Final Report for

Climate Variability Impact Studies in the Rathdrum Prairie and Treasure Valley Regions

Final Report submitted on 11/24/2010

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1. Executive Summary

- 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 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 broad range in streamflows, evapotranspiration and recharge during the simulation period of the entire 50 year period between 2010 and 2050. This was observed for the three emission scenarios (A1B, A2 and B1).
- 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 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 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. 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 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. 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.

2. Detailed Description of Progress on Tasks

Task 1:

Research and document current scientific literature on climate change and the potential impacts of that change on water supply specific to the Treasure Valley and Rathdrum Prairie.

2.1 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, 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.

Task 2:

Apply downscaling methodology of macroscale climate models to the watershed scale and develop at least three potential climate change scenarios for the Treasure Valley and Rathdrum Prairie, including temperature and precipitation changes for each scenario. Also include the rationale behind their choice of climate data and model.

2.2 *Climate Model Scenarios*

Forcing factors of GCMs are greenhouse gases and sulfate aerosols (which reflect sunlight and also promote cloud formation, thereby offsetting greenhouse gases locally) (Mote and Salathe, 2009). These forcing factors along with socioeconomic changes are highlighted by the three scenarios based on the emissions as in Figure 1 with B1 (550 ppm), A1B (750 ppm), and A2 (does not stabilize) scenarios. The forcing factors of all the scenarios are similar until about 2020. The rank of scenarios for mid -century (2020-2060) are A1B, A2 and B1 from the highest to the lowest. The rank is different for 2060-2100 with A2, A1B and B1.

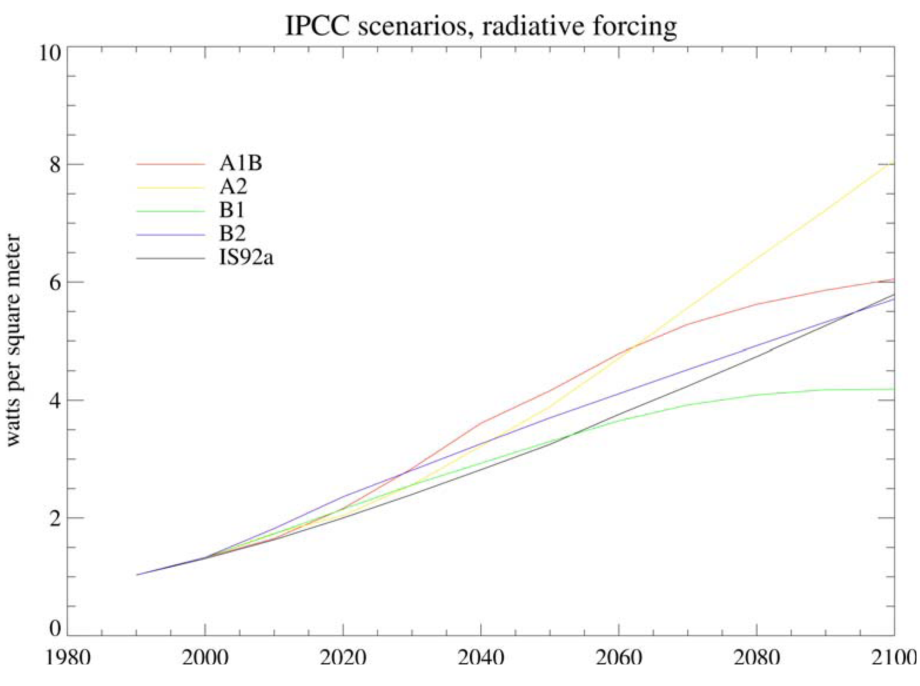


Figure 1. Globally averaged radiative forcing by greenhouse gases and sulfate aerosols for four of the six illustrative scenarios plus the older IS92a scenario from IPCC (2001) (Mote and Salathe, 2009)

Climate Models use quantitative methods to simulate the interactions and project future climate projections and past climate changes (Randall et al., 2007; Pierce et al., 2009). Current climate change studies use both global climate models (GCMs) and regional climate models (RCMs). GCMs are physically based numerical models of the ocean, atmosphere (6,000 and 15,000 grid squares horizontal and 12 and 56 atmospheric layers), land, and ice (Mote and Salathe, 2009). RCMs are preferred due to its mesoscale spatial representation of features controlling climatic variables (Salathé et al., 2009; Sylla et al., 2009). However, still GCMs downscaled data are used as major forcing inputs. Therefore it is important to know how GCMs should be chosen and what effect does such choice have?

The first criteria in GCM selection will be to determine how well the models perform under historic conditions. The second criteria will be to assess the ability of the model in capturing the range of predictive performance. The historic performance represents some degree of confidence in the accuracy of the models. However, it is also important to compare the interannual performance of the models in order to capture the range of possible future scenarios. Since our study focuses on water availability, any shortages that would likely occur with a model that consistently represents drier and warmer winter and summers would represent a worst case scenario, while a best case scenario is likely to include cooler and wetter summers and winters. It would also be important to compare the impacts of a wet versus dry summer or a dry cold winter versus a wet warm winter. Mote and Salathe (2009) compared the historic performance and predicted temperature and precipitation change of 21 GCM's in the Pacific Northwest (Table 1).

Name	Origin	Ensemble members (surface temp and precip)	Ensemble members (daily min temp)	Ensemble Mean JFM daily min temp trend, ºC/yr
BCCR_BCM2_0	Bjerknes Centere Clim. Res., Bergen,Norway	1	1	-0.02
CCCMA_CGCM3_1	Canadian Centre, Victoria, B.C., Canada	5	5	0.171
CNRM_CM3	Meteo-France, Toulouse, France	1	1	0.124
CSIRO_MK3_0	CSIRO Atmos. Res., Melbourne, Australia	3	3	0.043
CSIRO_MK3_5	CSIRO Atmos. Res., Melbourne, Australia	3	3	0.09
GFDL_CM2_0	Geophys. Fluid Dyn. Lab, Prinston NJ	3	1	-0.051
GFDL_CM2_1	Geophys. Fluid Dyn. Lab, Prinston NJ	3	3	0.024
GISS_AOM	NASA/Goddard Inst. Space Studies, NY	2	2	0.036
GISS_MODEL_E_H	ASA/Goddard Inst. Space Studies, NY	5	1	0.037
GISS_MODEL_E_R	ASA/Goddard Inst. Space Studies, NY	9	1	-0.013
IAP_FGOALS1_0_G	Inst. Atmos. Physics, Beijing, People's China	3	3	0.103
INGV_ECHAM4	Inst. Geophys. Volcanol., Bologna, Italy	1	1	-0.041
INMCM3_0	Inst. Num. Mathematics, Moscow, Russia	1	1	0.213
IPSL_CM4	Inst. Pierre Simon Laplace, Paris, France	2	2	0.039
MIROC3_2_MEDRES	Center Climate Sys. Res., Tokyo, Japan	12	12	0.036
MIUB_ECHO_G	Meteor. Inst. U. Bonn, Bonn, Germany	5	3	0.023
MPI_ECHAM5	Max Planck Inst. Meteor., Hamburg, Germany	4	2	0.086
MRI_CGCM2_3_2A	Meteor. Res. Inst., Tsukuba, Ibaraki, Japan	5	5	0.008
NCAR_CCSM3_0	Nat. Center Atmos. Res., Boulder, Co	8	6	0.07
NCAR_PCM1	Nat. Center Atmos. Res., Boulder, Co	4	6	0.068
UKMO_HADGEM1	UK Met Office, Exeter, Devon, UK	2	1	-0.009

Table 1. 21 GCMs coordinated through the Intergovernmental Panel on Climate Change (IPCC) (Source: Mote and Salathe, 2009; Pierce et al., 2009)

2.3 Evaluation of GCMs

How well can the predictive model simulate the past? In other words, a comparison of modeled against observed historic climate provides if there is any bias in them. Also, considerable knowledge on the trends to see if they are in the same direction is helpful in evaluating the models.

2.3.1 Bias Study

GISS-ER, MIROC-hi, INMCM3, and CNRM showed the least bias in annual average temperatures. For precipitation, all of the models show a positive bias (wet bias) with 50% extreme. Mote and Salathe (2009) also identified BCCR, GISS_ER, HadCM, PCM1, and CGCM_T47 models as least precipitation bias models. Therefore, among other models GISS-ER performed better for both temperature and precipitation simulation during the historical periods.

2.3.2 Trend study

It is found that the observed trend is close to the median trend from the models based on the trend analysis done by Mote and Salathe (2009) (Figure 2). GFDL2.1, IPSL CCSM3 can be identified as good models and CSIRO3.5 and CGCM3.1_t63 are the perfect models (show exactly same 0.8 positive trend as observed increasing trend in temperature). Mote and Salathe (2009) noted that they did not perform the same comparison for precipitation since there was no evidence that precipitation responded to greenhouse forcing in the 20th century, either globally or in the zonal mean at these latitudes.

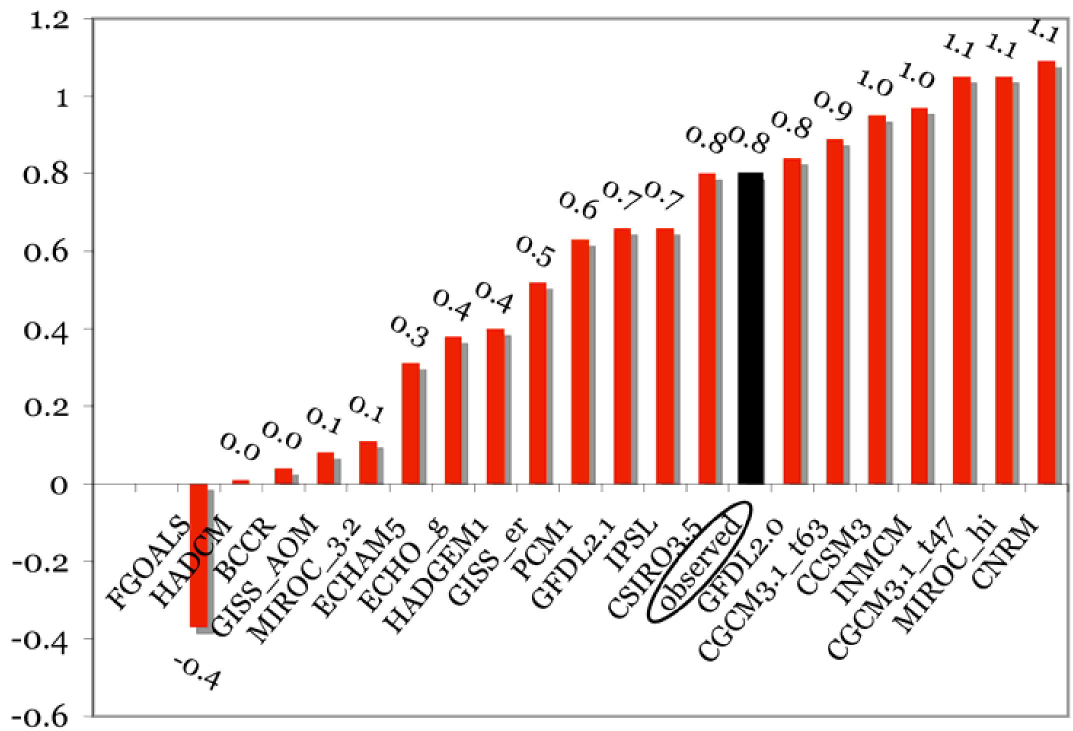


Figure 2. Trend in each model's annual mean temperature for the PNW during the 20th century, and the observed trend calculated from the United States Historical Climatology Network (USHCN) data. (Source: Mote and Salathe (2009))

2.3.3 Based on mesoscale modeling capability

Evaluation of GCMs based on mesoscale modeling capability helps to determine their quality. Studies have shown that most climate models simulated temperature fairly well, however, sea level pressure (SLP) and precipitation simulated by these models were not superior and there was a wide range in their performance, especially for SLP.

In order to understand the regional climate impacts for the watersheds in Idaho through 2060, we further follow the recommendation of the Climate Impacts Group of University of Washington suitable for the region as a whole. Figure 3 shows the predicted temperature and precipitation for all three scenarios by a group models for 2020s, 2040s and 2080s adopted from Mote and Salathe (2009). The summary of these models are presented in Table 2.

Since none of the models predicted changes in the cooler/dryer winter range, we decided that it was not necessary to consider the full spectrum of models and chose to not to evaluate these conditions. Furthermore, with regard to water availability and management scenarios under warming conditions, ideally warmer and wetter winter (which triggers earlier melt and runoff), warmer and drier summer (as crop water demand may increase) and cooler/drier summer (as crop water demand may decrease) conditions are desirable to consider for hydrological modeling.

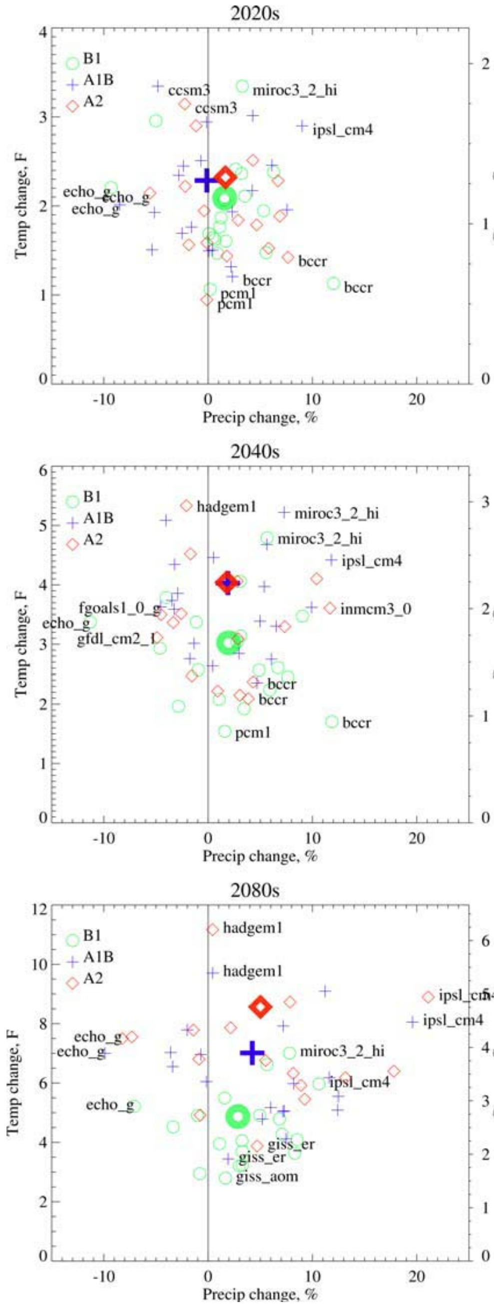


Figure 3. Scatter plot of change in annually averaged PNW temperature and precipitation for each of the 20 models and 3 SRES scenarios, for the decades indicated. Green circles indicate B1, blue crosses A1B, and red diamonds A2. Large bold symbols indicate the REA value for each scenario and decade. Model names label the four extremes for each scenario. (Source: Mote and Salathe, 2009)

Year	Wetter Winter	Warm Winter (wet)	warmer summer (dry)	cooler summer (dry)
2020	BCCR	BCCR	CCSM3	PCM1
	IPSL_CM4	MIROC3_2_HI		BCCR
2040	INMCM3_0	BCCR	HADCM3	PCM1
	IPSL_CM4	MIROC3_2_HI		BCCR
	BCCR			
2080	IPSL_CM4	IPSL_CM4	HADGEM1	GISS_ER
		MIROC3_2_HI		GISS_AOM

Table 2. Climate models projecting wetter and warmer winters and dry summers for the Pacific Northwest.

2.4 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

2.4 Downscaling of Climate Model Outputs

The outputs, primarily precipitation and temperature, from the GCMs are coarse and they need to be first downscaled to a specific area if we are to get a meaningful interpretation of the impacts of climate change at the local scale. The original climate projections are from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report. As the first step we have downloaded the bias-corrected and spatially downscaled climate projections derived from CMIP3 data and served at: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/, described by Maurer et al (2007).While there are many methods for downscaling the climate data that can be useful, we preferred this method of bias-corrected and spatially downscaled climate projections for the following reasons. i) We are using this dataset currently for our Snake River Basin modeling project ii) The PI is intimately familiar with this downscaling procedure iii) It has been widely used in the climate modeling community around the world. The resolution of these available datasets is monthly, 1/8th degree gridded products for both the Treasure Valley and the Rathdrum Prairie basins. Since we required daily precipitation and temperature data for hydrological modeling, we temporally disaggregated to a daily time step. The disaggregation scheme used for this purpose is shown in Figure 4. There is a six-step procedure we performed to temporally disaggregate the GCM climate model data downloaded from the link above.

1. Randomly pick a historical year to compute mean of the daily precipitation and temperature of the gridded observed record for the same month as the future year
2. Calculate the difference between future monthly mean temperature and historical mean of monthly mean temperature, ‘Δt’
3. Calculate the ratio between future monthly mean precipitation and historical mean of monthly mean precipitation, ‘r’
4. Add “Δt” to daily temperature of the month of the randomly selected year; Multiply daily precipitation by “r” for the month of randomly selected year
5. Continue step 1-4 for other months of the year for future years
6. Repeat these steps for the remaining grid cells.

