availability in the Mountainous Watersheds of Idaho, American Water Resources Association 2010 Summer Specialty Conference, GIS& Water Resources VI, Orlando, Florida, March 29-31, 2010.

Sridhar, V., (2010) Climate Variability Impact Studies in the Rathdrum Prairie Aquifer Region, Presentation at the Comprehensive Aquifer Management Plan (CAMP) Meeting by Idaho Department of Water Resources, Coeur d'Alene, ID, July 19, 2010

Sridhar, V., (2010) Climate Variability Impact Studies in the Treasure Valley region, Presentation at the Comprehensive Aquifer Management Plan (CAMP) Meeting by Idaho Department of Water Resources, Boise, ID, Nov 10, 2010

Jin, X., V. Sridhar (2010). Impacts of climate change on hydrology and water resources in the Boise and Spokane River Basins, Journal of American Water Resources Association (in review)

Sridhar, V., Jin, X (2010). Climate change impacts: Streamflow conditioning for useful water resources planning and management, Journal of Hydrology (in preparation)

Human Resources:

Muluken Muche was partially supported by this grant between March 2009 and Dec 2009. Dr. Xin Jin, Postdoc was also supported by this project.

Notable Achievements or Awards:

Dr. Sridhar (PI) and his team's work was reported in the Regional Newspapers. Both Coeur d'Alene Press and Spokesman Review carried the article on climate change and water availability issues based on the presentation given by Dr. Sridhar in July, 2010 at Coeur d'Alene Advisory Council Meeting. The highlights are shown here below.

COEUR d'ALENE PRESS
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2 for $3 PAPA JOE
CDA • Rathdrum • Post Falls • Hayden • St. Maries

Saturday
July 17, 2010

Sunny
High 81, Low 54
Weather, A2

Tribe land appeal dropped

Commissioners feel understanding can be reached with Tribe

By ALECIA WARREN
Staff writer

COEUR d'ALENE — Upon further review, they changed their minds.

The Kootenai County commissioners announced Friday that they had withdrawn their appeal on the trust status awarded to 142.6 acres of Coeur d'Alene tribal land.

"We withdrew yesterday or the day before," said Commissioner Rick Currie.

He declined to give reasons for the withdrawal. He said further details are being worked out with the Tribe on a memorandum of understanding, though over what he wouldn't say.

Currie had no worries about the appeal being withdrawn before the memorandum was completed.

"We feel we can reach an understanding with the Tribe," he said.

Currie

The Tribe welcomed the news, said spokesman Marc Stewart.

"This is extremely important to the Coeur d'Alene people, because this is their homeland," Stewart said. "All they're trying to do is get it back."

Tribal Chairman Chief Allan said, "The Tribe sees this as

see APPEAL, A2

The Press, Saturday, July 17, 2010

SECTION C Local

For news or story ideas, call city editor Bill Bailey at 664-6176, Ext. 2016; e-mail bailey@cdapress.com

CALENDAR:
Here's what's happening this weekend / C2

Obituaries / C2
TV Listing / C3

BETTER THAN NEW
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Evidence of design abound

Gavin Young, in the June 25 edition of The Press, wrote to object to Creationism being taught in our schools. His well-reasoned arguments were against the inclusion of religious teaching in public schools and the well-worn "separation of church and state" issues. In the reality of today's increasingly secular public school system his viewpoints

Study: Climate affects aquifer

BSU professor spent 10 months analyzing impact on water source

By ALECIA WARREN
Staff writer

Maybe you think climate change is a bunch of hooey, or that it only impacts polar bears.

But some like Dr. Venkataramana Sridhar think it will affect resources a little closer to home.

Like our drinking water.

The assistant professor of civil engineering at Boise State University has recently completed a study on how climate change will impact the Rathdrum-Prairie Aquifer over the next 50 years.

"There are no questions about these changes. It's going to happen," said Sridhar, who will be presenting his study on Monday at the Coeur d'Alene Public Library. "We are now looking to see how we can adapt and modify and mitigate these impacts."

Sridhar discovered a range of potential effects global warming will have on the aquifer in his 10-month study, which included analyzing global climate models and a hydrology model.

"We look at rainfall, time magnitude of snow melt, variability in water balance components, soil moisture and recharge," he said.

He has predicted several different scenarios, ranging from conservative to extreme.

see AQUIFER, C7

HREI to honor

NO EASY ANSWERS

Five questions you need to ask yourself before hiring or becoming a caregiver | TODAY, C1

SPORTS, B1

Boise puts stop to Indians' winning streak

THE SPOKESMAN-REVIEW

TUESDAY, JULY 20, 2010 | SUNNY, WARM ▲86 ▼58 | WWW.SPOKESMAN.COM

Homicide victim had overcome much

Rep. Walt Minnick

Fish, Wildlife officers threatened

Two anglers arrested after license check

From staff reports

An 18-year-old Mattawa, Wash., man has been charged with attempted first-degree murder after officers say he shot at a Washington Department of Fish and Wildlife police captain Saturday in Grant County.

Jose J. Garcia-Meraze is being held in Grant County Jail on $1 million bail, along with his 60-year-old father, Nicholas Garcia-Godinez, who is accused of drawing a knife on another Fish and Wildlife officer. Garcia-Godinez has been charged with second-degree assault and is being held on $100,000 bail.

The men, who made a preliminary appearance Monday in Grant County Superior Court, are to be formally arraigned next week. U.S. Immigration and Customs Enforcement also placed holds on both men.

The two were arrested Saturday evening following a vehicle pursuit by Fish and Wildlife and the Washington State Patrol.

The incident began about 8:30 p.m. Saturday when an officer was checking an angler at Crab Creek, a popular fishing area near Beverly in Grant County. The officer contacted Garcia-Meraze, who had been fishing but did not have a license, according to police reports.

As the officer was escorting Garcia-Meraze back to his vehicle to confirm whether he had purchased a license, Garcia-Meraze drew a gun and pointed it at the officer, according to police. His father approached the officer brandishing a knife, police reports said.

Garcia-Meraze escaped in a car. During the pursuit, he turned his vehicle around and drove toward officers in a marked police vehicle, firing shots and penetrating the driver's side door with one round, according to police reports. An officer returned fire after the suspect attempted to shoot at him a second time, police said.

After a pursuit of several miles, the suspect was apprehended after his car stalled on state Route 28 near Ephrata.

The incident is being investigated by the Columbia Basin Investigative Team, a regional law enforcement consortium. Investigations are routinely conducted following police use of force involving fatalities.

released from the hospital. They were identified Monday as Mark Burbridge, Jan Pogachar and Doug Orr, all of whom were on duty when Tonia Vansant crashed into their car.

Burbridge suffered a

Sandpoint will be replacing and resetting manhole covers as needed.

Interstate Concrete and Asphalt of Coeur d'Alene has a $150,000 contract for its share of the work.

Warming could change aquifer, study finds

By Becky Kramer
beckyk@spokesman.com
(208) 765-7122

A warming climate could diminish the volume of water in the Spokane Valley-Rathdrum Prairie Aquifer, which supplies drinking water to most of Spokane and Kootenai counties.

A Boise State University assistant professor, Venkataramana Sridhair, ran different modeling scenarios to analyze how climate change would affect the aquifer.

Over the next 50 years, temperatures are projected to rise about half a degree per decade in the Spokane River Basin as a result of higher carbon dioxide levels and other so-called greenhouse gases. Annual precipitation should stay roughly the same. But even with stable precipitation, the aquifer could experience declines, said Sridhair, an engineer who specializes in water resources.

The warmer temperatures will trigger more rain-on-snow events, he said. Instead of snow piling up in the mountains, the rain will rush over frozen ground, with less reaching the groundwater to recharge the aquifer, Sridhair said.

"More of it falls as liquid precipitation," he said. "It doesn't get into the system."

Sridhair presented the study results Monday in Coeur d'Alene to members of an aquifer advisory committee established by the state of Idaho. The group works on long-range planning issues for the aquifer, which supplies drinking water for more than 500,000 of the region's residents. The aquifer – often described as a bathtub full of gravel with water flowing through – covers more than 325 square miles, extending from the southern part of Lake Pend Oreille to the Little Spokane River.

At the moment, very little water-storage capacity exists in the Spokane basin, noted Paul Katt, a local engineer and committee member. So, there aren't opportunities to store the water from rain-on-snow events for future use, he said.

Help Protect Your Family:

Children's Blood-Lead Testing Coming July 13, 2010 - July 22, 2010

This month parents have another opportunity to protect their children's health. Panhandle Health District (PHD) will offer free blood-lead testing for eight days.

Why Test? Lead can cause health problems, especially for young children and pregnant women. Many metals-contaminated soils have been cleaned up. But, people can still come into contact with lead.

It is Easy and Fast. Testing is first come first served, and requires a simple finger stick. It will take 15-20 minutes per child and the test is free. Samples are checked while you wait. You will get results right away. Children with a blood lead result of 8 micrograms per deciliter (µg/dL) or greater will need to have a venous sample drawn at the visit. Each child gets $20.00 for completing a short lead exposure questionnaire and getting tested.

Who Can Be Tested? Children six months to six years old and pregnant women who live in the Coeur d'Alene River Basin near the Coeur d'Alene River from Black Lake to Mullan. All children must be accompanied by their parent or legal guardian.

Where Can My Child Get Tested?

Osburn Seventh-Day Adventist Church
206 N 5th, Osburn, Idaho
(Behind Active Communications)
July 16, 19, 20, 21, & 22, 2010
9:30 AM – 6 PM

The Screening Area Includes:

Mediimont Cataldo

IDAHO RECORDS

Police blotter

Coeur d'Alene police

Lars Johansson reported Friday the $725 theft of a stereo, CDs and fish finder from his boat parked on the 1100 block of North Government Way.

Michele Kelo reported July 13 [illegible] Wrangler parked at his home on the 1100 block of East Deerhaven Avenue.

Don Reilly, worley, reported Friday the $1,225 theft of four snowplows from his property on the 4100 block of North Rolling Hills Road.

[illegible]

Timothy A. Nile 23, Hayden, driving under the influence: $740 fine, 180 days in jail (147 days suspended), 60 days unscheduled jail time, 90 days driver's license suspension, two years probation.

Judge Scott Nass

Dale E. Davis, 44, Coeur d'Alene: driving under the [illegible]

[illegible] Keurey, plaintiff awarded $4,329.

Discover Bank v. Christine Canova, plaintiff awarded $6,208.

Capital One Bank v. Jessica Basdier, plaintiff awarded $7,051.

ShowPlace Adjustment Bureau v. Chestra Hughes, plaintiff awarded $7,439.

[illegible]

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Determining the Cause of Elevated Uranium Concentrations in the Shallow Treasure Valley Aquifer

Basic Information

Title:	Determining the Cause of Elevated Uranium Concentrations in the Shallow Treasure Valley Aquifer
Project Number:	2010ID158B
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Principal Investigators:	Shawn Benner

Publications

There are no publications.

2010ID 158B Shawn Benner, Boise State University
Determining the Cause of Elevated Uranium Concentrations in the Shallow Treasure Valley Aquifer

Project Summary

This study was initiated to evaluate the potential source of elevated uranium in the groundwater underlying the Treasure Valley in southwest Idaho. **Groundwater in the area exhibits widespread but diffusely distributed uranium concentrations up to 110 μg L^{-1}, well in excess of the U.S. Environmental Protection Agency (EPA) drinking water standard of 30 μg L^{-1}.** The elevated values are found in both private and public supply well waters. Data generated by field sampling (surface water, groundwater, and solid sediments) and laboratory experiments and analysis constrains the source of the observed elevated uranium concentrations. Results from surface water sampling indicate that irrigation return waters (runoff and shallow groundwater return) contain elevated dissolved uranium concentrations, suggesting that a near surface uranium source exists within the valley. When evaluated for isotopic composition, these surface waters indicate a consistent $^{234}U/^{238}U$ and $^{87}Sr/^{86}Sr$ isotopic source signature (See Figure 1); a signature that is also evident in the groundwater containing the most elevated uranium concentrations. To constrain the location of the uranium source, a wide variety of geologic samples, representing the stratigraphy of the Treasure Valley aquifer, were collected for bulk and leachable uranium analysis. Additionally, several phosphate fertilizers and ore samples were analyzed. The analyzed aquifer solids did not contain particularly high bulk uranium contents (avg. of 3.4 parts per million). Furthermore, isotopic analysis allowed nearly all the sampled sediments to be eliminated as potential source materials. In addition, these analyses **definitively indicate that the analyzed fertilizers, as well as the phosphate rich rock used to make those fertilizers, cannot be the source of the uranium.** Only one near-surface sample collected from Gowen Terrace matched the projected geochemical source signature, **suggesting that discrete units in the river terrace sediments may be the source of much of the elevated uranium observed in the Treasure Valley aquifer.** Elevated alkalinity values may be a useful, inexpensive, indicator waters at higher risk for elevated uranium concentrations. While this study was not able to confirm that deeper groundwater generally has lower uranium concentrations, the evidence of a near-surface source, coupled with the lack of a matching isotopic signature from deep sediments, **generally supports the remedial strategy of drilling deeper wells to reach water with lower uranium concentrations.** More work on further constraining potential source sediments is needed.

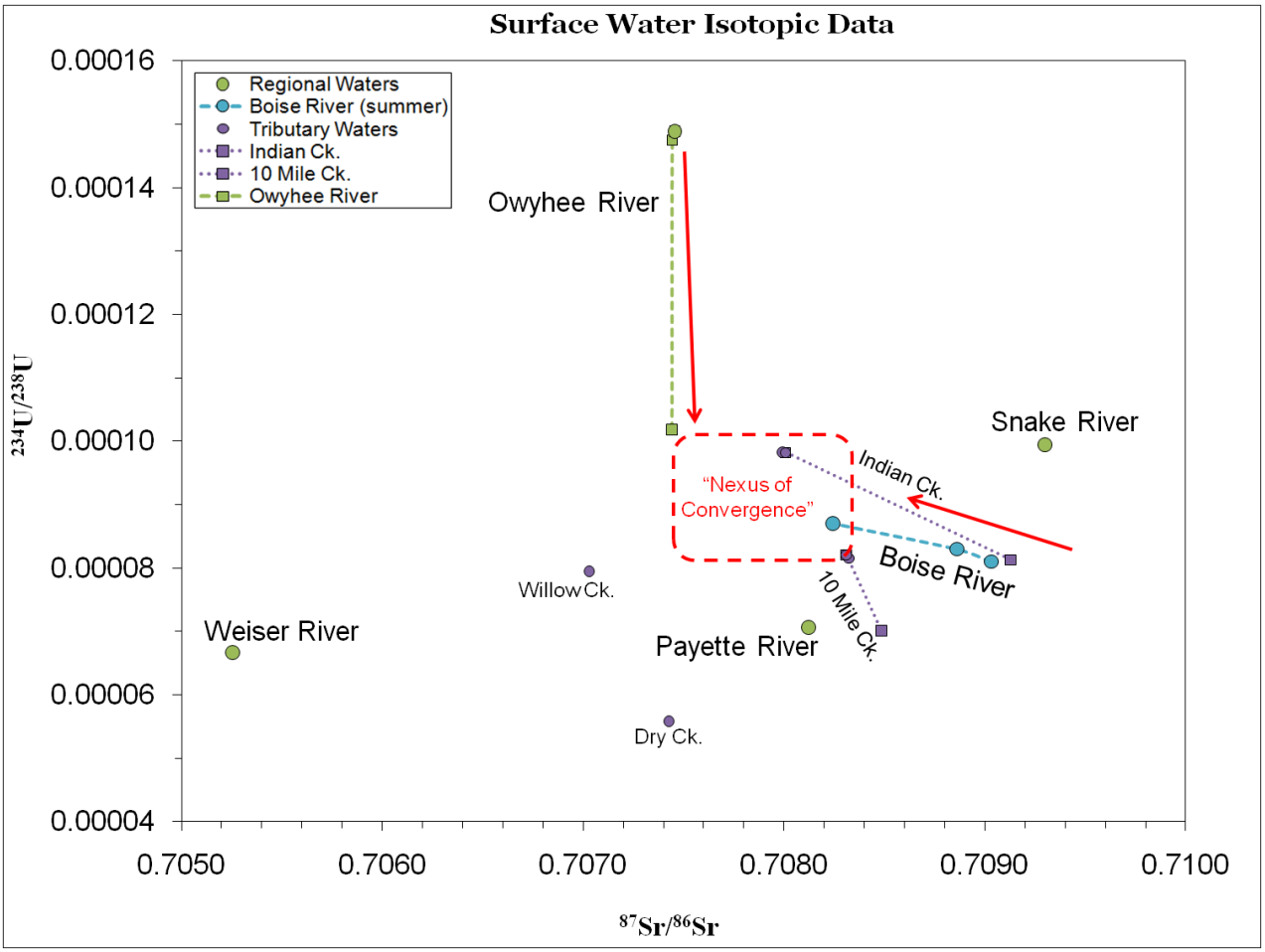

Figure 1: Boise River Watershed and regional river isotopic compositions. Arrows indicate the direction towards which the waters are evolving as sampling progresses downstream.

Publications Resulting from the Project: A report entitled: ***Isotopic and Geochemical Investigation into the Source of Elevated Uranium Concentrations in the Treasure Valley Aquifer, Idaho*** has been submitted to the Idaho Department of Environmental Quality.

Undergraduate and Graduate Student Researchers supported on the project: Brian Hanson, a MS student in the Hydrologic Sciences Program at Boise State University was supported by this project, graduation in pending

Notable Achievements or Awards: None

Managed Aquifer Recharge in the Treasure Valley: A component of a comprehensive Aquifer Management Plan and a Response to Climate Change

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Principal Investigators:	Bryce Contor, Stacey Taylor

Publications

There are no publications.

Managed Aquifer Recharge in the Treasure Valley: A Component of a Comprehensive Aquifer Management Plan and a Response to Climate Change

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Managed Aquifer Recharge in the Treasure Valley: A Component of a Comprehensive Aquifer Management Plan and a Response to Climate Change

INTRODUCTION

Historically the mountain snow pack upstream of Idaho's Treasure Valley has provided a storage mechanism to retain wintertime precipitation and release it in the spring and summer. In the last century surface-water storage reservoirs were built to provide additional storage, and elaborate canal systems were constructed to deliver water for agriculture, industry and growing cities. Percolation from these canals and from irrigation enhanced existing aquifers, and increasingly these aquifers are also utilized.

In a proactive and forward-looking step, the State of Idaho has embarked on a planning process known as the Comprehensive Aquifer Management Plan (CAMP). One of the anticipated drivers of future needs and supply constraints is climate change, and one anticipated response is to provide additional storage capacity to mitigate the effects of altered patterns of runoff from mountain snow pack. Local aquifers can potentially provide additional storage. Managed aquifer recharge means to intentionally place water in the aquifer at times when supplies exceed current needs, for later withdrawal when supplies are short. It may provide storage at lower cost than building new surface-water structures, protects water from evaporation, and does not carry the threat of catastrophic flood from infrastructure failure.

Aquifer recharge can also mitigate the potential loss of surface storage capacity due to increased flooding risks posed by climate change. With a robust and active aquifer recharge program, carryover water that is at high risk of being spilled for flood-control purposes can be moved to storage in the aquifer and thereby retained in the basin for future use.

This paper provides an initial look at managed recharge, to set the stage and provide context for consideration by participants in the CAMP process. It addresses:

1. Hydrogeology and current aquifer conditions.

2. Potential storage capacity of the Treasure Valley Aquifers available for managed recharge.

3. Location of potential recharge sites.

4. Capacity to deliver water to the recharge sites.

5. Approximate residence time of water stored in the aquifer, before it is depleted by migration to hydraulically-connected surface-water bodies.

METHODS

Hydrogeology was assessed by review of existing data and reports by professional geologists, combined with mapping of stratigraphy from existing well-log data.

Potential Storage Capacity was addressed by Geographic Information Systems (GIS) mapping of the land surface elevation and water-table elevations in the Treasure Valley. Geologic materials deeper than 50 feet below land surface and above the water table were considered as available space which could store water.

Location of Potential Recharge Sites was based on GIS mapping of existing gravel-pit data, along with comparison with aerial images, consultation with local practitioners, and field inspection.

Delivery Capacity was assessed based on information from the Boise Board of Control, along with examination of historical diversion records.

Residence Times were assessed using an adaptation of the Balmer/Glover/Jenkins stream depletion methodology.

HYDROGEOLOGY

General Description

The hydrogeology of the area consists of basalt flows and sedimentary units of the Idaho Group (Ralston and Chapman, 1970). The area of interest (Figure 1; all figures are at the end of the text, preceding the References section) is bisected by a northeast trending zone of complex faulting and is at the edge of the basalt flows that are exposed at the surface southwest of Kuna (Mitchell, 1981). Shallow basalt flows encountered during drilling are generally thicker in the south portion of the study area. Sand, silt, clay, and gravel layers are below the basalt units and form the primary aquifer of the area. The area has undergone significant faulting and both northeast and northwest trending faults

are present (Otto and Wylie, 2003). Fault zones impact water temperatures by providing a conduit for geothermal water to flow upward into the overlying cold water aquifer within the Idaho Group (Mitchell, 1981). The diagrams and cross sections do not take into account faulting but rather provide general trends in mega scale hydrostratigraphic units in relation to the water table.

Figure 1 shows a shaded relief map with higher elevations of darker blue tones and lower elevations shown with darker brown tones. Wells used for the geologic model are shown with yellow circles and wells used for water levels with blue circles. The locations of eight geologic cross sections are noted with black lines and letters A through H. For scale the red lines note the Township and Ranges of six square miles. Sections are illustrated in Figure 2 through Figure 5.

Figure 7 shows a solid three-dimensional model with a color air photo draped over the geologic model that has a vertical exaggeration of 50 times the horizontal scale for better viewing. The gray color represents basalt and the orange tones sediments of sand, silt, clay and gravel. The south vertical panel for the basalt is removed to provide a view inside the model. The water table is modeled with a color spectrum for different elevations with the highest elevations shown as red tones and the lowest elevations with purple and dark blue tones. Generally, the water table has a dip from the northeast to the southwest and groundwater flow is interpreted to flow in this same general direction.

The deepest wells are typically about 900 feet below land surface with one exception of an oil and gas exploration well (Figure 6) drilled by Champlin Petroleum Company in 1980 to a depth of 9,022 feet below ground surface (Idaho Geological Survey). The well helps define sediments extending down to about 2,000 feet before the first interbedded basalt is encountered, then more sediments with minor interbeds of basalt on down to 9,022 feet. It is reasonable to assume this general stratigraphy extends below the project area in Figure 1 and the wells used in the geologic model. There is a 'blue' clay commonly described in the well drilling logs from numerous wells and possibly has a more extensive spatial distribution than can be identified from wells, since wells typically don't penetrate deep enough to encounter the clay in the eastern area in Figure 1. This blue clay probably plays a major role in the behavior of the groundwater systems of the area and any aquifer recharge efforts should take this into account. This layer of clay could limit the movement of recharge water into deeper parts of the aquifer unless engineering solutions (discussed later in this report) are pursued.

