RECLAMATION

Managing Water in the West

DRAFT Hood River Basin Study:

Final Report

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Pacific Northwest Regional Office
Boise, Idaho

May 2014

Mission of the U.S. Department of the Interior

Protecting America's Great Outdoors and Powering Our Future

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

Mission of the Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acronyms

Basin Study	Hood River Basin Study
CMIP	Coupled Model Inter-comparison Project
DCP	Downscaled climate projections
DCP	Downscales climate projection
DHSVM	Distributed Hydrologic Soil Vegetation Model
DID	Dee Irrigation District
EFID	East Fork Irrigation District
ESA	Endangered Species Act
FID	Farmers Irrigation District
GHG	Greenhouse gases
HD	Hybrid-Delta
HRCWPG	Hood River County Water Planning Group
IFIM	Instream Flow Incremental Methodology
km	Kilometer
km	kilometer
LW/D	Less Warming/Drier climate scenario
LW/W	Less Warming/Wetter climate scenario
MED or C	Median or Central climate scenario
MODSIM	Hydrologic modeling program
MFID	Middle Fork Irrigation District
MW/D	More Warming/Drier climate scenario
MW/W	More Warming/Wetter climate scenario
MW-hr	Megawatt-hour

Acronyms

OWRD	Oregon Water Resources Department
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
SECURE Water Act	Science and Engineering to Comprehensively Understand and Responsibly Enhance Water Act
SP	Stress period
SWCD	Water Conservation District
SWCD	Soil and Water Conservation District
USGS	U.S. Geological Survey
WaterSMART Program	Sustain and Manage America's Resources for Tomorrow Program
WPN	Watershed Network Professionals
WRIS	Water Rights Information System
WRIS	Water Rights Information System
WUR	Water user reports

EXECUTIVE SUMMARY

In April 2012, the Bureau of Reclamation (Reclamation) initiated the Hood River Basin Study (Basin Study) in collaboration with Hood River County (County) and other stakeholders throughout the Hood River basin. Located in northern Oregon, the Hood River basin extends from the summit of Mount Hood to the south, the ridgeline of the Cascade Range to the west, and the Columbia River to the north. This 482-square-mile region includes the City of Hood River, as well as many unincorporated communities, all of which are located in Hood River County. There are five major irrigation districts and multiple water districts, including the City of The Dalles, which is located outside the basin, but obtains its potable water supply from the Dog River, which is in the Hood River basin.

The West Fork Hood River, the Middle Fork Hood River, and the East Fork Hood River are the three primary forks to the mainstem Hood River (Figure ES-1). The West Fork Hood River subbasin accounts for 30 percent of the total Basin area, but due largely to the orographic effects of the Cascade Mountain range, contributes greater than 40 percent of natural flow through the mainstem Hood River. The Middle Fork and East Fork combine to form the East Fork Hood River drainage, which accounts for approximately 45 percent of the total basin area and natural flow through the mainstem Hood River. The headwaters of Middle Fork and East Fork drainages are fed in part by the glaciers along the north and east sides of Mount Hood. The mainstem Hood River, located downstream of the confluences of the three forks, makes up the remaining 25 percent of the basin.

There are two major reservoir systems in the basin. Laurance Lake is located on a tributary to the Middle Fork Hood River (Clear Branch), and Upper and Lower Green Point reservoirs on Ditch Creek drain into the mainstem Hood River. The Green Point Reservoir system is also partially fed by water diverted from the neighboring West Fork Hood River drainage. These reservoir systems, in addition to supporting agriculture, instream flows, and recreation, supply water to several hydropower facilities. Middle Fork Irrigation District (MFID) operates Laurance Lake and the three uppermost powerplants in the basin, and Farmers Irrigation District (FID) operates the Green Point Reservoir system and the two powerplants near the mouth of the Hood River. Additionally, there are several reaches in the Hood River basin where instream flow rights or agreements exist to maintain minimum flows during some or all months of the year.

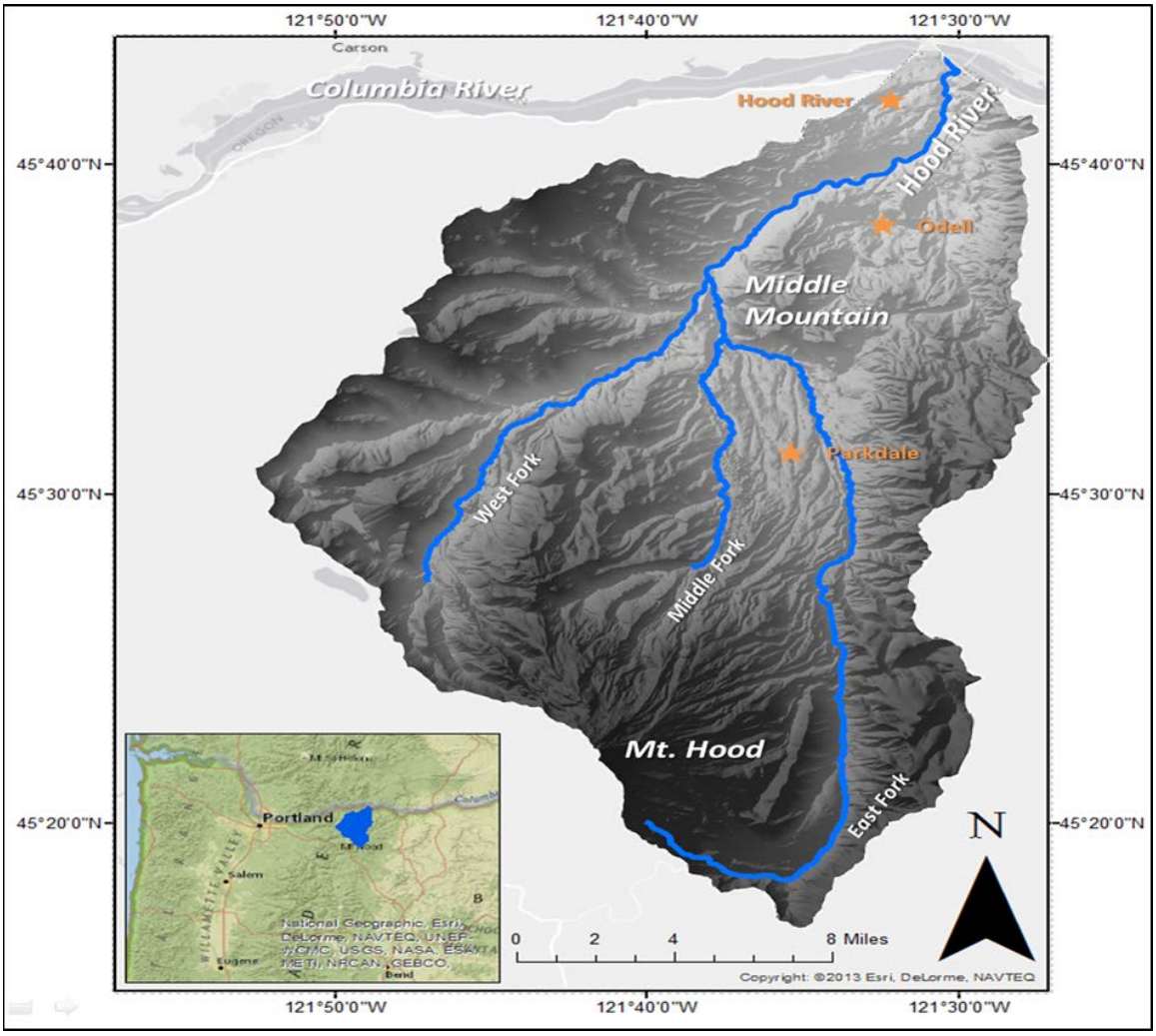

Figure ES-1. Shaded relief map of the Hood River basin study area.

The purpose of this Basin Study was to define current imbalances and identify potential future imbalances in water supply and demand in the basin through 2060, and to develop and analyze adaptation and mitigation strategies to resolve those imbalances. This included developing an understanding of potential changes in snowpack, of the connection between surface water and groundwater in the basin, and how climate change may affect Mount Hood glaciers. To accomplish this work, additional data were collected and multiple physical and network-based models were constructed to evaluate these data. Multiple work groups were established throughout the process to review work products and results as they were available. Regularly scheduled webinars were held to share progress on each task throughout the entire process.

Several concurrent efforts were completed along with the Basin Study, including the Hood River Basin Water Use Assessment, the Hood River Basin Water Conservation Assessment, the Instream Flow Incremental Methodology (IFIM) Study, and the Oregon Water Resources

Department Reservoir Storage Study. With the exception of the IFIM Study, which was not available at the time of this Basin Study Report, these documents are summarized in this Basin Study Report and are available from Reclamation's website.[1]

In addition to these concurrent studies, Reclamation constructed multiple physical models to establish a baseline of historical conditions for comparison to simulations of future climate change scenarios. In addition, adjustments were made to these models to evaluate the alternatives selected for further analysis, compare to the historical baseline, and to understand how these alternatives may attenuate potential future climate change impacts. One key issue in the Hood River basin is the limited amount of data available for use in these physical models. In general, less than 10 years of monthly data were available for water diversion estimates, hydropower, and reservoir operations. In addition, the basin has two river gages with relatively long periods of record (more than 30 years), but no other gage data are available with long records. Finally, there were minimal groundwater data sources for use in the groundwater model. Because of the limited data used in these models, the results presented in this Basin Study Report should be interpreted as trends and not as absolutes. Significant collaboration with County partners helped ensure that the results of the models were reasonable and represented the system correctly. As additional field data are collected, the model and results should be updated.

More information on each model, input, and calibration, and appropriate results are provided in five technical memorandums that were produced during this Basin Study:[2]

- *Technical Memorandum 1 - Potential Reservoir Storage Locations*: This technical memorandum provides an overview of the Basin Study area geology and describes the preselected areas as potential new reservoir storage locations or expanding storage at existing reservoir storage sites. Hood River County provided input for this technical memorandum.

- *Technical Memorandum 2 - Climate Change*: This technical memorandum describes the approach, methodology, and results of the climate change analyses that generated the projected precipitation and temperature patterns used in the Basin Study.

- *Technical Memorandum 3 - Groundwater*: This technical memorandum describes the collection and use of groundwater information to develop a water budget and MODFLOW model and the results of the analyses.

[1] These reports may be found at http://www.usbr.gov/pn/programs/studies/oregon/hoodriver/index.html.
[2] These technical memorandums can be found at http://www.usbr.gov/pn/programs/studies/oregon/hoodriver/index.html/.

- *Technical Memorandum 4 - Hydrology*: This technical memorandum describes the Distributed Hydrologic Soil Vegetation Model (DHSVM) used to generate historical and future runoff patterns and the results of that analysis.

- *Technical Memorandum 5 - Water Resources*: This technical memorandum describes the use and construction of the water resource model, MODSIM-DSS, to analyze historical and future streamflow patterns and water use and results of the modeling.

Alternatives Evaluation

The Hood River basin has already experienced shifts in timing and quantity of runoff in the recent past. Water resource managers have been adapting and improving operations and infrastructure to continue providing water despite these shifts. Basin Study analyses were conducted on how water resource managers might be impacted in their ability to deliver water for irrigation, domestic water, and instream flow for ecological processes. The potential benefits of conservation actions and either expansion of existing storage facilities or consideration of new facilities were also evaluated. Specific measures relative to groundwater were studied and results were reported.

A comprehensive list of all potential alternatives to address these issues are described in Table ES-1, while Table ES-2 presents specific alternatives evaluated in this Basin Study. Table ES-1 also lists the alternative type (e.g., demand, conservation), and if known, estimated costs and the alternative's effect on water budget. The sediment collection alternatives were discussed and are listed, but no analyses were conducted on this issue in the basin. Additional data on sediment transport during storm events and hydraulic modeling of future streamflow rates because of potential future climate change would be required.

Table ES-1. Potential alternatives considered in the Hood River Basin Study.

Potential Alternatives Considered	Type of alternative	Cost, if applicable ($)	Effect to Water Budget
Dee Irrigation District transition from impact sprinkler to micro-and drip irrigation	Irrigation Water Conservation	217,200	155 acre-feet/year
East Fork Irrigation District transition from impact sprinkler to micro-and drip irrigation	Irrigation Water Conservation	2,950,312	2,297 acre-feet/year
Farmers Irrigation District transition from impact sprinkler to micro-and drip irrigation	Irrigation Water Conservation	634,385	401 acre-feet/year
Middle Fork Irrigation District transition from impact sprinkler to micro-and drip irrigation	Irrigation Water Conservation	2,515,200	1,800 acre-feet/year
Mount Hood Irrigation District transition from impact sprinkler to micro-and drip irrigation	Irrigation Water Conservation	227,506	163 acre-feet/year

Potential Alternatives Considered	Type of alternative	Cost, if applicable ($)	Effect to Water Budget
Dee Irrigation District completion of piping main conveyance canal (completed 2012)	Irrigation Water Conservation	1,435,000	1.5 cfs
East Fork Irrigation District transition of open canal to piped system and operational changes	Irrigation Water Conservation	16,108,000	21.5 cfs
Farmers Irrigation District transition of open canal to piped system and operational changes	Irrigation Water Conservation	--	--
Middle Fork Irrigation District transition of open canal to piped system and operational changes	Irrigation Water Conservation	--	--
Mount Hood Irrigation District elimination of overflows from main canal	Irrigation Water Conservation	134,426	1 cfs
Retrofitting indoor fixtures	Potable Water Conservation	--	0.4 – 0.6 cfs reduction
Reduce outdoor water use	Potable Water Conservation	--	0 to 0.6 cfs reduction
Implement Use-based rate structure	Potable Water Conservation	--	1 to 2.2 cfs reduction
Increased pumping due to increased agricultural needs	Groundwater	--	- average 16 cfs in summer
Aquifer injection; storage for future use	Groundwater	--	Location specific
Aquifer injection; streamflow augmentation	Groundwater	--	Unknown
East Fork Irrigation new settling basin	Sediment Collection	--	--
Middle Fork Irrigation District improvement of existing settlement basin	Sediment Collection	--	--
Farmers Irrigation District hydropower benefits of on-farm conservation (e.g., piping, transition to micro-irrigation etc.)	Power	Additional 17,700/year	Noted above
Farmers Irrigation District hydropower benefits of on-farm conservation (e.g., piping, transition to micro-irrigation etc.)	Power	Additional 18,415/year	Noted above
County Parcel off Smulin Road	Reservoir Storage	--	493 acre-feet
Rimrock Creek Site 1	Reservoir Storage	--	170 acre-feet

Potential Alternatives Considered	Type of alternative	Cost, if applicable ($)	Effect to Water Budget
Rimrock Creek Site 2	Reservoir Storage	--	53 acre-feet
Neal Creek Site 1	Reservoir Storage	--	2,850 acre-feet
Neal Creek Road	Reservoir Storage	--	922 acre-feet
Dog River	Reservoir Storage	--	8200 acre-feet
Yellow Jacket	Reservoir Storage	--	1,954 acre-feet
County Parcel NW of Dog River - Site 1	Reservoir Storage	--	275 acre-feet
County Parcel NW of Dog River - Site 2	Reservoir Storage	--	261 acre-feet
County Parcel near Laurance Lake Road Site 1	Reservoir Storage	--	50 acre-feet
County Parcel near Laurance Lake Road Site 2	Reservoir Storage	--	30 acre-feet
County Parcel near Laurance Lake Road Site 3	Reservoir Storage	--	15 acre-feet
Expansion of Upper Green Point Reservoir – Alternative 1.A	Reservoir Storage	1,272,000	561 acre-feet
Expansion of Upper Green Point Reservoir – Alternative 1.B	Reservoir Storage	2,347,500	561 acre-feet
Expansion of Laurance Lake Reservoir	Reservoir Storage	328,000	3,565 acre-feet
Construction of new Neal Creek Reservoir - Alternative 1.A	Reservoir Storage (assume fill present nearby)	13,213,500	2,557 acre-feet
Construction of new Neal Creek Reservoir - Alternative 1.B	Reservoir Storage (assumes fill from outside the basin)	27,872,500	2,557 acre-feet

Each of the alternatives discussed in Section 6.0 has the potential to decrease the gap between demand and supply for water in the Hood River basin. The degree of complexity varies among the alternatives and significant obstacles remain for implementation, particularly for some of the alternatives such as charging for water use. Public acceptability, funding, legal ramifications, and regulatory compliance issues would need to be resolved before moving any of these alternatives toward implementation.

Findings

Of the 17 alternatives considered in this Basin Study, nine alternatives were selected for further analysis that represented changes in water demand, water conservation, groundwater, and water storage (Table ES-2). The reservoir storage alternatives included evaluation of three storage facilities in the Hood River basin, two of which considered expansion of existing sites and one of which was a proposed facility on Neal Creek. Cost estimates were provided where data were sufficient to calculate these estimates.

Table ES-2. Alternatives selected for further analysis in the Hood River Basin Study.

Alternatives Selected	Type of alternative	How applied
Potable Water Demand	Increased Water Demand	Monthly average factors to account for population growth were determined for each water district and applied in the MODSIM model.
Irrigation Water Demand	Increased Water Demand	Average annual factors for each major irrigation district were determined based on the impacts of increasing temperatures on irrigation demand.
Irrigation Water Conservation	Conservation	Estimated reduction of water use based on converting 49 percent of existing impact sprinklers to micro- or drip-irrigation.
Expansion of Upper Green Point Reservoir	Reservoir Storage	Evaluated the potential of raising the dam by ten feet to increase storage from 988 to 1,549 acre-feet.
Expansion of Laurance Lake	Reservoir Storage	Evaluated the potential of raising the dam by three feet to increase storage from 3,565 to 3,935 acre-feet.
Construction of Neal Creek Facility	Reservoir Storage	Evaluated the potential of constructing a new facility with a storage volume of 2,557 acre-feet.
Increased pumping due to increased agricultural need	Groundwater	Evaluated increased pumping due to increased agricultural need under existing or baseline conditions and climate change conditions.

Alternatives Selected	Type of alternative	How applied
Aquifer injection; storage for future use	Groundwater	Evaluated aquifer injection at various locations in the basin to determine potential benefits to aquifer storage.
Aquifer injection; streamflow augmentation	Groundwater	Evaluated aquifer injection at various locations in the basin to determine potential benefits to streamflow augmentation.

Climate Change Projection Development

Climate change projections were obtained from the International Panel on Climate Change (IPCC) Coupled Model Intercomparison Program Phase 3 (CMIP3) documented in Assessment Report 4 (AR4), which is available online at the Bias-Corrected and Downscaled Climate Projections website under the Downscaled Climate Projections (DCP).[3] These CMIP3 projections were statistically downscaled (coarse data refined to finer, planning scale data) for the Hood River basin to represent a wide range of future climate. Five climate change scenarios, informed by an ensemble of the average of ten individual projections, were evaluated to determine which three provided a wet, dry, and average future in the basin. Projections that represented the 20th and 80th percentile change in temperature and precipitation when compared to historical conditions were selected along with the 50th percentile or median future. The selected ensemble indicates a potential increase in annual future temperature compared to the historical period that ranged from between 0.5 to 2.2 degrees Celsius (°C). The 20th, 50th, and 80th percentile temperature changes were approximately 0.9, 1.3, and 1.7 °C, respectively. The projections also show a change in precipitation that ranges between -10 to 20 percent with the 20th, 50th, and 80th percentile values at -2, 3, and 7 percent, respectively.

The three climate change scenarios were selected for analysis in this Basin Study that represented the More Warming/Drier (MW/D), Median (MED), and the Less Warming/Wetter (LW/W) selected percentile change in temperature and precipitation. The MW/D represented an 80th percentile change (T80) in temperature from historical and a 20th percentile change in precipitation (P20). The MED represented a 50th percentile change in both temperature and precipitation (T50 P50) and the LW/W represented the T20, P80 percentile range. These three scenarios provided the widest range of future climate in the basin that Hood River County and their partners could plan around. Table ES-3 lists the range of changes, by season for all three climate change scenarios.

[3] See http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.

Table ES-3. Summary of climate change scenarios used to evaluate future water supply, demand, and conservation alternatives in the Hood River Basin Study.

Climate Change Scenario	Average Precipitation Change (%)				Average Temperature Change (°C)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
More Warming Dry (MW/D)	-3	-7	-33	+4	+1.2	+1.5	+2.4	+1.5
Median (MED)	+7	0	-14	+3	+1.2	+1.1	+1.5	+1.2
Less Warming Wet (LW/W)	+5	0	-15	+12	+0.8	+0.7	+1.3	+0.9

Streamflow

The Hood River at Tucker Bridge and the West Fork near Dee gages were the two major gages available on the Hood River system to determine historical streamflow patterns. In general, streamflow patterns have historically peaked during the late spring with lower flows observed through the summer and early fall.

The three climate change scenarios were used as input to the DHSVM hydrologic model to generate natural (or unregulated) streamflow at 42 specific locations throughout the Hood River basin. In general, results showed that peak flow timing occurred earlier and was greater than historical flow. Summer flow was lower than historical streamflow conditions throughout the basin. These patterns have implications for flooding and sediment transport during high flow events and for water supply demands of all types during the summer months.

Figure ES-2 shows the change in streamflow from historical flow (represented by the 0 percent line on the y-axis) at the Hood River at Tucker Bridge gage, which is located upstream of the confluence of the Hood River and the Columbia River. In all three future climate change scenarios, streamflow at this location is expected to be higher between November and March or April and lower throughout the rest of the year. Even in the wettest climate change future scenario (projected 5 percent increase in precipitation above historical conditions in the winter and 12 percent increase in the fall), decreases in streamflow during the summer months was expected to exceed more than 10 percent at this location compared to historical streamflow. Similar results were projected throughout the basin.

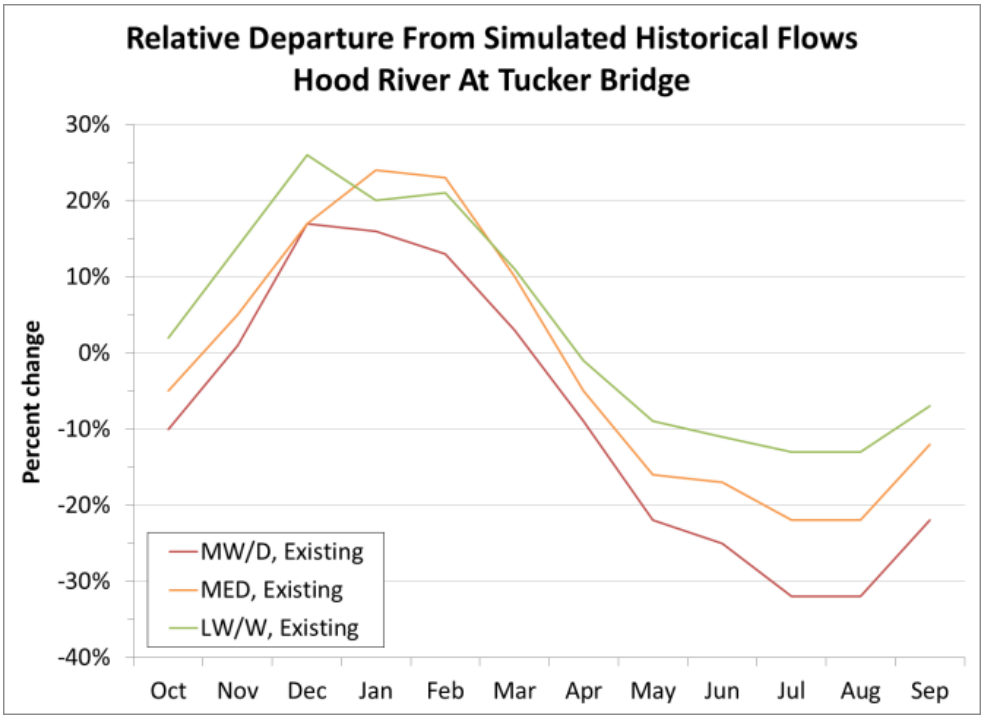

Figure ES-2. Departure from historical streamflow for the MW/D, MED, and LW/W future climate change scenarios at the Hood River at Tucker Bridge gage.

Figure ES-3 shows the distribution of streamflow for the July-to-September timeframe is plotted for the MW/D climate change scenario for the Hood River at Tucker Bridge gage. Under the MW/D climate scenario, streamflows remain lower than the simulated historical flow during the summertime period regardless of alternative simulated. Under the existing alternative, the driest future climate evaluated shows a nearly 200 cfs decrease in flow at the 50th percentile. Increasing demands exacerbate that impact slightly. The additional storage increases streamflow at the Tucker Bridge gage by approximately 50 cfs at the 50th percentile from those under the increased demands alternative. Similar results were projected throughout the basin.

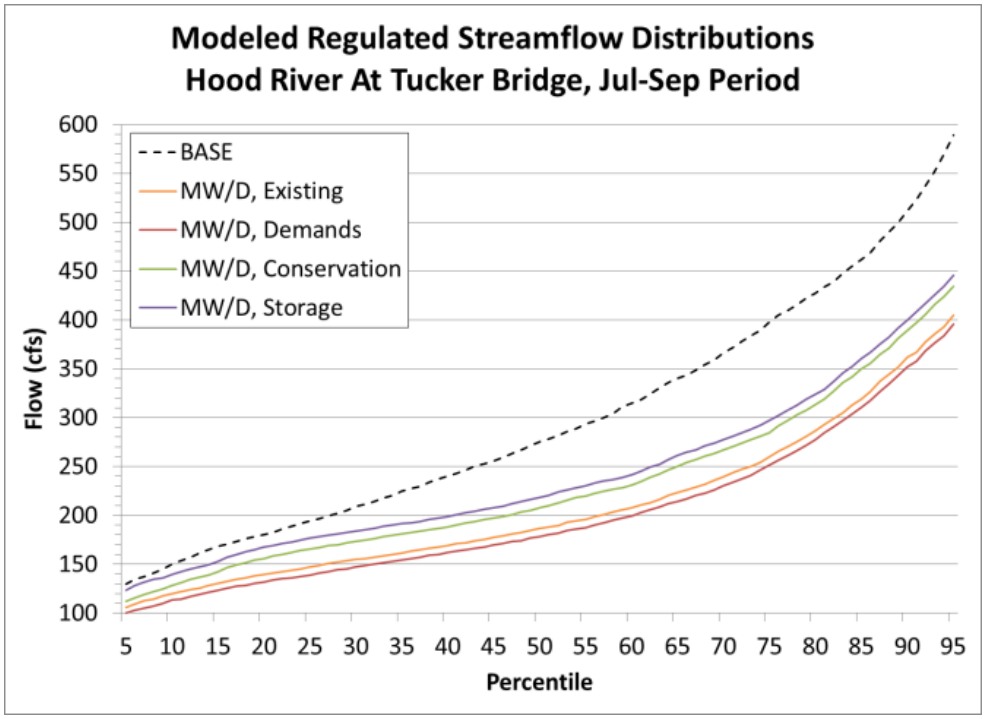

Figure ES-3. Distribution of streamflow for the MW/D future climate change scenario compared to baseline conditions at the Hood River at Tucker Bridge gage.

Mount Hood Glaciers

The Middle Fork and East Fork of the Hood River are fed in part by the glaciers of Mount Hood. The Coe and Eliot Branches are the main headwater streams of the Middle Fork Hood River that are fed predominately by the Mount Hood glaciers. These systems have a high percentage of glacier melt contribution to their overall total streamflow, with Nolin (2007) reporting that glacial melt contributes up to 74 percent of the stream during August.

A dynamic glacier component in the hydrologic model was used to simulated current glacier contributions to streamflows and potential impacts of climate change on these glaciers. Historically, the glacier volume has stayed relatively static since the early 1950s; however, the aerial extent of the glacier has continued to decline since the 1920s. Changes in glacier volume reflect short-term glacier mass gains or losses (i.e., during wet or dry periods). However, changes in glacier extent largely reflect longer-term trends. In all three future climate change scenarios evaluated, the extent of the Mount Hood glaciers are expected to continue decreasing (Figure ES-4). This decrease in glacial area leads to increased glacial melt of up to 20 percent during the time period evaluated in this Basin Study, however, at some point when the glaciers stop retreating (or have retreated far enough), these increased levels of melt will stop and melt will be less than historical levels.

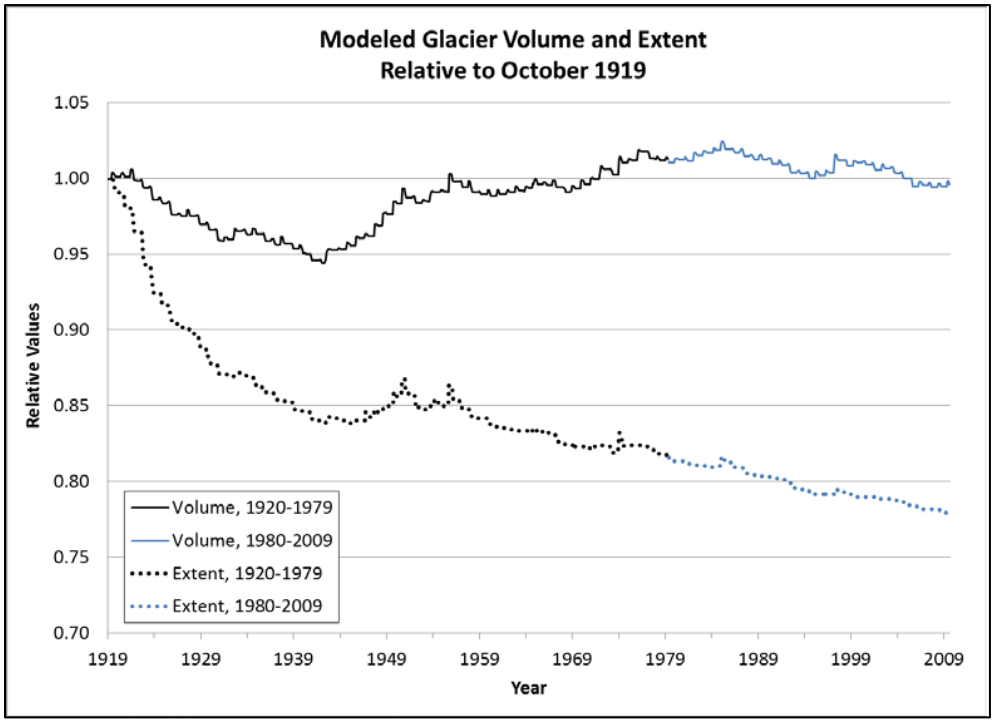

Figure ES-4. Simulated historical volume and extent of the Mount Hood glaciers.

Snowpack

Snowpack extent was averaged over the basin and compared to historical conditions. Since the 1920s, the modeled average basin-wide snow aerial extent as of April 1 of every year has trended downward at a rate of approximately 5 percent every 30 years (Figure ES-5).

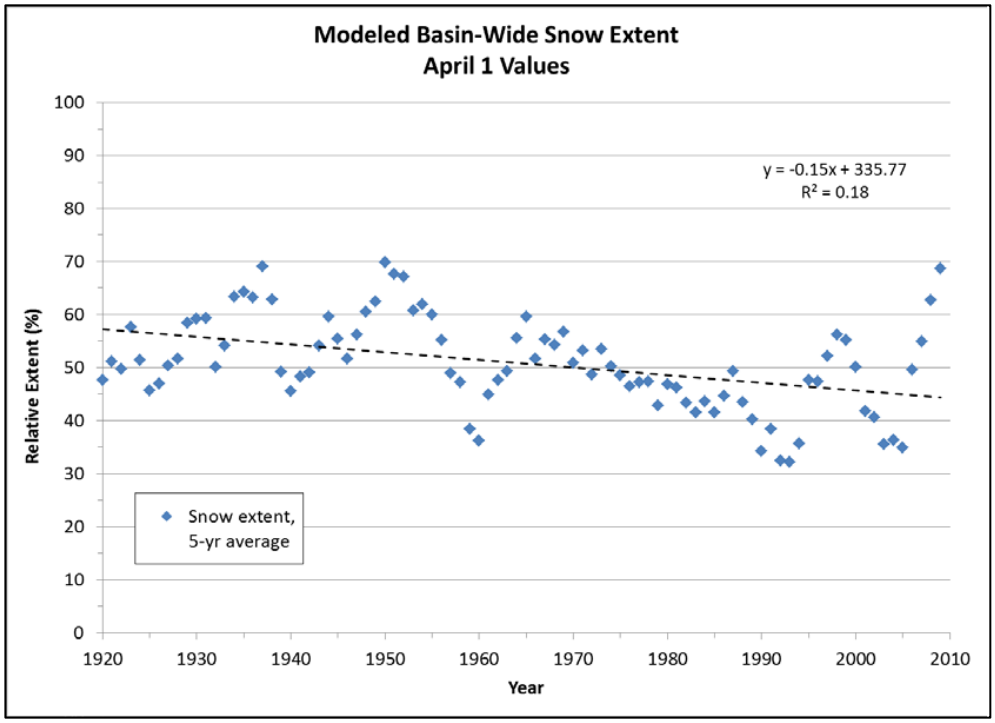

Figure ES-5. Modeled basin-wide snow extent every April 1 since 1920.