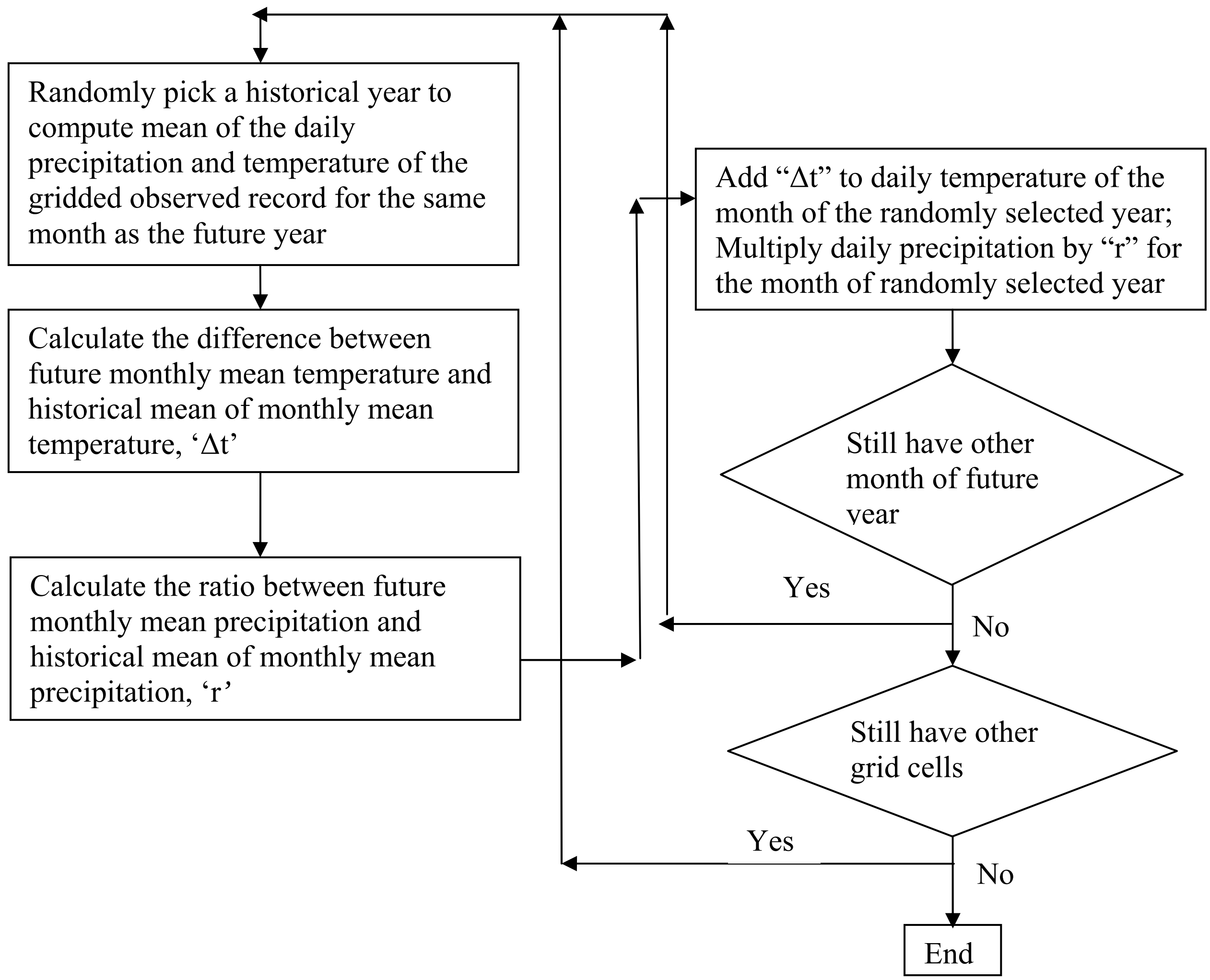


Figure 4. Flow Chart showing the climate model output downscaling approach.

3. SWAT model Calibration for the Boise River Basin

Task 3:

Using the scenarios developed in Task 2 the contractor will describe and quantify the possible impacts of climate change on the water supply in the Treasure Valley and Rathdrum Prairie. This will include changes in the amount of rainfall, change from snow to rain, and the frequency and intensity of drought and flood. The contractor will simulate stream flows for each scenario at gaging locations mutually selected by the contractor and the IWRB, including the magnitude and timing of flow. These estimates will include simulations through 2060 at ten year intervals.

Task 4:

Using the scenarios developed for Task 2, the contractor will analyze hydrologic mass balance impacts (SWE, stream flow, base flow, actual ET, precipitation) in the basin. This task will include estimates of the potential increase in irrigation water demand and natural vegetation evapotranspiration. The contractor will also examine the potential impact of temperature change, and the timing and amount of precipitation, on environmental and DCMI water requirements and surface water temperature.

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 5. 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.

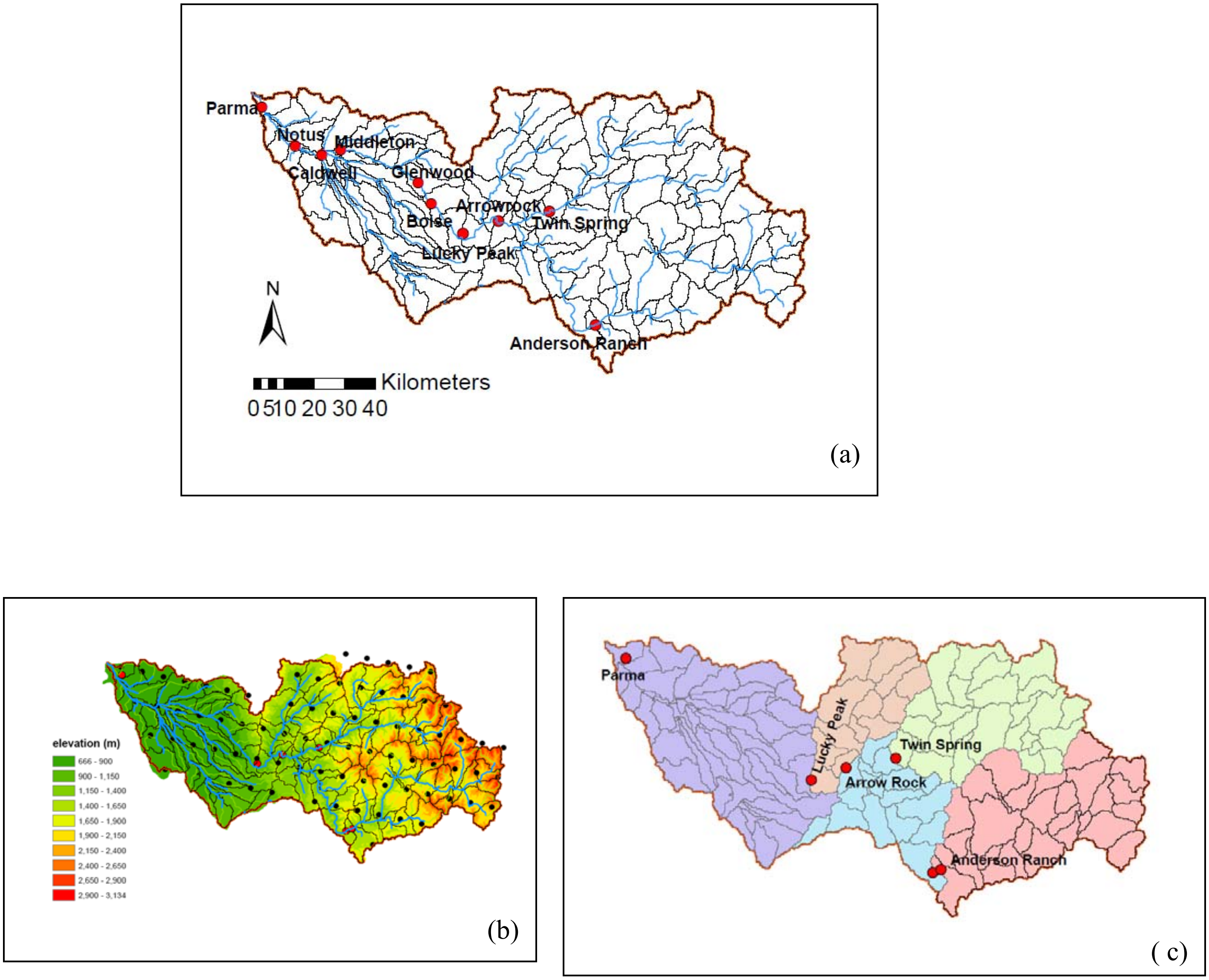


Figure 5. (a) The Boise River basin with sub-basins and calibration/validation streamflow sites (b) the climate model grids (c) delineation of sub-basins for calibration

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 3 (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 3(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 Lucky Peak	Arrowrock	Twin Springs	Anderson Ranch	scale level
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 3 (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 3 (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 4. 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 4. Calibration and Validation statistics for various gaging locations in the Boise River - Basin.

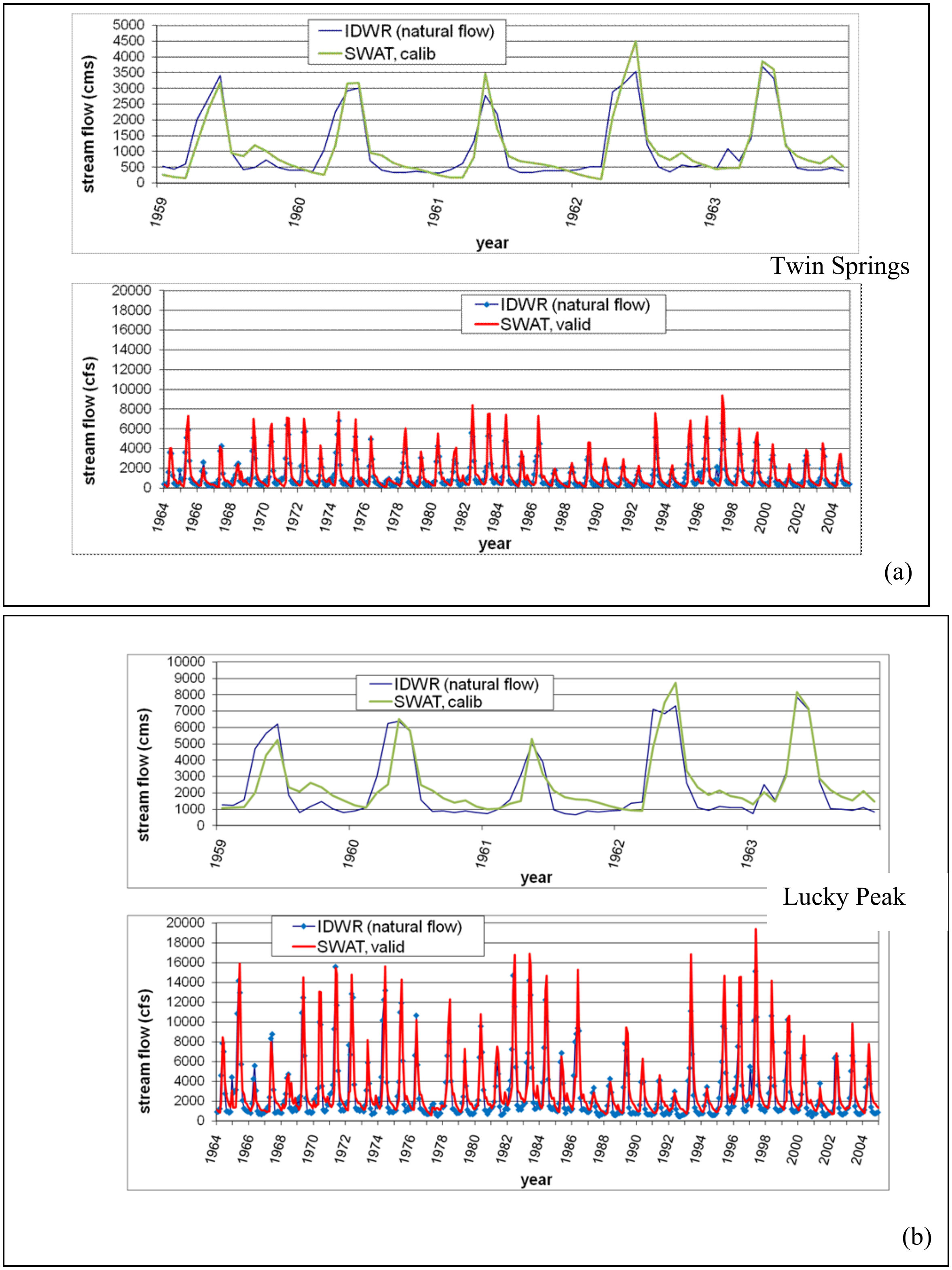


Figure 6. Streamflows for (a) Twin Springs and (b) Lucky Peak simulated by the SWAT model during the calibration (1959-1963) and validation period (1964-2004).

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 6 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 4. Natural or unmanaged high flows ranged between 4000-6000 cfs for the upstream locations and 12000-16000 cfs for the downstream gaging stations and low flows were between 1000-2000 cfs in the Boise River basin. Flows at Twin Springs, Anderson Ranch, Arrow Rock, Lucky Peak, Glenwood, Middleton, Caldwell and Parma were verified and the results are presented in Appendix I. 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. SWAT model Calibration for 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 7 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 5. 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.

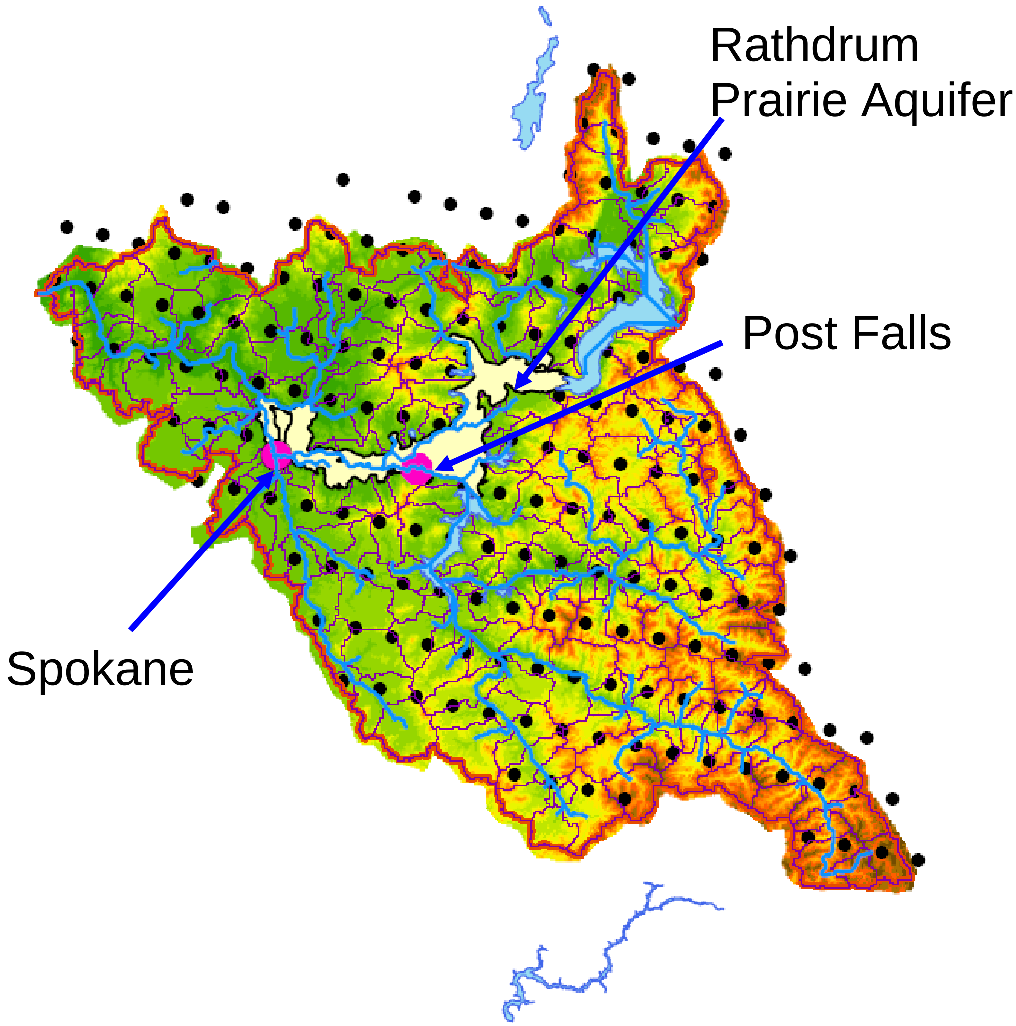


Figure 7. The Rathdrum Prairie aquifer region with the Spokane River basin, sub-basins and weather grids.

Parameter name	Parameter definition:Parma	low bound	up bound	imet	Calibration Sites Post Falls	Spokane to Post Falls	scale level
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 5. 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 6. 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 6. Calibration and Validation statistics for various gaging locations in the Rathdrum Prairie Basin.

For the Spokane River basin, 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 8 shows the time series of streamflows captured by the model for the Post Falls and Spokane gaging stations.

