GeoSystems Analysis, Inc.
Innovations in Hydrology

September 15, 2017

Steven Patten
Senior Environmental Scientist
Walla Walla Basin Watershed Council
810 S. Main
Milton-Freewater, OR 97862

RE: Walla Walla Basin Integrated Water Flow Model: Alternative Climate Scenario Water Resources Report

Dear Steven,

Please find enclosed the final report for the Walla Walla Basin Integrated Water Flow Model alternatives climate scenario water resources report. Revisions have been incorporated to address all comments on previous draft versions. Should you have any questions, please do not hesitate to give us a call.

Sincerely,

Jason Keller, R.G.
Senior Hydrogeologist

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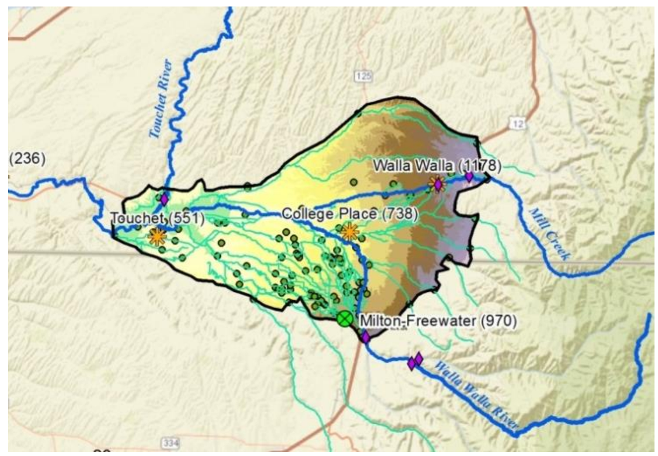

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Walla Walla Basin Integrated Water Flow Model: Alternative Climate Scenario Water Resources Report

Prepared for:
Walla Walla Basin Watershed Council
810 S. Main St.
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Walla Walla Basin Integrated Water Flow Model: Alternative Climate Scenario Water Resources Report

Citation

GeoSystems Analysis, 2017. Walla Walla Basin Integrated Water Flow Model: Alternative Climate Scenario Water Resources Report. Prepared for the Walla Walla Basin Watershed Council. Prepared by GeoSystems Analysis, Inc., Hood River, OR. September 2017.

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DOCUMENT CONTROL SUMMARY

<table>
<tr><td>Title:</td><td colspan="3">Walla Walla Basin Integrated Water Flow Model: Alternative Climate Scenario Water Resources Report</td></tr>
<tr><td>Client Company:</td><td colspan="3">Walla Walla Basin Watershed Council</td></tr>
<tr><td>Client Contact:</td><td colspan="3">Steven Patten</td></tr>
<tr><td>Contract Number:</td><td colspan="3">Task Order #3</td></tr>
<tr><td>Status:</td><td colspan="3">Final</td></tr>
<tr><td>GeoSystems Analysis Job #:</td><td colspan="3">1632</td></tr>
<tr><td>Project Manager:</td><td colspan="3">Jason Keller</td></tr>
<tr><td>Author(s):</td><td colspan="3">Jacob Scherberg, Jason Keller</td></tr>
<tr><td>Version Number:</td><td colspan="3">2</td></tr>
<tr><td>Notes:</td><td colspan="3">Summary report of predicted Walla Walla Basin water resources for Water Year 2003 and Water Year 2016 climate scenario models compared to Baseline model. All comments on previous draft version have been addressed.</td></tr>
<tr><td>Date:</td><td colspan="3">09/15/2017</td></tr>
<tr><td>Checked By:</td><td colspan="3">Jason Keller</td></tr>
<tr><td>Issued By:</td><td colspan="3">Jason Keller</td></tr>
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EXECUTIVE SUMMARY

The Walla Walla Basin Watershed Council and Walla Walla Watershed Management Partnership have initiated the Walla Walla Basin Integrated Flow Enhancement Study (Flow Enhancement Study), aiming to develop water resource management strategies to enhance stream flows in the basin while maintaining the long-term viability of water supplies for irrigated agriculture, residential, and urban use. The Flow Enhancement Study includes analysis of how future climate conditions may impact water resource availability and stream habitat conditions throughout the basin.

In support of the Flow Enhancement Study, GeoSystems Analysis, Inc. applied a calibrated surface water - groundwater finite element numerical model for the Walla Walla Basin (Basin) to evaluate the potential impacts of hypothetical climate scenarios on hydrological conditions in the Basin. The basin model utilizes the code Integrated Water Flow Model (IWFM), developed by the California Department of Water Resources Bay-Delta Office. Model scenarios were determined by assessing historic Basin climate data and selecting water years (WY) (October through September) where conditions were similar to Basin climate projections for the years 2070 through 2099. WY 2003 was determined to be the most similar to Basin climate projections and was selected to represent year round temperature increase, slightly increased precipitation that is concentrated in the winter months, an increased fraction of precipitation arriving as rain rather than snow, and typical spring and summer conditions becoming drier than present. The scenario representing WY 2003 is referred to herein as the Low Snow-Increased Temperature Scenario (LS-IT). WY 2016 was selected to inform water management planners as to how water resource availability may be altered if warmer winter temperatures lead to a greater reduction in snow pack and lower spring and summer stream flows than predicted by the Basin climate projections. The scenario representing WY 2003 is referred to herein as the Early Snow Melt-Increased Temperature Scenario (ES-IT). Climate scenario Basin model results were evaluated relative to a baseline scenario (Baseline model) representing current average climate conditions and management practices.

LS-IT and ES-IT model predicted July through October flows in the Walla Walla River and its tributaries were generally lower than in the Baseline model due to warmer spring conditions and earlier snow melt in the LS-IT and ES-IT models, relative to the Baseline model. Reduced flows were predicted from July through October for the LS-IT and ES-IT models, relative to the Baseline model, with generally greater reductions predicted at more downstream reference locations. The Baseline model predicted flows below at Beet Rd. were below the current minimum flow target, 18 cfs, for 77 days of the year increasing to 121 days of the year in the LS-IT model

and 163 days of the year in the ES-IT model. The Baseline, LS-IT and ES-IT models predicted there to be at least one dry portion of the WWR channel for 11 days, 88 days, and 132 days annually, respectively.

LS-IT model predicted groundwater storage was predicted to range from 17,000 to 26,000 acre-ft less than in the Baseline model, approximately a 0.4 percent decline. ES-IT model predicted groundwater storage was predicted to range from 96,000 to 114,000 acre-ft less than in the Baseline model, a decline of approximately 2.5 percent.

LS-IT model predicted groundwater elevation was predicted to be within two feet of the Baseline model predicted groundwater elevation for the majority of the model area; however, groundwater elevation declines of up to 12 feet were predicted within subregion six, representing portions of the Gardena Farms and Hudson Bay District Improvement Company irrigation districts. The ES-IT model predicted much broader declines in groundwater elevation, with predicted groundwater elevations up to 14 feet lower than the Baseline model in subregion six and the eastern portion of the model area. Reduced groundwater elevations resulted in reduced summer time groundwater discharge into surface streams being predicted relative to the Baseline model.

Reduced surface water available for irrigation during the summer months resulted in increased groundwater pumping of 0.13 and 0.18 acre-ft/acre/yr predicted for LS-IT and ES-IT, respectively; 20 and 28 percent above Baseline model levels. The LS-IT model predicted increased groundwater pumping in areas already reliant on groundwater for summer irrigation, such as Gardena Farms and Lowden. The ES-IT model also predicted increased pumping for areas currently reliant on groundwater for summer irrigation, but also predicted increases in the Walla Walla River Irrigation District and Hudson Bay District Improvement Company irrigation district areas where reduced stream and canal flows left shortages of surface water deliveries for irrigation. Additionally, the reduced availability of surface water was compounded by increased LS-IT and ES-IT model predicted agricultural water demand through the summer due to warmer conditions.

Model results indicate that warmer winter and earlier snowmelt conditions will result in greater reliance on groundwater and increased difficulties in meeting target Walla Walla River flows over summer months and into the fall. It’s important to note that long-term climate conditions will have annual variations that include wetter than average and drier than average WYs, which will influence hydrologic conditions in the Basin. Nonetheless, model results serve as a basis to evaluate water management strategies to meet water resource needs under potential future climate conditions.

1.0 INTRODUCTION

The Walla Walla Basin (Basin) is located in a semi-arid region of Eastern Washington and Oregon (Figure 1), receiving an average of 17 inches of annual rainfall, primarily over the winter and spring months. The basin is heavily agricultural, with farms generating water demand that strains the viability of fish habitat due to low flows and high temperatures in the Walla Walla River (WWR) over the summer months (Mendel et al., 2005). This has led to the listing of steelhead and bull trout populations native to the Basin on the federal list of endangered species. An agreement between local irrigation districts and federal and state regulators in 2000 established a minimum flow of 25 cubic feet per second (cfs) in the Walla Walla River below the outtake for the Little Walla Walla canal and 18 cfs below the Gardena Canal outtake, with the objective of promoting viable habitat for endangered fisheries (Mahoney et al., 2011). In spite of this, flows below 10 cfs have been recorded at gauges downstream of these locations.

The Walla Walla Basin Watershed Council (WWBWC) and Walla Walla Watershed Management Partnership have initiated the Walla Walla Basin Integrated Flow Enhancement Study (Flow Enhancement Study), aiming to develop water resource management strategies to enhance stream flows in the basin while maintaining the long-term viability of water supplies for irrigated agriculture, residential, and urban use. The Flow Enhancement Study includes analysis of how future climate conditions may impact water resource availability and stream habitat conditions throughout the basin.

In support of the Flow Enhancement Study, GeoSystems Analysis, Inc. (GSA), in a collaborative effort with the WWBWC, developed a calibrated surface water - groundwater numerical finite element model for the Basin using the code Integrated Water Flow Model (IWFM), developed by the California Department of Water Resources Bay-Delta Office (Dogrul 2013). The Basin model was developed using data from numerous sources to define basin geology, precipitation, groundwater and surface water conditions, land use classification, agricultural and urban water demand, and soil properties. The model has been applied as a tool for evaluating the potential impacts of alternative climate scenarios on hydrological conditions in the basin. The model boundary was defined by the areal extent of the alluvial basin deposits and encompasses the land surface and five sedimentary geologic units that overlay the Columbia River Basalt formation within the Walla Walla Basin (Lindsey 2007). Overall, the model encompasses 239 mi^2 and extends to a maximum depth of 940 ft below ground surface. The model area was divided into 12 subregions based on physical characteristics or management entities, allowing for focused evaluation of water use and available resources for a subregion. The model subregions are each assigned a name and number for reference purposes, presented in Table 1. A detailed description of the Walla Walla Basin model, including model development and calibration, is provided in GSA (2015).

This report presents model predicted surface water and groundwater conditions in the Basin for two scenarios devised to represent hypothetical future climate conditions. Model applied climate conditions were determined by assessing historic data and selecting years where conditions were similar to Basin climate projections for the years 2070 through 2099 published by the University of Washington Climate Impact Group (UWCIG) (Hamlet et. al, 2010). The use of analog years for evaluating future conditions is well established in climate research (e.g. Sproles et al., 2017; Ramirez-Villegas et al. 2011). For example, Sproles et al. (2017) investigated the impact of reduced snow pack conditions in the McKenzie River Basin using below average snow pack water years (WY) (October through September) 2014 and 2015. Sproles et al. (2017) concluded that a shift in the elevation dependent relationship between snow fall and rain fall is likely to occur in the future. Ramirez-Villegas et al. (2011) developed a climate analog tool to inform climate change adaptation strategies. The climate analog tool was applied to evaluate projected climate change conditions and identify analog sites to be used for planning future agricultural development.

Alternative climate scenario Basin model results were evaluated relative to a baseline scenario (Baseline model) representing current average climate conditions and management practices (GSA 2015). The scenarios are designed to evaluate the impact of alternative climate conditions on groundwater levels and flow in the WWR and its tributaries. The selection of analog years to represent alternative climate scenarios is presented in Section 2.0. A description of alternative climate scenario model development is provided in Section 3.0. A comparative review of alternative climate scenarios predicted influence on surface water flows and groundwater storage relative to Baseline model conditions is provided in Section 4.0., followed by conclusions in Section 5.0.

