Integrated Hydrologic Model of the Wood River Valley and Stream Temperature Model of the Silver Creek Basin

Model Development, Calibration and Scenarios Report

by

Maria C. Loinaz

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The Nature Conservancy

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Unit Conversions

miles (mi) = kilometers (km) / 1.6

feet (ft) = meters (m) × 3.28

inches (in) = centimeters (cm) / 2.54

acres (ac) = square kilometers (km^2) × 247.1

cubic feet per second (ft^3/s) = cubic meters per second (m^3/s) / 35.3

acre-foot (ac-ft) = million cubic meters (Mm^3) × 810.7

°F = °C×1.8+32

Introduction

Silver Creek, located at the southeastern portion of the Wood River Valley, Idaho, is abundant in wildlife and is an important trout habitat. The Silver Creek Preserve, managed by The Nature Conservancy, provides valuable ecosystem services such as sport fishing, canoeing, bird watching, and hiking, which substantially contribute to the local economy. Nevertheless, local fishermen, scientists, and resources managers are concerned that this ecosystem is experiencing deteriorating habitat conditions in some areas and this poses a threat to the sustainability of fish and other species dependant on this system.

The Silver Creek Basin streams are mostly fed by the Wood River Valley aquifer system; thus, the river system is particularly vulnerable to changes in the landscape and to the water resources management in the valley. According to several hydrologic studies of the Wood River Valley, land use changes and increasing water use demand since the late 19th century have caused alterations in the hydrology of the valley and have impacted the water quality of Silver Creek (Brockway and Grover, 1978; Brockway and Kahlown, 1994; Wetzstein et al., 2000; Gillilan Associates, Inc., 2007; Skinner et al., 2007; Bartolino, 2009). Though there is very little information about the conditions prior to human settlement in the area, the anthropologic impact on the landscape and water resources is evident in changing factors such as river morphology, riparian vegetation, and decreasing water table elevation. These factors contribute to the interrelated effects of lower stream flow, higher stream temperatures, and sediment accumulation, which have potentially large impacts on the aquatic ecology and the deterioration of its ecosystem services. Due to the strong connection between the water management in the valley and stream conditions, the need to evaluate the processes that contribute to stream degradation at the catchment scale has been increasingly recognized. To this end, a catchment scale integrated hydrological model of the Wood River Valley was developed. The model can be further extended by adding water quality parameters such as sediment, temperature, chemical, and ecological processes.

This report documents the modeling work conducted as part of a PhD study at the Technical University of Denmark in collaboration with The Nature Conservancy of Idaho. The modeling tool developed consists of an integrated hydrological model of the Wood River Valley coupled to a stream temperature model of the Silver Creek Basin. The hydrologic model was calibrated for the period of 2003-2009 and the temperature model for the period of 2007-2009. Several model scenarios were run to evaluate the relative impacts of various contributing factors to changes in stream flow and temperatures in the Silver Creek Basin.

Site Description

The Silver Creek Basin (SCB) occupies the southeastern portion the Wood River Valley (WRV), a triangular valley surrounded by high mountainous terrain on all sides (Figure 1). Mountain peak elevations reach ~3800 meters above mean sea level (mamsl) and elevations in the valley range from 1460 in the south (near Picabo) to 2214 mamsl in the north (near Ketchum).

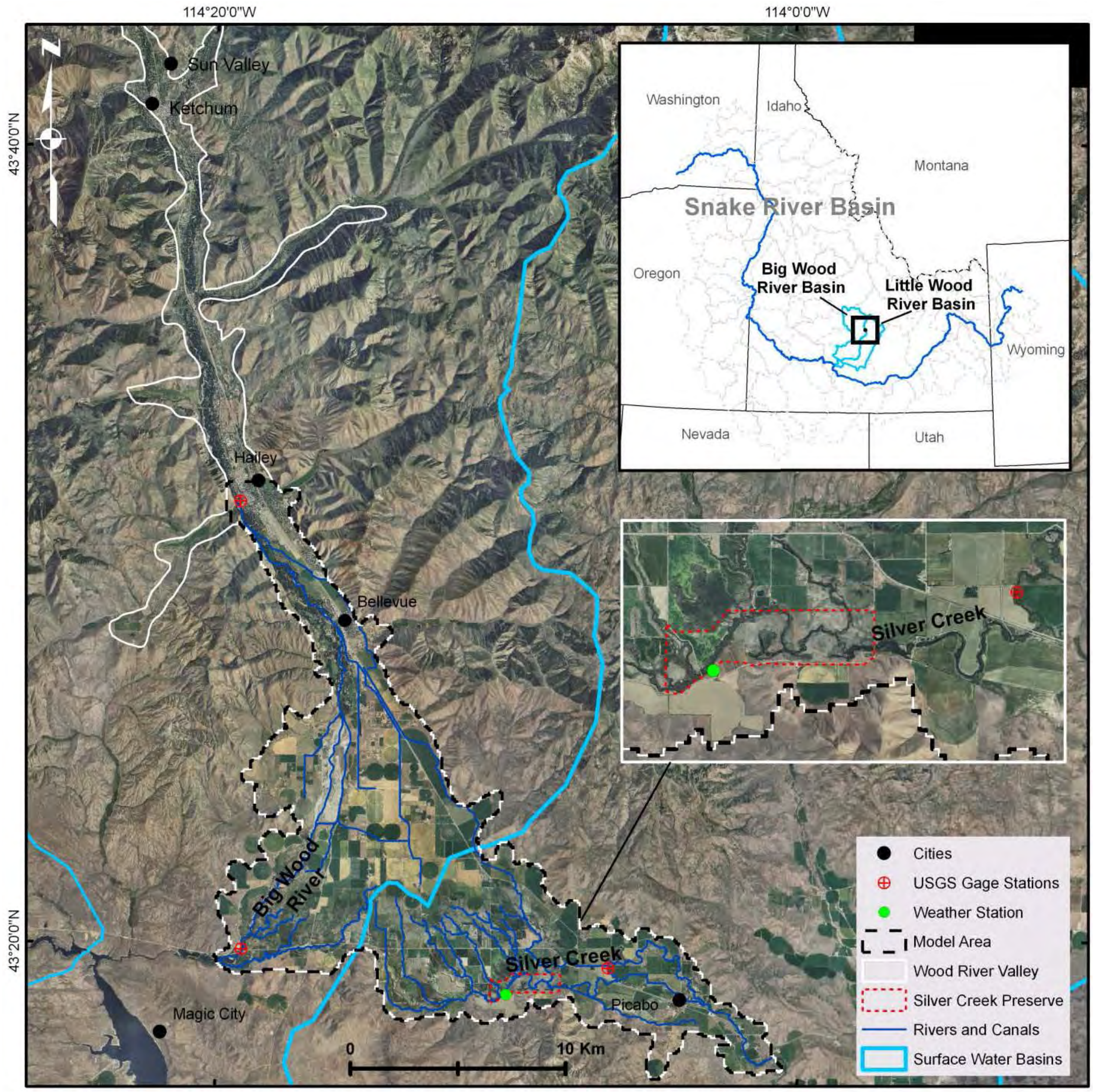

Figure 1. Wood River Valley and Silver Creek, Idaho. Model area, streams, and measured data locations.

An alluvial aquifer system underlies the valley and is the source of water to Silver Creek. The aquifer system links two surface water basins, the Big Wood River Basin (BWRB) and the Little Wood River Basin. Silver Creek is a tributary of the Little Wood River, but the Big Wood River (BWR) and its diversion canals recharge the aquifer that feeds the Silver Creek Basin. The WRV aquifer system consists of unconfined and confined aquifers comprised primarily of the fluvial and glacial sediments of the Quaternary period (Skinner et al., 2007). The valley is filled to depths of as much as 150 m with a sequence of interbedded clay, silt, sand, and gravel (Moreland, 1977). In the south-central portion of the valley thick, extensive layers of fine-grained material serve as barriers to groundwater flow. Springs form in the central area of the valley where the confining units constrain the movement of groundwater. Some of these springs flow to the west into the Big Wood River and some form tributaries that flow southeast to Silver Creek.

The climate of the Lower Wood River Valley is semi-arid with low precipitation and high evapotranspiration (Brockway and Kahlown, 1994). The average annual precipitation during the study period (2003-2009) was 31 cm. Approximately 60% of the precipitation falls during winter, mostly as snow (Bartolino, 2009). The average annual potential evapotranspiration for the crops in the valley ranges from 66 to 115 cm. Average air temperature is -4°C in the winter months and 19°C in the summer months.

The valley is intensely cultivated (approximately 64% of the area) and approximately 80% of the crop area is irrigated (Brockway and Kahlown, 1994). The types of crops (and percentage of the total agricultural area) are: alfalfa (34.5%), other hays (6.9%), barley (20.6%), corn (0.3%), spring wheat (0.5%), winter wheat (0.2%), oats (0.6%), beans (0.2%), potatoes (0.6%), peas (0.1%), unclassified cultivated crops (10%), and pasture (19.9%). Urban areas, grassland, and forests and wetlands occupy 9.7%, 19.4%, 6.5% of the study area, respectively.

The growing season typically occurs from May until the end of September. Over half of the irrigation water applied is diverted from streams by irrigation canals and the rest is abstracted by groundwater pumping. Irrigation water is distributed based on a system of water rights which is regulated by a local water distribution authority (Water Master) based on water right priorities and water availability. According to the Idaho Department of Water Resources database, there are over a thousand irrigation water rights in the study area (http://www.idwr.idaho.gov/GeographicInfo/GISdata/water_rights.htm). The total maximum permitted rates of groundwater abstractions and surface water diversions are approximately 13 and 37 m^3/s, respectively. The average annual surface water diversions during the study period are 128 million m^3 (Mm^3) (Water District 37 and 37M, 2010). Actual groundwater abstraction volumes for the study period are not available, however, Brockway and Kahlown (1994) measured groundwater abstraction volumes for irrigation in 1993 to be 63.5 Mm^3 and Bartolino (2009) estimated a total of 67.8 Mm^3/yr based on the maximum diversion volumes permitted. Approximately one quarter of this groundwater is pumped from the confined (artesian) aquifer and the rest from the unconfined aquifer. In the lower valley domestic and commercial water use is a small portion of the total water use (~4.2 Mm^3 annually) (Brockway and Kahlown, 1994) and it is highest in the northern areas of the valley where the largest population centers are located.

The flow in the Big Wood River at the city of Hailey is on average ~10 m^3/s. The peak flows occur from the middle to the end of May and can be as high as 190 m^3/s. At the southwest outlet, flow in the BWR averages about 34% of the flow in Hailey as a result of seepage losses and canal diversions. The Silver Creek hydrograph is relatively smooth throughout the year because it is a spring-fed system. The average flow in Silver Creek is around 4 m^3/s. Maximum flows (~10-12 m^3/s) occur during March or April due to local snowmelt runoff from surrounding mountains and low flows (~1.5-3 m^3/s) occur in the summer. Average water temperatures in the SCB in the summer range from 15 to 19°C and maximum temperatures have exceeded 22°C in measured locations (http://www.savesilvercreek.org/main_page.html).

Hydrologic Model

The hydrologic processes that dominate the Lower Wood River Valley system are shown in (Figure 2). Surface and subsurface flows from the northern BWRB enter the lower valley at Hailey; some of this flow is diverted by a system of irrigation canals, some is lost to the groundwater by seepage from the BWR, and the rest leaves the valley in the southwest corner. The irrigation canals deliver the diverted water to the crops; some irrigation water seeps into the aquifer and the rest is lost by evapotranspiration of crops. Groundwater abstractions wells also supply crops, as well as domestic users. Groundwater flow is unconfined in the northern areas of the valley; transmissivity decreases towards the south due to fine sediment layers beginning at the center of the valley and increasing in thickness to the south. The fine sediment layers in the south form a confining unit. The flow direction is split into the southeast and southwest areas of the valley where some of it discharges as springs. In the southeast corner of the valley the transmissivities are higher due to basalt formations through which groundwater flows out of the valley. Water for agriculture is also diverted from the spring-fed creeks and canals in the south.