Figure 8 shows the same geologic model as in Figure 7 but with panel fences and the water table. The view is from above but note how the contact between the base of the basalt and the underlying sediments is undulatory in nature with

the water table 'cutting' a more horizontal plane and 'passing' through both sediments and basalt. This relation is important to take into account when interpreting hydrograph trends. Figure 9 shows the same panels as Figure 8 but the view angle is from below the wells and demonstrates how wells are completed in sediments, basalt or a ratio of both. Wells such as the 'Whitehead Construction' well (T2N R2W 22) or other wells in this proximity are pumping water from sediments which tend to have much different hydraulic properties and lower yields than wells completed in basalt 'lows' which typically produce greater yields and different water level patterns. The basalt lows may be due to faulting but the modeled trends support ancient topographic lows, probably old canyons cut into the sediments from streams and rivers that later filled with basalt. This geologic phenomena was identified by Harold Stearns et. al. (1938) in the Glenns Ferry Formation of the Hagerman Valley area. Farmer and Blew (2011) present groundwater flow tracking data that appears to validate Harold Stearns observations.

Landslide Hazard

A geologic hazard that is often overlooked is the possibility of landslides induced by perched aquifers. Landslides are common in this area of the Snake River Canyon and in the Hagerman Valley area. Some landslides in the Hagerman Valley were caused by anthropogenic perched aquifers created by irrigation water from the Bell Rapids Irrigation Project (Farmer, 1999). One landslide destroyed a million dollar pumping station and nearly killed two workers.

The same hydrogeologic conditions are present south of Boise with Figure 10 highlighting one area in the southwest corner of section 30 T2N R3W. This area shows an elevated plateau with irrigation ponds and crops. Perched aquifers are readily present flowing through sediments that can easily fail when saturated. Slope failures in this area and other areas of similar hydrogeology are likely. While the hazard currently exists as a result of irrigation on the bench above the river, managed recharge very near the Snake River in this area could exacerbate the problem. Careful investigation is in order prior to recharge on high-elevation lands near the river.

In this area (T2N and R3W sections 22 and 28) the pattern of geology described above appears to be present, based on data from nearby wells. However if recharge were contemplated in this area a more detailed study would be needed, beyond the scope of this report. Wells in the area near section 28 show little basalt and deep sediments with the 'blue' clay present at depth. The area to the north has a greater thickness of basalt overlying the sediments and probably produces a greater yield. The south area appears to have furrow irrigation which probably recharges the aquifer in the fine grained sediments which explains a high in the water table in this area. An adjacent low in the water table to the

north near section 22 has center pivots which have less recharge to the aquifer than furrow irrigation. The important concept to retain is understanding the subsurface geology before interpreting water level trends which may be localized due to a 'pocket' or valley filled with basalt and bounded by fine grain sediment 'ridges' or highs in the contact. These ridges and valleys in the underlying sediments will play a key role in how groundwater levels respond to changes in land use, irrigation practices and aquifer recharge.

Current Recharge Patterns and Water Level Conditions

Primary sources of recharge to the cold water aquifer are irrigation leakage (canal seepage and flood irrigation) and geothermal input from beneath (Otto and Wylie, 2003). Hydrographs for two area wells (02N01W18BBB1 and 02N01W04DDA1) suggest a positive response to development of the canal system in the Treasure Valley in the early 1900's (Figure 11). These hydrographs lend support to the notion that irrigation water is a significant source of aquifer recharge. The first well (02N01W18BBB1) is 300 feet deep and experienced a water level increase of approximately 50 feet between 1917 and 1953. The second well (02N01W04DDA1) is 203 feet deep, and demonstrates a water level increase of approximately 80 feet between 1914 and 1953. Based on these two hydrographs, it appears the response to surface recharge is less significant at depth since the shallower of the two wells showed the greater response.

Ground water flow direction in the study area is generally to the south/southwest towards the Snake River, perpendicular to water-level contours illustrated in Figure 12 and Figure 13. Although gage data is limited, Snake River to the south of the study area is a gaining reach and receives ground water that discharges from this study area (Petrich, 2004; Newton, 1991).

Based on the potentiometric maps of the region (Figures 12 and 13), a significant gradient exists towards the Snake River. Typically steep gradients are caused by either high flows, low hydraulic conductivity, or a combination. Based on indications of low riverbed conductance in the Snake River (Schmidt, 2011), general lack of seeps and springs (other than those induced by irrigation, as discussed above) and the presence of faults (which can limit lateral movement of water), it is possible that flows from the aquifer to the Snake River are somewhat limited.

The hydraulic conductivity of the aquifer varies, depending on the type of aquifer material encountered, with production rates ranging from 11 to over 3,000 gallons per minute (gpm). Transmissivity estimates based upon analysis of specific capacity data from well driller's reports range from approximately 1,000 ft^2/day to 250,000 ft^2/day.

Water levels have been declining since the 1960's with measured declines of approximately 10 to 13 feet during the past 30 years (Figures 14 through 16). The average rate of decline is approximately 0.3 to 0.4 feet per year, indicating the rate of aquifer recharge has been exceeded by rate of withdrawal. Figure 17 shows individual hydrographs for a suite of wells with detailed water level histories.

The cold water aquifer (upper aquifer) has sufficient productivity to develop large capacity irrigation or municipal wells. This statement is based on the fact that many deep wells exist throughout this area that produce cold water. In addition, specific capacity data reviewed from driller's reports indicates high transmissivity values, supporting the conclusion that the aquifer has sufficient productivity for developing deep cold ground water wells.

Although the cold ground water supply is currently sufficient for additional well development in terms of aquifer productivity, the declining water levels indicate the aquifer is currently in an overdraft with respect to the local ground water budget. Future impacts from ground water permit applications and approved but undeveloped ground water permits may increase the rate of water level decline and could cause an increase in water temperature from the geothermal contribution to the aquifer.

The recharge rate to the cold ground water aquifer appears insufficient to sustain additional ground water development without additional water level declines or an increase in recharge. Hydrographs and water level data indicate that the ground water pumping in this area has exceeded the recharge rate, resulting in ground water level declines. The declines indicate a portion of the ground water currently being withdrawn is being removed from storage. The magnitude and timing of the additional water level declines cannot be accurately predicted, but it can be assumed to at least be equal to or more likely exceed the historic water level declines. It is likely that ground water levels will continue to decline, until ground water withdrawals and recharge rates reach an equilibrium. The timing and water level at which this new equilibrium will be met cannot be accurately forecasted at this time.

Interaction Between Cold Water and Geothermal Aquifers

At some point in the future, the depletions and decrease in head may be sufficient to allow the geothermal contribution to impact the cold water supply, resulting in elevated ground water temperatures across the area. The timing and depth at which this may occur cannot be precisely determined due to a lack of data regarding the locations and rates of geothermal input into the cold water aquifer system.

To assess the potential of encountering low temperature geothermal water, a review of driller's reports and records within the IDWR geothermal database was conducted. Between the two data sources, 237 water temperature records were reviewed. Reported temperatures ranged from 50 to 99 degrees, with six wells reporting water temperatures classified as low temperature geothermal (85 degrees or greater).

Figure 18 is a plot of water temperature versus well depth. The relatively low correlation coefficient (R^2) of 0.31 indicates that temperature is not strongly correlated to total well depth. The weakly correlated data suggest a temperature gradient of approximately 17 degrees Fahrenheit for every 200 feet of depth (8.5 °F/100 ft). This gradient is approximately three times higher than the gradient of 29 degrees Fahrenheit for every 1000 feet of depth (2.9 °F/100 ft) reported by Otto, and Wylie (2003) and roughly two times higher than the gradient of 9 degrees Fahrenheit for every 200 feet of depth (4.5 °F/100 ft) reported by Mitchell (1981) for this same aquifer system.

The average temperature gradient for the data on Figure 18 is biased upward by data from several wells that exhibit significantly elevated temperatures. Most notably, the warmest water (99 degrees Fahrenheit) is from a well that is only 553 feet deep. The temperature is considered anomalous because there are 27 wells deeper than 553 feet in which the water temperature is consistently cooler than 99 degrees. This variability required a review of the spatial distribution of elevated water temperatures to determine the potential of applicants to encounter warm water. The relative importance given to these wells in analysis may explain the variation in results among different investigations.

Figure 19 shows wells with elevated (68 degrees or warmer) temperatures in the study area are located throughout the area and do not appear to be completely controlled by structural features. A mapped "zone of complex faulting and northeastern edge of the basalt flows" (Mitchell, 1981) southwest of Kuna appears to correlate with a linear trend of wells with elevated temperatures in that area (Figure 20). In addition to well depth, this zone of faulting appears to be a contributing factor to elevated water temperatures.

Additional unmapped faults may exist in this area that also contribute to the elevated temperatures by providing a conduit of deep geothermal water to enter

the cold water aquifer system of the area. It appears that elevated water temperatures within the area of interest can be attributed to a combination of well depth and proximity to conductive fault zones.

The mapped faults to the northwest of the study area have a NW/SE trend. If this trend was extrapolated linearly to the southeast into this area of concern, the extrapolated location of the fault zone would be positioned in the direct vicinity of permit applications associated in the area off of South Cole Road. Therefore, there is the potential for encountering geothermal waters in this area, and any future drilling should be conducted cautiously, so that low temperature geothermal water is not developed. This also suggests a target area for recharge; recharge could maintain the hydrostatic pressure in the upper cold-water aquifer, which may be limiting the upwelling of deeper thermal waters.

Groundwater Supply Considerations

Based on analysis of the hydrographs, water levels have declined across the study area for approximately 50 years. The water level trends suggest that the aquifer has not yet stabilized. The fact that the water levels are declining suggests that the withdrawal rates of ground water have exceeded the rate of natural recharge. Additional withdrawals from the aquifer in this area are expected to result in additional ground water declines. The rate of decline is difficult to predict without a transient numerical groundwater flow model, but it is reasonable to assume that the average rate of decline will equal or exceed the long-term approximate average rate of 0.3 to 0.4 feet per year. Development of a transient version of the Treasure Valley numerical groundwater flow model is underway but it is not scheduled to be available for at least a year.

Based on the relatively high aquifer transmissivity estimates that are derived from specific capacity data submitted on driller's logs, well to well impacts will most likely be minimal. In combination, indications that the aquifer is transmissive and that the rate of withdrawals exceed the rate of recharge make it likely that regional water level declines will continue to be a more significant problem than well to well impacts. If required, the distribution of water level declines that results from pumping (i.e., drawdown) can be calculated on a case by case basis using the semi logarithmic approximation of the Theis (1935) equation. Previous research in this area has predicted drawdown associated with a well pumping 1,550 gpm will result in approximately seven feet of drawdown at a distance of ¼ mile, and less than a foot of drawdown at ¾ mile (Baker, 1993). Wells with water levels at or near the level of the pump intake will either have to have the pumps lowered or be deepened if the water level declines continue into the future.

Summary of Hydrogeology

In summary, it appears that this area of the Treasure Valley is experiencing water level declines associated with withdrawal rates exceeding natural recharge. In addition, the fact that elevated ground water temperatures exist in the area limits the potential of developing the deeper cold water aquifer system. This points to the need to consider either supporting new development with surface-water sources or to provide managed aquifer recharge to offset and mitigate current and new groundwater withdrawals.

RECHARGE POTENTIAL IN THE TREASURE VALLEY

General Considerations and Discussion

Groundwater Flow Principles. In a widespread aquifer with full hydraulic connection, the water-supply benefits of recharge propagate in all hydraulically-connected directions. Counter-intuitively, this is true even when there is flow in the aquifer and an underlying hydraulic gradient (Reilly and others, 1987; Leake, 2011). Consider an aquifer with a hydraulic gradient towards a gaining river, illustrated in Figure 21. Natural and irrigation recharge takes place uniformly across the aquifer and wells pump at various locations. In Figure 22, additional managed recharge has occurred somewhere in the middle of the aquifer and created a mound of stored water. This created mound of water causes three effects:

1. The water-table is flattened up-gradient of the recharge site, slowing flow from the upper regions of the aquifer.
2. The water table is made steeper down-gradient of the recharge site, increasing flow to the river.
3. Water levels are elevated both up-gradient and down-gradient of the recharge site, reducing pumping lift and pumping costs.

The implication of these principles is that recharge can be effective in supporting groundwater pumping whether the recharge occurs up-gradient or down-gradient of the pumping.

Storage of Water in Aquifers. Some aquifers are called confined aquifers. The water is under pressure between nearly impermeable geologic materials above and below. When water is released from the aquifer, the primary mechanism of release is the elasticity of the geologic materials and the water itself. Even when water is released, because the water is confined in a pressurized zone of geologic materials, the physical dimensions of the water body are essentially unchanged.

Other aquifers are called unconfined aquifers. The top of the aquifer is at atmospheric pressure, and the water level moves up and down through the geologic materials as water enters and leaves the aquifer. The Treasure Valley aquifers considered in this report are the upper-most aquifers in the system and are generally unconfined. Water may be delivered to these aquifers by percolation from land surface or recharge basins.

In either case, the depth of water released for a given change in hydrostatic pressure (confined aquifer) or water-table elevation (unconfined aquifer) can be called the storage coefficient. This can be used to quantify the storage capacity of a potential recharge zone. For instance, if the water level were raised ten feet in an area of 1,000 acres, with a storage coefficient of 0.10, 100 acre feet of water would have been placed into storage.

Recharge Management and Preliminary Preferred Location. Recharge will be easiest to manage when the water table is far below land surface. This avoids the hazards of intercepting basements or buried waste, and minimizes the potential of damaging foundations and other structures. As described earlier, Figure 12 shows the general map of depth to water in the Treasure Valley, based upon observations at shallow wells. We recommend that a 50-foot buffer be maintained between land surface and the water surface after recharge, to prevent water from entering basements or damaging infrastructure. This could be refined with site-specific investigation.

Early in the project, IDWR identified a preferred area of potential recharge based on depth to water, location of potential recharge sites, and distance from the Snake River. This area is circled in green in Figure 23. The New York canal is marked in yellow and a gravel-pit GIS data set (IDWR, 2003) is marked in red. IDWR's initial assessment was that "Locations further west have too shallow of depth to water table and further south is too close the Snake River which will short circuit recharge water to the river."

Recharge Locations to Avoid. In addition to controlling recharge to keep groundwater out of basements, waste deposits and infrastructure, recharge sites should be selected to avoid:

1. Close proximity to community drinking water wells.
2. Locations that require high-bank constructed infrastructure above homes or schools.
3. Locations that require high pumping lifts to deliver recharge water. However, the costs of pumping should be evaluated in the context of the costs of other storage options; some moderate-lift pumping may still be rational.

Water Level Changes. Figures 14 through 16 show water level changes between 1996, 2001 and 2008. These indicate areas where existing water use may exceed local supplies, and where managed recharge can be especially beneficial. Existing cones of depression can be back-filled by recharge without raising the water table above historical levels.

Recharge Where Water Levels are Near land Surface. With careful management, Aquifer Recharge can also be used in areas where the water table is near the surface, as practiced in California (Thomas, 2001). The first step is to pump the aquifer to sustain a use for which surface water is not currently available. This creates a cone of depression, making space for recharge of surface water that is delivered later at times of high flow and low water demand.

Other Considerations. Additional considerations for managed recharge are beyond the scope of this report. They include:

Water Storage in Deep Aquifers. Water can also be recharged into deep aquifers, which are often confined. Injection wells are often required and additional technical challenges can arise, including chemical compatibility issues. This practice is often called Aquifer Storage and Recovery (ASR). While it may also be a promising storage technique in the Treasure Valley, it is not considered in this report.

Recharge methods and infrastructure. This project did not thoroughly investigate all the engineering methods and solutions that may be applied in physically performing managed recharge. However, techniques do exist for various physical or geological conditions that might arise. For instance, Figure 24 shows a method that US Bureau of Reclamation and US Geological Survey (Mundorff, circa 1962) have described for overcoming limitations of low-permeability materials that may lie between permeable surface materials that could accept recharge and permeable materials at depth which host a receptive aquifer. As water enters the geologic materials in the upper layer, it is filtered in the same manner that natural recharge from streams and precipitation has always been filtered, and the way the irrigation recharge has been filtered for over 100 years. A cased well is completed through the upper materials, through the confining layer (perhaps the blue clay discussed earlier in this report) and into a lower aquifer, perhaps a cold-water aquifer currently utilized and which it is desirable to protect from upwelling of warm water. The casing is solid near the surface, protecting the aquifer from surface contamination. Deeper in the upper geologic materials, screens or perforations allow water to enter the well casing and flow down into the deeper aquifer. Of course there are additional technical considerations to be analyzed, including chemical compatibility between the recharge waters (as altered by transit through the upper geologic materials) and the waters in the receiving aquifer.

Accounting for Benefits of Recharge. Because recharge provides general benefits to the public at large, recharge can rationally be conducted without any detailed accounting of the fates and benefits of recharged water. Conceptually, the benefits of recharge can also be quantified specifically and applied to offset particular uses of groundwater. Though beyond the scope of this paper, the technological ability to perform this accounting has been demonstrated (Contor, 2009). The method allows quantification of the depletion of stored water, as the recharge mound migrates to hydraulically-connected water bodies.

Water Rights and Water Availability. Any consideration of additional storage by the CAMP process must address availability of water to store, and the associated water-rights issues of authority to place this water into storage. This is true for both surface-water storage and groundwater storage and is beyond the scope of this report.

Land Ownership, Access, Easements, Rights of Way, and Conveyance Agreements. This report does not investigate the ownership of any of the potential sites, nor discuss easements for ditches nor conveyance agreements for water delivery. Nevertheless, these are all essential elements of any recharge program. There is no intent to assume or recommend use of any facility or property for recharge purposes without the full input and participation of the owners and managers of those facilities.

Infrastructure and Management Costs. This report provides the context of potential capacity for storage in the aquifer, but it does not address costs of conveyance, infrastructure, or management. Costs for aquifer recharge should be considered in the context of costs of other storage and supply options.

Aquifer Storage Capacity

Assuming a 50-foot buffer between land surface and the post-recharge water table, the depth of available geologic materials was mapped in GIS. This was multiplied by the storage coefficient 0.10 from the USGS aquifer model of the Treasure Valley (Newton, 1991) and by a storage coefficient of 0.05 from textbook values for typical geologic materials in the Boise Valley (Freeze and Cherry, 1979).[1] Figure 25 shows the average volume of potential storage in each Public Land Survey Township (approximately 36 square miles) using the textbook storage coefficient. The USGS storage coefficient would indicate twice this volume. Across the study area, the text-book coefficient indicates

[1] Note that these values are higher than preliminary values from ongoing modeling efforts (Schmidt, 2010). However the values used here are consistent with pump-test data and are realistic for the expected geologic materials.

approximately 4,000,000 acre feet of potential storage and the USGS coefficient indicates about 8,000,000 acre feet.

Of course this assumes that every available cubic foot of the aquifer would be accessible and useful for storage. Excluding the high-elevation lands on the south and east of the study area leaves approximately 800,000 to 1,600,000 acre feet of capacity, depending on the storage coefficient. If realistically one-fourth of this could be utilized, potentially 200,000 to 400,000 acre feet of storage could be accessed by carefully managed aquifer recharge.

As discussed below, current infrastructure may not be adequate to deliver this volume of water to storage. Costs of needed Infrastructure improvements might be considered in the context of costs for of other storage options.

Additional storage space may be created in the northwest regions of the study area, by first pumping groundwater and then back-filling the created cone of depression with recharge water at a later time (Thomas, 2001). The available storage volume will be the volume pumped, less any flow from the Boise River that is induced by the pumping before the recharge takes effect. Additional considerations for this practice are described in the "Residence Time" discussion, below.

Potential Recharge Sites

A field inspection trip was conducted on November 30, 2010 to field verify the potential sites identified by IDWR staff. A total of 26 sites were visited, mostly in southern Ada County (Figures 26 and 27). Specifics related to each site are presented below. Owners of sites and delivery infrastructure have ***not*** been consulted; obviously this would be an important first step for further consideration. Many of these sites are currently actively mined and therefore are candidates for future recharge development, after extraction of sand and gravel is completed.

<u>Sites 1-5, Southeast Boise</u>. The five sites located around the airport and Gowen Road have high potential for recharge. All of the sites are relatively close to the New York Canal and all are fairly large excavations that could store a significant quantity of water. A recharge site with large storage capacity can be filled rapidly to maximize capture of short-duration runoff at a rate that exceeds the rate of infiltration; stored water can continue to infiltrate after the window of opportunity to divert recharge water has passed. The coarse sands and gravels in the area suggest permeable conditions exist in and around the excavation sites. Details on each of the sites are as follows:

Site 1. Site 1 is the location of an active recycling facility, located in an inactive gravel pit. The New York Canal flows approximately 700 feet to the east of the site.

Site 2. Site 2 contains an active gravel pit and several inactive gravel pits that are currently being operated as a wastewater storage facility. The New York Canal borders this site to the west, approximately 250 feet away.

Site 3. Site 3 is an active quarry, currently operating as a concrete manufacturing plant. The New York Canal borders this facility and is less than 300 feet to the north.

Site 4. Site 4 is a large complex of gravel pits, active and inactive, south of Interstate 84 and east of the Boise Airport. The site is rather extensive in size and depth. The New York Canal flows to the north of the site, approximately 2/3 of a mile away.

Site 5. Site 5 is a gravel pit surrounded by industrial operations of lumber and manufacturing. Access for inspection of this site was limited. The New York Canal flows approximately 0.5 miles to the north of the site.

Sites 6-8, Black's Creek Area. Sites 6, 7, and 8 are near Black's Creek and the Black's Creek Reservoir. Inspection of these sites indicates that permeable conditions exist, however a reliable water source and conveyance mechanism do to not exist. Black's Creek, the nearest surface-water feature of the area, is an intermittent stream and does not flow year-long. The potential to capture spring runoff (in excess of existing reservoir capacity) would be the optimal scenario for sites in this area. Details related to each of the sites visited area as follows:

Site 6. Site 6 is an intermediate sized active gravel pit, located to the south of Interstate 84 near the Black's Creek exit. Black's Creek, an intermittent stream, flows to the south of this site approximately 400 feet away.

Site 7. Site 7 is an Idaho Department of Transportation source material site, and is an active gravel pit. The site is located to the north of Interstate 84, near the Black's Creek exit. Black's Creek flows to the south of the site approximately 2/3 miles away.

Site 8. Site 8 is the location of Black's Creek Reservoir. This reservoir is managed by multiple state and federal agencies to serve as a wildlife refuge. The source of water to the reservoir is Black's Creek.

Sites 9-22. Tenmile Ridge Sites. These sites are existing sand and gravel quarries, most of which are active. The majority of the sites are excavations into the ridgeline, significantly higher in elevation in comparison to existing stream channels. The stream that flows adjacent to these sites is intermittent and does not appear to be a reliable source of water. Sites 21 and 22 are closest in proximity to a potential recharge source, the New York Canal, which flows less than a half mile from these two quarries. Infrastructure and pumping costs are obstacles to the use of sites 9-22, but these should be considered in the light of the costs of other storage and supply options.