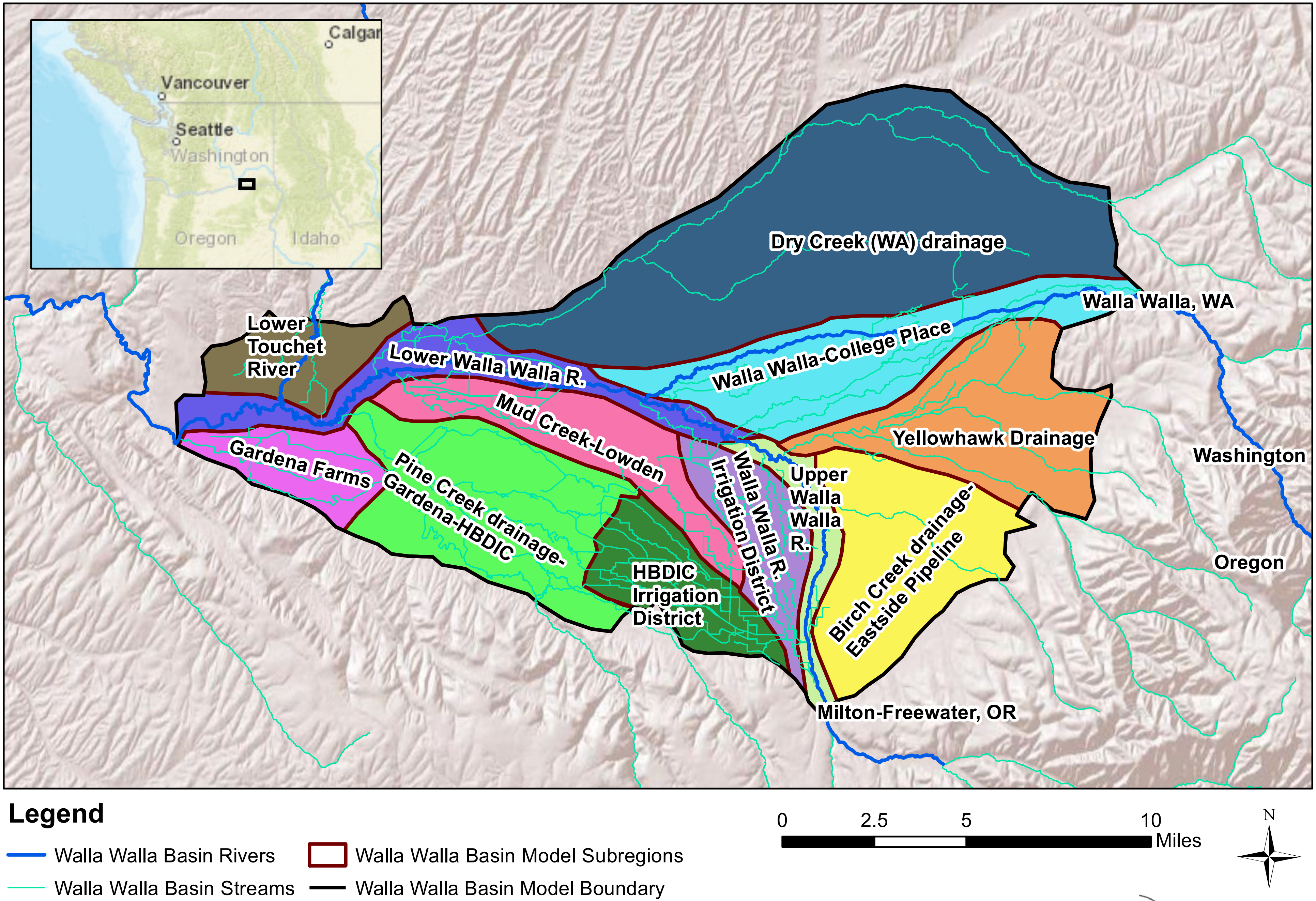


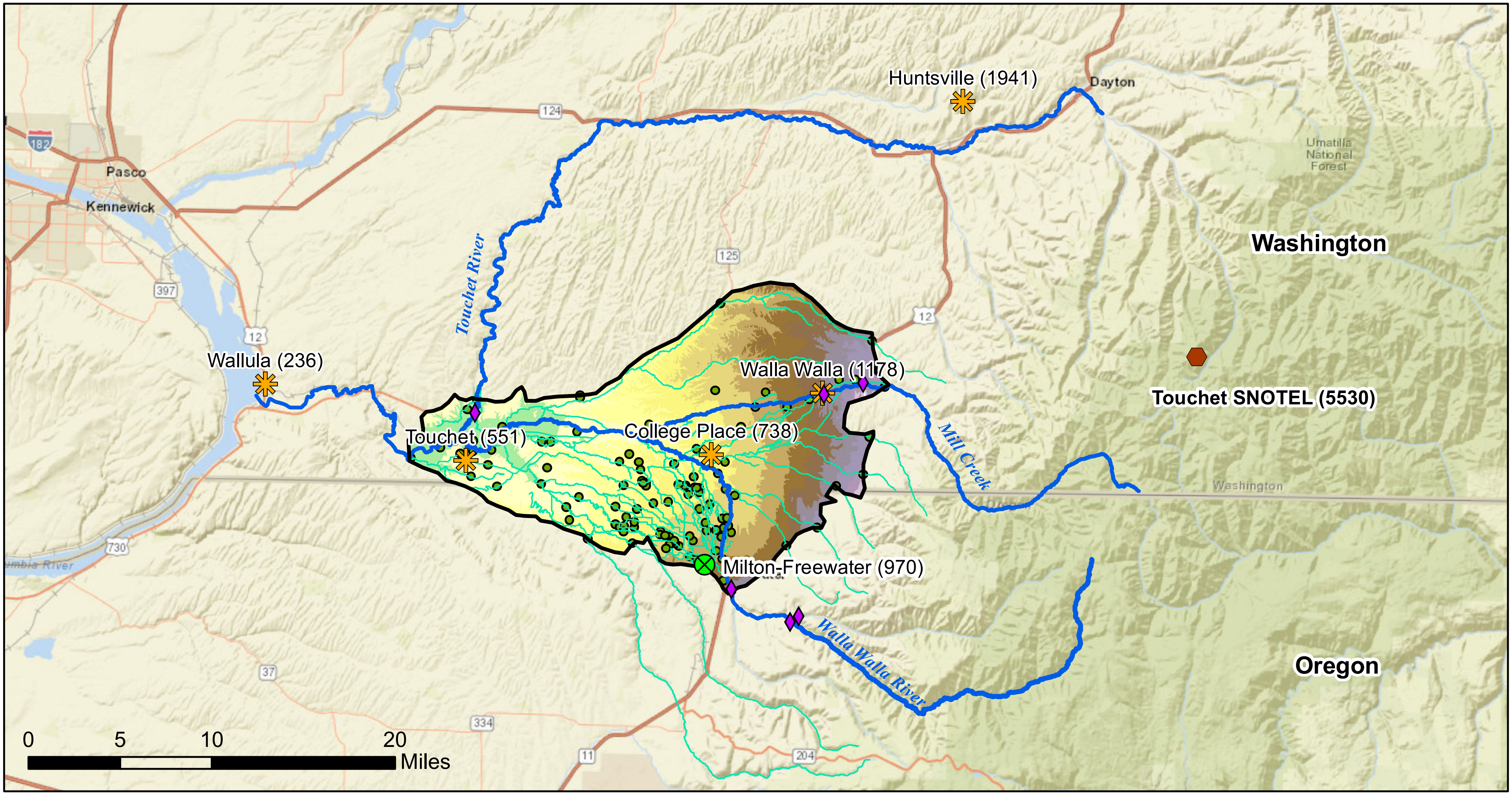
Figure 1. Walla Walla Basin model location and model subregion boundaries

Table 1. Walla Walla Basin model subregions

Subregion Number	Name
1	Upper Walla Walla River
2	Lower Walla Walla River
3	Birch Creek Drainage-Eastside Pipeline
4	Walla Walla River Irrigation District
5	HBDIC Irrigation District
6	Pine Creek Drainage-Gardena-HBDIC
7	Mud Creek-Lowden
8	Yellowhawk Creek Drainage
9	Walla Walla-College Place
10	Dry Creek (WA) Drainage
11	Gardena Farms
12	Lower Touchet River

2.0 ANALOG CLIMATE AND STREAMFLOW

Historic stream flow, precipitation, temperature, and snow water equivalent (SWE) data was obtained from gauges and weather stations within or near the Basin model area (Figure 2). These data sets were compiled by monthly average and by water year (WY). Each gauge was assessed with consideration for location relative to the model area, time span of data set, and completeness of data set (number of missing days). Groundwater elevation data was obtained from the WWBWC monitoring network (WWBWC 2015b) and interpolated over the model area. Groundwater monitoring locations are included in Figure 2. SWE data was not directly input into the model; however it was evaluated to assess the relationship between stream flow observations and annual cycles of snow accumulation and melting.



Legend

- Walla Walla Basin Model Boundary
- Walla Walla Basin Rivers
- Walla Walla Basin Streams
- Surface Water Gauges
- Groundwater Monitoring Locations
- Utah Climate Center Milton-Freewater monitoring location (elevation in ft amsl)
- NRCS Touchet SNOTEL (elevation in amsl)
- Ag-Weather Net stations (elevation in ft amsl)

Elevation (ft amsl)

397 - 400	701 - 800	1,201 - 1,300
401 - 500	801 - 900	1,301 - 1,400
501 - 600	901 - 1,000	1,401 - 1,500
601 - 700	1,001 - 1,100	1,501 - 1,600
	1,101 - 1,200	1,601 - 1,700

N

Figure 2. Monitoring locations used to determine model input climate and boundary conditions

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To simplify data assessment the water year data was then divided into quarterly (three month) periods as follows; Q1: October through December; Q2: January through March; Q3: April through June; Q4: July through September. Annual and quarterly data was compared to gauge averages to determine the relative magnitude of stream flow, precipitation, and temperature for each year where data was available.

2.1.1 Stream Flow Data

Stream flow data was obtained from the United States Geological Survey (USGS) gauge on the Walla Walla River near Touchet, Washington (USGS 14018500) (Figure 2). This gauge was selected because it is located near the outflow of the Basin model and therefore represents the sum of upstream inflows and withdrawals. This gauge also has a relatively complete data set spanning back to 1951. Monthly and quarterly average flows were calculated and assessed with regard to annual and quarterly flow variability. Data from the USGS WWR gauge near Touchet, Washington is included in Appendix A.

2.1.2 Precipitation Data

Precipitation data was collected and evaluated from eight different measurement stations within the Basin model area. Of the eight measurement stations, the Utah Climate Center (UCC, 2016) data set for Milton-Freewater, Oregon (USC00355593) was selected for detailed analysis of meteorological data because of its length of record (1928 to present); however there were several years since 2004 with one or more months missing five or more days of data. In these instances, missing data was estimated using a regression equation derived from precipitation measured at Milton-Freewater versus the Ag-Weather Net station at College Place, Washington (Figure 3), approximately 9 miles north of Milton-Freewater (Figure 2).

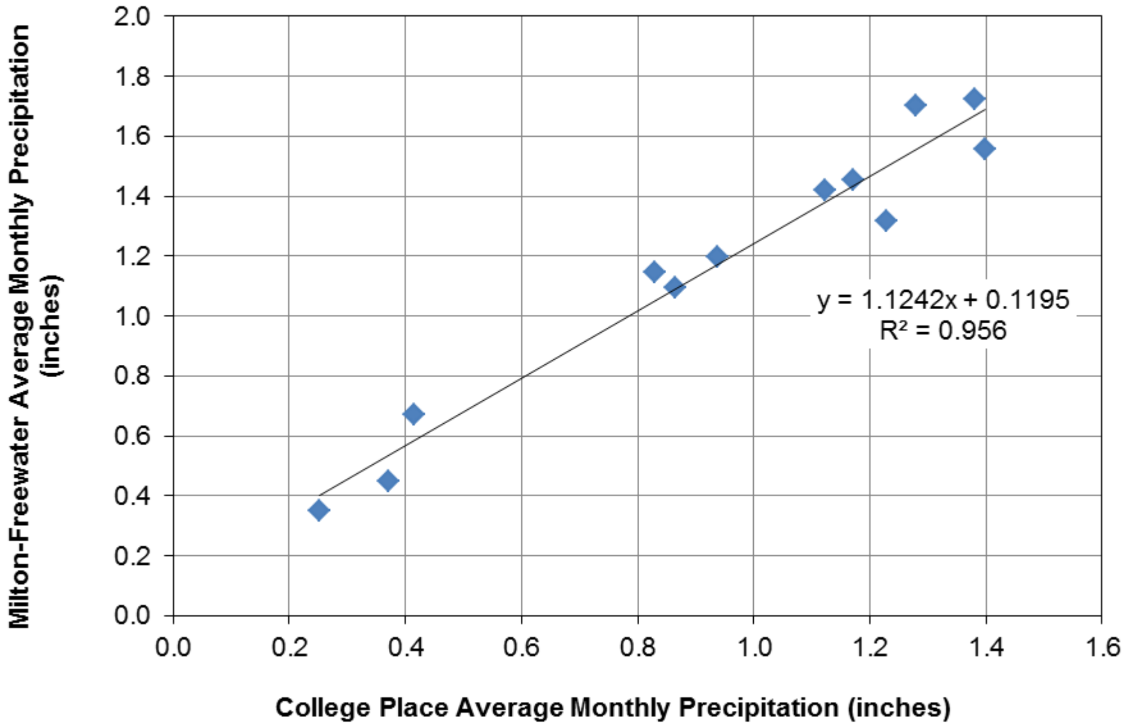

Figure 3. Regression analysis of monthly average precipitation data for Milton-Freewater, OR (1928-2016) vs. College Place WA (1992-2016).

2.1.3 Temperature Data

Temperature data was collected and evaluated from seven different measurement stations within the Basin model area. As with the precipitation data set, the Utah Climate Center data set for Milton-Freewater, Oregon was selected for detailed analysis because it had the longest data set available. Dates with no data from the Milton-Freewater gauge were estimated using a regression equation for Milton-Freewater station measured temperature versus College Place, Washington Ag-Weather Net station measured temperature (Figure 4).

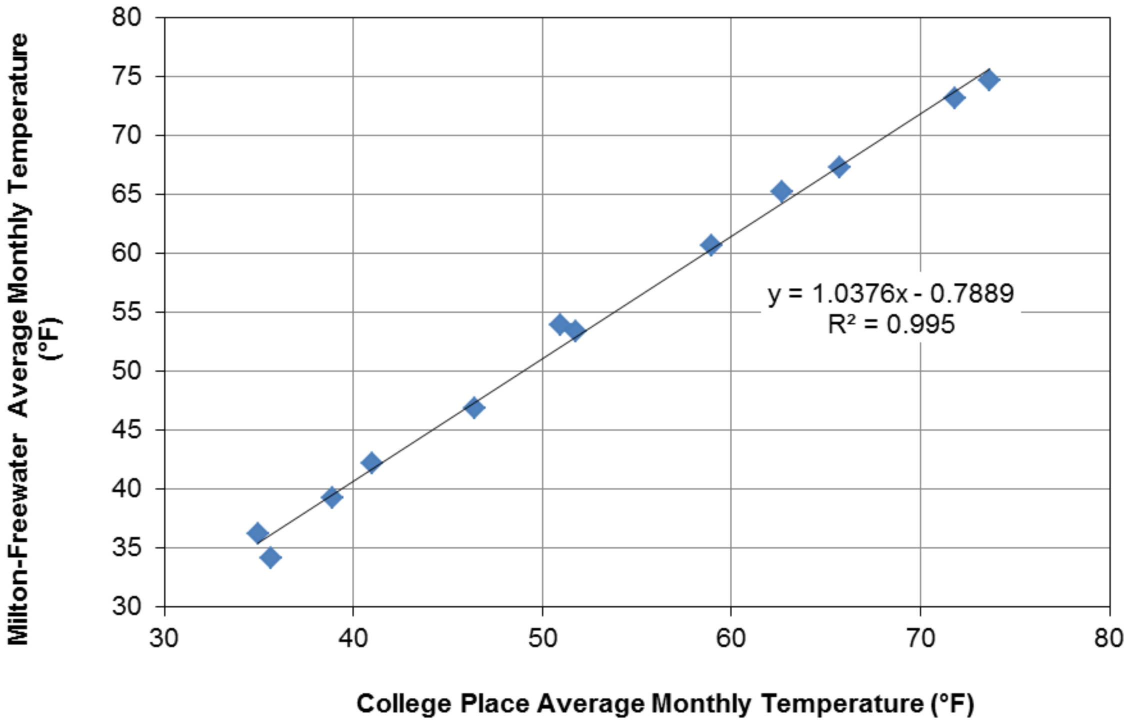

Figure 4. Regression analysis of monthly average temperature for Milton-Freewater, OR (1928-2016) vs. College Place WA (1992-2016).

2.2 Projected Climate Data

The Columbia Basin Climate Change Scenarios Project" (CBCCSP) (Hamlet et al., 2010) was used as a basis for creating model scenarios reflecting hypothetical future climate conditions. The CBCCSP developed predictions for future emissions scenarios from gridded historic meteorological data (e.g. precipitation, temperature, and wind speed) over the Pacific Northwestern United States for the period from 1915 through 2006 into 20 global climate models (GCM) (Hamlet et al. 2010). The 10 best GCM's were selected based on their simulation of historic conditions and used to generate predicted future climate conditions under two future emissions scenarios referred to as A1B and B1 (Mote and Salathe, 2010). The A1B scenario assumes increasing global population and widespread economic growth peaking in the mid-21st century. The A1B scenario predicts radiative forcing increasing approximately 200 percent between 2020 and 2100 (Mote and Salathe, 2010). In the A1B scenario greenhouse gas emissions are predicted to increase despite the introduction of more energy efficient technologies as global differences in regional per capita income and development are reduced (IPCC 2000). The B1 scenario assumes the same global population as the A1B scenario but development that emphasizes a service and information economy with decreased material consumption. The B1 scenario predicts radiative forcing increasing approximately 100 percent between 2020 and 2100 (Mote and Salathe, 2010) despite the adoption of more resource efficient technologies reducing annual greenhouse gas emissions below present levels by 2060 (IPCC 2000). A statistical downscaling approach was applied to the GCM results to generate hypothetical weather conditions based on model outputs for the A1B and B1 emissions scenarios (Hamlet et al. 2010).

The alternative climate conditions were then applied into the Variable Infiltration Capacity (VIC) model to generate associated hydrological parameters such as SWE, reference evapotranspiration (ETo), and surface flows (computed as runoff plus baseflow) (Hamlet et al. 2010). Results were compiled as a composite average for the 10 GCM's for three 30 year periods, 2010-2039, 2030-2059, 2070-2099.

The composite assessment of model results for the Pacific Northwest is that the climate will become warmer in the coming century and that annual precipitation will increase slightly, with more rainfall in the winter and less in the summer (http://warm.atmos.washington.edu/2860/scenarios/).

2.3 Selection of Analog Years

Historic stream flow, precipitation, and temperature data were considered in the selection of analog WYs to represent hypothetical future climate conditions. Temperature is not a direct model input, however it was considered in the selection of analog years because streamflow and ETo, which are model inputs, directly reflect air temperature through the rate and timing of snow melt and timing and magnitude of agricultural water demand, respectively.

Annual precipitation, mean temperature, and mean flow data from the selected gauges was reviewed for WYs 1980 through 2016. Years prior to 1980 were not considered due to lack of historic groundwater elevation data necessary to develop model boundary conditions. An initial review identified WYs 2003, 2009, 2010, 2015, and 2016 as analog WYs that most closely resembled the annual precipitation, temperature, and streamflow trends reported in the CBCCSP. These WYs were then further assessed in terms of quarterly variation from mean conditions. These results were compared to the quarterly variations predicted in the CBCCSP A1B and B1 scenarios. A summary of collected and compiled stream flow and climate data for the WWB is provided in Appendices A and B, respectively.