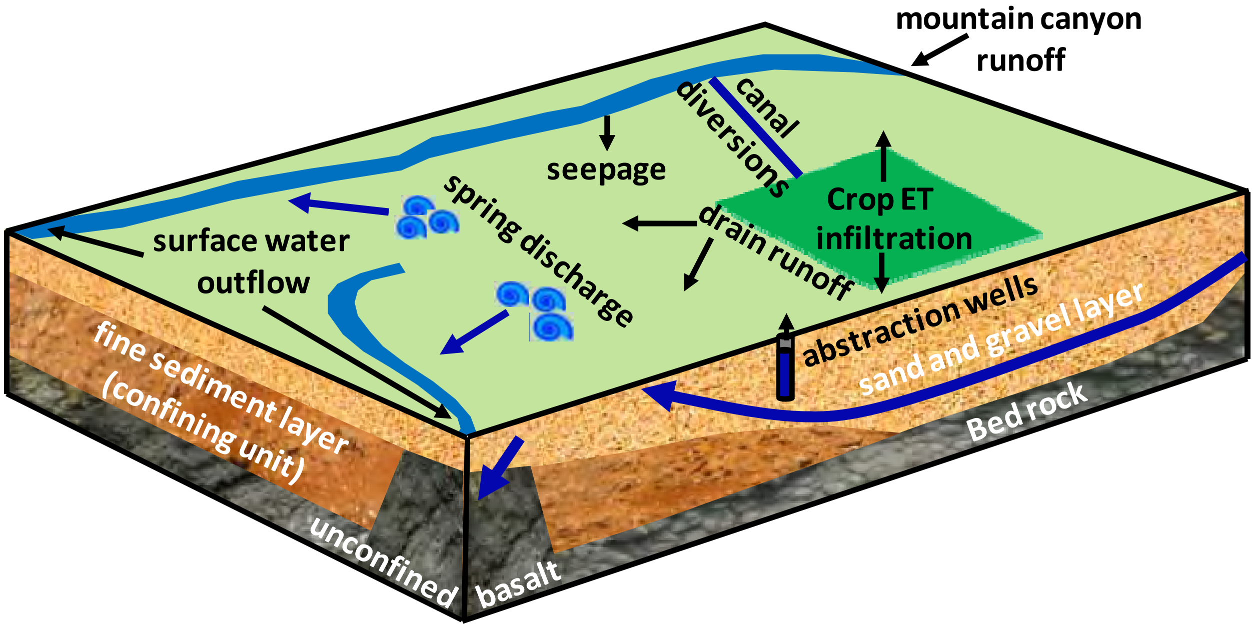

Figure 2. Conceptual hydrologic diagram of the Wood River Valley

The hydrologic model was built in MIKE SHE which is a physically based and spatially distributed modeling tool for simulating the main processes of the hydrological cycle. The model is fully integrated, i.e., all processes are dynamically coupled. Simulated hydrologic processes include snowmelt, interception, overland flow, infiltration into soils, evapotranspiration from vegetation and subsurface flow in the saturated and unsaturated zones (Refsgaard and Storm, 1995; Graham and Butts, 2006). MIKE SHE can be dynamically coupled to MIKE 11, which is a one-dimensional surface water model that simulates fully dynamic channel flows and control structures (Thompson et al., 2004). MIKE SHE has been widely used for integrated surface water-groundwater interactions and it is an appropriate tool to model the hydrology of the Wood River Valley because it is able to describe both the irrigation effects and the basin scale surface water-groundwater interactions in the valley.

The model area includes the lower Wood River Valley, south of the city of Hailey (Figure 1), an area of approximately 231 km^2. The northern boundary of the study area at Hailey was chosen to coincide with the location of the U.S. Geological Survey (USGS) flow gage at the Big Wood River with long-term continuous measurements (http://waterdata.usgs.gov/nwis). A model cell size of 300 meters was chosen after a trial and error process, trading off computational time, stability of the surface water-groundwater exchange, and representation of spatial details of the landscape. The model components and data inputs and sources are described below. Detailed descriptions of the calculation methods for all the model components are included in the MIKE SHE and MIKE 11 reference manuals available with the software download (http://mikebydhi.com/). The time steps for the time series of data inputs are hourly or daily.

Topography

The topography in MIKE SHE defines the upper elevation of the groundwater model. The USGS National Elevation Dataset (http://ned.usgs.gov/) was used to create the topographic map in the model. The 10-meter resolution dataset was interpolated to the model cell size by using an averaging method in ArcGIS. The resulting map was then smoothed out in certain areas where there were large elevation differences such as the boundary cells and in cells adjacent to the streams to reduce numerical instabilities.

Climate

MIKE SHE uses input time series data of precipitation and air temperature to calculate rainfall and snow. Snow dynamics are calculated using a degree-day method in which the rate of melting increases as the air temperature increases.

Precipitation and air temperature time series for the simulation period were obtained for the Picabo weather station from the AgriMet database of the U.S. Bureau of Reclamation (http://www.usbr.gov/pn/agrimet/wxdata.html). To calculate snowmelt the degree-day factor used is 2 mm/°C/d and the melting temperature was set to 0°C.

Evapotranspiration and unsaturated subsurface flow

The two-layer water balance approach in MIKE SHE was selected to calculate actual evapotranspiration, infiltration rate, and moisture content of the soils. This method was chosen because it is more computationally efficient and more appropriate at the regional scale than the more complex Richards equation approach. The method assumes that all water stored in the root zone is available for transpiration and calculates average moisture content based on the depth of the water table and the storage capacity of the soil. The input requirements for this module are a time series of reference evapotranspiration, a land use/vegetation map, vegetation parameters, a soil map, and soil parameters.

Time series of reference evapotranspiration was obtained for the Picabo weather station from the Agrimet dataset (http://www.usbr.gov/pn/agrimet/wxdata.html). The 2009 Idaho Cropland Data from the U.S. Department of Agriculture National Agricultural Statistics Service (NASS) (http://datagateway.nrcs.usda.gov/) was used to develop a land use/vegetation map for the model area. The dataset combines the land use data from the USGS National Land Cover Dataset (http://www.mrlc.gov/index.asp) and NASS crop types. A total of 22 land use/vegetation types were included in the model (Figure 3). Time series for the vegetation parameters required for the actual ET calculation (crop coefficients, root depths, LAI) were created based on vegetation and crop cycles from Allen et al. (1998). The crop cycles were assumed to be the same for every year of the simulation. A soil map and soil parameters for each soil type (moisture content at saturation, field capacity, and wilting point; and maximum infiltration rates) were obtained from the Natural Resource Conservation Service Soil Survey database for Blaine County, Idaho (http://soildatamart.nrcs.usda.gov/). A total of 58 soil types were included in the model.

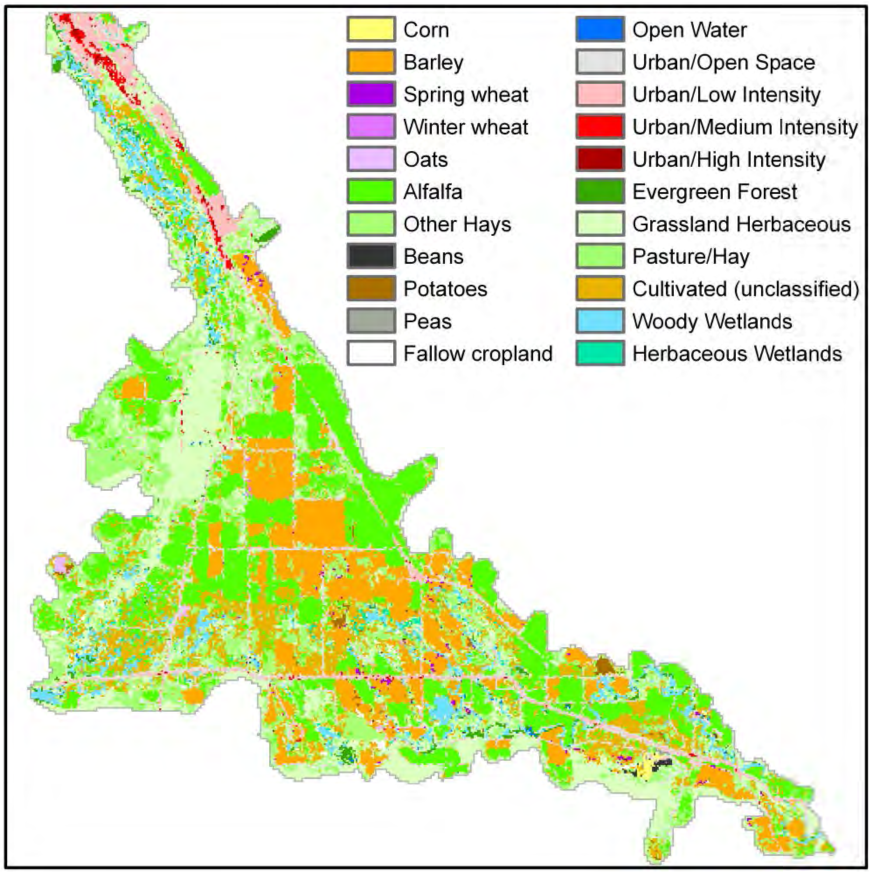

Figure 3. Land use/vegetation and crop types in the model area

Surface water

MIKE 11 surface water flow model uses a finite difference approach to solve the one-dimensional dynamic wave Saint Venant Equations. It calculates water levels and discharges for alternating gridpoints along the length of the streams. MIKE 11 also has different types of operating and non-operating control structures (weirs, culverts, gates, and pumps).

The main inputs for the surface water model are a map of the rivers and canals and cross-sectional data. The river center lines were based on data from the USGS National Hydrography Dataset (http://nhd.usgs.gov/) and refined with aerial photography (Figure 1). Much of the cross-sectional data for the Silver Creek Basin was obtained from a cross-section survey conducted by The Nature Conservancy in 2010. For the Big Wood River and canals aerial photography was used to define the channel widths and approximate depths were estimated based on site inspection. All of the stream bank elevations were matched to the interpolated MIKE SHE topography to ensure consistency and reduce numerical instabilities in the surface water-groundwater exchange. A total of 284 cross-sections were defined in the model. Operating gates and pumps in MIKE 11 were used to control the irrigation diversions based on data from the Water Master (see Water use section).

The exchange flow between the groundwater and the streams occurs in the direction of the head gradient at a rate determined by the conductance. The calculated conductance is a function of a specified streambed leakage coefficient and/or the aquifer hydraulic conductivity and stream geometry. If the conductance type chosen is streambed leakage + aquifer conductivity, then the model calculates an average conductance using both parameters. The leakage coefficient values and the conductance type (streambed leakage coefficient only = 1 or leakage coefficient + aquifer conductivity = 2) were changed during the calibration of the model. The final values are shown in Table 1.

Table 1. Final streambed leakage coefficients

Stream	Conductance type[a]	Value (sec^{-1})
Big Wood River (northern 19.5 km)	1	1×10^{-4}
Big Wood River (southern 8.7 km)	1	1×10^{-6}
Black Slough	1	1×10^{-5}
Crystal Creek	1	1×10^{-5}
Spring Creek	1	1×10^{-5}
Willow Creek	1	1×10^{-5}
Baseline Canal	2	1×10^{-5}
Black Ditch	2	1×10^{-5}
By-Pass Canal	2	1×10^{-5}
Cove Canal	1	1×10^{-5}
District45 Central Canal	2	1×10^{-5}
District45 East Canal	2	1×10^{-5}
District45 West Canal	2	1×10^{-5}
Glendale Canal	2	1×10^{-5}
Buhler Drain	1	1×10^{-5}
Cain Creek	1	1×10^{-5}

Stream	Conductance type[a]	Value (sec^{-1})
Chaney Creek	1	1×10^{-5}
Gillihan Ditch	1	1×10^{-5}
Grove Creek	1	1×10^{-5}
Iden ODrain	1	1×10^{-5}
Kilpatrick Canal	1	1×10^{-5}
Loving Creek	1	1×10^{-6}
Mud Creek	1	1×10^{-5}
Patton Creek	1	1×10^{-5}
Silver Creek	1	1×10^{-6}
Stalker Creek	1	1×10^{-5}
Thompson Creek	1	1×10^{-5}
Wilson Creek	1	1×10^{-5}

[a] Conductance type = 1 if it uses the streambed leakage only and 2 if it uses both the streambed leakage and the aquifer conductivity.

The measured flows at Hailey were specified at the northern surface water boundary. The flows at this location comprise most of the mountain runoff to the BWR. To simulate runoff from the mountain basins in the southern valley the NAM rainfall-runoff model in MIKE 11 was linked to the surface water model. The NAM is a lumped parameter, catchment-based rainfall-runoff that routes water from defined catchments to the MIKE 11 rivers. This module can be used to simulate runoff from mountain catchments that are not included in the MIKE SHE model domain. The mountain catchments were delineated using the StreamStats web tool (http://water.usgs.gov/osw/streamstats/).

Saturated groundwater flow

MIKE SHE uses a finite difference solution to the 3-dimensional Darcy equation for aquifer flow. The saturated groundwater module (SZ) can be spatially discretized vertically and horizontally according to the complexity required.

The Wood River Valley geologic model consists of 3 layers: the unconfined aquifer, the confining unit, and the confined aquifer. The thickness of these layers is spatially defined based on borehole data from the Idaho Department of Water Resources Well Drillers Reports (http://www.idwr.idaho.gov/WaterManagement/WellInformation/DrillerReports/dr_default.htm). Due to the complexity of the hydrogeologic layers in the model area several geologic interpolation iterations were performed during the calibration process. Figure 4, Figure 5, and Figure 6 show the final interpolated thickness of the three hydrogeologic layers.