Site 23. Site 23 is the Hubbard Reservoir. The reservoir is connected to the New York Canal and is operated for flood control and wildlife habitat. At the time of the field visit, the reservoir was nearly empty, with additional holding capacity available. The footprint of the highwater mark of the reservoir covers approximately 250 acres. The standing water in the reservoir at the time of the field visit suggests that either the parent materials have low permeability or that a seal of low-permeability materials has formed over time. In the latter case, periodic maintenance with mechanical disturbance may be used to increase the infiltration capacity of the site. The reservoir appears to be a good candidate for recharge based on the existing structure, conveyance mechanisms, and source of water.

Sites 24, 25 and 26. Only two of these sites could be field verified. Both have good potential as recharge sites due to the presence of irrigation laterals near each site. However, these sites are located in areas of shallow depth to groundwater. Recharge at these sites may have to be managed under a regime of pumping first and then back-filling the cone of depression.

> Site 24. This site could not be located during the field inspection. It appears that if a potential recharge did exist previously, it has been built on with residential development.
>
> Site 25. Site 25 is another Idaho Transportation Department source material site. Currently, several large, active sand and gravel quarries exist. A small irrigation ditch runs along the site, providing a potential conveyance for source water.
>
> Site 26. Site 26 is a large sand and gravel quarry located south of Interstate 84, just west of Meridian. The site is extensive and has at least one minor irrigation lateral running adjacent to it which could serve as conveyance for source water.

Eagle Site. In January an additional site was inspected near Eagle (not mapped). This site is where the Farmers Union Canal crosses Dry Creek. The canal

appears to be hosted in sandy material and crosses the creek at an elevation that would facilitate infrastructure to deliver Dry Creek water into the canal for direct percolation from the canal bed during the non-irrigation season.

Conveyance Capacity

The most cost-effective means to convey water to recharge sites is to use existing infrastructure to the extent possible. As recharge is contemplated, the Boise Board of Control and local canal managers should be involved early in the planning process. The preliminary evaluation in this report begins to explore the potential capacity of the New York Canal to deliver water to recharge.

In general, existing canals in the New York Canal system operates up to the freeboard limit from April 15 through October 15 (Deveau, 2011). While canals are theoretically available for recharge before and after those dates, icing and maintenance considerations provide some practical limitations to the period during which recharge water might be delivered. However, the historical record shows that some water has been diverted by the New York Canal in each of the twelve months, at some time during the last 20 years. Water users in Eastern Idaho have demonstrated that off-season recharge can occur even in the harsh winters of Fremont County (Taylor and others 2010; Contor and others, 2009).

The necessity to check up canals to maintain head for diversions can create the appearance of no freeboard and no available capacity, even though the canal is delivering less water than it does at other times of the year. Generally, at those times, check structures could be adjusted to allow some delivery to recharge sites without threatening the necessary operational freeboard.

Following work done for the Eastern Snake Plain Aquifer CAMP process (Contor and others, 2008), historical flows in the New York Canal have been analyzed for periods of time when diverted flows are typically less than maximum. Figure 28 shows the historical record of monthly diversion volume. The red line marks 140,000 acre feet per month, suggested as a first estimate of safe monthly diversion volume (in the period 1928-2006, ten percent of monthly deliveries exceeded 158,000 acre feet and the maximum was 187,000).

Figure 29 shows diversions for the last 20 years of canal operation. The wide yellow bars give the average and the whiskers give the maximum and minimum. For instance, the July average diversion was 130,000 acre feet but one year the July volume was almost 150,000 acre feet and it has been as low as 100,000 acre feet.

Using 140,000 acre feet as a safe maximum monthly diversion, the historical potential canal capacity for the period 1990 - 2009 was calculated by subtracting actual volume from the 140,000 maximum during each month of the irrigation season (April - October). For each of the off-season months, the 90th percentile of 1990 - 2009 diversions was used to represent the safe maximum, in an attempt to accommodate maintenance periods and icing conditions. Figure 30 illustrates the calculated monthly average potential capacity as a wide blue bar, with the dark whiskers representing minimum potential capacity during the 1990 - 2009 period.

Caution is needed in interpreting these data; it is quite likely that the years when recharge water might have been most available are years when adequate supplies allowed full canal deliveries and available capacity was at its minimum. During the 20-year period, the minimum potential annual available capacity was 270,000 acre feet and the 25th percentile (which was exceeded 15 years of the 20) was 330,000 acre feet.

This is still less than the potential storage capacity; additional conveyance infrastructure would be required to fully access storage potential in the aquifer. The cost of this infrastructure should be considered in context of infrastructure costs for other storage options, and its necessity should be considered in light of the timing and volume of water available to be stored and the need for additional storage.

This capacity analysis considers only the New York Canal, but water must still be conveyed from the canal to the recharge site. Local lateral capacity and/or new infrastructure should be investigated on an individual basis as potential recharge sites are considered.

Residence Time

In a surface-water reservoir, water remains available for future use, unless it must be spilled for flood-control purposes. Except for usually minor losses to evaporation and seepage, it can be retained in storage until called for. If an aquifer is connected to a surface-water body, however, the recharge mound effectively migrates into the river (via either increased gains to the river, or decreased losses from the river). While this benefits the river, especially in the late summer when cool aquifer water can sustain fisheries, it depletes the stored volume of water. For this report, the time to depletion of 50% of the recharged volume was assessed for seven representative locations in the aquifer, as shown in Figure 31. Point 4 is the location of the Hubbard Reservoir site discussed above.

The residence time depends upon the storage coefficient discussed previously, transmissivity (which is a measure of the ability of water to move through the aquifer) and distance (to the river) squared. Large storage coefficients, large distances and small values of transmissivity all increase the residence time in the aquifer.

The time to depletion can be calculated using a method known as both the Balmer-Glover method and the Jenkins method. It assumes a semi-infinite aquifer in communication with an infinitely long river. In this case, the Boise River has a finite length of connection to the aquifer, and the aquifer is bounded by the Snake River and impermeable hills. For this report, the method was adapted to represent these bounding conditions, as described by Contor (2011).

The adapted methodology was applied using aquifer properties from Newton (1991) and text-book values (Freeze and Cherry, 1979). The aquifer properties acquired from the Newton's investigation were based on model-assigned hydraulic conductivity values and storativity for the upper rock unit (layer 1) with a thickness of 500 feet. These values are displayed in Table 1. The aquifer properties acquired from Freeze and Cherry are values for a low conductivity gravel and/or high conductivity silty sand. These unconsolidated materials seem to best represent the uppermost geologic layer in the Treasure Valley. The storage coefficient of an unconfined aquifer is typically 0.01 to 0.30 (Freeze and Cherry 1979). Based on these given values and values for shallow aquifers in the Treasure Valley provided in recent studies (Thomas and Dion 1974, Newton, 1991), a median value of storage coefficient was chosen from the text. Likewise, the textbook transmissivity values in Table 1 are within the range of Thomas and Dion's investigation of the Treasure Valley.

Based on indications that the Snake River has significantly less communication with the aquifer than does the Boise River (Schmidt, 2010), these calculations were performed with the Snake River as a no-flow boundary. This is reasonable in light of the apparent lack of springs and wetlands on the southern margin of the Treasure Valley. It is also consistent with geologic mapping of faults (which may impede groundwater flow) parallel and just north of the Snake River (Othberg, 1994). Nevertheless, to test this assumption the calculations for Point 5 (near the Snake River) the calculations were repeated with the Snake River as connected.

Table 1 gives the calculated time to 50% depletion for the seven locations in Figure 31, along with the aquifer properties and boundary conditions utilized for each point.

Table 1
Time to 50% Depletion of Recharged Volume,
for Representative Aquifer Locations

Point	Snake Bound-ary	USGS Data			Textbook Values		
		T (ft^2/day)	S	Time to 50%	T (ft^2/day)	S	Time to 50%
1	No Flow	2,000	0.1	> 5 yr	140,000	0.05	570 d
2	No Flow	8,500	0.1	710 d	140,000	0.05	14 d
3	No Flow	8,500	0.1	88 d	140,000	0.05	4 d
4	No Flow	8,500	0.1	> 5 yr	140,000	0.05	> 5 yr
5	No Flow	8.500	0.1	> 5 yr	140,000	0.05	> 5 yr
5	River	8,500	0.1	> 5 yr	140,000	0.05	3 yr
6	No Flow	19,500	0.1	> 5 yr	140,000	0.05	310 d
7	No Flow	19,500	0.1	> 5 yr	140,000	0.05	780 d

From Table 1 it is apparent that there is significant uncertainty associated with the wide range of possible values for aquifer characteristics.[2] It is also apparent that except for points close to the Boise River, residence times in aquifer storage are long compared to the typical residence times in a surface-water reservoir. Also note that aquifer storage is not subject to spill for flood control requirements.

Comparing Figure 31 (points for depletion-time calculations) with Figure 23 (preliminary map of preferred locations) and Figure 12 (depth to water), it is clear that Points 1, 2 and 6 are in areas where storage will only be possible if space is first created by pumping a cone of depression. If this scheme were employed, the period of time that the cone of depression would remain available for back-filling is the same as the estimated residence time of storage from Table 1. Even with the uncertainty inherent in Table 1, it appears that at Point 1, the aquifer could be pumped to meet summertime needs, and the space created by the cone of depression would still largely be available for back filling by recharge that fall or the following spring. Timing of impacts to surface water would need to be carefully considered; perhaps the recharge would need to take place nearer the river than the pumping that created the space in the aquifer. The accounting methodology mentioned earlier (Contor, 2009) would facilitate this analysis and administration.

Point 3 is included to assess the Eagle/Dry Creek potential recharge location. It

[2] Current IWRRI work (Schmidt, 2010) gives preliminary aquifer characteristics that indicate generally shorter times than in Table 1.

is clear that further investigation into aquifer characteristics is called for. However, if the USGS data are approximately correct, it appears that water recharged in the spring would mostly still be available for use in the drier summertime periods of the same year. This site could be considered to provide about the same timing of storage and release as typical surface-water reservoir operations.

The two different values for Point 5 show that representing the Snake River as connected, rather than as a no-flow boundary, reduces the residence time by about half. Nevertheless, these data indicate that in either case, recharge in the southern-most potential sites could have residence times useful for water management.

The depletion of recharged water in Table 1 is also a potential benefit to the river(s). Even if not recovered by pumping, recharge can benefit surface-water users and fisheries late in the summer as it sustains river gains from the aquifer or reduces river-bed loss in hydraulically-connected reaches of the river. The tools used for the residence-time analysis can also be specifically applied to assess the impact of recharge upon surface-water bodies.

NEXT STEPS

The next logical steps in investigation of storage in the Treasure Valley apply both to surface-water storage and storage in the aquifer:

1. Assess needs for storage, based on projected demands for additional water and current water-supply shortages (if any).
2. Assess availability and timing of water that could be stored. Both physical supply (hydrology) and legal access (water rights) must be considered.
3. Assess the implied per-acre-foot cost of water delivered from storage, including capital costs, operational costs (including water treatment), and expected percentage of fill.
4. Compare this to expected economic demand for stored water.

Required steps specific to managed aquifer recharge are:

1. Contact and coordinate planning with owners and operators of canals and managed recharge sites that are considered for use.
2. Refine understanding of conveyance capacity and timing, and infrastructure or operational changes that might be necessary.
3. Coordinate with Idaho Department of Water Resources and Idaho Department of Environmental Quality to ensure that plans are within

existing water right and water quality guidelines.

4. Refine understanding of aquifer characteristics and expected residence time for promising sites.
5. Consider opportunities to maximize use of water stored in surface reservoirs by moving carryover storage to the aquifer, at times when it is expected that flood-control operations would otherwise cause spill of carryover.

SUMMARY AND CONCLUSIONS

It appears that the Treasure Valley Aquifer has the practical potential to store an additional 200,000 to 400,000 acre feet of water above what occurs naturally and incidentally to other human activities. This can potentially provide a meaningful contribution to water management. Much additional work is needed, but it appears that recharge sites can be identified to accept this water.

Most of the potential exists in the southwest, including the Hubbard Reservoir site. With the California practice of pumping first to create a cone of depression, and then back filling later with recharge water, additional opportunities (beyond 200,000 to 400,000 acre feet) could be accessed in the northwest Treasure Valley.

While uncertainty remains concerning aquifer residence times, it appears that in general recharge water stored in the aquifer is available for periods of months to a few years, except for locations very near the river.

Current infrastructure cannot deliver all the water that potentially could be stored in the aquifer. Managers and operators of canals should be consulted early in the planning process. Construction costs of additional infrastructure should be considered in context of construction and water-treatment costs of other storage alternatives. Tools and methodology exist to quantify the impact that recharge would have upon surface-water bodies, and to facilitate management of recharge and match it to withdrawal activities.

ACKNOWLEDGMENTS

The authors are grateful for the financial support of the US Geological Survey and the Idaho Department of Water Resources. Paul Deveau of the Boise Project Board of Control and R.D. Schmidt of Idaho Water Resources Research Instituted provided valuable input.

FIGURES

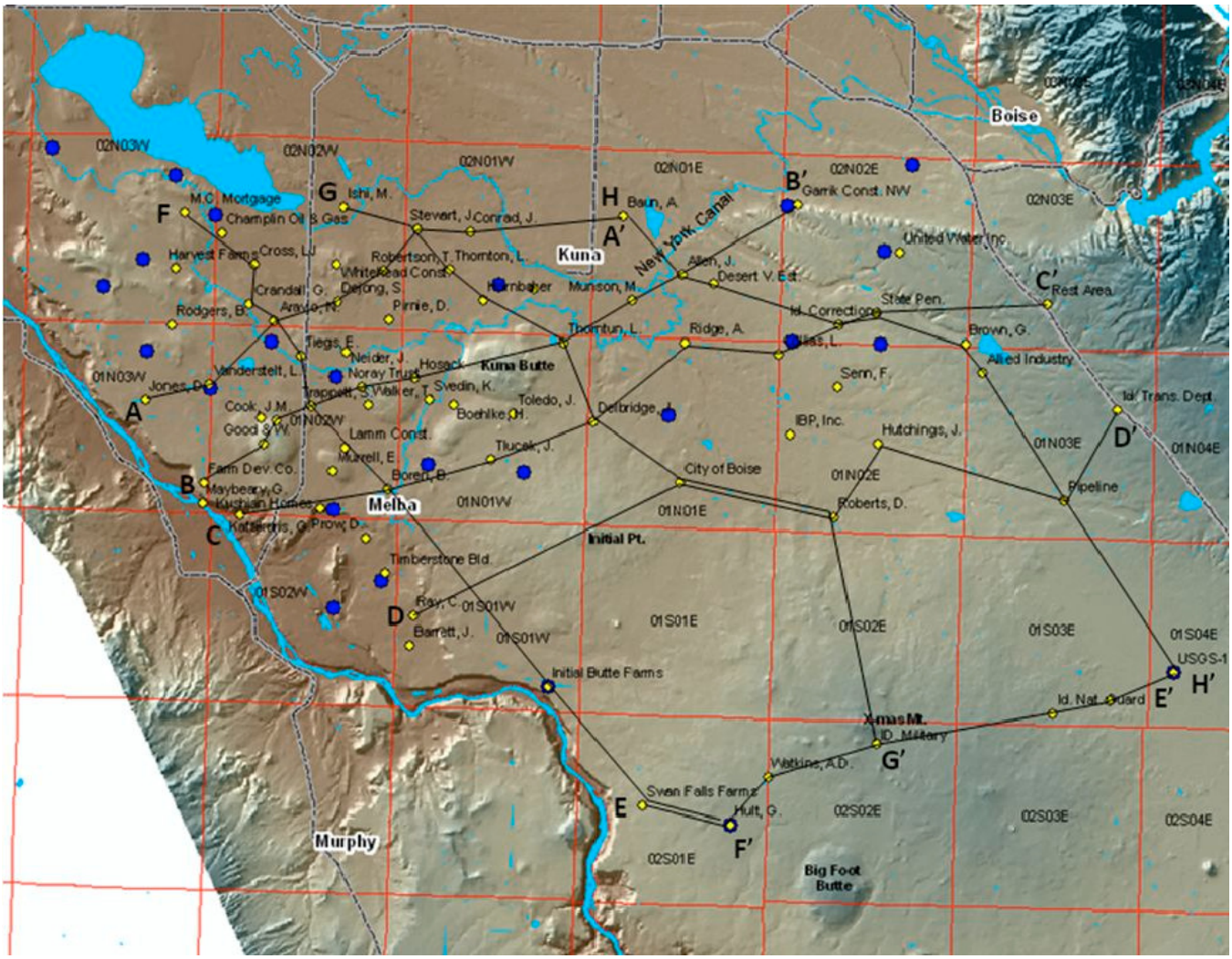

Figure 1. Shaded relief map showing wells used in the geologic 3-D model and cross sections shown as yellow circles and wells used for water levels shown with blue circles. The Township and Range grids are 6 square miles for scale.

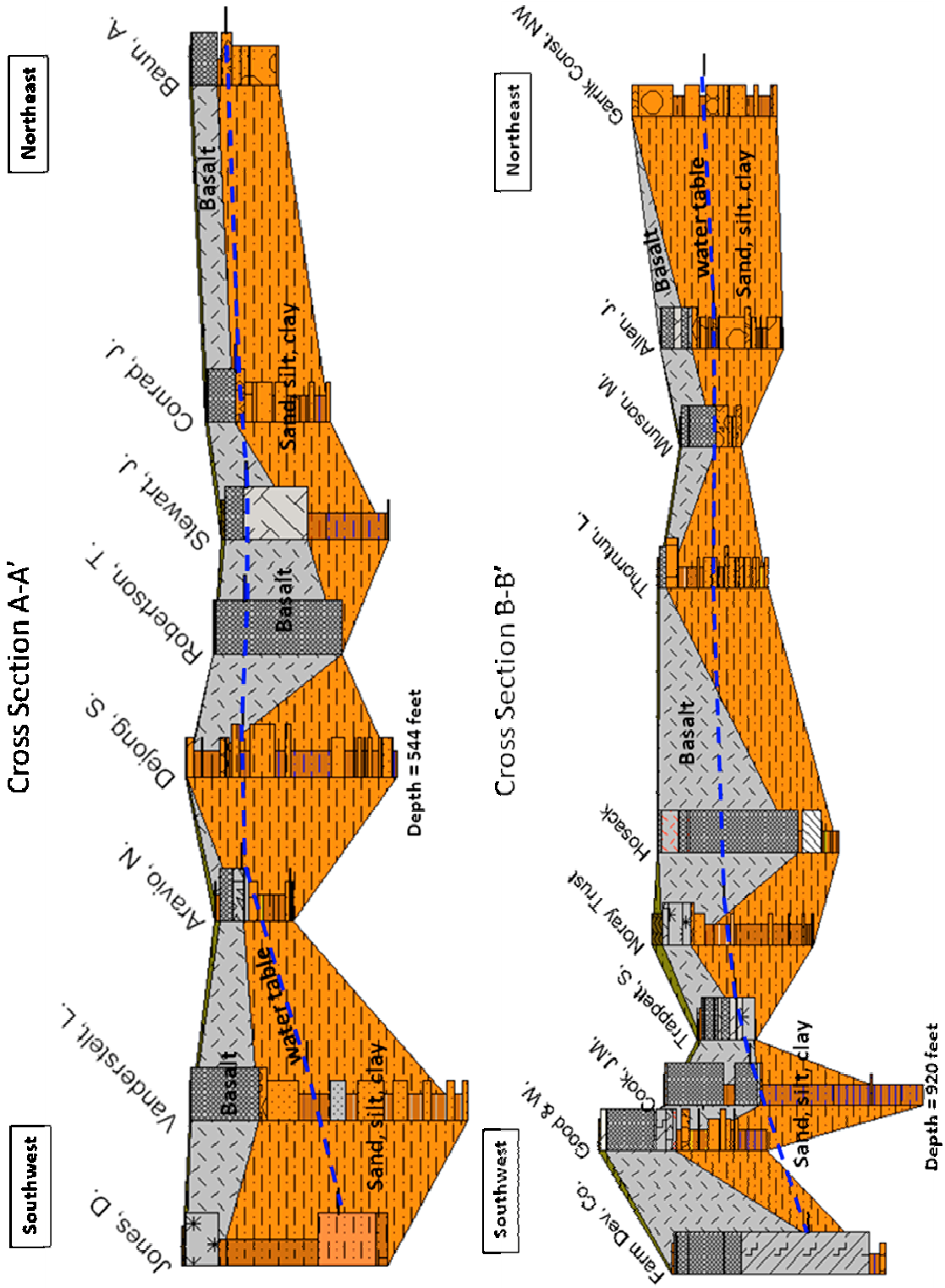

Figure 2. Cross sections A-A' and B-B'

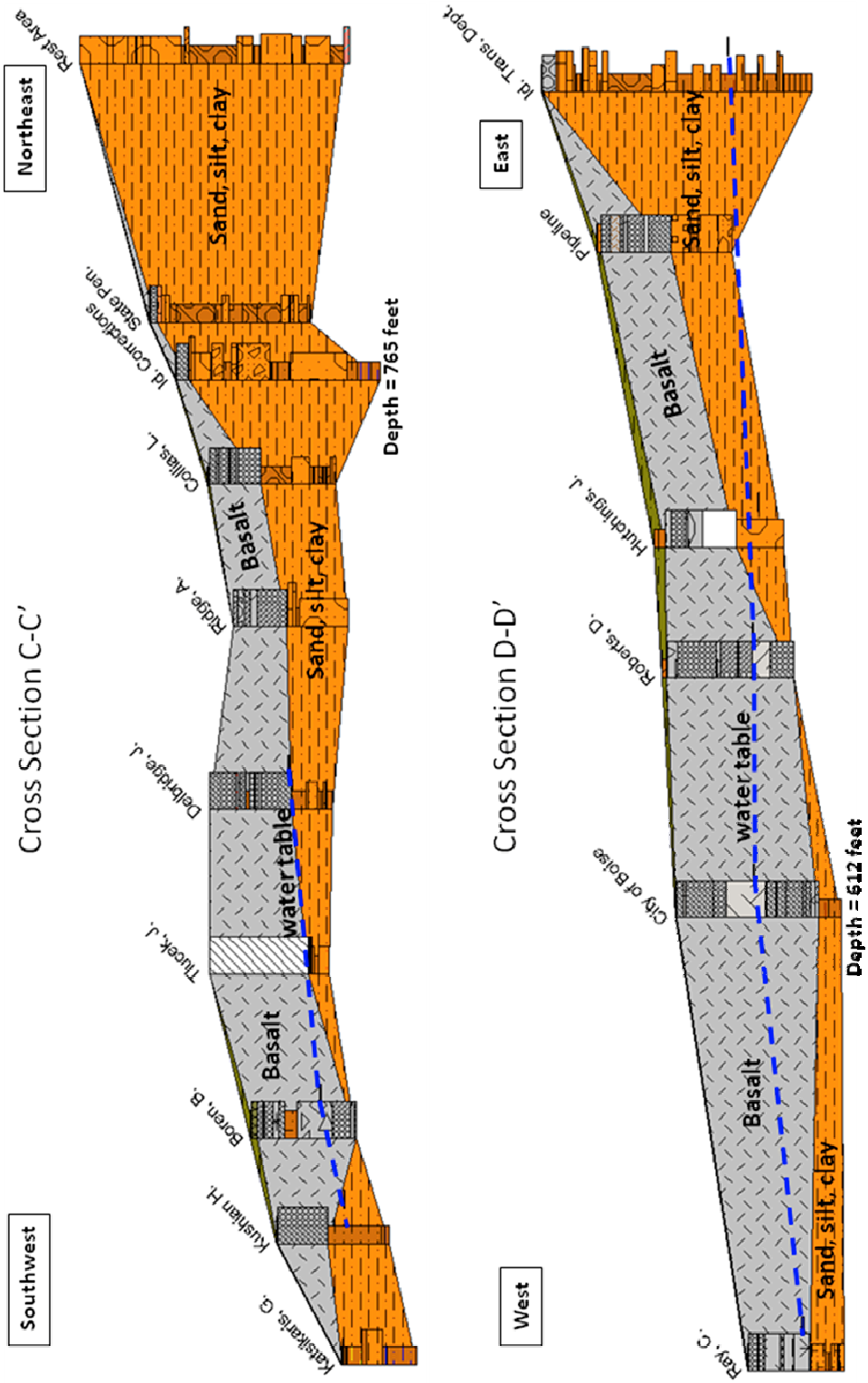

Figure 3. Cross sections C-C' and D-D'