All three climate change scenarios project warmer temperatures, which will continue to decrease the snowpack. Peak snow extent occurs in January of each year and is projected to decrease by 10 to 15 percent in the LW/W and MW/D scenarios, respectively. This decrease in snowpack results in higher streamflow in the winter and lower streamflow runoff during the spring and summer months. In the MW/D scenario, up to 50 percent less snowmelt-driven streamflow is projected during the critical water use period between May and September.

Ecological Resources

The potential impacts on ecological resources were conducted by Normandau Associates (Normandau) in the Instream Flow Incremental Methodology (IFIM) study. Reclamation coordinated with Normandau to determine what locations flow time series were needed for their analysis. Data were generated by Reclamation and provided to Normandau for inclusion in their habitat models (i.e., PHABSIM). Due to the timing of their effort relative to this Basin Study timeline, the results of that analysis is not known at this time. A separate report will be prepared by Normandau documenting their methods and the potential impacts of the simulated future climate change projections compared to historical conditions.

Structural and Non-Structural Alternatives

Table ES-2 listed the selected surface water and groundwater alternatives under existing and future climate change. This section summarizes the results of the analyses conducted on the structural and non-structural alternatives that include increased potable and irrigation water demands (or consumptive use), implemented water conservation actions, and three reservoir storage alternatives. In addition, the potential impacts of implementation of these alternatives on streamflow, minimum flows, and water demand for hydropower were evaluated and results are included. Finally, a discussion of the results of the evaluation of the groundwater alternatives is also presented.

Demand Alternative

The Demand Alternative evaluated in this Basin Study included increased potable and irrigation water demands through 2060. These demands are reported using consumptive use, which means that water diverted is used in its entirety and does not return to the system. Adjustments were made to monthly average historical water use and simulated using the water resource management model, MODSIM-DSS.

Potable Water Demand

Future potable water demands were based on anticipated increases in population (ECONorthwest 2008). The overall annual potable use was projected to increase by 33 percent by the year 2050. Estimates of monthly adjustment factors were generated and the future climate change scenarios applied to all seven major water districts, which includes the City of The Dalles. The results, averaged across all potable water districts, are shown in Figure ES-6 by quarter and by quarterly and annual average. Although all three future climate change scenarios projected shortages during in potable water supply during the summer, the shortages may be outside the sensitivity of the models used in this Basin Study. Nonetheless, because shortages are projected, it is suggested that each potable water district conduct a more extensive evaluation of their projected water supply under future climate scenarios with respect to projected population and demand increases.

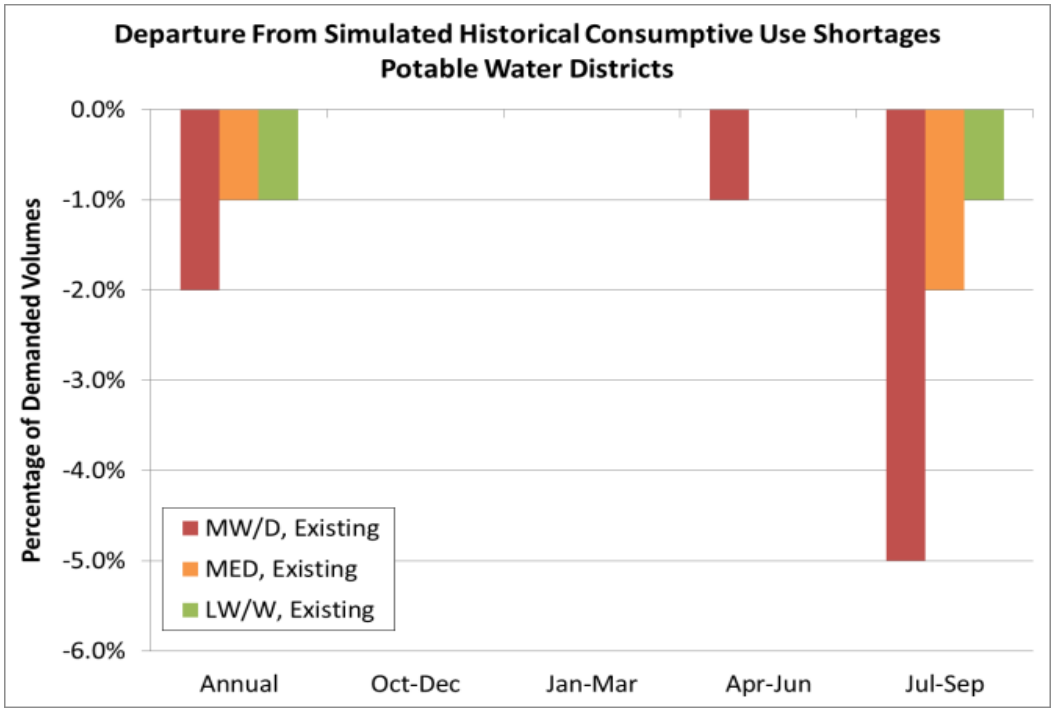

Figure ES-6. Potable water district projected demand shortages under the MW/D, MED, and LW/W future climate change scenarios.

Irrigation Water Demand

Future irrigation demands were based on expected increases in evapotranspiration due to higher projected temperatures in the future. The best available data at the time of this Basin Study Report indicated for every 1 °C increase in temperature, a 10 percent increase in irrigation demand was expected. Median projected temperature increases for the period 2030-2059 during the irrigation season (April through September) was estimated at 1.4 °C, which resulted in a 14 percent increase in irrigation demand. The increase to irrigation demands was applied differently in each of the five major irrigation districts based on the type of application methods in each (e.g., many orchardist are currently using impact sprinklers and already over-meeting demand).

Impact sprinkler use was projected to decrease by 49 percent in 2050, which would likely force irrigation to be converted to micro-irrigation or drip systems. The conversion would be expected to conserve water, which is documented in Section 5.2. Factors for each major irrigation district were used to adjust historical use. These factors were incorporated into the water resources management MODSIM-DSS model to evaluate projected demand changes from simulated historical conditions for each water and irrigation district (not by specific water right).

Figure ES-7 shows the results for the MFID, which obtains its water off the headwaters to the Middle Fork Hood River. The results are reported by consumptive use shortage relative to the historical conditions. In the MW/D climate change scenario, MFID experiences an increase in water shortages under existing conditions. This increased shortage is applicable to all four irrigation districts. In the MFID, shortages increase in each major season, but in the remaining irrigations districts, the major change in water shortages occur from July through September when flow in rivers tend to be is at the lowest levels historically. In the LW/W climate change scenario, existing shortages are actually reduced because more water is available from January through March when an increase in streamflow runoff is projected above historical conditions.

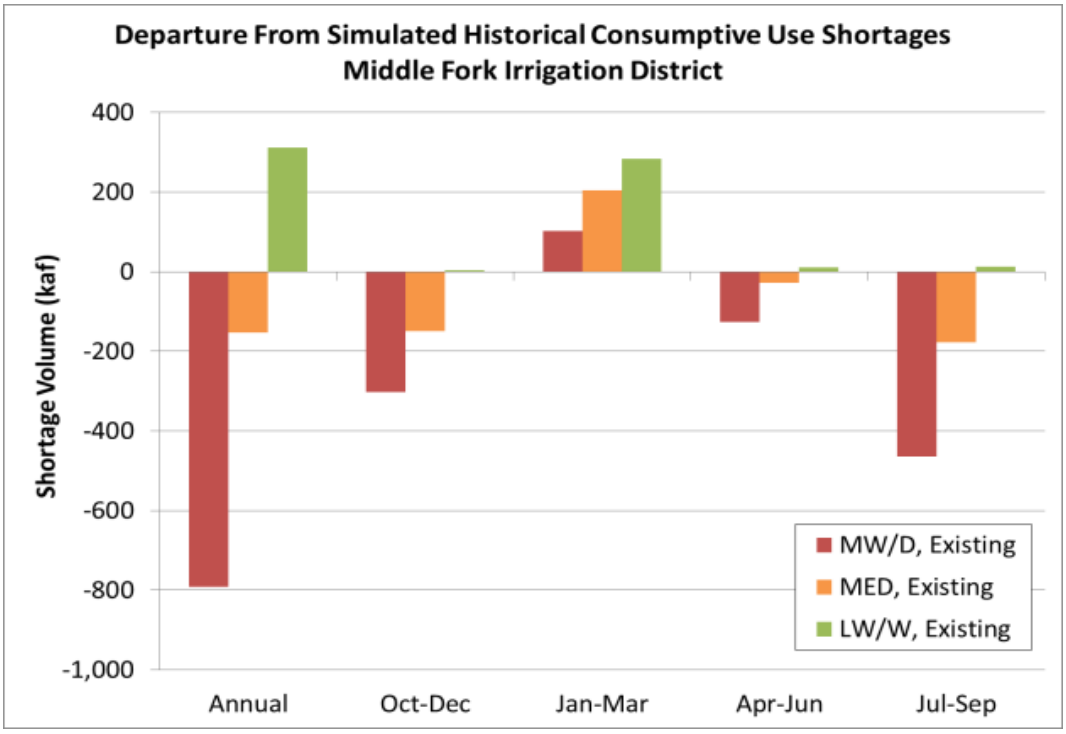

Figure ES-7. Middle Fork Irrigation District projected shortages for existing conditions, in the MW/D, MED, and LW/W future climate change scenarios.

Figure ES-8 shows the results for the Mount Hood Irrigation District (MHID). MHID obtains its water from the Main Canal, which is a diversion off the East Fork Hood River. MHID is expected to experience average shortages between nearly 3 percent to almost 15 percent during the summer months depending on the climate change scenario evaluated. This shortage is in part because MHID has a lower water right priority than that of EFID and of an instream water right along the East Fork below the Main Canal point of diversion. Thus, during water scarce periods, the instream water right is satisfied first, followed by EFID, and then MHID.

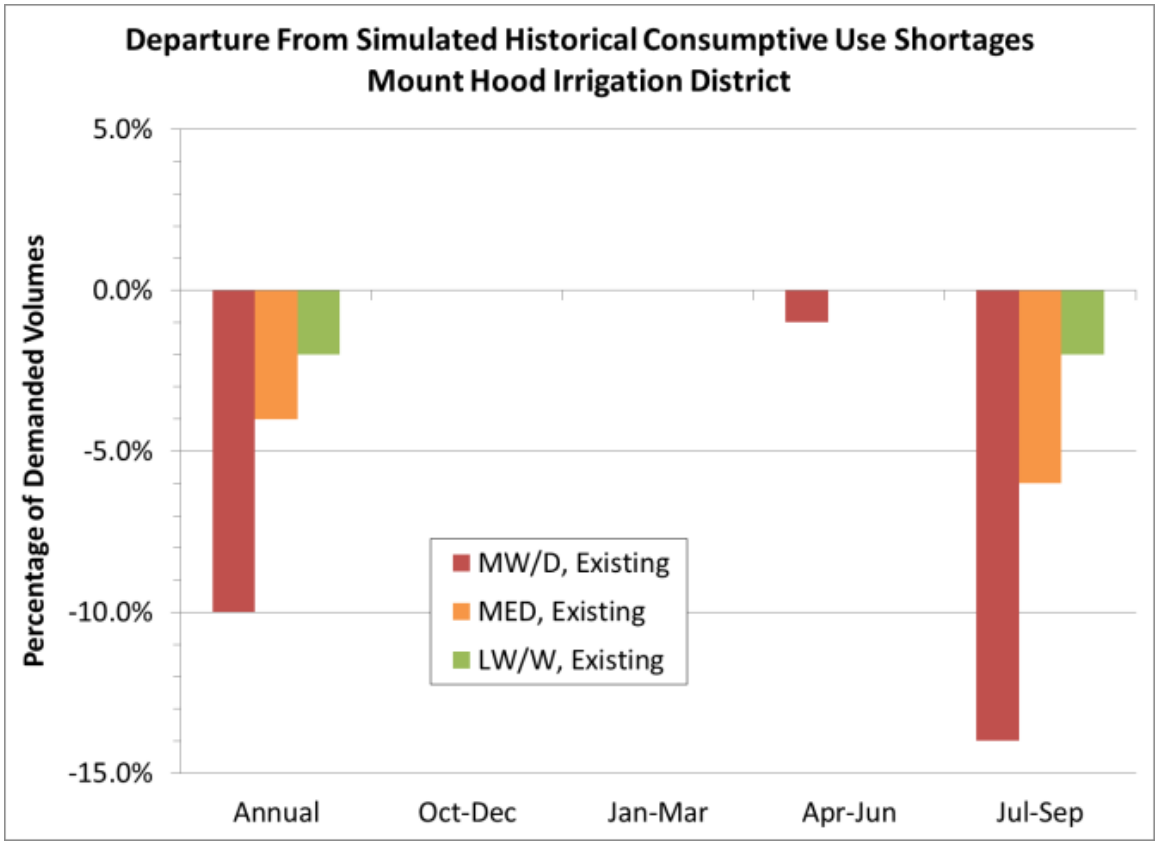

Figure ES-8. Mount Hood Irrigation District projected shortages for existing conditions in the MW/D, MED and LW/W future climate change scenarios.

Minimum Instream Flow

Minimum flow requirements were reported at several locations in the basin including Clear Branch and Coe Creek on the Middle Fork, the East Fork below the Main Canal and above the confluence with the Middle Fork, the West Fork below Lake Branch, Neal Creek, and Hood River at Tucker Bridge. Instream water rights and agreements are generally junior to other water rights in the basin and because of that, these rights may potentially be more impacted in the future than consumptive use and hydropower rights. On the Middle Fork tributaries the average instream shortages are projected to increase under the future climate change scenarios if no conservation or storage action is taken. Increasing the storage capacity of Laurance Lake near the headwaters of the Middle Fork Hood River attenuates these shortages slightly. However, because the Clear Branch and Coe Creek flow requirements are formal agreements, not legal water rights, increasing Laurance Lake storage capacity primarily benefits other more senior water needs in MFID. Similar patterns were projected to occur on the West Fork.

On the East Fork Hood River, the average minimum instream flow shortages increase above historical conditions if no conservation actions are taken or if demands increase in a changing climate. Implementation of conservation actions and construction of the Neal Creek Reservoir provide significant decreases in the projected shortages on the East Fork Hood River because less water is diverted to the Main Canal. Shortages in average minimum flows along the East Fork could be decreased by over 20 percent. This additional flow was translated downstream at the Hood River at Tucker Bridge gage in which instream shortages were reduced by more than ten percent. The MW/D climate scenario simulations suggest that implementing both the conservation measures and the new storage along Neal Creek could not only mitigate the effects of climate change, but may actually result in more streamflow in the East Fork when compared to the historical period.

Conservation Alternative

The Conservation Alternative evaluated savings in potable and irrigation water supply. For potable water conservation, estimates were made on the amount of water saved per household if indoor fixtures were retrofitting and outdoor use was reduced. This volume was smaller when compared to the potential water supply savings that could be obtained if sprinkler systems were exchanged for micro- or drip-irrigation systems. Because of that, potable water conservation was not modeled in this Basin Study, but estimates costs and potential savings of supply per household were made.

A use-based rate structure was also evaluated, but unlikely to be pursued in the Hood River Basin (City of Hood River 2013). Cost estimates to improve conservation of potable and irrigation water supply were made. Costs for irrigation conservation through sprinkler retrofits varied by irrigation district and range between $217,200 in DID to almost $3 million in EFID, of which almost $200,000 is for an additional settling basin. Shifting from open water system to piped irrigation, another conservation measure, was projected to cost between approximately $135,000 to over $16 million in the EFID. In EFID, 22 miles of the system would need to be converted.

Reservoir Storage Alternatives

Of the 17 proposed reservoir alternatives (2 were added later), 3 sites were evaluated more closely by Hood River County and were modeled by Reclamation. The Upper Green Point Reservoir storage capacity expansion, the Laurance Lake storage capacity expansion, and a proposed facility on Neal Creek were simulated using the MODSIM-DSS model to determine the potential benefits to flow, ecological resources, and attenuating demand shortages. Because the reservoir data used to construct the model were limited to 10 years at most, only average values were used to construct the water resource management model. The use of these average values as opposed to a long period of record means that impacts and benefits are likely tempered in an average number. In addition, year-to-year variation is not captured, but trends in one direction or another could be. The short period of record is not sufficient to

obtain a broad range of dry, average, and wet years to fully evaluate using the MODSIM-DSS model. Recommendations have been made to Hood River County to improve upon their current data records and update the water resource management model as that occurs.

Impacts of projected future climate change are somewhat mitigated by expansion of Upper Green Point Reservoir. Modeling shows that the proposed additional capacity would be able to store any increased inflow projected in the future; however, it should also be noted that some part of climate change impacts may be mitigated for by simply filling the reservoir sooner. Although the reservoir would still be drawn down quicker than historically during irrigation season (due to reduced summertime inflow), it would at least allow the reservoir to start the irrigation season full.

The future climate change scenarios are projected to have a greater effect on Laurance Lake as shown in Figure ES-9. Peak storage volume shifts to earlier in the year and the minimum average monthly storage volume that occurs in October were projected to decrease by approximately 28 to 55 percent. These results were indicative of how the runoff regime in the basin is expected to change under future climate change in which greater stream flow occurs in the winter with lower stream flow in the summer. These impacts are more predominate in the storage volume patterns of Laurance Lake because the reservoir receives inflows and releases outflows continuously throughout the year.

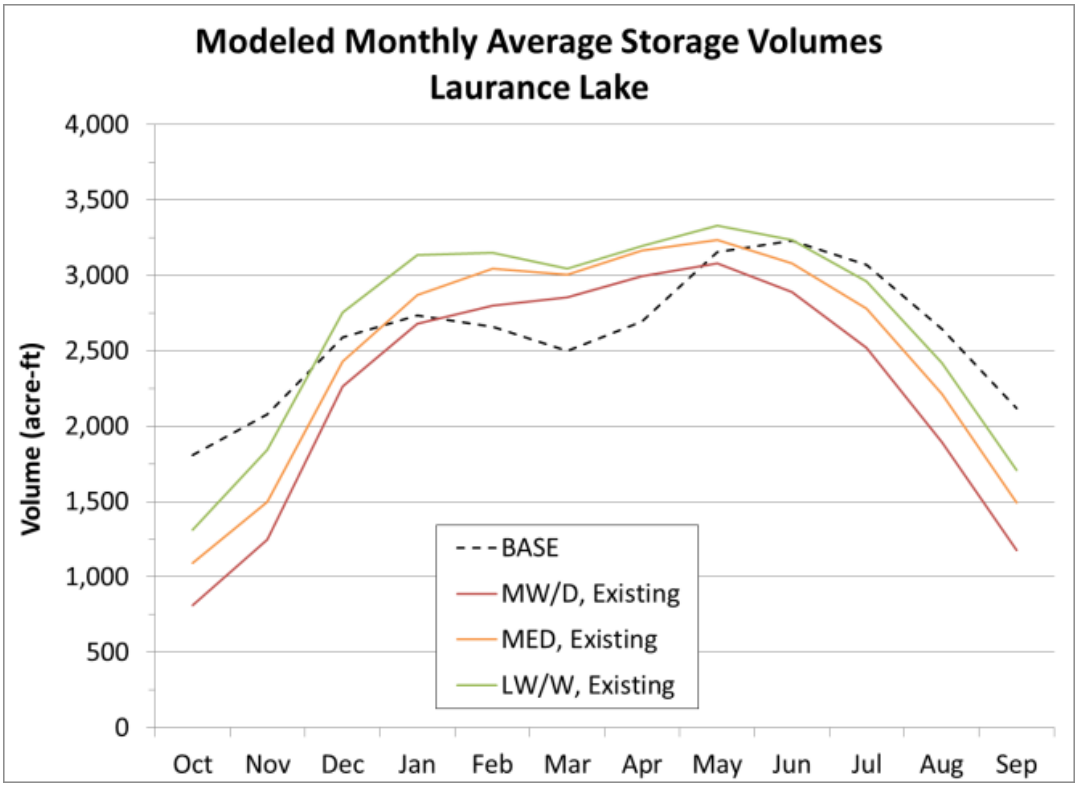

Figure ES-9. Comparison of existing conditions with expanded storage capacity at Laurance Lake Reservoir.

Costs estimates and evaluation of all three storage facilities are provided in Section 6.0. While all three provide added benefits to water users in the basin, Neal Creek facility provides the most significant value because the water users east of the Hood River do not currently have a storage facility; however, it also is the highest cost in terms of money and potential impacts to the surrounding environment. Further analysis of this and the other two options would be needed if these storage options are to be pursued.

Groundwater Alternatives

Groundwater has not been fully developed in the basin and, therefore, little is known about the hydrogeology in the basin. All available information was used to construct a water budget and develop a conceptual model of the aquifer system. A single layer MODFLOW model of the basin was developed and used to evaluate current and future conditions. Due to the limited amount of data used to develop the model, it is recommended that the model results be interpreted on a qualitative rather than quantitative basis.

Three options were evaluated using the MODFLOW model, including increased pumping; aquifer storage and recovery; and streamflow augmentation. The modeled increased pumping scenario under current climate conditions show groundwater level drawdowns of up to several feet in the DID, MFID, and MHID service areas as a direct result of significant irrigation with

groundwater. Drawdowns are relatively more substantial in the EFID service area with water level decreases of up to a few tens of feet given the modeled increase in pumping. Baseflows at the Hood River at Tucker Bridge gage are generally decreased on average in the summer due to the groundwater pumping.

The climate change analysis showed a potential increase in precipitation and temperature. Because precipitation has the greatest impact on recharge, increased precipitation could have a direct impact to groundwater conditions in the basin. Increased recharge would result in an increase in groundwater levels and an increase in baseflows. Warming temperatures could counter these potential positive impacts because it is likely that warmer temperatures would cause increased crop water demand and decreased summer streamflows, both of which could be supplemented by groundwater pumping. Although the timing of recharge may be impacted by a warming climate due to change in snow hydrology, modeling this mechanism was outside the scope of this Basin Study.

Streamflow augmentation and aquifer storage and recovery options were simulated by injecting water into the aquifer and observing the relative travel and residence times. The results showed that a direct injection in the fall and winter months (when additional water is available) could increase the groundwater contribution to summer streamflows when additional streamflow is needed. Additional hydrogeologic data to further constrain the calibrated parameters in and around areas of interest for aquifer injection might help to quantify the viability of managed recharge. An option for further investigation would be the use of infiltration ponds which could impose a time-lag before water is seen in the aquifer. This activity would require a more in-depth site selection and investigation process to quantify the feasibility of the use of infiltration ponds.

The modeled results show that there are areas where direct injection to the aquifer could be beneficial for aquifer storage and recovery. The area south of Odell retains a large proportion of injected volume two seasons after injection and it also has the added benefit of improving summer streamflows. Further investigation is required to assess the feasibility of aquifer injection in this location.

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1.0 INTRODUCTION

In 2009 Congress enacted the Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act that authorizes the Bureau of Reclamation (Reclamation) to determine the impacts of climate change on water supply, demands, and reservoir evaporation. It further authorizes Reclamation to evaluate those impacts on water delivery, power production, flood management, and ecological resources (e.g., ecological resiliency).

To implement the SECURE Water Act, the U.S. Department of the Interior established the Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program in 2010. This program enabled all bureaus of the U.S. Department of the Interior to collaborate with states, Tribes, and local agencies to determine the potential impacts of climate change and develop mitigation and adaptation strategies to address those impacts. WaterSMART grants were established to facilitate these collaborative efforts. These grants are provided every year based on a competitive process with the requirement that non-Federal entities cost-share the effort 50/50.

In April 2012, Reclamation initiated the Hood River Basin Study (Basin Study) in collaboration with Hood River County and other stakeholders throughout the Hood River Basin. The purpose of the Basin Study was to define current and future imbalances in water supply and demand in the Hood River basin over the next 50 years (through 2060), and to develop and analyze adaptation and mitigation strategies to resolve those imbalances. Adaptation strategies and mitigation options were developed and analyzed to determine how future imbalances could be addressed. Hood River County and Reclamation collaborated to address four main components of the Basin Study Program including:

1. Projections of water supply and demand within the Hood River basin, or improvements on existing projections, taking into consideration the impacts of climate change.

2. Analysis of how existing water and power infrastructure and operations will perform in the face of changing water realities such as population increases and climate change.

3. Development of structural and nonstructural options to improve operations and infrastructure to supply adequate water in the future.

4. A trade-off analysis of the options identified and findings and recommendations as appropriate. Such analysis examines all proposed alternatives in terms of their relative cost, environmental impact, risk, stakeholder response, or other attributes common to the alternatives. The analysis can be either quantitative or qualitative in measurement.

In addition to this Basin Study, Hood River County entered into an agreement with the Oregon Water Resources Department (OWRD) to conduct a Water Supply and Storage Feasibility Study (OWRD Storage Study) in the Hood River basin. The work associated with the OWRD Storage Study was used as cost-share with the Basin Study. More information on the results from the OWRD Storage Study, which leveraged efforts by Reclamation completed as part of this Basin Study, is provided in Section 3.3.2.

1.1 Study Approach

The Plan of Study, completed by Reclamation in mid-2011, outlined the overall Basin Study strategy and management approach. In addition, concurrent activities were conducted by Watershed Network Professionals (WPN), Hood River County's Study Manager, including the Water Use and Water Conservation reports. Significant support and input from WPN was provided to Reclamation ensure that the results of all the modeling efforts represented the Hood River basin water processes correctly. In addition, several teams were established to complete this Basin Study and included:

- The Core Team, composed of the Reclamation Study Manager and technical staff and the Hood River County Study Manager and technical staff, met weekly initially, then slowly extended meetings to monthly to track communication and results of each major task of the Basin Study. The budget and schedule of the Basin Study were also reviewed as needed.

- The Project Team, composed of the Core Team and stakeholders from the Hood River County Water Planning Group (HRCWPG), irrigation districts, and other interested parties, met monthly to review the status of tasks, discuss outcomes, and course-correct where necessary.

- Technical Subteams, composed of the Core Team leads and interested stakeholders from Hood River area, participated in the completion of the technical tasks.

    - The Reservoir Storage Subteam included Reclamation staff and interested stakeholders from the HRCWPG to evaluate the potential sites for either additional storage or enhancing storage at existing facilities that were provided by Hood River County.

    - The Climate Change Development Subteam included Reclamation staff in addition to interested stakeholders from the HRCWPG. This sub-team conducted the climate change analyses, discussed results, and documented results.

- The Groundwater Modeling Subteam included Reclamation staff in addition to groundwater experts from the United States Geologic Survey (USGS) and interested stakeholders from the HRCWPG. The subteam described the needs, established goals, conducted the groundwater modeling analyses, and documented results.

- The Surface Water Modeling Subteam included Reclamation staff in addition to hydrologic modeling experts from the University of Washington and interested stakeholders from the HRCWPG. This subteam conducted the hydrologic model analyses, discussed results, and documented results.

- The Water Resources Modeling Subteam included Reclamation staff in addition to the Hood River County Study Manager, technical staff, and interested parties from the HRCWPG. This subteam conducted the water resource model analyses, discussed and documented results.

To accomplish the work in this Basin Study, interim assessments and technical memorandums were published to document the on-going work of the participants. This *Hood River Basin Study Report* (Basin Study Report) provides a summary of these interim assessments and the technical memorandums including:

- *Hood River Basin Water Use Assessment* (WPN 2013a)
- *Hood River Basin Water Conservation Assessment* (WPN 2013b)
- *Hood River Basin Surface Storage Feasibility Assessment Report* (Hood River County 2014)
- *Instream Flow Incremental Methodology* (Normandau Associates 2014)

In addition to the above assessments, Reclamation completed five technical memorandums (TM) to document the technical efforts carried out in this Basin Study. These technical memorandums are summarized in this Basin Study Report and include:[4]

- *Technical Memorandum 1 - Potential Reservoir Storage Locations* provides an overview of the geology and describes the potential of using pre-selected areas as potential new reservoir storage locations or expanding storage at existing reservoir storage sites. Hood River County provided input for this Basin Study.

[4] These technical memorandums are available at http://www.usbr.gov/pn/programs/studies/oregon/hoodriver/index.html.

- *Technical Memorandum 2 - Climate Change* describes the approach, methodology, and results of the climate change effort that resulted in generation of projected future precipitation and temperature patterns that were used in the Basin Study.

- *Technical Memorandum 3 - Groundwater* describes the collection and use of groundwater information to develop a water budget and MODFLOW model and the results of those efforts.

- *Technical Memorandum 4 - Hydrology* describes the Distributed Hydrologic Soil Vegetation Model (DHSVM), which is the hydrologic model used to simulated historical and future runoff and results.

- *Technical Memorandum 5 - Water Resources* describes the water resource management model (MODSIM-DSS) used to analyze historical and future streamflow patterns, water use, and results.

1.2 Study Outreach

In 2008, the HRCWPG was developed by Hood River County as a way to bring together a group of stakeholders from a wide array of interests and backgrounds to create a comprehensive water planning document. Hood River County advertised openings on the committee for interested members of the public as well as soliciting membership from representatives of irrigation districts, municipal water suppliers, the watershed group, the local water master, the local Soil and Water Conservation District (SWCD), and County Planning Department. The group had its first official meeting in January 2009.

Since then, the HRCWPG has initiated compilation of existing data and baseline information including water availability and use, hydrogeology, and water storage and infrastructure information. This information was used to better understand the current challenges and anticipated needs that could be addressed in the Basin Study. The major gaps identified were the lack of sufficient data and physical modeling to better evaluate their challenges and needs. The goal of this Basin Study was to help fill those gaps as part of meeting the objectives identified of the Basin Study Program.

1.3 Coordination

The Basin Study was conducted in collaboration with stakeholders throughout the basin. Interest was broad and included irrigation districts within the Hood River basin, domestic water suppliers, Hood River County, HRCWPG, Hood River SWCD, The Confederated Tribes of the Warm Springs, OWRD water master, Natural Resources Conservation Service,

and various interested citizens in Hood River County. Regular updates on the status of tasks and any results were provided to the HRCWPG at their monthly meetings using webinars. Feedback was obtained and incorporated into the effort as appropriate.

Several methods were used to share information with all of the stakeholders and interested parties. Hood River County's HRCWPG webpage was used to share all of the information provided at the webinars, status updates, and other information relevant to the Basin Study.[5] Reclamation established a webpage to share draft technical memorandums and other documents that needed review by stakeholders.[6] The final presentation material, monthly status reports, and final technical memorandums were also posted to this site. In addition to these outreach efforts, the results of the analyses by the multiple subteams described in Section 1.1 were shared with the full team through regular monthly or sub-monthly briefings.

[5] See http://www.co.hood-river.or.us/index.asp?Type=B_BASIC&SEC={FE70783E-39E7-462A-B147-2F58DE75EC63}.

[6] See http://www.usbr.gov/pn/programs/studies/oregon/hoodriver/index.html.

2.0 BACKGROUND

The Hood River basin is located in northern Oregon just south of the Columbia River extends from the summit of Mount Hood to the south, the eastern ridgeline known as Surveyors Ridge to the east, the ridgeline of the Cascade Range to the west, and the Columbia River to the north. This 482 square mile region includes the unincorporated communities of Parkdale, Mt. Hood, Odell, Dee, Pine Grove, and Oak Grove, as well as the City of Hood River, which is located in Hood River County (Figure 1).

Precipitation in the basin varies widely by elevation and east/west location. The summit of Mount Hood receives approximately 150 inches of precipitation per year while the Hood River Valley receives between 30 and 45 inches per year depending on location in relation to east/west direction (the eastern portion of the watershed receives considerably less precipitation than the western portion). The basin relies heavily on surface water flows for irrigation and groundwater springs for drinking water supplies. The primary source for surface water and spring fed groundwater is snowmelt from the snowpack and glaciers on Mount Hood.