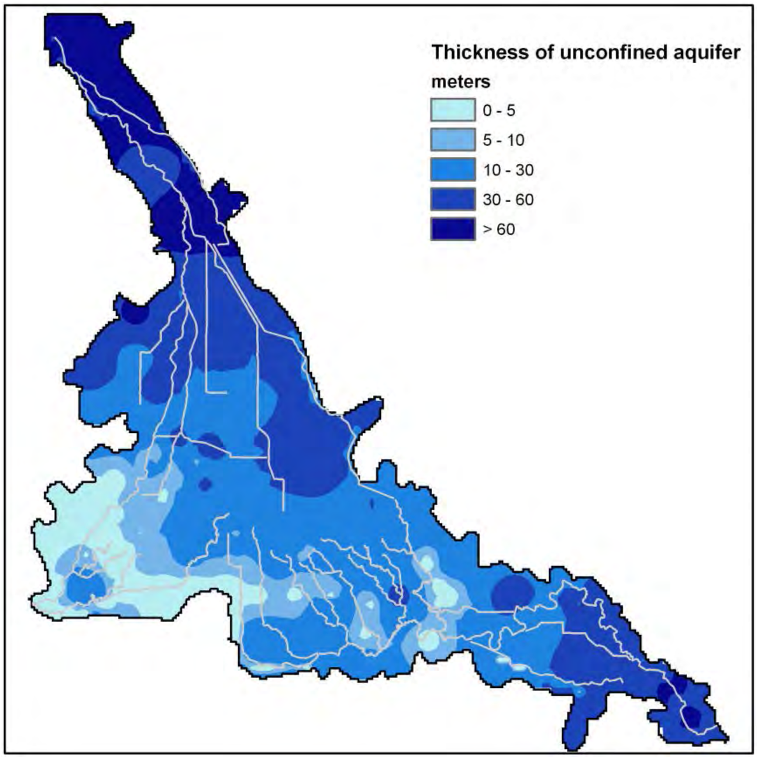

Figure 4. Interpolated thickness of the unconfined aquifer from borehole data.

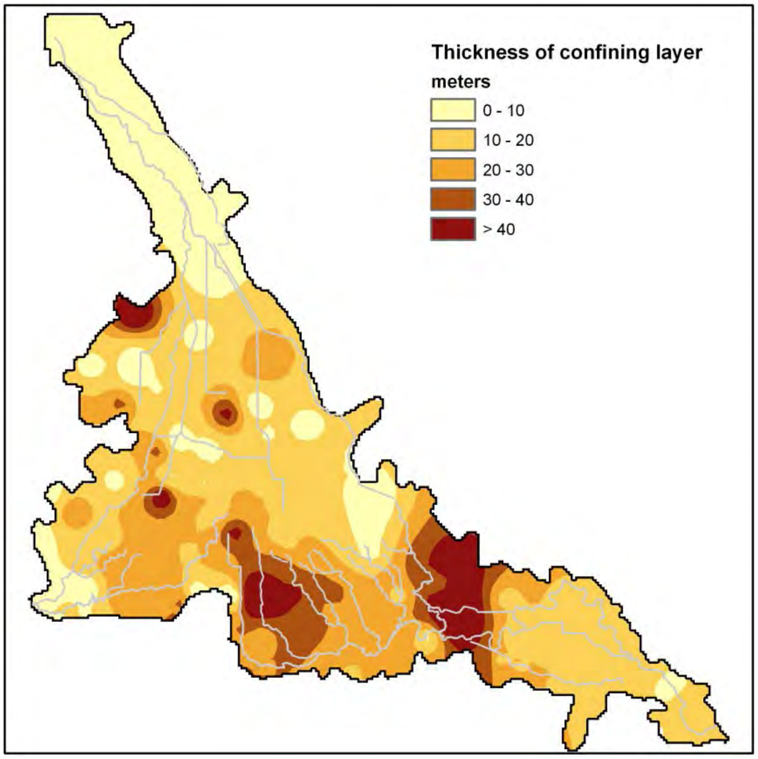

Figure 5. Interpolated thickness of the confining unit from borehole data

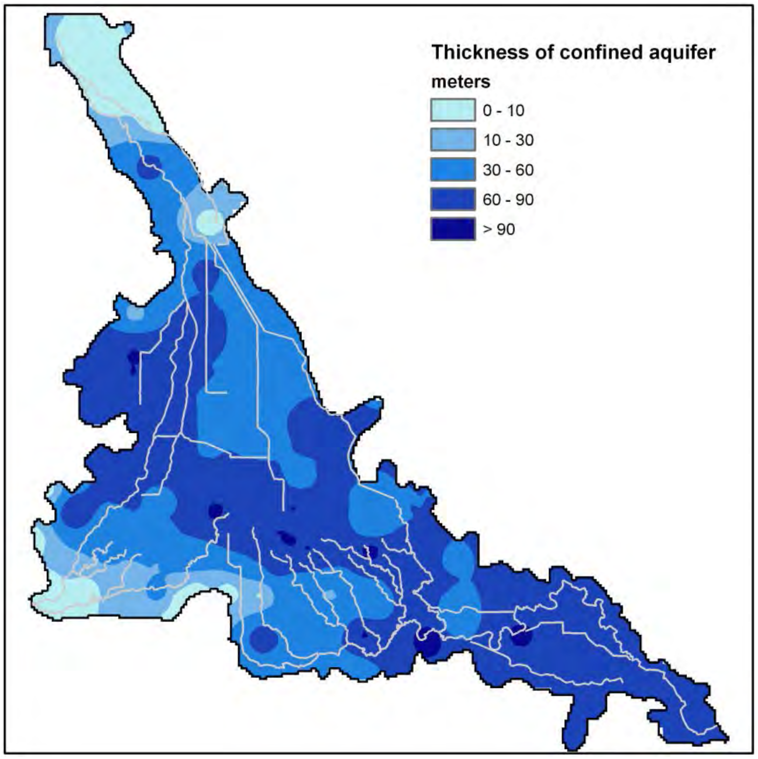

Figure 6. Interpolated thickness of the confined aquifer from borehole data

The hydraulic conductivities for the geologic layers were also varied during the calibration. Since there is a large degree of heterogeneity in the sediments of the unconfined aquifer, the first layer was divided into four zones based on the transmissivity map from Moreland (1977). The four zones consist of: 1) the northern narrow section of valley, 2) the wide center of the valley, 3) southwest (where the BWR southern tributaries are located) and south-center (where the Silver Creek tributaries are located), and 4) the southeast corner of the model boundary that is dominated by basaltic formations. The final conductivities for all layers are listed in Table 2.

Table 2. Final hydraulic conductivities

Hydrogeologic layer	$K_{horizontal}$ (m/s)	$K_{vertical}$ (m/s)
Unconfined aquifer[a]	0.005, 0.03, 0.001, 0.005	0.005, 0.03, 0.001, 0.005
Confining unit	1×10^{-8}	1×10^{-8}
Confined aquifer	0.001	0.0001

[a] The conductivity values for the four zones in the order described above.

The groundwater boundaries were defined as follows; 1. a northern flow boundary - the subsurface flow was estimated following a similar gradient-based procedure by Bartolino (2009), 2. a fixed head boundary at the southeast corner using measured groundwater elevations from the USGS, and 3. a zero-flow boundary around the rest of the model boundary.

Agricultural fields are drained by a system of ditches that route the water to canals, streams, and recharge ponds. The SZ module includes a drainage option that routes the groundwater that is above a specified elevation to the nearest streams at a specified rate. Agricultural runoff is simulated by the drainage module and was specified for all the crop cells of the model. The drainage level specified was 0.3 meters below the ground surface and a drainage time constant of 1×10^{-7} sec^{-1}. Thus, if the water table elevation is above 0.3 meters less than the elevation of the ground then the volume of water in the model cell that exceeds this elevation will be routed to the nearest stream at the rate specified by the drainage time constant.

Although time series of groundwater abstractions are not available, pumping wells were included in the model in several selected locations throughout the basin (Figure 7). The well data from the Idaho Department of Water Resources (http://www.idwr.idaho.gov/GeographicInfo/GISdata/wells.htm) was used to select the locations of the highest production wells in each irrigation area (see Irrigation section below) . The total annual maximum diversion volume estimated by Bartolino (2009) was assumed to be the total abstraction volume every year of the simulation. The abstraction volume was distributed among the wells based on the ICA size and in time according to the distribution of irrigation demand (based on the annual crop cycles).

Crop Irrigation

The irrigation module in MIKE SHE distributes water to crop cells or irrigation command areas (ICAs) from a specified source (groundwater and/or surface water) according to the crop water demand and the water availability in the specified sources. In this case, the irrigation water was added to the precipitation component, simulating sprinkler irrigation. Irrigation demand was specified based on calculated crop evapotranspiration requirements for each crop type.

The ICAs were grouped according to the source canal that supplies water to specific areas in the valley (Figure 7). The measured flows by the Irrigation District 37 Water Master (Water District 37 and 37-M, 2010) were used to specify the amount of water diverted to the irrigation canals. Some of this diverted water is lost by seepage to the aquifer and the remaining water does not satisfy all of the irrigation demand. Thus, an external source that represents groundwater supplies the necessary water when water is not available in the canals.

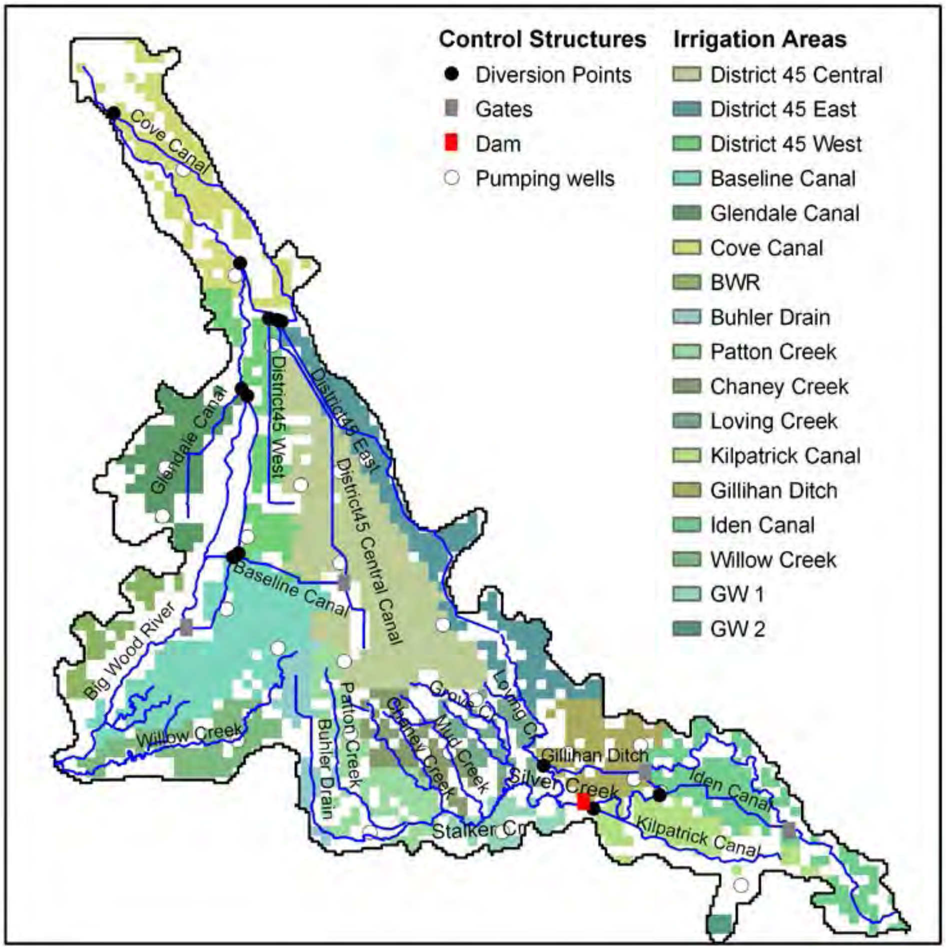

Figure 7. Distribution of irrigation areas in the model, main diversion canals and control structures.

Temperature Model

A stream temperature model that is dynamically coupled to the hydrologic model was developed for Silver Creek and all of its tributaries. A MIKE SHE-MIKE 11 model of the Silver Creek Basin area was cut from the larger model of the valley at the BWRB-SCB surface water basin divide. The groundwater flow at the divide was extracted from the larger model and used as boundary conditions to run an integrated flow and temperature model of the SCB. This model outputs daily flows and hourly temperatures for a period of 3 years (2007-2009).

The temperature model has two components: heat transport and a net heat source/sink. Heat is transported similar to a mass solute in the advection-dispersion module in MIKE 11. The net heat source/sink is the net heat exchange between water and atmosphere and water and bed sediments via several processes (shown in Figure 8). The heat balance processes are coded in an equation solver called ECO Lab which is coupled to MIKE 11. A detailed description of the stream temperature model processes and parameters is given by Loinaz et al., (2012a).