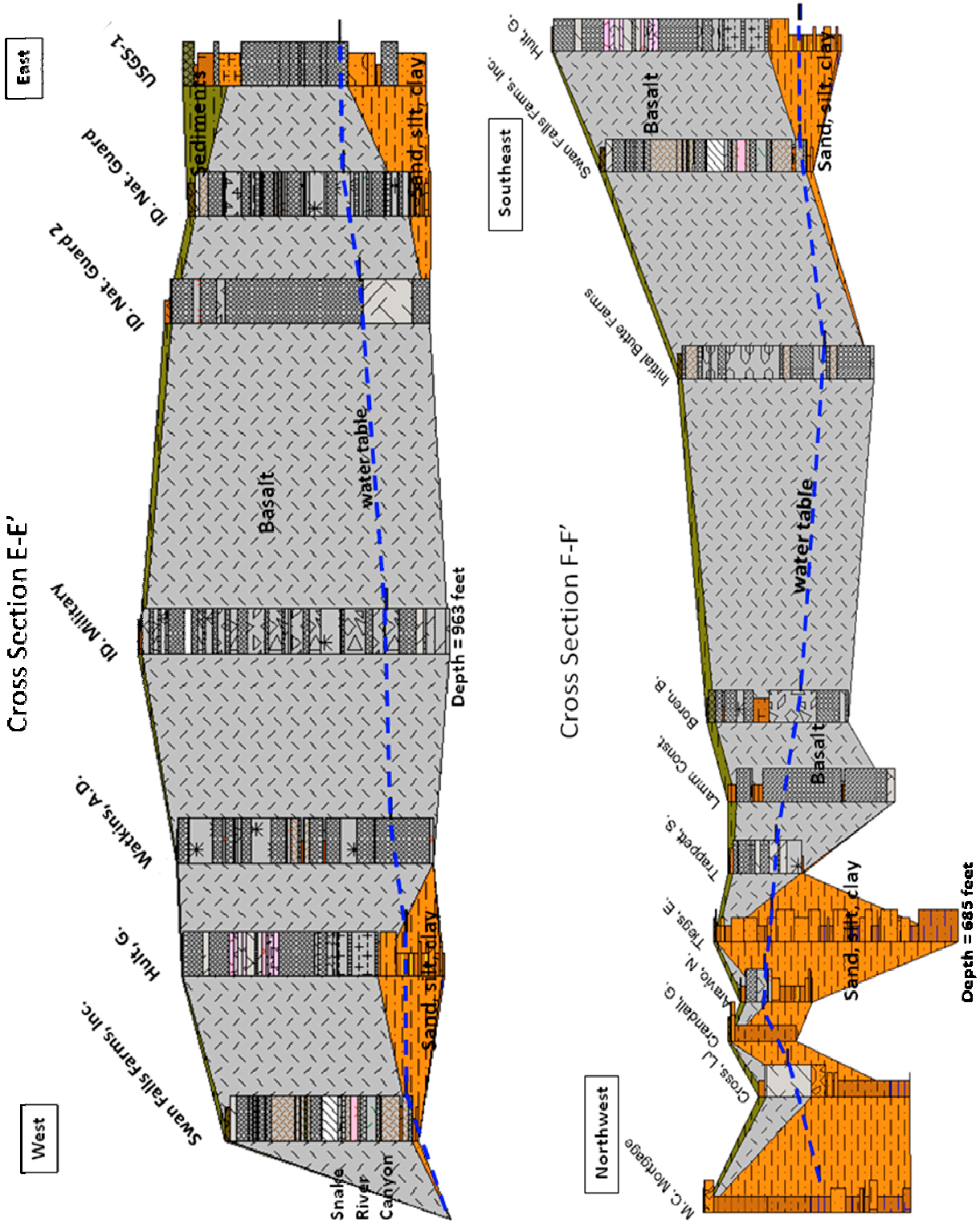

Figure 4. Cross sections E-E' and F-F'

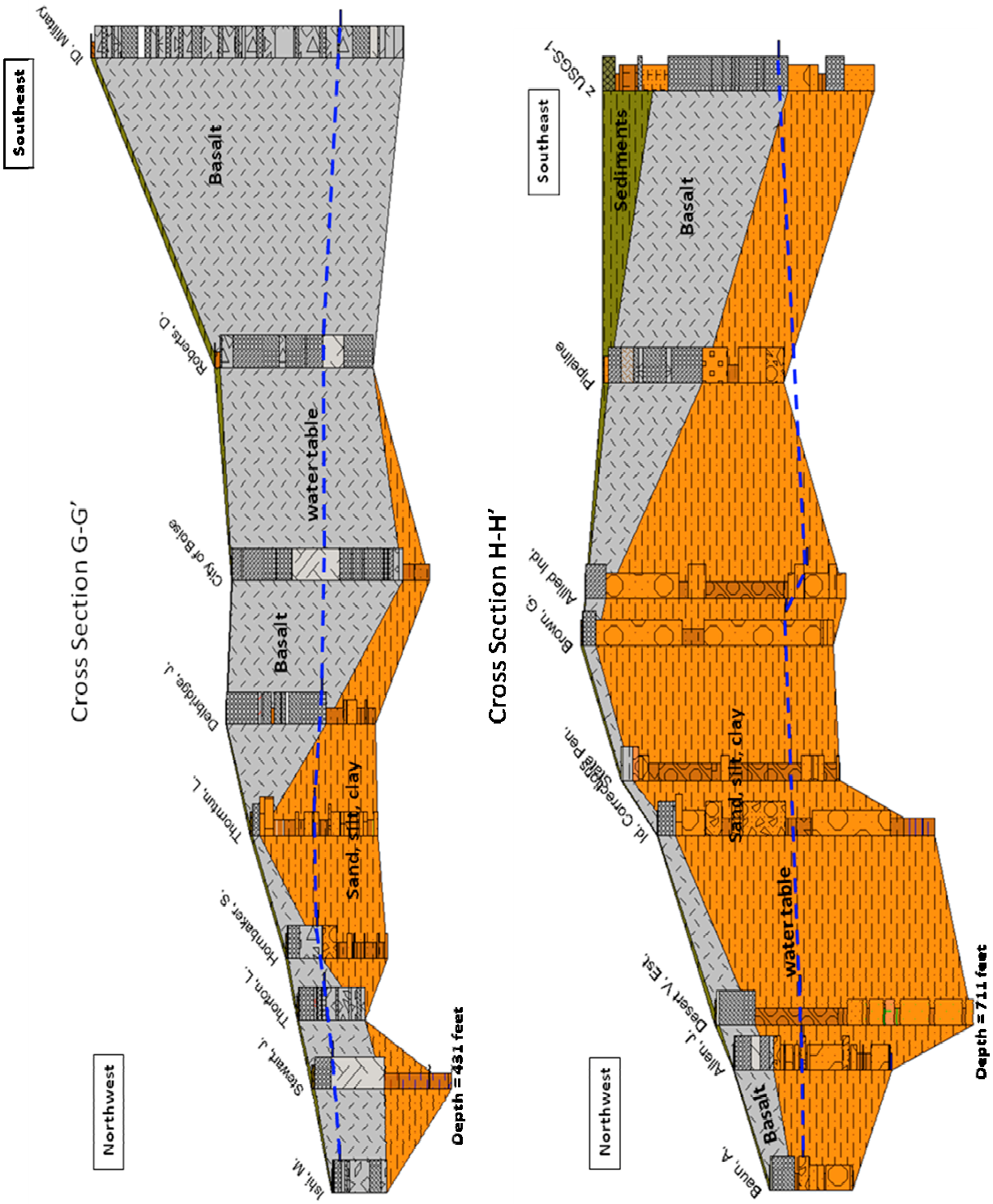

Figure 5. Cross sections G-G' and H-H'

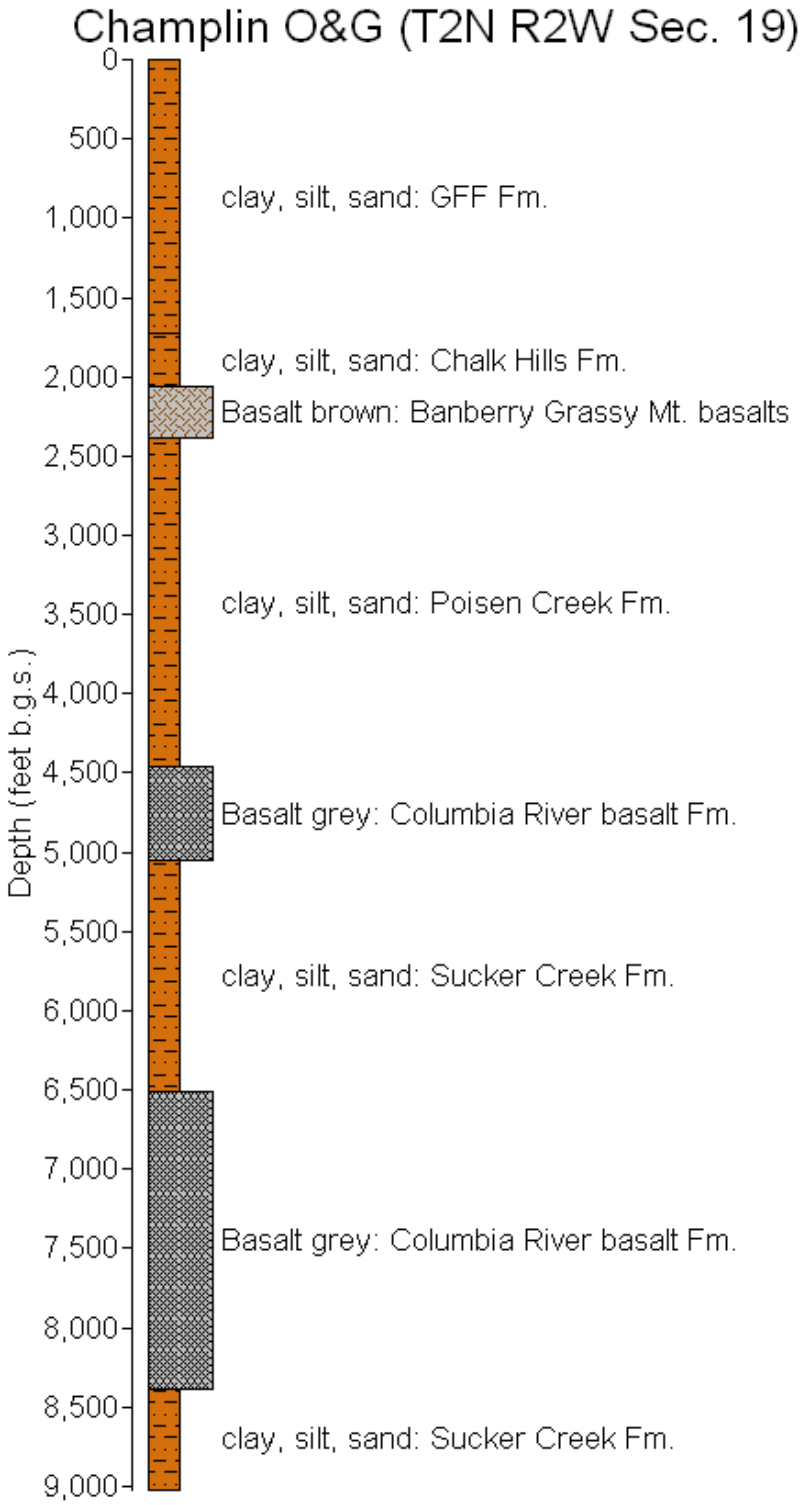

Figure 6. Champlin Oil and Gas well drilling geologic log showing Glenns Ferry Fm. sediments extending down to at least 1,500 feet. These sediments are assumed to extend under the project area cross sections A-H. (source: Idaho Geological Survey)

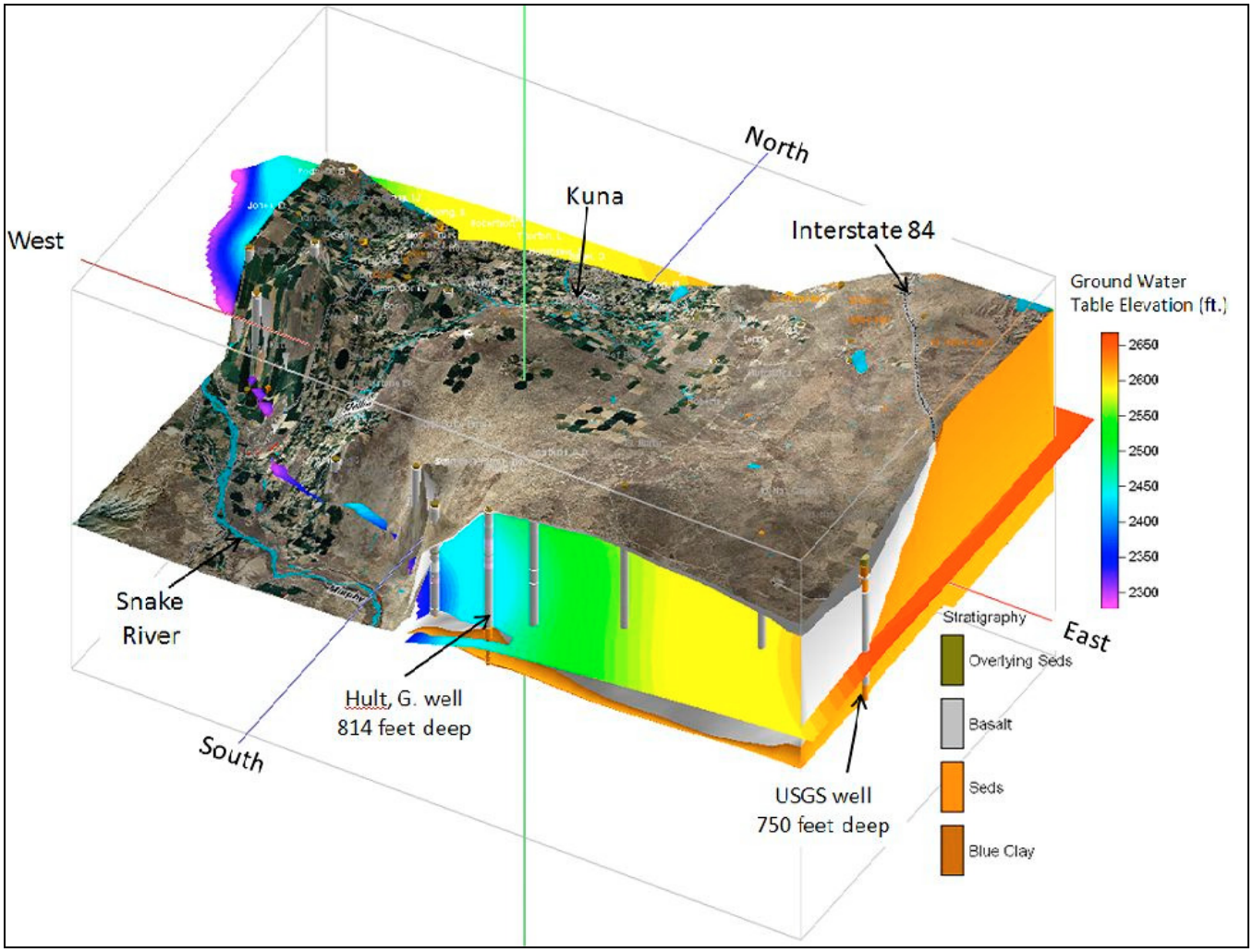

Figure 7. Three-dimensional model of the area in Figure xx showing a color air photo draped over the model surface. The south panel of the basalt is removed to show the interior. High areas of the water table are colored red and low areas of the water table colored blue.

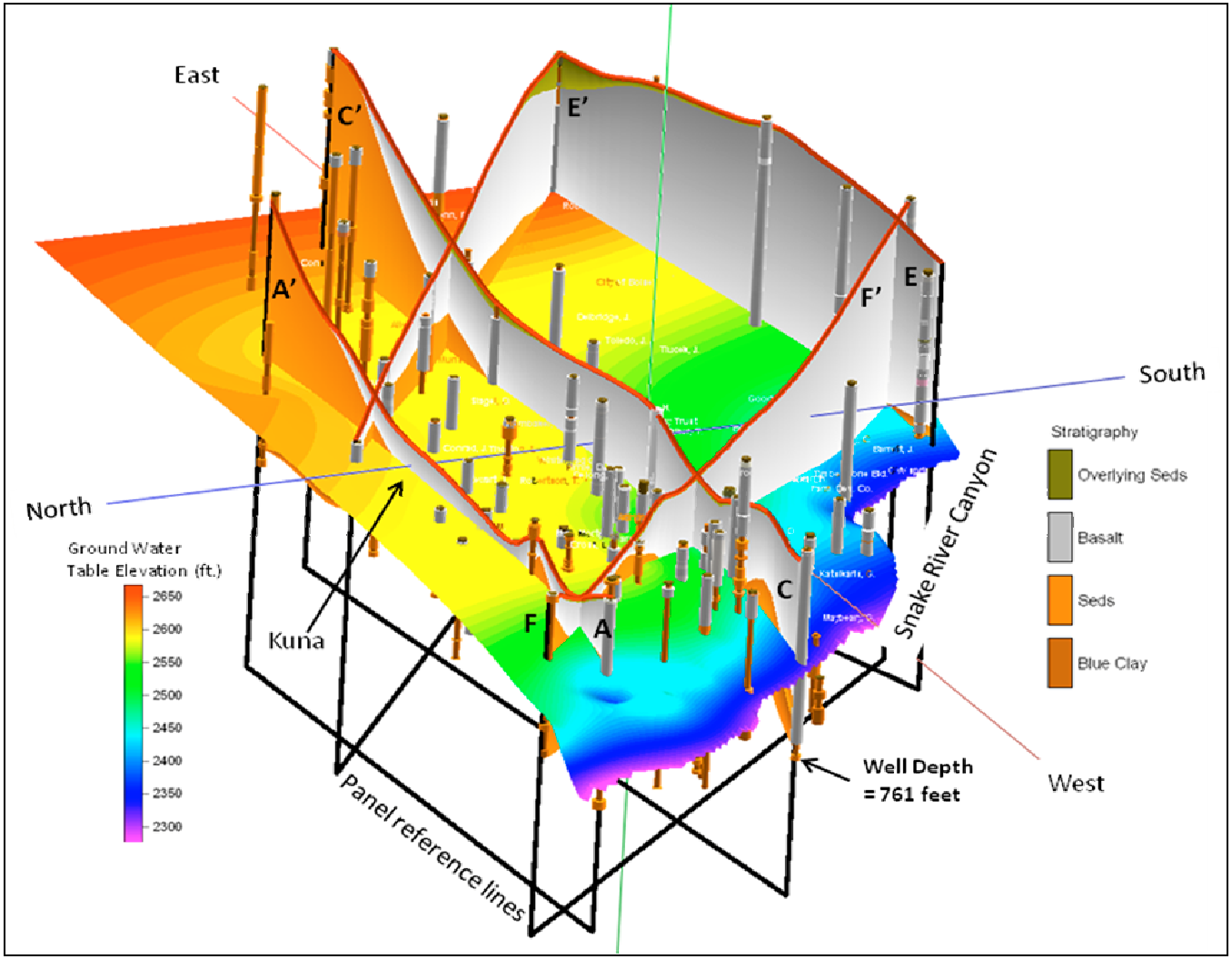

Figure 8. Top view angle fence diagram showing the relation between water table and sediment highs and basalt lows.

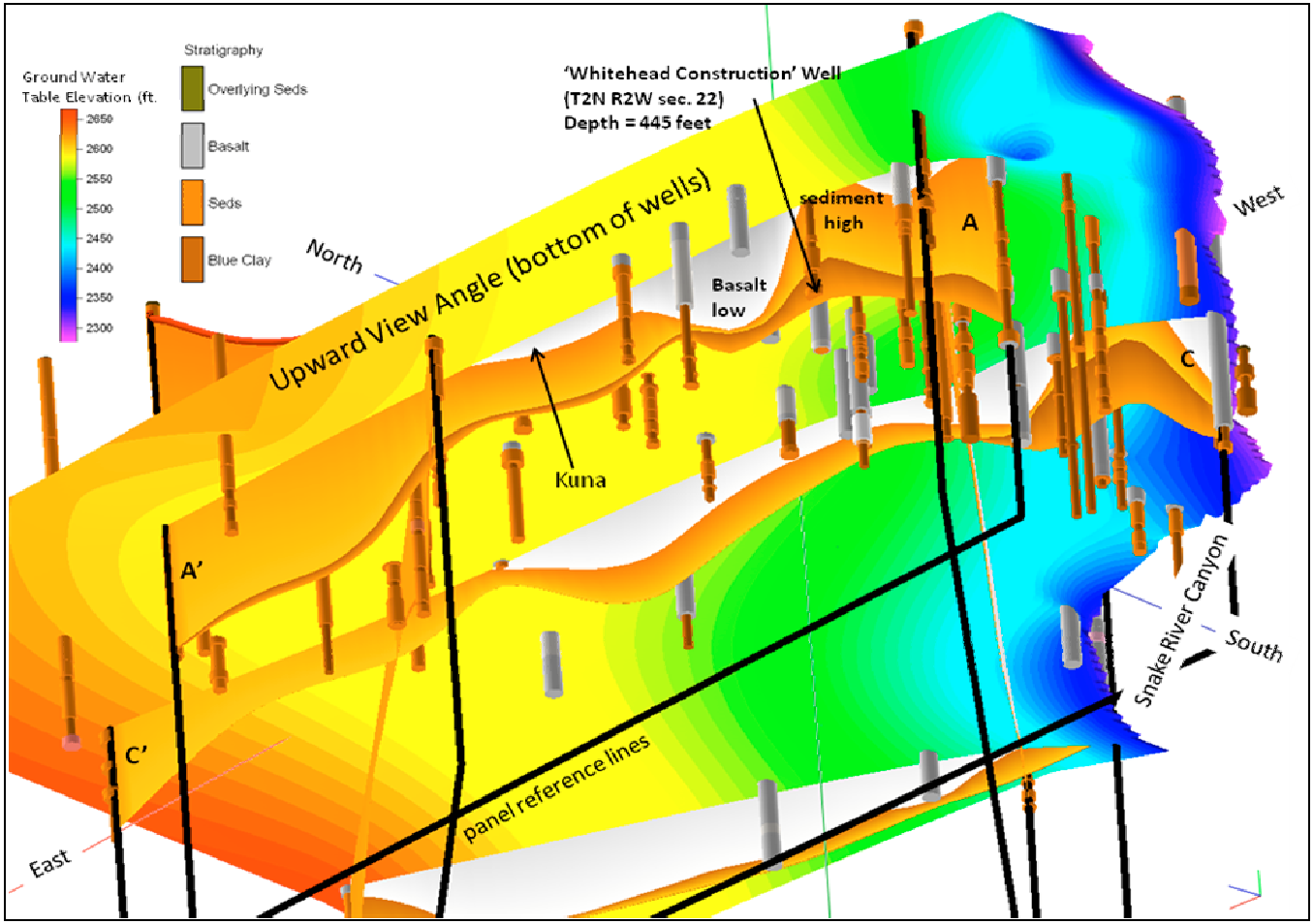

Figure 9. Upward view angle showing the base of wells in relation to the water table and general geology. Note the sediment 'high' at the 'Whitehead' well and adjacent basalt low.