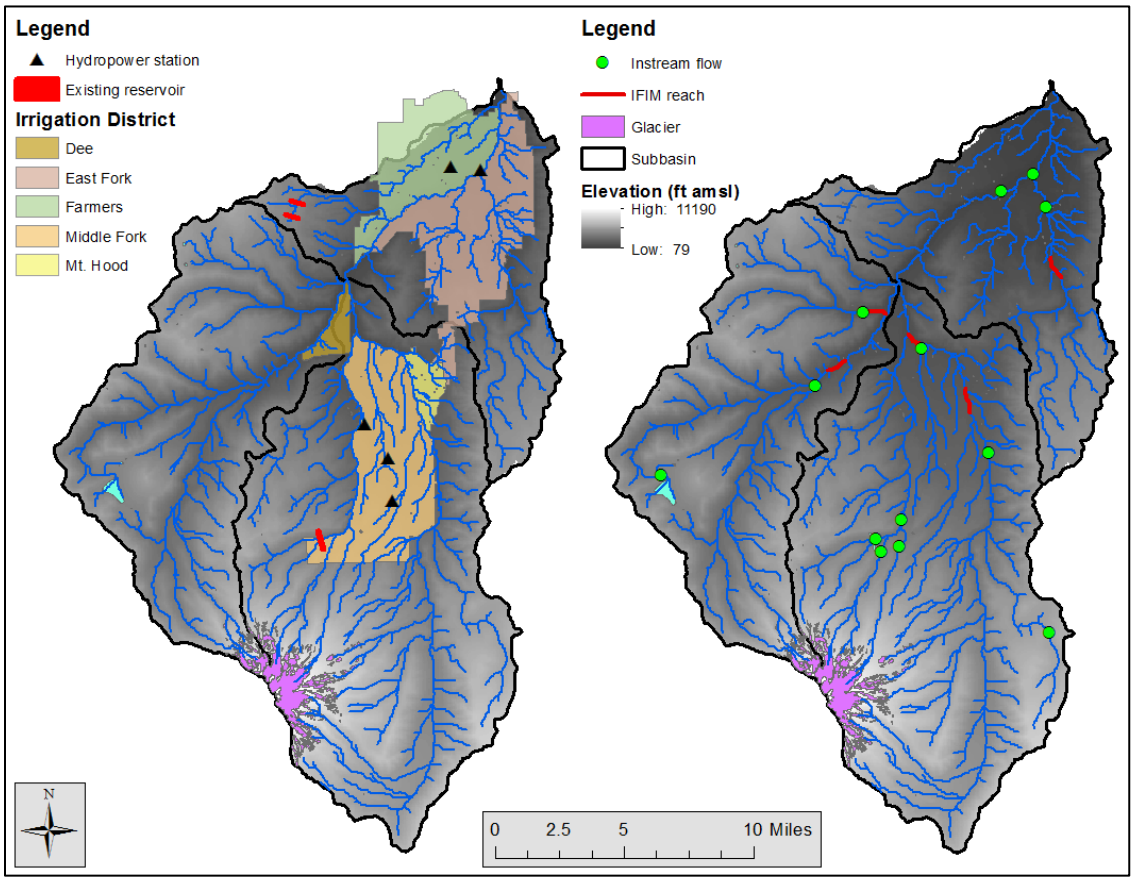


Figure 1. Hood River Basin irrigation districts, reservoir system, and stream network.

2.1 Domestic/Potable Water

The basin supplies drinking water to approximately 20,000 people in the basin (17,000 of these are served by community drinking water supplies) plus an additional 20,000 people in the City of The Dalles, which is outside of the basin. The water districts in the basin are comprised of Crystal Springs Water, Ice Fountain Water, the City of Hood River, Parkdale Water, and Odell Water. Groundwater wells are also used around the Hood River basin for domestic water for individuals.

Drinking water in the basin comes primarily from springs. While these water sources are technically groundwater, the water rights are surface water rights because the flows are captured on the surface at springs without the use of wells. Little is known about the hydrogeology of the Hood River Valley, which makes the impact of surface water flows on these domestic water sources difficult to predict (Keller 2010). Since the completion of this Basin Study, significant actions have been taken to collect new well data and compile existing hydrogeologic data. Of the six domestic water districts, only one has completed a detailed analysis of the zone of contribution for the source water (Crystal Springs, Yinger 2003).

The projected increase in demand for domestic water supplies is minimal due to the zoning of the majority of the basin. The vast majority of land located in the Hood River Valley is zoned for exclusive farm use or for forestry and therefore is not subject to urbanization. The major water supplies for areas where growth could occur appear to have sufficient water rights to accommodate all potential growth.

2.2 Groundwater

Groundwater is a resource that has not been extensively developed in the basin so data that are critical to understanding the system are limited. Previous reports that attempted to define hydrogeologic patterns in the basin include a 1966 Ground Water Report document developed by the State of Oregon (Sceva 1966) and a 1983 Water Resources Investigations Report published by the United States Geological Survey (Grady 1983; Keller 2010). Geologic understanding in the basin was improved considerably in 2012 with the completion geologic mapping of the basin by McClaughry et al. (2012).

Additional geologic and hydrogeologic information can be gained from wells, but a relatively small number of wells exist in Hood River County. Approximately 450 wells were registered through the year 2008. In recent years, wells have been tapped for irrigation use late in the irrigation season when water quality and quantity concerns could cause more irrigators to turn to groundwater in the future. Adjacent watersheds have seen significant groundwater declines due to over appropriation and the slow recharge of the Columbia River Basalt aquifers (Keller

2010). An increase in wells tapped for irrigation could conceivably affect existing domestic wells as well as surface water flows.

2.3 Surface Water

Surface water flow is important for a variety of reasons including meeting irrigation needs, hydropower, protection of aquatic species, maintenance of healthy riparian areas, recreation, and scenic value. The economy of Hood River County is primarily dependent on irrigated agriculture, which has approximately 23,954 acres of agricultural land. In 2010, raw agricultural commodity sales in Hood River County were $87,598,000 (Oregon State University Extension). The economy of Hood River County is clearly dependent on a reliable supply of irrigation water now and in the future.

Irrigated agriculture began in earnest in the Hood River Valley in 1874 with the development of the Water Supply Company of Hood River Valley. In the intervening 137 years, the surface water of the Hood River basin has been fully appropriated (for withdrawal between April 15 and September 30) and has seen many cycles of scarcity of supply and changes in water quality. Cycles of drought have caused water rotations and in severe drought years have resulted in a complete lack of water for some water users for the latter part of the irrigation season (Bryan 2011). Currently, estimated actual consumptive diversion for the peak summer irrigation period is 40 percent of the average natural flow of the Hood River (Stampfli 2008).

In addition to supplying irrigation water, two of the irrigation districts, Farmers Irrigation District (FID) and Middle Fork Irrigation District (MFID), in the Hood River basin produce electricity through hydropower facilities. This hydropower production has historically provided valuable income to the respective districts that has allowed them to continually work to improve operational efficiencies.

Since 1998, four species of fish residing in the Hood River basin have been listed as threatened under the Endangered Species Act (ESA). Protection of aquatic species has been a driving factor for much of the restoration work performed in the Hood River basin over the past 20 years.

3.0 Existing Water Supply and Demand

This section describes efforts completed by Reclamation and WPN that provided data and additional information needed in this Basin Study and includes a link to the specific document where applicable. Normandau Associates is in the process of completing an Instream Flow Incremental Methodology report, but that work was not available in time to summarize in this Basin Study Report.

3.1 Water Use Assessment

In June 2013, the WPN completed the *Hood River Basin Water Use Assessment* (WPN 2013a). The Water Use Assessment is divided in to six major parts:

1. Potable water use
2. Irrigation water use
3. Hydropower water use
4. Instream water use
5. Industrial water use
6. Water resource modeling data.

Parts 1 through 5 contain general information, detailed OWRD water rights and water use information, plus a discussion of the quality of that information, and where applicable, new and better information. Part 6 contains historical Hood River streamflow, data and results for naturalizing (i.e. removing the effects of storage and diversions) streamflow, and an analysis of the contribution from baseflows and glacial melt to streamflows. Data in Part 6 were used in the hydrologic and water resource modeling performed by Reclamation. These six parts are summarized in this Basin Study Report in the following pages. Additional details can be found in the Water Use Assessment.

3.1.1 Approach

Information contained in the Water Use Assessment is a combination of data obtained from OWRD and data obtained directly from the stakeholders of the HRCWPG. The OWRD data includes information from their Water Rights Information System[7] (WRIS), water user reports,[8] and geospatial database.[9] Individual districts provided access to past reports,

[7] See http://www.oregon.gov/owrd/pages/wr/wris.apex.
[8] See http://www.oregon.ogv/owrd/pages/wr/water_use_report.aspx.
[9] See http://www.oregon.gov/owrd/Pages/maps/index.aspx.

unpublished data, and information on general operations. Information contained in this report represents the best, most accurate information from these sources. Data from the websites described above were downloaded, assembled into tables, and all non-cancelled water rights were extracted. Geospatial data were extracted and compared against the WRIS database. Comparisons were made, mapping errors corrected, and a final layer of diversions was developed and provided to the Hood River County for inclusion in their web map server.[10]

Data that underwent a quality review are provided using summary tables, figures, and discussion in the body of the Water Use Assessment, while raw data with additional fields (e.g., township/range, stream code) obtained from OWRD are contained in electronic appendices (Microsoft Excel). Data contained in the Water Use Assessment and appendices are also available through an interactive web map hosted on the Hood River County website.[11] Data from the various sources were combined with data provided by the local County Watermaster. Multiple reviews by individual irrigation districts, and water companies were held by WPN until approval of the results contained in the Water Use Assessment were obtained.

3.1.2 Summary of Results

Potable Water Use

Hood River basin supplies water to multiple potable water districts including The City of Hood River, Crystal Springs Water District, Ice Fountain Water District, Odell Water Company, Parkdale Water Company, Mount Hood Meadows Resort, Port of Hood River, and the City of The Dalles (Figure 2).

[10] See http://www.co.hood-river.or.us/index.asp?Type=B_BASIC&SEC={874DEC00-B8C0-4CE2-A2D9-C088E3325A16}.
[11] See http://www.co.hood-river.or.us/.

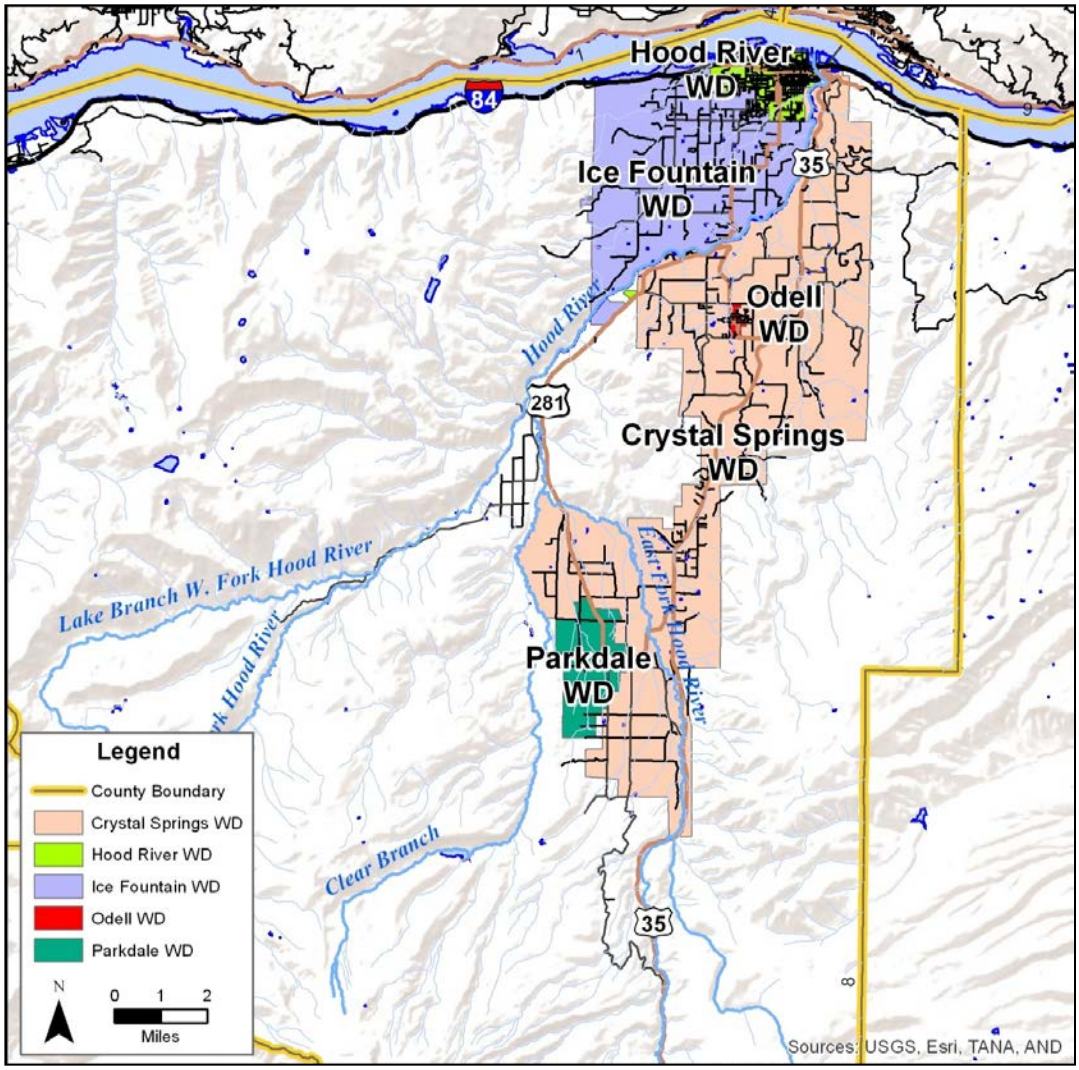


Figure 2. Geographic boundaries of the potable water districts in Hood River County, Oregon.

Annual water use varies significantly by water district (Figure 3). The Dalles, Crystal Springs, and Hood River County are the three highest consumers of average monthly water (Figure 4). A summary of each major water company's potable water use is listed in Table 1, in addition to the main source of their water supply and general water use information. Several other potable water users are documented in the *Hood River Basin Water Use Assessment*, but are not included in this summary.

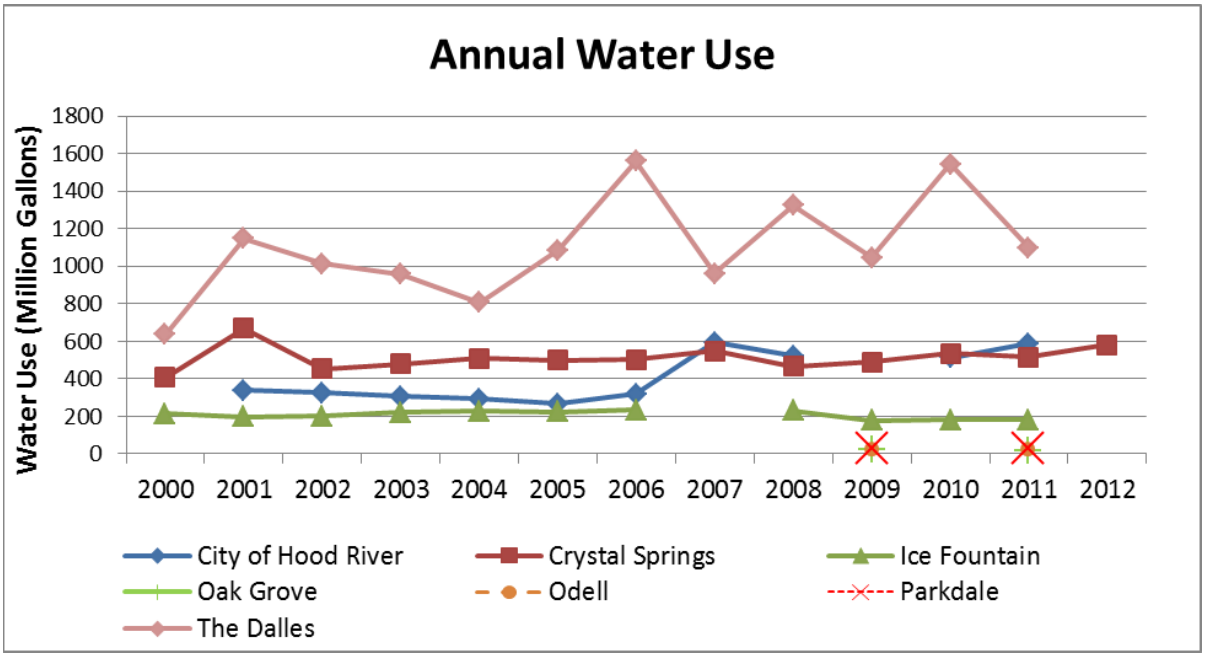


Figure 3. Annual water use for major potable water districts in the Hood River basin, Oregon.

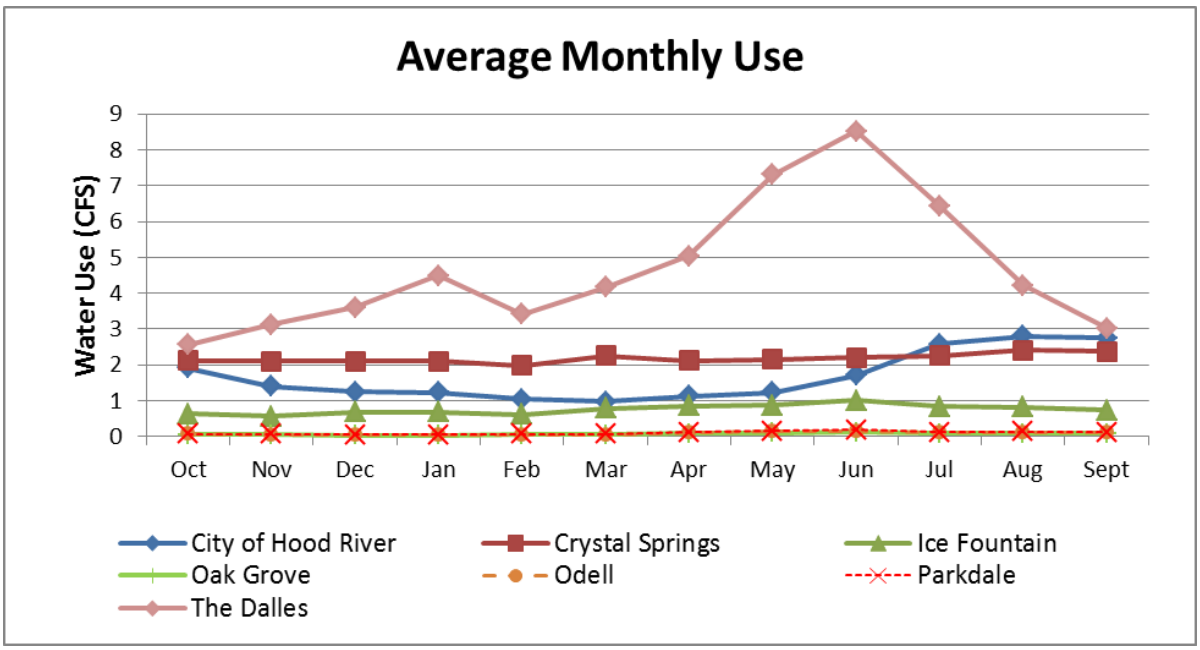


Figure 4. Average monthly water use for major potable water districts in the Hood River basin, Oregon.

Table 1. Summary of potable water use by major water company.

Water Company	Source	Use
City of Hood River	Springs	7.1 cubic feet per second per year (cfs/ year). Average use throughout the year ranges from 2.8 cfs in July to 0.98 cfs in March.
Crystal Springs Water District	Springs	7.15 cfs/year. Average use throughout the year ranges from 1.98 cfs in February to 2.41 cfs in August.
Ice Fountain Water District	Springs (plus intertie with City of Hood River for backup)	3 cfs. Average use ranges from 0.57 to 1.01 cfs
Oak Grove Water Company	Spring	No records. Values were estimated.
Odell Water Company	Springs that are tributaries to McGuire Creek	1.25 cfs. No records of monthly use so values were estimated.
Parkdale Water Company	Spring	1.5 cfs
The Dalles	Dog River	Average of 4.7 cfs over the year. The water right is for all streamflow at diversion.

Irrigation Water Use

Five irrigation districts are in Hood River County: the Dee Irrigation District (DID) on the West Fork, East Fork Irrigation District (EFID) and Mount Hood Irrigation District (MHID) on the East Fork, FID on the mainstem of Hood River, and MFID on the Middle Fork (Figure 5). The irrigation districts range in size from 870 acres to 15,150 acres. FID and MFID both have hydropower facilities and operate diversions year-round. The remaining irrigation districts generally divert during the irrigation season from April 15 to September 30. Table 2 provides an overview of the major irrigation districts (acreage), the source of their supply, and a water use summary.

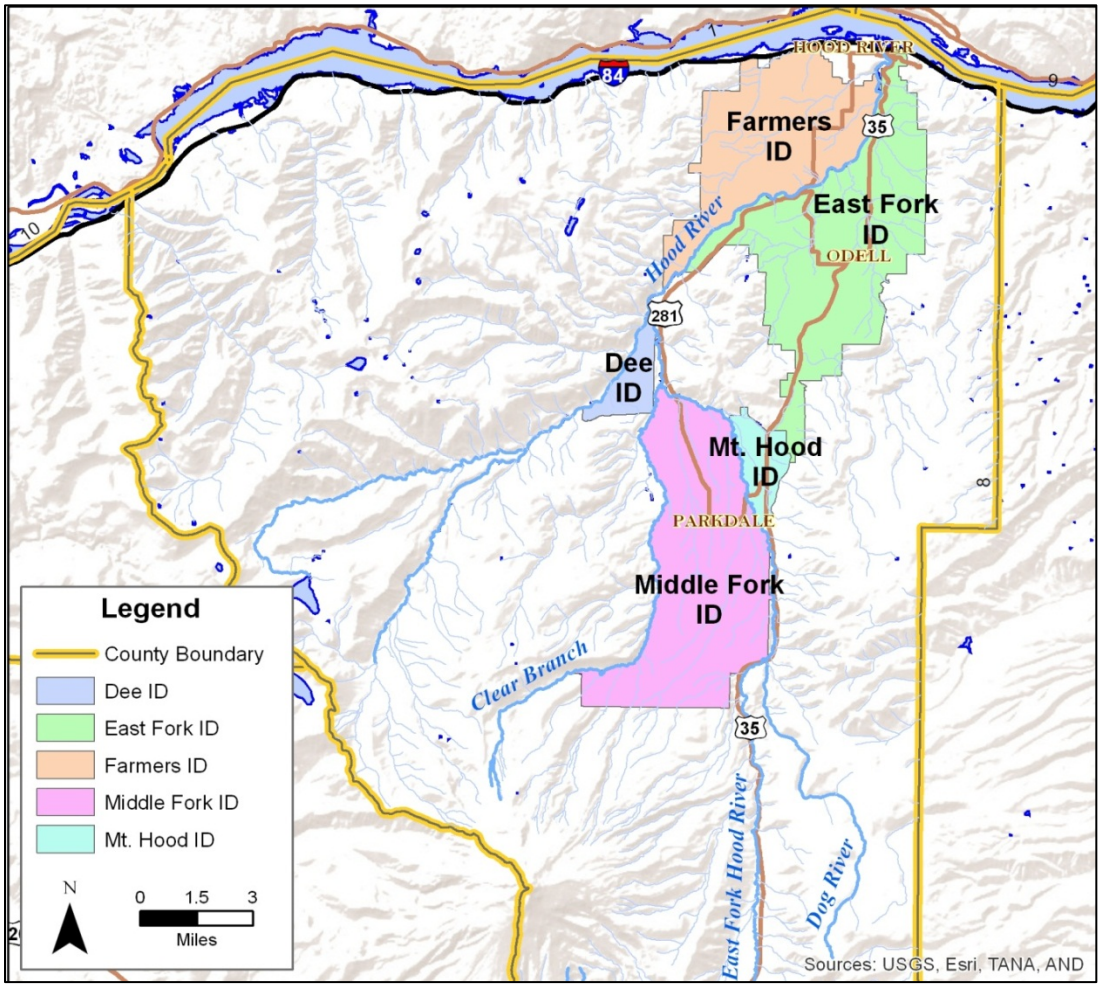


Figure 5. Irrigation district boundaries in Hood River County, Oregon.

Table 2. Summary of major irrigation districts in Hood River County, Oregon.

Irrigation District	Source	Reservoirs	Use
Dee Irrigation District (870 irrigated acres)	West Fork Hood River, Deer Creek, Camp Creek, and three springs	None	10.6 to 12.3 cfs at the peak in July or August (reduced to 8.8 cfs in 2013 due to seepage control)
East Fork Irrigation District (15,150 acres total with 9,612 acres with water rights)	East Fork Hood River (diverts for Mt. Hood too)	None	Peak irrigation demand is roughly 104 cfs in July.
Farmers Irrigation District (12,000 acres total with just less than 6,000 acres of water rights)	Mainstem Hood River	Operates Upper Green Point and Lower Green Point Reservoirs (combined capacity of 981 acre-feet) fed by Gate Creek and Cabin Creek via pipeline	73 cfs hydropower right from the mainstem; 40 cfs irrigation right, and 30 cfs for orchard spraying. The hydroelectric plants generate about 25,00MW-hoursr/year combined. Reservoirs are drained at the end of each irrigation season.
Middle Fork Irrigation District (6,362 acres)	Eleven major point of diversion from the East Fork Hood River (Emil, Evans, Griswell, Trout, and Wisehart creeks) and the Middle Fork Hood River (Clear, Coe, Eliot, Pinnacle, and Rogers creeks). One sediment basin and one small regulating facility	Laurance Lake Reservoir (3,565 acre-feet capacity). It also has three hydropower facilities.	106.2 cfs total irrigation water rights; 40 cfs at any one time for hydropower
Mt. Hood Irrigation District (1,110 acres)	Receives water from the EFID diversion off the East Fork Hood River	None	12.65 cfs annually. Peak use is 10.1 cfs in July.

Hydropower Water Use

MFID and FID have hydropower facilities as shown in Figure 6. FID operates two facilities while the MFID operates a total of three. Water diverted for irrigation by FID cannot be used to generate power so as irrigation season ramps up in May, there is a significant decrease in the amount of water available for hydropower production. Annual combined power production has increased slightly (ranging from 18,200 Megawatt-hour (MW-hr) in 2005 to 25,700 MW-hr in 2010) over the last 10 years, some of which is attributed to improved operational efficiencies (Figure 7).

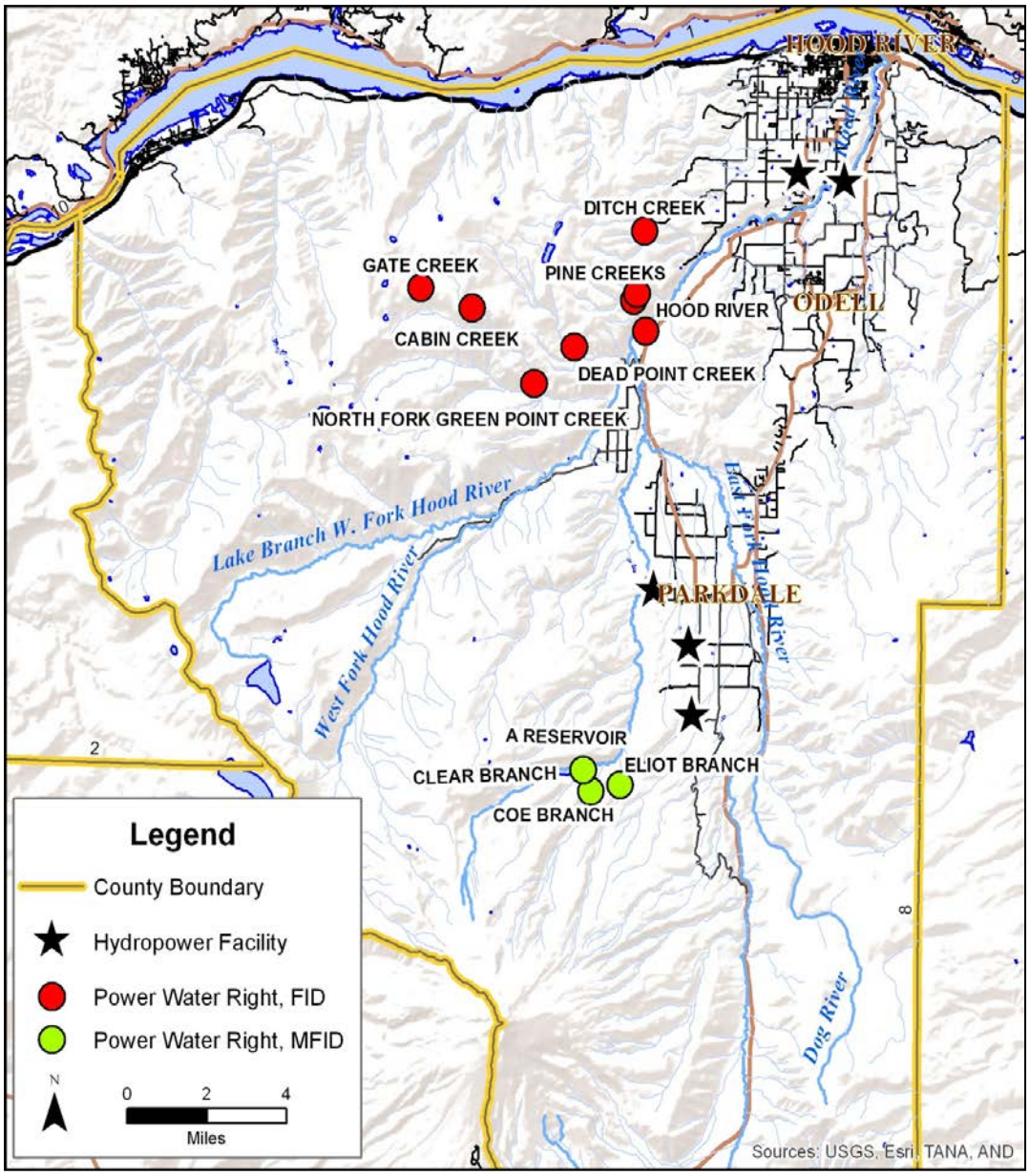


Figure 6. Hydropower facilities in the Hood River basin, Oregon.

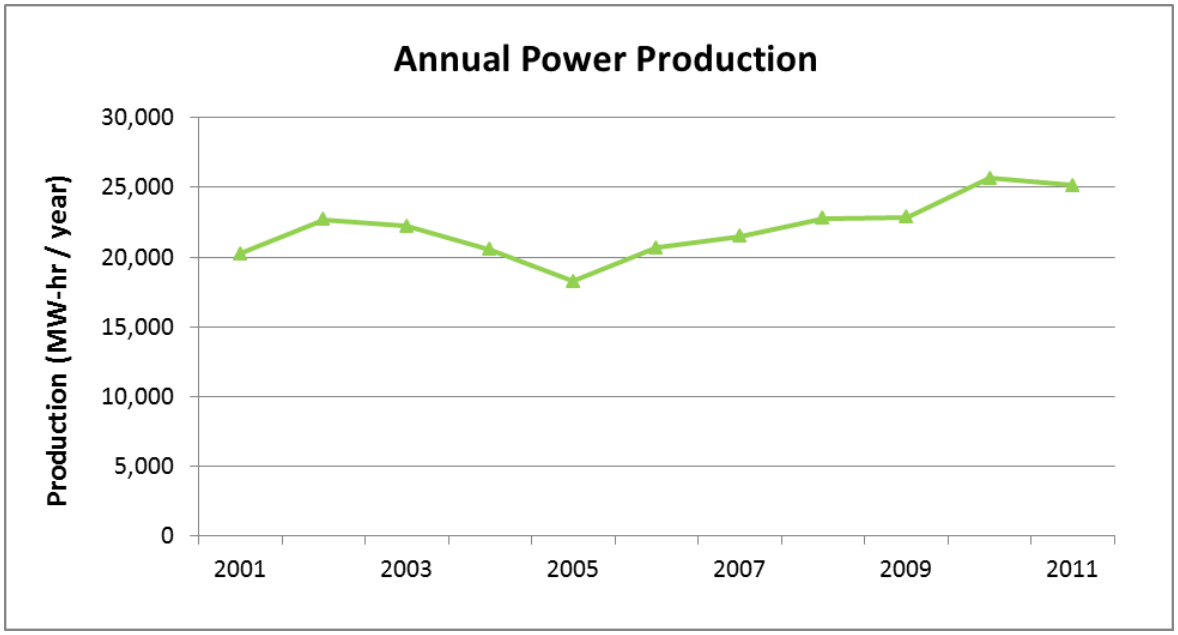


Figure 7. Annual combined power production for Farmers Irrigation District.

The MFID operates three hydropower facilities that are situated in a series as well. The upstream facility is Plant No. 1, the middle facility is Plant No. 2, and the downstream facility is Plant No. 3. Peak power production occurs in May during snowmelt and high reservoir elevations, and before significant consumptive irrigation demands must be met (Figure 8).