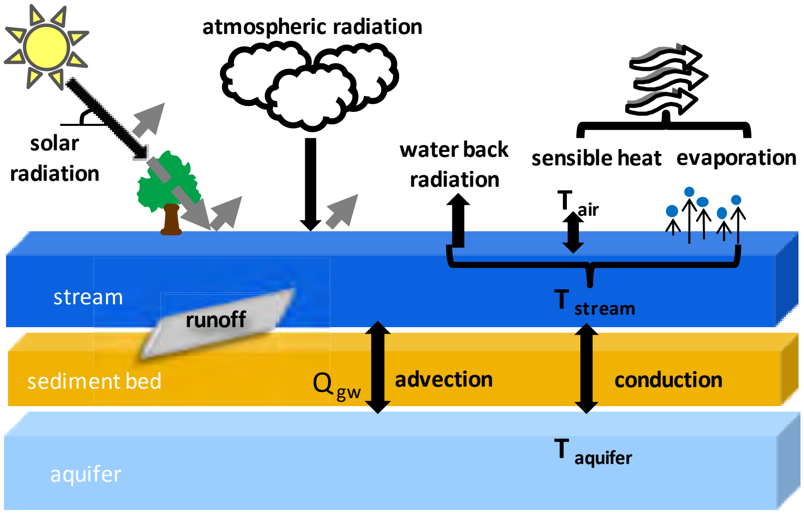

Figure 8. Heat balance components.

Input time series data for the temperature model were obtained from the Picabo weather station (http://www.usbr.gov/pn/agrimet/wxdata.html), located just south of Silver Creek (Figure 1). The following parameters were time series inputs to the atmospheric heat exchange:

- Global solar radiation
- Diffuse solar radiation
- Air temperature
- Relative humidity
- Wind speed

The stream orientation and the vegetation parameters needed for shading calculations were calculated for all the streams in the model using the TTools for ArcGIS (Boyd and Kasper, 2003), using a stream segment discretization of 500 meters. Other constant parameters for the heat balance equations were obtained by model calibration (Loinaz et al., 2012a).

Continuous groundwater measurements taken for one year as part of this study show that deep groundwater temperature is fairly constant throughout the year, but also that there is a seasonal variability in shallow groundwater temperature (~1 meter from the surface). Since shallow groundwater interacts directly with surface water, a time series of groundwater temperature was generated based on the one-year measurement of shallow groundwater.

Excess drainage from agricultural fields can be at temperatures much higher than in nearby streams (Fujimoto et al., 2008). Agricultural runoff temperature was simulated assuming that the temperatures in the drainage ditches are in equilibrium with the atmosphere. The equilibrium temperature is the water temperature at which the sum of all heat fluxes is zero.

Calibrated model

Calibration approach

In order to evaluate the model performance under different climate conditions, the flow model was calibrated for the period of 2003-2009. In terms of the ecological implications, the main interest of this study are the low flows and high temperatures in Silver Creek. Thus, the calibration of the flow model was mostly focused on minimizing the error in the Silver Creek flow hydrograph, specially the low summer flow. However, the BWR flow, the Silver Creek tributaries, and groundwater elevations were also taken into account as part of the calibration process.

One of the objectives of the calibration was that the distribution of water in the valley is properly represented. That is, the irrigation application, crop evapotranspiration, canal seepage, and spring discharges should be within a reasonable volume range compared to the data available and to previous studies of the area. Some work was also invested on reducing potential sources of the numerical errors that occur in the dynamics of surface water-groundwater exchange.

The interpolation of the geology is another critical part of the model. The depth of the confining unit in the southern part of the valley has a significant impact on both groundwater levels and Silver Creek flows. Because of the complexity of the geology, the interpolation into the three groundwater model layers can vary greatly and it should be carefully interpreted. During the calibration process the borehole data was carefully examined, compared to previous geologic studies of the valley, and re-interpolated several times.

The distribution of tributary flows in the SCB is particularly important for the temperature model because the different conditions of the tributaries can lead to different temperatures in Silver Creek. For example, tributaries may be exposed to different amounts of shade, have different flow regimes and receive flow from different sources (groundwater versus agricultural runoff).

Considering the objectives described above, a set of semi-automatic calibration runs was performed varying hydraulic conductivities and leakage coefficients.

Stream flow and water depth have a large influence on the temperature results. Thus, the temperature model parameters were calibrated using a simple stream model of Silver Creek where the stream hydraulic parameters are easier to calibrate. Flow and temperature boundary conditions at the location of the Silver Creek tributaries were defined using estimated tributary flow and measured temperature data. The estimated flow for each Silver Creek tributary was estimated by calculating the relative contribution from each tributary from the larger flow model and multiplying this fraction by the measured flow from the USGS gage at Picabo. Stream depths were calibrated against the USGS gage water depths by varying the manning roughness coefficient in the channel.

Flow model results

Calibration plots at the locations of the USGS flow gages close to the southern outlets of the model in the BWR and Silver Creek are in Figure 9 and Figure 10, respectively.

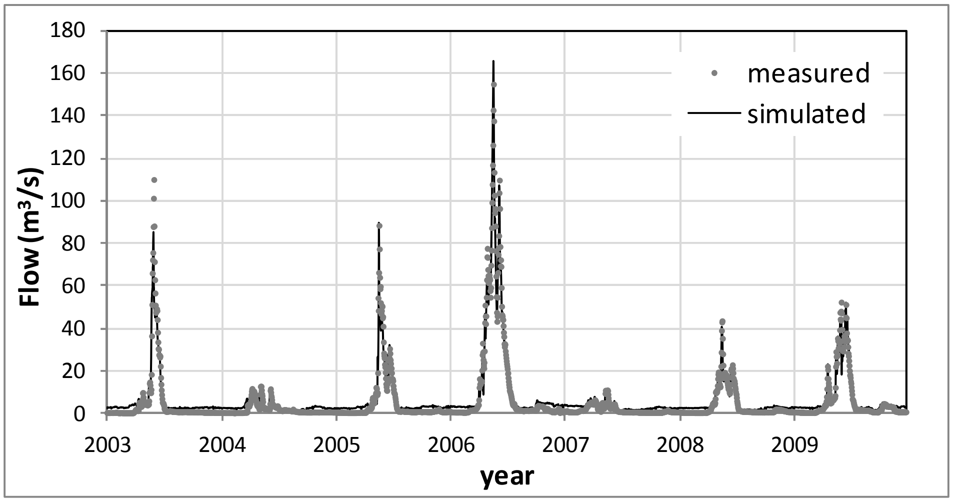

Figure 9. Simulated vs. observed flow at the Big Wood River flow gage at Stanton Crossing (USGS St. 13140800)

The BWR flow matches the observed data quite accurately, which means that the volume of water taken out by seepage losses and diversions in the river is fairly well represented, although the simulated baseflow tends to be higher than observed by ~2 m^3/s. The flow calibration statistics calculated for the period 2003-2009 for the BWR are: a mean error (ME) of -0.98 m^3/s the, root mean square error (RMSE) of 2.7 m^3/s, and a correlation coefficient (R) of 0.99. The equations used to calculate the statistics are shown below, where n is the number of observations, $Obs_{i,t}$ and $Calc_{i,t}$ are the measured and the simulated value at location i and time t, respectively (MIKE SHE reference manual).

$$ME = \frac{\sum_t \left(Obs_{i,t} - Calc_{i,t}\right)}{n}$$

$$RMSE = \frac{\sum_t \sqrt{\left(Obs_{i,t} - Calc_{i,t}\right)^2}}{n}$$

$$R = \frac{\sum_t \left(Calc_{i,t} - \overline{Calc}_{i,t}\right) \times \left(Obs_{i,t} - \overline{Obs}_{i,t}\right)}{\sqrt{\sum_t \left(Calc_{i,t} - \overline{Calc}_{i,t}\right)^2 \times \sum_t \left(Obs_{i,t} - \overline{Obs}_{i,t}\right)^2}}$$

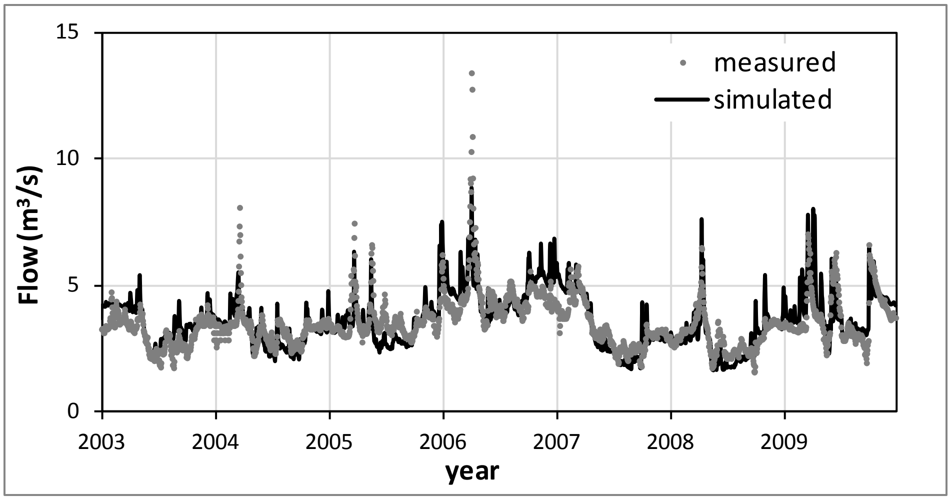

Figure 10. Simulated vs. observed flow at the Silver Creek flow gage near Picabo (USGS St. 13150430)

The simulated flow in Silver Creek at the USGS station follows the trends of the measured flow most of the times. The largest errors occur during the spring high flow periods, during which the model underestimates some of the peaks. A possible explanation could be that the runoff peaks from the mountain tributaries that occur mostly during the spring months were underestimated by the model. As previously mentioned, mountain runoff was simulated using the NAM rainfall-runoff model that is linked to the MIKE 11 streams; however, there was very limited data available to properly calibrate the model. The flow calibration statistics calculated for the period 2003-2009 for Silver Creek are: a mean error (ME) of -0.1 m^3/s the, root mean square error (RMSE) of 0.7 m^3/s, and a correlation coefficient (R) of 0.78.

The data available to compare the basin flow distribution among the Silver Creek tributaries is limited. The Nature Conservancy (TNC) has collected manual flow measurements at several locations around the Silver Creek preserve. A comparison of the model and the TNC flow measurements in Stalker Creek (Figure 11), Grove Creek (Figure 12) and Loving Creek (Figure 13) is shown below.

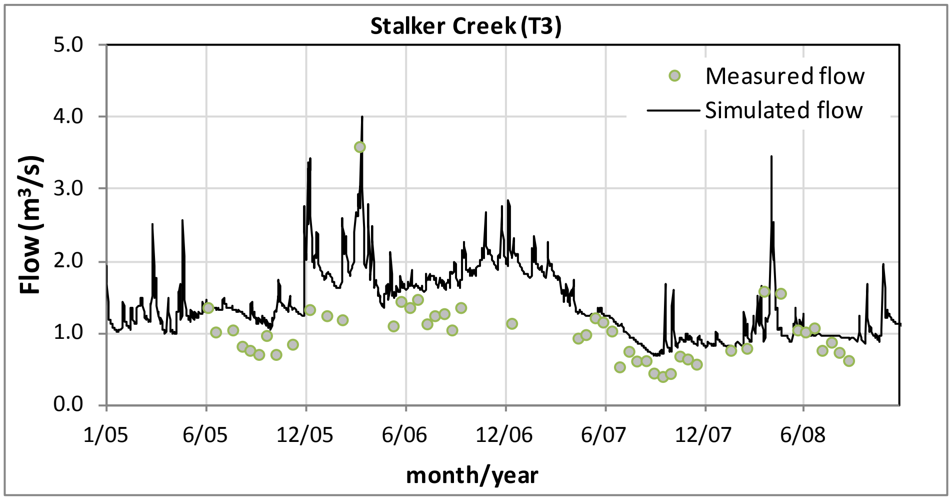

Figure 11. Simulated vs. measured flow at Stalker Creek (TNC T3)

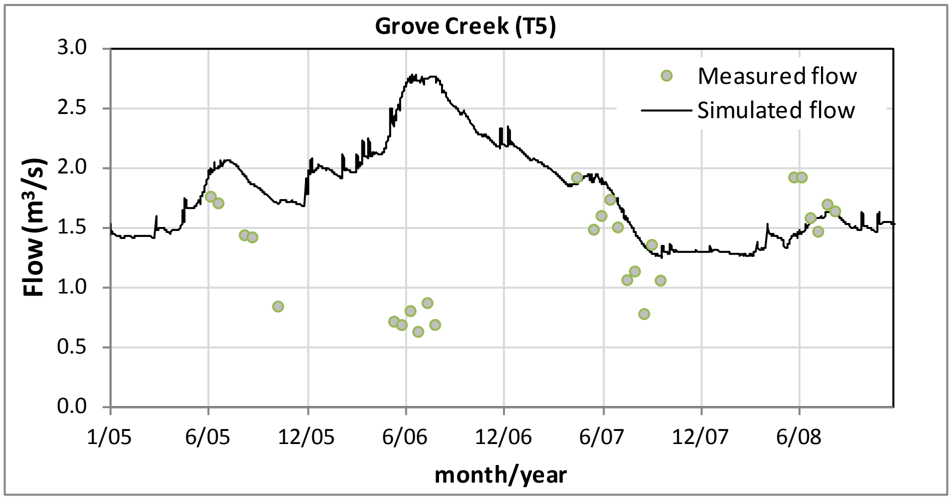

Figure 12. Simulated vs. measured flow at Grove Creek (TNC T5)