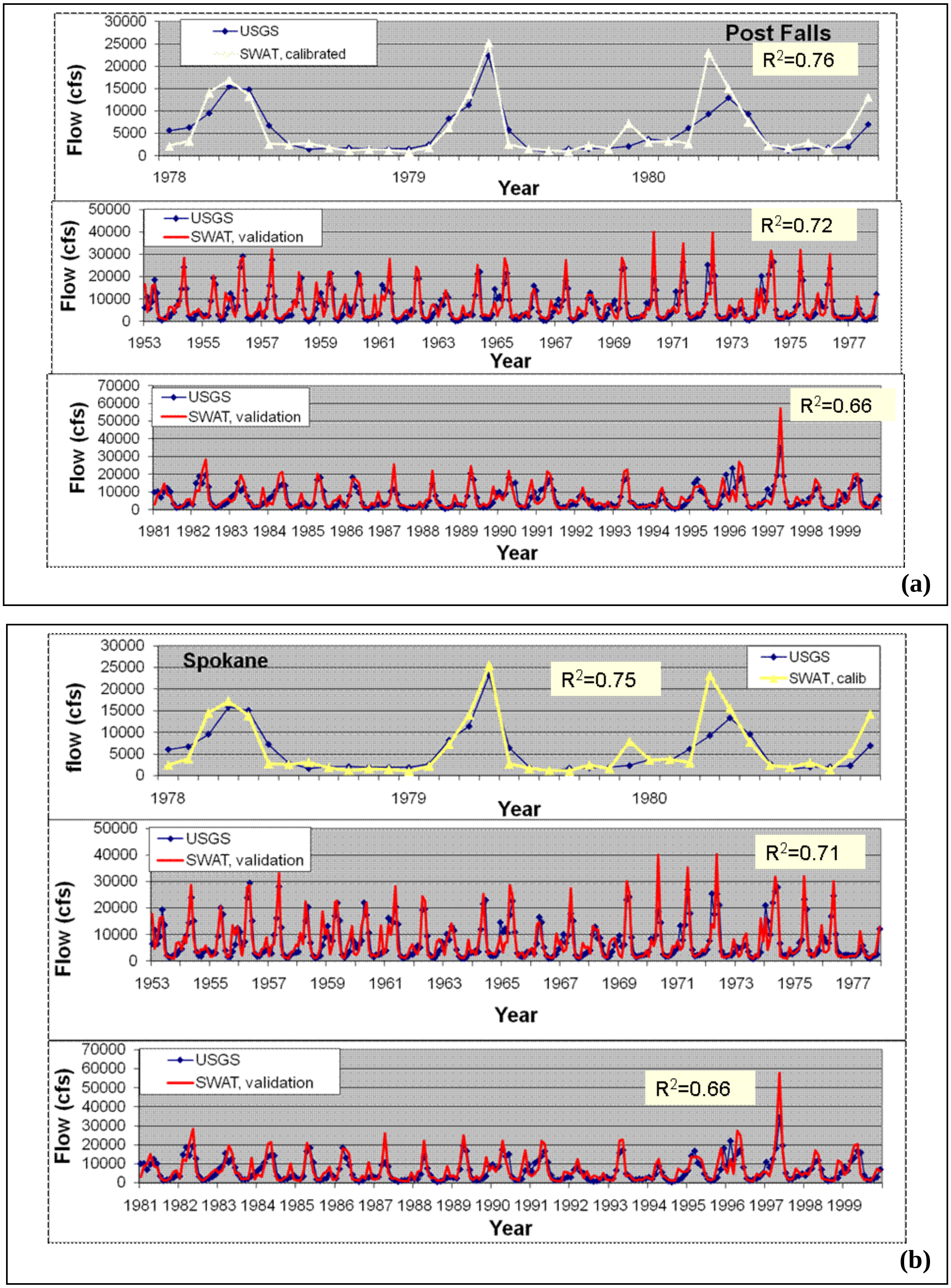


Figure 8. Streamflows for Post Falls and Spokane from SWAT model during the calibration (1978-1981) and validation period (1953-1977; 1981-2000)

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 7. 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 9 and Figure 10) . 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.

The plots of GCM-downscaled precipitation and temperature for all three scenarios (A2, A1B, and B1) for the Boise River Basin and the Spokane River basin are provided in Appendix II.

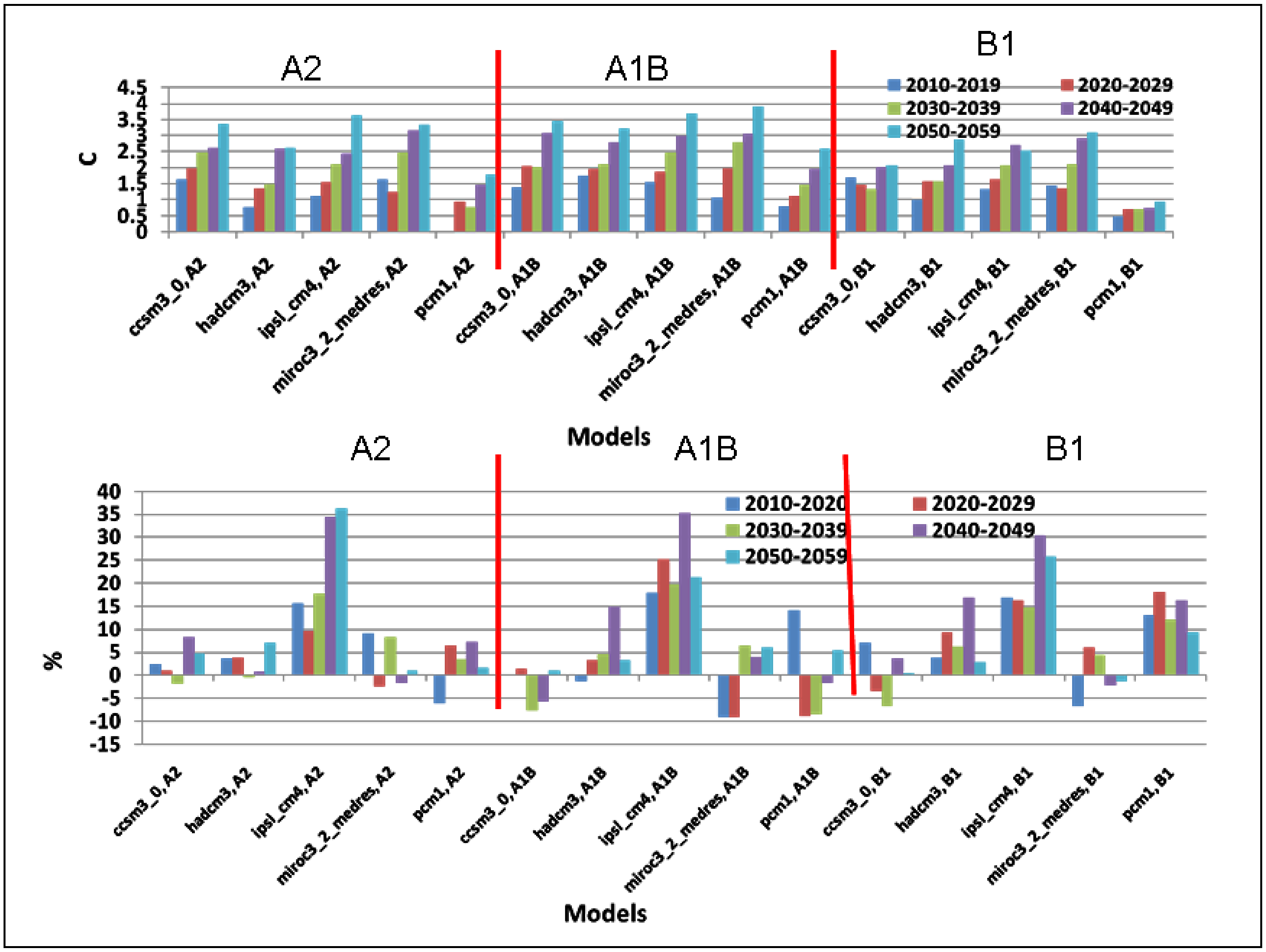


Figure 9. Precipitation and Temperature trends under climate change conditions for the Treasure Valley region between 2010 and 2060. The models used are CCSM3, HADCM3, IPSL CM4, MIROC 3.2 and PCM.

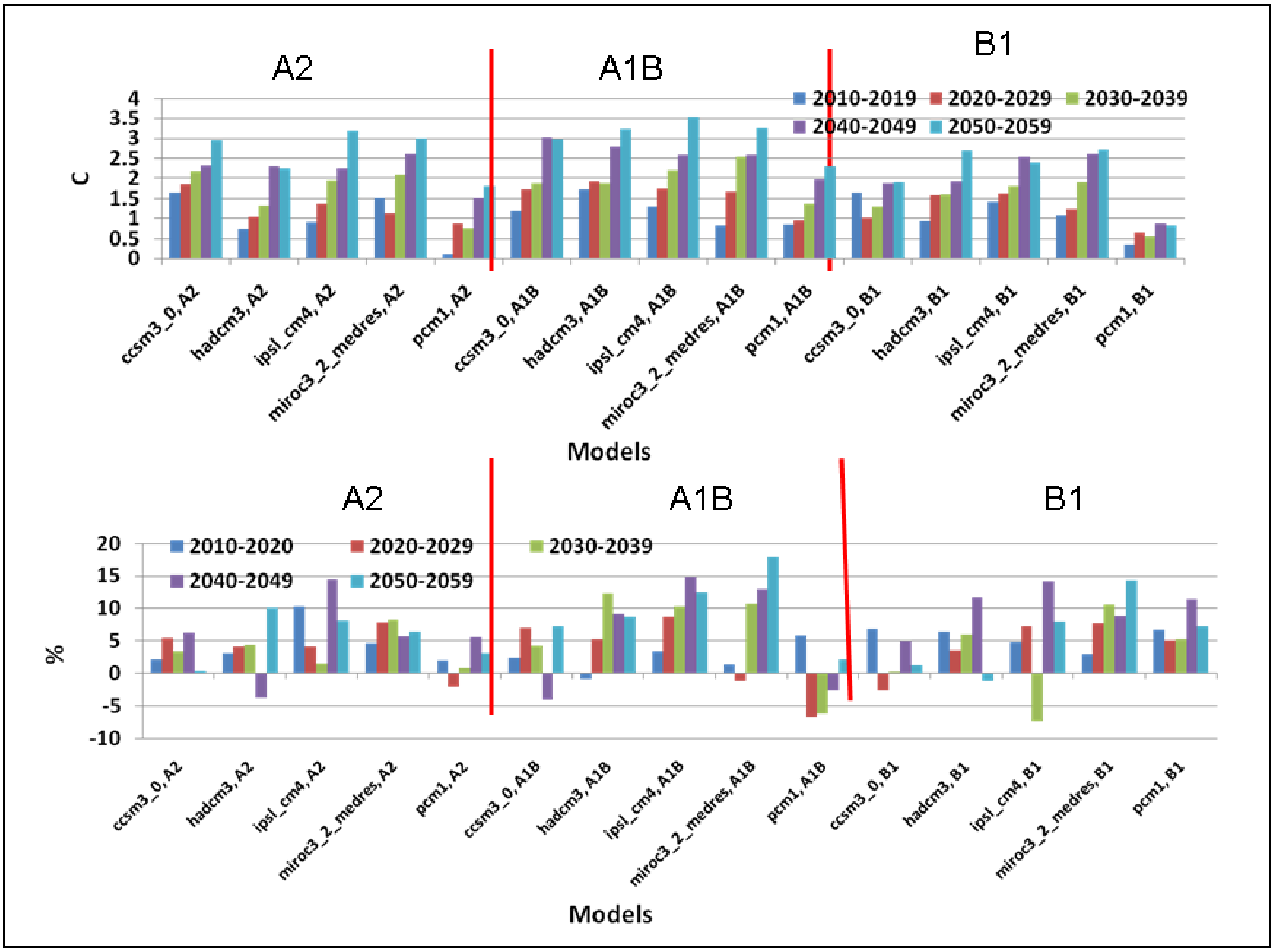


Figure 10. Precipitation and Temperature trends under climate change conditions for the Treasure Valley region between 2010 and 2060. The models used are CCSM3, HADCM3, IPSL CM4, MIROC 3.2 and PCM.

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 7. (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 11) 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. We have provided the plots of decadal average seasonal flows for the two basins in Appendix III. 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 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 12, 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. 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 historic low flows (Figure 13). The summertime minimum low flows in the Rathdrum Prairie appear to have decreased when compared against the historic conditions (Figure 14). 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 9. 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 9. The Spokane River Basin flow changes in comparison with the historical flows.

The entire range of change in flows from historic conditions by magnitude and percentage for the Rathdrum Prairie basin (Post Falls, Spokane) and the Treasure Valley basin (Twin Springs, Anderson Ranch, Arrowrock, Lucky Peak, Glenwood, Middleton, Caldwell and Parma) is provided in Appendix IV. The change in flows (both magnitude and percentage) is computed as the difference between historic averages of monthly flow to future flow.

The volume of flow changes in the Boise River basin at Lucky Peak was also computed. This was done by computing the area under the hydrograph (by adding the ordinates through the trapezoidal method) with the historic volumes. Table 10 shows the decadal averages of increase in flow volumes in acre-ft for A2, A1B and B1 scenarios. The increase in flow volumes are 201,896 ac-ft (A2), 120,547 ac-ft (A1B) and 265,384 ac-ft (B1). The overall average when combining all of these flow volumes results in increasing flow volume by

195942 ac-ft. The change in volume of flow by decade for each model and scenario is shown in Appendix V.

	Change in flow volume (ac-ft)		
Decade	A2	A1B	B1
2010-2019	200,738	97,195	184,812
2020-2029	72,193	78,271	382,690
2030-2039	191,419	101,483	174,700
2040-2049	276,108	218,825	358,348
2050-2059	269,021	106,963	226,368
Average	201,896	120,547	265,384
		Overall Avg	195,942

Table 10. Decadal averages of increase in flow volumes in comparison with historic volumes, calculated as the area under the hydrograph for each scenario.

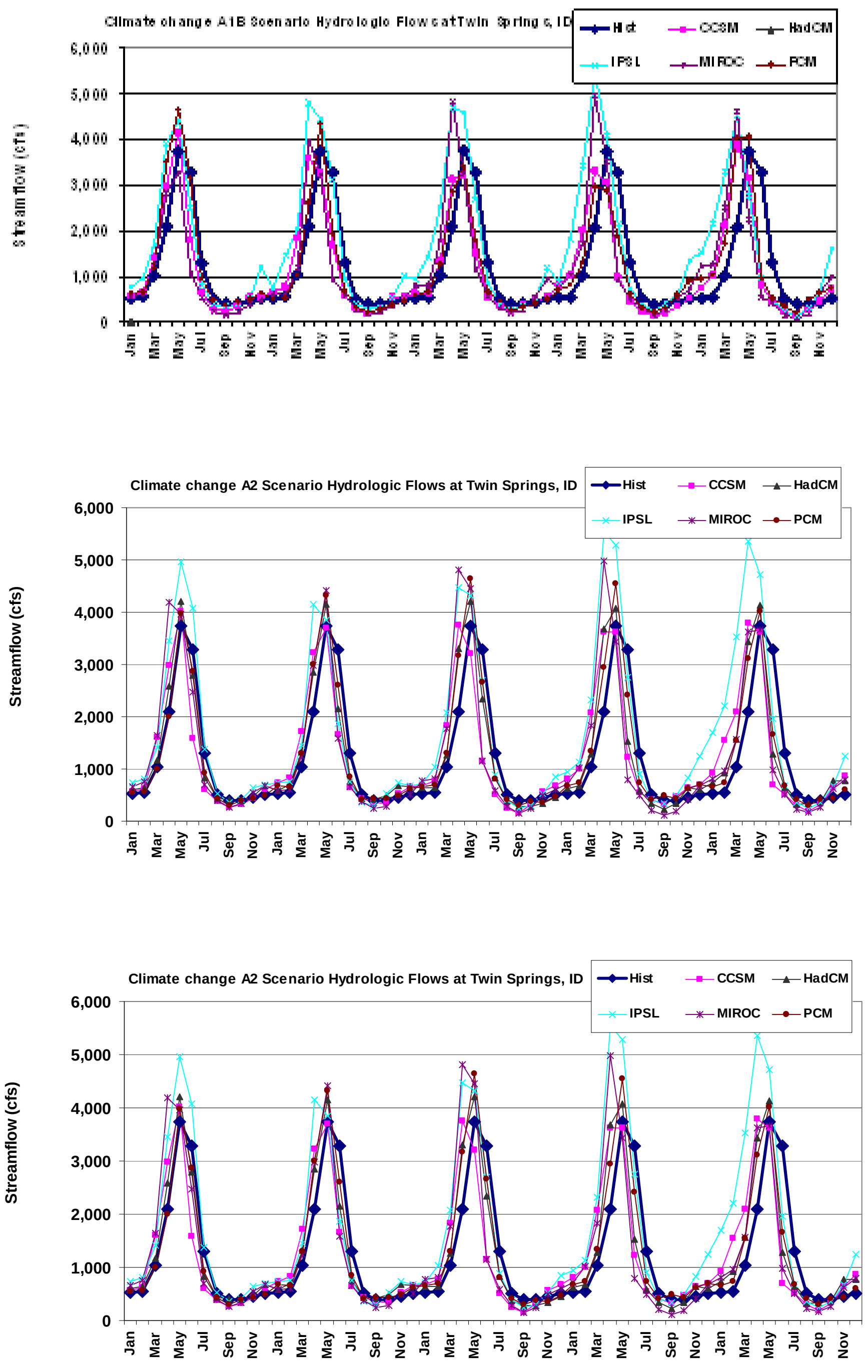
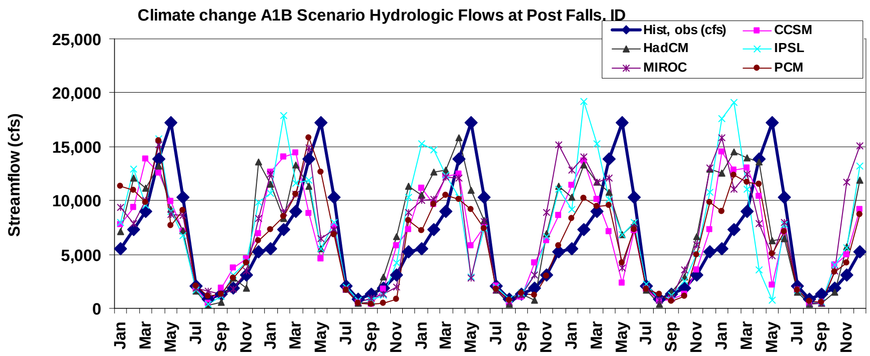
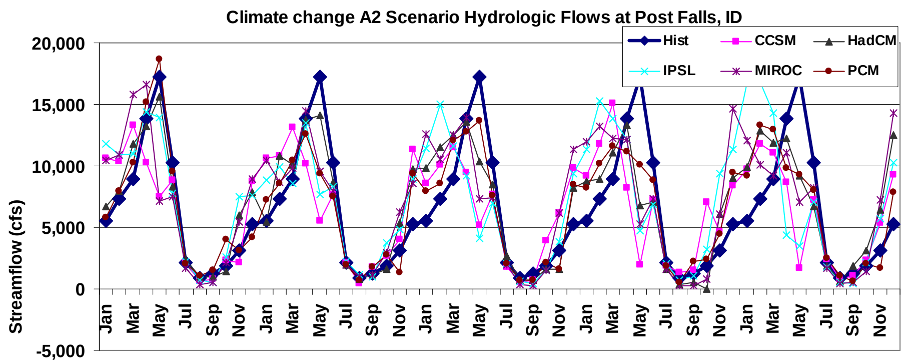


Figure 11. Seasonal streamflows for each decade between 2010 and 2060 at Twin Springs in the Upper Boise River basin for each scenario for A1B (top), A2 (middle) and B1 (bottom). Higher peak flows are expected to occur in May and low flows are about the same or slightly above when compared against the historic flows.