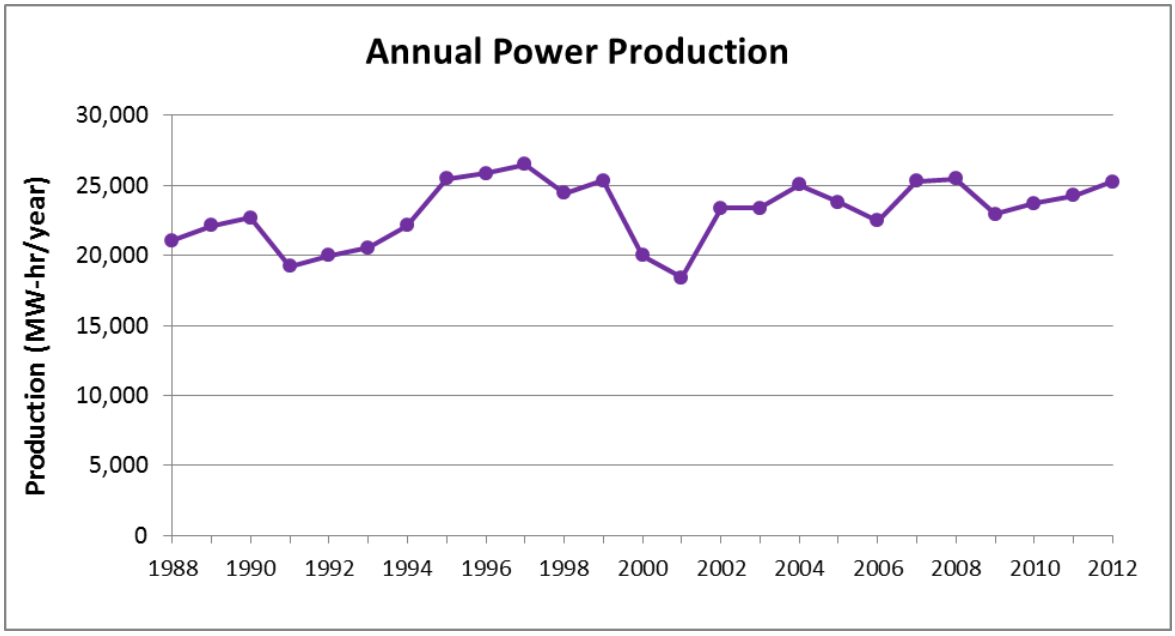


Figure 8. Annual combined power production for Middle Fork Irrigation District.

Instream Water Use

There are eight major instream water rights in the Hood River basin held in trust by OWRD for the people of Oregon (Figure 9). These rights establish flow levels in a stream on a month-by-month basis usually for specific stream reaches measured at a specific location on the stream. There are also two smaller instream water rights (typically a few cfs) that are the result of conserved water agreements, an agreement that ensure a portion of the water conserved will remain instream. For example, DID recently installed 4.5 miles of pipe, from which it will conserve 3 cfs. This right (as of this writing) is currently in the process of being transferred to an instream water right. The hydropower facilities of MFID and FID also have instream flow agreements. Instream flow agreements are legally binding to the parties involved in the agreement, but do not have a priority date.

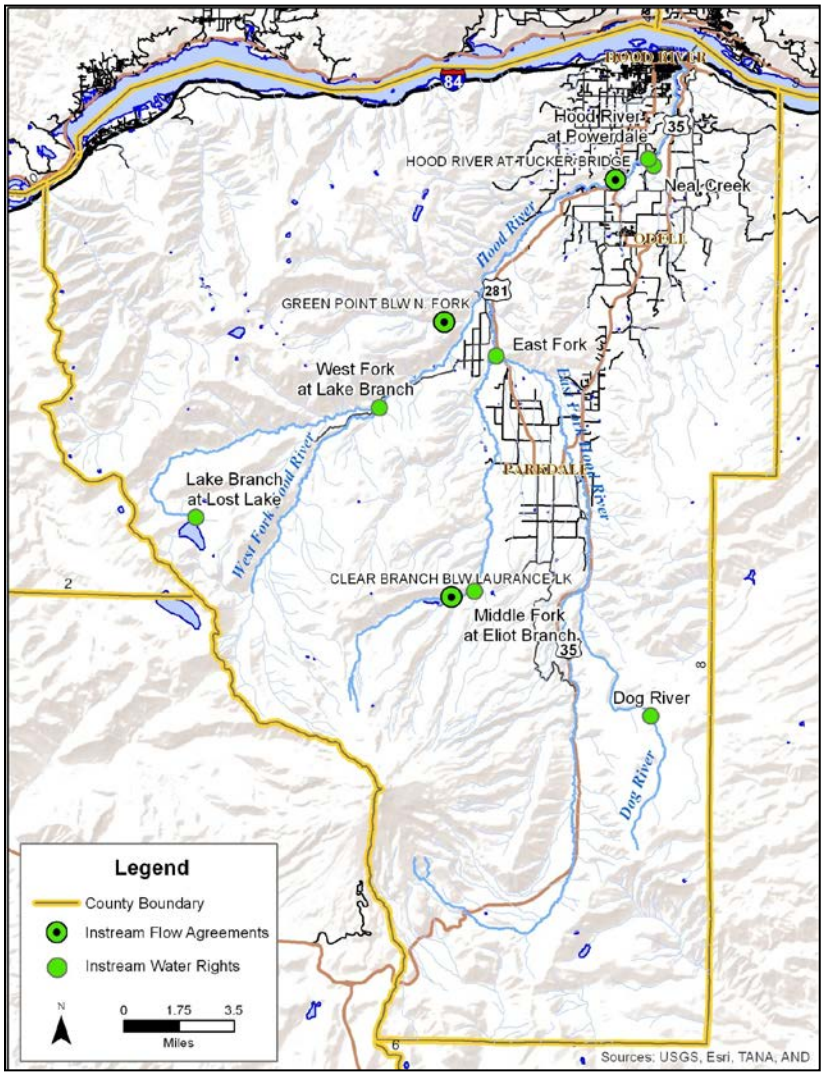


Figure 9. Location of instream water rights and flow agreements in the Hood River basin, Oregon.

Industrial Water Use

Although there are 17 water rights in the Hood River basin that fall under the OWRD use group of commercial, industrial, or manufacturing (Figure 10), most industrial water use in the Hood River basin is quite small and is often also served by other sources. Only two of the water rights list water use report IDs, which is a way to link a specific water user to their water right and document their water needs over time. One of those is EFID water use (WUR ID 16087) and the other contains no actual water use values. Nonetheless, most of the industrial water rights, as well as most of the industrial use in the basin, can be categorized into 1) cold storage/packing houses, 2) lumber mill, or 3) other/small use from which they can be analyzed.

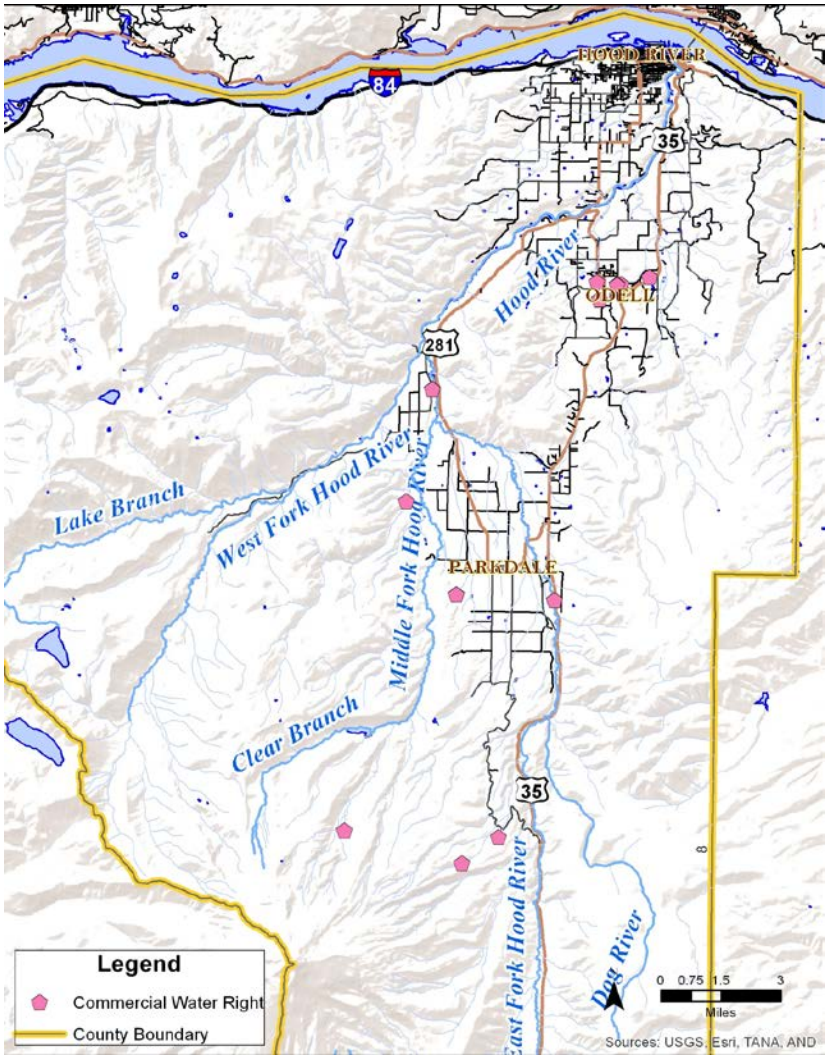


Figure 10. Location of all industrial water rights in the Hood River Basin, Oregon.

Water Resource Modeling Data

Data to support Reclamation's hydrologic and water resource modeling included an analysis of historical streamflow data, naturalizing (removing the impacts of irrigation diversions and reservoir operations) historical streamflow data, and analyzing baseflow recession and glacial contribution to streamflow in the basin.

Two gages in the basin have an extensive period of record and include the West Fork at Dee gage and the Hood River at Tucker Bridge gage. Of those two, the USGS gage at Tucker Bridge (No. 14120000) offered the most complete and long-term discharge data in the Hood River basin. The gage operated intermittently between 1897 and 1899 and 1914 and 1916. Since January 16, 1965 it has been operating almost continuously.

DHSVM is the hydrologic model that was constructed to simulate the basin and to generate simulated historical and future climate change streamflow throughout the basin (described in more detail in Section 4.2). Simulated historical natural streamflow was generated at 42 locations throughout the basin. Natural streamflow is flow unaffected by operations or irrigation diversions. Because the streamflow at the Hood River at Tucker Bridge is regulated streamflow (included operations and diversion affects), the regulated flow was "naturalized" for use in calibrating the DHSVM model by removing the effects of regulation from the following sources:

1. Laurance Lake operations
2. MFID diversions
3. MFID Plant 3 return flow
4. DID diversions
5. EFID diversions
6. MHID diversions
7. Combined Green Point reservoirs operations
8. FID diversions (return flow not included since location is downstream of Tucker Bridge gage)
9. Potable water diversions

To create naturalized streamflow, a time series was created by adding together values that reduce the natural streamflow (i.e., diversions and filling of reservoirs) and subtracting out values that supplement natural streamflow (i.e., return flows and reservoir drawdowns). This adjusted time series was then added to the Hood River at Tucker Bridge regulated streamflow to create Hood River at Tucker Bridge naturalized streamflow. More details on the use of these data and the results are provided in Section 4.2.

3.2 Water Conservation Assessment

3.2.1 Approach

Implementing water conservation programs in the basin is increasingly important because of population increases, irrigated agriculture needs, and water supply needs for ESA listed fish. This section discusses the major sources of water use, including irrigation, drinking (potable) water, and hydropower, and the three areas in which significant water conservation can be achieved. Industrial water use and water used for fish production are relatively minor uses of water supply so limited gains would be achieved through water conservation in these areas. The next section briefly describes the conservation efforts in the three key areas. In addition, sedimentation impacts, which are significant in the basin due to the unlimited supply source of Mount Hood, are discussed.

3.2.2 Summary of Results

Conservation measures presented here and in the Water Conservation Assessment were considered in the context of each of the three measures' ability to increase instream flow during peak water demands. This peak demand period is during the summer months when streamflow is the lowest and when conservation efforts would have the most positive impact on flow.

Potable Water

Potable water conservation can be achieved through three primary pathways that include retrofitting indoor fixtures, outdoor water reduction through education and landscape conversion, and implementing a use-based rate structure. In general, all potable water conservation actions should be implemented, as feasible. However, The Dalles, a city outside of the basin uses 50 percent of the basin's total potable water. Because it is outside of the basin, it has less economic and political will to implement conservation measures and as such it reduces the effectiveness of conservation measure. The city supplements its basin water with groundwater in the summer. Pumping groundwater is more expensive than drawing water from the Hood River basin, so any reductions in The Dalles' overall water use would likely not affect its withdrawals from the basin.

According to the ECONorthwest (2008) report, water use changes due to population increases were estimated through 2040. The trends identified through 2040 were then extended to 2050 to better understand population growth, water use, and how climate change may affect the results. Average population growth per year is estimated at 2 percent in the city limits and less than 1 percent in rural areas (average of 1.39 over the basin included the City of The Dalles). While the population is anticipated to increase roughly 81 percent by 2050, water use

is expected to increase by approximately 31 percent over the same period. This estimate assumed increased indoor use and no changes to the outdoor irrigation use (lawn areas remain generally unchanged).

Domestic indoor water is primarily used for toilets, clothes washers, faucets, and showers (Colorado State University 2010). Conservation with these uses is achieved through retrofitting fixtures, addressing pipe leaks, and upgrading to more efficient appliances. Rebates on retrofitting showerheads and upgrading appliances is being considered and depending on how many households take advantage of such an offer, more than 36 million gallons of water per year could be saved at a cost of 0.68 cents per 1000 gallons.

Outdoor water use accounts for almost 30 percent of all residential water use in the United States, of which up to 50 percent is estimated to be lost to evaporation and seepage (EPA 2008). Addressing outdoor water use would be the most effective way to reduce potable use, particularly given that outdoor use peaks during the time the river flow is at or near its lowest. Actions such as constructing water efficient landscapes, paying residents to remove lawn (and replace with features that don't need water), or public outreach campaigns to minimize use are potential approaches to conservation. Instead of estimating each of these actions individually, an overall estimate of outdoor water savings of 25 percent was used to estimate the potential savings in water use in the Hood River basin. By reducing use of water for outdoor purposes, more than 50 million gallons of water can be saved each year in Hood River basin.

Other more politically sensitive options such as charging users based on the volume of water used (which was done at one time) or charging users more for water used above a certain threshold during peak times were also considered, but were not likely to be implemented (HRCWPG 2014).

Irrigation Water

Irrigation diversions occur from April 15 through September 30 peaking at 15 times that of potable water use peak. Because of that, small percentage reductions in irrigation water use could result in significant water savings. Irrigation water use can be reduced by converting to more efficient sprinklers (on-farm use changes), replacing open canals with pipes, implementing a use-based rate structure, and operational changes. On-farm use could be reduced by 16 cfs (about 6.5 percent of total on-farm use) through a program converting 49 percent of remaining traditional irrigation systems (impact sprinklers) to more efficient systems (micro or rotator sprinklers and soil moisture sensors). Eliminating losses in conveyance system would reduce irrigation use up to 35 cfs (or 9 percent of total use on average).

Hydropower

Five major hydropower facilities are located in the Hood River basin. Three of those are owned and operated by the MFID and two by FID. A sixth, smaller facility on Odell Creek is in the process of being decommissioned. Annual hydropower revenue could be increased by $17,700 in FID and $18,415 in MFID by implementing on-farm water conservation. While EFID's high flow rates would generate considerable power during irrigation season, the lack of flow outside of irrigation season makes the installation of a new hydropower facility economically impractical.

Sediment

The Hood River system has a high sediment load due to the considerable amount of glacial runoff it receives. Devastating flooding coupled with debris flows have historically occurred on the Hood River system. The frequency of flood/debris flow events have been increasing in recent years. From 1960 to 1995, one or two debris flows of record have occurred and since 1995, there has been one almost every other year (McMahan 2010). In 1996 and 2006, debris flows caused severe damage to infrastructure for all of the major irrigation districts. Debris flows in the Hood River basin are primarily caused by rain-on-snow events in the fall or in the spring. Glaciers receding on Mount Hood have exposed glacial silt and released massive quantities of saturated material that travel down the Hood River, causing extensive damage.

Sediment causes wear on high-efficiency sprinklers and drip irrigation systems, reducing their efficiency and potentially dissuading some growers from converting to such systems. Sediment also causes wear on turbines in hydropower facilities, requiring more frequent maintenance and more frequent turbine replacement that leads to higher costs. For these reasons, additional sediment control measures should be implemented. The high flow rates in the Hood River basin make active treatment technologies like chemical coagulation, electrical coagulation, and filtration impractical; therefore, physical settling should be targeted. EFID could develop a new settling basin, and MFID could improve its existing settling basin by installing silt curtains, as well as connect the Coe Creek diversion to the settling basin.

3.3 Reservoir Storage Studies

This section describes the results of Reclamation's two-day site visit and reconnaissance evaluation of potential sites for either additional reservoir storage facilities or enhancement of existing facilities in the basin (November 7, 2012 Memorandum and accompanying appendix). These potential sites were provided to Reclamation by Hood River County. Once the reconnaissance-level information obtained by Reclamation was refined and documented, HRC conducted additional analyses on three sites as part of a grant they obtained from OWRD. This section summarizes the results of both efforts

3.3.1 Reclamation

Approach

Staff from Reclamation's Regional Geology and Design groups participated in a two-day site visit to the basin to evaluate 17 reservoir alternatives that were under consideration for either new or expanded water storage sites (Figure 11). These sites had been identified by Hood River County in previous meetings with County stakeholders and through the HRCWPG. Additional variations to the dam height were later added to the Laurance Lake and Upper Green Point Reservoir. These included raising the Laurance Lake dam by three feet and Upper Green Point Reservoir dam by eight feet, which were selected as the preferred option and evaluated in more detail by Hood River County.

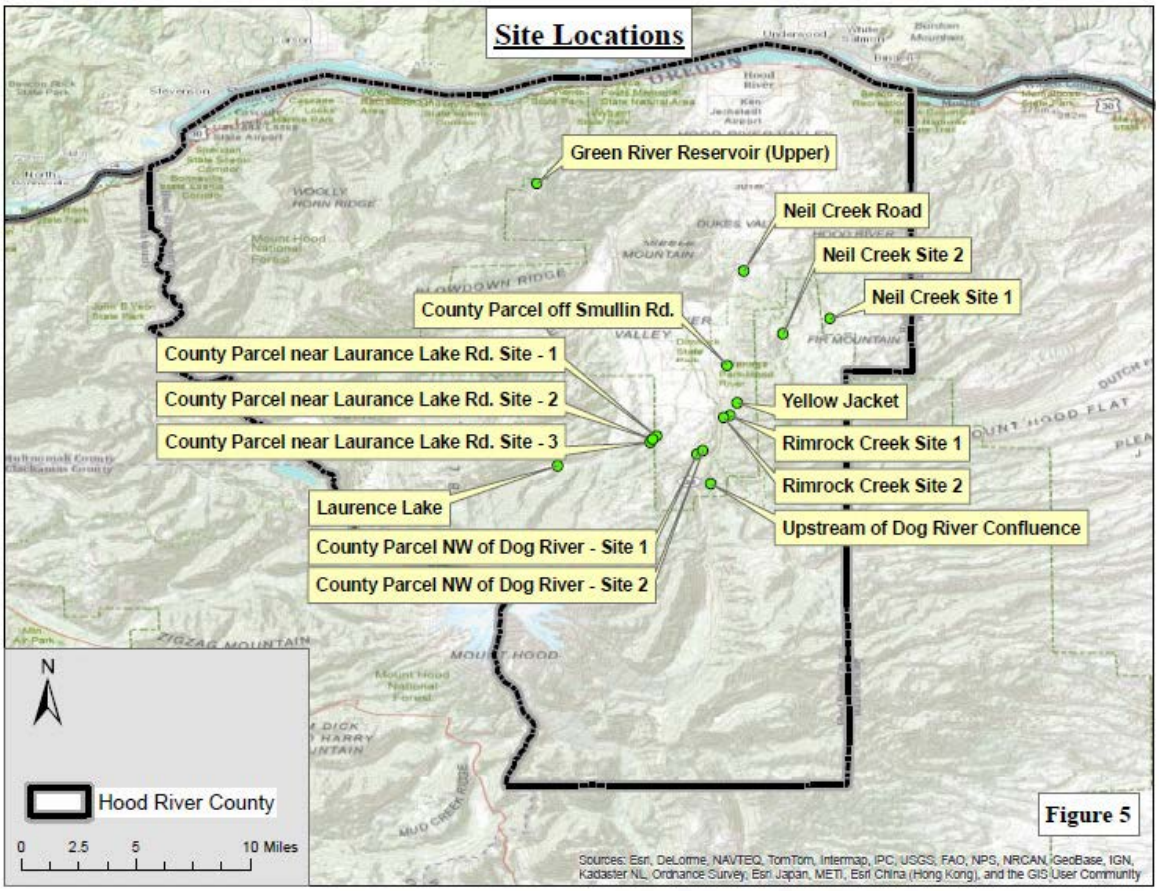


Figure 11. Potential locations for additional storage as identified by Hood River County.

Regional staff were tasked with conducting a site visit and qualitatively evaluating these potential sites using available information including geology, topographic maps, and any information available on the existing structures. Geologic hazards also were identified and documented along with the potential success of expanding existing structures.

Summary of Results

The geology of the proposed sites was difficult to assess onsite because of the presence of thick overburden and heavy vegetation. Regionally, the Hood River basin is in the Mount Hood/High Cascade Geomorphic Province of north-central Oregon (Reclamation 1982). The prominent physiographic feature to the north is the Columbia River Gorge and to the south is

Mount Hood (Figure 10). Table 3 provides general information about each site including potential dam dimensions and reservoir volume. Details on the sites that were selected for further analysis are provided in Section 6.3 of this Basin Study Report.

Table 3. Summary potential reservoir storage alternatives identified by HRCWPG.

Name	Dam Height (feet)	Dam Elevation (feet)	Dam Crest Length (feet)	Reservoir Area (acres)	Reservoir Volume (acre-feet)	Reservoir Length (feet)	Creek Slope (feet/feet)
County Parcel off Smulin Road	70	1850	830	20.9	493	1,107	0.06
Rimrock Creek Site 1	122	2110	439	4.4	170	957	0.13
Rimrock Creek Site 2	72	2200	355	2.2	53	583	0.12
Neal Creek Site 1	130	3090	1,038	65.2	2,850	3,691	0.04
Neal Creek Site 2	120	3090	1,572	60.1	2557	2,362	0.05
Neal Creek Road	50	1580	5,931	24.4	922	NA	NA
Dog River	286	2800	1,444	85.3	8,201	3,902	0.07
Yellow Jacket	240	2400	1,123	26.2	1,954	1,546	0.16
Laurance Lake[1]	3	2885	1616	--	370	--	--
Laurance Lake	18	3000	1,616	155.8	2,480	5,367	NA
County Parcel NW of Dog River - Site 1	60	2480	830	12.7	275	1,234	0.05
County Parcel NW of Dog River - Site 2	60	2540	592	11.6	261	1,093	0.05

Name	Dam Height (feet)	Dam Elevation (feet)	Dam Crest Length (feet)	Reservoir Area (acres)	Reservoir Volume (acre-feet)	Reservoir Length (feet)	Creek Slope (feet/feet)
County Parcel near Laurance Lake Road Site 1	38	2300	380	3.7	50	827	0.05
County Parcel near Laurance Lake Road Site 2	32	2334	273	2.6	30	693	0.05
County Parcel near Laurance Lake Road Site 3	24	2360	270	1.7	15	442	0.05
Green Point Reservoir [2] (Upper)	8	Tbd	Tbd	Tbd	561	Tbd	Tbd
Green Point Reservoir (Upper)	12	3176	1,156	63.2	676	2,906	NA

[1]Laurance Lake is an existing storage site with 3,565 acre-feet of storage. The value associated with this line item (raising the dam by three feet) is additional storage achieved with this new height. This alternative was carried forward for further analysis in the Oregon Water Resources Department Surface Storage Feasibility Assessment.

[2]Upper Green Point Reservoir is an existing storage site with 988 acre-feet of storage. The value associated with this line item (raising the dam by eight feet) is additional storage achieved with this new height. This alternative was carried forward for further analysis in the Oregon Water Resources Department Surface Storage Feasibility Assessment.

3.3.2 Oregon Water Resources Department

Approach

As a concurrent effort to this Basin Study, Hood River County completed an OWRD-funded Hood River Basin Surface Storage Feasibility Assessment (OWRD Storage Study), which leveraged the initial data that Reclamation had developed through the appraisal-level reservoir storage analysis in the Basin Study (see Section 3.3.1). Of the 17 storage options in Reclamation's preliminary investigation, 3 key sites were evaluated further in the OWRD Storage Study. Details about the physical, economic, regulatory, and ecologic feasibility of each site is in the OWRD Storage Study, but general information on the three selected for further analysis are described in the next section. In general, none of the sites were located in a highly seismic area so no significant concerns exist due to earthquakes.

Summary of Results

The OWRD Storage Study described in detail the 3 reservoir storage alternatives selected for further analysis. These three alternatives included the expansion of the Upper Green Point Reservoir to support FID needs, raising the dam height of the Laurance Lake Reservoir above the Middle Fork of Hood River to support the MFID, and constructing a new facility on Neal Creek for EFID's use.

Upper Green Point

The Upper Green Point storage alternative includes the expansion of Upper Green Point Reservoir by 8 feet with 2 feet of freeboard (already present on the existing dam). This proposed alternative would add 562 acre-feet of storage capacity, increasing the total capacity to 1,253 acre-feet. The dam was constructed using impermeable clay fill with a semi-permeable fill on the upstream slope and a permeable fill on the downstream slope of the embankment. This effort would likely involve replacing the existing spillway crest as well.

The amount of water available for further appropriation is constrained by natural flow and water rights currently held on the streams surrounding the reservoir. This alternative should not affect wetlands, but ESA habitat is affected, including the northern spotted owl. This will likely trigger the NEPA process in addition to Federal or state regulations.

Two cost estimates were developed for this alternative. The first assumed materials were sourced onsite and the other assumed materials were not. Total capital costs were $1.27 million and $2.35, respectively.

Laurance Lake

The Laurance Lake storage alternative considers raising the dam to Laurance Lake up 3 feet by installing a weir system with additional freeboard. This reservoir alternative proposes to add 370 acre-feet to the current capacity for a total reservoir storage capacity of 3,805 acre-feet. Most of the dam is on glacier moraine, alluvial, and possibly lake bed materials (found downstream of the dam). The alternative proposes embankment and concrete apron modifications.

Further appropriation of water is constrained by instream and out-of-stream uses held on the Clear and Pinnacle creeks. This proposed alternative is not expected to impact wetlands, but portions of the proposed inundation area are within the Mount Hood Forest Land, which contains northern spotted owl habitat. If releases from weir system affect downstream flow patterns, bull trout and steelhead habitat will be affected. These potential impacts to ESA habitat would trigger a NEPA action.

Total capital costs were estimated at $330,000, but these costs do not include the NEPA process costs. These could be significant given the ESA habitat likely affected by this alternative.

Neal Creek

The Neal Creek Reservoir storage alternative investigates the potential of constructing a new facility on Neal Creek. The new facility would provide 2,256 acre-feet of storage capacity and act as a multipurpose reservoir, providing irrigation flows to EFID, augmenting instream flows to Neal Creek, and public recreation. In addition, any reduced diversion to the Main Canal from the East Fork Hood River would benefit that system. The embankment would be constructed using an impermeable clay fill core with permeable fill on the upstream and downstream slopes. A concrete spillway is also proposed to convey extreme hydrologic events.

Water is available in the Neal Creek watershed for further appropriation. No wetlands are delineated in the potential impact area; however, ESA species and their habitat are present. In addition to the NEPA process, this alternative would require Federal permitting and land easements.

As with the reservoir storage alternative for Upper Green Point, two cost estimates were developed for the proposed Neal Creek storage facility. The first estimate for capital costs was $13.2 million assuming material was onsite. The second estimate was $27.9 assuming material for construction of the facility was offsite. In addition to capital costs, annual operation and maintenance costs were estimated between $1.24 million and $2.43 million, depending on location of maintenance material.

Details on the evaluation of each option are provided in Section 5.3. The analysis of the storage options including impacts to water supply, operations, and demand benefits are provided in Section 6.2.

4.0 Future Water Supply and Demand

This section summarizes four technical memorandums written to document the physical and network flow models constructed to evaluate the simulated historical and simulated future water supply in the Hood River basin. This section also summarizes the climate change process including selection of projections, climate change scenarios, and other decision points used to generate simulated historical and simulated future climate change flows.

Figure 12 shows schematically how the physical models incorporate climate or hydrology developed by the climate change process. The three models used in this Basin Study are identified on the top row and include:

1. MODSIM is a water resource model used to simulate reservoir operations, irrigation diversions, and minimum flows. This model is used to evaluate various alternatives developed in this Basin Study.

2. MODFLOW is a groundwater model that evaluates changes in groundwater patterns throughout the basin.

3. DHSVM is a physical hydrologic model used to generate flow that does not include the impacts of reservoir, demands, or other diversions (e.g., industrial).

4. Climate change projections is a process in which climate change forecasts are selected and processed into climate data (e.g., temperature, precipitation) for use in a hydrologic model such as DHSVM.

In general, the climate change process generated simulated historical and simulated future climate data over the study area. That climate data is used as input to the hydrologic model (DHSVM) or the groundwater model (MODFLOW) to generate hydrology (simulated historical and simulated future).

For more detailed information on each model and specific results, please refer to the appropriate Technical Memorandum.

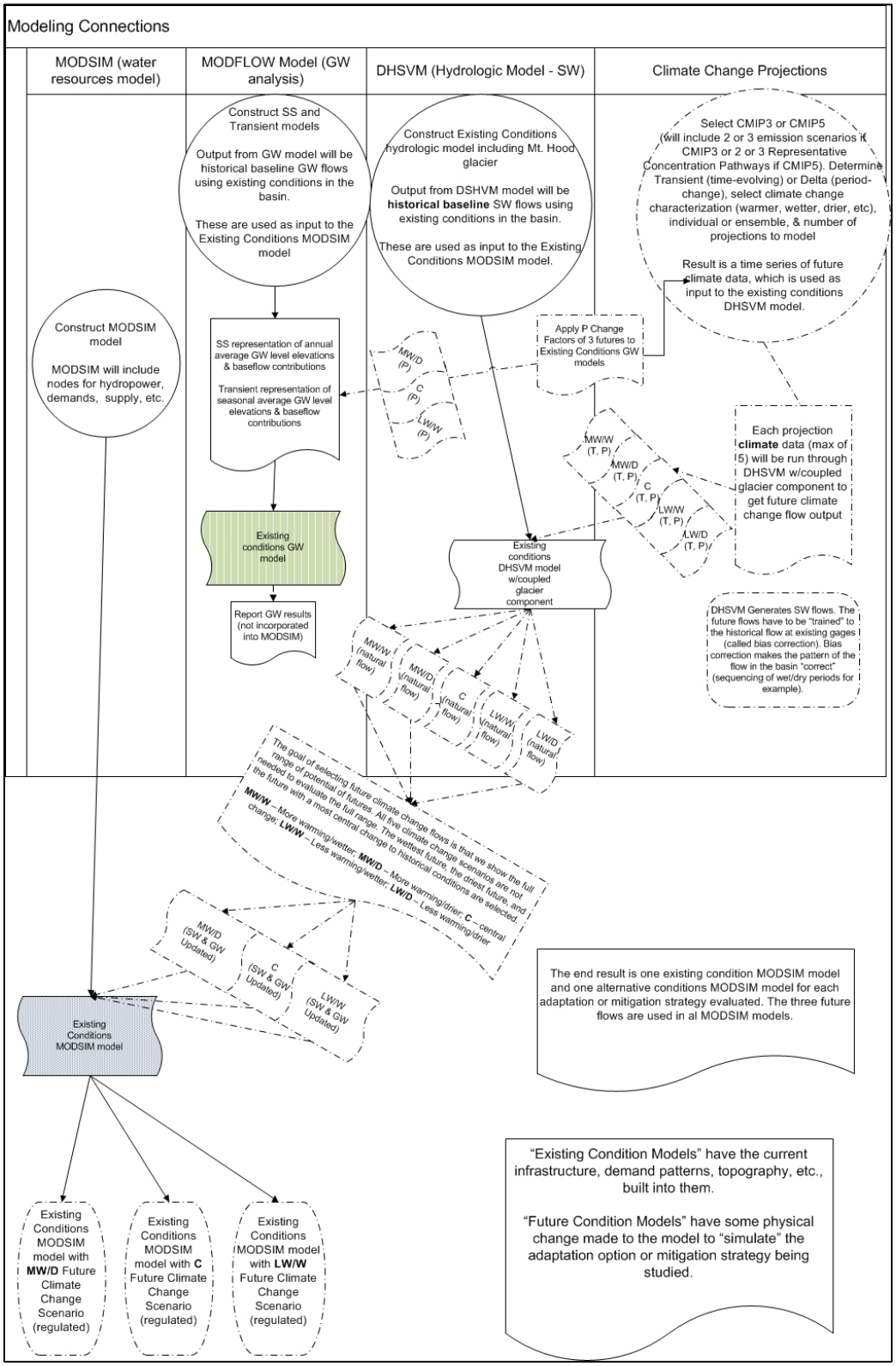


Figure 12. Schematic of climate change analysis and modeling interaction.