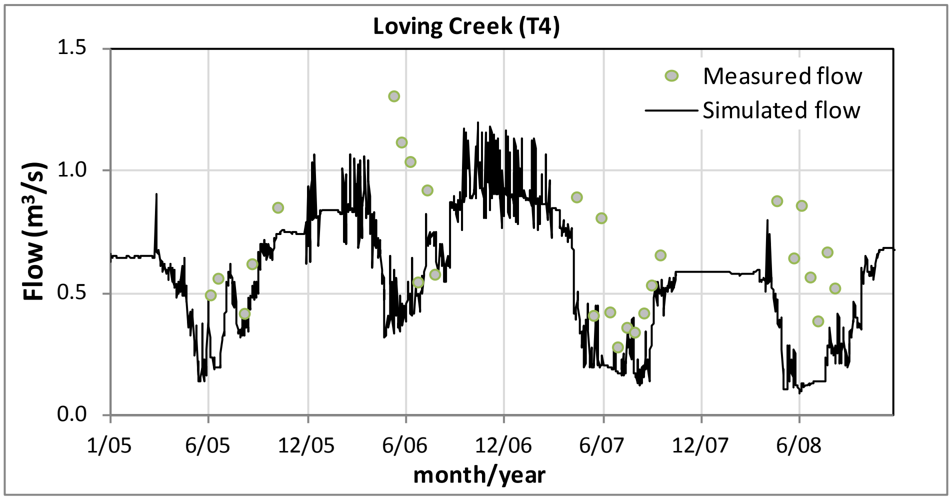

Figure 13. Simulated vs. measured flow at Loving Creek (TNC T4)

It is difficult to conduct a proper dynamic comparison at these locations between the model and the observed data because of the low frequency of the measurements. Even though, in many of the times the simulated flow are of similar magnitudes to the measured data, in Loving Creek the simulated flow is underestimated, whereas in Stalker Creek and Grove Creek the simulated flow is overestimated. The average flow contribution from the tributaries to Silver Creek was also compared and shown in Table 3. The percentages were calculated by taking the average flow for the period of available data (2005-2008).

Table 3. Average contribution of tributaries to Silver Creek flow

tributary	simulated flow	measured flow
Stalker Creek[a]	37%	34%
Grove Creek	48%	44%
Loving Creek	15%	22%

[a]includes Buhler Drain, Patton Creek, Chaney Creek, and Mud Creek

The model simulates 48% of the Silver Creek flow as coming from Grove Creek, whereas the measured flow indicates that 44% of the flow comes from Grove Creek. This difference could potentially lead to colder simulated temperatures in Silver Creek because Grove Creek is a colder system than both Stalker Creek and Loving Creek. The distribution of flow in the tributaries could be improved when more data becomes available through calibration of stream leakage coefficient and aquifer conductivities.

Water budget calculations served to guide the model development and calibration. Moreover, the water budget is useful for understanding the distribution of flows in the valley, which is important in understanding the results of the model scenarios. Data to perform a quantitative comparison of the water budget components were not available, but a qualitative comparison was performed of some of the model components for which limited data was available from previous studies (e.g., evapotranspiration, irrigation, seepage, subsurface flows) and adjustments made where necessary. The water budget for the entire model area for the final calibration simulation is shown in Table 4.

Table 4. Simulated water budget of the Wood River Valley

Water budget component	annual average (10^6 m^3/yr)
Inflows	
Precipitation	68
Runoff from mountain catchments	422
Subsurface inflow	32
Total inflows	521
Internal surface water-groundwater flows	
Surface water diversions	82
Groundwater abstractions	57
Total irrigation	128
Net seepage loss from the BWR and canals	185
Groundwater recharge from soils	45
Groundwater flow across the BWR-SCB divide	159
Total spring discharge	129
Outflows	
Evapotranspiration	151
Big Wood River surface water outflow	231
Silver Creek surface water outflow	101
Subsurface outflow (southeast)	48
Total outflows	531

The largest inflow to the model is through the Big Wood River (BWR) at the northern boundary, which are measured flows at Hailey. This flow gage receives most of the runoff from the mountainous tributaries in the Big Wood River Basin. Approximately 25% of this flow is diverted from the BWR to an extensive network of irrigation canals. The BWR and the diversion canals lose a significant portion of the flow to the aquifer. Approximately a third of the total inflow volume flows from the BWR Basin to the Silver Creek Basin through groundwater flow discharges at the headwaters of the Silver Creek tributaries; another third is lost to evapotranspiration (mostly from crops); and the rest flows out of the valley through the Big Wood River.

Stream temperature model results

The simulation period for the temperature model is shorter than for the flow model (April, 2007 to September, 2009) because of the availability of the model input and calibration data. A plot of the average daily temperature for this period at the USGS Picabo station is shown in Figure 14. An hourly frequency plot for the summer of 2008 is shown in Figure 15. In general, the simulated temperature matches the trends of the measured temperature. The mean error for the hourly data for the period of 2007 – 2009 is 1.4°C, the RMSE is 1.7°C, and the R is 0.98. The high correlation coefficient indicates that the dynamics are well represented, i.e., the timing of the peaks and lows matches very closely with the measured data. The positive mean error indicates that the model temperatures are in average cooler than the measured temperature. As Figure 15 illustrates, the high peaks of the summer months are well matched by the model. However, the amplitude of the diurnal oscillations is larger in the model than in the measured data because the simulated lower night temperatures are colder than observed thus, resulting in a lower average daily value. Errors in the diurnal amplitude are likely caused by inaccuracies in the representation of the stream geometry because water depth and surface area affect the thermal inertia (the ability to conduct and store heat) and hence, the diurnal amplitude.

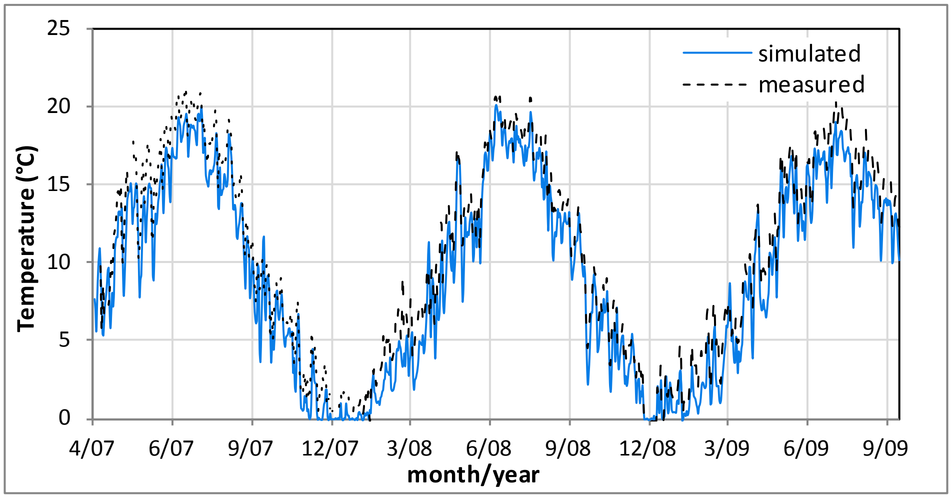

Figure 14. Simulated vs. observed daily temperature the Silver Creek flow gage near Picabo (USGS St. 13150430)

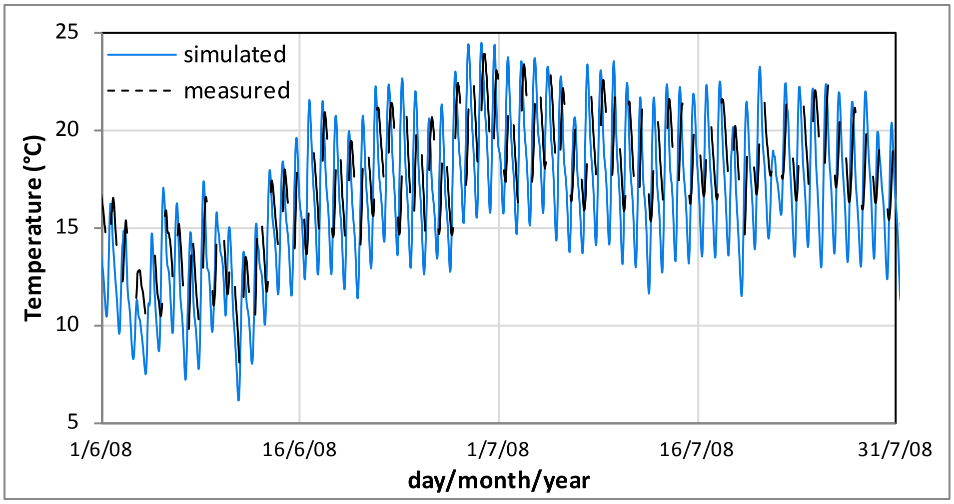

Figure 15. Simulated vs. observed hourly temperature the Silver Creek flow gage near Picabo (USGS St. 13150430)

A map of simulated stream temperatures for all the streams in the Silver Creek Basin at the hour of the warmest water temperatures in Silver Creek (June 29th, 2008 16:00) is shown below (Figure 16). The headwaters of Stalker Creek, the stream that turns into Silver Creek after Grove Creek, shows extremely high and lethal temperatures (>25°C) due to the warm flows from Buhler Drain and Patton Creek. The stream cools as it receives the flow from Mud Creek. Grove Creek, which has larger spring flows, reduces the temperatures from Stalker Creek at the headwaters of Silver Creek. Loving Creek gets warmer as it flows toward Silver Creek, possibly because of the irrigation diversions by the Gillihan Ditch and higher exposure to solar radiation. The downstream areas of Silver Creek also get warmer due to irrigation diversions and large segments of open water areas.

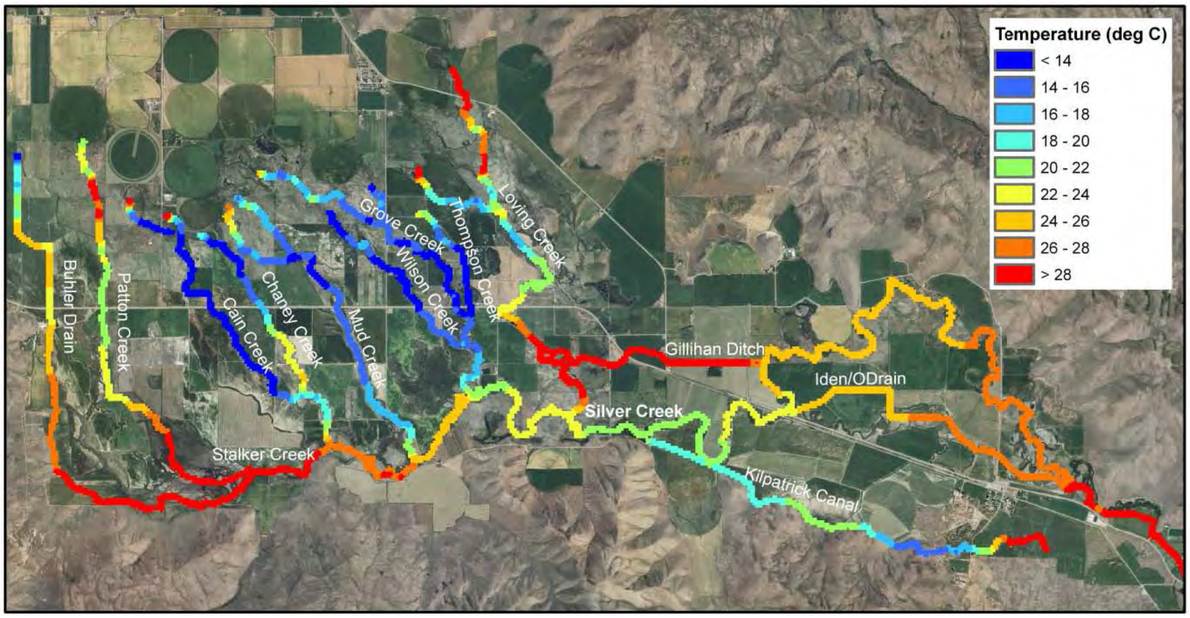

Figure 16. Simulated stream temperatures at the hour of warmest water temperatures in the downstream portions of Silver Creek (June 29th, 2008 16:00)

The spatial distribution of temperatures in the Silver Creek Basin can be better understood by examining the various heat balance components for the Silver Creek tributaries. The fraction of the incoming heat components of the total heat input for each of the tributaries was calculated for each day for the year 2008 (Figure 17). The incoming heat components are: solar, atmospheric, groundwater, and drainage runoff. For the calculation of total atmospheric heat input, the sensible heat was added to the atmospheric heat at the times when it is a heat gain to the stream (i.e., when the temperature of the air is higher than the water temperature). Figure 17 also shows the percentage of the total flow that each tributary contributes to the total flow in Silver Creek and the daily average temperature in the stream.