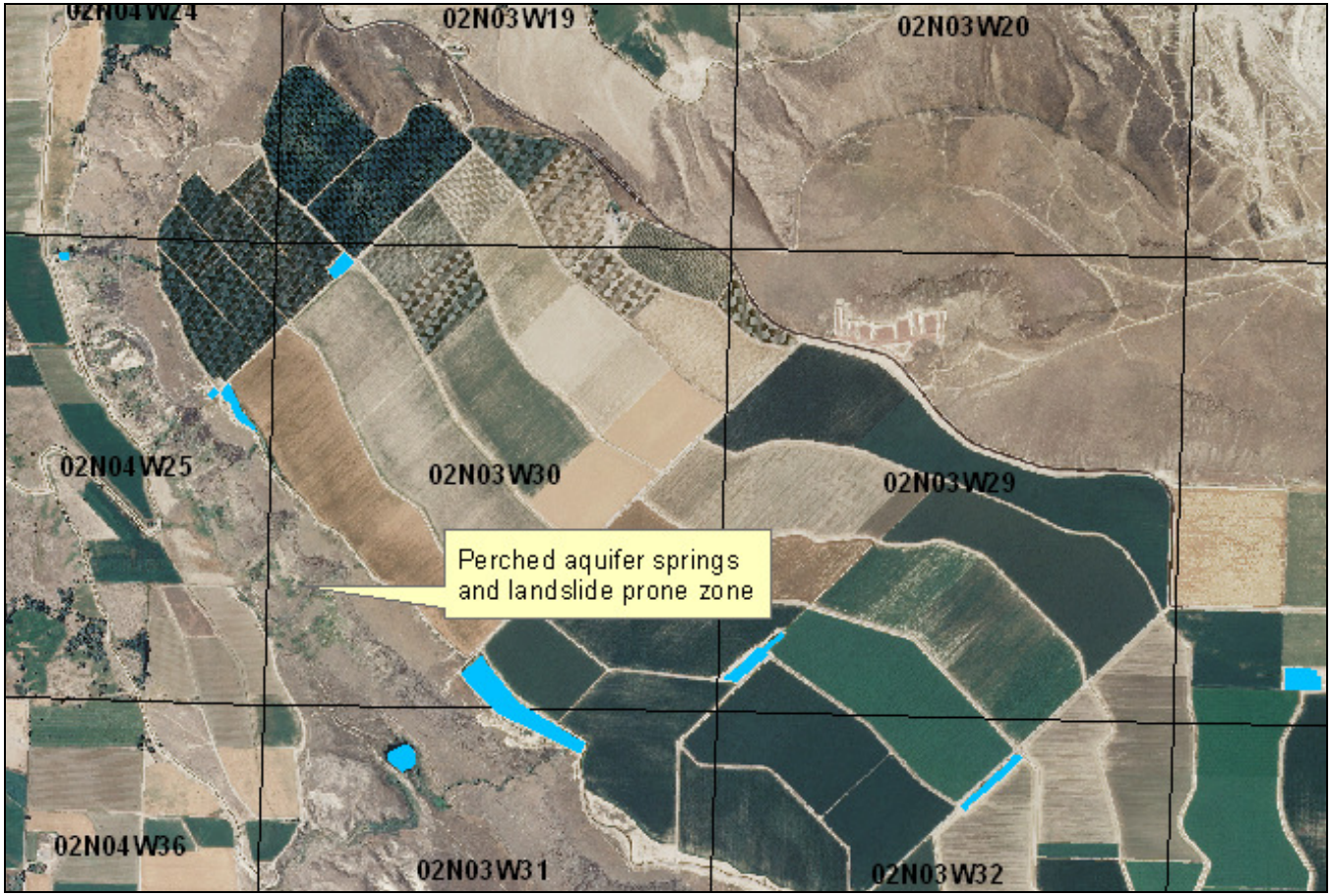

Figure 10. Perched aquifer springs discharging from sediments, probably associated with irrigation above the canyon rim.

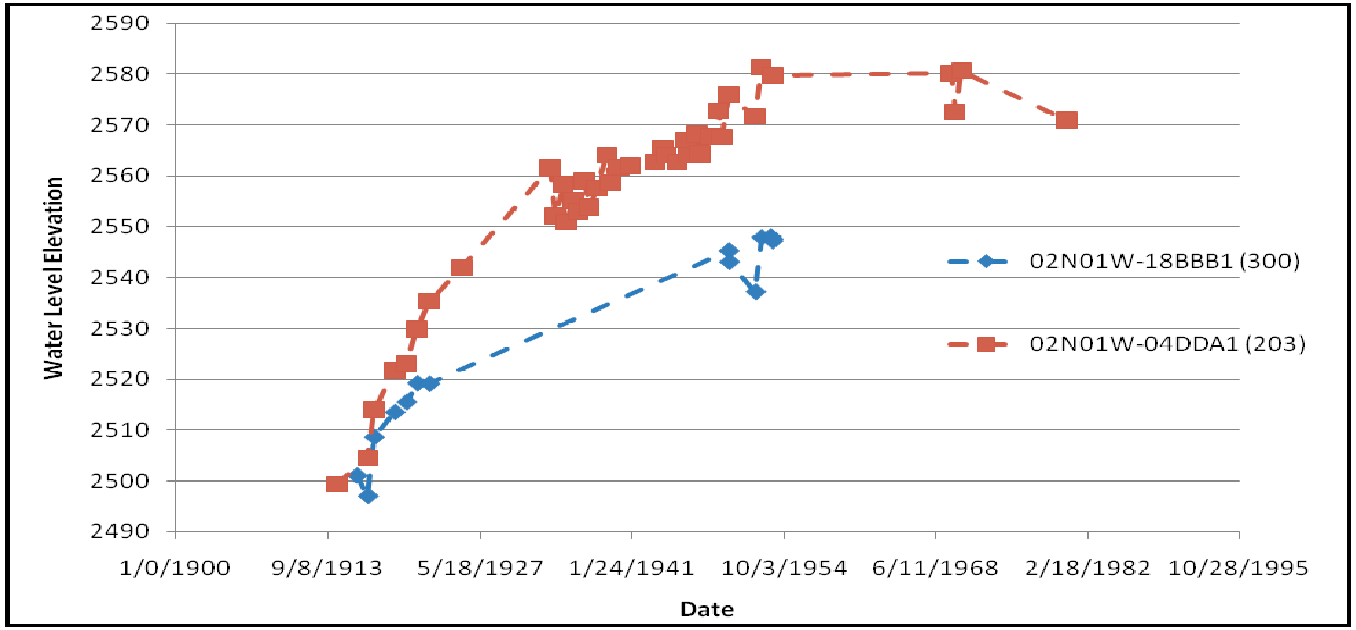

Figure 11. Hydrographs showing water level increases during the period following development of surface water irrigation in the area.

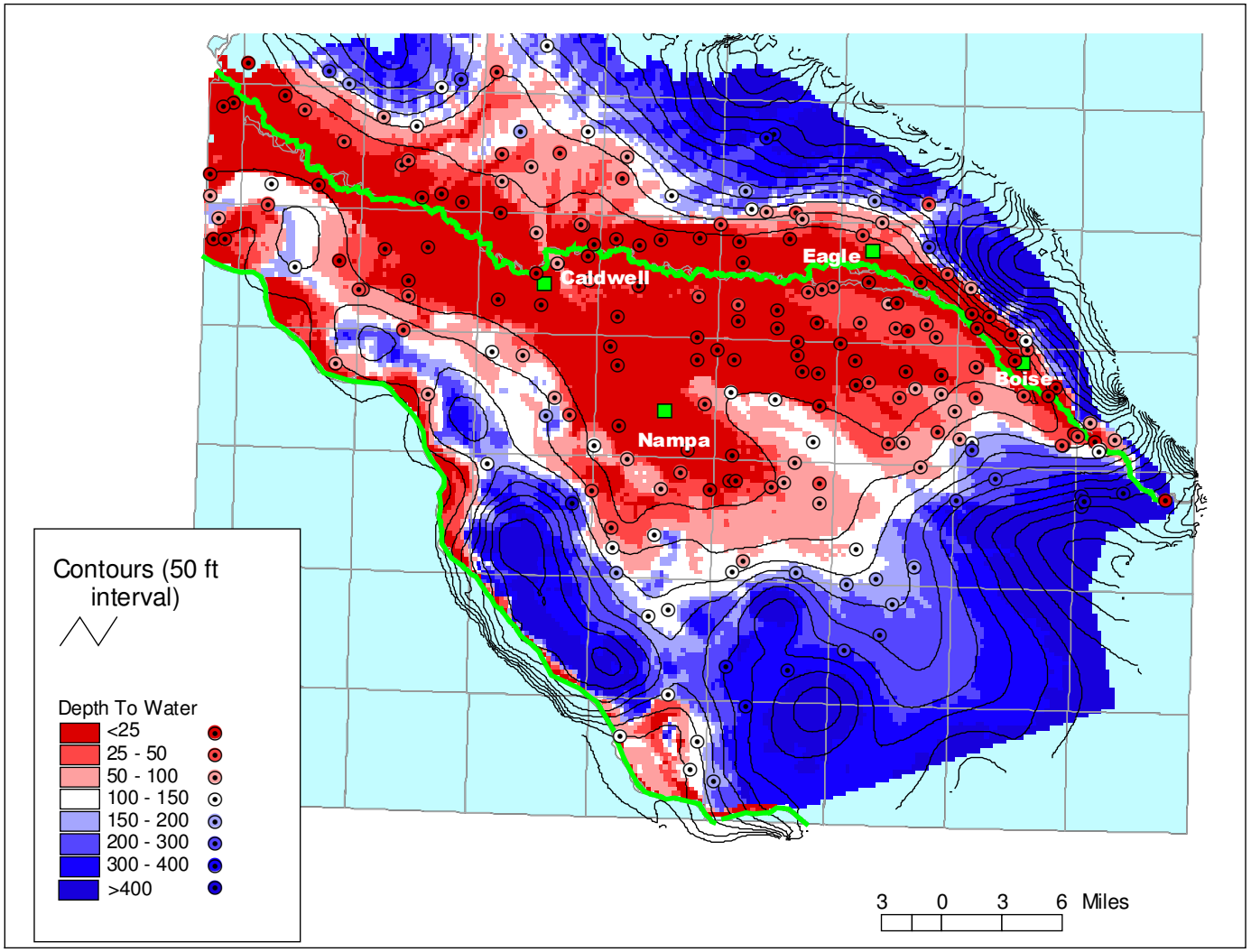

Figure 12. Approximate depth to water. The circles are measurements at individual wells. Note that in some cases the interpolated, smoothed water level surface does not match individual wells. Variations in well completion depth, measurement conditions (such as well pumping) and time of measurements introduce some imprecision. This applies also to the water-level change maps.

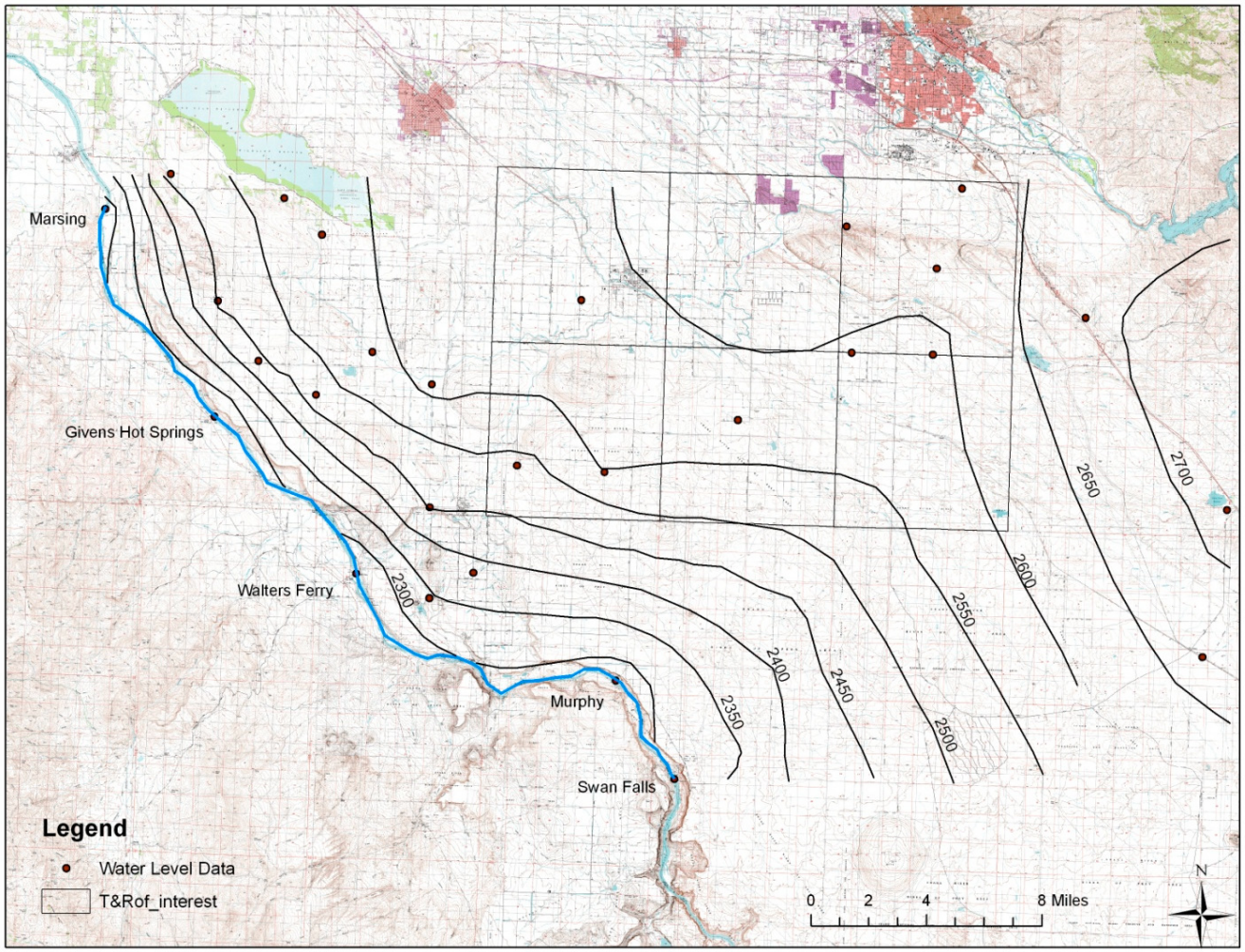

Figure 13. Potentiometric surface map for spring 2009, in the south part of the study area.

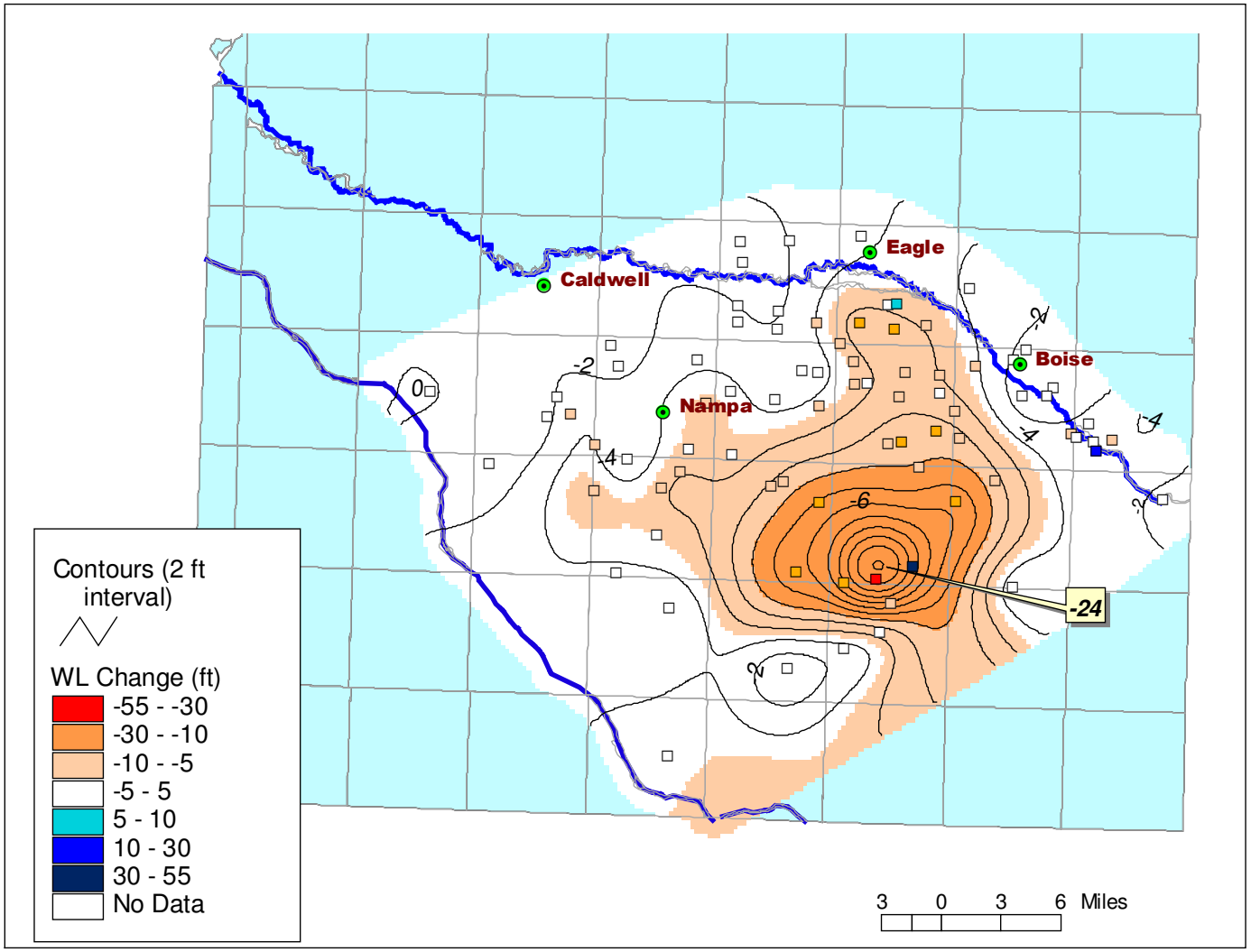

Figure 14. Water level changes fall 1996 to fall 2001. Individual wells are marked with squares, with individual water level changes coded with the same color ramp as the map background. Note that the water level change color map and contours are smoothly interpolated between individual-well results.

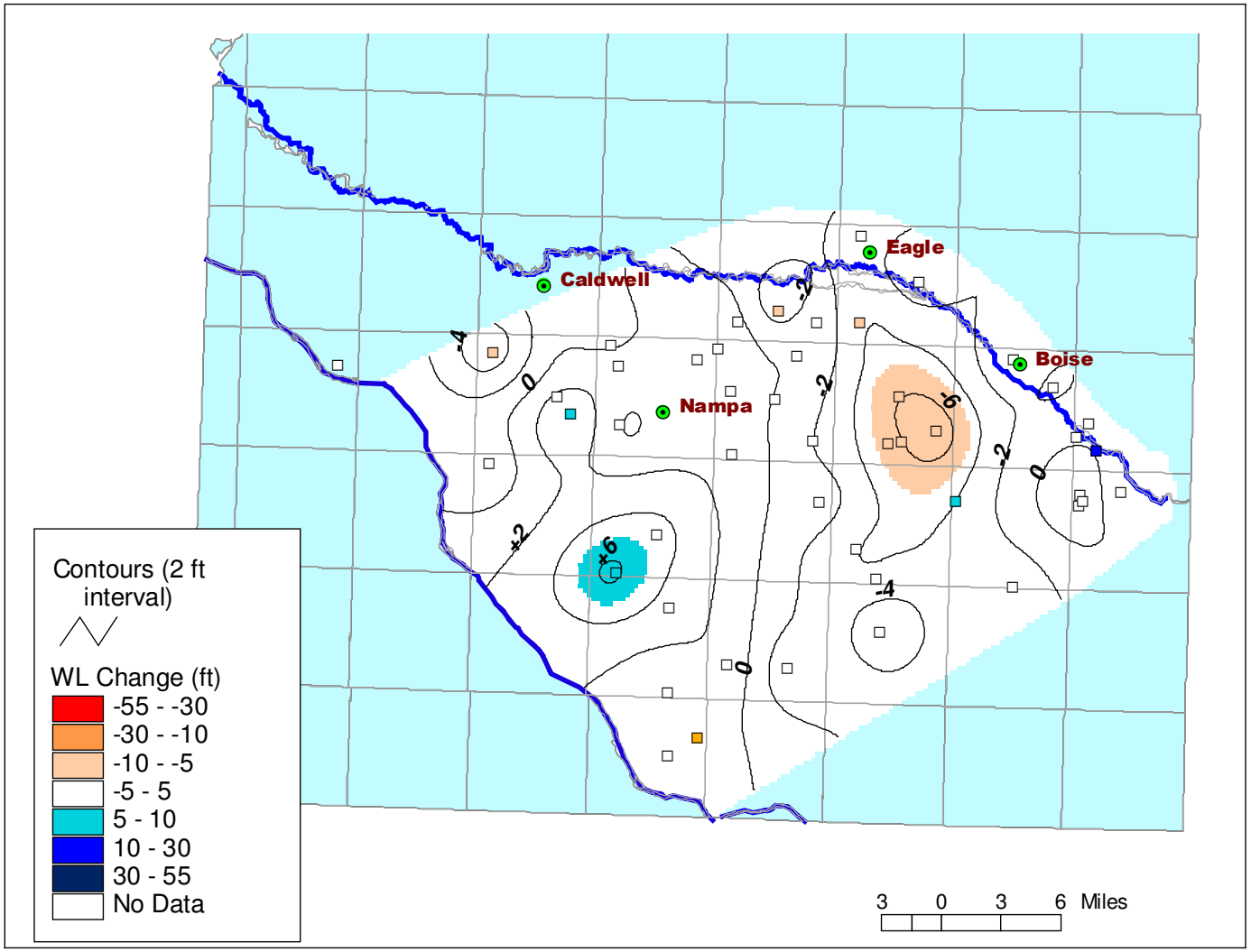

Figure 15. Water level changes fall 2001 through fall 2008.