4.1 Climate Change Analysis

4.1.1 Approach

The climate change analysis performed for this Basin Study is consistent with past and recent climate change analyses conducted by Reclamation for other river basins and uses the best currently available data, methodologies, and processes. The *Hood River Basin Climate Change Analysis Technical Memorandum* (Reclamation 2014) describes the process and methodologies used to simulate and project climate change for this Basin Study. The selections, details, and justifications for each of the multiple decision points involved with the projection selection are discussed in more detail in the technical memorandum. Table 4 presents a summary of the options, decisions, and the rationale behind each decision made during the course of the analysis. Multiple Core Team and Project Team meetings were held to develop and agree upon these decision points to evaluate climate change impacts in the basin.

Table 4. Summary of decision points, available choices, and selections made to evaluate climate change in the Basin Study.

Description of Step/Decision Points	Available Choices	Choice Selected
Select Global Climate Projection Context	CMIP3 or CMIP5	CMIP3
Select how future climate will be characterized	Period-change (Delta or Hybrid Delta) or transient	Period-change (Hybrid Delta)
Selection of percentile range	Selections of either 10/50/90 percent, 25/50/75, or 20/50/80 percent are common	Selected 20/50/80 percentile range
Select number of change scenarios	Selections of any or all of five potential scenarios that include Less Warming/Drier (LW/D), Less Warming/Wetter (LW/W), More Warming/Wetter (MW/W), and More (MW/D) Warming/Drier and MED indicating the central change (50 percent) will be selected as well.	Selected three climate change scenarios bracketed by MW/D, LW/W, MED
Select whether change scenarios informed by a single projection or an ensemble of several	Single projection or ensemble	Ensemble (nearest 10 to intersection of interest)

4.1.2 Summary of Results

The climate change projections and datasets selected for this Basin Study were selected from the third phase of the Coupled Model Inter-comparison Project (CMIP3), which is available online[12] at the Bias-Corrected and Downscaled CMIP3 Climate Projections website under the Downscaled Climate Projections (DCP).[13] The DCP archive data were used as simulated historical climate change projection dataset that defined climate change scenarios. A total of 112 climate projections were downloaded from the DCP archive composed of spatial averages for both monthly precipitation and average monthly air temperatures. The projections were specified on a monthly time step from 1950 to 2099 and at roughly a 12-kilometer (km) (1/8 degree) spatial resolution over the contiguous United States and those relevant to the Hood River basin were processed.

In addition to the selection of which archive to use, historical and future timeframes to evaluate, decisions on how to characterize future climate (e.g., the range of wetter or drier future climate the stakeholders wanted to evaluate) and projection uncertainty were also made. To understand uncertainty, mean changes of temperature and precipitation over the selected time period are generated for both a future time period and an historical time period.

The uncertainty percentiles selected for the Basin Study were those representing the 20th, 50th, and 80th percentiles (20/50/80). This percentile range is appropriate for a planning-level study as it results in a wide spread of projected temperature and precipitation change, but excludes the effects of projections that may be considered outliers or more extreme. This process yields five possible future climate change scenarios:

- More Warming/Wetter (MW/W)
- More Warming/Drier (MW/D)
- Less Warming/Wetter (LW/W)
- Less Warming/Drier (LW/D)
- Median or Central (MED or C) change

Three climate change scenarios were selected for analysis in this Basin Study and included the MW/D, MED, and LW/W. These scenarios result in the largest range of future climate change, which provided the stakeholders a better understanding of the range of potential impacts on the areas of most interest to them. In addition to the uncertainty range and characterization of climate, the technique used to generate that projection information is a decision point as well. The Hybrid-Delta (HD) uses the distribution of the parameter (e.g.,

[12] See http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html.
[13] See http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.

temperature) in the time period of interest in the future. The Hybrid-Delta is aligned with the distribution of the same parameter in the historical time period selected using cumulative distribution frequency curves so consecutive periods of wetter timeframes and drier ones in the historical period are retained. The Basin Study partners selected the HD technique.

Individual projections at the intersection of the red and blue lines in Figure 13 can be selected or an "ensemble" of projections that surround that intersection can be selected. For this Basin Study, the nearest ten projections to each intersection of interest were selected. This approach reduces "noise" (less erratic variation in the time series) in the time series and provides a more stable representation of the future climate. Generally, the ensemble approach is preferred because it attenuates dramatic swings between time steps in a time series. The HD ensemble approach is referred to as HDe.

Finally, the two 30-year periods identified for this Basin Study included the historical time period from 1980 to 2010 and a future window from 2030 to 2060. While the full historical record in the basin was from 1928 through 2005, the shorter, more recent 30-year historical time period was found to better represent current conditions in the basin and was indicative of more recent climate patterns when compared to the entire period of record. The future window selected coincided with studies that either had been already conducted in the basin or was a timeframe of interest for future work.

Each selected ensemble of 10 projections is shown in Figure 13. The 10 projections nearest the intersection of the 20th percentile for both temperature and precipitation represent the LW/D ensemble projection (highlighted blue triangles in Figure 13 and shown at T20, P20). The 10 projections nearest to the intersection of the 50th percentile represent the MED ensemble projection (highlighted red asterisks in Figure 13 and shown at T50, P50). The 10 projections nearest to the intersection of the 80th percentile represent the MW/W ensemble projection (highlighted in green upside down triangles in Figure 13 and shown at T80, P80). The selected ensemble of projections indicates a potential increase in annual future temperature compared to the historical period that ranged between 0.5 and 2.2 °C (on the y-axis). The 20th, 50th, and 80th percentile temperature changes were approximately 0.9, 1.3, and 1.7 °C, respectively. The projections also show a change in precipitation that ranges between -10 to 20 percent (on the x-axis) with the 20th, 50th, and 80th percentile values at -2, 3, and 7 percent, respectively.

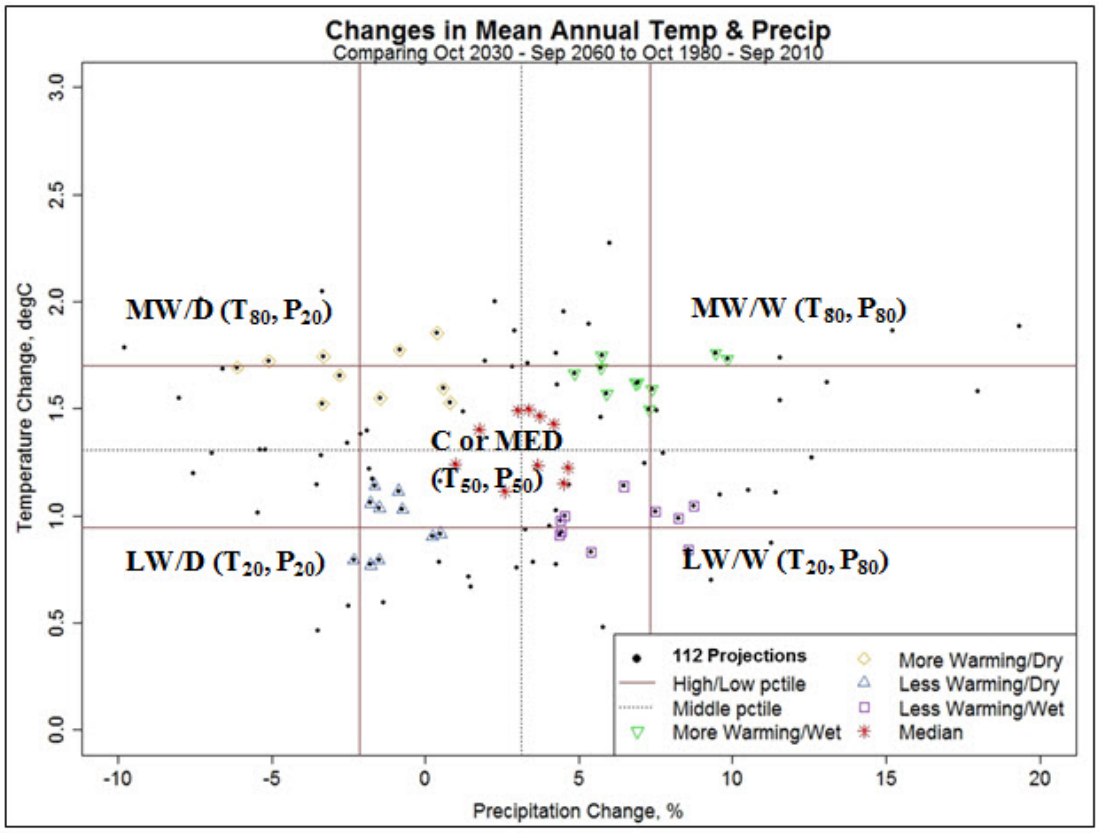


Figure 13. Climate change projection selection results.

The climate change scenarios selected for analysis in this Basin Study were the MW/D, MED, and the LW/W. Results from the HDe processing technique are shown in Table 5 for each selected climate change scenario with its corresponding change in precipitation and temperature in each season. Using the average of the ensemble of ten projections, the LW/W shows an increase in precipitation during every season except summer, where a decrease in precipitation of 15 percent is projected. Increases are shown as positive numbers with plus (+) signs while decreases are shown as negative numbers with minus (-) signs in Table 5.

Table 5. Hybrid-Delta ensemble adjustment factor seasonal trends.

Climate Change Scenario	Average Precipitation Change (%)				Average Temperature Change (°C)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
More Warming Dry (MW/D)	-3	-7	-33	+4	+1.2	+1.5	+2.4	+1.5
Median (MED)	+7	0	-14	+3	+1.2	+1.1	+1.5	+1.2
Less Warming Wet (LW/W)	+5	0	-15	+12	+0.8	+0.7	+1.3	+0.9

The results and trends shown in Table 5 are consistent with expected results of the three selected climate change scenarios. Annual temperature projections increase from LW/W to MW/D climate change scenario while annual precipitation projections have a general increasing trend from MW/D to LW/W. Temperature increases are highest during the summer while precipitation changes vary with respect to each season. The precipitation projections show a discernible trend in the seasonality of the change. During the winter months, precipitation trends were generally higher than historical conditions. During the summer and early fall months, precipitation generally decreased below historical conditions.

4.2 Hydrologic Analysis

4.2.1 Approach

The Distributed Hydrologic Soil and Vegetation Model or DHSVM (Wigmosta et al. 1994; Wigmosta and Lettenmaier 1999) was selected to generate natural streamflow in the basin because a calibrated version of the model already had been constructed. In addition, the University of Washington added a glacier component to the Hood River DHSVM model so that potential climate change impacts to the Mount Hood glaciers could be evaluated. After obtaining the surface water model, additional steps had to be taken to refine the model for the purposes of this Basin Study. In addition, when the updated glacier module was added to the model, the University of Washington took an active role in assisting Reclamation and Hood River County with additional calibration and validation efforts. The model was calibrated using NRCS SNOTEL data and USGS stream gages with varying lengths of record. The period of record in the model was extended from its original time period of analysis of 2000 through 2010 to 1915 through 2010.

4.2.2 Summary of Results

Glacier Characteristics

The simulated glacier volume is shown in Figure 14 from 1920 to 2009. In general, the glacier volume generally has remained unchanged over the last 60 years. The slight decrease in volume through approximately 1940 may be due to the climate conditions during that time. The extent of the glaciers, shown as dotted lines in Figure 14, has continued to decline over the entire period of record. This difference in pattern is because glacier volume is generally controlled by how much mass is accumulated in short-term periods (e.g., during annual wet periods). Glacier area largely reflects changes in the extent of the lower reaches of the glacier. The lower reaches will respond more slowly to volume changes because of the year-to-year variability in volume because of the slow dynamic flow of ice from higher to lower elevations. Extent is more reflective of long-term changes on the fringe areas of the glacier.

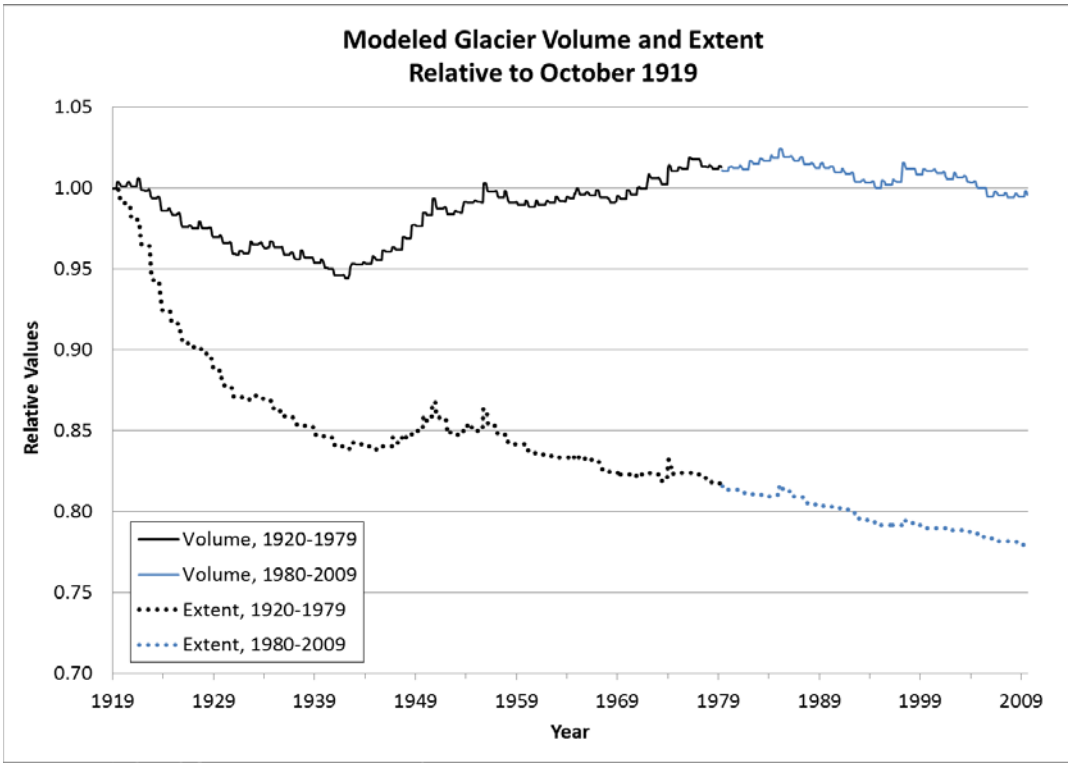


Figure 14. Simulated historical volume and extent of glaciers on Mount Hood from water years 1920 through 2009.

The three climate change scenarios were used to evaluate the impact of increasing temperatures and changing precipitation on the Mount Hood glaciers using the DHSVM glacier component as well. Figure 15 reflects the changes projected in a 30-year window initiating in year zero (2030) through year 30 (2060) compared to the glacier extent (or long-term patterns) in 1920 (Figure 14). In general, these results indicate that in all three climate change scenarios, the extent of the Mount Hood glaciers will continue to decrease over time due to increasing temperature. Depending on which climate change scenario is viewed, the extent of the glaciers continues to shrink over time with a change of 1 to 4 percent depending on the scenario.

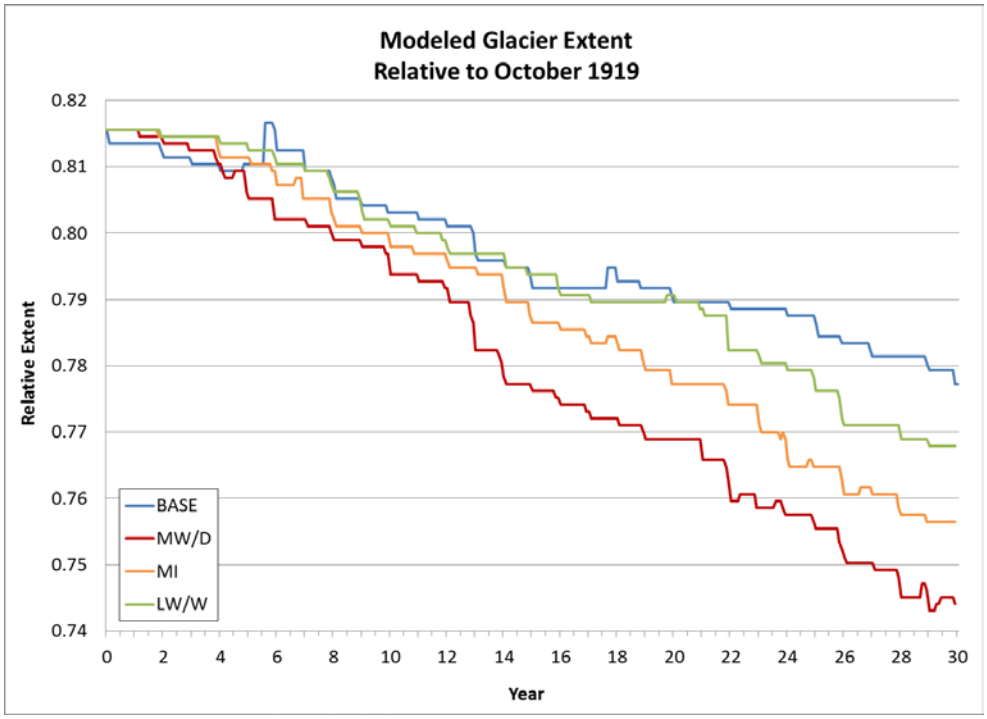


Figure 15. Comparison of simulated historical glacier extent with simulated future glacier extent under each climate scenario.

Glacier melt has historically contributed almost 40 percent of the total flow (50th percentile) in the Eliot Branch (a tributary to the East Fork Hood River) during August and slightly more than 50 percent in September. In all three climate change scenarios, the warming temperatures increase the melt water from the glaciers to between 48 and 60 percent in August and 55 and 59 percent in September in the LW/W and MW/D, respectively (Figure 16). Similar changes, though smaller percentage contributions, to other locations impacted by snowmelt water runoff are found on the Middle Fork above the East Fork Hood River and on the Hood River at Tucker Bridge.

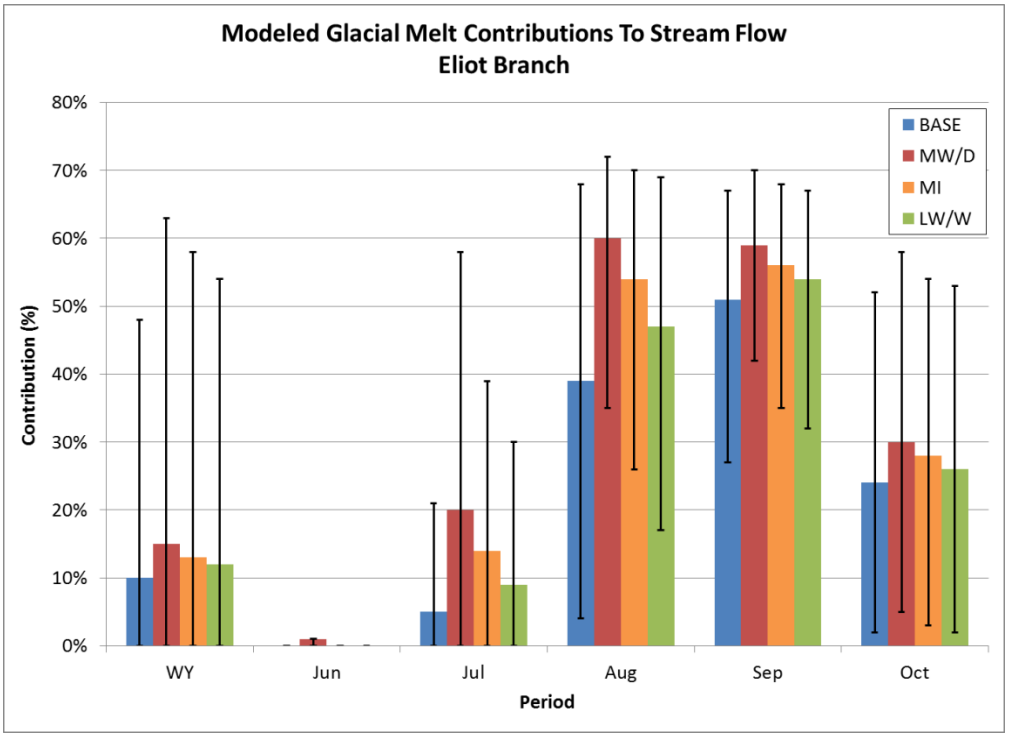


Figure 16. Comparison of simulated historical glacier melt contributions shown as percent of total streamflow with simulated future glacier melt contributions under each climate scenario for Eliot Branch.

Snowpack

In general, a decrease of roughly 5 percent of snow extent every 30 years is evident in simulated historical record. In Figure 17, basin-wide averaged snowpack is shown for three 30-year historical ranges. In each successive 30-year period, the snow arrives later and departs earlier over each 30-year historical increment.

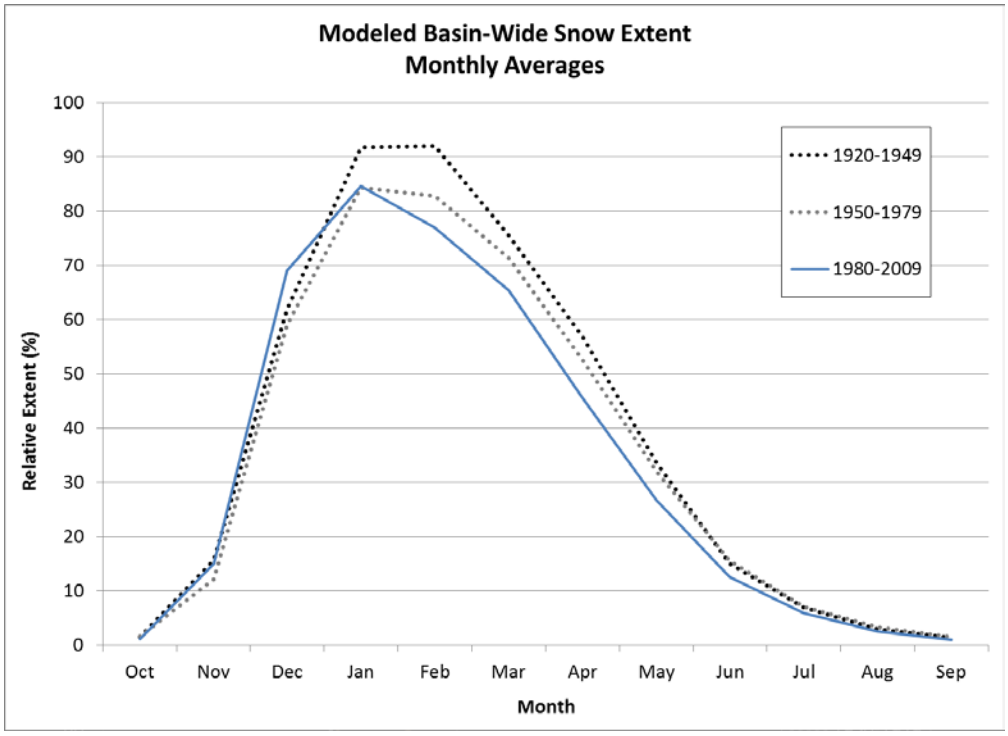


Figure 17. Simulated historical monthly snow extent values, averaged across the Hood River basin.

As shown in Figure 18, in each of the three future climate change scenarios, increasing temperatures result in less snowpack than the simulated historical run. The baseline period of 1980 to 2009 (shown as the blue solid line in Figure 17), is compared to the monthly average of modeled snow extent for the 2030 to 2060 period. These results indicate that rivers and streams in the basin will experience less snowmelt-driven streamflow in the future.

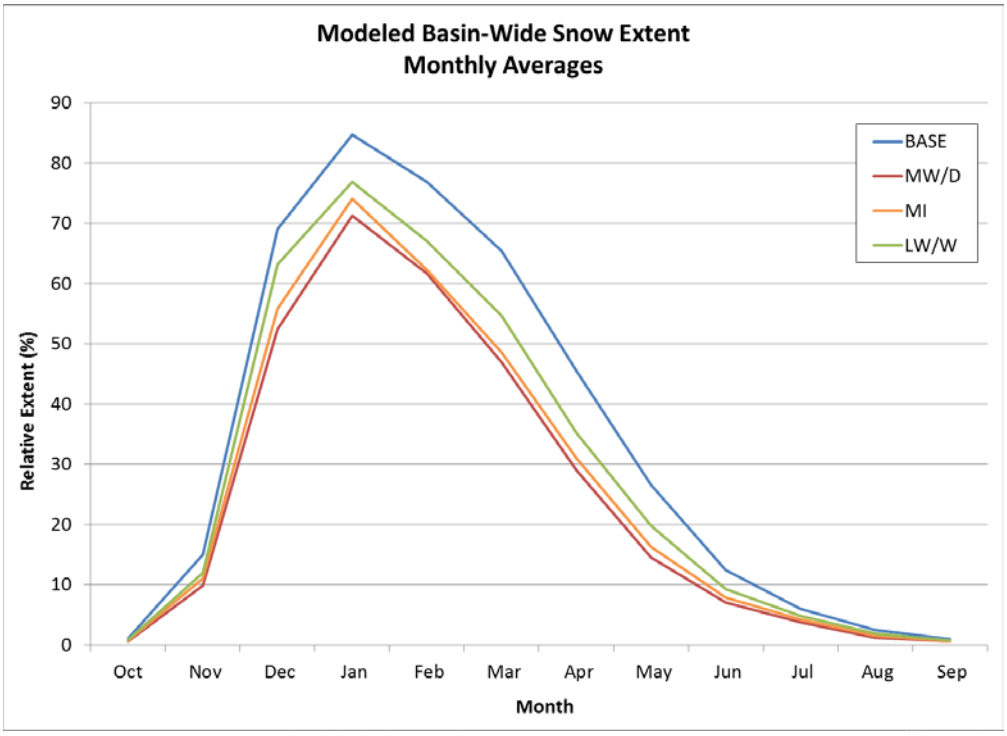


Figure 18. Comparison of simulated historical snow extents with simulated future snow extents under each climate scenario for the entire basin.

Streamflow

Simulated historical and simulated future streamflow was generated at a total of 42 locations on all three forks, major tributaries to those forks, and on the main Hood River channel (Figure 19). The streamflow, generated by the Hood River DHSVM model, was used as input to other water resource models including the Hood River MODSIM model and the IFIM habitat model (which may have used output from both Hood River models). The simulated historical and the simulated future climate change flow results were also compared to better understand future water supply changes in the basin.

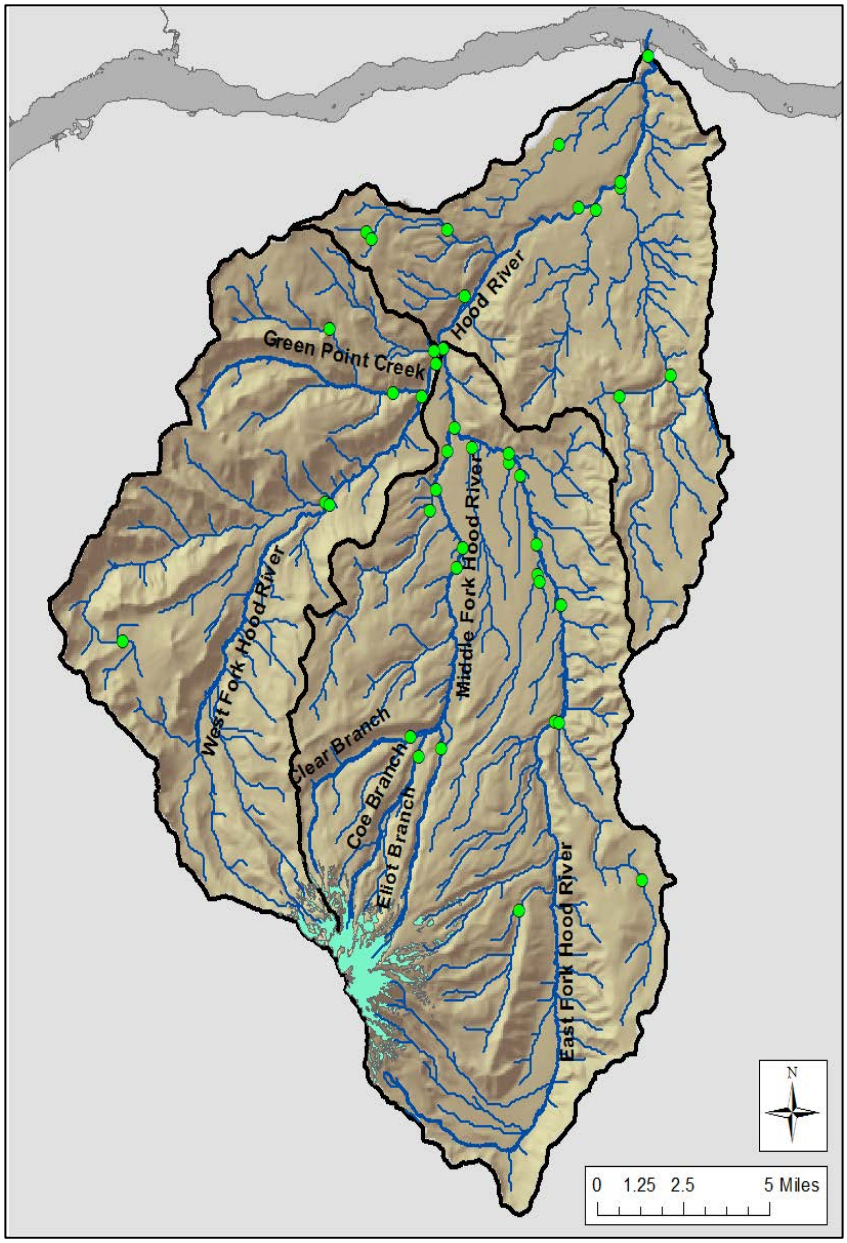
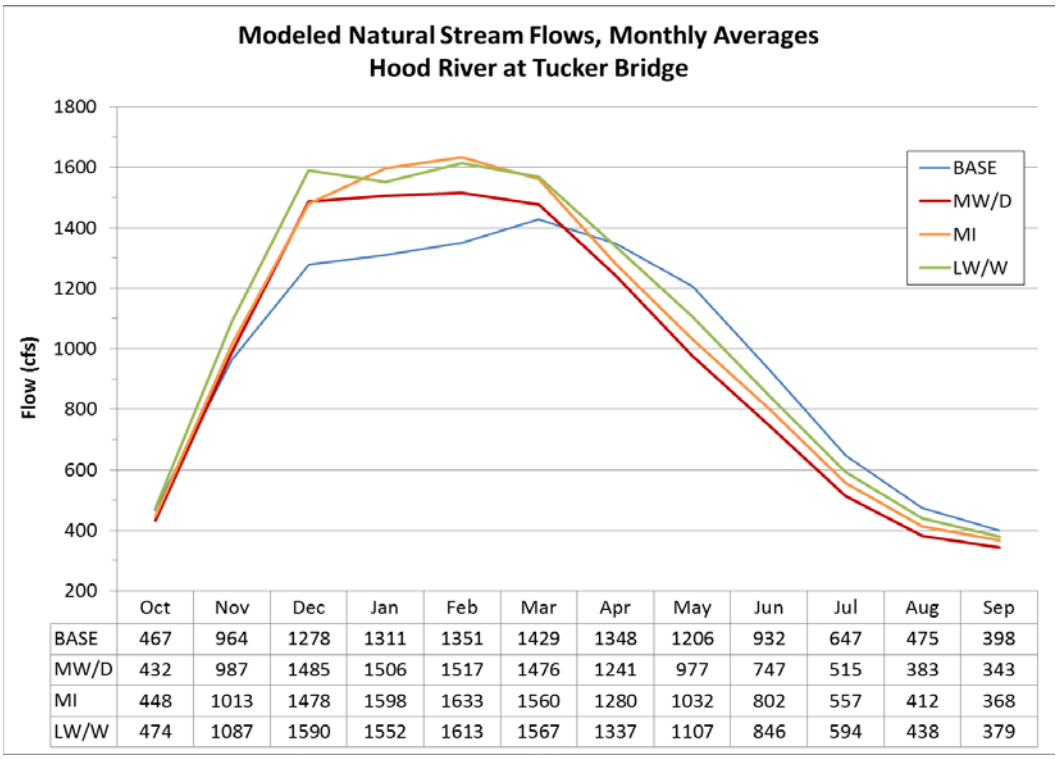


Figure 19. Locations specified for DHSVM model streamflow outputs.