Figure 5 shows the quarterly average mean daily flow for the WWR at Touchet, WA and the percent variation from the mean flow at this location for the selected WYs and for the two CBCCSP scenarios compared to the historic data set compiled for running the CBCCSP models. The historic data set consists of 1915 through 2003 daily data from the National Climatic Data Center (NCDC) Cooperative Observer (COOP) network and Environment Canada (EC) stations in the Columbia Basin compiled and processed and re-gridded using methods described in Hamlet et al. (2010).

The CBCCSP model scenarios both predict moderately above average flows for the first two quarters of the WY, slightly below average in the third quarter and approximately average in the fourth quarter. There is little variation in predicted flow between the A1B and B1 scenarios. The WY 2003 quarterly average flows for the last three quarters of the WY were similar to the A1B and B1 scenario predictions in variation from mean and trend (Figure 5). Flow in the first quarter of WY 2003, however, was more than 50 percent lower than the average WY whereas the CIG A1B and B1 scenarios predicted 26 and 20 percent above average flows, respectively. None of the other WYs matched the CBCCSP predictions for variation from mean flow, with WY 2016 being the closest based on the second and fourth quarters of the WY. WY 2009 was also comparable in variation from the mean for the second and fourth quarters but was 133 percent above average flow in the third quarter compared to 11 percent below average predicted flows in the two CIG scenarios.

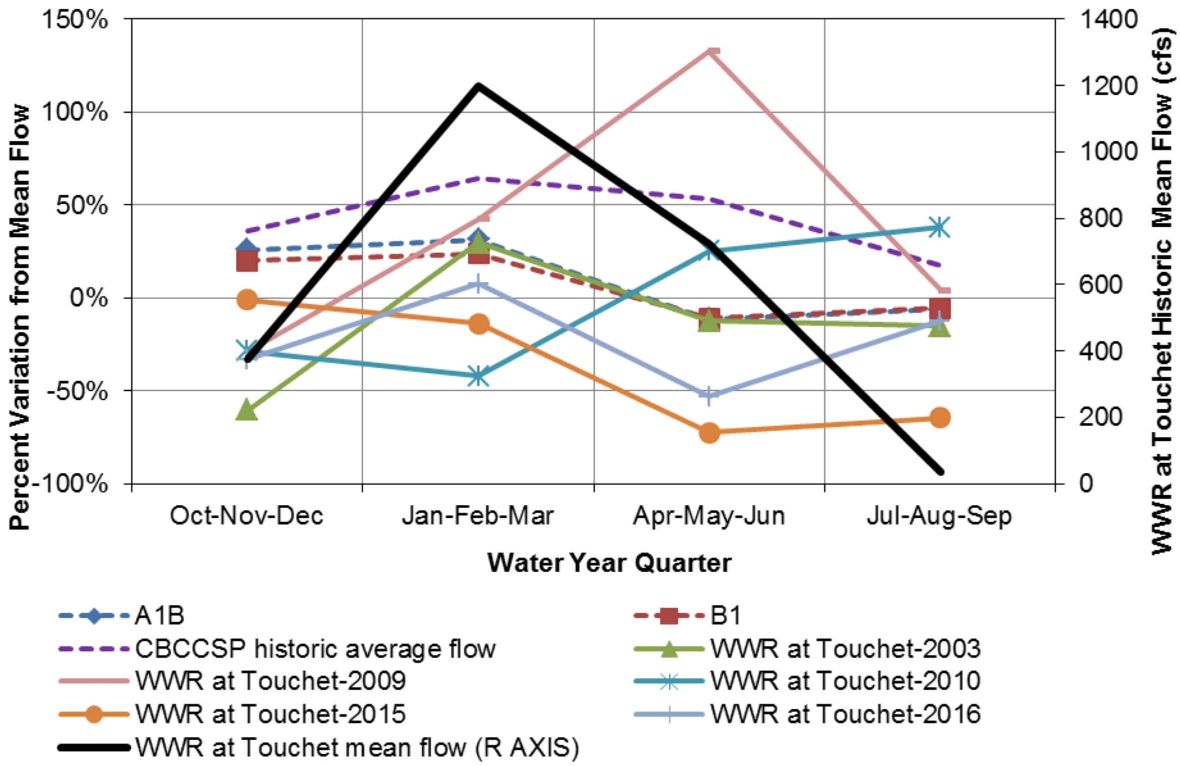

Figure 5. Mean quarterly flow for the Walla Walla River at Touchet, WA, and percent variation from the mean flow for select WYs and CBCCSP A1B and B1 climate scenarios

Figure 6 shows mean quarterly precipitation measured at Milton-Freewater, OR and the variation from the mean for the selected WYs as well as the percent variation from mean precipitation predicted by the AIB and B1 emission scenarios as compared to the CBCCSP historic data set.

Though none of the selected analog years were an exact match for these trends, WY 2003 and WY 2009 were the closest to the CBCCSP predictions. The variation from mean precipitation for WY 2003 was approximately 20 percent below the CBCCSP model predictions for the first, third and fourth WY quarters and 24 and 31 percent above the predicted variation for the second quarter in the CBCCSP A1B and B1 scenarios, respectively. The variation from mean precipitation for WY 2009 ranged from zero to nine percent below the CBCCSP model predictions for the first, third and fourth WY quarters and was 32 and 39 percent above the predicted variation for the second quarter in the CBCCSP A1B and B1 scenarios, respectively. WY 2016 had similar trends in the first two quarters of the WY before falling 49 percent below mean precipitation in the third quarter as compared to approximately average precipitation predicted in the two CBCCSP scenarios.

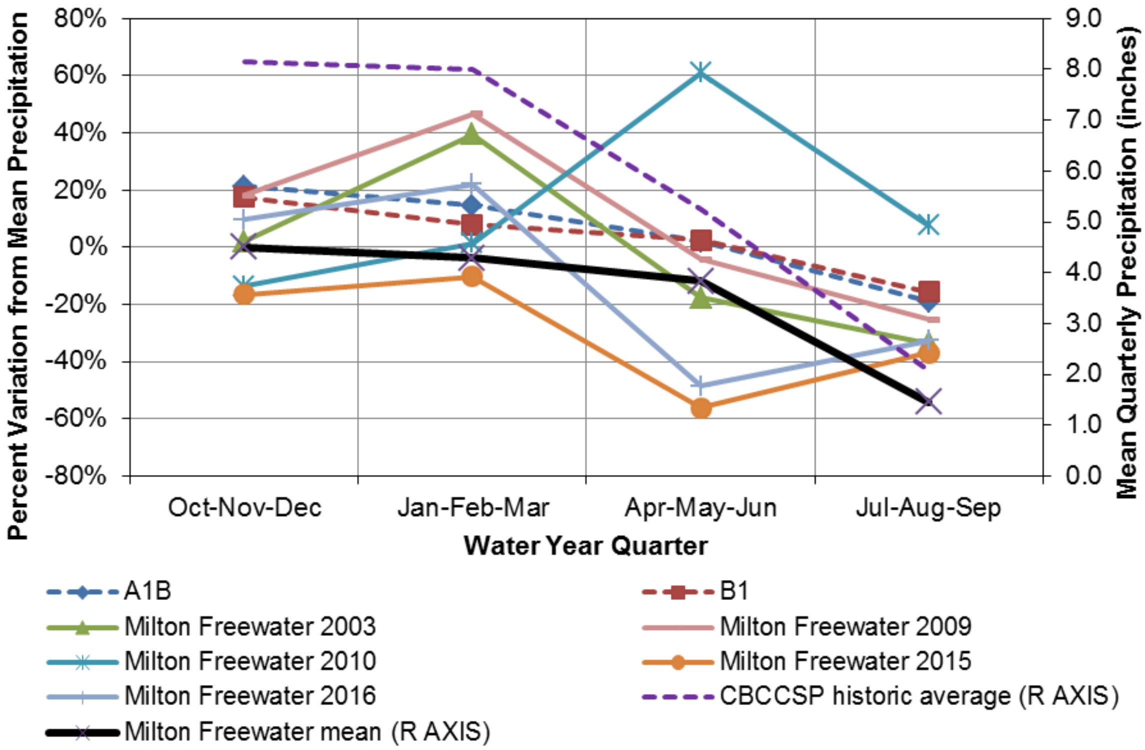

Figure 6. Mean Milton-Freewater, OR, and basin wide precipitation and percent variation from the mean for select WYs and CBCCSP A1B and B1 climate scenarios

Figure 7 shows the quarterly mean temperature for Milton-Freewater, OR, and the basin wide average temperature from the CBCCSP historic data set, along with the net variation from mean for the selected WYs and the CBCCSP A1B and B1 scenarios. Average quarterly temperatures for the two CBCCSP scenarios ranged from 0.3 to 3.1 degrees higher than the basin wide historic average. The closest match among the selected WYs was WY 2003, for which the variation from average temperature was similar to the CIG scenario predictions in the first and third quarters, though second and fourth quarter average variation from mean temperature was significantly warmer than predicted in either CBCCSP scenario (Figure 7). Among the other WYs, WY 2010 was similar to the CBCCSP scenarios for the second and fourth quarters but several degrees cooler for the first and third quarters. WY 2016 was within 1.6 degrees of the predicted variation from mean temperature for the CBCCSP A1B and B1 scenarios for the first, second, and fourth quarters, though the difference was greater than three degrees in the third quarter. In all but the fourth quarter, WY 2016 temperatures were greater compared to mean than was predicted by either CBCCSP scenario.

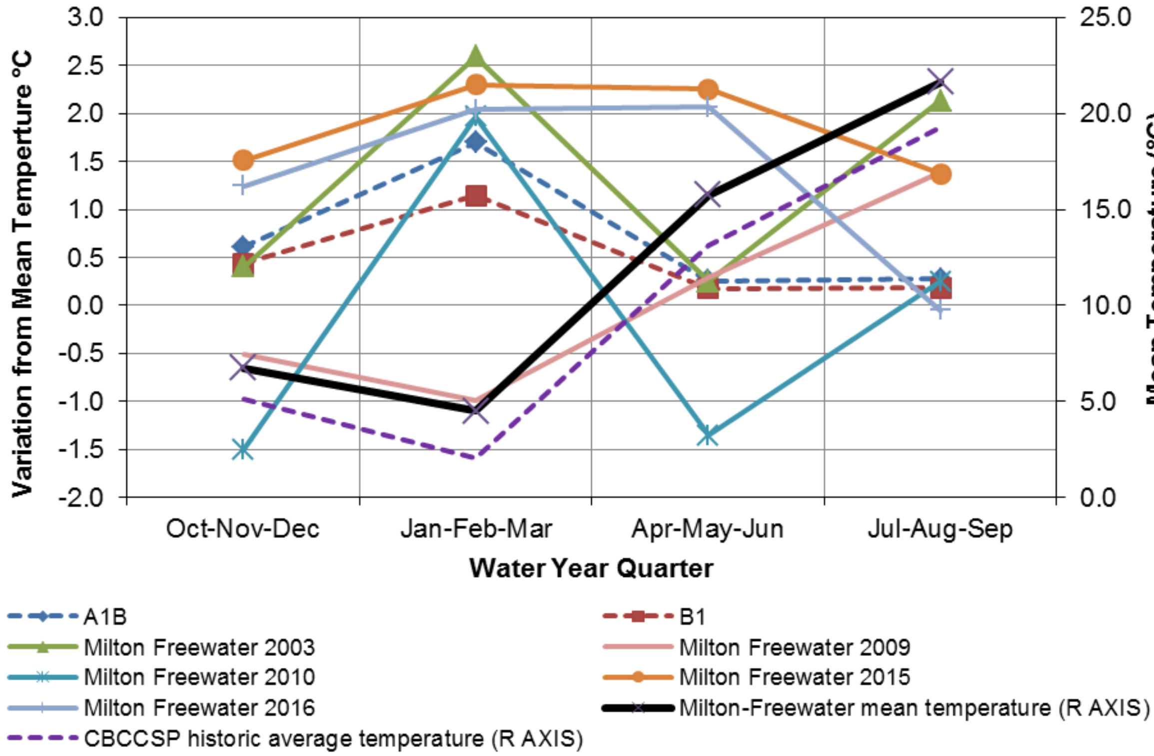

Figure 7. Mean quarterly Milton-Freewater, OR, and basin wide temperature and percent variation from the mean temperature for select WYs and CBCCSP A1B and B1 climate scenarios

SWE is not a direct input into the model, however it is indirectly incorporated through surface water and groundwater boundary conditions and was therefore included in the data analysis used to select analog WYs to represent alternative climate scenarios. There are two snow telemetry (SNOTEL) sites within the WWB, Milk Shakes (17D20S) and Touchet #2 (17C05S). The Touchet SNOTEL, shown in Figure 2, had a 35 year data record whereas the Milk Shakes SNOTEL had a 10 year data record. The Milk Shakes SNOTEL site is location 5,580 feet above mean sea level (amsl) and the Touchet #2 SNOTEL is located 5,530 feet amsl. The Touchet #2 station was selected for this analysis because of its longer available data record. Figure 8 shows monthly average SWE for WY 2003, WY 2016, the Baseline model period (2007-2013), and the period of record for the Touchet SNOTEL (1980-2016). The Baseline model SWE is similar to the measured average, with the greatest variation occurring in May where the Baseline model is 3.2 inches greater than the average over the entire SNOTEL data set. SWE in WY 2003 is 6.2 inches (66 percent) below average in December and 7.0 and 10.4 (41 percent and 44 percent) below average, respectively for the following two months. The peak WY 2003 SWE in April is 1.5 inches (18 percent) below the data period measured average. WY 2003 SWE in May exceeded the historic average by 2.6 inches (20 percent) before melting away entirely in June. WY 2016 had approximately average SWE from November through April, ranging from 83 to 111 percent of the average for the period of record. Warm conditions in May rapidly melted the snow pack, resulting in the mean SWE for May being 10.6 inches (80 percent) below average and the snow being entirely melted by June.

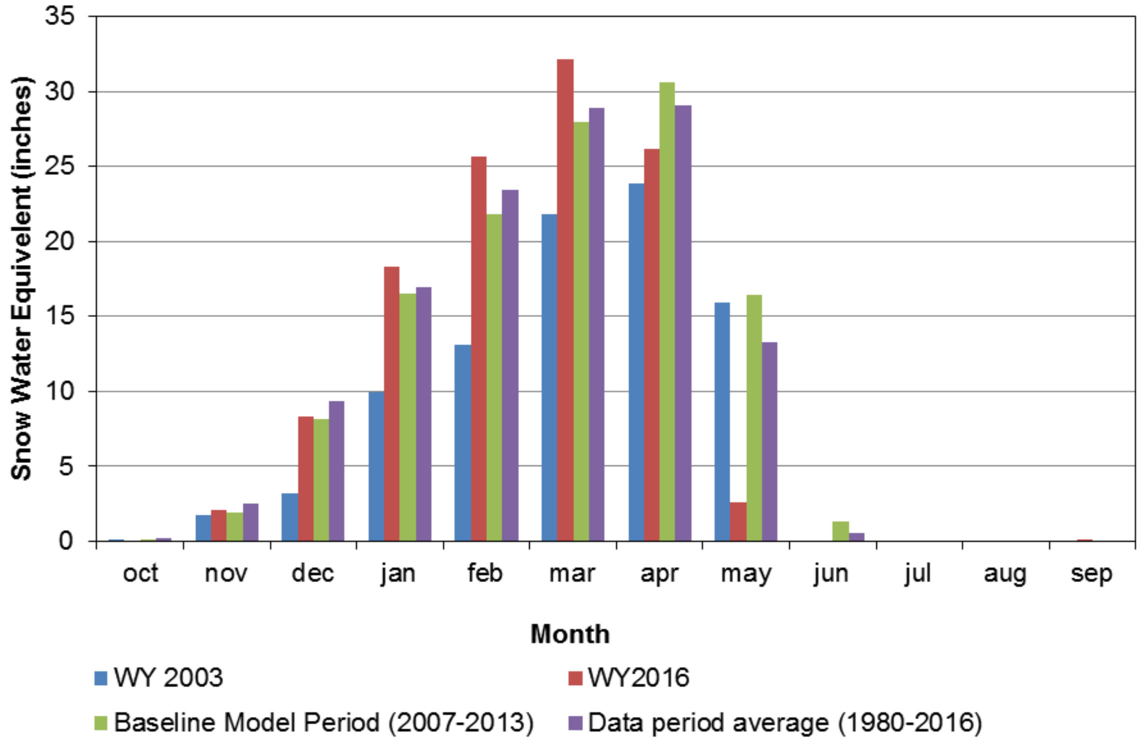

Figure 8. Snow water equivalent at the Touchet #2 SNOTEL site

Given that no WY was a perfect match to the CBCCSP A1B and B1 model scenario predictions, the data for the selected WYs was considered with equal weight given to quarterly stream flow, precipitation, and temperature data. On the whole, WY 2003 was determined to be the most similar to CBCCSP scenarios in terms of the quarterly variation from mean. The model scenario representing WY 2003 is referred to herein as the Low Snow-Increased Temperature (LS-IT) scenario. Because the two CBCCSP scenarios were more similar to each other than they were to any WY, WY 2016 was selected to represent year round temperature increase with precipitation concentrated in the winter months, an increased fraction arriving as rain rather than snow, and typical spring and summer conditions becoming drier than present (Hamlet et al., 2013; Elsner et al., 2010). Such conditions could alter both stream habitat and agricultural practices if they become prevalent in the Pacific Northwest and are therefore useful to study in the interest of contingency planning on the part of water managers. The model scenario representing WY 2016 is referred to herein as the Early Snow Melt-Increased Temperature (ES-IT) scenario.