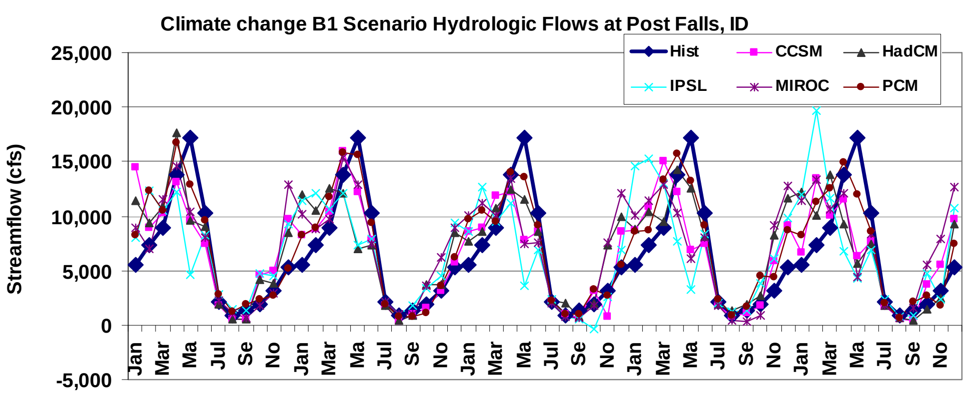


Figure 12. Seasonal streamflows for each decade between 2010 and 2060 at Post Falls in the Spokane River Basin for each scenario for A1B (top), A2 (middle) and B1 (bottom). Higher peak flows are expected to occur in May and low flows are about the same or slightly above when compared against the historic flows.

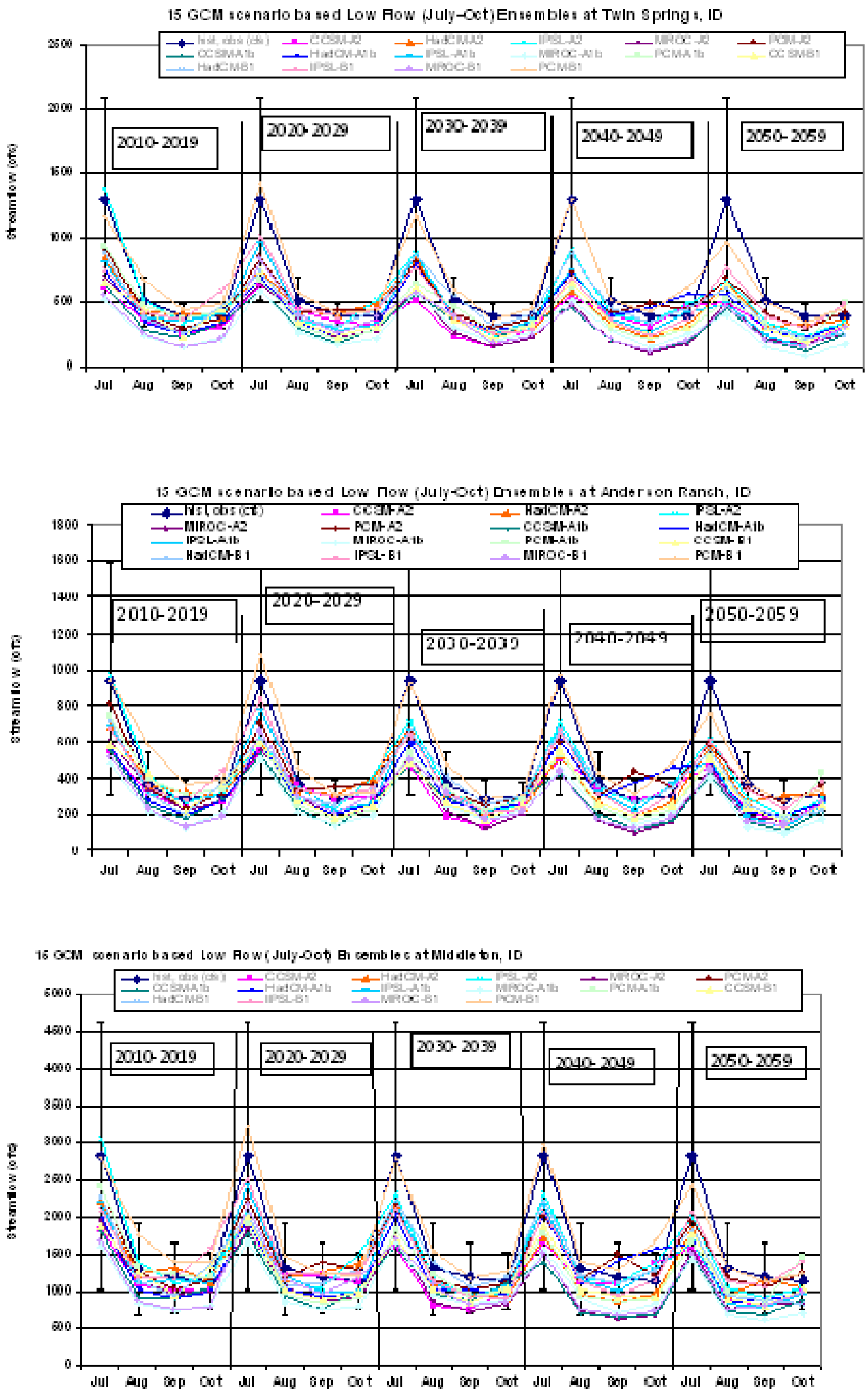
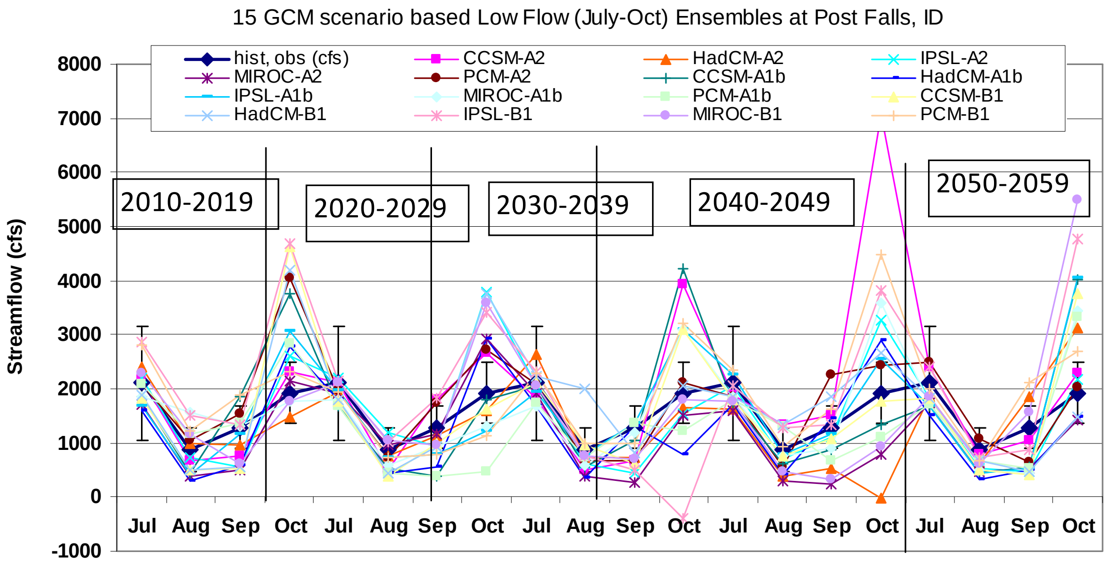


Figure 13. Low flows for each decade between 2010 and 2060 at Twin Springs, Anderson Ranch and Middleton in the Boise River Basin.



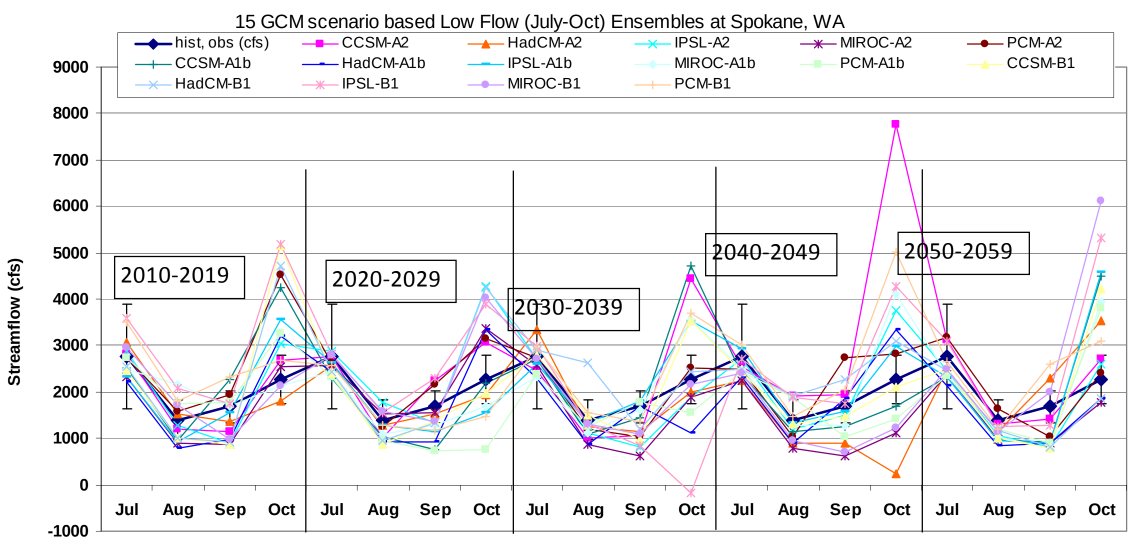


Figure 14. Low flows for each decade between 2010 and 2060 at Post Falls in the Spokane River Basin. Low flows are about the same or slightly below when compared against the historic flows.

5.3 Time Map of Streamflow

When simulating the flows under the climate change scenarios, one of the main things is to verify the timing of peak flow and its shift in the future. Using the time maps, we show that there is a shift in timing for all the three emission scenarios at least by 3-4 weeks in the Rathdrum Prairie aquifer region whereas Boise River basin showed 2-3 weeks of shift in the timing of peak flow. This shift is significant when the runoff needs to be stored or released from the system for flood control or irrigation. If we have to let the inflows released due to earlier melting, potentially there will be less water available for the crop growing season water demand. If we consider storing them, an additional analysis is critical to see if we have adequate storage capacity and room for flood control in both the basins. Figure 15 shows Lucky Peak in the Boise River basin and Post Falls in the Rathdrum Prairie region for A2 scenario streamflow generation in the future. Recall that A2 scenario considers increased emission leading to higher temperatures than any other scenarios and therefore melt timing analysis it is appropriate to consider A2 as a worst case scenario where maximum shift to be expected. While the other scenarios have shown a shift in the timing, Time maps of other locations are shown in Appendix VI.

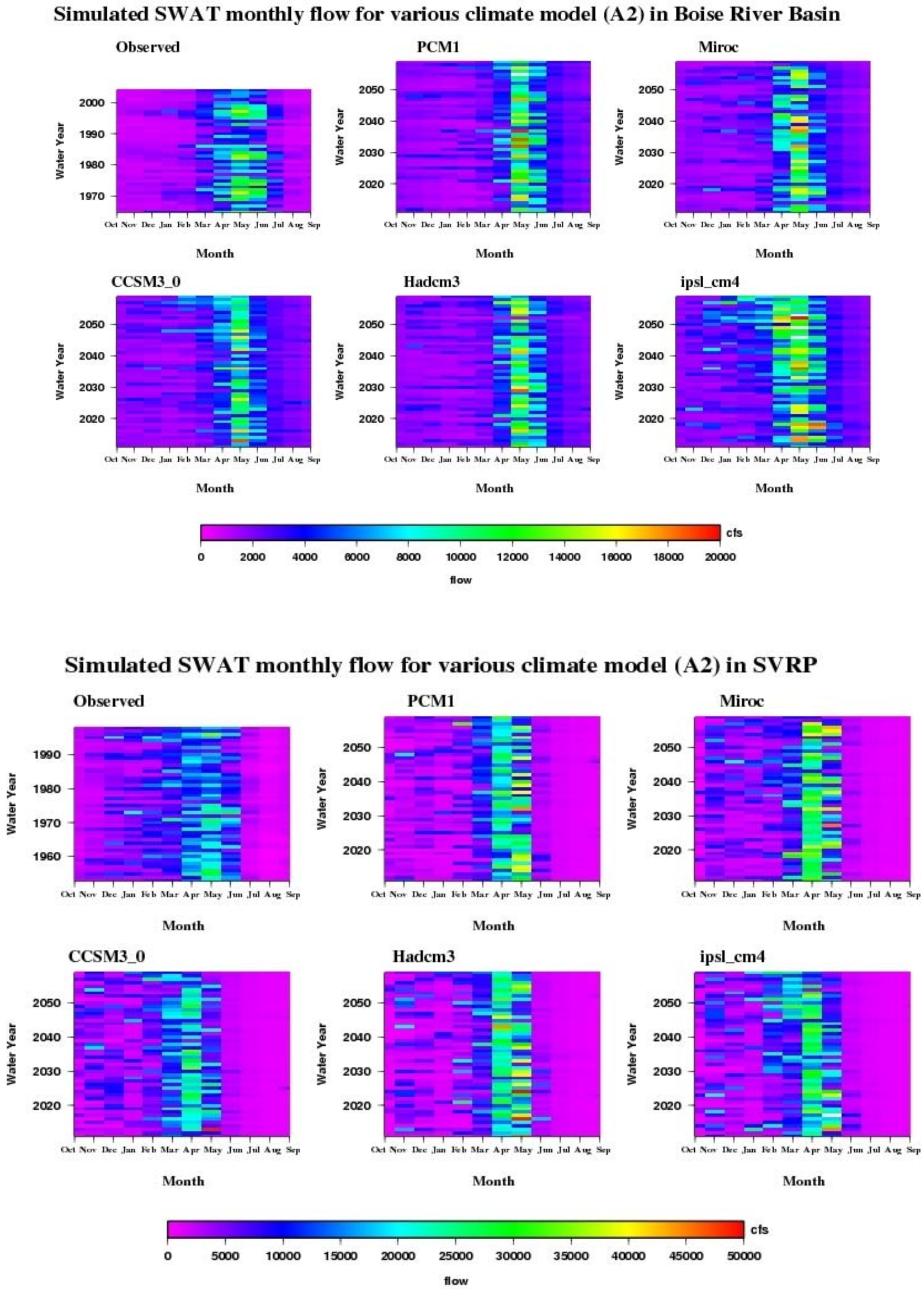


Figure 15. Time map showing historical vs. GCM-model based streamflows with a shift in the peakflow (from May to April) at Lucky Peak, Boise and Post Falls, Rathdrum Prairie region under A2 scenario.