While there are several gages in the Hood River basin, only two have a long enough record that could be used for calibration of the simulated historical record to observed flows. These included the Hood River at Tucker Bridge and the West Fork River near Dee. For other areas where flow was generated but a historical record was unavailable, the USGS method to develop statistical flow estimates at ungaged locations in Oregon was used to determine with biases existed in the streamflow at a particular location (Risley et al. 2009). Biases occur when a model results show differences in output from the observed record. Methods are available to adjust for those biases, but none were employed at the ungaged locations

To evaluate the potential impacts of future climate, the simulated historical streamflow was compared to the simulated future streamflow for the three climate change scenarios at several locations throughout the basin. Figure 20 shows the results of this comparison for the Hood River at Tucker Bridge gage. Consistent with other studies in the Pacific Northwest (RMJOC-I Climate Change Study 2011; Boise River Study 2009), peak streamflow on the Hood River is expected to shift to earlier in the year with a loss of flow during the summer months. In addition to higher peaks, the rising limb of the climate change scenarios is steeper and begins earlier than historical. The falling limb of the hydrograph indicates that future runoff is expected to be less than historical runoff during the spring and summer months.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
BASE	467	964	1278	1311	1351	1429	1348	1206	932	647	475	398
MW/D	432	987	1485	1506	1517	1476	1241	977	747	515	383	343
MI	448	1013	1478	1598	1633	1560	1280	1032	802	557	412	368
LW/W	474	1087	1590	1552	1613	1567	1337	1107	846	594	438	379

Figure 20. Comparison of simulated historical streamflow (in cfs) with simulated future streamflow (in cfs) under each climate scenario for the Hood River at Tucker Bridge.

4.3 Groundwater Analysis

4.3.1 Approach

This Basin Study focused on gaining a better understanding of the hydrogeologic system through the compilation of existing data into a water budget and conceptual model of the system. A simple simulation model of the system was developed to provide insights regarding how increased development in the basin and climate change may impact groundwater. Options such as managed recharge and aquifer storage and recovery were also considered, but were evaluated separately from surface water options.

4.3.2 Summary of Results

Estimated Water Budget

Initial water budget estimates, which quantify the inputs to and outputs from an aquifer system, are shown in Table 6. Shaded cells in the table are estimates made with limited or incomplete data and therefore have a higher degree of uncertainty.

Table 6. Estimated annual water budget table for the Hood River basin.

Water Budget			
Aquifer Inflow	**Volume (acre-feet per year)**	**Aquifer Outflow**	**Volume (acre-feet per year)**
Precipitation Recharge	789,000	Pumping	12,000
Stream Losses	-	Discharge to Stream	290,000
Boundary Inflows	-	Boundary Outflows	482,000
Canal Losses	8,000	Springs	13,000
On-Farm Infiltration	-		
Sum	**797,000**	**Sum**	**797,000**

Details on how each of these parameters was estimated are provided in the Groundwater Technical Memorandum, Section 4.0.

Recharge from precipitation, which is the largest contributor to recharge, is dependent on many physical parameters including soil type, geologic conditions, slope of the landscape, and vegetation cover. In addition, the volume, duration, intensity, and form (snow or rain) of precipitation all play an important role in the quantity of water that becomes recharge. Based on the observed groundwater hydrographs, it is evident that recharge increases immediately following the rainy season, which on average is from November to April, with peak water levels on average having a three-month lag in comparison with monthly peak precipitation (Figure 21).

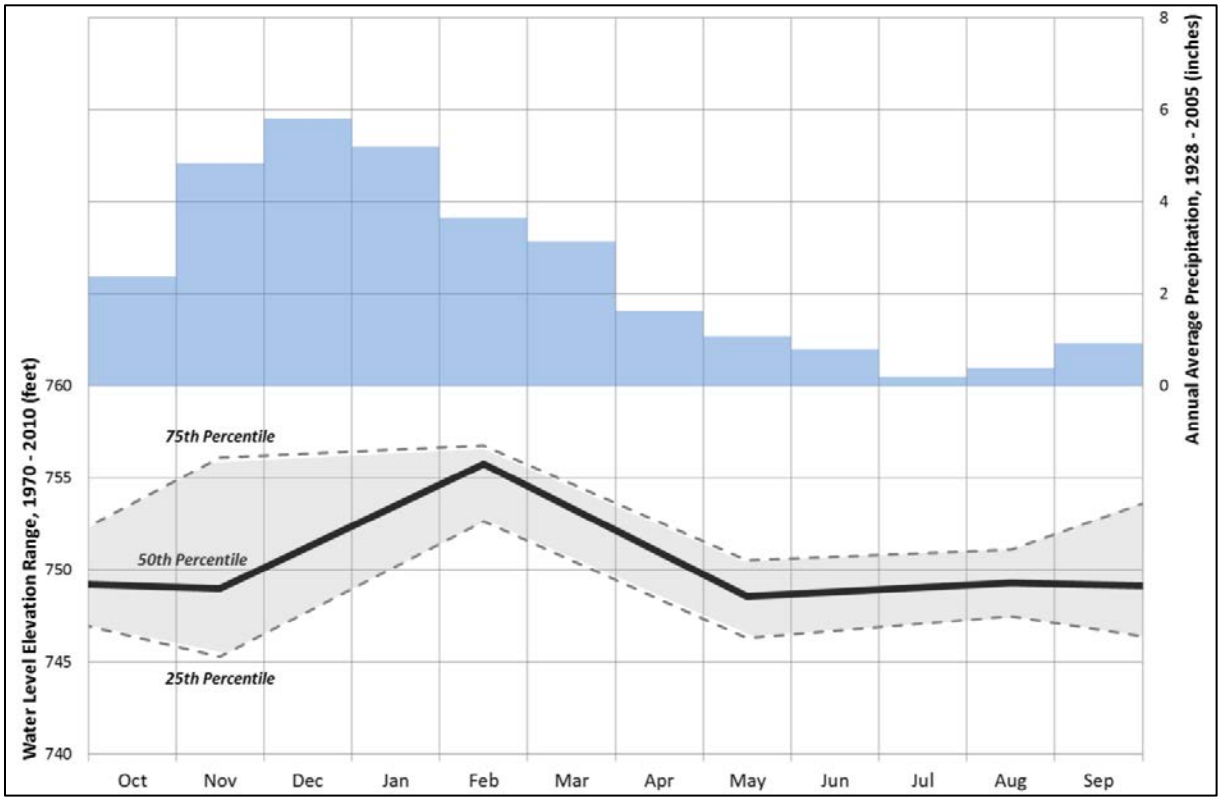


Figure 21. HOOD372 (Section 4 of T2N, R10E). Water level elevation range and Hood River Experiment Station annual average precipitation.

Generally, modeling techniques can be used to provide detailed estimates of recharge based on the basin specific and environmental factors, however, the level of analysis required for those techniques were beyond the scope of this Basin Study. As an alternative to a recharge model, recharge was estimated using a regression equation formulated by Bauer and Vaccaro (1990). The numerical model of the Hood River aquifer system was developed using the USGS MODFLOW-2000 modeling code (Harbaugh et al. 2000), a three-dimensional, finite-difference modeling system that simulates flow through porous media. The model was calibrated using a parameter estimation tool and adjusting parameters of interest (e.g., hydraulic conductivity). The model is relatively simple because of the small amount of available data and basic understanding of the hydrogeological setting, so results interpreted on a qualitative and not quantitative basis.[14]

[14] See Section 6.0 of the Hood River Basin Groundwater Technical Memorandum for more information on the model design. It is posted at http://www.usbr.gov/pn/programs/studies/oregon/hoodriver/reports/groundwater/index.html.

Baseline Conditions

Figure 22 shows the modeled and observed average baseline of the average water level conditions in the Hood River Basin for the years 1980 through 2010.

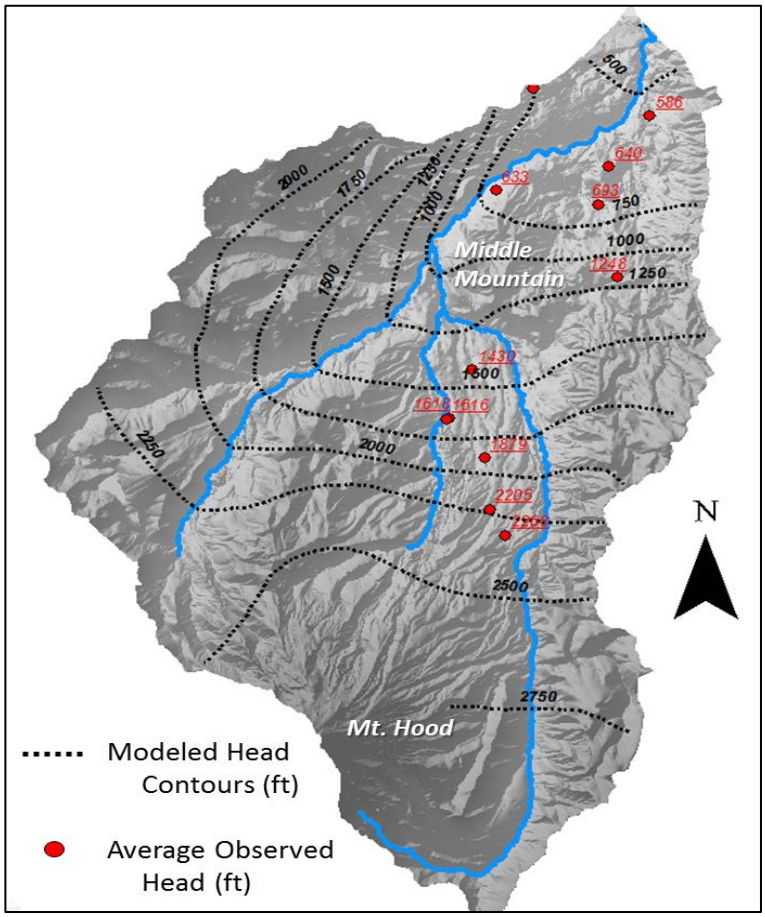


Figure 22. Modeled vs. observed groundwater levels.

As described in Section 4.1, the scenarios used in the groundwater analysis compared the simulated historical time period of 1980 through 2010 to the simulated future time period of 2030 through 2060. As shown in Figure 12, the climate change precipitation and temperature data, as opposed to the hydrologic results, were used to adjust the input to the groundwater models.

4.4 Water Resource Analysis

This section summarizes the results of the water resource analysis to evaluate the potential impacts of the three climate change scenarios (i.e., MW/D, MED, and LW/W) in existing irrigation and potable water demands, storage and streamflow. Impacts to existing storage capacity and subsequent operations at the Green Point Reservoir system and Laurance Lake (described in Section 3.3.2) were evaluated as well.

The MODSIM-DSS model was the water resources management model used to evaluate future climate change in the Hood River basin. It was constructed to simulate historical and projected future regulated streamflows across the basin for both the historical period (water years 1980 through 2009) and the future period (water years 2030 through 2059). The model accounts for all existing major flow diversions, reservoir operations, and minimum flow requirements.

4.4.1 Water Demands

Existing demands were evaluated using the historical and simulated future climate change flows representative of current use for potable and irrigation water as outlined in the *Hood River Basin Water Use Assessment* and in Section 3.1 of this Basin Study Report.

Potable Water Demand Evaluation

Potable water demands were determined for each major water district. Crystal Spring, Ice Fountain, Oak Grove, Odell, Parkdale, The Dalles, and the City of Hood River all use water from the basin. With the exception of the City of The Dalles, the water source comes from the many springs. The Dalles uses water from Dog River and pumps groundwater from outside of the basin during summer months to supplement water supply.

Figure 23 shows the combined potable water shortage as a percent of demand compared to historical conditions. All three climate change scenarios evaluated indicate increased shortages in the future; however, the MW/D consistently shows the largest increase in shortages. Historically, potable water shortages have occurred two percent of the time, but only during the driest period of the year of July through September.

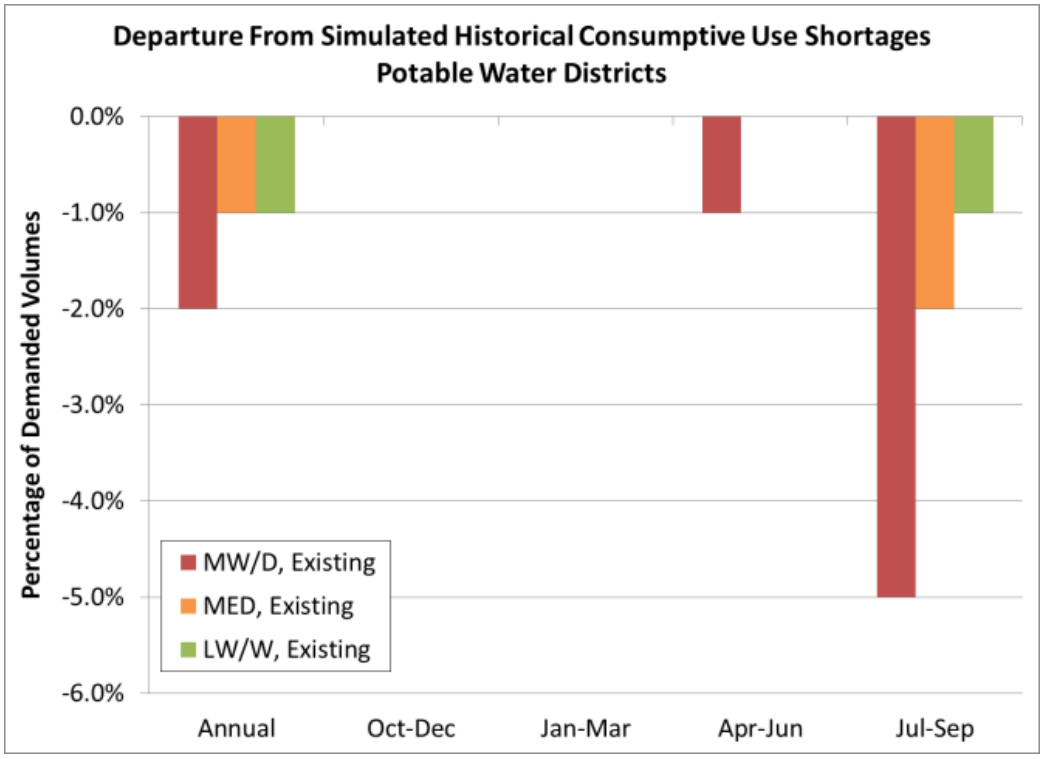


Figure 23. Average annual and quarterly shortages of existing potable water demands projected using the MW/D, MED, and LW/W future climate change scenarios.

In the future, these results suggest that shortages during the summer will likely increase above historical conditions, but these shortages generally occur only in the City of The Dalles and Crystal Springs located along tributaries to the upper East Fork Hood River. The Dalles obtains its potable water from the Dog River, which is unable to satisfy average historical demands of this water district under the climate scenarios during low water years. The Crystal Springs water rights are junior to the instream right along the East Fork below the Main Canal and to the EFID and MHID rights and also experience an increase in shortages during dry periods.

Some of these increased shortages also may be the result of comparing the future results to a historical potable water use that was calculated using the average of less than ten years of data. That means that the range of the shortage may be overestimated in any or all of these results, but given shortages are projected in even the wettest future climate change scenario, it is likely that some level of planning for potable water shortages during dry years should be considered.

Irrigation Water Demand Evaluation

As described in Section 3.1 and Section 3.2 of this Basin Study Report, the primary irrigation districts in the Hood River County include DID, EFID, FID, MFID, and MHID. On an

average annual basis, the simulated historical demands meet the reported deliveries within 9 percent.

Existing irrigation demands were evaluated using adjusted hydrology from the three future climate change scenarios for each irrigation district. In addition, the consumptive use results include reservoir releases and are shown in the non-irrigation seasons in Figure 24. Figure 24 has four panels, each representing a major irrigation district in the Hood River basin (i.e., MFID, EFID, MHID, and FID). Each panel represents how the existing irrigation demands may be affected by future climate change. The results are reported by consumptive use shortage for each irrigation district relative to the historical conditions. DID had no measurable changes so it is not shown.

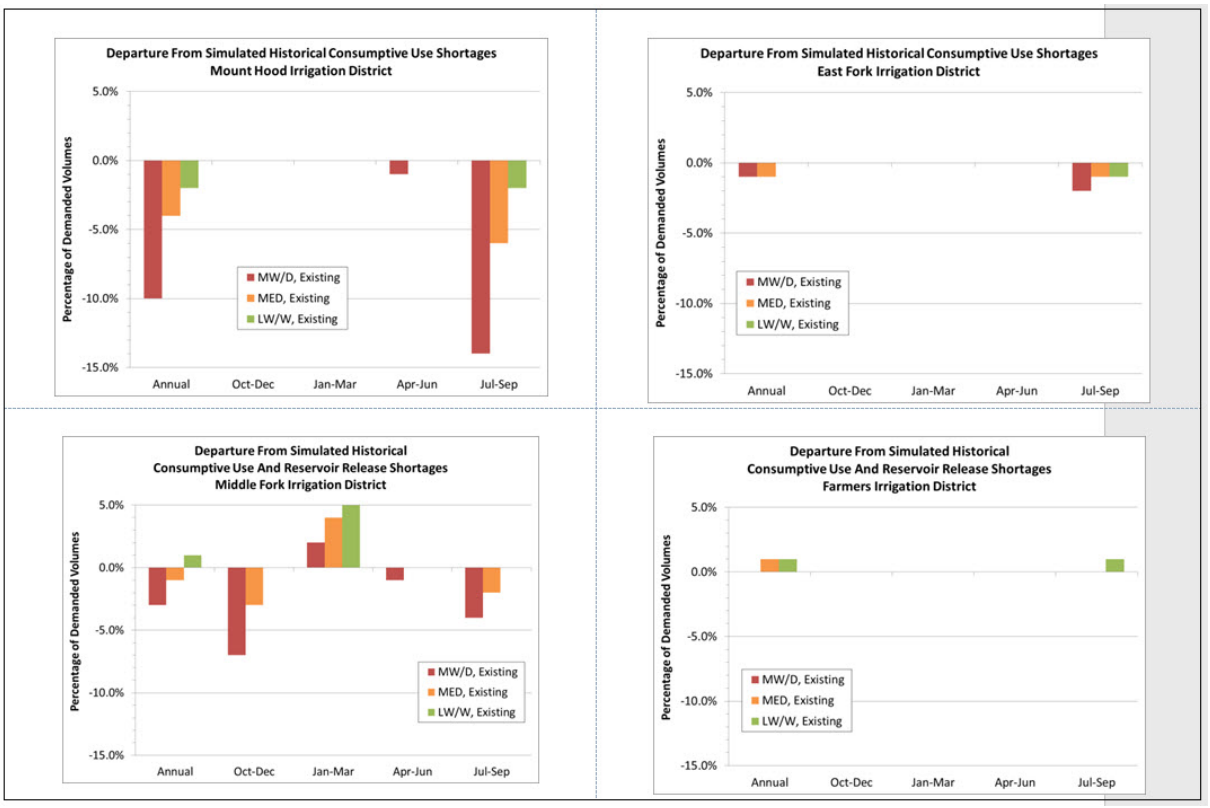


Figure 24. Future consumptive use shortages evaluated using existing conditions for major irrigation districts in the Hood River basin.

For MFID, the additional shortages from October through December and the decreases during January through March are due to Laurance Lake releases. Neither of these periods corresponds to when irrigation occurs in MFID. The releases from Laurance Lake that occur in the fall and winter months support hydropower operations. Other than the impacts to Laurance Lake releases during the irrigation off-season, the effects of future climate change on MFID were not projected to be significant.

In the MW/D climate change scenario, all four districts experience an increase in water shortages under existing conditions. In all of the irrigations districts, the major change in water shortages occur during the July to September timeframe when streamflow is low. While some shortages are experienced earlier in the irrigation season, the late summer months reflect the most significant changes.

Some of these shortages may be a function of the lack of data available for input to the water resource model. The results are based on average demands calculated using a 10-year time period or less. They provide insight into potential issues and patterns of shortages, but without additional data, actual shortages are difficult to measure. Thus, while the shortages resulting from the simulations should not be viewed in a quantitative manner, the results do indicate trends suggesting additional strains on water supplies may result under future climate change.

Hydropower Water Demands

Hydropower was simulated as a water demand using monthly average reported flows through each power facility, as well as the decreed flow and priority date of each water right assigned to power generation obtained from the Hood River Basin Water Use Assessment (WPN 2013a). The two FID hydropower facilities and the three MFID facilities were simulated by using the Hood River MODSIM-DSS water resource management model.

Figure 25 and Figure 26, adapted from the Hood River Basin Water Use Assessment (WPN 2013a), illustrate the average total hydropower production in FID and MFID, respectively, over the last 10 years. As shown, peak hydropower demands occur in the early to late spring, when consumptive use demands are low and streamflows remain relatively high throughout both the historical and future periods.

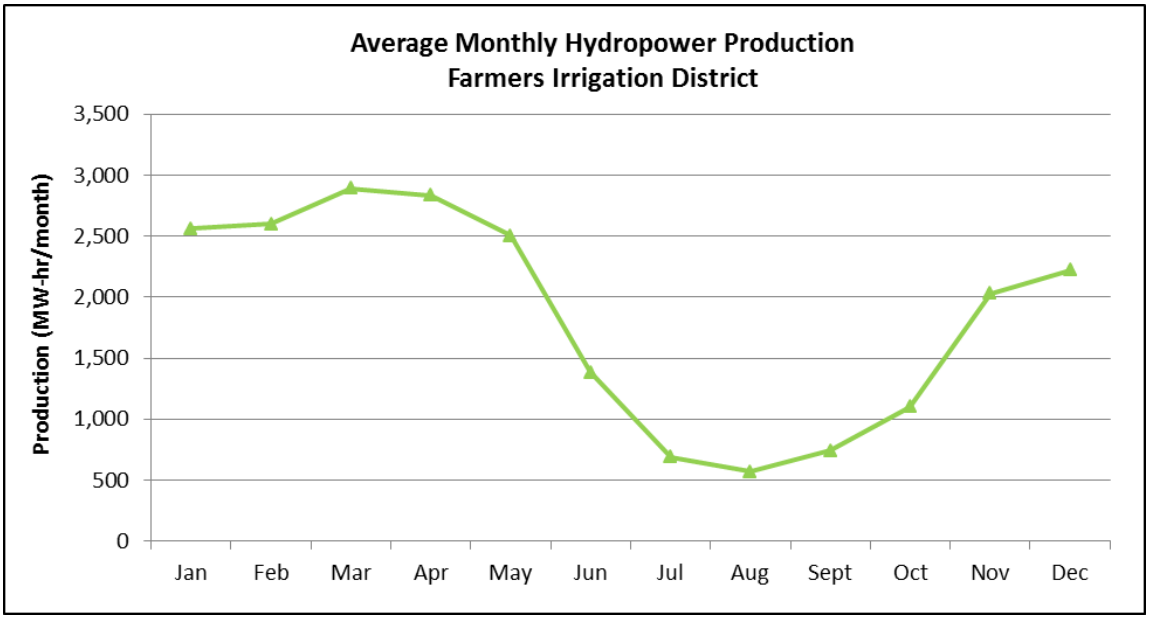


Figure 25. Average monthly hydropower production for Farmers Irrigation District.

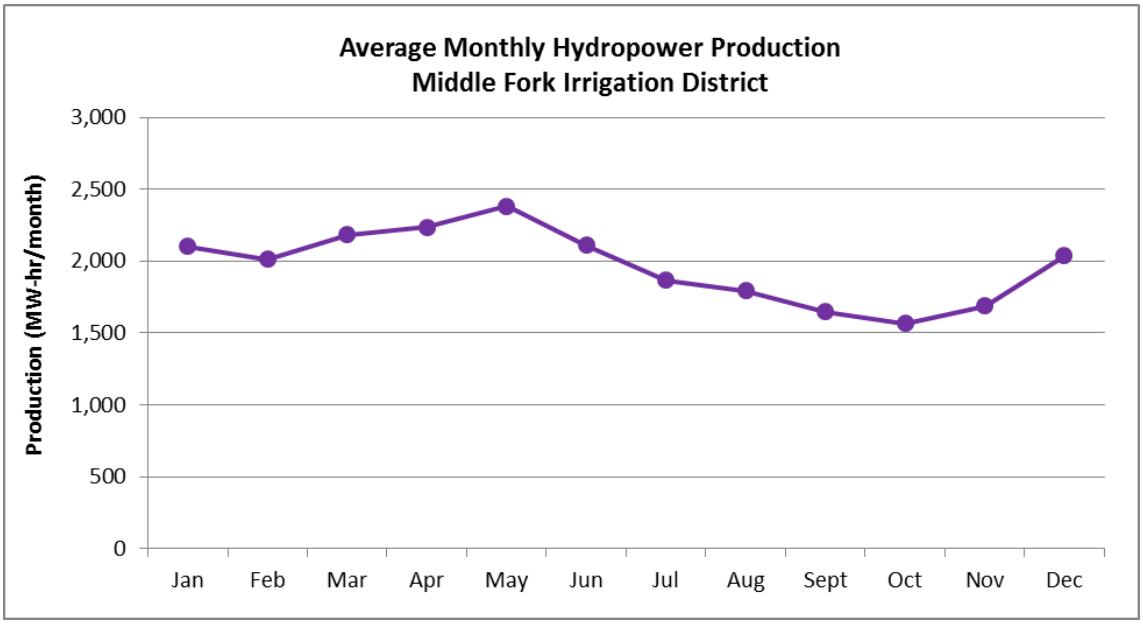


Figure 26. Average monthly hydropower production for Middle Fork Irrigation District.

Power generation was not modeled in this Basin Study. This additional step would require calibrating each power facility's physical characteristics and efficiencies, which could not be accomplished during the time this Basin Study was completed.

4.4.2 Storage

Of the 17 storage options Hood River County considered for either new or enhanced storage options, 3 reservoir storage alternatives were evaluated using the Hood River MODSIM-DSS water resource management model. These alternatives included raising the dam at Upper Green Point Reservoir, raising the dam at Laurance Lake, and constructing a new storage facility on Neal Creek. The MODSIM-DSS modeling analysis was conducted on these three facilities only. Impacts of climate change on the existing storage capacity at Upper Green Point Reservoir and Laurance Lake are described in this section.

Upper and Lower Green Point Reservoir System

The observed reservoir elevation, storage, and release data for the Upper and Lower Green Point Reservoir system were obtained from the Hood River Basin Water Use Assessment (WPN 2013) or provided by either the MFID or FID. The observed record for the Green Point Reservoir system consisted of only 4 years of data. Anecdotal information, along with the observed record, was used to simulate historical average monthly storage patterns of fill and release. Historically, the reservoir fills in March and releases a constant 5 cfs for irrigation in June to meet irrigation demands. In addition, the reservoir fills and drafts to empty each year on a schedule. There is more inflow than capacity in the reservoir system.

Because of the short period of record, the MODSIM-DSS model was constructed to fill, release, and empty at specific times of years regardless of changing conditions. This means that changes to timing of inflow from local tributaries and timing of changes in releases to meet demands are likely not captured by the model. However, changes in volume are observed and were documented. When additional observed data are available, the model can be updated to better capture potential changes in timing and duration of inflow and operational capacity.

Figure 27 depicts the current storage capacity and presents hydrographs for historical conditions and the three future climate change scenarios. Under existing conditions, the reservoir reaches its peak storage volume in May and the pattern under which the reservoir fills and releases the volume of inflow is relatively unchanged in each future climate change scenarios. Peak volume in the MED and LW/W climate change scenarios are approximately 200 acre-feet more than in historical conditions indicating the reservoir would likely not have issues filling to full capacity during these future conditions. The MW/D scenario, which is the driest future projection, suggests that the reservoir will likely not fill entirely. This could mean difficulty meeting water demands for irrigation or hydropower under this condition.

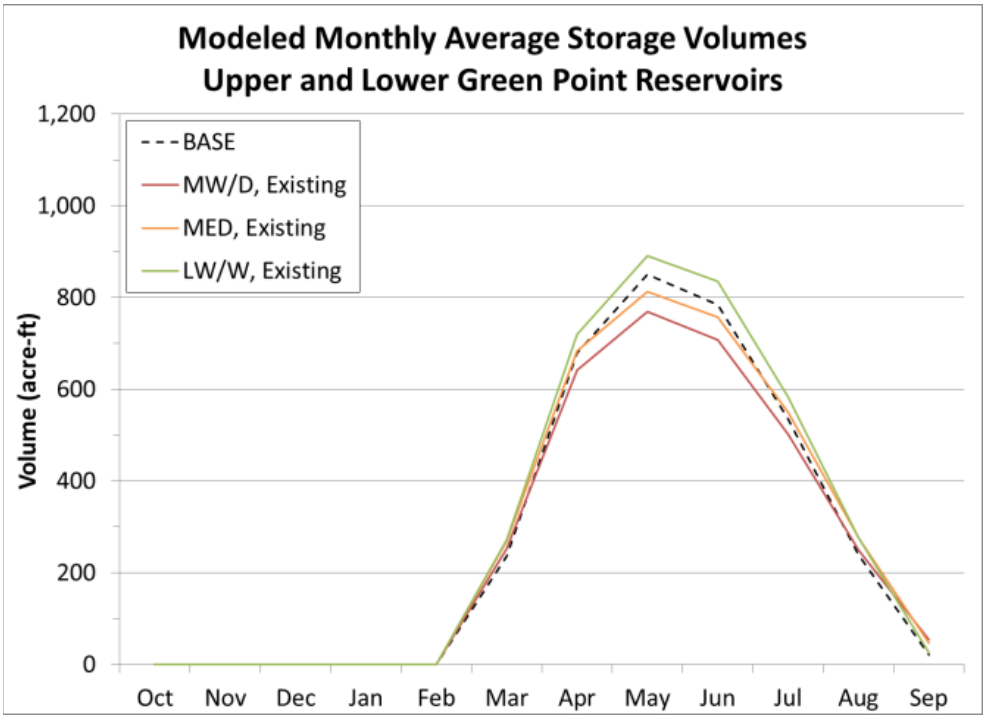


Figure 27. Future climate change impacts on existing storage volume at Upper and Lower Green Point Reservoir.

Laurance Lake

Because Laurance Lake is located at the headwaters of the Middle Fork Hood River, any alterations to this reservoir would impact the three hydropower facilities and any irrigation needs downstream. In the historical (or baseline) scenario, reservoir volume fluctuates slightly for several months, peaking twice, once in the winter and again in early summer (Figure 28). In March, the average reservoir volume decreases to approximately 2,500 acre-feet, which occurs because releases to meet hydropower demands exceed inflows during the spring.

In all three of the future climate change scenarios, this dip in the reservoir volume that occurs in March is reduced due to a combination of factors, including more winter/spring snow melt runoff driven by warmer temperatures, and more winter precipitation falling as rain versus snow earlier in the year. The projected climate change scenarios increase the winter peak storage volume for Laurance Lake and cause a shift in timing to earlier in the year. The simulated minimum average monthly storage volume in October decreased by approximately 28 to 55 percent relative to historical conditions.

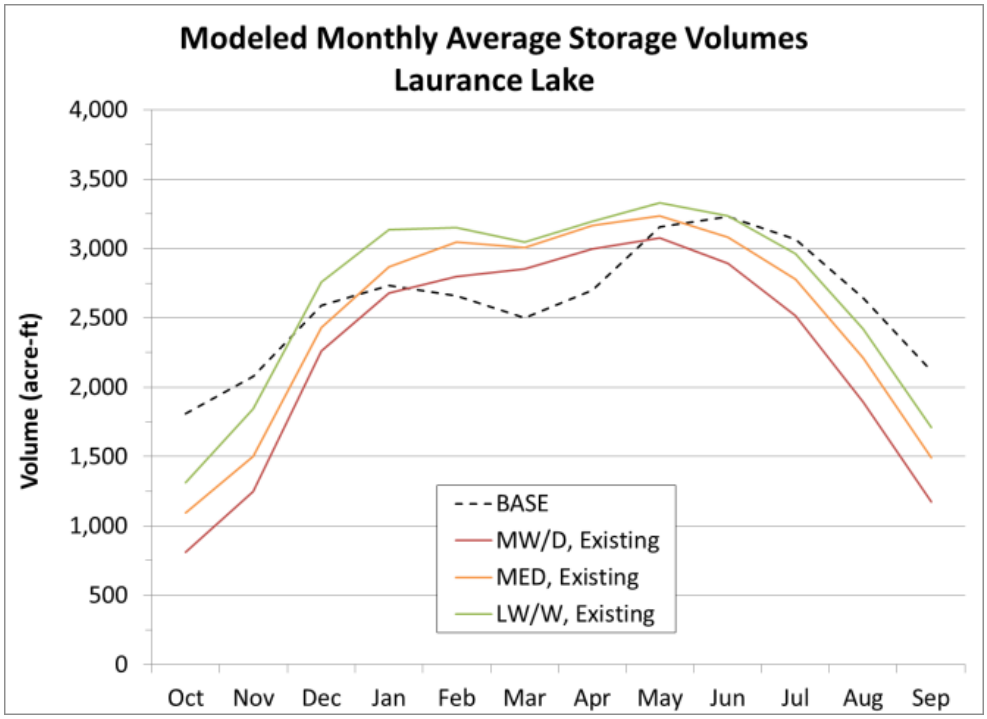


Figure 28. Future climate change impacts on existing storage volume at Laurance Lake.