In summary, WY 2003 was selected because it was the closest to the conditions predicted by the two CBCCSP scenarios and was developed into the LS-IT scenario. WY 2016 was developed into the ES-IT scenario, selected to inform water management planners as to how water resource availability may be altered if warmer winter temperatures lead to a greater reduction in snow pack and lower spring and summer stream flows than predicted in the CBCCSP study. It's important to note that long-term climate conditions will have annual variations that include wetter than average and drier than average WYs, which will influence hydrologic conditions in the Basin. However, analyzing single WYs allows for direct comparison between current and hypothetical climate conditions.

3.0 MODEL DEVELOPMENT

3.1 Baseline Model

The Baseline model developed for aquifer recharge and canal piping analysis (GSA, 2016) was used to predict baseline conditions. This model was developed using climate data, groundwater and surface water boundary conditions, and agricultural and urban water use for the years 2007 through 2013. All model inputs were averaged for each day of the year and input as a repeating annual cycle, representing current climate conditions, water management, and water use practices. Full details of Baseline model development and results are provided in GSA (2016) and the complete set of Baseline model input files is provided in Appendix C.

3.2 Alternative Climate Scenarios

Daily data from WY 2003 and WY 2016 was collected and processed to develop model inputs for surface water inflows, precipitation, crop evapotranspiration, and groundwater inflows in the LS-IT and ES-IT scenarios, respectively. Complete input files for the LS-IT and ES-IT models are provided in Appendix D and Appendix E.

3.2.1 Stream Flow Boundary Conditions

Surface water boundary conditions were defined by the flow rate of streams where they intersect the model boundary. There are 13 total inflowing rivers and streams, with the primary surface inflows being the WWR, the Touchet River, and Mill Creek (Figure 2).

Historic daily flow data was available for the WWR, the Touchet River, and Mill Creek; however, daily flow data was not available for the remaining ten streams that flow into the model and therefore had to be estimated. Inflows for these streams were estimated using regression analysis to estimate flows based on historic flow data for the Touchet River. The Touchet River was selected for estimating stream inflows because it provided better correlations to available data from Dry Creek (OR), Dry Creek (WA) and Pine Creek than did the WWR or Mill Creek. Details for estimating stream inflows are provided in GSA (2015).

The Grove School Bridge gauge, near Milton-Freewater, Oregon, is maintained by the WWBWC (S-105) and located on the WWR, just inside of the model boundary (WWBWC 2015a). This gauge was used to determine WWR inflows into the model domain. ES-IT model inflow data was applied directly from the Grove School Bridge gauge. For LS-IT the rating table for the Grove School Bridge gauge was not well established and there were long periods of missing data (personal communication, WWBWC). Instead, a regression equation relating combined measured flow on the North and South Fork Walla Walla River (Oregon Water Resources Department gauges 14010800 and 14010000) to Grove School Bridge flow rates was developed (Figure 9) and applied to estimated LS-IT inflow.

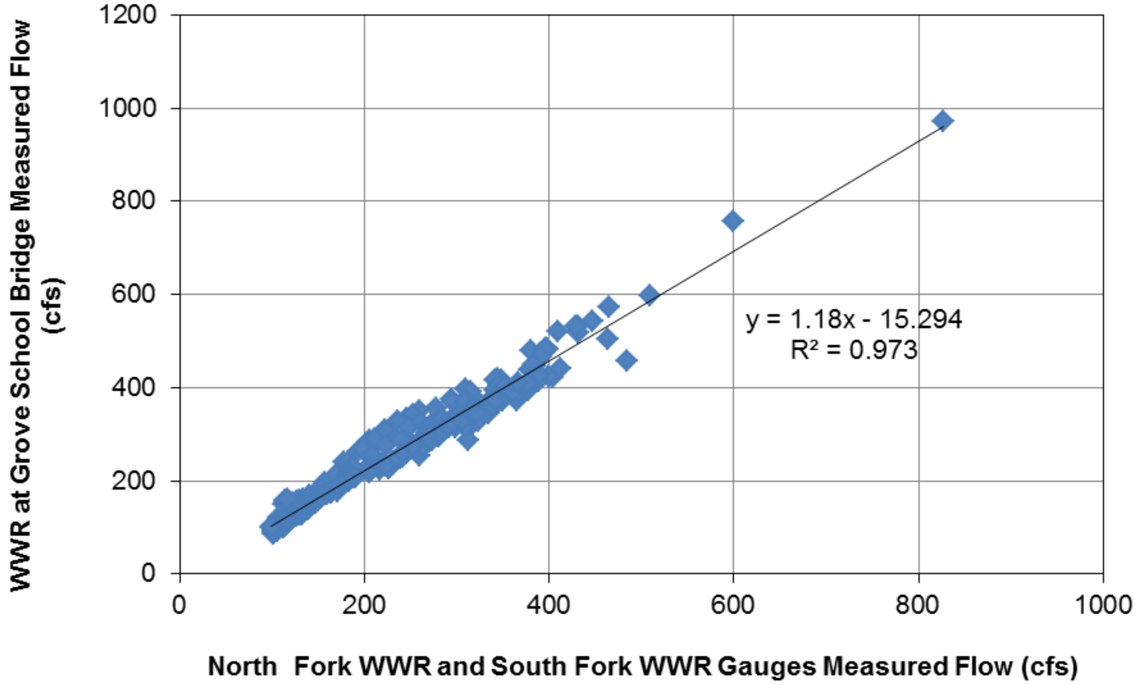

Figure 9. Regression relationships between Grove School Bridge gauge measured and combined North Fork and South Fork Walla Walla River gauges measured flow

Touchet River model inflows for WYs 2003 and 2016 were obtained from the Washington Department of Ecology gauge on the Touchet River at Cummins Road (32B075 and applied directly into the model.

Mill Creek model inflows for WYs 2003 and 2016 were primarily obtained from the USGS gauge at Five Mile Road (14013700). For dates where data was unavailable, data from the USGS Mill Creek gauge at Walla Walla (14015000) was used after applying a regression equation developed to relate Mill Creek gauge measured flows to the Five Mile Road gauge flow measurements (Figure 10).

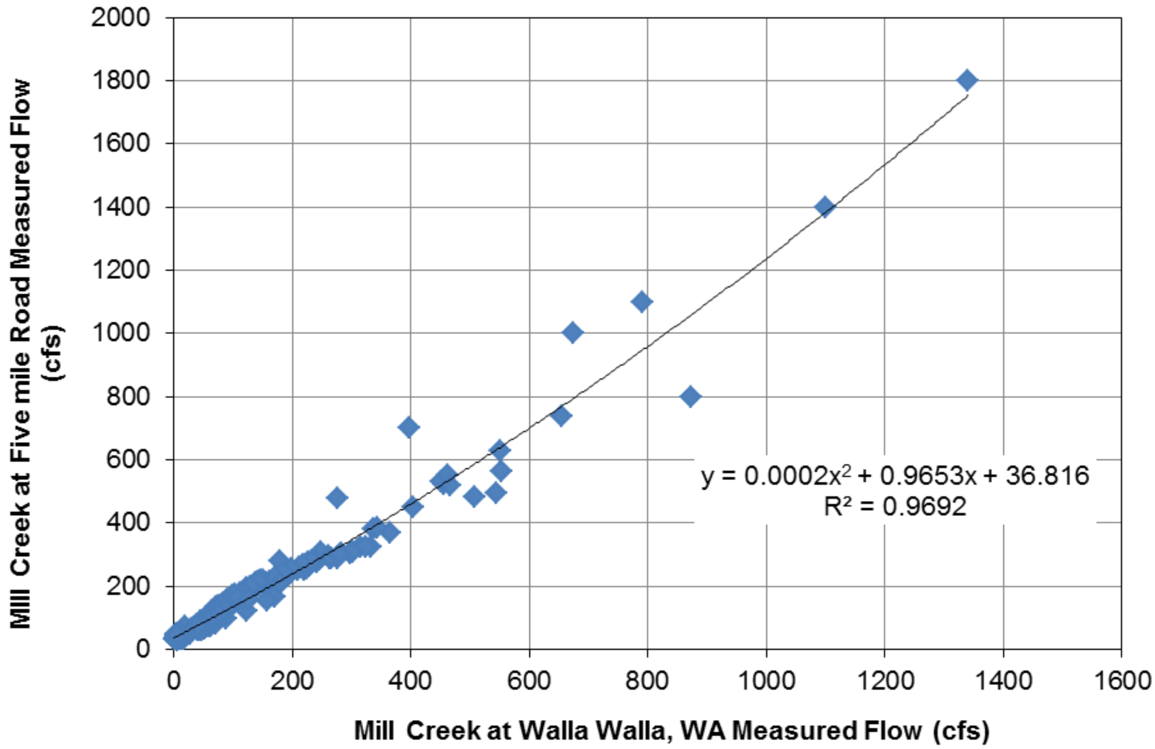

Figure 10. Regression relationship between Mill Creek Five Mile gauge measured and Walla Walla gauge measured flow

Figure 11 through Figure 13 show LS-IT, ES-IT, and Baseline model mean monthly flows entering the model domain for the WWR, Touchet River, and Mill Creek, respectively. The complete model inflow data set is provided in Appendix F. The relative trends for the scenarios were similar for the three rivers. July through November model inflow rates were similar for LS-IT, ES-IT, and Baseline models. December model inflows for the LS-IT model were less than the Baseline model due to reduced precipitation in WY 2003. December model inflows for the ES-IT model were greater than the Baseline model due to WY 2016 having greater precipitation and warmer conditions, causing precipitation to arrive primarily as rainfall as opposed to snow. Warmer winter conditions in the WY 2003 and WY 2016 resulted in early snow melt and greater model inflows in the LS-IT and ES-IT models than the Baseline model in February and March. As a result of the early snow melt, LS-IT and ES-IT model inflows were less than the Baseline model for April through June (Figure 11, Figure 12).

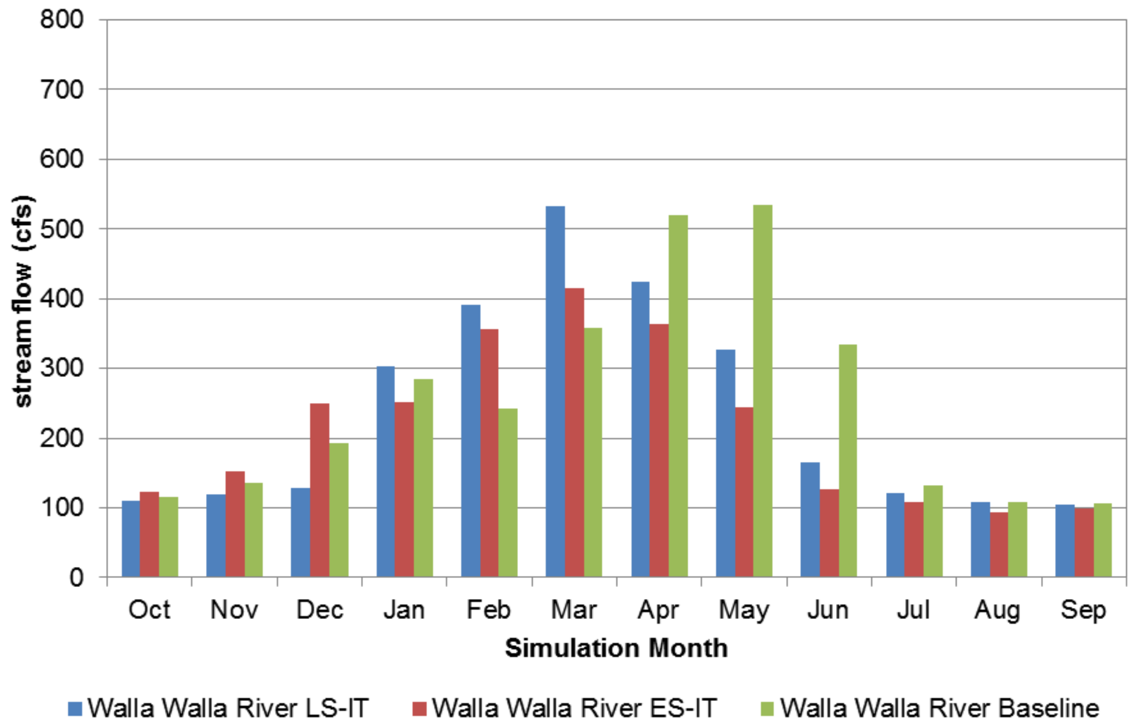

Figure 11. Walla Walla River flows into the model area for LS-IT, ES-IT, and Baseline models

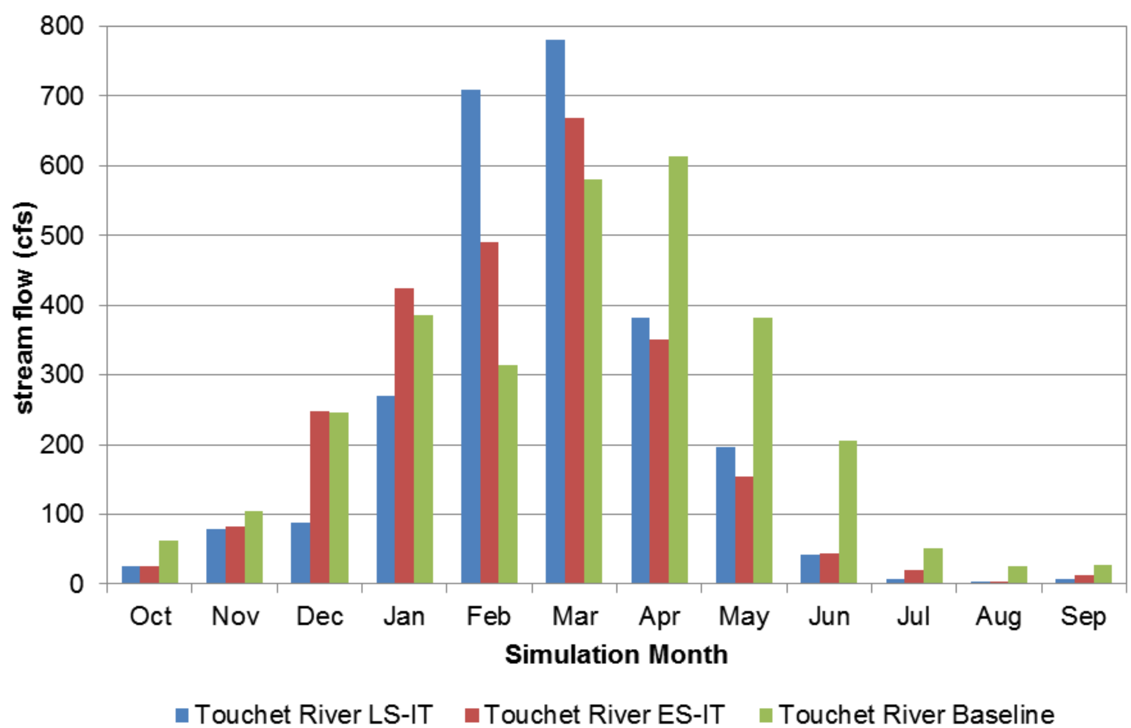

Figure 12. Touchet River flows into the model area for LS-IT, ES-IT, and Baseline models