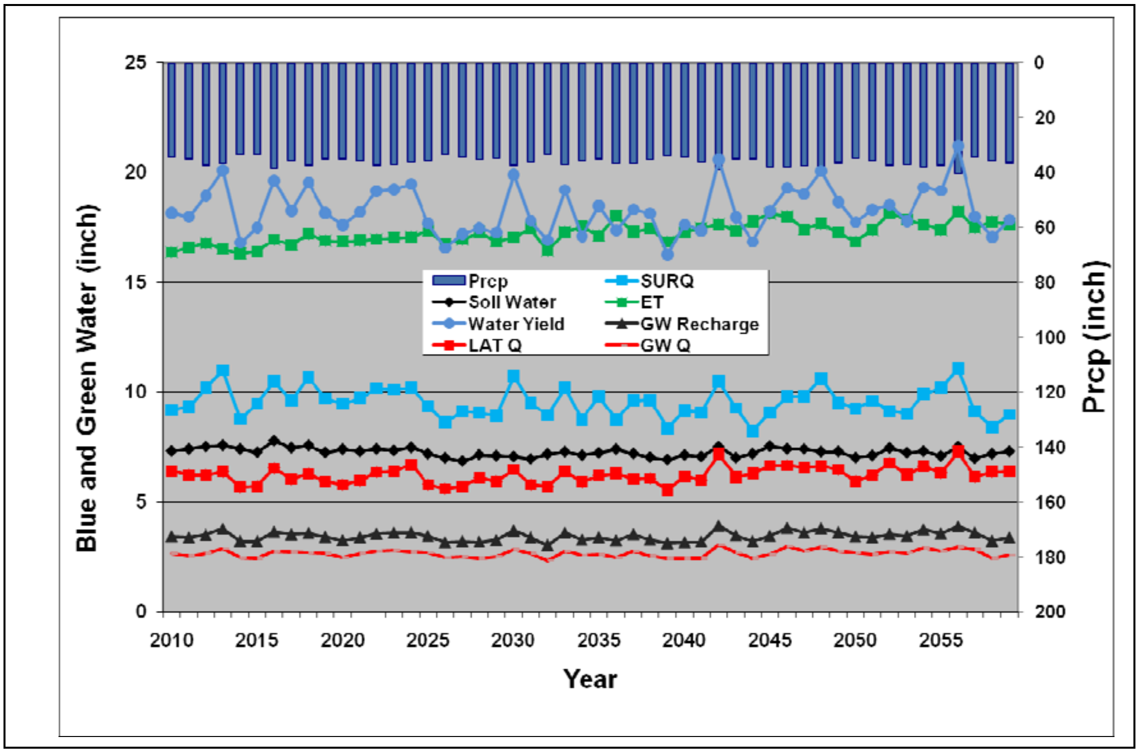
5.4 Annual Hydrologic Mass Balance estimates under future climate

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 16, 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.

Appendix VII shows the major water balance components including precipitation, streamflow, soil moisture, evapotranspiration and recharge by decade for each scenario (A2, A1B and B1) based on the chosen climate model predictions.



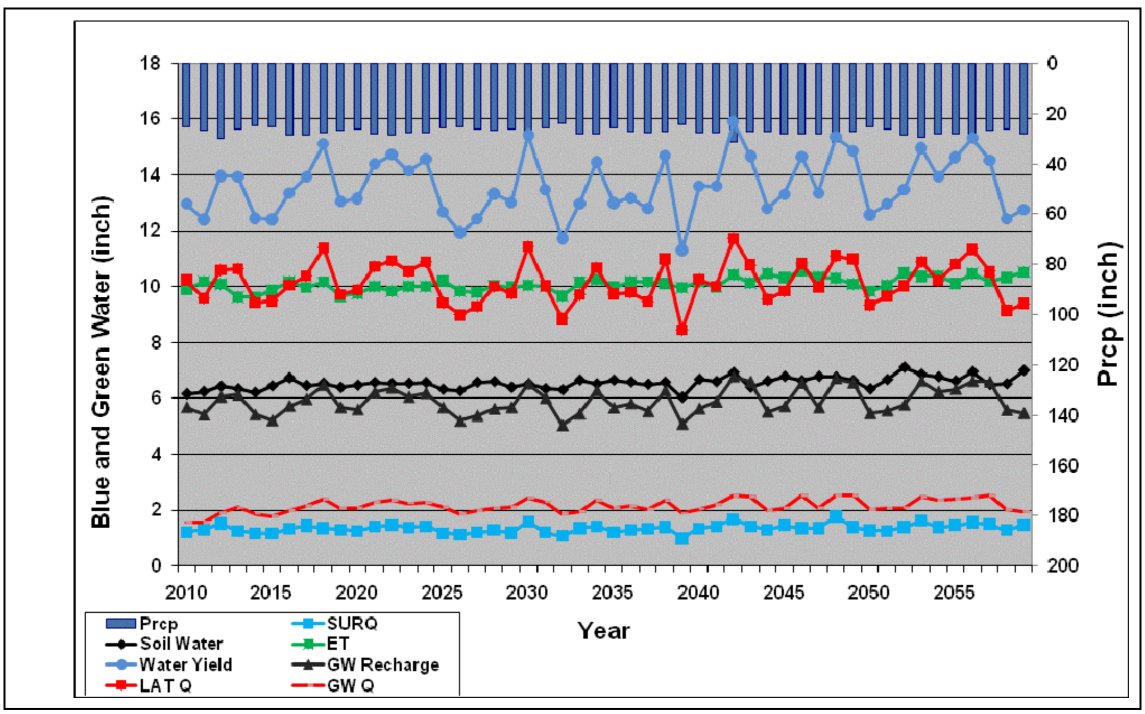


Figure 16. The annual Water balance estimates for the Spokane River basin (top) and the Boise River (bottom) basin and averaged over all GCMs and scenarios (15 members).

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 historic low flows and high flows are anticipated to be higher than 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.

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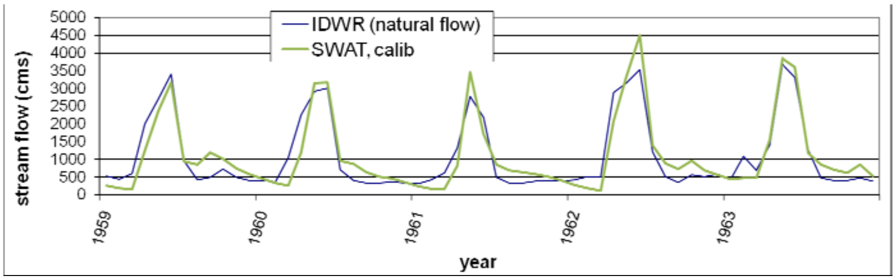
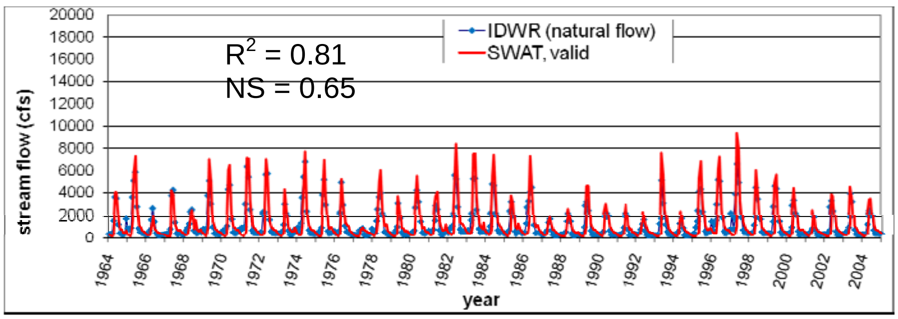
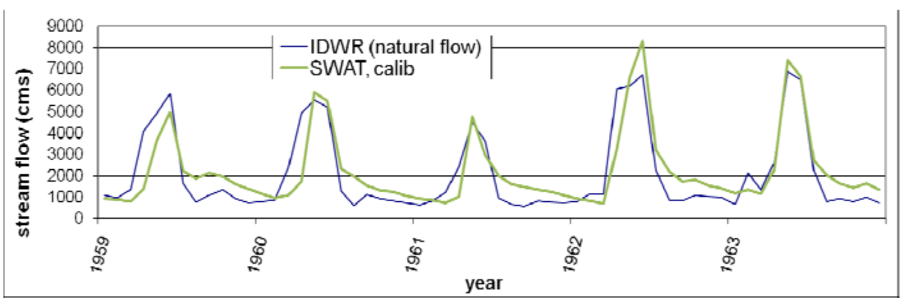
Appendix I

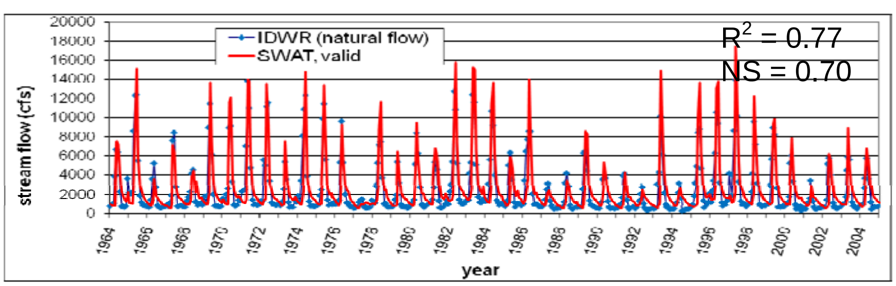
Validation of simulated flows for various locations in the Treasure Valley basin. The points are (a) Twin Springs (b) Arrowrock (c) Anderson Ranch (d) Parma



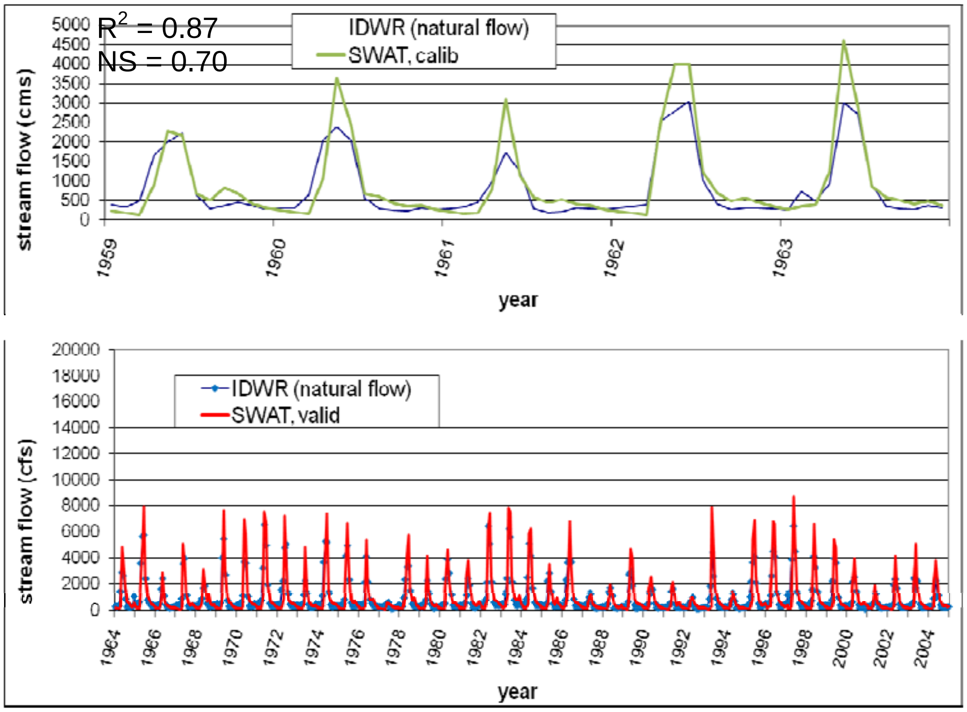


Twin Springs

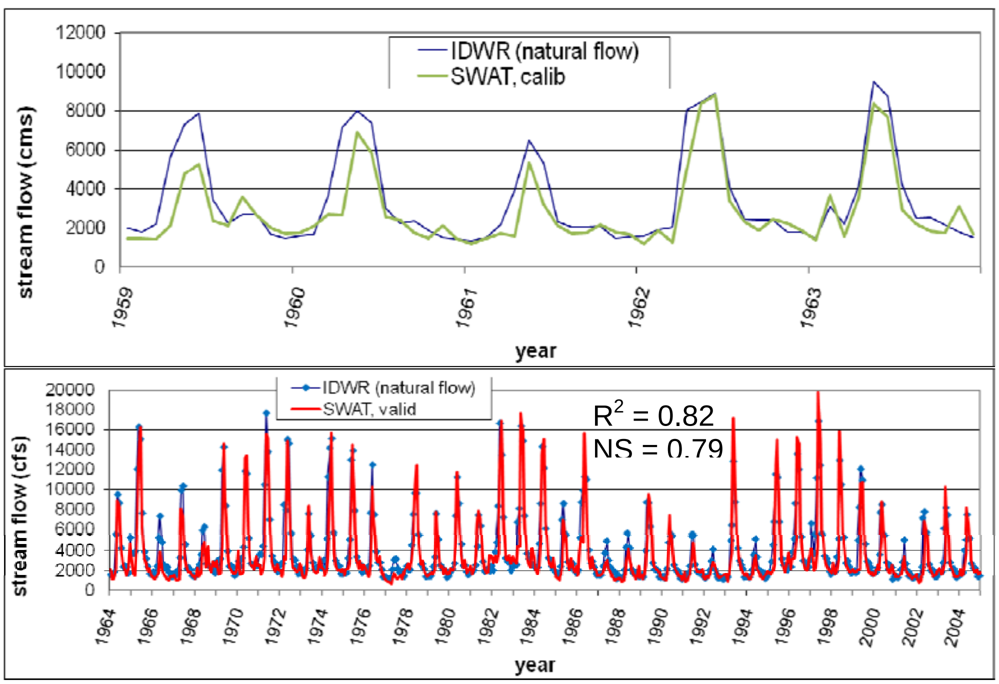




Arrowrock



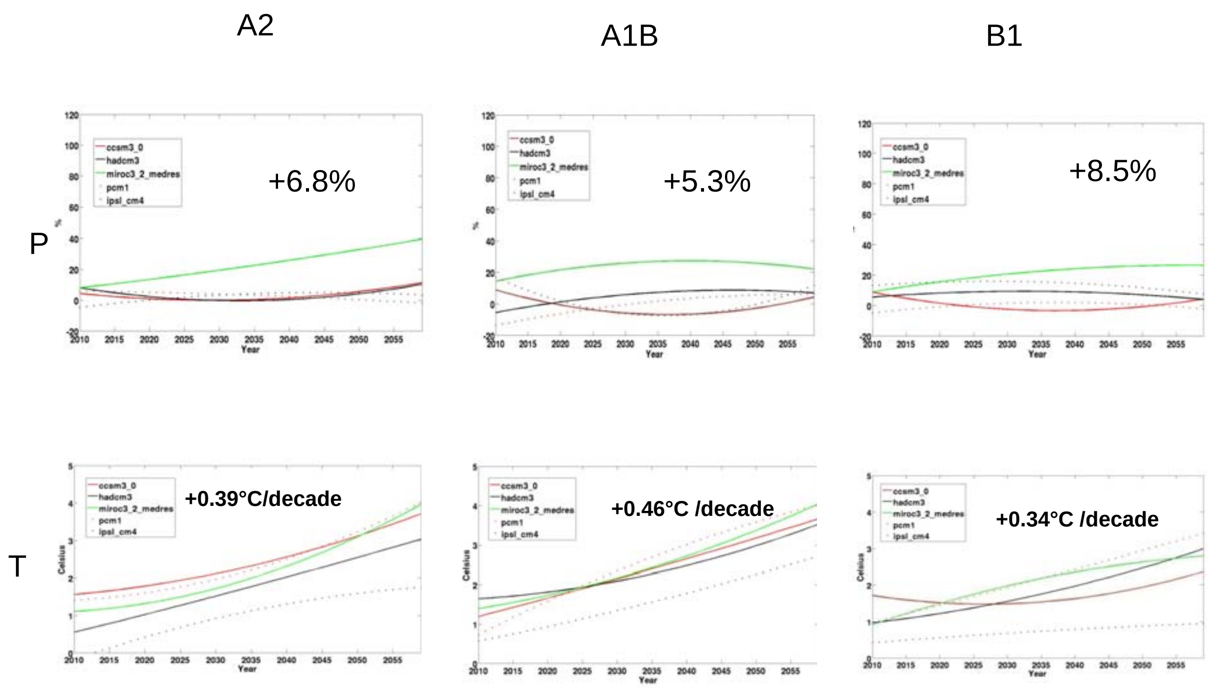
Anderson Ranch



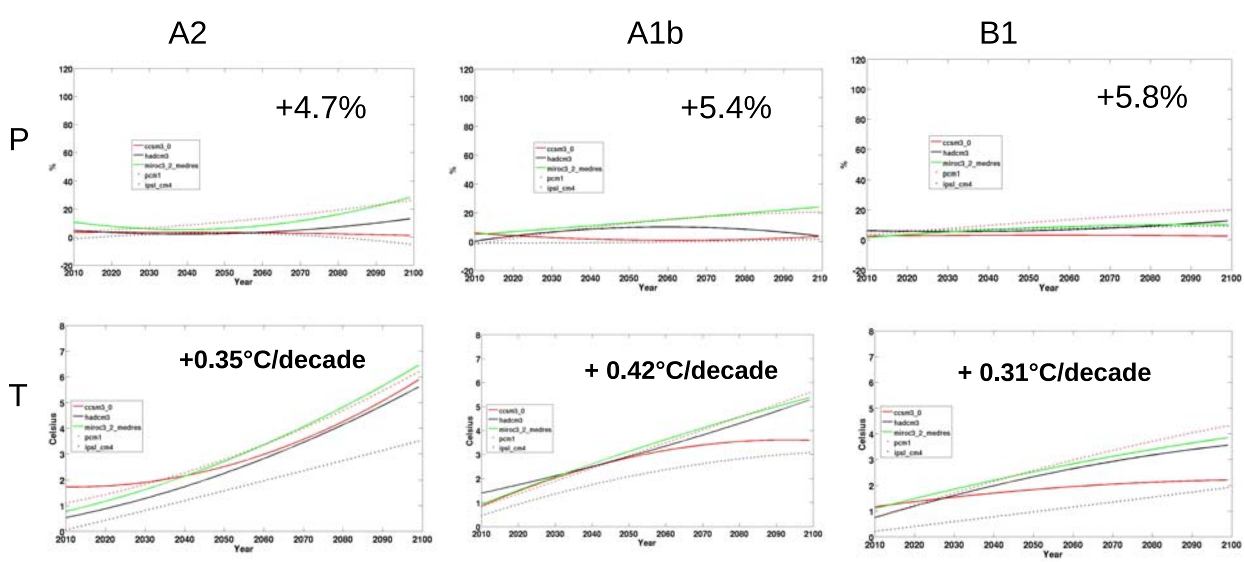
Parma

Appendix II

GCM-downscaled Precipitation and Temperature for all three scenarios (A2, A1B, and B1) (a) Boise River Basin (b) Spokane River basin