4.4.3 Streamflow

Naturalize streamflow generated using the DHSVM model (Section 4.2) was used as input to the Hood River MODSIM-DSS water resource management model, which regulated the flows according to existing reservoir operations, irrigation demands, and other use properties. Flow from the three climate change scenarios was compared to historical streamflow at the Hood River at Tucker Bridge gage and at the West Fork near Dee gage. Figure 29 depicts the simulated changes in average monthly streamflow in the three future climate change scenarios at the Hood River at Tucker Bridge gage. In general, runoff during the winter and early spring is higher in volume and peak flow timing occurs earlier in all three future climate change scenarios. Summertime flow is more than 10 to 30 percent lower than simulated historical streamflow in the LW/W and MW/D climate change scenarios, respectively.

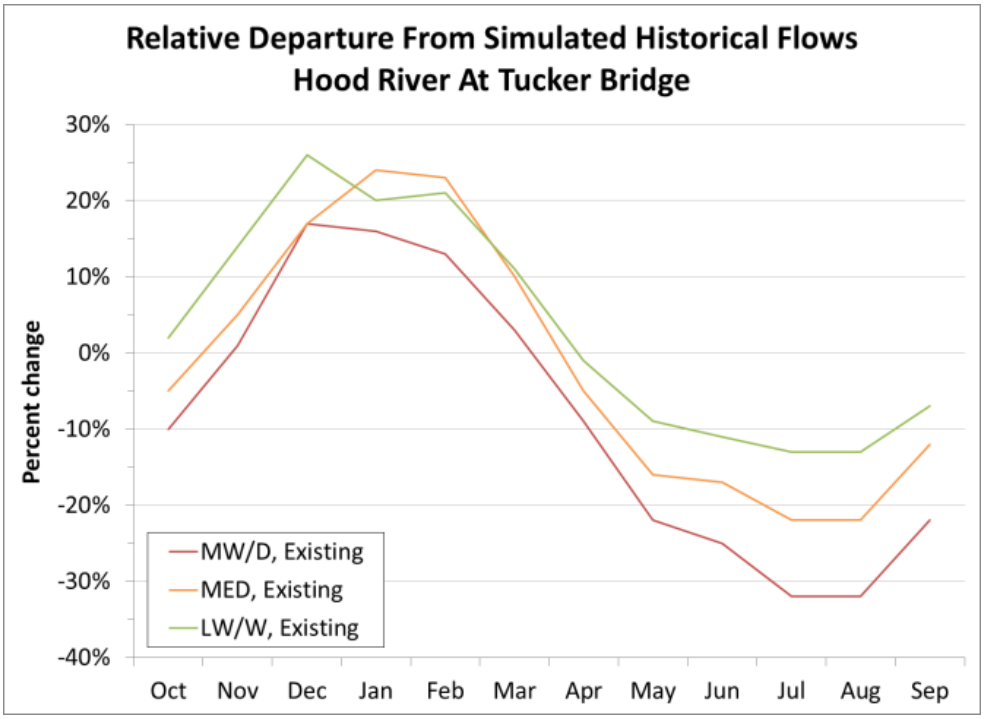


Figure 29. Departure of the MW/D, MED, and LW/W climate change scenarios from simulated historical streamflow at Hood River at Tucker Bridge gage.

Flow from the three climate change scenarios was compared to historical streamflow at the West Fork near Dee gage is shown in Figure 30. As with the Hood River at Tucker Bridge gage, streamflow at the West Fork gage depicts higher spring runoff volumes and earlier peak flow timing in all three future climate change scenarios. Peak summertime streamflow was projected to decrease between approximately 11 to 23 percent in the LW/W and MW/D climate change scenarios, respectively.

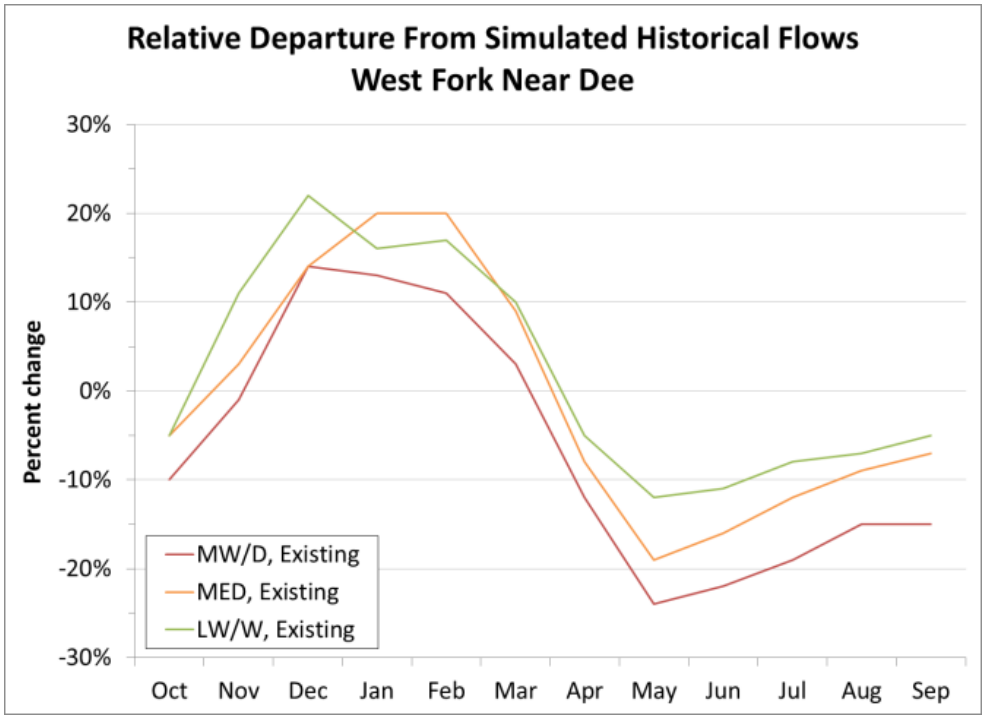


Figure 30. Departure of the MW/D, MED, and LW/W climate change scenarios from simulated historical streamflow at West Fork near Dee gage.

5.0 DEVELOPMENT OF ALTERNATIVES

A list of potential surface water and groundwater alternatives were developed to address the water supply and demand imbalances in the basin (Table 7). The climate change scenarios were developed using the projected changes in climate between 2030 and 2059. All future uses (demands, conservation, etc.) were estimated through 2050 (not 2059) to align with the estimation in population growth estimated in the Hood River County Coordinated Population Forecast, 2008-2028 Study (ECONorthwest 2008). Hood River County extrapolated population growth out to 2050 for use in this Basin Study.

Three surface water management alternatives were developed in which potable water and irrigation water demands were increased, conservation actions were implemented, and reservoir storage capacity was increased at two facilities (Green Point and Laurance Lake) and another facility was proposed (Neal Creek). Three groundwater management alternatives were also developed and investigated. In addition, cost estimates were developed for each alternative where available.

Table 7. Summary table of alternatives evaluated in the Hood River Basin Study.

Alternatives Selected	Type of alternative	How applied
Potable Water Demand	Increased Water Demand	Monthly average factors to adjust potable water demand were determined for each water district and applied in the MODSIM model.
Irrigation Water Demand	Increased Water Demand	Average annual factors for each major irrigation district were determined based on the impacts of increasing temperatures on irrigation demand.
Irrigation Water Conservation	Conservation	Estimated reduction of water use based on percentage of average available for conversion of sprinkler to micro- or drip-irrigation.
Expansion of Upper Green Point Reservoir	Reservoir Storage	Evaluated the potential of raising the dam by eight feet to increase storage from 1003 to 1654 acre-feet.
Expansion of Laurance Lake	Reservoir Storage	Evaluated the potential of raising the dam by three feet to increase storage from 3,565 to 3,935 acre-feet.
Construction of Neal Creek Facility	Reservoir Storage	Evaluated the potential of constructing a new facility with a storage volume of 2,557 acre-feet.
Increased pumping due to increased agricultural need	Groundwater	Evaluated increased pumping due to increased agricultural need under existing and climate change conditions.

Alternatives Selected	Type of alternative	How applied
Aquifer injection: storage for future use	Groundwater	Evaluated aquifer injection at various locations in the basin to determine potential benefits to aquifer storage.
Aquifer injection; streamflow augmentation	Groundwater	Evaluated aquifer injection at various locations in the basin to determine potential benefits to streamflow augmentation.

5.1 Water Demand

Future potable demands were based on anticipated increases in water demand in 2050 due to increases in population (ECONorthwest 2008). The overall annual potable use was projected to increase by 33 percent by the year 2050. Monthly adjustment factors were determined for each water district and used to adjust future water demand for use in the MODSIM model.

Future irrigation demands were based on expected increases in demand due to higher evapotranspiration in a warmer climate. The best available data at the time of this Basin Study Report indicated for every 1 °C increase in temperature, a 10 percent increase in irrigation demand was expected. Median projected temperature increases for the period 2030-2059 during the irrigation season (April through September) was estimated at 1.4 °C (which resulted in a 14 percent increase in irrigation demand). However, this 14 percent increase in demand would be somewhat attenuated in the future because many irrigators currently use impact sprinklers, which results in overwatering. Many of these irrigators are expected to transition to drip or micro-irrigation in the future. Because of that assumption, only the acreage that currently delivers close to the 1.49 acre-feet per year of actual crop demand were scaled up (WPN 2013a). An annual average adjustment factor for each major irrigation district was calculated and included in the MODSIM model.

Summer precipitation is expected to decrease with climate change, which would add additional demand for irrigation water. This component was not included in this Basin Study due to uncertainties in the timing and volume of projected changes.

5.2 Water Conservation

Existing water conservation was based on current practices in the basin as documented in the *Water Use Assessment* (Christensen and Salminen 2013). Both potable water and irrigation water conservation measures were estimated for inclusion in the MODSIM model; however, because the high cost of the potable conservation measure, only irrigation water conservation was evaluated in the conservation alternative. The approaches are summarized here.

5.2.1 Potable Water Conservation

Potable water conservation in the Hood River basin can be achieved through three primary pathways:

1. Retrofitting indoor fixtures (0.4 to 0.6 cfs reduction of use per household to likely participate).
2. Reducing outdoor water use through education and landscape conversion (0 to 0.58 cfs reduction).
3. Implementing a use-based rate structure (0.9 to 2.2 cfs reduction).

In general, all potable water conservation actions should be implemented, as feasible. The water districts receive their potable water from springs located in the basin, however, The Dalles, which uses 50 percent of the basin's total potable water, receives its water from Dog River and from groundwater pumping in the summer. Because The Dalles has such a high percentage of the total potable water use and it is outside the Hood River basin, it has less economic and political will to implement conservation measures, which reduces the effectiveness of conservation measures.

5.2.2 Irrigation Water Conservation

Future water conservation for irrigation was determined by estimating that 49 percent of impact sprinklers would be converted to micro-irrigation or drip system, which would conserve water (WPN 2013b). Reclamation incorporated the percent changes identified by Hood River County and into the MODSIM model analysis to evaluate future climate change options.

In addition to conversion of water sprinklers to micro-sprinklers, piping or other water delivery changes were evaluated. Table 8 shows the reduction in overall use (in flow) for each irrigation district if that district converted from open-water conveyance systems to another delivery mechanism.

Table 8. Water conservation achieved through piping and conveyance changes.

District	Reduction of use (cfs)	Notes
DID	1.50	Based on piping DID's distribution system, which was completed in fall 2012. Although this project has already occurred, it is included here to facilitate reduction of DID 2000-2010 historical use in the MODSIM model.
EFID	21.50	Estimate of water use reduction ranges from 21.5 cfs based on comparison of MFID per acre use during peak season to 32 cfs based on water use reports and on-farm calculation.
FID	0.00	Limited/no potential available.
MFID	0.00	Limited/no potential available.
MHID	1.00	Eliminates 50 percent of overflow where MHID receives water from EFID.

The total water conservation amounts evaluated in the conservation alternatives for each irrigation district included the percent reduction of sprinkler conversion plus the reduction in use due to conveyance changes shown in Table 8. Irrigation water conservation was considered a significant source of water savings. Generally, the basin irrigation districts are transitioning from impact sprinklers, which use a high volume of water, to micro-irrigation or drip systems, which use a low volume of water. This transition is projected to continue and estimates of water volume reduction and associated costs are shown in Table 9 and Table 10. These costs assume that 49 percent of existing impact sprinklers are converted to micro-sprinklers in the future at a cost of $1,200 per acre (IrriNet 2007).

Table 9. Water conservation by major irrigation district achieved through converting 49 percent of impact sprinklers to micro-sprinklers.

District	Reduction of on-farm use (%)	Reduction of use (acre-feet/year)	Cost ($)
DID	9.5	155	217,200
EFID*	12.0	2,297	2,950,312
FID	3.5	401	634,385
MFID	13.1	1,800	2,515,200
MHID	6.7	163	227,506

*EFID cost includes $195,000 for additional settling facility.

Table 10. Water conservation achieved through water delivery changes.

District	Reduction of use (cfs)	Cost	Notes
DID	1.5	$1,436,000	Based on project cost from piping DID's distribution system.
EFID	21.5	$16,108,000	This is a planning-level cost for piping the remaining 22 miles of EFID system. Most of funding would come from outside sources.
FID	0	0	Limited/no potential available.
MFID	0	0	Limited/no potential available.
MHID	1	$134,426	Estimated costs are 50 percent of the EFID surge pond.

5.3 Storage Options

As described in Section 3.3 of this Basin Study Report, the HRCWPG developed a list of potential storage sites that were either existing facilities that were considered expandable or new sites that would need significantly more evaluation if selected at this appraisal level. A total of 17 storage alternatives were included in the qualitative evaluation completed in Reclamation's November 7, 2012 Trip Report. This section briefly describes the three alternatives selected for further analysis in the OWRD Storage Study.

5.3.1 Reservoir Alternative 1 – Expansion of the Upper Green Point Reservoir

Green Point Reservoirs have a capacity estimated at 938 acre-feet (Wy' 2002). This alternative evaluated the potential of raising the upper dam by 10 feet that includes 2 feet of freeboard, adding 561 acre-feet resulting in a new total storage capacity of 1,469 acre-feet (Figure 11). There may be some constraints on the amount of water available in additional appropriations of water because of natural flow and water rights currently held on the streams surrounding the Upper Green Point Reservoir. The OWRD Storage Study has more information on about the natural flow and water rights.

To evaluate this alternative in the MODSIM model, simulations were performed for storage increased to 1,549 acre-feet.

Estimated Costs for Alternative 1

Costs estimates for this alternative were completed by Hood River County and their stakeholders. Table 11 outlines the total costs for two alternatives associated with the Green Point reservoirs. The cost estimate for Alternative 1.A uses materials surrounding the project site for the fill material to expand and retrofit the embankment and only places riprap on 20 percent of the embankment where wave action would typically occur. Alternative 1.B includes the cost of hauling fill material from offsite and places riprap on the entire upstream face of the embankment.

Table 11. Project cost alternatives associated with Alternative 1, expansion of Upper Green Point Reservoir.

Cost Category	Alternative 1.A ($)	Alternative 1.B ($)
Construction Costs	$835,500	$1,552,500
Non-Construction Costs	$227,500	$407,000
Contingency	$209,000	$388,000
Total Capital Cost	$1,272,000	$2,347,500
Unit Storage Costs ($/acre-foot)	$2,267	$4,184

5.3.2 Reservoir Alternative 2 – Expansion of Laurance Lake

Laurance Lake Reservoir has a storage capacity of 3,565 acre-feet and a current dam height of 106 feet. Two creeks discharge to the reservoir: Clear Creek and Pinnacle Creek (Figure 11). Outflow from the dam flows to Clear Creek (tributary to the Middle Fork Hood River) or into the penstock for the MFID first hydroelectric plant (Plant No. 1). This alternative consists of raising the maximum operating level of the dam by 3 feet, which would provide a total capacity of 3,935 acre-feet. The dam embankment would not be modified.

Most of the dam on Laurance Lake is on glacier moraine, alluvial, and possibly lake bed materials found downstream of the dam. Further appropriations are constrained by instream and out-of-stream uses held on the Clear and Pinnacle creeks. This alternative should not affect wetlands, but ESA habitat is affected, including the northern spotted owl. This will likely trigger the NEPA process in addition to Federal or state regulations.

To evaluate this alternative in the MODSIM model, simulations performed for storage increased to 3,935 acre-feet.

Estimated Costs for Alternative 2

Table 12 presents the estimated project costs for expanding Laurance Lake. The total capital cost for Alternative 2 is considerably less expensive than Alternative 1 because modifications to the embankment and spillway are not required for Alternative 2. The unit cost associated with the storage capacity is also significantly lower than Alternative 1 as a result of Alternative 2's lower capital cost and larger storage capacity. The O & M costs were estimated as 1.5 percent of the total project. Costs associated with the NEPA process could significantly increase the total capital cost due to the presence of ESA-listed species' habitat that surrounds and is within the project site.

Table 12. Project costs associated with Alternative 2, expansion of Laurance Lake.

Cost Category	Cost ($)
Construction Costs	$193,000
Non-Construction Costs	$67,500
Contingency	$67,500
Total Capital Cost	$328,000
O & M Cost	$5,000
Unit Storage Cost ($/acre-feet)	$886

5.3.3 Reservoir Alternative 3 – Neal Creek Reservoir

This alternative includes construction of a new 2,557-acre-foot reservoir on the West Fork Neal Creek to serve irrigation needs, instream flow augmentation, and recreational purposes (Figure 11). The current appropriations will constrain the amount of water available. No wetlands are delineated in the potential impact area; however, ESA-listed species and their habitats are present.

To evaluate this alternative in the MODSIM model, simulations were performed for the virtual reservoir in the MODSIM model.

Estimated Costs for Alternative 3

This alternative is the most expensive of the three alternatives as shown in Table 13. Two alternatives are presented, one of which represents the assumption that fill material for construction of the dam is nearby and the other assumes it is not. The costs per unit water of storage are extremely high in either case.

Table 13. Capital cost alternatives associated with Alternative 3, construction of the Neal Creek Reservoir.

Cost Category	Alternative 3A ($)	Alternative 3B ($)
Construction Costs	$8,751,500	$18,521,000
Non-Construction Costs	$2,274,000	$4,721,000
Contingency	$2,188,000	$4,630,500
Total Capital Cost	$13,213,500	$27,872,500
Unit Storage Cost	$6,653	$14,173

The MODSIM-DSS model results suggest that increasing the capacities of Laurance Lake and Upper Green Point Reservoir could provide enough additional storage during the April-through-September period to enable supplementing streamflows during temporary, critical low water situations.

5.4 Hydropower

The impacts of water supply to the hydropower facilities are described in this Basin Study; however, the potential impacts of climate change on hydropower production was not evaluated in detail. Specific parameters of to each hydropower facility would be required in the MODSIM model, which was outside of the scope of this Basin Study. After additional data are collected, it is recommended that hydropower production be further evaluated to understand the impacts of climate change on this important economic component.

While hydropower production was not evaluated, costs estimates assuming implemented conservation practices to reduce water use were determined. Annual hydropower revenue could be increased by $17,700 in FID and $18,415 in MFID by implementing on-farm water conservation. While EFID's high flow rates would generate considerable power during irrigation season, the lack of flow outside of irrigation season makes the installation of a new hydropower facility would not be economically feasible.

5.5 Groundwater Options

The groundwater alternatives evaluated were determined by Reclamation with input from USGS, OWRD, the Confederated Tribes of Warm Springs Reservation of Oregon, Oregon Department of Geology and Mineral Industries, and Hood River County. The simulation model served to inform additional data needs, direct future investigations, and demonstrated basic hydrologic functioning of the basin. The results from the modeling effort should be interpreted on a qualitative rather than quantitative basis.

Model scenarios were developed to evaluate increased pumping and aquifer injection under existing and future conditions. As with the surface water analyses, current climate conditions (1980-2009) were compared to future climate conditions (2030-2059) and results from each simulation were documented. The future precipitation changes generated in the climate change process (Section 4.1) were used to scale the recharge input parameter.

The increased pumping scenario relied on the addition of wells within each irrigation district based on the amount of irrigable land that was not being irrigated, an irrigation volume demand of 2 acre-feet per acre, and the assumption that each additional well can serve as much as 200 acres. This resulted in an average pumping demand of 1 cfs per well during the irrigation season for each added well.

The aquifer storage and recovery and streamflow augmentation scenarios were evaluated by iteratively adding an injection well in selected model cells and comparing the model response with the baseline model. By using this approach, spatial locations and localized regions that are potential candidate sites for either aquifer storage or streamflow augmentation became more evident. This approach does not make inferences on the practicality and constructability of a well at a specific location, but rather is intended to be used to identify general locations where aquifer injection could prove to be beneficial. In this scenario, a continuous 10 cfs flow rate is injected into the model cells for two consecutive seasons (fall and winter) and the model response for the seasons and years that follow was evaluated. The model response of particular interest occurred during the spring and summer that immediately followed injection because these are the periods when irrigation withdrawal and streamflow augmentation would be most needed.

For the increased pumping, aquifer storage and recovery, and streamflow augmentation scenarios, model outputs under different climate change conditions were compared to the current conditions baseline model and the change in the 30-year quarterly average head and discharge to streams were reported. Each climate change model scenario was developed by applying precipitation adjustment factors to the recharge values from the baseline model and adjusting groundwater pumping based on the two possible scenarios described in Section 4.1.

6.0 EVALUATION OF SELECTED ALTERNATIVES

This section summarizes the results of the evaluation of the selected surface water and groundwater alternatives under existing and future climate change that include increased potable and irrigation water demands (or consumptive use), water conservation actions, and three reservoir storage alternatives. In addition, the potential impacts of implementation of these alternatives on streamflow, minimum flows, and water demand for hydropower were evaluated and results are included. Finally, a discussion of the results of the evaluation of the groundwater alternatives is also presented.

Each section contains plots depicting results. The plots contain information for the existing conditions simulation (current conditions) and for the three alternatives. Information presented for potable and irrigation water demands, labeled as "demands," and is representative of increased demands as described in Section 5.0. Information for conservation, labeled as "conservation," is representative of a combination of the demand adjustments and the conservation adjustment, but storage is held at existing storage capacity. The reservoir storage alternatives (labeled "storage") are inclusive of all three alternatives. Additional information is provided on stream flow and minimum flow at key locations in the basin.

6.1 Increased Water Demands Alternatives

Results for the increased water demand alternative are referred to as consumptive use, which means it is assumed that water diverted for irrigation is used completely and does not return to the system. The majority of consumptive uses across the basin are assumed to not return to the stream network based on the considerable amount of piped conveyance and relatively efficient sprinklers. The one exception to this is in EFID, which has both overflows and seepage losses in its conveyance system. However, most of this return flow comes in below the Tucker gage which is the most downstream location evaluated.[15]

Figure 31 depicts the average July-to-September consumptive use shortages for irrigation water in each major irrigation districts and a combined total for all potable water districts in the MW/D climate change scenario. The results are presented as a percentage of historical demands. How these consumptive use shortages are affected by each of the three major options (demand, conservation, and storage) is also presented. The error bars reflect the 10th and 90th percentile ranges for each result in Figure 31.

[15] Refer to the *Hood River Water Resource Management Model Technical Memorandum* for more details on these locations, as well as for a complete list of consumptive uses and associated water rights incorporated into the MODSIM model.

In the driest future climate change scenario, all but DID experience shortages in the future regardless of which adaptation action is pursued. MHID experiences the greatest relative shortage under in existing conditions (i.e., climate change but no alternatives are implemented) and in the demands alternative, in which it is projected that up to 60 percent of historical demands are not met during the summer. If demands are increased but conservation measures are implemented or when all three alternatives, including the Neal Creek storage facility, are implemented, MHID experience the greatest reduction in future shortages.

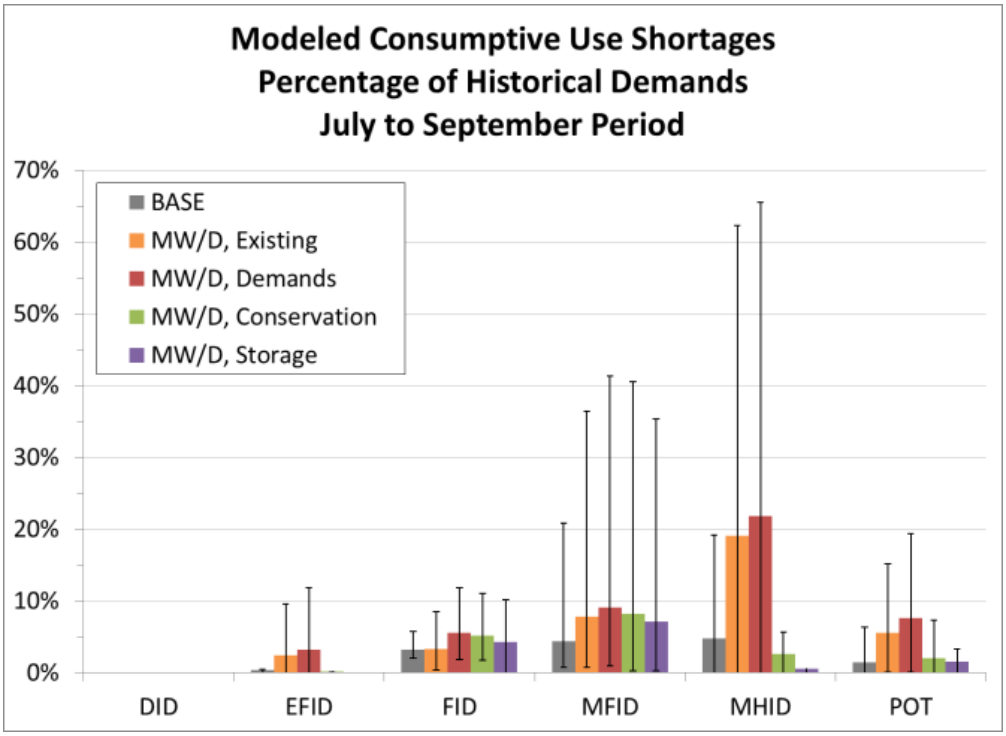


Figure 31. Average July-to-September consumptive use shortages as a percent of historical demands for the five major irrigation districts in the MW/D climate change scenario.

6.2 Storage Alternatives

6.2.1 Storage Reservoir Alternative 1 – Upper Green Point Reservoir

The Green Point Reservoir system alternative evaluated the potential of raising the Upper Green Point dam by 10 feet, with 2 feet of freeboard resulting in a new total storage capacity of 1,499 acre-feet. The Green Point Reservoir system is configured to fill in the spring and release water through September, at which time it is emptied until refill the following year (WPN 2013).

Figure 32 and Figure 33 represent the average storage volume results for the LW/W and the MW/D climate change scenarios, respectively, which encapsulate the full range of future climate change results evaluated in this Basin Study. Figure 32, which represents the driest climate change scenario (MW/D), illustrates that an increase in future demands is projected to impact the ability to fill the reservoirs. Implementation of conservation actions do not resolve this significantly. In addition, lower volumes of water are projected throughout the summer and early fall as well. Only when the all three alternatives are implemented is the reservoir projected to fill above historical levels during the driest climate change future. One potential additional option to evaluate is allowing the reservoir to fill earlier in the year, which may mitigate for the lower storage volumes shown here. That was outside the scope of the Basin Study at this time, but could be considered in the future.

This reservoir supports irrigation demands for FID. As shown in Section 4.0, no shortages were projected for FID under the Demands Alternative so it may be that the projected inability to fill under the driest future is not significant.

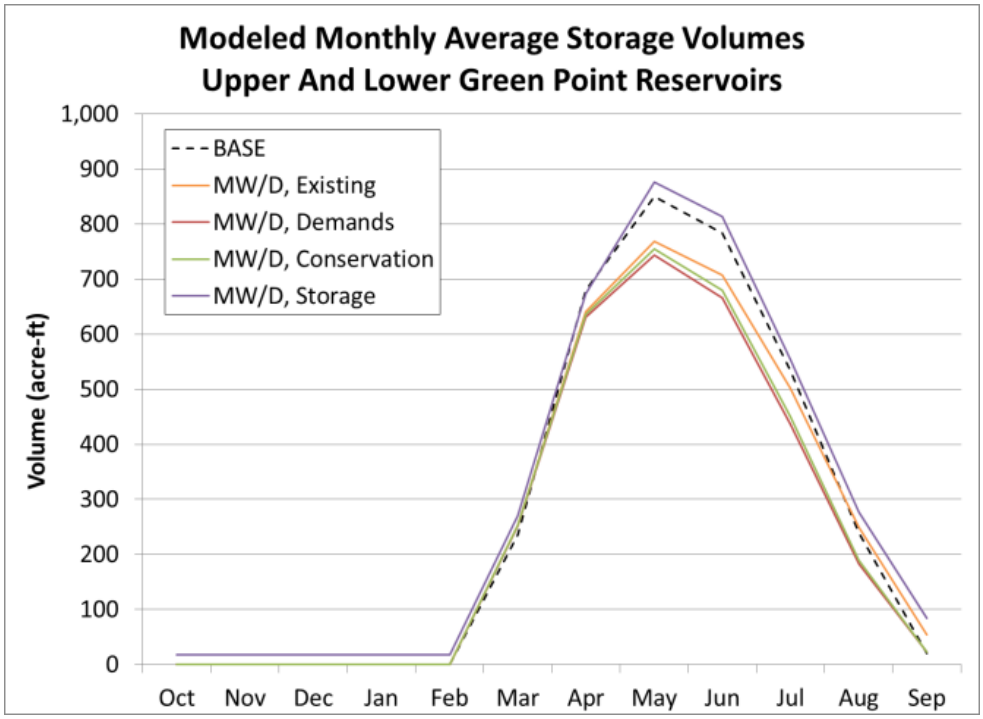


Figure 32. Change from simulated historical storage capacity for the MW/D climate change scenario in the Upper and Lower Green Point reservoirs.

Figure 36, which represents the wettest climate change scenario, illustrates the increase in demands that is attenuated by the increase in inflow to the reservoir due to the wetter projected climate scenario. The most significant change in this wetter climate change scenario is the higher volume throughout the year in the reservoir. This is in part due to the

increased capacity (1,499 acre-feet), but also the increase in general runoff due to wetter conditions in the future. More than 200 acre-feet of water is added to the reservoir capacity at the peak during the May and June periods, which was projected to satisfy current and future irrigation demands. In addition, during the October through February time period, storage volume is higher than other alternatives.

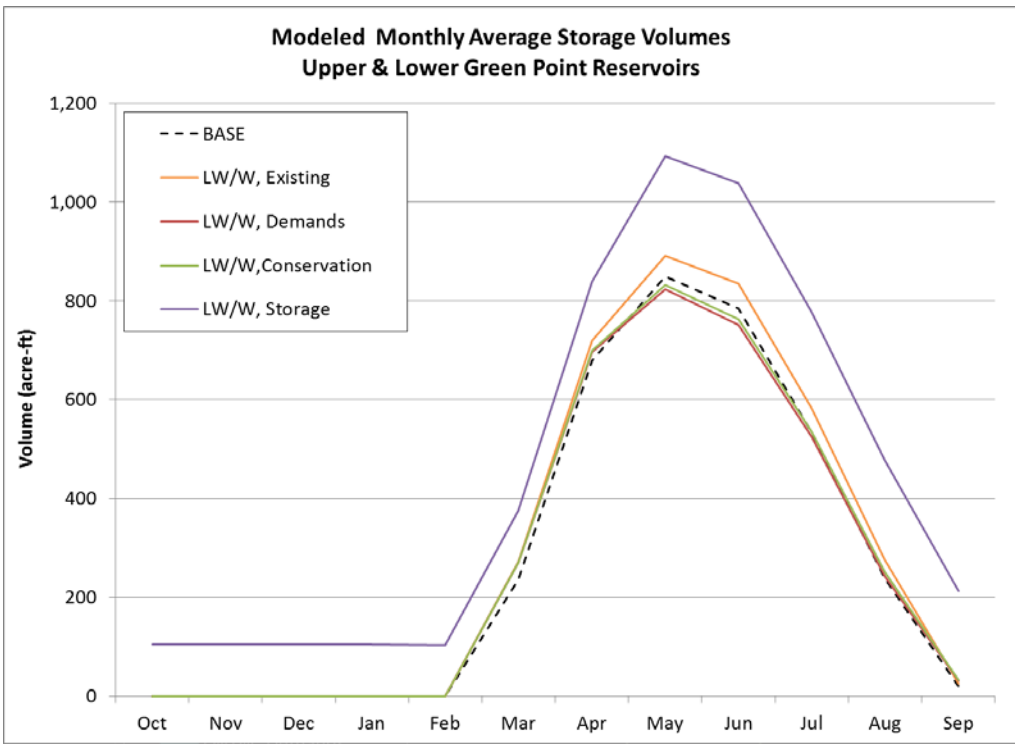


Figure 33. Change from simulated historical storage capacity for the LW/W climate change scenario in the Upper and Lower Green Point Reservoir system.