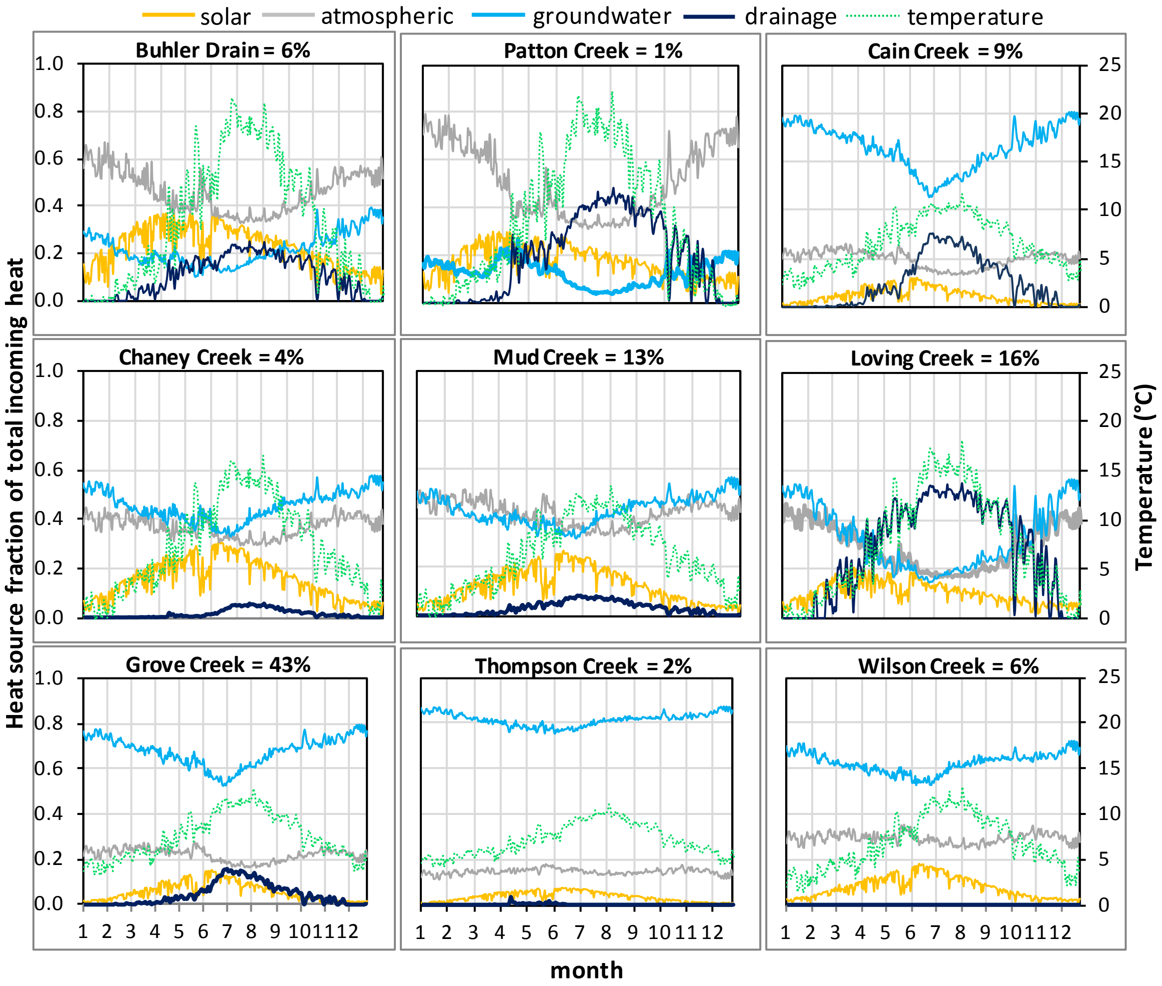

Figure 17. Simulated fraction of heat sources, temperature, and flow contribution in 2008.

The results reveal that in addition to the volume of flow, the source of heat and flow determines the stream temperature signal. Buhler Drain and Patton Creek have high summer temperatures (>20°C) because of low flow volume, with a high percentage of it from drainage runoff, and high solar radiation. Thompson Creek also has low flow volume (2% contribution), but the flow is almost exclusively spring-fed, thus the temperatures are much lower and have low seasonal variation. Moreover, all the streams for which groundwater heat is a larger fraction of the heat input, have much lower and stable temperatures (Cain, Grove, Thompson, and Wilson creeks). Chaney Creek and Mud Creek, have similar heat source fractions, but Chaney Creek has a lower flow volume; thus, it has higher temperatures due to lower thermal capacity. Finally, Love Creek has the second largest flow, but most of it is fed by drainage runoff; thus, it has high temperatures and a large seasonal variation. This model output reveals the strong influence of the flow volume and source in stream temperature, and therefore the value of the temperature model and temperature data in the flow model calibration.

Model Limitations

Given the complexity of the model there are some limitations in the input data, the model setup, and the calibration. Some of the areas in which the model could be improved are discussed below:

1. Water diversions and abstractions are important components of the water balance. The volume and spatial distribution water use has been simplified due to a lack of more detailed data.
2. The distribution of flow in the tributaries could be adjusted by further calibration of the leakage coefficients and by adjusting the rate and distribution of agricultural runoff. The tributaries are formed as springs, thus further knowledge of the geology and calibration of the groundwater model would also impact the flows in the tributaries.
3. Spring runoff flows from mountain catchments tend to be overestimated by the model. Large spring cold-water flows are could cause of the low simulated temperatures in the spring. Also, the assumption of drainage runoff at being at the equilibrium temperature should be verified with measured data. The rainfall runoff model that was used to generate mountain runoff uses the only weather station available for the model area, which is located in the southern valley. The air temperature measured at the valley is expected to be somewhat higher than the air temperature in the mountains; this could cause larger and earlier snow melting than in reality. Correction of the temperature data for higher elevations should be applied for the rainfall-runoff model.
4. Potential errors in the geometry of the stream can lead to under or overestimated diurnal variations. Thus, more cross-sectional data is important to improve the temperature model.
5. Sediment erosion is not taken into account in the model. Sediment loads can affect the thermal loads into the streams. Thus, thermal effects of the land use and vegetation scenarios could be underestimated. Soil erosion estimates could be added using for example the Universal Soil Loss Equation approach.

Simulated Management Scenarios

A number of management scenarios were evaluated to measure the impact of changing some of the different factors contributing to flow and temperature changes in the catchment. Water use practices and changes in land use are key drivers of water temperature in Silver Creek. Thus, scenarios changing these practices, at the catchment scale, were modeled. In addition, two additional scenarios changing secondary drivers that impact the temperature at the stream scale are considered: changes in stream morphology and changes in stream bank vegetation. The simulation of these scenarios is explained below. Loinaz et al., 2012b also includes the results from a climate scenario as well as the potential impacts to fish based on a fish model.

Land use scenarios

The types of crops cultivated can have a significant impact on water use in the basin. Table 5 lists the water requirements for the different types of crops in the model. Alfalfa and barley are two of the most common crops in the valley, however alfalfa requires approximately 40% more water than barley. To quantify the potential benefit of replacing a high water demand crop with a low water demand crop, a scenario was developed in which all areas current under alfalfa cultivation were converted to barley. A total of 55.8 km^2 of alfalfa was converted to barley, which resulted in a decrease in irrigation and evapotranspiration of 43 and 44 cm/yr (or 24.1 and 24.6 Mm^3/yr), respectively. In addition it was assumed that the groundwater pumping was reduced by 17% (based on the area converted and the water demand change), which results in a reduction of 12 Mm^3/yr of the total groundwater abstracted.

Table 5. Average annual crop water demands[a]

Crop type	Demand (cm/yr)
Corn	100
Barley	69
Winter wheat	100
Alfalfa	113
Beans	64
Potatoes	101
Pasture	87

[a] Crop potential evapotranspiration from April to October

Conservation organizations and some government agencies purchase land or conservation easements that limit development for the protection of important natural resources. Some private conservation-oriented landowners in the basin have also restored farm field back into upland game habitat in this area. To represent this type of approach, the impact of changing from agriculture to non-irrigated grassland was also evaluated. For this scenario a total of 47.3 km^2 of alfalfa crops were converted to grassland, which resulted in a difference in irrigation and evapotranspiration of 112 and 100 cm/yr (or 62.3 and 55.6 Mm^3/yr), respectively. In addition it was assumed that the groundwater pumping was reduced by 35%, which results in a reduction of 23 Mm^3/yr of the total groundwater abstracted.

Water use scenarios

The Wood River Valley is intensely irrigated due to its low precipitation and high crop water demand. However, estimates of crop water demand are much lower than estimates of actual water abstracted for irrigation. This means that there are substantial water losses resulting from inefficiencies in irrigation technology. There are currently projects in the valley that provide incentives to farmers to apply more efficient irrigation technologies. It has been estimated that the introduction of relatively simple measures could result in more than 10% water savings. In order to evaluate the potential benefits from these types of projects, a number of model scenarios decreasing water abstractions by 10, 20, and 30% were run to reflect increases in irrigation efficiency.

In the calibrated model only the groundwater abstraction volume is set as a boundary condition, whereas the surface water abstractions are based on the crop water demand. In order to control the total amount of water abstracted from both surface water and groundwater sources, a baseline model was created which differs from the calibrated model in that the total amount of both surface water and groundwater abstracted is defined as boundary conditions. The reductions were then applied on the total volume of water abstracted, while the crop water demand remained the same for all cases. The total volume of water abstracted in the baseline model is 160 Mm^3/yr. This value was derived based on estimates from water uses in one of the farms in the study area and extrapolated to the entire basin based on crop area. Thus, the reduction in the total amount of removed in the 10%, 20%, and 30% water savings scenarios was 16, 32, and 48 Mm^3/yr, respectively.

River morphology scenario

Land use changes in the basin, specifically the conversion of natural areas to cropland, have increased sediment loading and transport of fine sediments in Silver Creek basin. This, in turn has caused changes in the drainage patterns and morphology of the streams (Manuel et al., 1979; Perrigo, 2006). Excess accumulation of fine sediment can decrease stream depths and possibly reduce the surface water – groundwater exchange flows. In addition, the removal of natural vegetation can lead to excess stream bank erosion and widened cross-sections. All of these changes can impact the stream temperature regime.

In this scenario, stream morphology was restored in selected areas of the Silver Creek Basin. The areas were selected by identifying river sections that are currently wider than in the past. This was done by comparing the open water areas in an aerial photograph from the 1940s with the open water areas from an aerial photograph taken in 2009. The cross-sections in those areas were narrowed to the 1940s widths. Changes in cross-sections of selected areas were performed using old aerial photographs as a reference. The restored areas included the removal of the Kilpatrick pond and dam and a ponded area at the headwaters of Stalker Creek, which are projects that are currently under evaluation.

Stream bank vegetation scenario

Stream bank vegetation can have a significant impact in reducing the amount of solar radiation that reaches the stream. During peak hours the radiation can vary from less than 300 Watts/m^2 in shaded areas to over 800 Watts/m^2 in non-shaded areas. To isolate the impact of changing the vegetation a separate scenario simulation was run where the natural vegetation was restored. The natural vegetation map was created by removing the urban or agricultural areas and filling them in by interpolating the existing natural vegetation.

Simulated natural state

A natural state model that represents restoring the catchment to natural conditions was developed to serve as a reference case for all the scenarios. This reference model uses the parameters from the calibrated model but with the following changes:

1. The current land use map was replaced with the natural vegetation map (see the Stream bank vegetation scenario section above).
2. The irrigation and drainage systems were removed. The irrigation system includes the manmade canal system and control structures that are used to divert and distribute irrigation water from the surface water network and the groundwater abstraction pumps.
3. The cross-sections generated for the river morphology scenario were used.
4. The stream bank vegetation representing present conditions was replaced with the vegetation from the natural vegetation map.

Scenario results

The average groundwater elevations were calculated for the present conditions model and the land use and water use scenarios for a 6-year period (2004-2009), the first year of the simulation was excluded to minimize the impact of the initial groundwater storage conditions. Groundwater elevations are expected to be higher under all of the land use and water savings scenarios when compared to the present conditions model; so the average groundwater elevation from the present conditions model was subtracted from each of the scenarios (Figure 18). For the water savings scenarios, the baseline model, instead of the calibrated model, was subtracted from each of the cases.