Boise River Basin

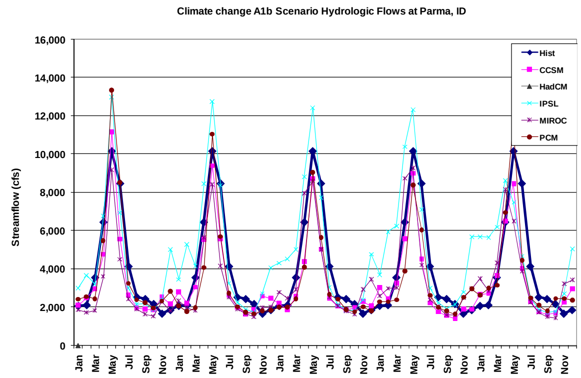


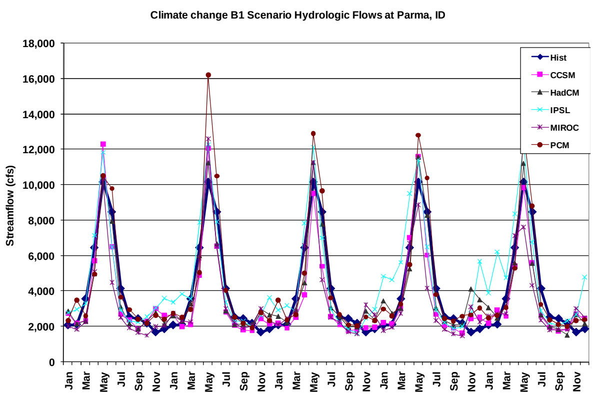
Spokane River Basin

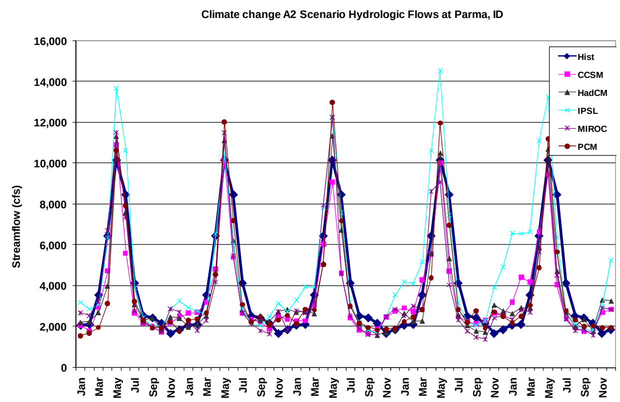
Appendix III

Projected seasonal streamflows averaged for each decade between 2010-2060 in the Treasure Valley basin (a) Parma (b) Caldwell (c) Anderson Ranch (d) Lucky Peak

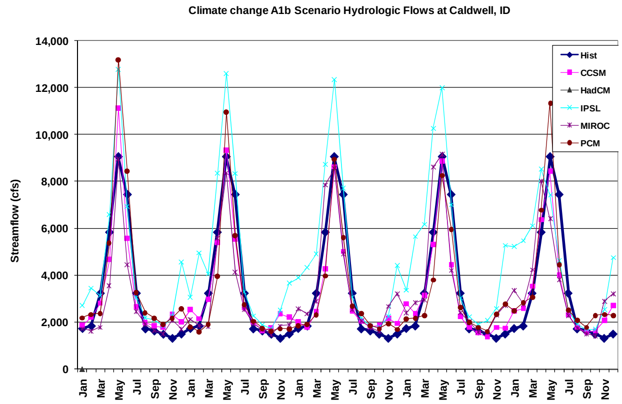
GCM B1, A1b and A2 scenario-based seasonal streamflows at Parma, ID

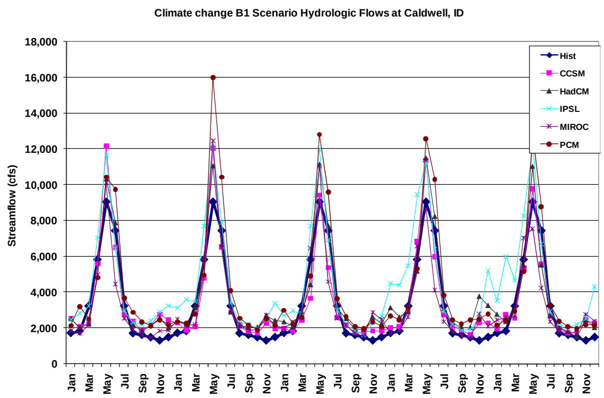


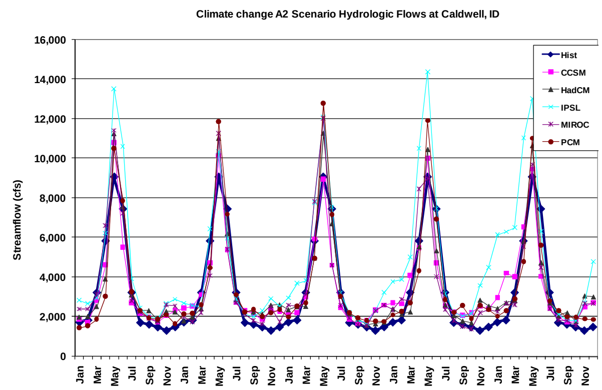




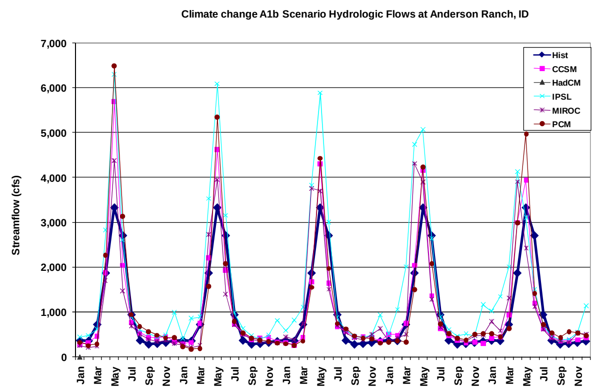
GCM B1, A1b and A2 scenario-based seasonal streamflows at Caldwell, ID

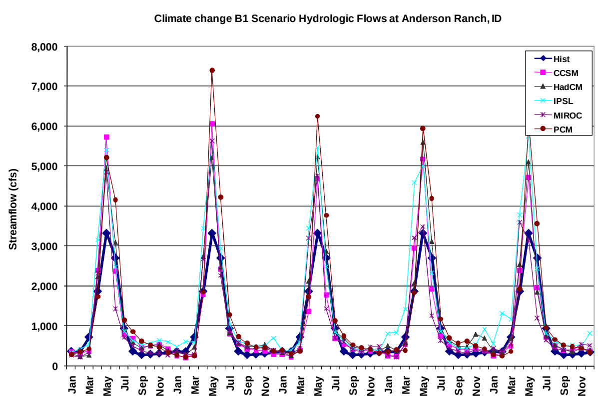


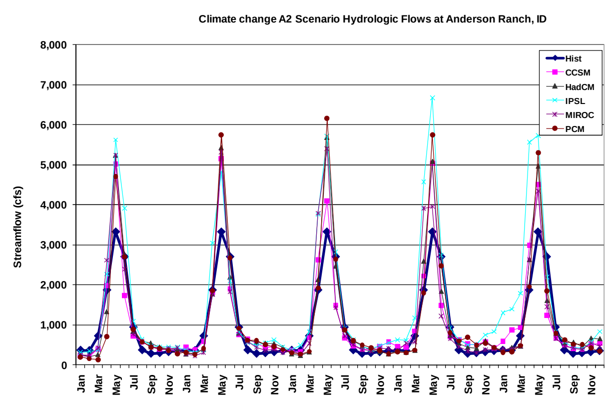




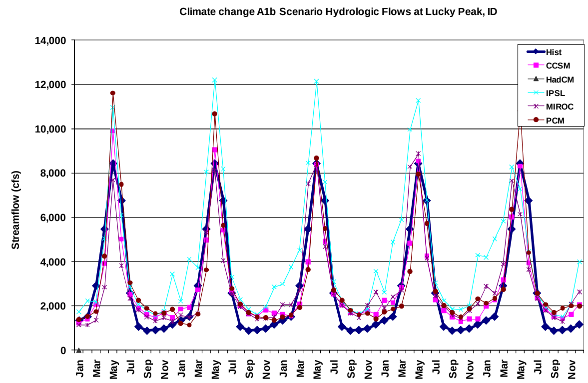
GCM B1, A1b and A2 scenario-based seasonal streamflows at Anderson Ranch, ID

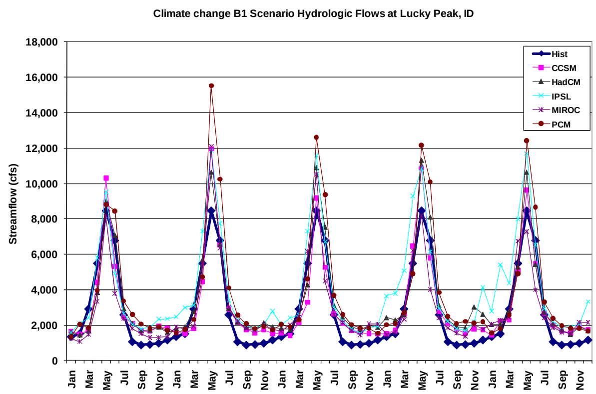


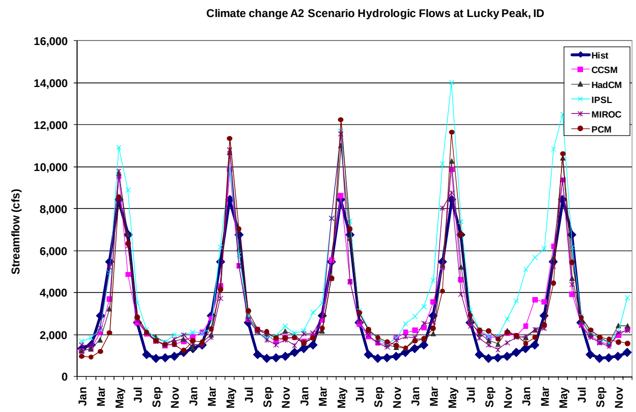




GCM B1, A1b and A2 scenario-based seasonal streamflows at Lucky Peak, ID







Appendix IV

Table 1. The change in flows (difference between historic conditions to future flow) by magnitude and percentage for the Rathdrum Prairie basin (Post Falls, Spokane) is provided below.

A2	Change in Flow (cfs)		Change in Flow (%)	
Post Falls	min	max	min	max
Jan	-1568	9690	-28	176
Feb	-1972	6892	-27	95
Mar	-1334	5833	-15	65
Apr	-5451	6799	-39	49
May	-12306	4585	-71	27
Jun	-7659	-4850	-74	-47
Jul	-563	476	-27	23
Aug	261	1314	30	152
Sep	-337	1675	-26	130
Oct	-349	6736	-18	351
Nov	2098	10060	68	325
Dec	-1156	9296	-22	176

A1B	Change in Flow (cfs)		Change in Flow (%)	
Post Falls	min	max	min	max
Jan	25	10503	0	191
Feb	-2029	9328	-28	128
Mar	-481	5322	-5	59
Apr	-6262	6029	-45	44
May	-13295	-1365	-77	-8
Jun	-7908	-5321	-77	-52
Jul	-649	88	-31	4
Aug	267	1523	31	176
Sep	-207	1257	-16	97
Oct	132	3878	7	202
Nov	1589	12445	51	402
Dec	447	9860	-3	187

B1	Change in Flow (cfs)		Change in Flow (%)	
Post Falls	min	max	min	max
Jan	-447	7576	-8	138
Feb	-2947	9783	-40	134
Mar	-499	5073	-6	57
Apr	-3028	7850	-22	57
May	-10726	1605	-62	9
Jun	-7522	-4741	-73	-46
Jul	-397	692	-19	33
Aug	342	1974	39	228
Sep	-245	1544	-19	119
Oct	-723	5162	-38	269
Nov	1525	9885	49	319
Dec	-173	7526	-3	142

A2	Change in Flow (cfs)		Change in Flow (%)	
Spokane	min	max	min	max
Jan	-1481	10516	-26	182
Feb	-1643	7264	-22	97
Mar	-1157	6103	-13	67
Apr	-5284	7071	-38	51
May	-12328	4660	-71	27
Jun	-8117	-5218	-75	-48
Jul	-1185	-67	-43	-2
Aug	-260	880	-19	63
Sep	-676	1445	-40	86
Oct	-618	6895	-27	303
Nov	2152	10604	64	315
Dec	-853	10264	-16	188

A1B	Change in Flow (cfs)		Change in Flow (%)	
Spokane	min	max	min	max
Jan	315	11399	5	197
Feb	-1805	10166	-24	136
Mar	-254	5483	-3	60
Apr	-6045	6499	-44	47
May	-13307	-1329	-76	-8
Jun	-8385	-5655	-77	-52
Jul	-1273	-486	-46	-18
Aug	-259	1103	-19	79
Sep	-556	974	-33	58
Oct	-112	3869	-5	170
Nov	1586	13206	47	393
Dec	805	10777	5	197

B1	Change in Flow (cfs)		Change in Flow (%)	
Spokane	min	max	min	max
Jan	-250	8248	-4	142
Feb	-2799	10506	-37	140
Mar	-302	5364	-3	59
Apr	-2797	8211	-20	60
May	-10624	1719	-61	10
Jun	-7952	-5101	-73	-47
Jul	-1009	162	-37	6
Aug	-173	1574	-12	113
Sep	-599	1300	-36	77
Oct	-1024	5248	-45	231
Nov	1596	10428	47	310
Dec	271	8427	5	154

Table 2. The Treasure Valley basin (Anderson Ranch, Twin Springs, Arrowrock, Lucky Peak, Glenwood, Middleton, Caldwell and Parma)

A2	Change in Flow (cfs)		Change in Flow (%)	
Anderson	min	max	min	max
Jan	-130	946	-35	255
Feb	-174	1033	-48	284
Mar	-553	1072	-76	147
Apr	-954	3702	-51	197
May	618	3340	19	100
Jun	-1488	1820	-55	67
Jul	-296	238	-31	25
Aug	79	338	21	90
Sep	66	403	23	141
Oct	7	253	2	84
Nov	8	439	3	135
Dec	-76	479	-22	135
A1B	Change in Flow (cfs)		Change in Flow (%)	
Anderson	min	max	min	max
Jan	-141	651	-38	175
Feb	-190	990	-52	272
Mar	-541	1287	-74	177
Apr	-368	2868	-20	153
May	-902	3159	-27	95
Jun	-1585	446	-58	16
Jul	-332	43	-35	4
Aug	43	309	12	83
Sep	66	346	23	121
Oct	14	298	5	99
Nov	2	231	1	71
Dec	-57	816	-23	230
B1	Change in Flow (cfs)		Change in Flow (%)	
Anderson	min	max	min	max
Jan	-107	452	-29	122
Feb	-145	970	-40	266
Mar	-464	710	-64	98
Apr	-501	2720	-27	145
May	-180	4079	-5	122
Jun	-1504	1527	-55	56
Jul	-300	346	-32	37
Aug	72	491	19	132
Sep	94	339	33	119
Oct	30	332	10	111
Nov	2	478	1	147
Dec	-80	582	-23	164

A2	Change in Flow (cfs)		Change in Flow (%)	
Twin Falls	min	max	min	max
Jan	-130	946	-35	255
Feb	-174	1033	-48	284
Mar	-553	1072	-76	147
Apr	-954	3702	-51	197
May	618	3340	19	100
Jun	-1488	1820	-55	67
Jul	-296	238	-31	25
Aug	79	338	21	90
Sep	66	403	23	141
Oct	7	253	2	84
Nov	8	439	3	135
Dec	-76	479	-22	135

A1B	Change in Flow (cfs)		Change in Flow (%)	
Twin Falls	min	max	min	max
Jan	-141	651	-38	175
Feb	-190	990	-52	272
Mar	-541	1287	-74	177
Apr	-368	2868	-20	153
May	-902	3159	-27	95
Jun	-1585	446	-58	16
Jul	-332	43	-35	4
Aug	43	309	12	83
Sep	66	346	23	121
Oct	14	298	5	99
Nov	2	231	1	71
Dec	-57	816	-23	230

B1	Change in Flow (cfs)		Change in Flow (%)	
Twin Falls	min	max	min	max
Jan	-107	452	-29	122
Feb	-145	970	-40	266
Mar	-464	710	-64	98
Apr	-501	2720	-27	145
May	-180	4079	-5	122
Jun	-1504	1527	-55	56
Jul	-300	346	-32	37
Aug	72	491	19	132
Sep	94	339	33	119
Oct	30	332	10	111
Nov	2	478	1	147
Dec	-80	582	-23	164