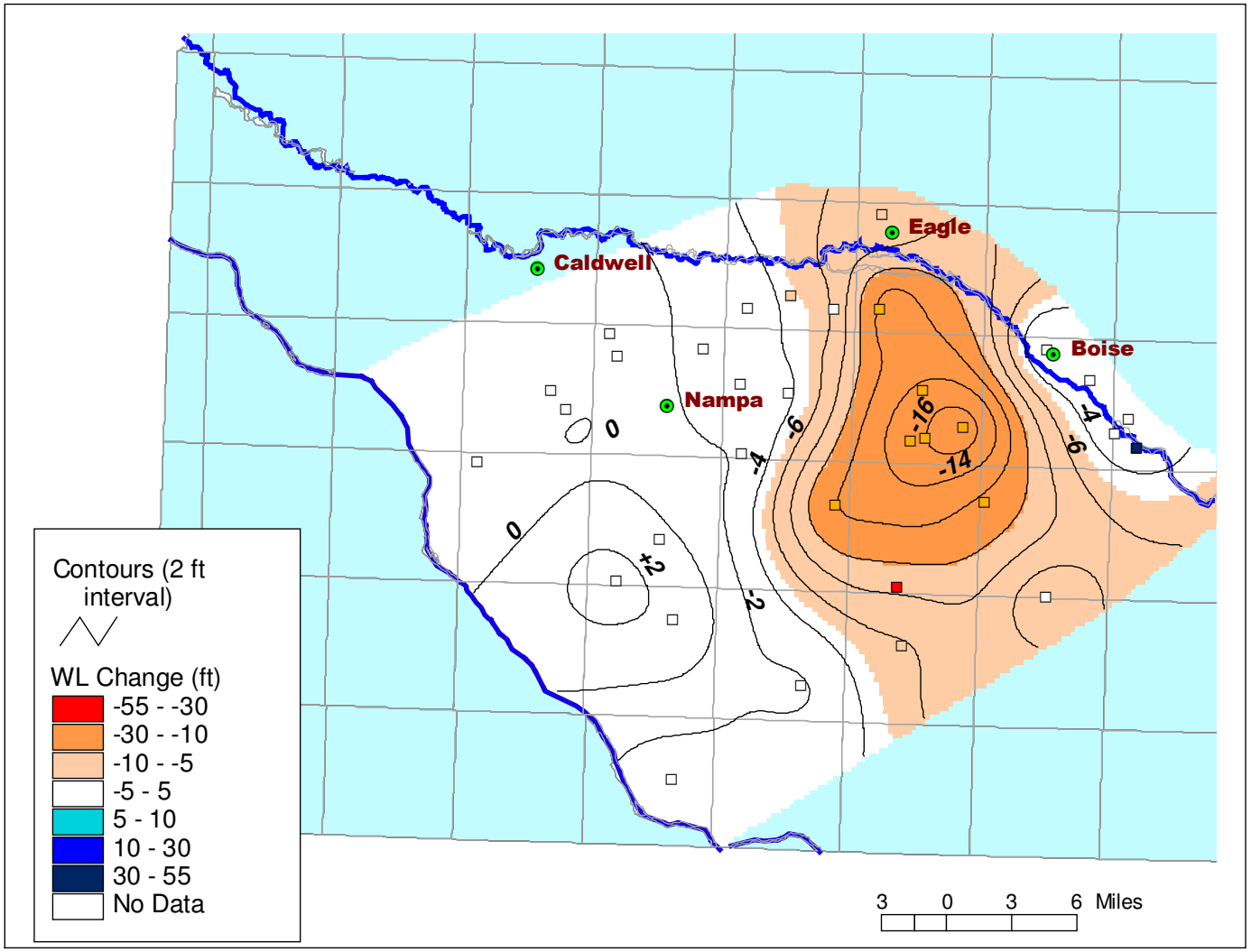

Figure 16. Water level changes fall 1996 through fall 2008.

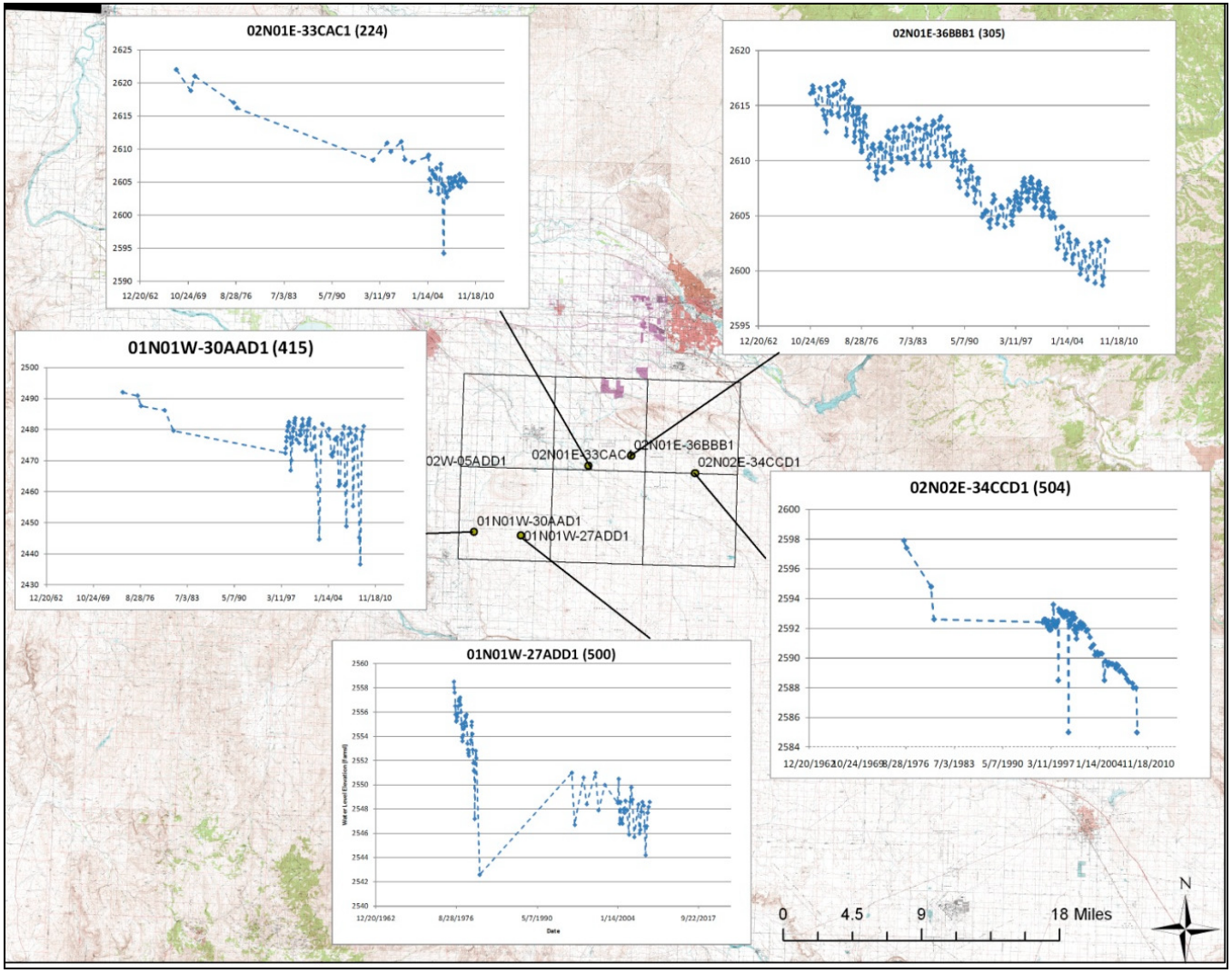

Figure 17. Hydrographs for selected study area wells.

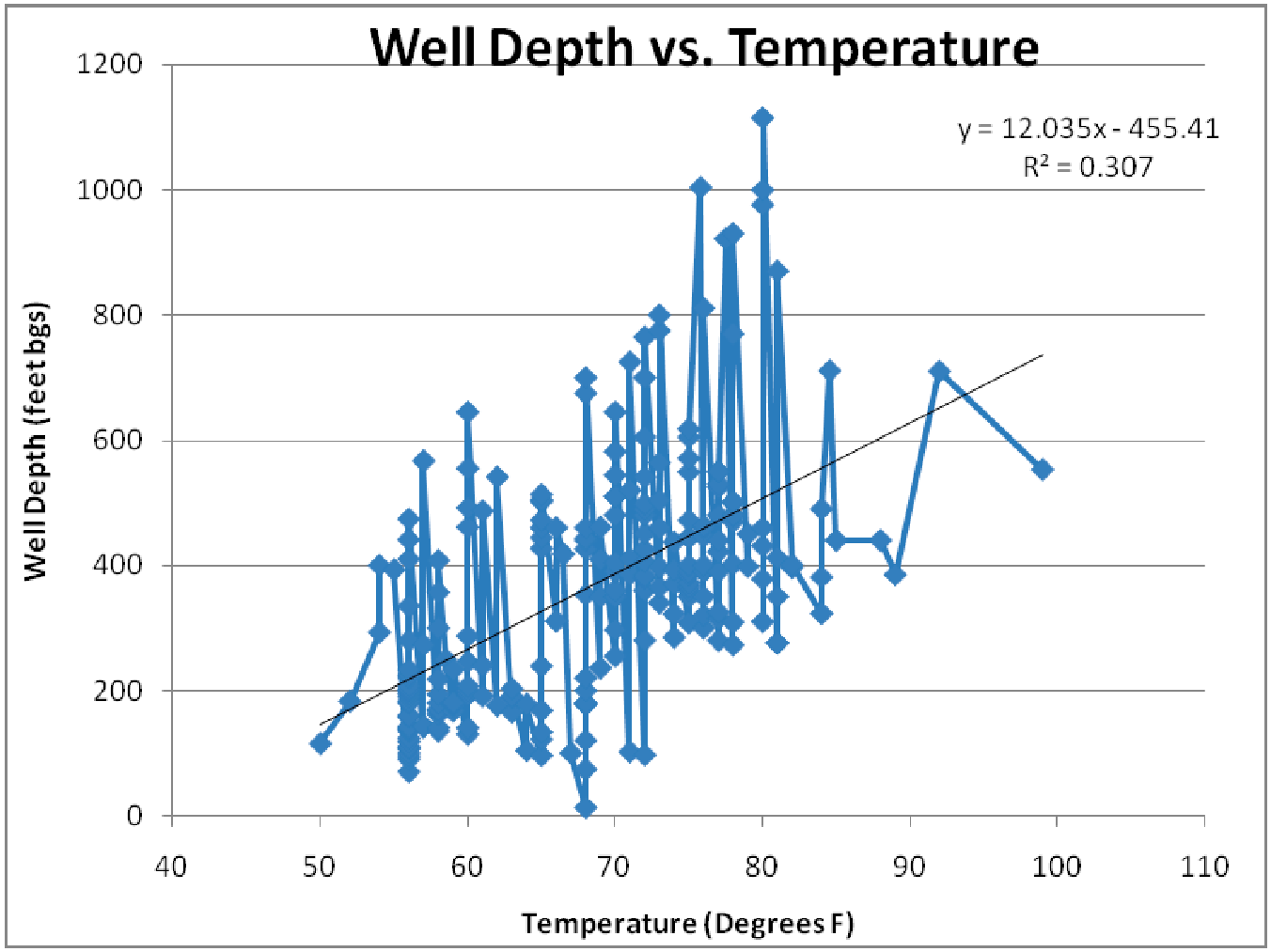

Figure 18. Plot of well depth versus temperature within the study area.

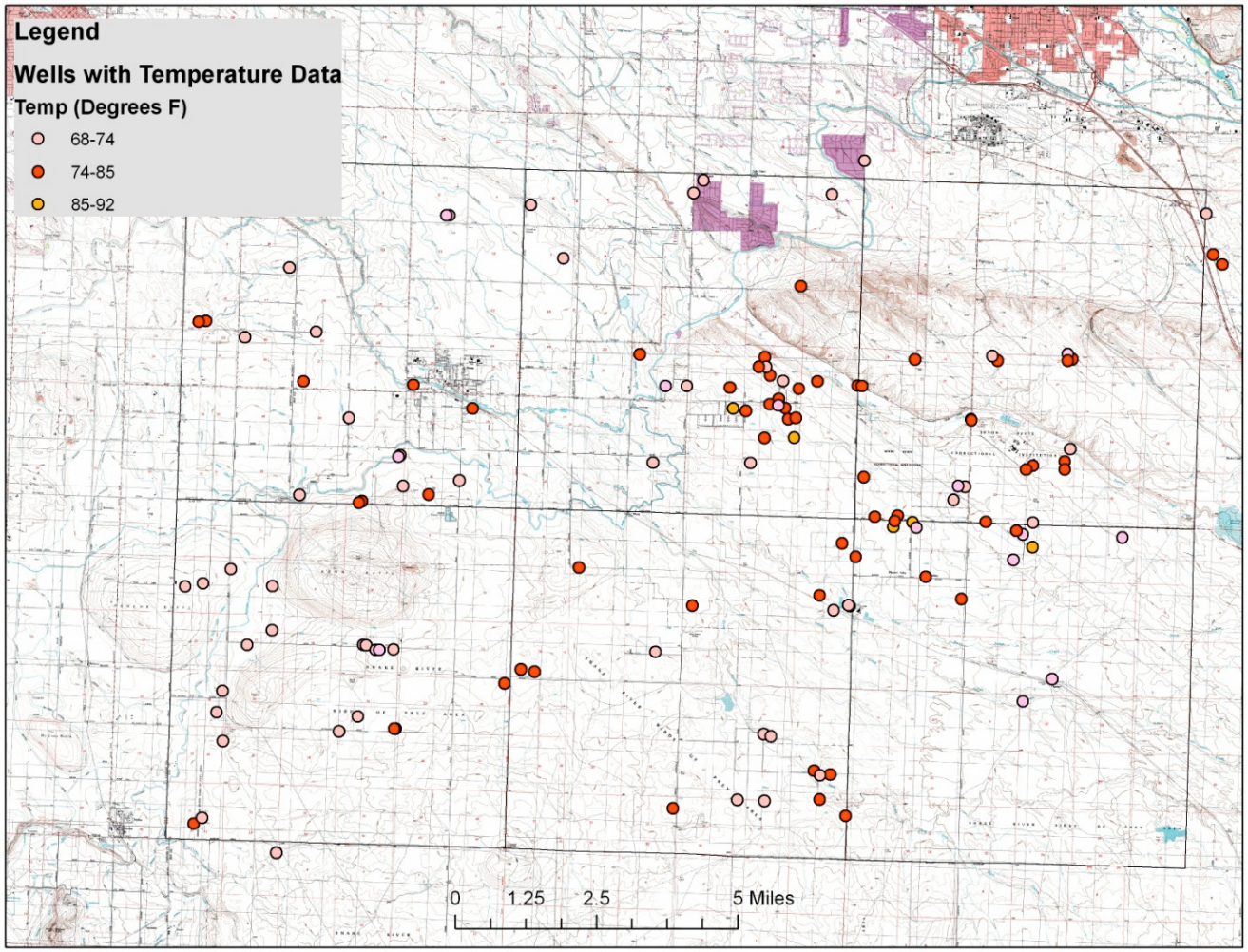

Figure 19. Wells with elevated temperatures (above 68 degrees).

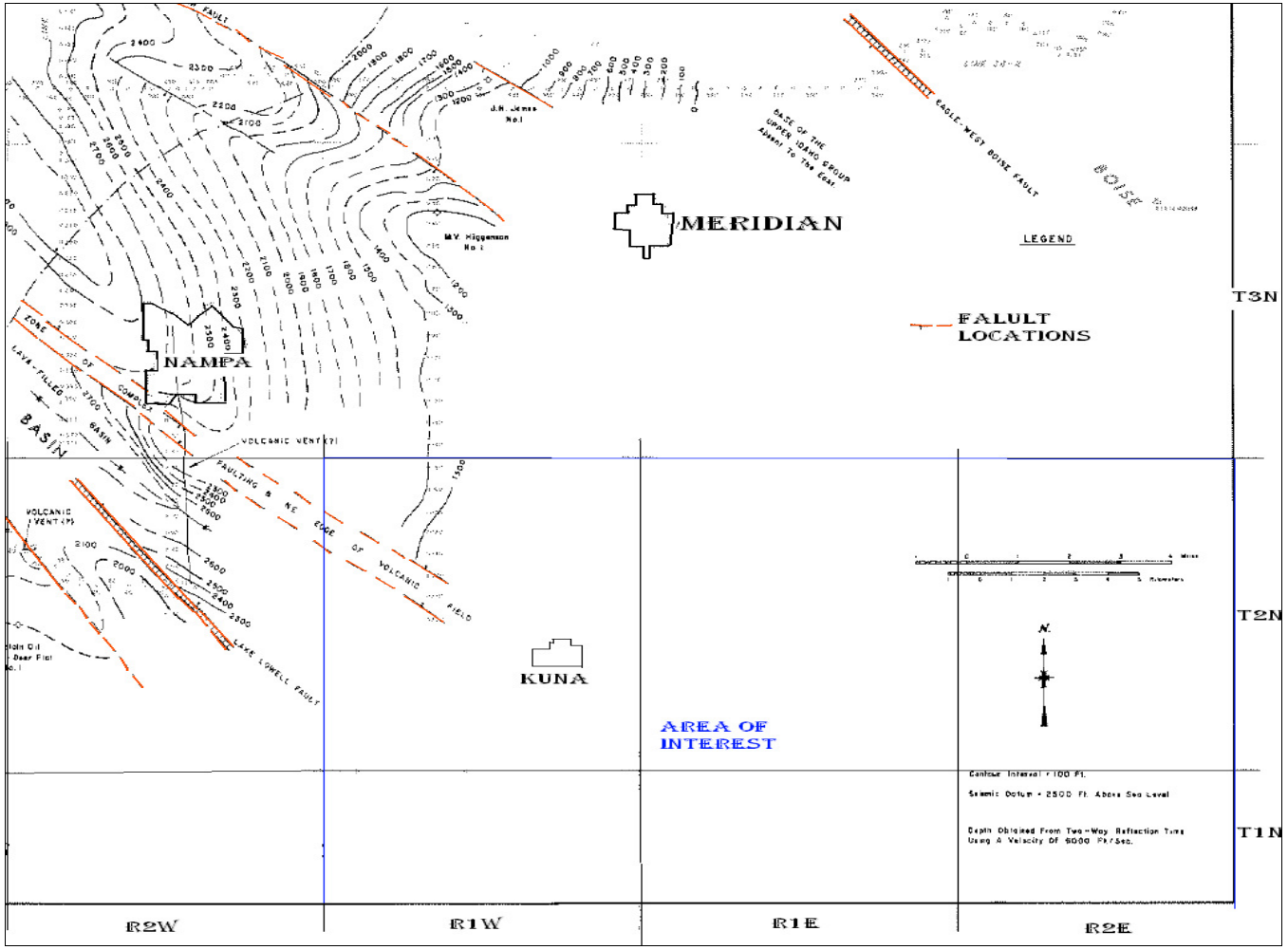

Figure 20. Structural map of the Idaho Group sediments showing the locations of mapped faults in the area (modified from Mitchell, 1981).

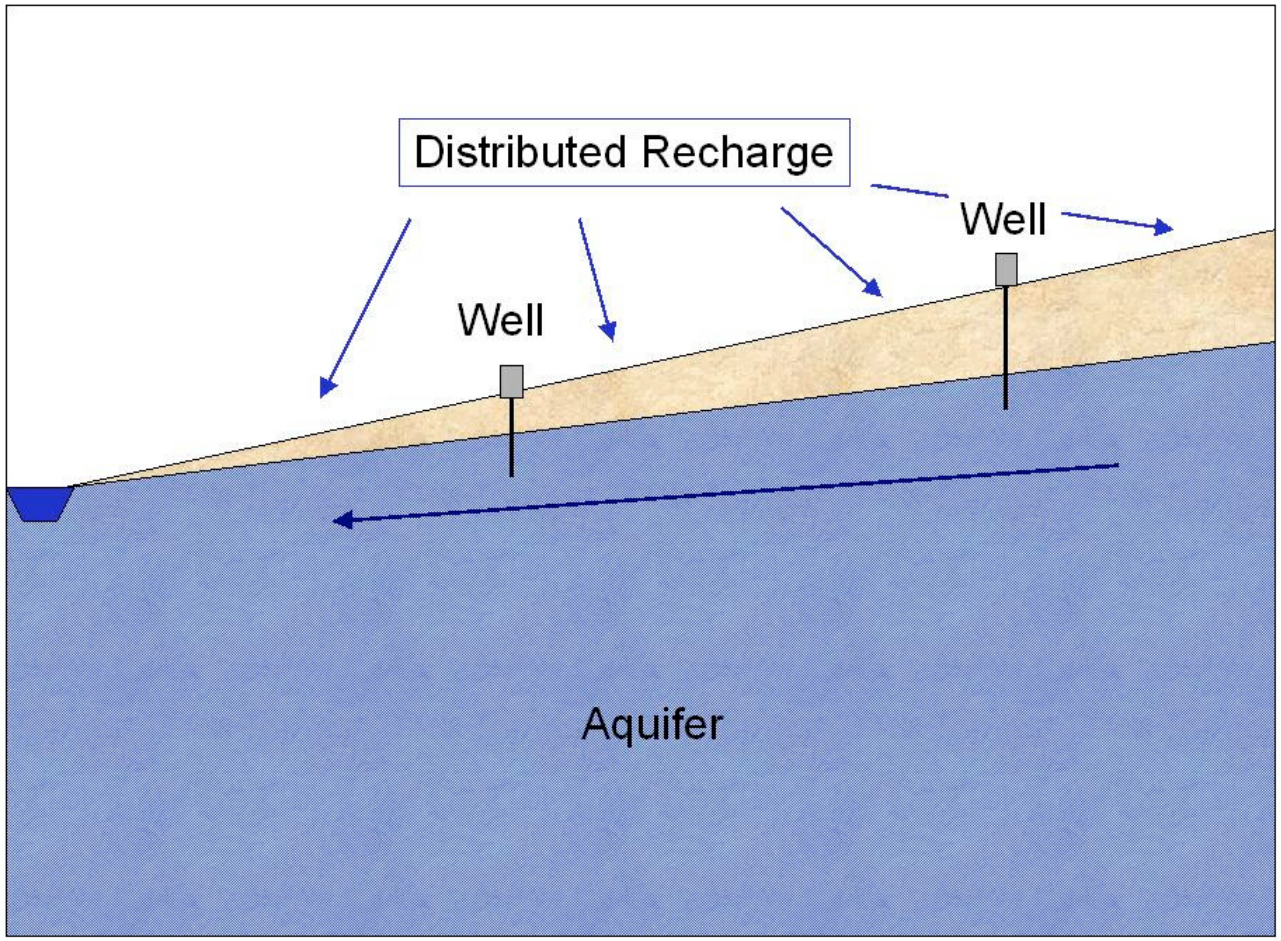

Figure 21. Pre-recharge sketch of water table, wells, and typical spatially-distributed recharge from precipitation and irrigation.