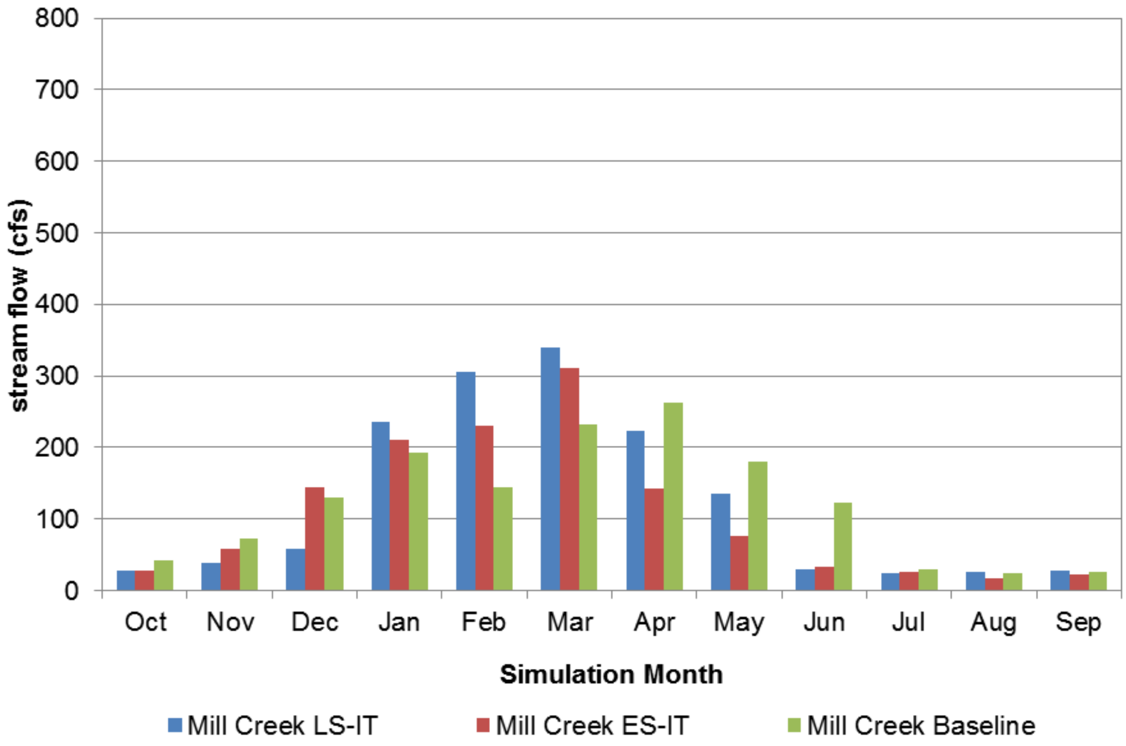

Figure 13. Mill Creek flows into the model area for LS-IT, ES-IT, and Baseline models

3.2.2 Precipitation

Daily precipitation was derived from five Ag-Weather Net weather stations managed by Washington State University (Figure 2). The weather stations span an elevations ranging from 236 ft above mean sea level (amsl) to 1,941 ft amsl, encompassing the surface elevations within the model area. Measured daily precipitation was linearly interpolated between stations at 65.6 foot (20 meter) elevation intervals. The interpolated precipitation was input into the model such that every model element received rainfall corresponding to its surface elevation. Monthly and WY cumulative precipitation over the model area for the LS-IT (WY 2003), ES-IT (WY 2016), and Baseline models is shown in Figure 14. A notable precipitation event occurred on September 8th, 2003 where the model area received, on average 1.0 inches of precipitation. LS-IT and ES-IT models exceeded the annual precipitation in the Baseline model by 3.2 and 1.9 inches, respectively (Figure 14).

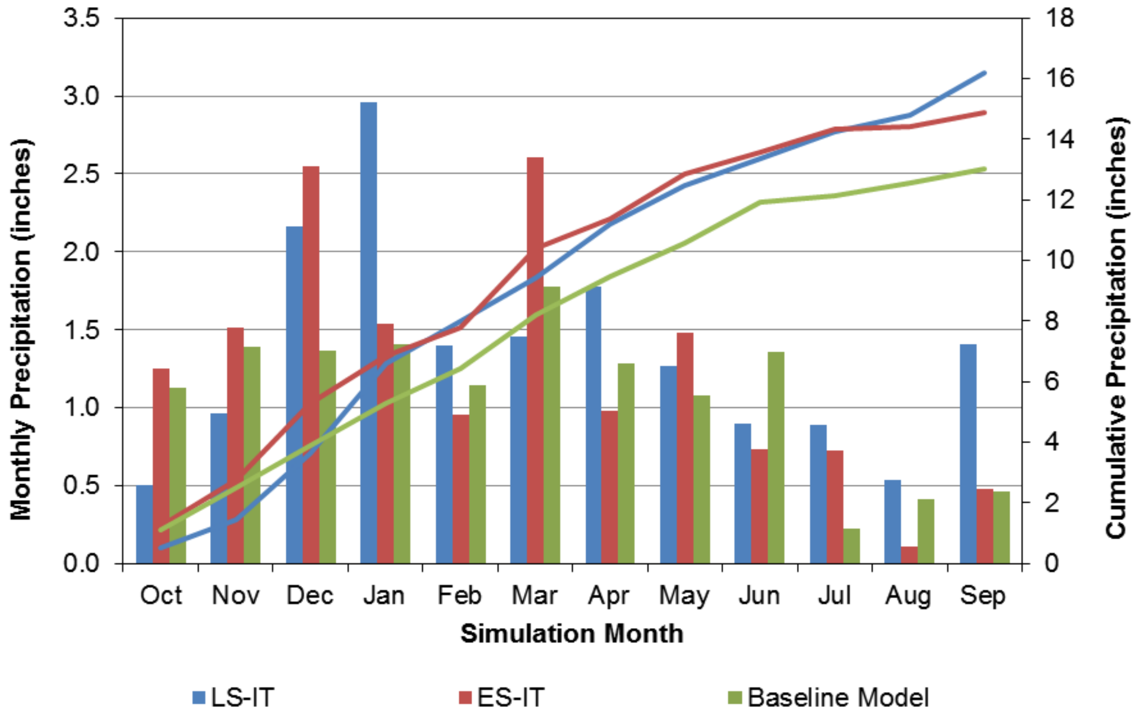

Figure 14. Monthly total and WY cumulative precipitation for the LS-IT, ES-IT, and Baseline models

3.2.3 Potential Evapotranspiration

ETo for a grass crop was collected from the five Ag-Weather Net stations used for the precipitation analysis (Figure 2) and ETo values were interpolated by elevation to generate an estimated daily ETo for each model subregion based on the mean elevation of the subregion. ETo was then modified for each land use by multiplying ETo by seasonal crop coefficients found in Allen (1998) to generate the crop specific potential evapotranspiration (ETc) data sets applied in the Baseline, LS-IT, and ES-IT models. Actual evapotranspiration (AET) is calculated for each model subregion as a function of model inputs for land use, crop type, and crop water use efficiency. Specific algorithms for the computation of AET are discussed in Dogrul (2013) and land use and crop characteristics as applied in the model are provided in GSA (2015). Figure 15 shows the average ETc over the model area for LS-IT, ES-IT, and Baseline models. For all models, ETc is small over the winter and peaks in July.

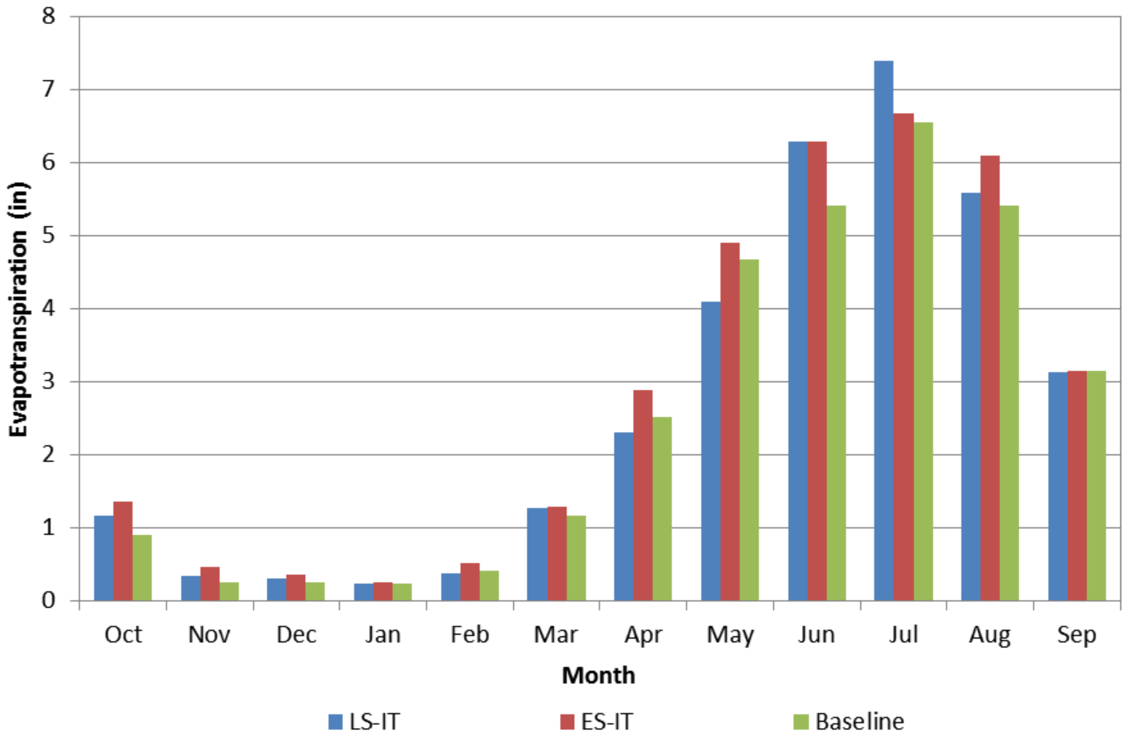

Figure 15. Monthly total ETc for the LS-IT, ES-IT, and Baseline models

3.2.4 Groundwater Boundary Conditions

A specified head boundary condition was used to estimate lateral groundwater inflow into the model area. Groundwater elevation data was obtained from a collection of 97 monitoring wells within the model area. These wells are actively monitored by WWBWC personnel with data collected at intervals that range from hourly to quarterly (WWBWC 2015b). Some wells have groundwater elevation data records that go back over 50 years whereas others have only recently been added to the WWBWC groundwater monitoring program. Monthly average groundwater elevation for WY 2003 and WY 2016 were estimated for the model area using an ArcGIS (ESRI, 2011) spline interpolation of the monthly average groundwater elevation for each well location. Results were extracted at points around the model boundary to project estimated monthly groundwater boundary conditions for the LS-IT and ES-IT models, respectively. Groundwater boundary conditions for the Baseline model were the average of the seven year data set (2007-2013) used for developing the calibrated model (GSA, 2015; 2016).

The resulting groundwater elevation data set was assumed to represent groundwater head along the model boundary for the fifteenth day of each month, and a linear interpolation was then performed to estimate groundwater elevation along the boundary for each day to satisfy the daily time step input of the model. At locations where spline estimated groundwater elevation was below the bottom elevation of a given aquifer, it was assumed that there was no boundary inflow into that aquifer at that location.

Data sets for some monitoring wells began after WY 2003 or were missing data and resulted in incongruent month to month interpolated groundwater elevations. This necessitated estimating groundwater elevations for monitoring wells with missing data. Groundwater elevations were estimated by assuming a linear regression between measured data points in instances where a missing month of data had groundwater elevation measurements available for the neighboring months. If consecutive months of groundwater elevation data were missing, the groundwater elevation for those months was estimated by multiplying the range of groundwater elevation measurements for a given well by the average of normalized groundwater elevations for other wells in the Basin during the same month. The result was added to the minimum groundwater elevation recorded for the given well.

The thin layer of aquifer material along the northern and eastern portions of the model boundary limits groundwater inflow at these areas (GSA, 2015). As a result, the model is relatively insensitive to the groundwater boundary conditions along the northern and eastern model boundary, limiting the effect of possible errors associated with the sparse monitoring well data that is available for these areas (Figure 2). Interpolated monthly groundwater elevations along the model boundary and daily groundwater boundary conditions assigned in the model are provided in Appendix G.

3.2.5 Other Model Inputs

LS-IT and ES-IT model inputs other than precipitation, ETc, stream flow, and groundwater boundary conditions were assigned to be the same as the Baseline model for the purposes of projecting the impact of climate conditions on water resources. These model inputs included land use, crop types, irrigation methods, managed aquifer recharge, urban water demand and treated wastewater return flows.

4.0 RESULTS

The results of the LS-IT, ES-IT, and the Baseline model scenarios described in the preceding section are presented below, with a focus on summer habitat conditions in the WWR and the predicted impact of scenario conditions on water resource availability. Model results are presented in terms of annual total and monthly averages to highlight predicted trends rather than daily variations that result from daily model inputs. Models were run in an annual repeating cycle using a daily time step for a 30 year period to allow steady state conditions to be achieved. Model results are presented for model year 30. Complete model output files for the Baseline, LS-IT, and ES-IT models are included in Appendix C, Appendix D, and Appendix E, respectively.

4.1 Surface Water

4.1.1 Walla Walla River Flows

Five locations along the Walla Walla River were selected by the WWBWC as reference points for simulated surface water flows and are shown in Figure 16. These reference locations were chosen because at each location there is a stream gauge that allows managers to determine if flow targets are being met. Figure 17 summarizes predicted monthly average flow in the Baseline, LS-IT, and ES-IT models during the low flow season (July through October) at each of the five reference locations.