A2	Change in Flow (cfs)		Change in Flow (%)	
Arrowrock	min	max	min	max
Jan	-40	2608	-4	234
Feb	-236	2997	-20	249
Mar	-1330	2623	-59	116
Apr	-2814	5463	-63	122
May	240	5371	3	71
Jun	-2666	3589	-42	57
Jul	-146	1275	-6	53
Aug	756	1349	78	139
Sep	608	1133	75	139
Oct	411	908	51	112
Nov	432	1198	50	140
Dec	174	1775	18	180

A1B	Change in Flow (cfs)		Change in Flow (%)	
Arrowrock	min	max	min	max
Jan	-56	1886	-5	169
Feb	-305	2578	-25	214
Mar	-1348	2518	-60	111
Apr	-2072	4504	-46	100
May	-1947	4110	-26	54
Jun	-2986	1382	-47	22
Jul	-265	717	-11	30
Aug	709	1256	73	129
Sep	576	1143	71	140
Oct	395	1078	49	133
Nov	315	864	37	101
Dec	168	2276	18	231

B1	Change in Flow (cfs)		Change in Flow (%)	
Arrowrock	min	max	min	max
Jan	23	1577	2	142
Feb	-171	2727	-14	227
Mar	-1133	1561	-50	69
Apr	-2097	3959	-47	88
May	-829	6505	-11	86
Jun	-2685	3230	-43	51
Jul	-154	1445	-6	60
Aug	753	1595	77	164
Sep	627	1209	77	148
Oct	451	1145	56	142
Nov	364	1488	43	174
Dec	178	2081	18	212

A2	Change in Flow (cfs)		Change in Flow (%)	
Lucky Peak	min	max	min	max
Jan	-834	2721	-12	280
Feb	-1797	2017	-23	274
Mar	-1252	2562	-48	110
Apr	-1750	4967	-50	98
May	-1344	4111	2	66
Jun	-688	5198	-42	55
Jul	-260	1185	-7	52
Aug	-359	340	73	132
Sep	-386	288	71	147
Oct	-562	293	42	115
Nov	-674	675	43	181
Dec	-718	1645	16	222

A1B	Change in Flow (cfs)		Change in Flow (%)	
Lucky Peak	min	max	min	max
Jan	-982	1805	-10	213
Feb	-1630	2547	-25	232
Mar	-1545	2359	-45	103
Apr	-2268	4768	-39	82
May	-3220	3538	-27	51
Jun	-1228	3454	-46	21
Jul	-225	601	-11	28
Aug	-302	532	68	124
Sep	-387	316	68	146
Oct	-430	354	42	133
Nov	-440	910	44	119
Dec	-657	2346	24	270

B1	Change in Flow (cfs)		Change in Flow (%)	
Lucky Peak	min	max	min	max
Jan	-1067	1462	6	170
Feb	-2156	1716	-10	255
Mar	-1227	1548	-38	75
Apr	-1332	4106	-40	70
May	-2067	5637	-14	84
Jun	-972	5465	-41	52
Jul	-166	1375	-7	59
Aug	-1194	693	73	160
Sep	-1140	420	75	149
Oct	-946	463	48	142
Nov	-1102	840	44	205
Dec	-1105	2163	24	254

A2	Change in Flow (cfs)		Change in Flow (%)	
Glenwood	min	max	min	max
Jan	-149	4022	-11	285
Feb	-297	4287	-19	272
Mar	-1318	3282	-45	112
Apr	-2663	5422	-49	99
May	233	5643	3	67
Jun	-2871	3703	-42	54
Jul	-306	1222	-11	45
Aug	672	1306	58	113
Sep	527	1306	54	133
Oct	358	1097	37	114
Nov	472	1990	46	196
Dec	237	2854	19	234

A1B	Change in Flow (cfs)		Change in Flow (%)	
Glenwood	min	max	min	max
Jan	-27	3113	-2	221
Feb	-304	3606	-19	229
Mar	-1295	3044	-44	103
Apr	-2083	4577	-38	84
May	-2242	4406	-27	52
Jun	-3143	1410	-46	21
Jul	-416	615	-15	23
Aug	618	1231	54	107
Sep	508	1264	52	129
Oct	369	1226	38	127
Nov	507	1330	50	131
Dec	245	3380	29	277

B1	Change in Flow (cfs)		Change in Flow (%)	
Glenwood	min	max	min	max
Jan	112	2464	8	175
Feb	-112	3993	-7	253
Mar	-1052	2265	-36	77
Apr	-2067	3872	-38	71
May	-1093	7195	-13	85
Jun	-2784	3474	-41	51
Jul	-304	1414	-11	53
Aug	680	1642	59	142
Sep	573	1261	59	129
Oct	419	1320	44	137
Nov	542	2193	53	216
Dec	357	3244	29	266

A2	Change in Flow (cfs)		Change in Flow (%)	
Middleton	min	max	min	max
Jan	-1413	4355	-95	293
Feb	-1577	4470	-96	273
Mar	-2973	3373	-98	112
Apr	-5468	5431	-99	98
May	-8550	5656	-99	66
Jun	-6990	3561	-100	51
Jul	-2827	1080	-100	38
Aug	-1305	1149	-100	88
Sep	-1184	1266	-100	107
Oct	-1116	1070	-99	95
Nov	-961	2237	-88	204
Dec	-1222	3181	-95	248

A1B	Change in Flow (cfs)		Change in Flow (%)	
Middleton	min	max	min	max
Jan	-1413	4355	-95	293
Feb	-1577	4470	-96	273
Mar	-2973	3373	-98	112
Apr	-5468	5431	-99	98
May	-8550	5656	-99	66
Jun	-6990	3561	-100	51
Jul	-2827	1080	-100	38
Aug	-1305	1149	-100	88
Sep	-1184	1266	-100	107
Oct	-1116	1143	-99	101
Nov	-961	2237	-88	204
Dec	-1222	3688	-95	287

B1	Change in Flow (cfs)		Change in Flow (%)	
Middleton	min	max	min	max
Jan	-1413	4355	-95	293
Feb	-1577	4470	-96	273
Mar	-2973	3373	-98	112
Apr	-5468	5431	-99	98
May	-8550	7236	-99	84
Jun	-6990	3561	-100	51
Jul	-2827	1265	-100	45
Aug	-1305	1541	-100	118
Sep	-1184	1266	-100	107
Oct	-1116	1256	-99	111
Nov	-961	2414	-88	220
Dec	-1222	3688	-95	287

A2	Change in Flow (cfs)		Change in Flow (%)	
Caldwell	min	max	min	max
Jan	-281	4414	-16	255
Feb	-285	4455	-15	242
Mar	-1357	3273	-42	101
Apr	-2786	5207	-48	89
May	-115	5335	-1	59
Jun	-3413	3173	-46	43
Jul	-876	674	-27	21
Aug	95	739	6	43
Sep	-118	956	-7	59
Oct	-114	825	-8	55
Nov	336	2268	25	172
Dec	166	3295	11	220

A1B	Change in Flow (cfs)		Change in Flow (%)	
Caldwell	min	max	min	max
Jan	-9	3505	-1	202
Feb	-244	3813	-13	207
Mar	-1449	2942	-45	91
Apr	-2282	4446	-39	76
May	-2648	4130	-29	46
Jun	-3628	993	-49	13
Jul	-984	58	-30	2
Aug	43	687	3	40
Sep	-117	831	-7	51
Oct	-103	854	-7	57
Nov	418	1582	32	120
Dec	205	3784	24	253

B1	Change in Flow (cfs)		Change in Flow (%)	
Caldwell	min	max	min	max
Jan	-33	2754	-2	159
Feb	-137	4154	-7	226
Mar	-1170	2253	-36	70
Apr	-2175	3618	-37	62
May	-1513	6941	-17	77
Jun	-3309	2995	-44	40
Jul	-870	857	-27	26
Aug	116	1182	7	69
Sep	-44	729	-3	45
Oct	-43	986	-3	66
Nov	515	2461	39	187
Dec	362	3709	24	248

A2	Change in Flow (cfs)		Change in Flow (%)	
Parma	min	max	min	max
Jan	-521	4483	-25	215
Feb	-413	4439	-19	209
Mar	-1589	3068	-45	86
Apr	-3297	4663	-51	72
May	-1098	4391	-11	43
Jun	-4427	2176	-52	26
Jul	-1814	-257	-44	-6
Aug	-748	-100	-30	-4
Sep	-946	339	-39	14
Oct	-792	299	-36	14
Nov	39	2232	2	133
Dec	-78	3398	-4	182

A1B	Change in Flow (cfs)		Change in Flow (%)	
Parma	min	max	min	max
Jan	-225	3622	-11	174
Feb	-390	3847	-18	181
Mar	-1740	2700	-49	76
Apr	-2844	3948	-44	61
May	-3663	3202	-36	31
Jun	-4592	64	-54	1
Jul	-1924	-876	-46	-21
Aug	-800	-109	-32	-4
Sep	-935	158	-38	6
Oct	-781	277	-36	13
Nov	141	1557	8	93
Dec	-60	3844	7	206

B1	Change in Flow (cfs)		Change in Flow (%)	
Parma	min	max	min	max
Jan	-304	2763	-15	133
Feb	-299	4093	-14	193
Mar	-1441	2065	-40	58
Apr	-2671	3040	-41	47
May	-2545	6034	-25	59
Jun	-4304	2023	-51	24
Jul	-1808	-78	-44	-2
Aug	-727	430	-29	17
Sep	-852	-30	-35	-1
Oct	-717	411	-33	19
Nov	254	2450	15	146
Dec	125	3829	7	206

Appendix V

Table showing the change in flow volumes in comparison with historic volume of flow at Lucky Peak, Boise River basin

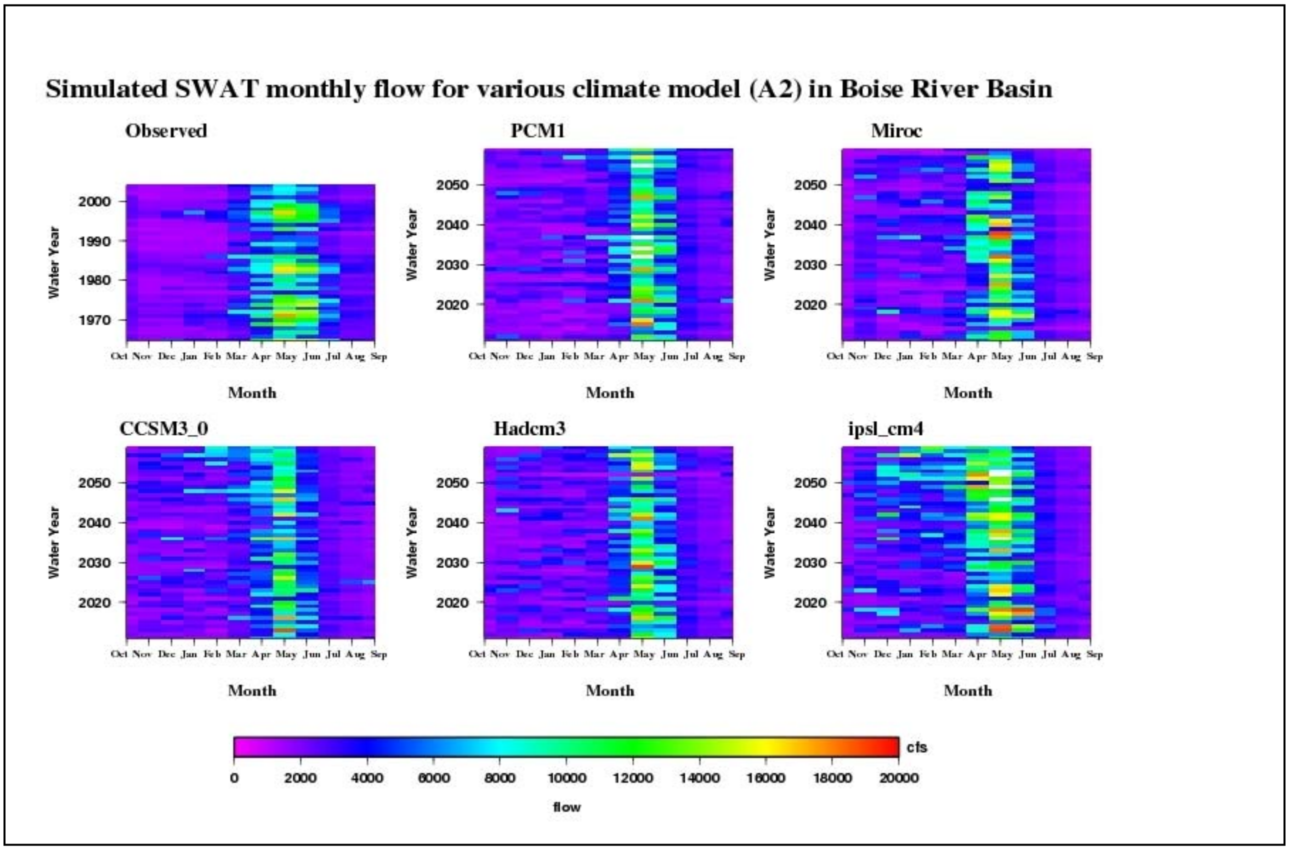
A2		Change (ac-ft)	Avg/decade
2010-2019	ccsm3_0	-63399	
	hadcm3	107618	
	ipsl_cm4	728522	
	miroc3_2_medres	297502	
	pcm1	-66552	200738
2020-2029	ccsm3_0	21904	
	hadcm3	68342	
	ipsl_cm4	193226	
	miroc3_2_medres	-107177	
	pcm1	184672	72193
2030-2039	ccsm3_0	-112281	
	hadcm3	82714	
	ipsl_cm4	577703	
	miroc3_2_medres	204933	
	pcm1	204026	191419
2040-2049	ccsm3_0	99780	
	hadcm3	12679	
	ipsl_cm4	1087860	
	miroc3_2_medres	-7766	
	pcm1	187990	276108
2050-2059	ccsm3_0	130194	
	hadcm3	108456	
	ipsl_cm4	1174059	
	miroc3_2_medres	-86311	
	pcm1	18708	269021
		Avg	201896

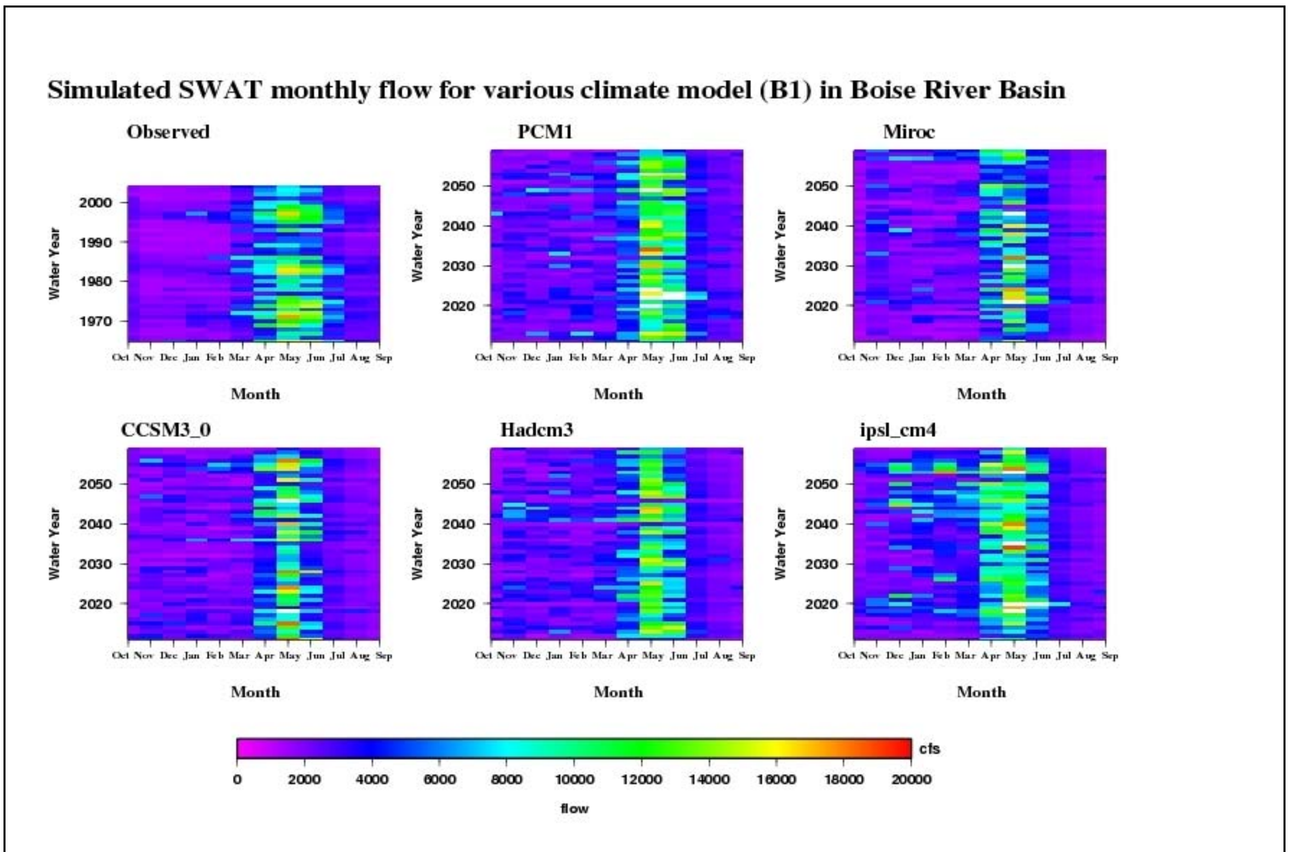
A1B		Change (ac-ft)	Avg/decade
2010-2019	ccsm3_0	-11006	
	hadcm3	47913	
	ipsl_cm4	494376	
	miroc3_2_medres	-427418	
	pcm1	382110	97195
2020-2029	ccsm3_0	-48846	
	hadcm3	127243	
	ipsl_cm4	801435	
	miroc3_2_medres	-315050	
	pcm1	-173428	78271
2030-2039	ccsm3_0	-254951	
	hadcm3	102340	
	ipsl_cm4	821861	
	miroc3_2_medres	56178	
	pcm1	-218013	101483
2040-2049	ccsm3_0	-228129	
	hadcm3	470188	
	ipsl_cm4	999095	
	miroc3_2_medres	68592	
	pcm1	-215620	218825
2050-2059	ccsm3_0	-116935	
	hadcm3	75333	
	ipsl_cm4	483921	
	miroc3_2_medres	-50902	
	pcm1	143396	106963
		Avg	120547