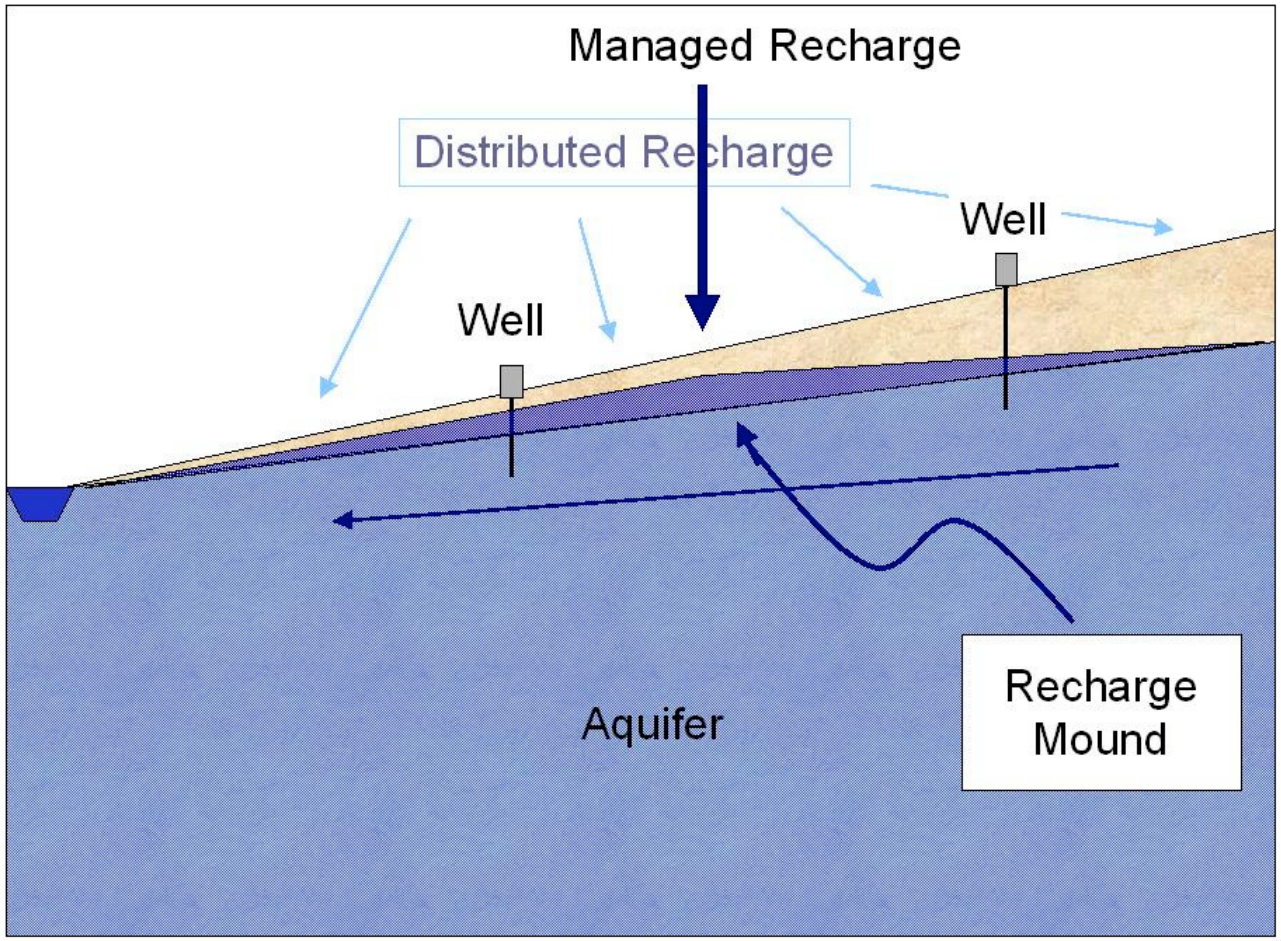

Figure 22. Alteration of water table following a managed-recharge event, benefiting both up-gradient and down-gradient locations.

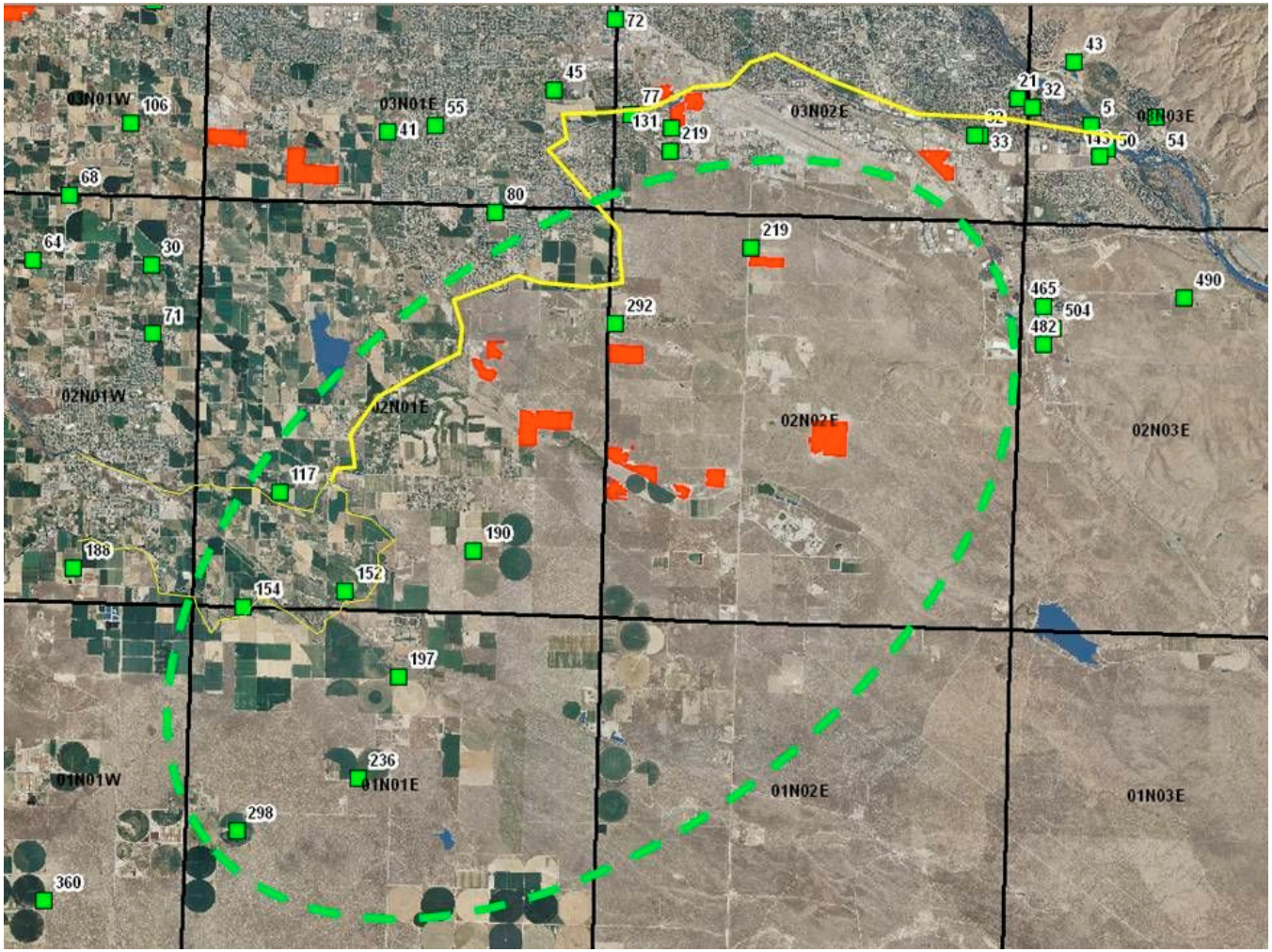

Figure 23. Preliminary map. The preliminary preferred focus area for recharge is circled in green. Red features are gravel pits and the blue features are existing water bodies.

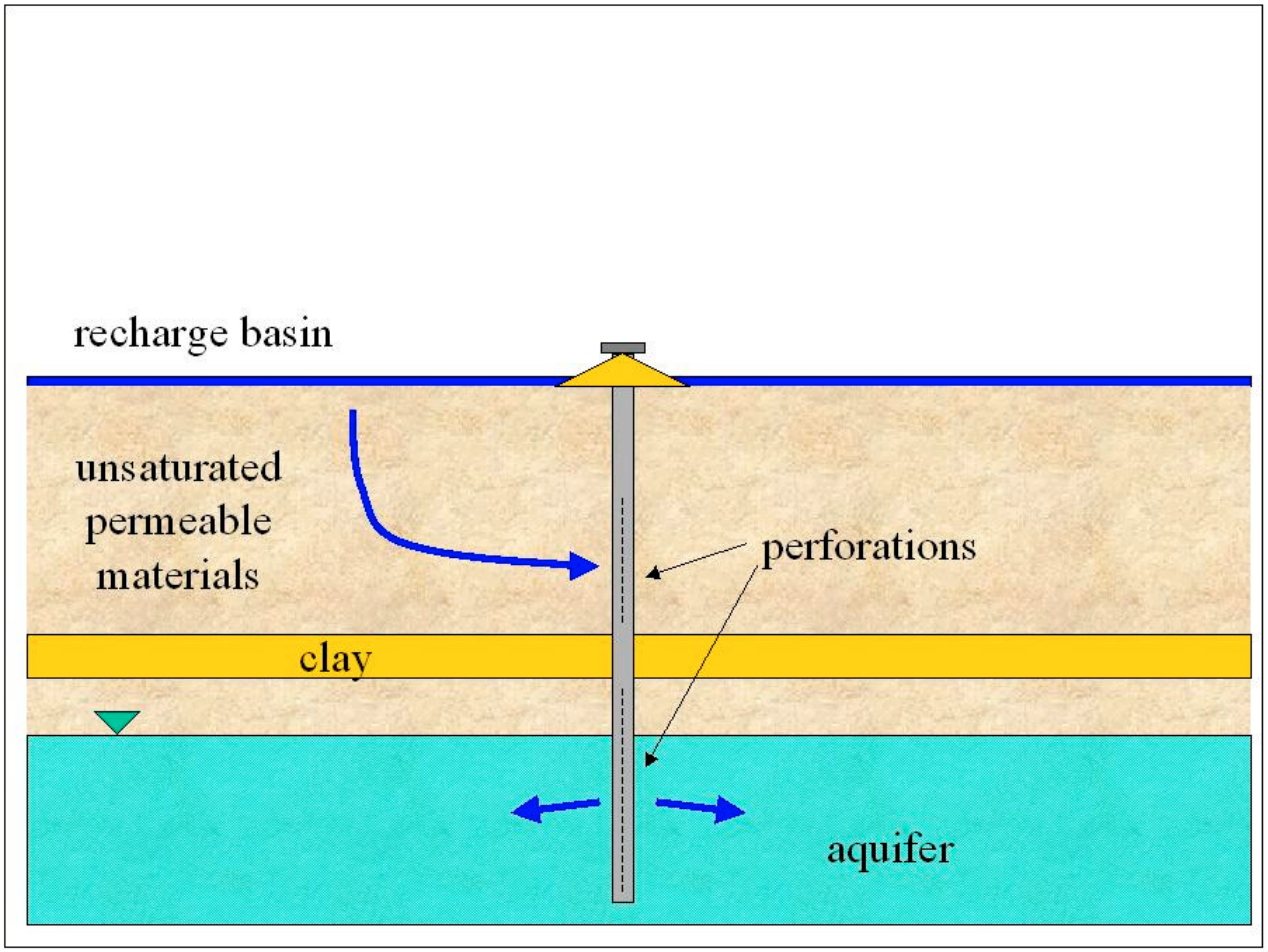

Figure 24. Potential engineering solution to impermeable materials between a recharge zone and the receiving aquifer (after Mundorff, circa 1962)

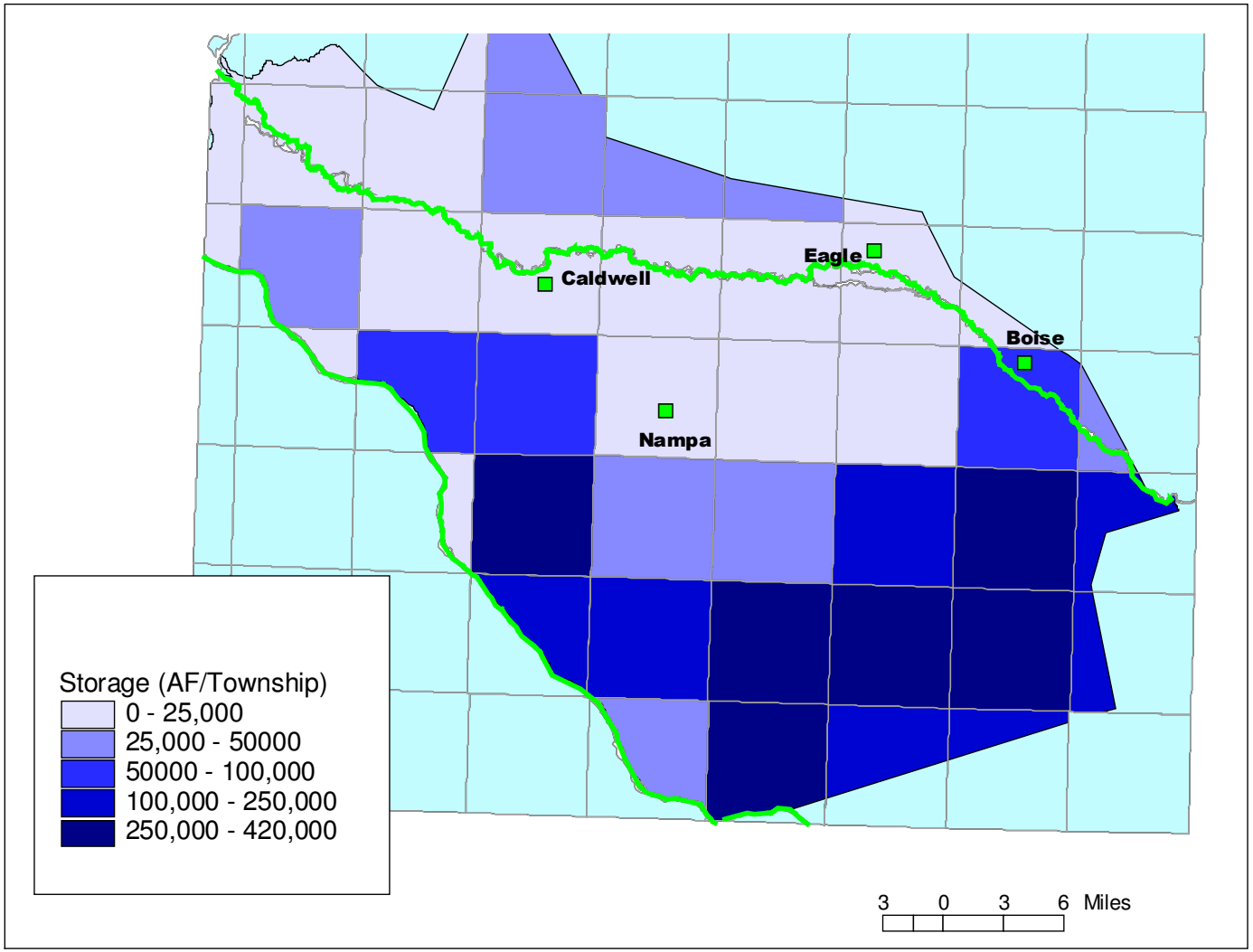

Figure 25. Potential maximum storage volume. This is the volume represented by unsaturated materials between the water table and a buffer 50 feet below land surface. A storage coefficient of 0.05 was used for this map; with a coefficient of 0.10, the capacity would be twice these values.

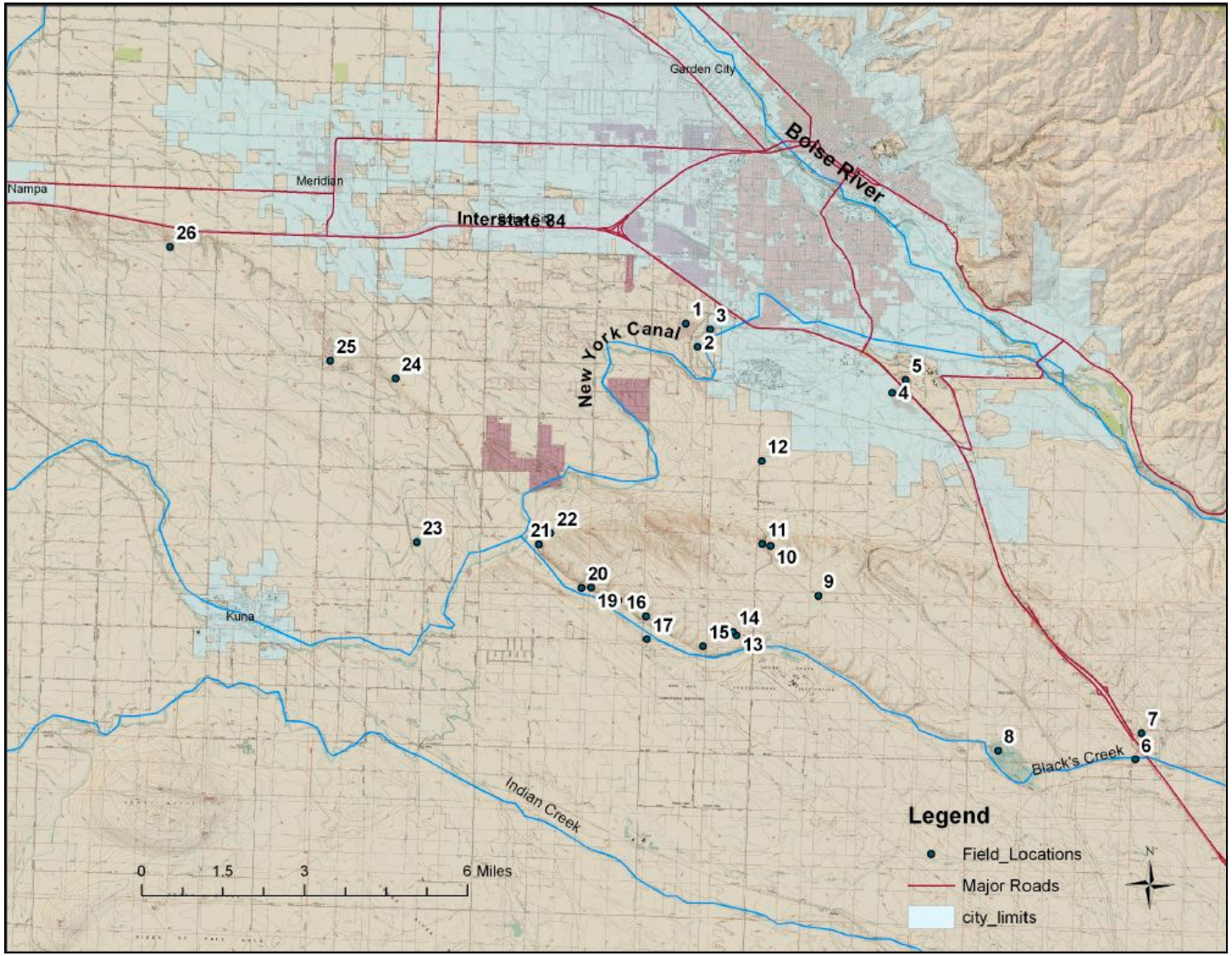

Figure 26. Sites inspected November 30, 2010.

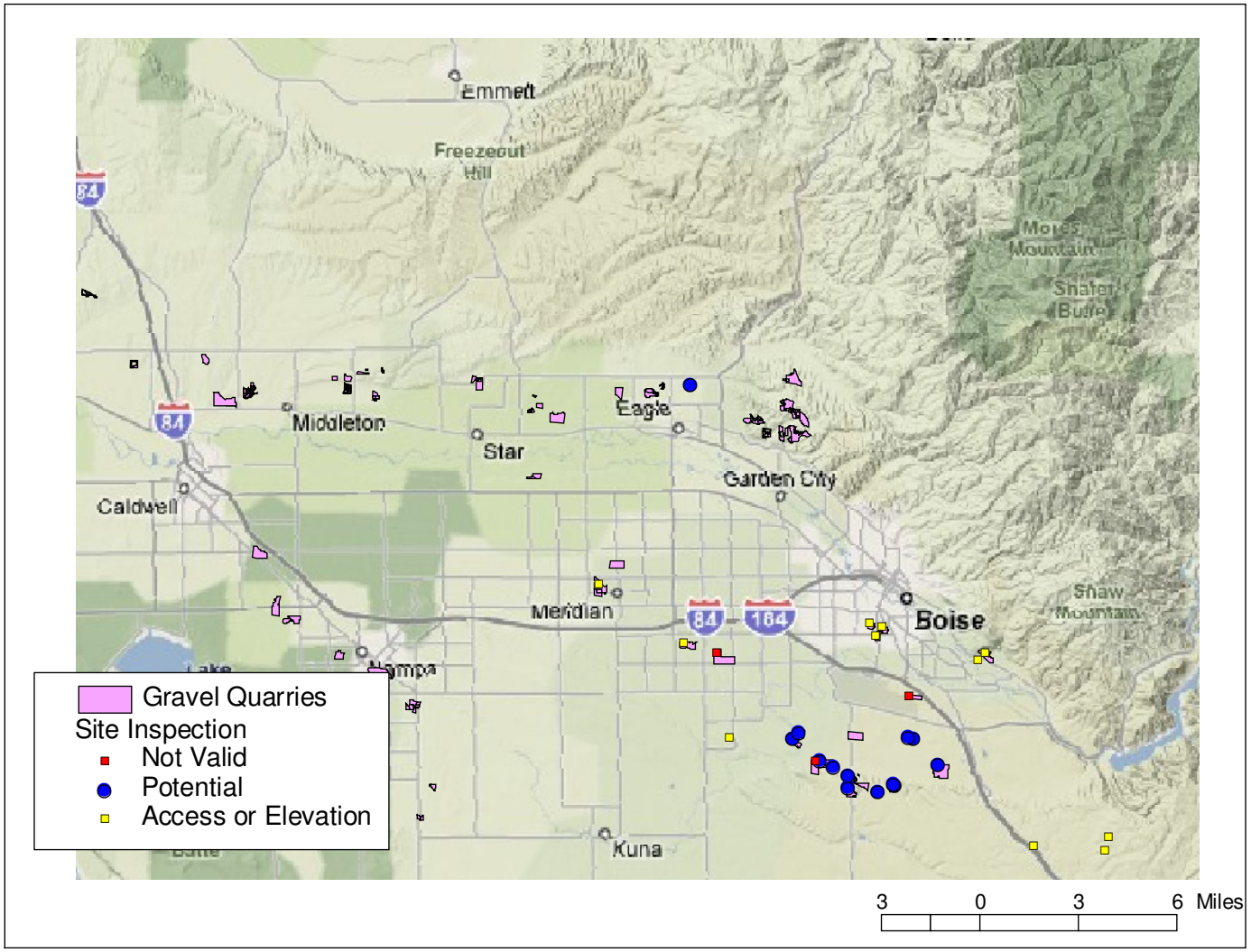

Figure 27. Summary of inspection results. "Not Valid" sites are locations where no gravel pit or potential recharge facility was found. "Potential" sites appear to be physically appropriate for recharge and are reasonably near delivery infrastructure. Sites marked "Access or Elevation" are sites where delivery of water might be difficult due to lack of infrastructure or high pumping lift. Site and facility owners have not been consulted.