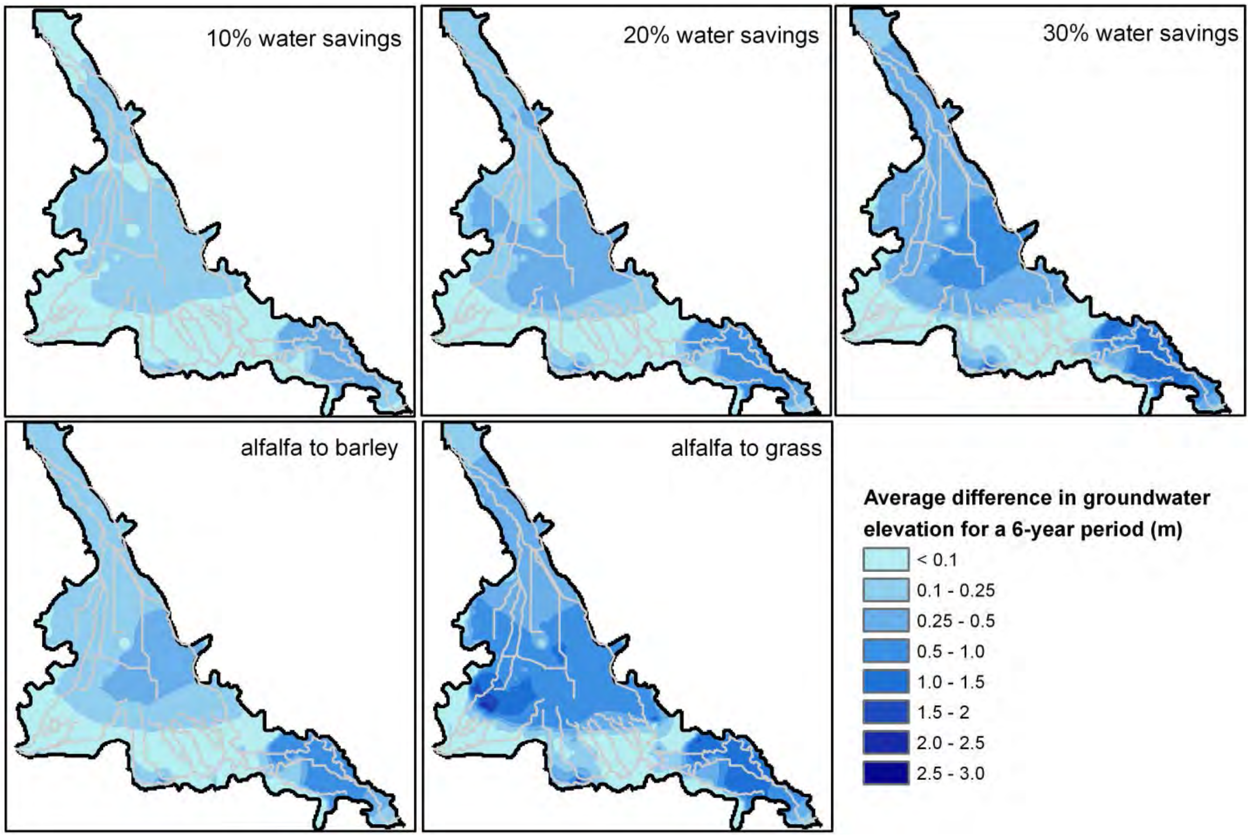

Figure 18. Average difference in water table elevation (scenario x – present conditions)

The results show groundwater level increases in all scenarios. The scenarios with the highest change were the conversion of alfalfa to grass and the 30% water savings, which show increases over 2 meters in some areas and average increases of 0.5 and 0.4, respectively. The areas with the highest impact are the central areas where much of the irrigation takes place and the southeast portion of the model.

Flow duration curves were calculated for the 7-year simulation period to measure the impact of the different scenarios on the low flows in Silver Creek. For this discussion, we will refer to the calibrated model as the present conditions model and the baseline model for water savings scenarios as the baseline model. Figure 19 presents the observed data, the present conditions, natural conditions, and baseline models, and for land use and water use scenarios at the location of the USGS Picabo gage station in Silver Creek. The minimum flow line in Figure 19 (at ~2.8 m^3/s) is based on a water right granted to the Idaho Department of Fish and Game and serves as guidance for minimum ecological stream flows. A higher percentage of flows above the minimum flow line is considered a benefit to the ecosystem.

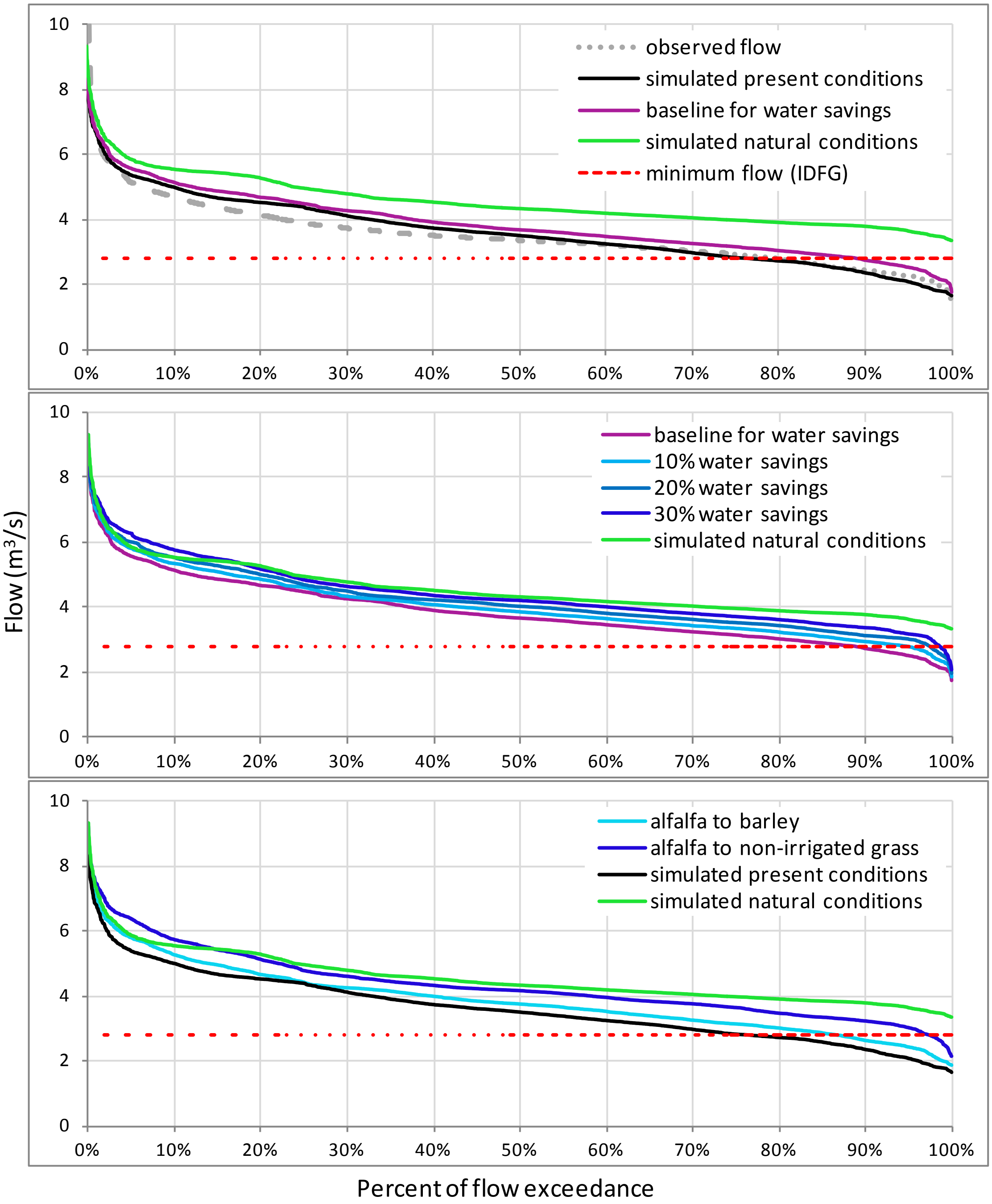

Figure 19. Flow duration curves for simulated present and natural conditions and for the water use and land use scenarios.

The results show that only the natural conditions model produces flows consistently above the minimum flow line. However, all scenarios produce higher low flows than the simulated present conditions. The average difference between the calibrated model and the observed flows is 0.1 m^3/s, however, the largest differences occur during periods of the spring peak flows. The average difference between the present conditions and the natural conditions model is 0.92 m^3/s with the largest differences (1.7 m^3/s) occurring during the low flow periods. The baseline model produces slightly higher flows than the calibrated model (0.23 m^3/s on average).

The flow duration curves for the water savings scenarios increasingly approach the natural conditions curve and reduce the amount of times that the Silver Creek flow falls below the minimum line. The average increases in flow from the baseline model are 0.18, 0.36, and 0.55 m^3/s for 10%, 20%, and 30% water savings, respectively. This means that a water use reduction of 16 Mm^3/yr causes an average increase of 0.185 m^3/s in Silver Creek or that it takes ~86 Mm^3/yr of water savings in the WRV to increase the average flow in Silver Creek by 1 m^3/s.

As they were conceptualized, the land use scenarios represent the combined effects of reducing: evapotranspiration, irrigation supply (which as in the present conditions model is first extracted from the surface water system), and total groundwater abstractions. Changing alfalfa crops to barley produced an average increase of 0.3 m^3/s in Silver Creek flows. And changing alfalfa to grass produced an average increase of 0.7 m^3/s. One thing to note is that this conversion-to-grass scenario, as well as the 30% water savings scenario, produces slightly larger high flows than the natural conditions simulation. This occurs because of the excess agricultural drainage flows which are not present in the natural conditions model.

The potential for a distributed reduction in the maximum stream temperatures between the simulated present conditions and the natural conditions is illustrated in Figure 20.

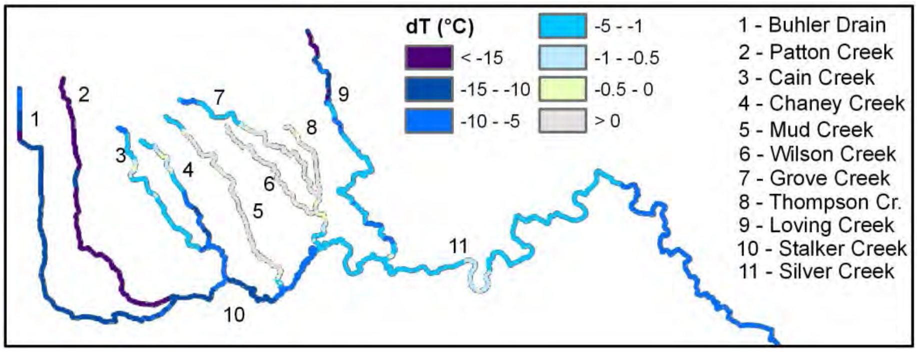

Figure 20. Difference in maximum temperature for simulated natural conditions (natural conditions – present conditions)

The simulated natural maximum temperatures were on average > 5°C lower than present temperatures, but even lower at some locations, such as Patton Creek and Loving Creek, and generally lower in all streams, except for Grove Creek and its tributaries and Mud Creek. The increases in maximum temperatures in these areas were caused by the vegetation mapping used for restored vegetation conditions, as explained below.

The change in the maximum stream temperatures in the Silver Creek Basin was also calculated for all the scenarios by subtracting the present conditions model from the scenario run (i.e., scenario x – present conditions model) (Figure 21, Figure 22, and Figure 23).