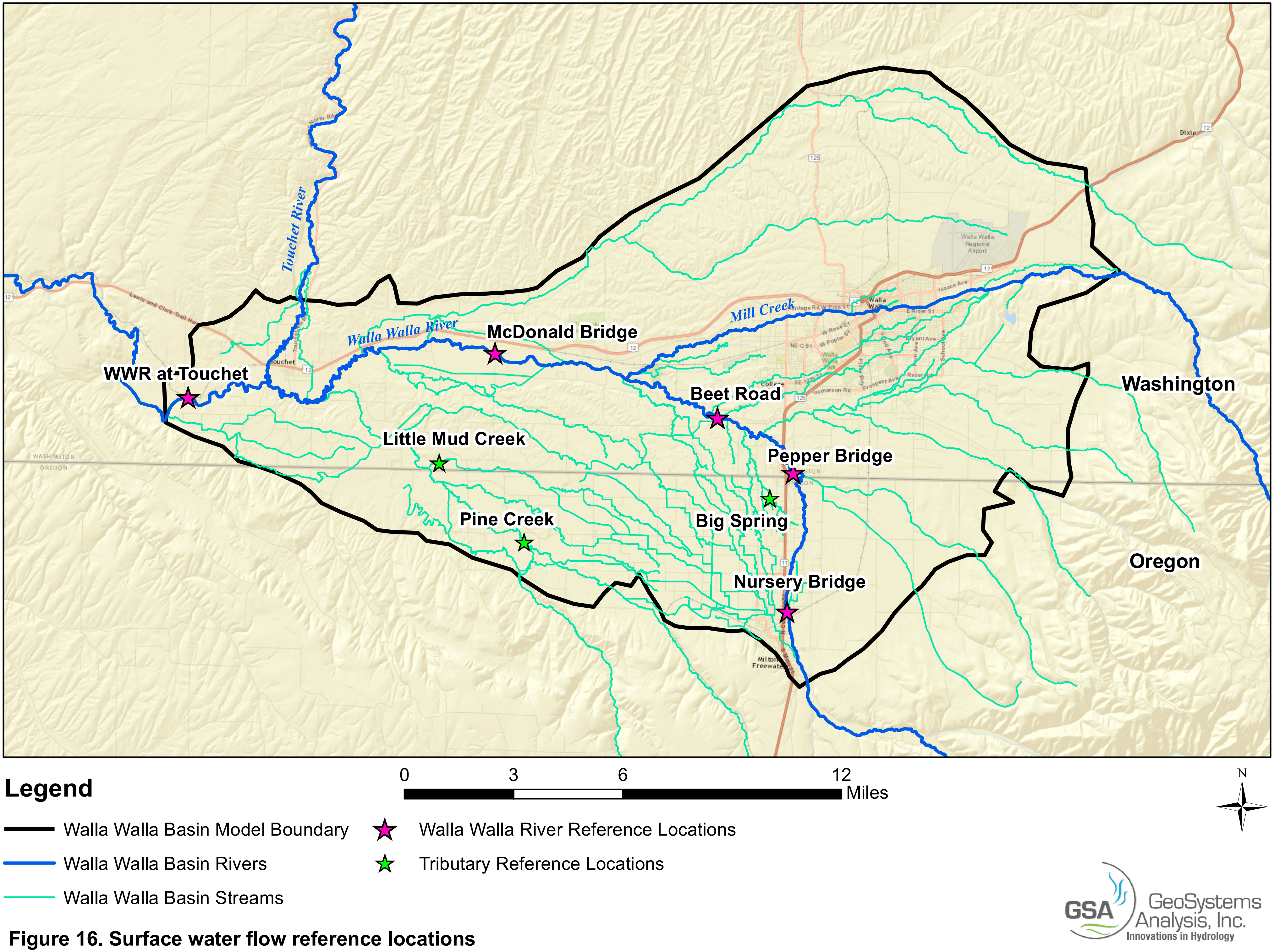

Figure 16. Surface water flow reference locations

LS-IT model predicted July flows at all reference locations were lower than those predicted in the Baseline model. The difference between July flows predicted in the LS-IT model and the Baseline model increased at more downstream reference locations, being 28 percent (33 cfs) less in the Baseline model at Nursery Bridge and 95 percent (70 cfs) less at Touchet River. LS-IT and Baseline model flows at Nursery Bridge and Pepper Bridge were similar from August through October. LS-IT and Baseline model flows at Beet Road and McDonald Bridge were similar in August, 14 percent (7cfs) and 32 percent (13 cfs) greater in September, and approximately 43 percent (12 cfs) and 82 percent (14 cfs) less in October, respectively. The increased LS-IT model predicted flows in September is due to several large precipitation events during this month. The decrease in LS-IT model predicted flows in October is due to diversions into the Gardena Canal taking a large portion of available WWR flow and low inflows in the WWR and Mill Creek. Canal diversions are based on the Baseline model and are not modified in the WY scenarios when inflowing streams are low. At the Touchet River reference location, the LS-IT model predicted flows were 136 percent (44cfs) greater than Baseline model predicted flows in August because of a peak in return flows generated by increased pumping to meet increased agricultural demands predicted for August of LS-IT. LS-IT model predicted flows in October were 81 percent (68 cfs) less than those predicted at the Touchet reference location in the Baseline model predicted flows due to upstream irrigation diversions from the WWR, and low inflow from the Touchet River, Pine Creek, and Mill Creek. In October of LS-IT the inflow from the Touchet River was, on average, 36 cfs less than in the Baseline model.

ES-IT model predicted July through September flows were less than or similar to Baseline model predicted flows at all reference locations. The difference between ES-IT model and Baseline model predicted flow ranged from 19 to 55 percent (7 to 20 cfs) at the Nursery Bridge reference location and increased downstream, being 42 to 73 percent (23 to 33 cfs) at the Touchet River reference location. ES-IT model predicted October flows were similar or greater than Baseline model predicted flows at the Nursery Bridge through McDonald Bridge reference locations due to the predicted WWR monthly average inflow being 7 cfs greater in ES-IT than in the Baseline model. At the Touchet River reference location the ES-IT model predicted flow in October was 46 percent (39 cfs) less than the Baseline model prediction primarily due to inflow from the Touchet River being 36 cfs less than in the Baseline model.

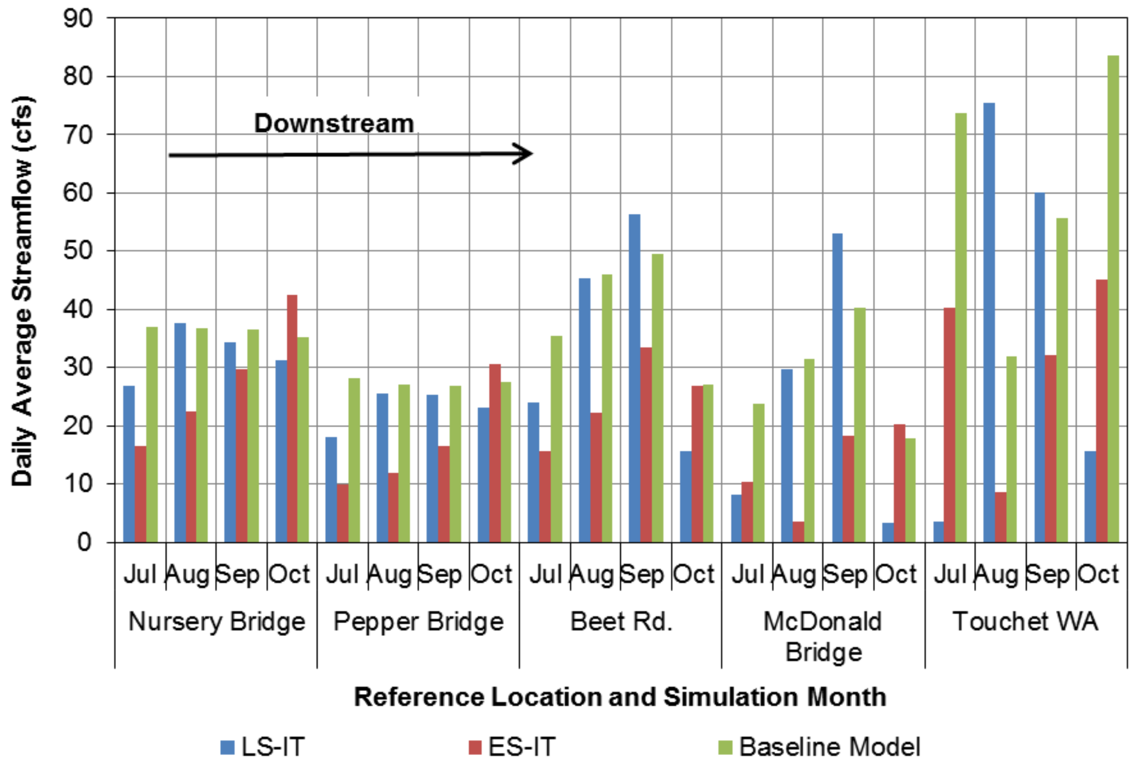

Figure 17. Predicted Walla Walla River July through October flow rates

Current management practices aim to maintain a minimum of 18 cfs in the WWR below the Gardena Canal diversion (Beet Road reference location). Table 2 provides the model predicted number of days in which flow at the Beet Road reference location is less than 18 cfs, number of days in which the WWR channel is dry, and maximum length of dry channel. The Baseline model predicted flows below Beet Rd. were below 18 cfs for 77 days of the year and increased to 121 days of the year in the LS-IT model and 163 days of the year in the ES-IT model (Table 2); the latter case indicating the current minimum flow threshold would not be met for the majority of the time from late May through early November. Furthermore, the model predicts that significant portions of the WWR would dry out in both alternative climate scenarios. LS-IT results predicted 88 days of the year with some portion of the WWR running dry. The maximum length of dry WWR channel under LS-IT conditions was 4.9 miles. The ES-IT model predicted 132 days annually where the WWR would dry out, with a predicted maximum of 8.3 miles of dry river bed. Baseline model results predicted 11 days per year of dry WWR channel conditions and for a maximum length of 1.2 miles; significantly less than either of the alternative climate scenarios (Table 2). Predictions for length of dry channel within the model area do not necessarily indicate a continuous length of dry channel, but rather the total predicted dry channel length out of the 33.4 miles of WWR channel within the model area.

Table 2. Model predicted number of dry channel days and days with predicted flow less than 18 cfs at the Beet Road reference location

Model	WWR Less Than 18 cfs Below Beet Rd (days/year)	Dry Location on WWR Channel (days/year)	Maximum Length of Dry WWR Channel (mi.)
Baseline Model	77	11	1.2
LS-IT	121	88	4.9
ES-IT	163	132	8.3

4.1.2 Tributary Channel Flows

Small channels that contribute flow to the WWR provide important off channel habitat and cold water refuge for salmonids residing in the WWR system (Wolcott, 2010). Model predicted flow rates in small tributaries are more uncertain than predicted flows in the WWR due to low flow rates magnifying relative error in flow predictions and irregular flow due to ungauged irrigation diversions (GSA, 2015). Despite the increased uncertainty it is informative to evaluate model predicted trends in stream flows relative to the Baseline model.

Three locations, shown in Figure 16, were selected to evaluate LS-IT and ES-IT model predicted tributary flow. Two of these locations, Big Spring and Little Mud Creek are spring fed tributaries to the WWR that occur entirely within the model area. Big Spring gains water that seeps from the Tum-A-Lum reach of the WWR, a reach known to have particularly high seepage losses (Baker, 2014), and the Little Walla Walla Canal. The third tributary reference location, Pine Creek, is a stream that flows from outside of the model area, converging with another inflowing stream, Dry Creek, just upstream from the reported reference location.

LS-IT model results for Little Mud Creek and Big Spring follow similar trends from January through May, with predicted flows in both streams generally exceeding the Baseline model predicted flows by ten percent or less and slightly higher relative flows in Big Spring (Figure 18). Warm spring conditions and early snow melt in the LS-IT model result in reduced predicted summer flows relative to the Baseline model (Figure 18). LS-IT model summer flows for Big Spring were predicted to decline less than Little Mud Creek due to Big Spring being supported by seepage losses from the WWR and Little Walla Walla Canal. LS-IT model predicted flows for Pine Creek were consistently lower than the Baseline model in November through July as basin wide groundwater levels decreased, reducing groundwater discharge into the stream. Several large August and September precipitation events in the LS-IT model increased flows in Pine Creek for those months relative to the Baseline model, though predicted monthly average Pine Creek flows were 6.1 cfs or less in all model scenarios (Figure 18).

ES-IT model predicted flows in the reference tributaries were consistently lower than the Baseline model, reflecting the warmer temperatures and drier spring and summer conditions in the ES-IT model. ES-IT model predicted summer flows for Big Spring decreased steadily relative to the Baseline model, whereas Little Mud Creek predicted flows declined steeply in June and were predicted to be dry in September and October (Figure 18). Similar to LS-IT model results, the greater predicted flow decline in Little Mud Creek compared to Big Spring was because Big Spring is supported by seepage losses from the WWR and Little Walla Walla Canal. ES-IT model predicted flows for Pine Creek in April through July were predicted to be nearly completely consumed by agricultural diversions upstream of the model reference location. ES-IT model predicted Pine Creek flow in September increased to 29 percent greater than the Baseline model, however, this represents an increase of only 0.8 cfs (Figure 18).

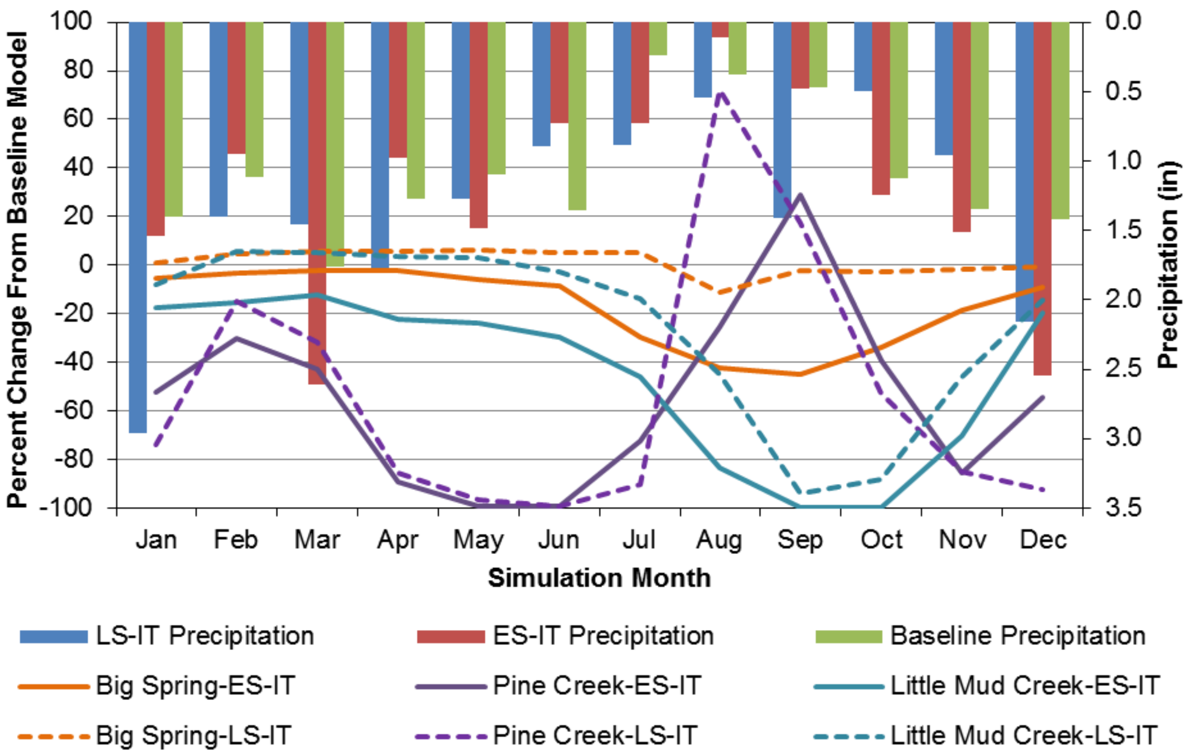

Figure 18. Predicted change from Baseline Model flow rates for select tributaries under alternative climate scenario conditions compared to monthly precipitation in Baseline Model and alternative climate scenarios

4.2 Groundwater

4.2.1 Groundwater Storage

Total groundwater storage within the model domain for the LS-IT, ES-IT, and Baseline models is shown in Figure 19. Figure 19 also includes the difference in groundwater storage between the alternative climate models and the Baseline model. LS-IT model predicted groundwater storage was predicted to range from 17,000 to 26,000 acre-ft less than in the Baseline model, with average annual groundwater storage predicted to be 0.4 percent less in the LS-IT scenario than in the Baseline model. ES-IT model predicted groundwater storage was predicted to range from 96,000 to 114,000 acre-ft less than in the Baseline model, with the average difference predicted to be 2.5 percent less groundwater storage over the model area.