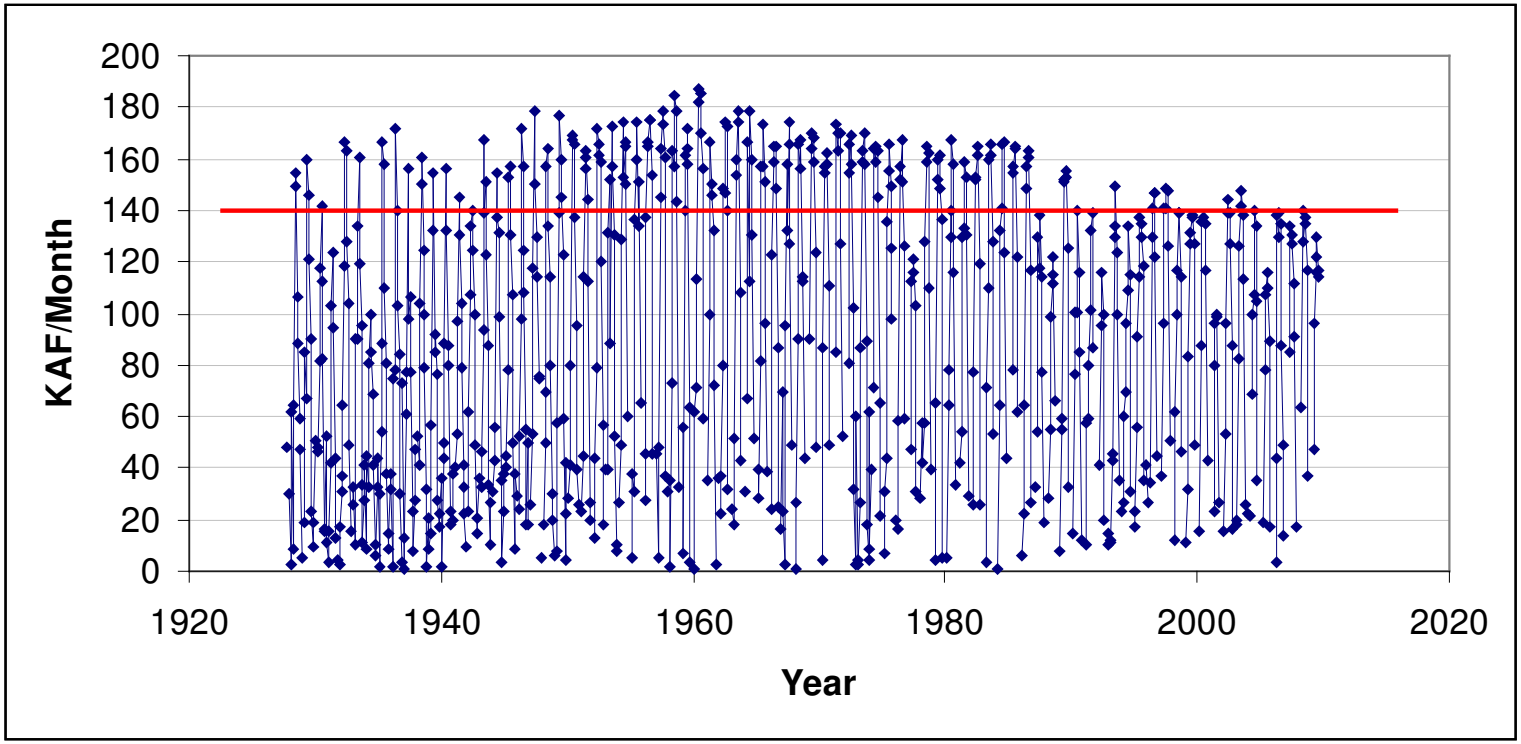

Figure 28. History of monthly diversions of the New York Canal.

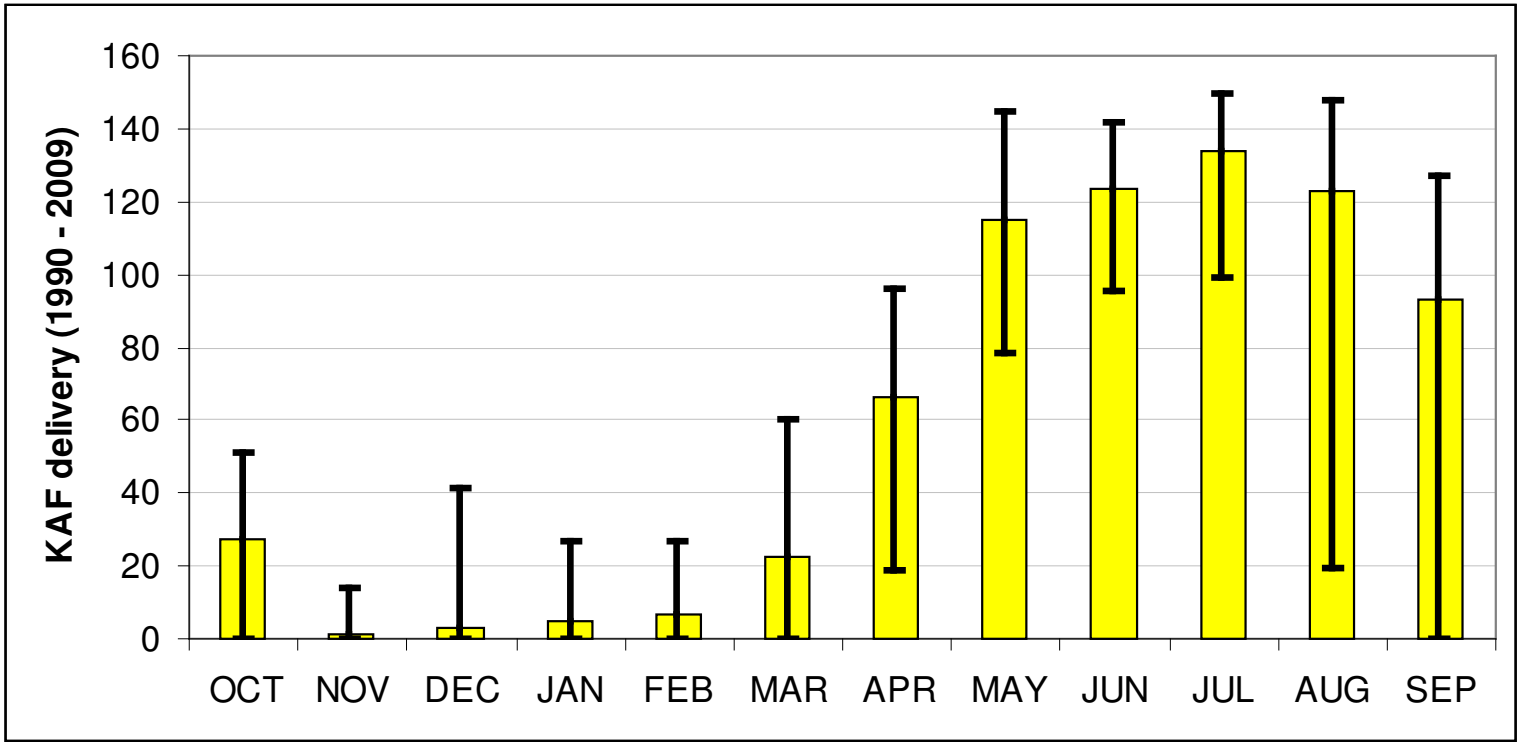

Figure 29. Monthly average, maximum and minimum diversions 1990 - 2009.

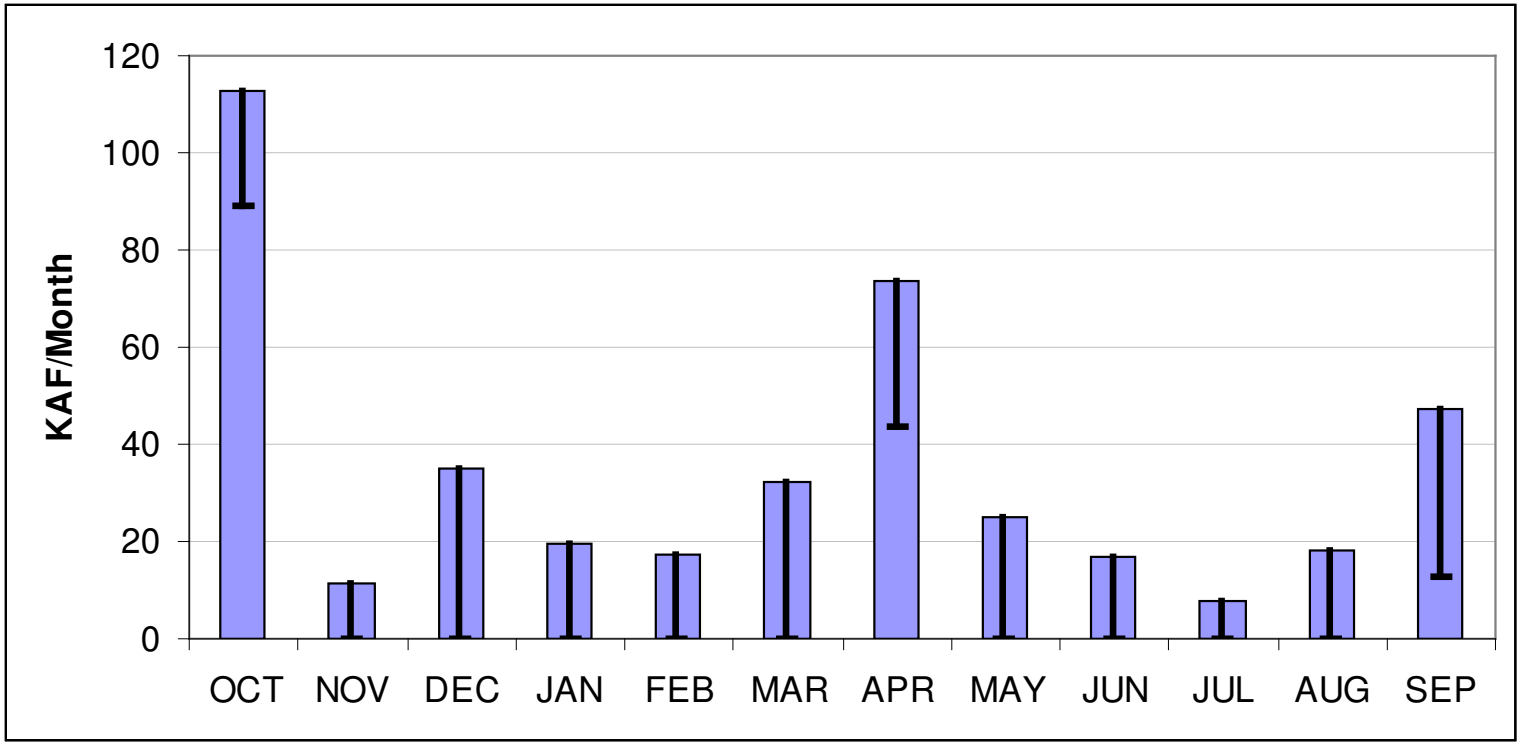

Figure 30. Average and minimum potential additional capacity above historical diversions for the period 1990 - 2009.

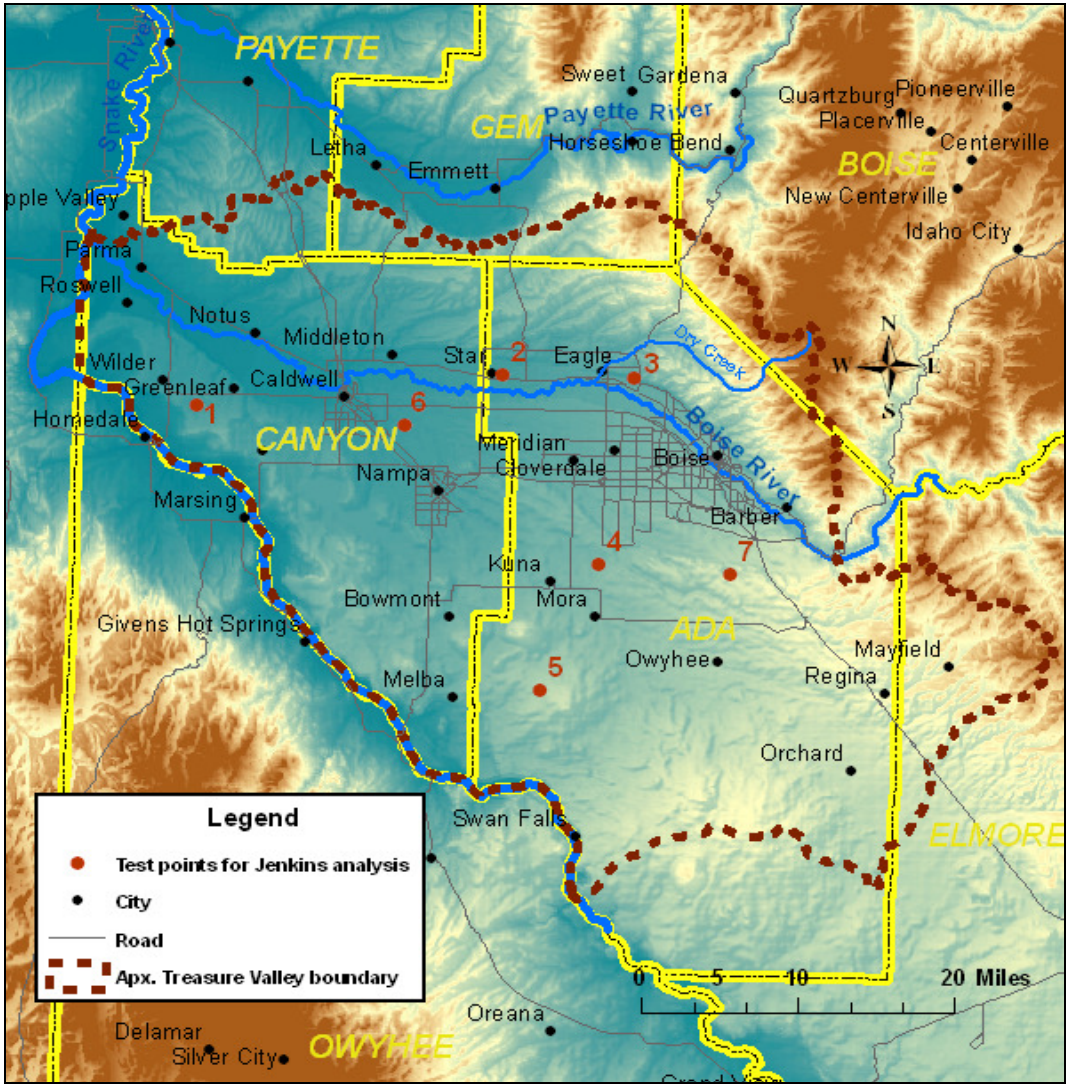

Figure 31. Locations of points for Residence calculations.

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Improving estimates of tributary underflow in the Eastern Snake River Plain

Basic Information

Title:	Improving estimates of tributary underflow in the Eastern Snake River Plain
Project Number:	2010ID161B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	ID-001
Research Category:	Climate and Hydrologic Processes
Focus Category:	Methods, Hydrology, Water Quantity
Descriptors:	None
Principal Investigators:	Stacey Taylor, Bryce Contor

Publications

There are no publications.

USGS 104B Summary Report for the Annual Report

Tributary Underflow

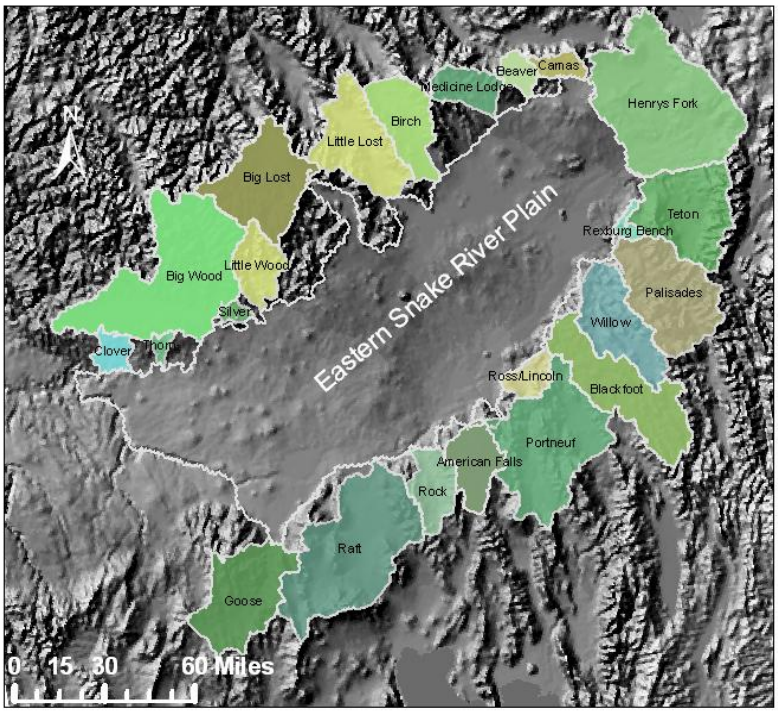
Stacey Taylor

Bryce Contor

Greg Moore

Project Summary

While groundwater withdrawals in the Eastern Snake River Plain Aquifer increase, the number of recharge sources to the aquifer remains the same. These sources of recharge include precipitation, stream and river losses, irrigation percolation, canal seepage, and subsurface flow from tributary basins. Most sources of recharge can be measured or closely approximated since they occur on the surface. However, flow that is underground from surrounding basins (also called tributary underflow) is much more difficult to quantify since it occurs beneath the surface. The Eastern Snake River Plain is surrounded by 23 tributary basins that are believed to contribute recharge. Tributary underflow is a key component of recharge in the Eastern Snake Plain Aquifer Model, representing approximately 20% of the water budget.



Several techniques have been developed to estimate underflow from tributary basins of the Eastern Snake Plain. This investigation pursued use of the Langbein method, published in a report on the Raft River Basin by Nace et al. (1961). The Langbein method estimates water yield for a basin based on relationships between temperature and potential evapotranspiration. Water yield for a basin is the manageable part of the water supply that is potentially available for consumptive use. For the Eastern Snake Plain tributary basins, resulting values of basin

yield were partitioned to three fates: irrigation ET, surface outflow, and tributary underflow. Tributary underflow was calculated as the difference between basin yield and water leaving the basin as streamflow and ET from irrigated lands.

Tributary underflow was calculated annually for each basin as a depth and a volume for 1980 – 2009. In some basins, data were lacking during this period of time and techniques were developed to approximate this data. Results showed that some estimates may not have been close enough approximations and potential sources of error were reviewed due to the presence of negative underflow values (indicates no underflow). When quality streamflow data were present for a basin, calculated values of underflow appeared reasonable. It was assumed that all basins discussed contribute some underflow to the Eastern Snake Plain, thus the negative underflow values that were calculated may indicate a temporary cessation of underflow or an error in the estimation of missing data.

While the Langbein method has been previously used to estimate basin yield in basins tributary to the Eastern Snake River Plain (Little Lost River basin, Raft River basin), this work suggests the values for basin yield may be underestimated and the method of choice not be optimal for use in an arid climate such as the Eastern Snake Plain. Other potential concerns for estimating underflow from basin yield are related to the limited information for streamflow and imprecision in the application of METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) Evapotranspiration data.

Finding better estimates of tributary underflow continues to be one of the goals for improving the Eastern Snake River Plain Aquifer Model. While the Langbein method did not result in better estimates of tributary underflow for the Eastern Snake Plain, it improved our knowledge of the data currently available and helped pave the way towards exploring a different and better technique. For future studies on tributary underflow in the Eastern Snake River Plain, each individual basin should be analyzed based on the amount of information available for that basin and the type of climate.

Publications Resulting from the Project

(none)

Undergraduate and Graduate Student Researchers

Greg Moore has completed 13 graduate credits and aims to complete a masters degree in the Waters of the West program at the University of Idaho.

Notable Achievements or Awards

(nothing to report here; although, the Department of Water Resources continues to fund IWRRI to update the Eastern Snake River Plain model data which includes finding improved methods of estimating underflow from surrounding tributary basins)

Information Transfer Program Introduction

During the 2010 Program Year, 104B program and state funds were used to support the Idaho Water Resources Research Institute Information and Technology Transfer Program. This program includes efforts to reach all water resource stakeholders in the state, from K to Grave. These efforts included; Water Education Workshops for Teachers (192 teachers were trained in 11 workshops across Idaho); coordinated with the Twin Falls Groundwater Quality Improvement Project to develop community/school monitoring projects; sponsoring the Youth Water Festival in Moscow and Salmon, Idaho; supporting the Steelhead Days held in Boise, ID; and a state wide water resources seminar series (17 seminars with an average attendance of 25 people per seminar) delivered statewide via a compressed video system.

In addition, during the 2010 Program Year, training opportunities for water professionals were continued through interactions with the Boise Watershed Center. The IWRRI also developed or sponsored four water resources workshops, conferences and symposia focusing on specific water resources issues of interest across the state, region and nation. These meetings were: the University Council on Water Resources annual conference held in Seattle, WA in July of 2010; a Water Resources Economics workshop for the Pacific Northwest Regional Office of the US Bureau of Reclamation, held in Boise, ID in August of 2010; the Palouse Water Summit, held in Moscow, ID, in October 2010; the Idaho Water Users Conference, held in Boise, ID in January 2011. IWRRI also collaborated with the Water Research Institutes in Colorado, Montana, Oregon and Washington in the planning of a regional water resources conference focusing on the issues associated with exempt domestic wells. This conference will be held during the FY 2011 project period in Walla Walla, WA. Finally, the IWRRI continued its support of the new Idaho State Chapter of the American Water Resources Association by recruiting members and providing sponsorship and publicity for several of its events.

In addition to these activities, one Information Transfer project was completed during the 2010 Program Year assess the economic impacts of water transfers within the Magic Valley (Twin Falls area) of Idaho, which is part of the Snake Plane aquifer which is currently undergoing the largest water rights adjudication effort in the United States.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	0	0	0	0
Masters	10	0	0	0	10
Ph.D.	2	0	0	0	2
Post-Doc.	1	0	0	0	1
Total	13	0	0	0	13

Notable Awards and Achievements

For Project 2009ID139B, Dr. Sridhar (PI) and his team's work was reported in the Regional Newspapers. Both Coeur d'Alene Press and Spokesman Review carried the article on climate change and water availability issues based on the presentation given by Dr. Sridhar in July, 2010 at Coeur d'Alene Advisory Council Meeting.

Publications from Prior Years