B1		Change (ac-ft)	Avg/decade
2010-2019	ccsm3_0	209432	
	hadcm3	136698	
	ipsl_cm4	417406	
	miroc3_2_medres	-241649	
	pcm1	402174	184812
2020-2029	ccsm3_0	82117	
	hadcm3	232743	
	ipsl_cm4	641312	
	miroc3_2_medres	230907	
	pcm1	726371	382690
2030-2039	ccsm3_0	-249096	
	hadcm3	200852	
	ipsl_cm4	388108	
	miroc3_2_medres	56819	
	pcm1	476818	174700
2040-2049	ccsm3_0	150599	
	hadcm3	435220	
	ipsl_cm4	801420	
	miroc3_2_medres	-206428	
	pcm1	610930	358348
2050-2059	ccsm3_0	-25874	
	hadcm3	76964	
	ipsl_cm4	806964	
	miroc3_2_medres	-126079	
	pcm1	399866	226368
		Avg	265384

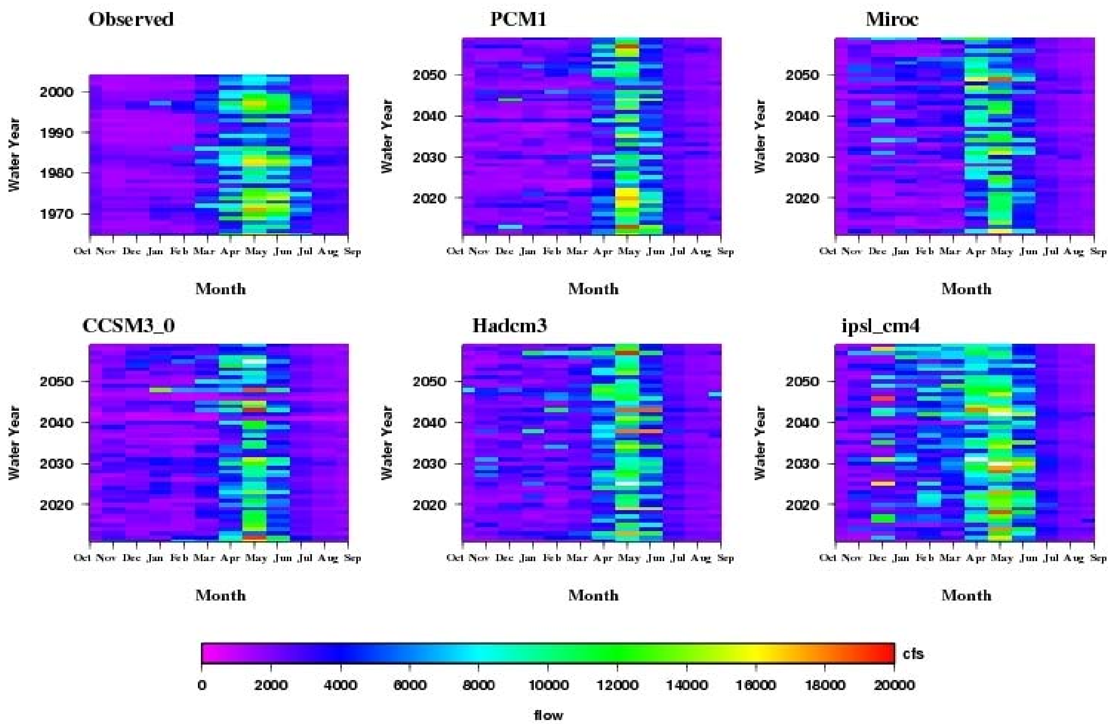
Appendix VI

Time maps of future flows for Parma under different emission scenarios





Simulated SWAT monthly flow for various climate model (A1B) in Boise River Basin



Appendix VII

Table 1. The Water Balance Components of the Boise River Basin based on the GCM-downscaled precipitation and temperature for each decade and scenario (A2, A1B and B1).

A2

Decade	Model	Precip (in)	Soil water (in)	ET (in)	Streamflow (in)	Recharge (in)
2010-2019	ccsm3_0	26.21	6.48	10.09	12.25	5.33
	hadcm3	26.48	6.37	9.83	13.06	5.61
	ipsl_cm4	29.56	6.34	9.88	16.34	7.01
	miroc3_2_medres	27.86	6.45	10.15	14.11	6.11
	pcm1	24.00	5.93	9.45	11.83	5.11
2020-2029	ccsm3_0	25.78	6.65	9.94	12.59	5.65
	hadcm3	26.49	6.51	9.85	12.99	5.48
	ipsl_cm4	28.07	6.85	10.43	13.71	5.93
	miroc3_2_medres	24.96	6.45	9.87	11.86	5.09
	pcm1	27.22	6.46	10.10	13.52	5.77
2030-2039	ccsm3_0	25.09	6.51	9.99	11.91	5.27
	hadcm3	25.42	5.96	9.72	12.58	5.57
	ipsl_cm4	30.06	6.56	10.45	15.71	6.78
	miroc3_2_medres	27.62	6.67	9.98	13.65	5.91
	pcm1	26.41	6.06	9.68	13.42	5.77
2040-2049	ccsm3_0	27.66	6.81	10.56	13.20	5.79
	hadcm3	25.76	6.57	9.93	12.58	5.34
	ipsl_cm4	34.36	7.09	10.34	18.99	8.16
	miroc3_2_medres	25.06	6.64	10.01	12.30	5.46
	pcm1	27.39	6.69	10.15	13.54	5.81
2050-2059	ccsm3_0	26.82	6.80	10.35	13.26	5.94
	hadcm3	27.31	6.76	10.01	13.33	5.64
	ipsl_cm4	34.85	6.88	10.86	19.42	8.58
	miroc3_2_medres	25.77	6.88	10.02	12.19	5.33
	pcm1	25.99	6.44	10.17	12.57	5.45
	min	24.00	5.93	9.45	11.83	5.09
	max	34.85	7.09	10.86	19.42	8.58

A1B

Decade	Model	Precip (in)	Soil water (in)	ET (in)	Streamflow (in)	Recharge (in)
2010-2019	ccsm3_0	25.60	6.40	9.60	12.38	5.39
	hadcm3	25.22	6.36	9.66	12.59	5.54
	ipsl_cm4	30.14	6.54	9.99	15.54	6.72
	miroc3_2_medres	23.21	6.06	9.82	10.14	4.32
	pcm1	29.17	6.31	10.12	14.57	6.26
2020-2029	ccsm3_0	25.92	6.52	9.90	12.28	5.46
	hadcm3	26.39	6.46	9.87	13.19	5.81
	ipsl_cm4	31.97	6.61	10.24	17.02	7.37
	miroc3_2_medres	23.17	6.03	10.06	10.55	4.53
	pcm1	23.27	5.81	9.30	11.36	4.76
2030-2039	ccsm3_0	23.58	6.54	9.88	11.03	4.83
	hadcm3	26.68	6.48	9.92	13.09	5.56
	ipsl_cm4	30.59	6.67	10.29	17.13	7.52
	miroc3_2_medres	27.14	6.83	10.80	12.98	5.50
	pcm1	23.38	6.10	9.95	11.03	4.93
2040-2049	ccsm3_0	24.14	6.08	10.05	11.28	4.98
	hadcm3	29.36	6.65	10.37	15.11	6.62
	ipsl_cm4	34.57	6.97	10.95	18.58	7.95
	miroc3_2_medres	26.54	6.56	10.30	12.87	5.63
	pcm1	25.17	6.55	10.16	11.49	5.07
2050-2059	ccsm3_0	25.78	6.68	10.01	12.03	5.32
	hadcm3	26.33	6.50	9.81	13.02	5.70
	ipsl_cm4	30.98	7.00	10.89	15.77	7.12
	miroc3_2_medres	27.03	7.05	10.73	12.56	5.52
	pcm1	26.98	6.82	10.30	13.33	5.99
	min	23.17	5.81	9.30	10.14	4.32
	max	34.57	7.05	10.95	18.58	7.95

B1

Decade	Model	Precip (in)	Soil water (in)	ET (in)	Streamflow (in)	Recharge (in)
2010-2019	ccsm3_0	27.35	6.74	9.98	13.66	6.00
	hadcm3	26.52	6.41	9.81	13.21	5.76
	ipsl_cm4	29.89	6.79	10.50	15.04	6.38
	miroc3_2_medres	23.83	6.26	9.87	11.04	4.81
	pcm1	28.92	6.39	10.18	14.57	6.40
2020-2029	ccsm3_0	24.64	6.19	9.27	12.68	5.45
	hadcm3	27.91	6.56	10.03	13.80	6.00
	ipsl_cm4	29.72	6.90	10.47	15.99	7.04
	miroc3_2_medres	27.10	6.69	9.99	13.71	5.86
	pcm1	30.21	6.45	9.88	16.35	6.87
2030-2039	ccsm3_0	23.83	6.26	9.49	11.06	4.78
	hadcm3	27.13	6.72	10.37	13.54	5.88
	ipsl_cm4	29.30	6.54	10.52	14.67	6.36
	miroc3_2_medres	26.64	6.67	10.20	12.79	5.55
	pcm1	28.64	6.40	9.59	15.05	6.39
2040-2049	ccsm3_0	26.51	6.45	9.92	13.34	5.71
	hadcm3	29.84	6.92	10.31	15.13	6.49
	ipsl_cm4	33.33	7.05	10.95	17.52	7.60
	miroc3_2_medres	24.98	6.59	10.33	11.43	4.96
	pcm1	29.72	6.55	9.93	15.90	6.89
2050-2059	ccsm3_0	25.65	6.61	9.78	12.36	5.25
	hadcm3	26.30	6.56	10.09	12.95	5.71
	ipsl_cm4	32.15	6.80	10.60	17.18	7.48
	miroc3_2_medres	25.22	6.90	10.74	11.83	5.19
	pcm1	27.92	6.28	9.83	14.56	6.17
	min	23.83	6.19	9.27	11.04	4.78
	max	33.33	7.05	10.95	17.52	7.60

Table 2. The Water Balance Components of the Rathdrum Prairie Basin based on the GCM-downscaled precipitation and temperature for each decade and scenario (A2, A1B and B1).

A2

Decade	Model	Precip (in)	Soil water (in)	ET (in)	Streamflow (in)	Recharge (in)
2010-2019	ccsm3_0	35.10	6.99	17.09	17.13	3.07
	hadcm3	35.47	7.32	16.18	18.59	3.57
	ipsl_cm4	37.83	7.60	16.81	20.36	3.94
	miroc3_2_medres	36.00	7.62	16.47	19.33	3.58
	pcm1	35.06	7.29	16.26	18.58	3.53
2020-2029	ccsm3_0	36.24	7.48	17.59	17.97	3.50
	hadcm3	35.91	7.17	16.53	18.46	3.38
	ipsl_cm4	35.88	7.44	17.59	17.61	3.28
	miroc3_2_medres	36.93	7.56	17.10	18.71	3.57
	pcm1	33.75	7.24	16.78	16.51	3.06
2030-2039	ccsm3_0	35.40	7.20	17.86	16.94	3.25
	hadcm3	35.90	6.78	17.27	18.17	3.29
	ipsl_cm4	34.78	7.05	17.25	17.05	3.17
	miroc3_2_medres	37.14	7.50	16.95	19.30	3.65
	pcm1	34.61	6.95	16.66	17.40	3.18
2040-2049	ccsm3_0	36.52	7.30	18.14	17.61	3.43
	hadcm3	33.08	6.69	16.25	16.22	2.75
	ipsl_cm4	39.40	7.71	17.81	20.51	3.92
	miroc3_2_medres	36.24	7.57	16.83	19.04	3.60
	pcm1	36.31	7.17	17.45	18.14	3.45
2050-2059	ccsm3_0	34.45	7.06	18.03	16.03	3.04
	hadcm3	37.85	7.35	17.15	19.92	3.68
	ipsl_cm4	37.18	7.15	18.11	18.72	3.57
	miroc3_2_medres	36.55	7.61	17.13	18.59	3.52
	pcm1	35.50	6.80	17.48	17.53	3.23
	min	33.08	6.69	16.18	16.03	2.75
	max	39.40	7.71	18.14	20.51	3.94

A1B

Decade	Model	Precip (in)	Soil water (in)	ET (in)	Streamflow (in)	Recharge (in)
2010-2019	ccsm3_0	35.12	7.38	16.65	17.91	3.38
	hadcm3	34.00	7.61	15.83	17.93	3.32
	ipsl_cm4	35.55	7.39	16.53	18.26	3.45
	miroc3_2_medres	34.82	7.33	16.56	17.41	3.12
	pcm1	36.45	7.40	17.00	18.16	3.31
2020-2029	ccsm3_0	36.71	7.05	17.38	17.97	3.40
	hadcm3	36.13	7.56	17.28	18.18	3.51
	ipsl_cm4	37.38	7.21	17.67	18.87	3.55
	miroc3_2_medres	33.90	6.85	16.64	16.99	3.09
	pcm1	32.08	6.69	15.68	16.44	2.92
2030-2039	ccsm3_0	35.78	7.41	17.42	18.26	3.46
	hadcm3	38.52	7.36	16.92	20.76	3.82
	ipsl_cm4	37.90	7.58	17.82	19.60	3.82
	miroc3_2_medres	37.97	7.66	17.84	19.29	3.69
	pcm1	32.24	6.79	16.71	15.25	2.84
2040-2049	ccsm3_0	32.99	6.70	17.51	15.07	2.76
	hadcm3	37.47	7.53	17.32	19.36	3.69
	ipsl_cm4	39.51	7.41	18.45	20.29	3.84
	miroc3_2_medres	38.75	7.48	18.13	19.70	3.85
	pcm1	33.47	7.00	17.40	15.43	2.95
2050-2059	ccsm3_0	36.67	7.09	17.57	18.17	3.29
	hadcm3	37.32	7.31	16.89	19.78	3.66
	ipsl_cm4	38.57	7.42	18.55	19.11	3.74
	miroc3_2_medres	40.36	7.90	18.29	21.00	4.30
	pcm1	35.06	6.95	17.71	16.88	3.34
	min	32.08	6.69	15.68	15.07	2.76
	max	40.36	7.90	18.55	21.00	4.30

B1

Decade	Model	Precip (in)	Soil water (in)	ET (in)	Streamflow (in)	Recharge (in)
2010-2019	ccsm3_0	36.67	7.73	16.84	19.25	3.59
	hadcm3	36.63	7.63	16.41	19.47	3.69
	ipsl_cm4	36.07	7.72	17.57	17.87	3.42
	miroc3_2_medres	35.41	7.47	16.70	18.12	3.25
	pcm1	36.74	7.33	16.95	19.12	3.58
2020-2029	ccsm3_0	33.44	6.73	15.99	17.24	3.19
	hadcm3	35.61	7.26	17.04	17.95	3.26
	ipsl_cm4	37.01	7.39	17.87	18.54	3.51
	miroc3_2_medres	37.08	7.60	17.00	19.55	3.70
	pcm1	36.18	7.14	16.85	18.73	3.38
2030-2039	ccsm3_0	34.43	6.84	17.08	16.60	3.07
	hadcm3	36.50	7.34	17.28	18.61	3.35
	ipsl_cm4	31.81	6.28	17.15	14.52	2.59
	miroc3_2_medres	37.86	7.44	17.50	19.03	3.66
	pcm1	36.26	6.92	16.96	18.32	3.35
2040-2049	ccsm3_0	36.04	7.04	17.41	18.29	3.41
	hadcm3	38.42	7.43	16.91	20.26	3.61
	ipsl_cm4	39.32	7.28	19.07	19.34	3.76
	miroc3_2_medres	37.35	7.56	17.68	18.91	3.73
	pcm1	38.39	7.44	17.56	20.21	3.92
2050-2059	ccsm3_0	34.78	7.13	16.77	17.21	3.11
	hadcm3	33.83	6.81	17.05	16.77	3.05
	ipsl_cm4	37.13	6.98	18.08	18.48	3.57
	miroc3_2_medres	39.10	7.75	18.34	20.29	4.01
	pcm1	36.90	7.00	17.37	18.79	3.51
	min	31.81	6.28	15.99	14.52	2.59
	max	39.32	7.75	19.07	20.29	4.01