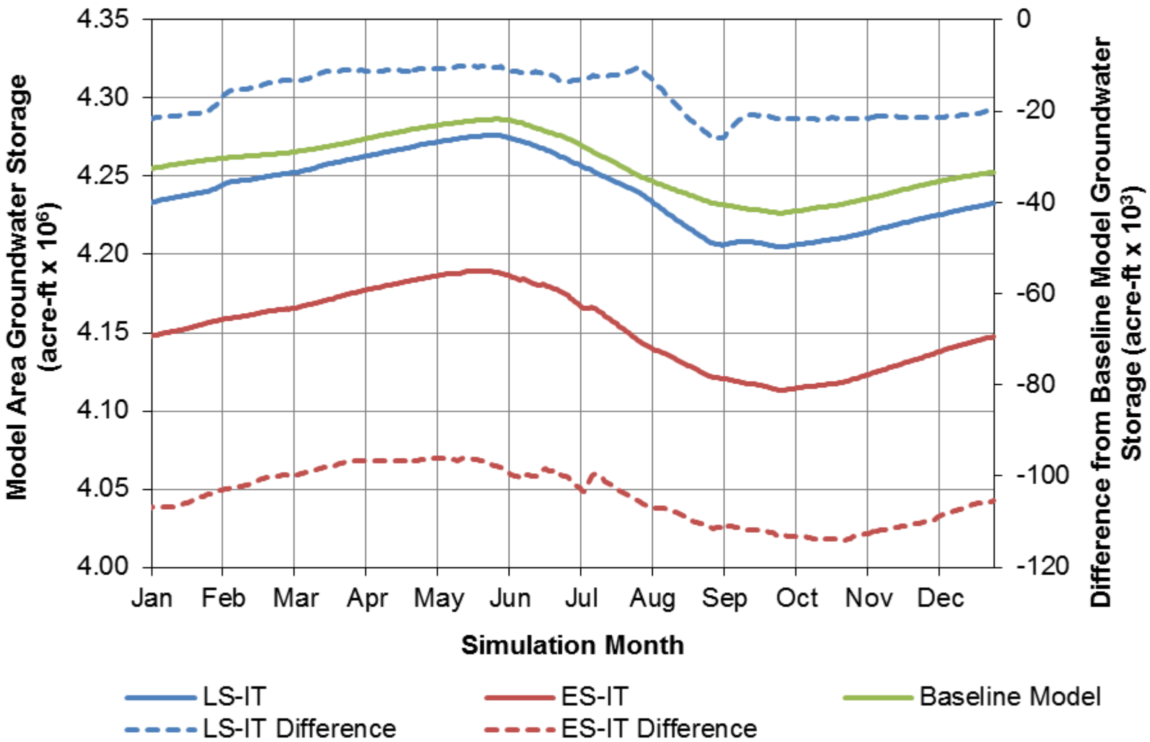

Figure 19. Model predicted groundwater storage and difference from Baseline model predicted groundwater storage

Figure 20 and Figure 21, respectively, show the mean annual LS-IT and ES-IT model predicted change in groundwater elevation relative to the Baseline model. LS-IT model predicted groundwater elevation was predicted to be within two feet of the Baseline model predicted groundwater elevation for the majority of the model area. Groundwater elevation declines of up to

12 feet were predicted for the northwestern portion of subregion six in response to increased groundwater pumping in this area (Section 3.3) (Figure 20). LS-IT model predicted groundwater elevations are greater than predicted groundwater elevations in the Baseline model near the north and east model boundaries. This is a result of WY 2003 having higher intensity rain events in the higher elevation areas of the model domain, leading to greater model predicted deep percolation, and greater measured groundwater head along the northern and eastern model boundaries producing greater groundwater inflows.

The ES-IT model predicted much broader declines in groundwater elevation, with predicted groundwater elevations up to 14 feet lower than the Baseline model in the northwest portion of subregion six and the eastern portion of the model area. ES-IT model predicted declines in groundwater elevation were greatest in areas where surface water supplies do not meet agricultural demand. Similar to the LS-IT model, though to a lesser extent, ES-IT model groundwater elevations were predicted to increase relative to the Baseline model around the northern and eastern model boundary due to increased boundary inflow and greater precipitation intensity at the higher elevations.

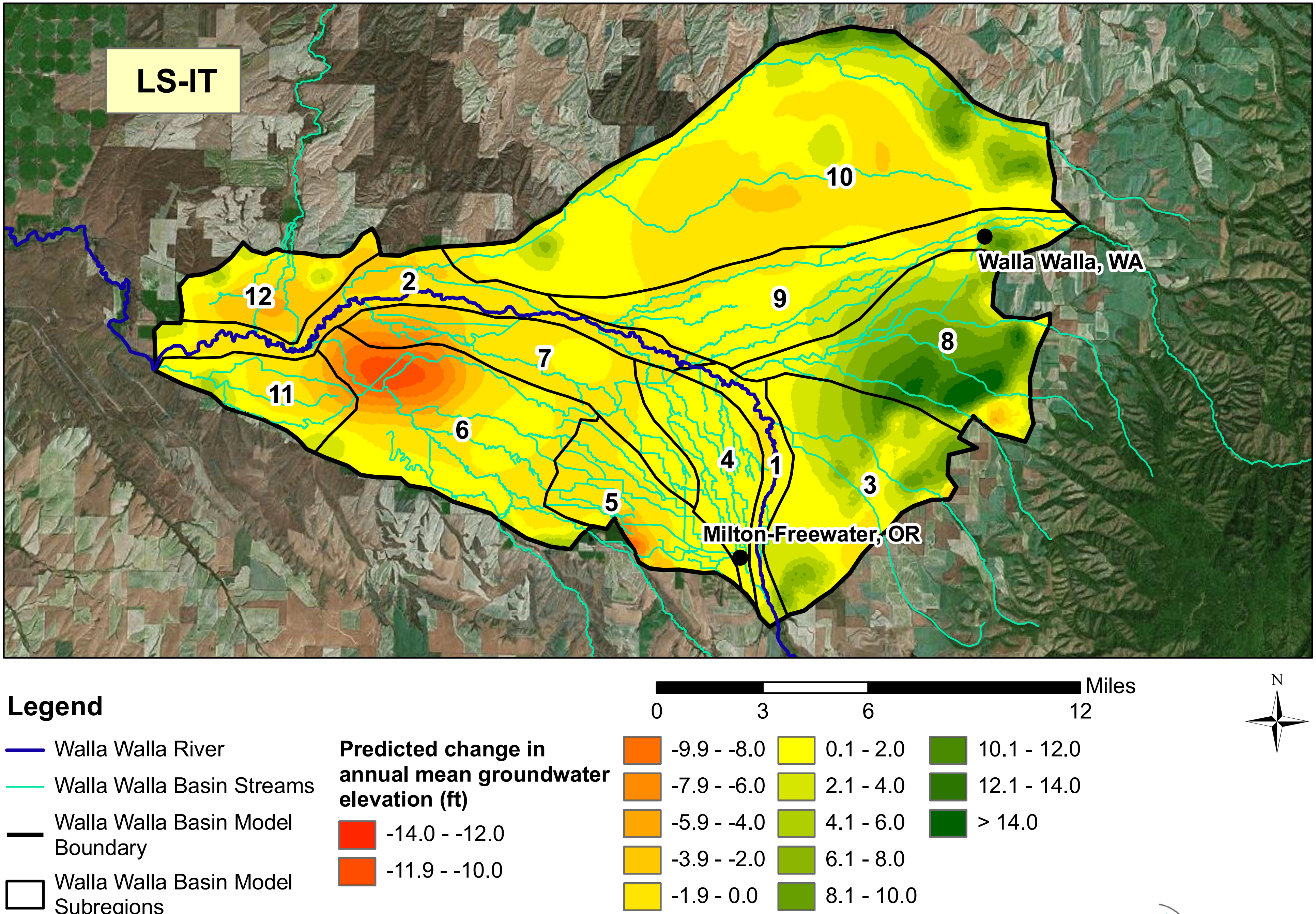

Figure 20. Difference in WY 2003 model predicted mean annual groundwater elevation relative to the Baseline model

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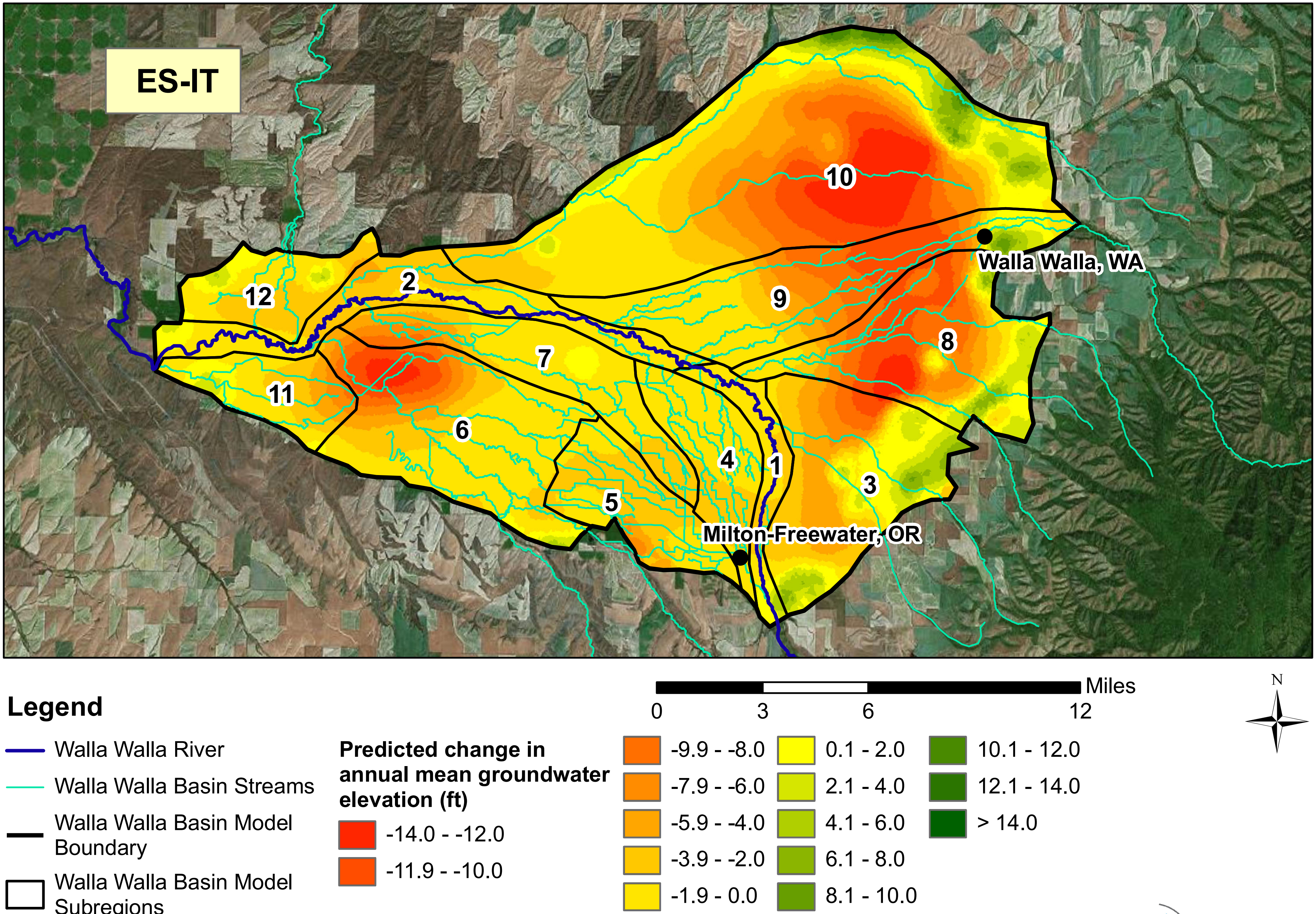

Figure 20. Difference in WY 2003 model predicted mean annual groundwater elevation relative to the Baseline model

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4.2.2 Groundwater Budget

Figure 22 shows daily average groundwater pumping and groundwater discharge to streams calculated on a monthly basis. The LS-IT model predicted groundwater discharge was similar to the Baseline model through March and exceeded the Baseline model from April through June. The LS-IT model predicted increased groundwater discharge from April through June was in response to warmer temperatures at high elevations in January through March relative to the Baseline model, resulting in earlier snowmelt and increased groundwater inflow. By June the WY 2003 snow pack had melted off, resulting in predicted groundwater elevations and groundwater discharge to streams falling below those predicted for the Baseline model, and remaining lower than the Baseline model for the remainder of the year. The LS-IT model predicted reduced groundwater discharge into surface streams relative to the Baseline model. This reduced surface water available for irrigation during the summer months resulted in increased groundwater pumping to meet the irrigation demand (Figure 22).

The ES-IT model predicted decreased groundwater discharge to surface streams relative to the Baseline model for the entire year due to warmer spring, summer, and fall conditions in WY 2016. The greatest ES-IT model predicted declines in groundwater discharge relative to the Baseline model were predicted to occur in July through September when precipitation was minimal and agricultural demand was high. In order to meet agricultural demand, greater groundwater pumping is predicted in the ES-IT model relative to the Baseline model (Figure 22).

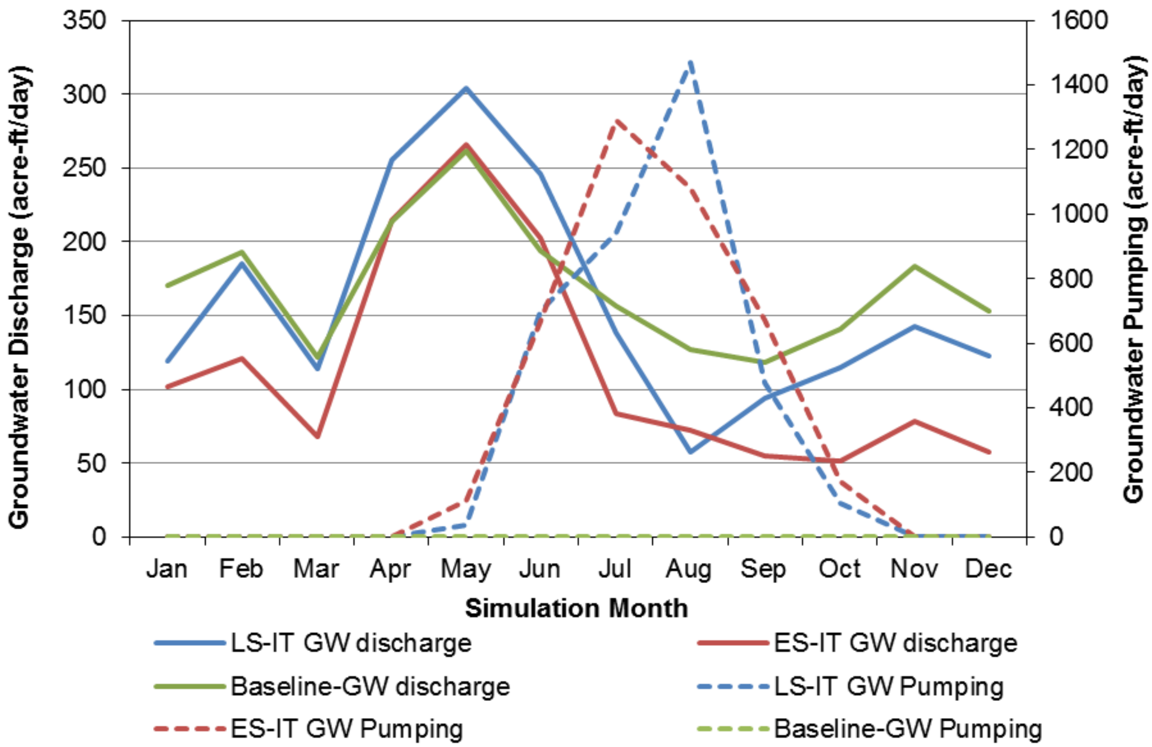

Figure 22. Mean model predicted daily groundwater discharge to streams and groundwater pumping

Groundwater pumping is the dominant factor in the model area groundwater budget from June through September (GSA, 2015). Figure 23 shows the LS-IT and ES-IT model predicted annual change in groundwater pumping relative to the Baseline model for the model subregions and entire model domain.