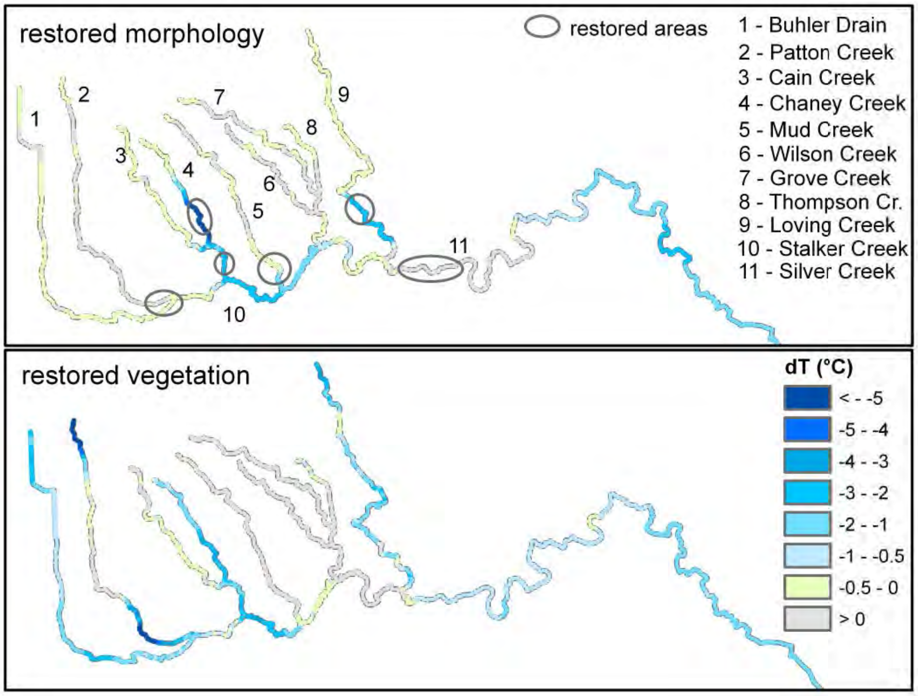

Figure 21. Difference in maximum temperature for stream scale scenarios (scenario – present conditions)

The morphology scenario reduced the maximum temperatures up to 7°C in some areas, such as Chaney Creek. Stalker Creek also had large reductions in maximum temperature. This is the result of changes in temperature from the upstream tributaries since the Stalker Creek cross-sections were not changed for this scenario. In Silver Creek, the maximum temperatures downstream of the pond increased with the removal of the dam because water velocities are reduced. However, the removal of the dam and narrowing the pond cross-sections also had the effect of stabilizing the temperature along the stream profile and ultimately reduced the maximum temperatures downstream.

The vegetation scenario also resulted in large decreases in maximum temperature is most of the tributaries (up to 9°C). However, temperature increases occurred in some of the tributaries where natural vegetation was present in the current conditions model. The interpolation of the natural land cover map resulted in less shading potential (lower vegetation heights) than in the current conditions model in some areas.

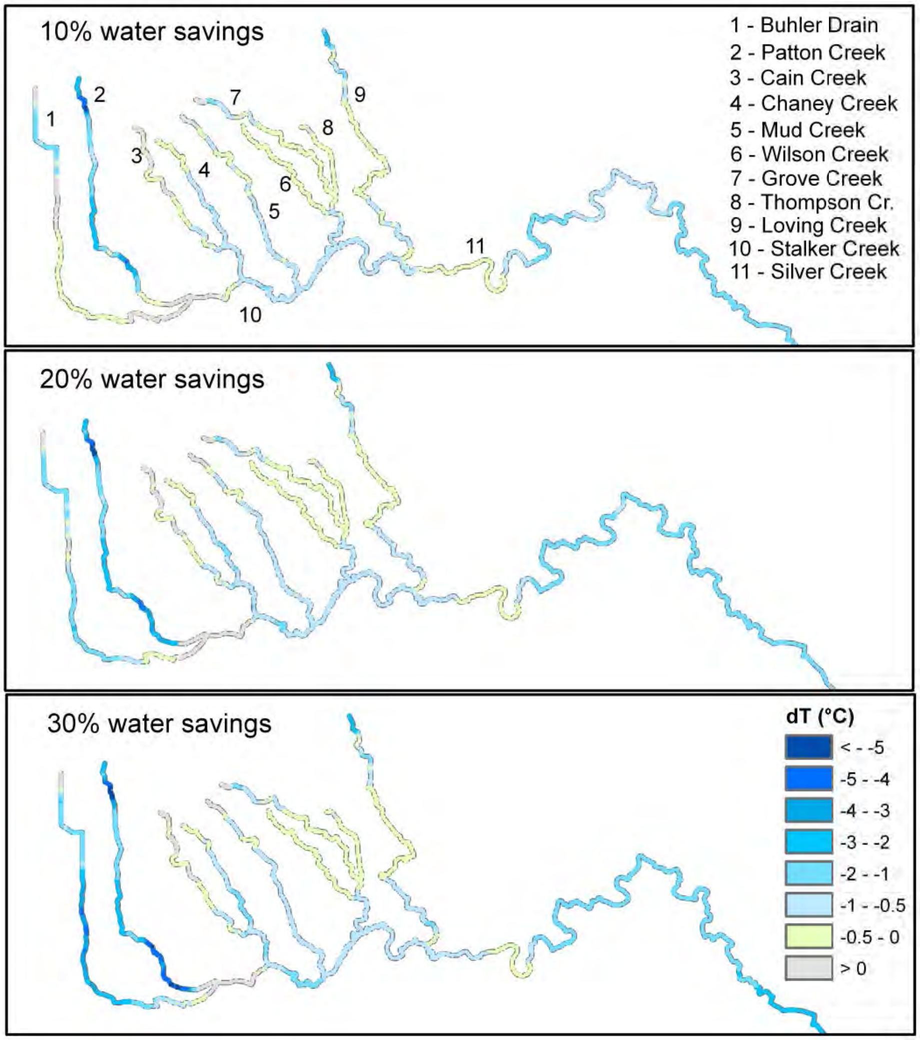

Figure 22. Difference in maximum temperature for water use scenarios (scenario – present conditions)

Figure 22 shows progressively colder maximum temperature in the water savings scenarios in most branches for each 10% water use reduction. The branches with the highest impact are in the western portion of the SCB (Buhler Drain and Patton Creek) and the southeastern portion of the model (Silver Creek). These are the areas where most of the water use takes place in the SCB and as evidenced by the large changes in groundwater levels (Figure 18).

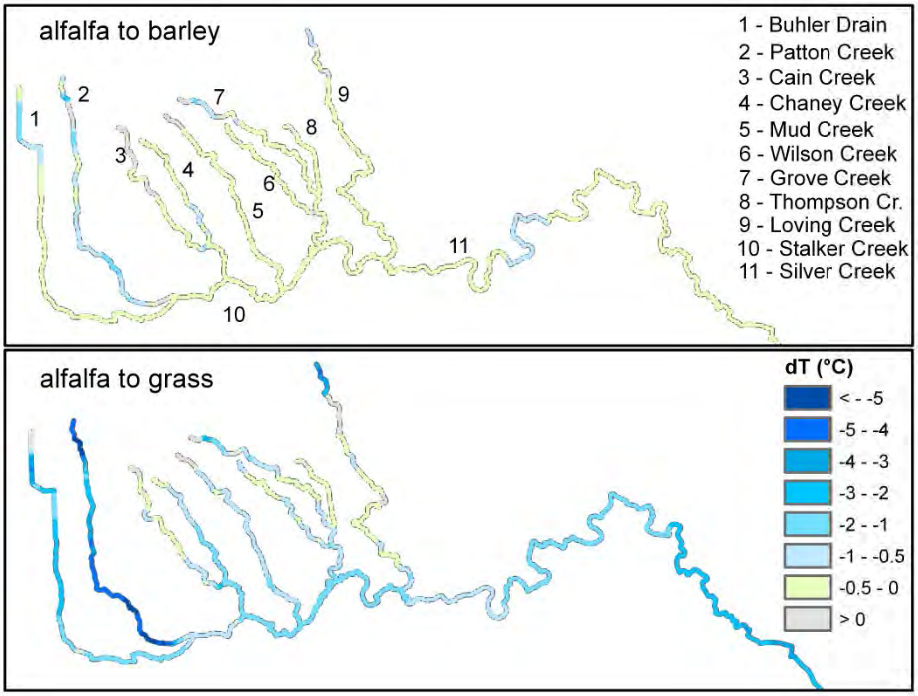

Figure 23. Difference in maximum temperature for land use scenarios (scenario – present conditions)

The conversion of alfalfa to barley slightly lowered the maximum temperatures, less that 0.5°C in most streams. However, converting alfalfa to grass produced the highest average change in maximum temperatures out of all the scenarios.

Various statistics were calculated for the entire length of Silver Creek for all model runs. These include the maximum hourly temperature, the maximum daily temperature, the average summer temperature, and the percent exceedance of the water quality standards for temperature (Table 6). The maximum hourly temperature is the instantaneous maximum from the hourly frequency output and the maximum value for all the computation nodes in Silver Creek. The maximum daily is the maximum temperature of the daily average and the average value for all the computation nodes in Silver Creek. The average summer temperature is the average temperature during the summer months (June-August). The standards used are the maximum temperature for salmonids spawning (13°C) and the potential lethal temperature for cold water fish (22°C) as defined by the Idaho Department of Environmental Quality (http://www.deq.idaho.gov/water-quality/surface-water/temperature.aspx). The periods used for counting the exceedance times were January 15 to June 15 for the spawning temperature standard, following Essig (1998), and May to September for the lethal temperature standard for the three years of temperature simulation.

Table 6. Temperature statistics at Silver Creek.

Scenario	Max hr (°C)	Max daily (°C)	Avg. summer (°C)	% TC[a]	% TL[b]
Natural conditions	21.9	16.9	13.3	4.4	0
Present conditions	28.8	19.6	15.7	11.2	1.60
Baseline for water savings	27.3	19.0	15.3	10.6	0.82
10% savings	25.9	18.5	15.0	10.2	0.38
20% savings	25.6	18.4	14.9	10.2	0.31
30% savings	25.3	18.4	14.9	10.1	0.26
Alfalfa to barley	28.5	19.4	15.4	10.9	1.21
Alfalfa to grass	26.0	18.7	15.1	10.3	0.47
Restored morphology	27.1	19.2	15.3	10.7	1.18
Restored vegetation	27.4	19.1	14.7	7.2	0.64

[a] Percent exceedance of critical temperature (13°C)

[b] Percent exceedance of lethal temperatures (22°C)

The simulated temperature in the natural conditions model never exceeded the lethal limit of 22°C and has a maximum daily average temperature of 16.9°C, 2.7°C lower than the present conditions model. Nevertheless, even in the present conditions model, lethal temperatures occur at fairly low frequencies in Silver Creek during the 3-year simulation period. In general, all the scenarios lowered the maximum temperatures in Silver Creek from the current conditions model. Out of all the scenarios, the lower maximum hourly and maximum daily temperatures occurred in the 30% water savings scenario, although the magnitude of the maximum daily change decreased during increased water reductions. The past climate simulation had a greater impact in lowering the average summer temperatures than the maximum temperatures. The lowest summer averages and the largest reduction of the spawning criteria percent exceedance occurred in the restored vegetation scenario. The largest reduction of the lethal temperature percent exceedance occurred in the 30% water savings scenario.

Conclusions

From the water balance calculations, nearly 80% of the inflow to the SCB, comes from the BWRB solely through the aquifer system. Seepage from the BWR and canals contribute a large volume of water to the aquifer system. Thus, it is necessary to understand the hydrology of the Wood River Valley and the water management of the BWRB to be able to accurately simulate the flow of Silver Creek.

Flow volume and flow source have a large impact in the stream temperature signal. Thus, it is important to accurately simulate spatial distribution of surface water and groundwater flow in the Silver Creek Basin to be able to accurately simulate the temperature of Silver Creek and its tributaries. Moreover, temperature data, which is easier and more inexpensive to collect than flow data, serves to constrain the flow model because there is a strong relationship between flow and temperature. Thus, stream temperature data in combination with a stream temperature model are powerful tools in an integrated flow model calibration.

The flow source and volume and temperature relationship was demonstrated by the results from the water use and land use scenarios. The water savings scenarios resulted in increasing groundwater elevations and stream flows with each 10% water use reduction and these hydrologic effects resulted in decreases in the maximum and average summer temperatures. Land use scenarios, which involve changes in various components of the hydrologic cycle, also led to increases in water table elevations and stream flow which led to temperature reductions. The crop conversion from alfalfa to barley resulted in changes comparable to the 10% and 20% water savings scenarios and the conversion of alfalfa to non-irrigated grass resulted in changes comparable to the 30% water savings scenario. Land use change scenarios are worth considering because they could have additional benefits to the ecosystem. For example, converting crops to grass could also cause decreases in sediment loads to streams. However, these types of solutions are associated to large financial costs. Thus, improvement in irrigation technology efficiency is likely to be more reasonable and can also achieve significant ecological benefits.

The river morphology scenario resulted in relatively moderate changes in the maximum temperatures in Silver Creek, but because it also had the effect of stabilizing the hydraulics along the length of Silver Creek and thus the temperatures, it can result in large benefits to the ecosystem.

The restored vegetation scenario resulted in relatively large reductions in maximum temperatures in Silver Creek, which illustrates the large contribution of solar radiation to the net heat balance. However, shading large portions of a stream also a reduces the incoming solar radiation in the winter and thus the winter temperatures, which can be detrimental to the aquatic organisms (Loinaz et al., 2012b). Seasonally stable thermal conditions are optimal for fish growth, for example, and this is achieved through the stabilization of the hydrologic conditions through changes in morphology and/or increases in groundwater fluxes.

Finally, since the natural conditions model included a combination of the effects discussed above, the results of this model showed that large differences in the thermal and hydrologic conditions can be achieved by a combination of different restoration strategies. Thus, it is likely that the most optimal solutions are obtained through combining one or more of these strategies. Multi-objective optimization analyses that balance societal and financial costs and benefits to the ecosystem could be performed in the future using multiple combinations of similar management strategies.

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