LS-IT model predicted groundwater pumping is predicted to increase relative to the Baseline model by 0.44, 0.37 and 0.35 acre-feet/acre/year for model subregions six, seven, and eleven, respectively, which incorporate the Gardena Farms and Lowden Irrigation Districts (Figure 6). In model subregions four and five, which incorporate the Walla Walla River Irrigation District (WWRID) and Hudson Bay District Improvement Company (HBDIC) irrigation district, relatively small increases in groundwater pumping were predicted (0.08 and 0.02 acre-feet/acre/year, respectively) due to these irrigation districts being supplied via the Little Walla Walla canal and its distributary network (Henry et al, 2013). LS-IT model predicted diversions from the WWR into the Little WallaWalla canal system were similar to Baseline model predicted diversions. Less water was available further downstream in the WWR due to upstream irrigation and low Touchet River flows, resulting in LS-IT model predicted groundwater pumping increases of 0.35 and 0.48

acre-feet/acre/year in model subregions eleven and twelve, respectively. Groundwater pumping in subregion two (Lower WWR) is predicted to be 0.31 acre-feet/acre/year greater than predicted in the Baseline model to compensate for reduced water available for irrigation from the WWR (Figure 23).

For the ES-IT model, warm and dry spring conditions coupled with predicted WWR flow rates that were less than half of those predicted for the lower WWR in the Baseline model for May and June resulted in an earlier start to the groundwater pumping season (Figure 22) and increased groundwater demand in all of the model subregions (Figure 23). ES-IT groundwater pumping was similar to LS-IT model predicted pumping for subregions two, six, seven, and ten. Increased ES-IT model groundwater pumping was particularly evident in subregions four and five due to less water being available in the Little Walla Walla Canal network. Likewise, shortages in surface water supply in subregions one (WWR), eight and nine (Yellowhawk Creek and Mill Creek, respectively) resulted in increased groundwater demand. Predicted groundwater pumping for subregions eleven and twelve was greater in the LS-IT model than the ES-IT model because of low flows on the lower WWR (subregion two) in June and July reducing available surface water resulting in increased groundwater pumping (Figure 23).

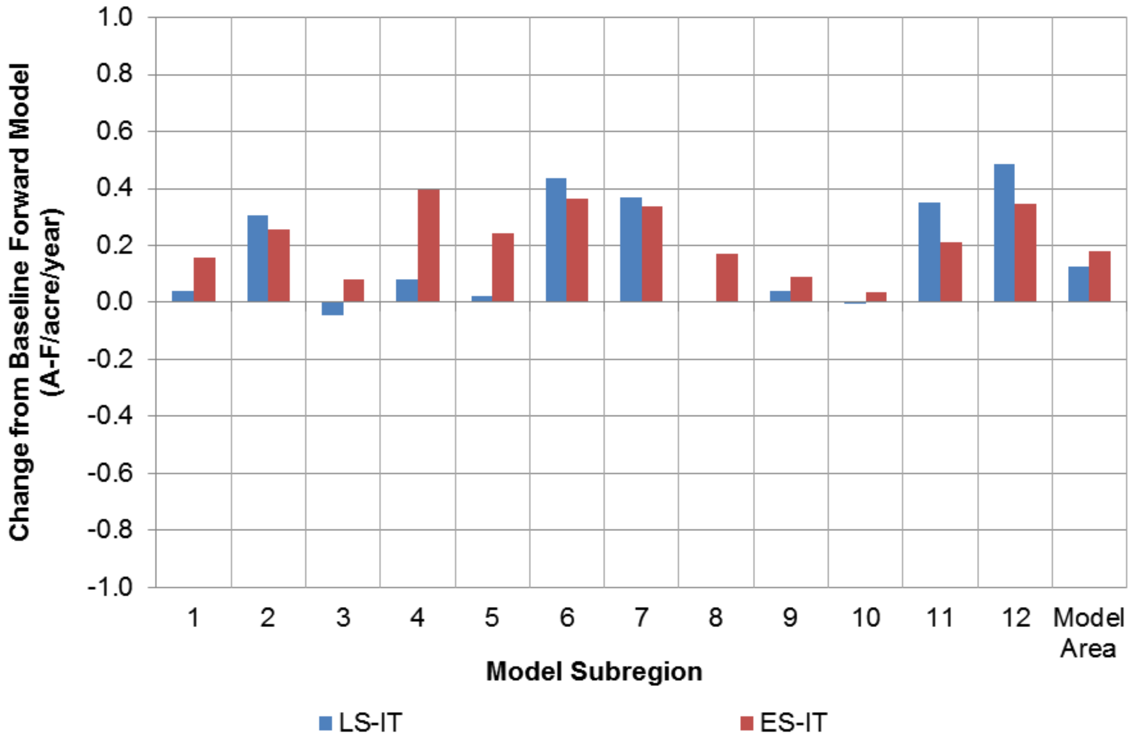

Figure 23. Change in groundwater pumping by model subregion for LS-IT and ES-IT models relative to the Baseline model

4.3 Agricultural Water Use

Model predicted agricultural water requirements and the water used to meet those requirements are provided in Figure 24. Groundwater pumping in the models is calculated based on the deficit between allocated irrigation from surface water and crop demand, factoring for inefficiencies in water conveyance and irrigation methods (Dogrul 2013). LS-IT and ES-IT model predicted agricultural water demand generally exceeded the Baseline model predicted agricultural water demand through the summer due to warmer conditions (e.g. increased ETo). Irrigating with surface water begins in March and peaks in April for all models, decreasing over the following months as stream flows decline. The predicted rate of decline in surface water application is greatest with the ES-IT model, followed by the LS-IT model, and the Baseline model. Predicted groundwater pumping to meet agricultural demand begins in mid-April and increases steeply with agricultural water demand in May. For all models, groundwater was predicted to be the primary source of irrigation by mid-June. Total annual model predicted groundwater pumping for the LS-IT and ES-IT models was predicted to be 20 percent and 28 percent greater than the Baseline model, respectively, in order to meet agricultural demand.

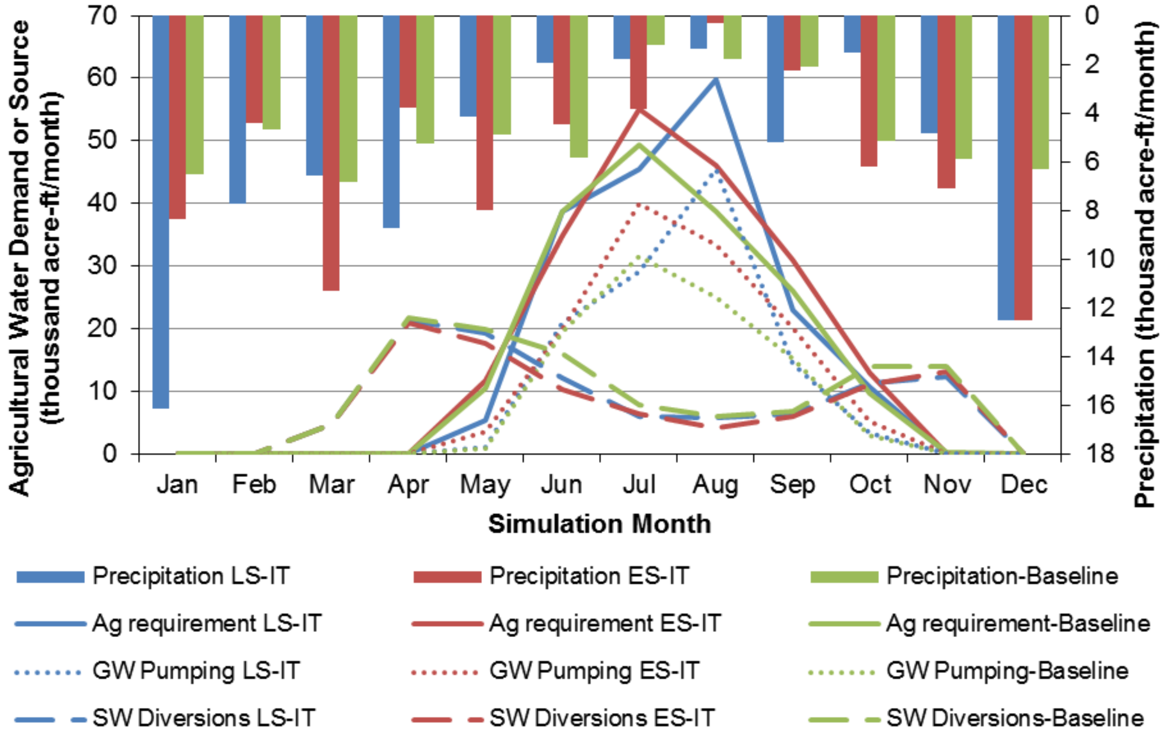

Figure 24. Precipitation and model predicted agricultural water demand and supply

Figure 25 provides the model predicted monthly average values for the primary components of the agricultural water budget. Applied water exceeded crop water use in the spring, partially due to the over application of water in the spring to increase soil water content prior to the dry summer months, a practice common in the Walla Walla Basin (Scherberg et al, 2014). Table 3 presents the model predicted annual agricultural water budget. AET presented in Table 3 includes native vegetation and dryland wheat and is therefore higher than crop water use. Model predicted water use by irrigated crops (crop water use) accounts for 73 percent of annual AET within the model area in the Baseline model and both alternative climate scenarios (Table 3). Surface runoff is predicted to account for up to three percent of the agricultural water budget in the LS-IT and ES-IT models, occurring in conjunction with large rain events. Less surface runoff is predicted in the Baseline model due to there being lower precipitation intensity. Return flow, defined as excess irrigation water that is routed back to streams, accounts for 11 to 14 percent of model applied water (irrigation plus precipitation), with the greatest return flows predicted for the Baseline model. There is very little return flow predicted in the summer months (Figure 25). Deep percolation, water that travels through the root zone and into the model unsaturated and aquifer layers, is predicted to range between 23 and 25 percent of model applied water (Table 3). The greatest deep percolation is predicted in the LS-IT model, with the ES-IT model predicting the least deep percolation during periods through the spring and summer (Figure 25).

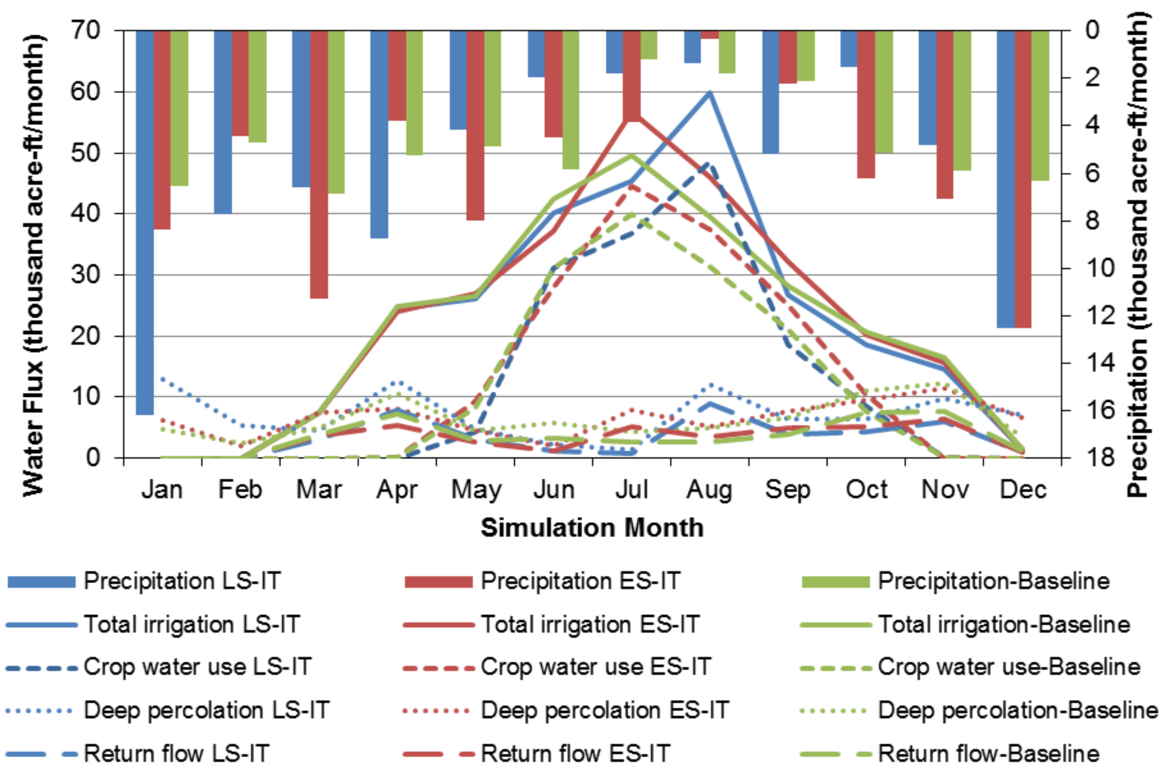

Figure 25. Model applied precipitation and predicted applied water, crop water use, deep percolation, and return flow

Table 3. Annual water budget for agricultural water use

Water Budget Term	Agricultural Water Budget					
	LS-IT Model		ES-IT Model		Baseline Model	
	Acre-Feet/yr	Fraction of Applied Water (Precipitation + Irrigation)	Acre-Feet/yr	Fraction of Applied Water (Precipitation + Irrigation)	Acre-Feet/yr	Fraction of Applied Water (Precipitation + Irrigation)
Precipitation	72,533	-	72,476	-	56420	-
Total Irrigation	264,991	-	267,839	-	257,649	-
Crop Water Use	147,836	0.44	154,815	0.45	139,701	0.44
Actual ET	201,777	0.60	212,005	0.62	192,073	0.61
Runoff	9,833	0.03	10,571	0.03	3,523	0.01
Return Flow	40,295	0.12	38,943	0.11	42,705	0.14
Deep Percolation	85,622	0.25	78,795	0.23	75,769	0.24

5.0 CONCLUSION

LS-IT and ES-IT model predicted July through October flows in the WWR and its tributaries were generally lower than in the Baseline model due to warmer spring conditions and earlier snow melt in the LS-IT and particularly the ES-IT models relative to the Baseline model. Predicted flow reductions for July through October for the LS-IT and ES-IT models, relative to the Baseline model, were generally greater at more downstream reference locations. The Baseline model predicted flows below Beet Rd. were below 18 cfs for 77 days of the year and increased to 121 days of the year in the LS-IT model and 163 days of the year in the ES-IT model. The Baseline, LS-IT and ES-IT models predicted a portion of the WWR was dry for 11 days, 88 days, and 132 days annually, respectively.

LS-IT model predicted groundwater storage was predicted to range from 17,000 to 26,000 acre-ft less than in the Baseline model, approximately a 0.4 percent decline. ES-IT model predicted groundwater storage was predicted to range from 96,000 to 114,000 acre-ft less than in the Baseline model, a decline of approximately 2.5 percent.

LS-IT model predicted groundwater elevation was predicted to be within two feet of the Baseline model predicted groundwater elevation for the majority of the model area; however, groundwater elevation declines of up to 12 feet were predicted within subregion six. The ES-IT model predicted much broader declines in groundwater elevation, with predicted groundwater elevations up to 14 feet lower than the Baseline model in subregion six and the eastern portion of the model area.

Reduced groundwater elevations resulted in a predicted reduction of summer time groundwater discharge into surface streams relative to the Baseline model.

Reduced surface water available for irrigation during the summer months resulted in predicted increases of 0.13 and 0.18 acre-ft/acre/yr in groundwater pumping over the model area for the LS-IT and ES-IT models, respectively. This represents a predicted groundwater pumping increase of 20 and 28 percent in order to meet irrigation demand in the LS-IT and ES-IT models, respectively. The LS-IT model predicted increased groundwater pumping in areas already reliant on groundwater for summer irrigation, such as Gardena Farms and Lowden. The ES-IT model also predicted increased pumping for areas currently reliant on groundwater, as well as predicting increases in the HBDIC and WWRID areas where reduced stream and canal flows left shortages of surface water deliveries for irrigation. Additionally, the reduced availability of surface water was compounded by increased LS-IT and ES-IT model predicted agricultural water demand through the summer due to warmer conditions.

Model results indicate that warmer winter and earlier snowmelt conditions will result in greater reliance on groundwater and increased difficulties in meeting target WWR flows. It's important to note that long-term climate conditions will have annual variations that include wetter than average and drier than average WYs, which will influence hydrologic conditions in the Basin. Nonetheless, model results serve as a basis to evaluate water management strategies to meet water resource needs under potential future climate conditions.

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