6.2.2 Storage Reservoir Alternative 2 – Laurance Lake

The Laurance Lake Reservoir storage alternative proposes to raise the maximum operating level of the dam by 3 feet, which would provide a total capacity of 3,935 acre-feet. The dam embankment would not be modified, but the spillway would have an adjustable weir that could retain snowmelt during spring runoff.

Because Laurance Lake is located in the headwaters of the Middle Fork of the Hood River, any alterations to this reservoir would impact the three hydropower facilities and any irrigation needs downstream. In the historical or baseline scenario, the reservoir volume fluctuates slightly for several months and peaking twice, once in December or January and once in June. In March, the reservoir volume decreases to approximately 2,500 acre-feet, which occurs because precipitation accumulates as snow and inflow to the reservoir is limited.

The June peak is slightly higher than the winter peak at around 3,300 acre-feet. Laurance Lake receives inflows and releases outflows continuously throughout the year for a variety of water uses, including irrigation and hydropower. In all three of the future climate change scenarios, this dip in the reservoir volume that occurs in March is reduced due to a greater amount of precipitation falling as rain.

In Figure 34, the MW/D climate change scenario suggests that the timing of the average inflow to the reservoir is impacted significantly. The second peak in June is projected to shift earlier in the year to May, with no impact observed in the first peak that occurs in December. Maintaining existing conditions, increasing demands in the future, or enacting conservation actions have minimal impact on the timing or peak volume. Peak storage volume is reduced in all but the increased storage alternative, particularly in the October-December and July-September timeframes.

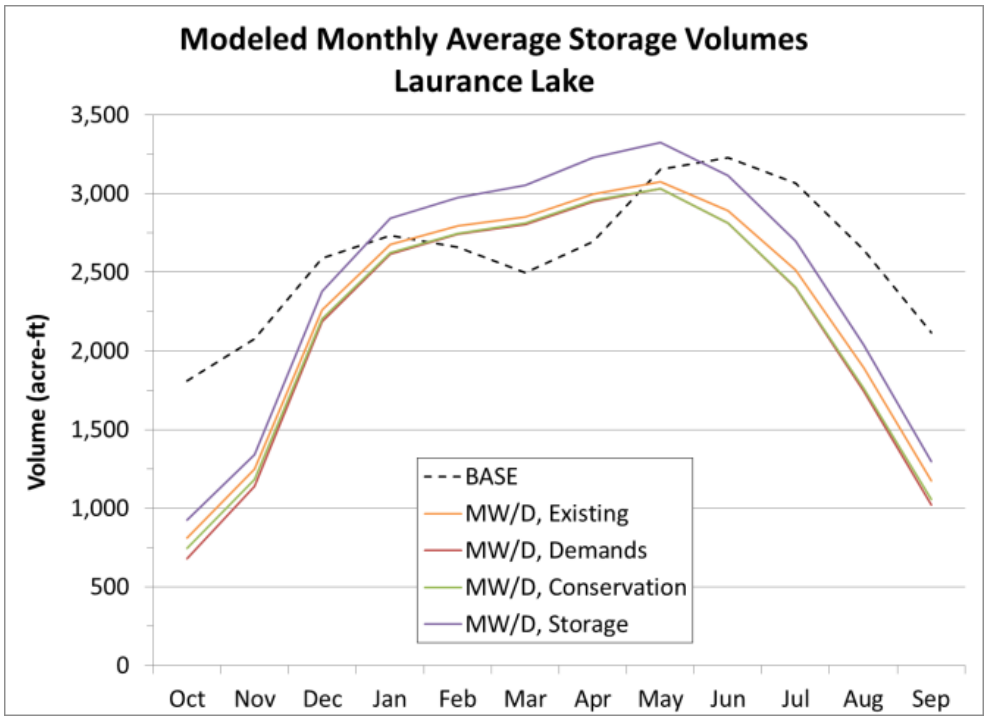


Figure 34. Change from simulated historical storage capacity for the MW/D climate change scenario in Laurance Lake.

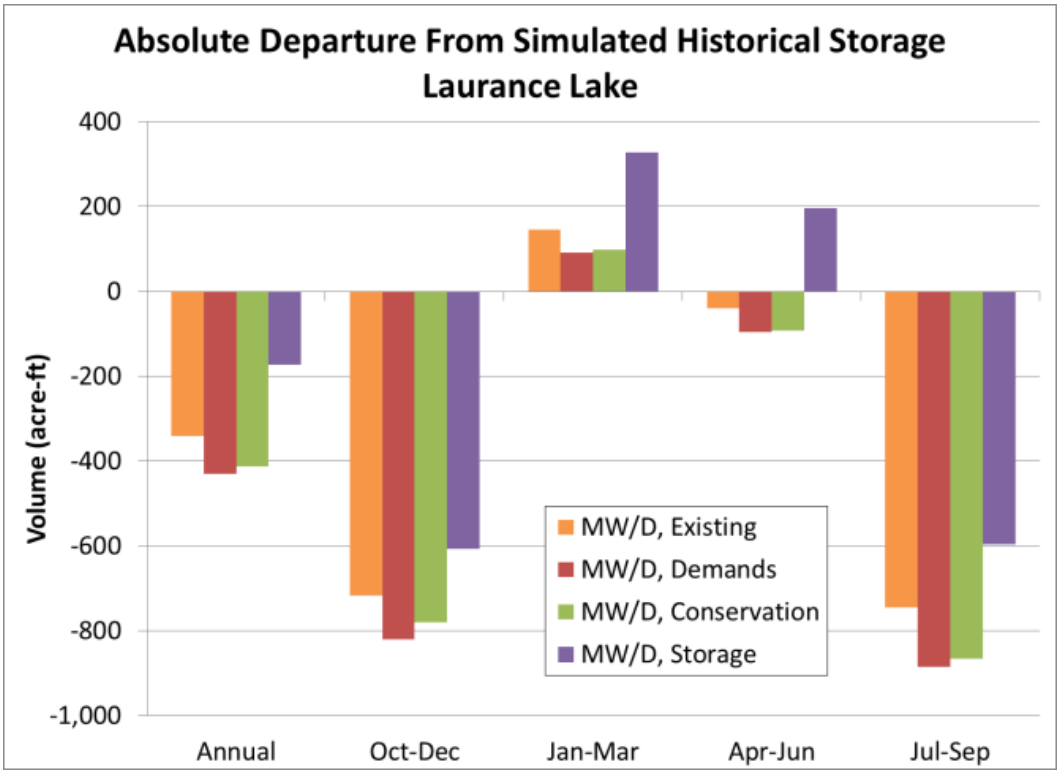


Figure 35. Change from simulated historical storage capacity for the MW/D climate change scenario in Laurance Lake.

Figure 36 depicts Laurance Lake inflow, releases, and peak volume during the wetter, LW/D climate change scenario. The October, November, and December storage volume is slightly below existing conditions, it is still higher than in the driest climate change future condition. Releases during the summer period of July, August, and September are lower with the increased demands alternative and in the implemented conservation alternative. By increasing the storage volume from 3,565 to 3,935 acre-feet, the storage alternative (with increased demands and conservation included) mimics the historical baseline in the fill and release of the reservoir storage, but provides significantly more storage volume from January through June.

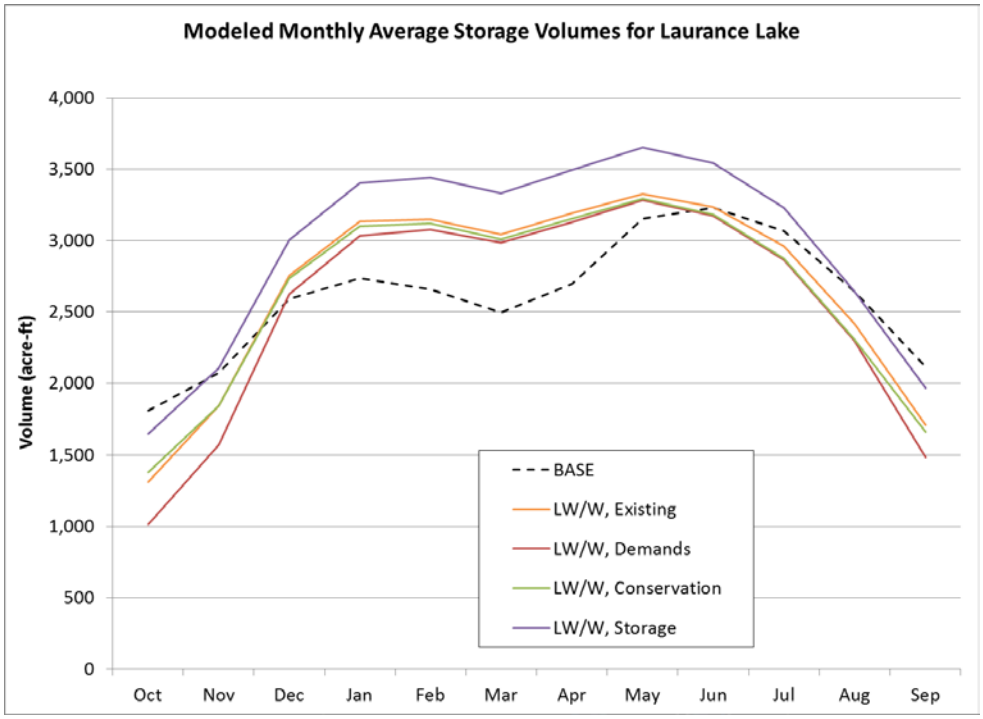


Figure 36. Change from simulated historical storage capacity for the LW/W climate change scenario in Laurance Lake.

6.2.3 Storage Reservoir Alternative 3 – Neal Creek Reservoir

Storage Reservoir Alternative 3 consists of the construction of a new reservoir on the West Fork Neal Creek with a total capacity of 2,557 acre-feet to help meet irrigation needs and instream flow augmentation (Figure 11). The proposed reservoir was simulated with releases of 10 cfs during the months of June through September to supplement flow provided to EFID. As Figure 37 shows, reservoir inflow and releases on the left y-axis and storage volume on the right y-axis for the proposed Neal Creek Reservoir. On average, inflows occur beginning in January through April and nearly fill the reservoir to the potential full capacity under the driest MW/D climate change scenario. Water releases of 10 cfs would remain in the East Fork Hood River during the summer months and reduce the amount diverted by the Main Canal. Because no shortages along Neal Creek were projected in the MODSIM simulations under any climate scenario-alternative combinations, the reservoir releases effectively augment flows along the East Fork under all summer flow conditions.

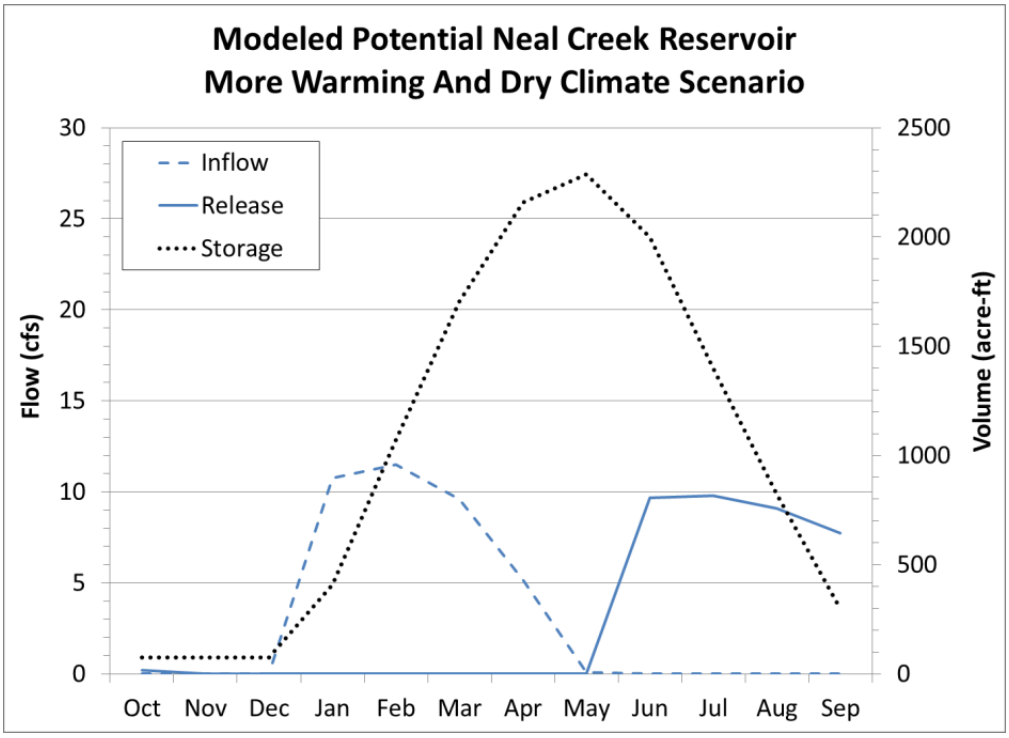


Figure 37. Simulation of inflow, release and storage patterns for the proposed Neal Creek Reservoir.

6.3 Streamflow Evaluation

Streamflow was evaluated at specific locations throughout the basin to understand the potential impacts of climate change on the historical flow and to determine if increased demands, implementation of conservation actions, or increased storage capacity attenuated any of those impacts. The following sections describe streamflow patterns at four major locations in the basin including the Hood River at Tucker Bridge gage, the West Fork near Dee gage, the East Fork above the Middle Fork, and the Middle Fork above the East Fork (Figure 38).

In general, the future climate change scenarios evaluated in this Basin Study were found to alter the timing and character of seasonal runoff across the basin. These changes are in part due to more precipitation and warmer temperatures relative to historical conditions. In the future, more of the precipitation falling in the form of rain as opposed to snow and the warmer temperatures increase snowpack melting. Natural runoff is projected to increase during the fall and winter months and decrease during the spring and summer months when water uses are greater.

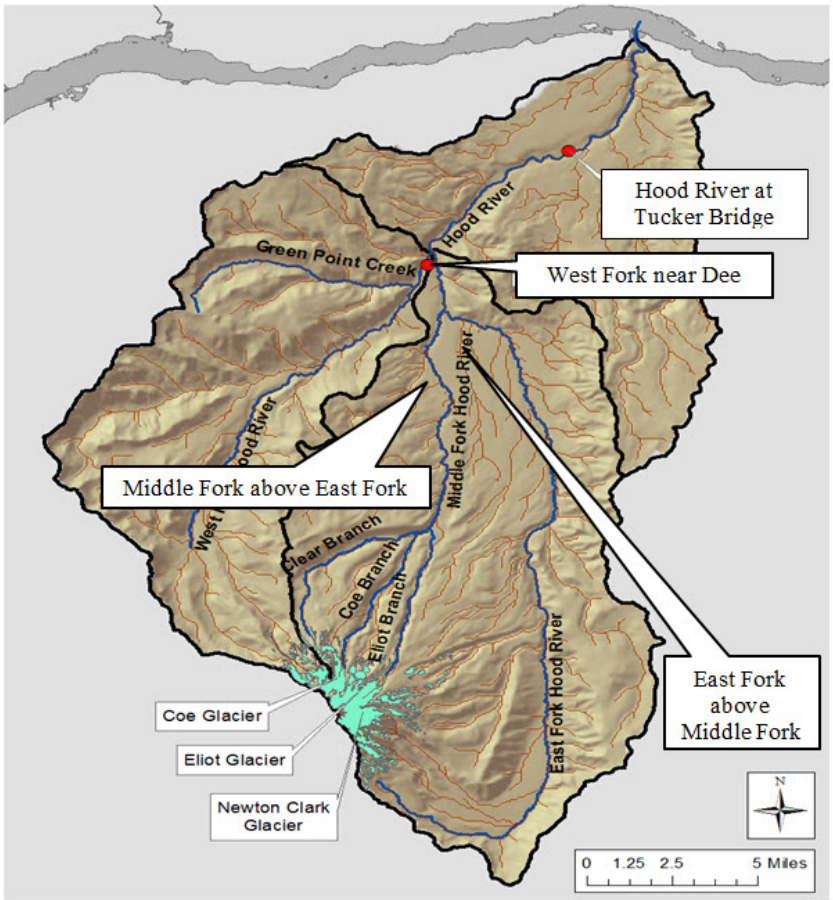


Figure 38. Location of streamflow evaluation points on the East Fork, Middle Fork, West Fork and mainstem of the Hood River.

6.3.1 Hood River at Tucker Bridge

Figure 39 depicts the average monthly flow at the Hood River at Tucker Bridge gage for the LW/W climate change scenario. The Tucker Bridge gage is located near the mouth of the Hood River. The streamflow under the LW/W climate change scenario is projected to be higher than the baseline condition during the winter season and lower than historical conditions during the late spring and summer months. None of the alternatives implemented attenuate the higher flows, but the storage and conservation options have some benefit during the late summer months.

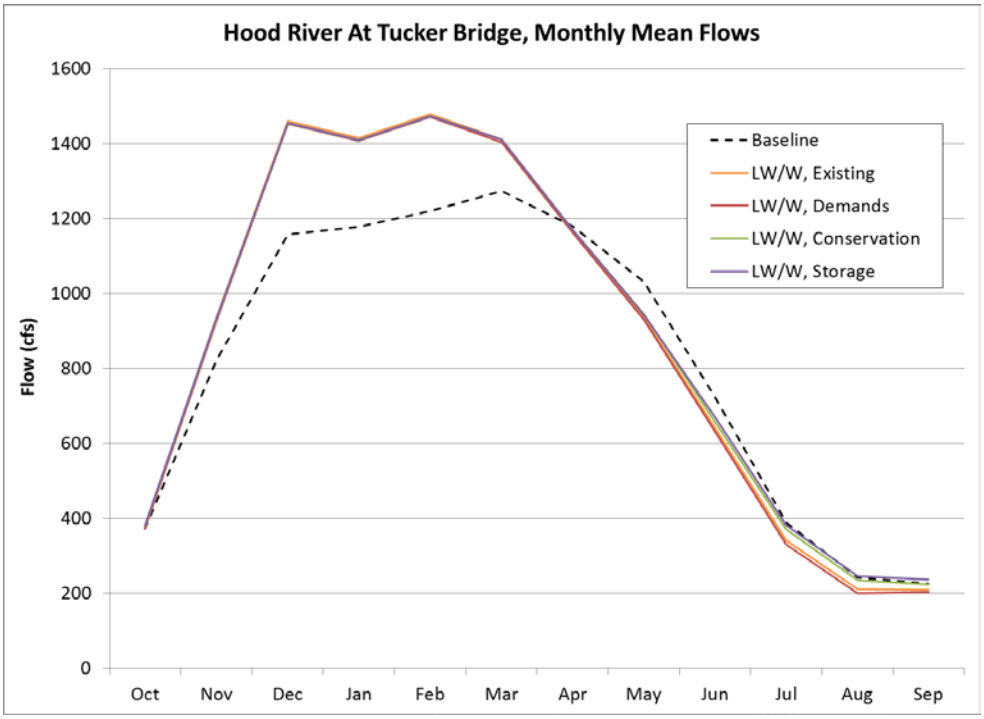


Figure 39. Average monthly regulated streamflow for the LW/W climate change scenario at the Hood River at Tucker Bridge.

In Figure 40, the distribution of streamflow for the July-to-September timeframe is plotted for the MW/D climate change scenario for the Hood River at Tucker Bridge gage. Under the MW/D climate scenario, streamflows remain lower than the simulated historical flow during the summertime period regardless of alternative simulated. Under the existing alternative, the driest future climate evaluated shows a nearly 200 cfs decrease in flow at the 50th percentile. Increasing demands exacerbate that impact slightly. The additional storage increases streamflow at the Tucker Bridge gage by approximately 50 cfs at the 50th percentile from those under the increased demands alternative.

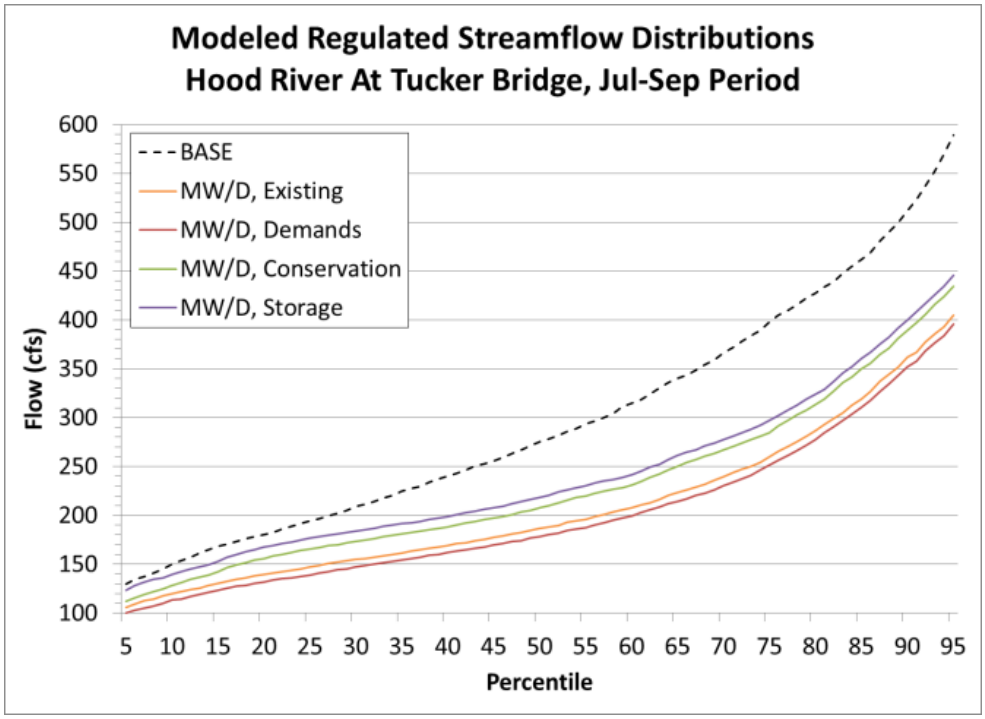


Figure 40. Distribution of average regulated streamflow at the Hood River at Tucker Bridge gage for the July through September period in the MW/D climate change scenario.

6.3.2 West Fork near Dee

The West Fork near Dee gage is located upstream of the confluence of the West Fork and mainstem of the Hood River. Figure 41 shows the percentile distributions of July to September streamflow in the MW/D climate change scenario for all three alternatives. Under existing conditions, streamflow at this gage ranges between 100 and nearly 300 cfs. Under the driest climate change scenario, this range is projected to decrease by roughly 20 cfs in the 5th percentile and nearly 50 cfs in the 95th percentile. Because there is relatively little water use on the West Fork Hood River and no storage facility (existing or proposed), none of the alternatives have a significant effect on that distribution.

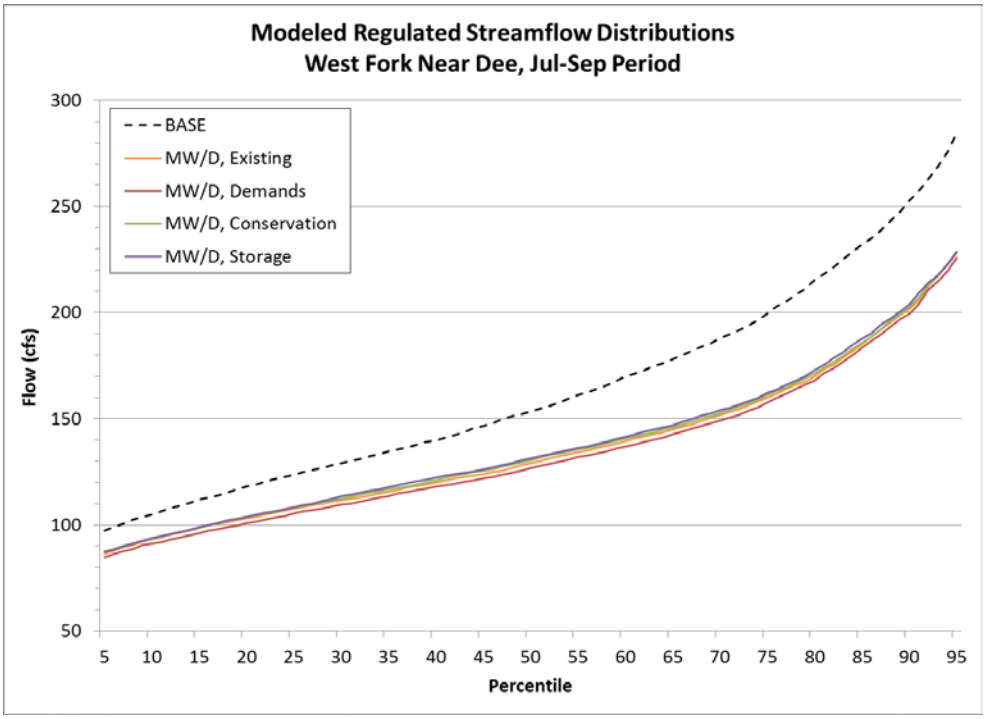


Figure 41. Distribution of average regulated streamflow at the West Fork near Dee gage for the July through September period in the MW/D climate change scenario.

6.3.3 East Fork above the Middle Fork

The East Fork Hood River streamflow site is located upstream of the confluence of the East Fork and Middle Fork. Streamflow is partially fed by glacier melt from the Mount Hood glaciers. Streamflow patterns at this site are also affected by diverted water to the Main Canal that supply water to the EFID and MHID (Figure 38).

Figure 42 shows the summary hydrograph for the MW/D climate change scenario (driest) and includes plot lines for the three options plus the existing conditions and historical simulated condition or baseline. Future flow is projected to be higher during the winter (November through March) and generally lower during the warmer months than historical (or baseline) conditions. However, if no alternative is implemented (existing conditions) and the driest climate change scenario occurs, low flows during the summertime are significantly lower than the baseline. In addition, if future demands are increased, similar low flow patterns are projected. This suggests that the East Fork may be more vulnerable to climate change if alternatives to attenuate climate change impacts are not taken. Unlike the West Fork, which has relatively few diversions, and the Middle Fork, which is buffered by storage capacity, the East Fork supplies a significant diversion (Main Canal), but currently has no mechanism to temper the late summer disparity of satisfying the greatest water demands with the lowest flows. The proposed Neal Creek storage alternative would enable more flow to remain in the

East Fork and the conservation alternative shows increases in East Fork flow, but both alternatives remain below historical conditions in the driest climate change scenario during the summer. This is because the releases from the Neal Creek Reservoir allow an additional 10 cfs to remain in the East Fork during the summer months by reducing the amount diverted by the Main Canal. The MW/D climate scenario simulations suggest that implementing both the conservation measures and the new storage along Neal Creek could mitigate the effects of the driest climate future and in a wetter future, shown next, could result in more streamflow down the East Fork relative to historical conditions.

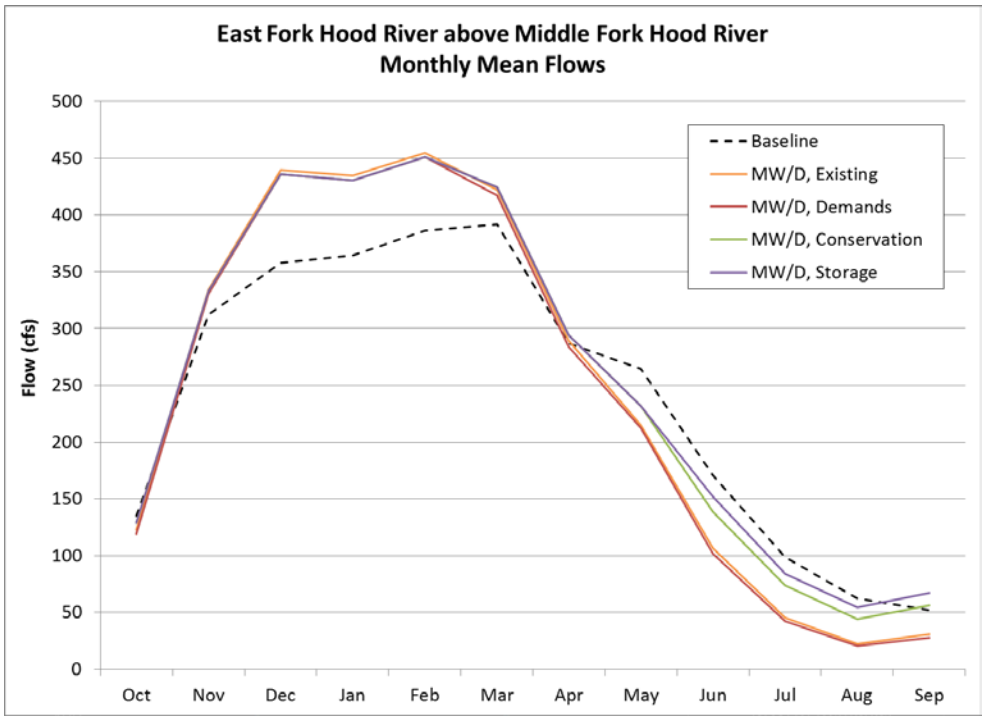


Figure 42. Mean monthly flow on the East Fork Hood River above the Middle Fork Hood River for the MW/D climate change scenarios.

Figure 45 depicts the monthly mean flows on the East Fork for the LW/W climate change scenario (wettest). While the lower summer flows are attenuated, future flows under the existing conditions or increased demands option were still projected to be lower than historical flows at this location. When conservation actions were simulated or a storage option implemented, some benefits to the East Fork were projected. The storage facility, while on Neal Creek, benefits the flow at on the East Fork location because the facility provides for more flow to remain in the East Fork below the Main Canal.

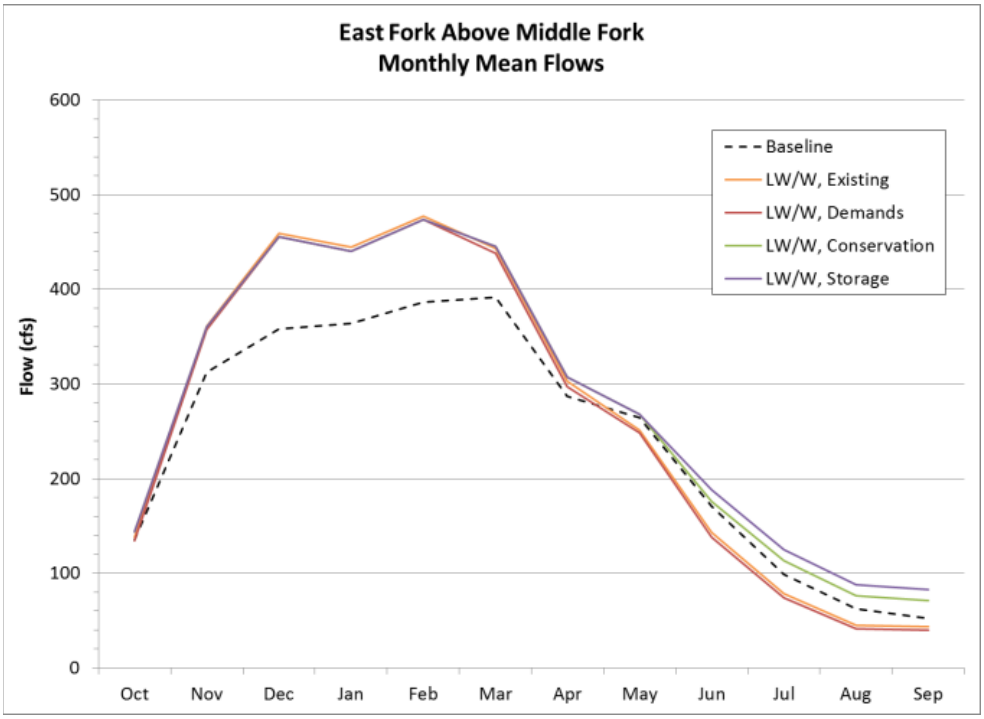


Figure 43. Mean monthly flow on the East Fork Hood River above the Middle Fork Hood River for the LW/W climate change scenarios.

6.3.4 Middle Fork above the East Fork

Flow on the Middle Fork Hood River was evaluated in a similar manner as in the West and East Forks. This location is near the confluence of the Middle Fork and the East Fork. While the pattern of increased flow in the winter and spring and decreased flows in the summer is consistent among all three locations, the Middle Fork Hood River has a runoff pattern with the falling limb of the hydrograph beginning in or around the month of June, as opposed to March or April in the West and East Forks. This pattern may be due to a number of reasons such as Laurance Lake operations, MFID diversions, and minimum flow requirements. Also, the Coe, Clear, and Eliot Branches of the Middle Fork are fed by glacier melt, which could affect the peak timing of streamflow, snowmelt, and a larger high-elevation contributing area.

In the MW/D climate change scenario, future flow patterns result in a compacted hydrograph in which a discernible peak in streamflow occurs in January and after which flows recede through late spring and summer. This recession, although gradual until June, is earlier than in the historical period and occurs regardless of which alternative is implemented. On average, future flows in April through the late summer are less than historical conditions (Figure 44). Implementation of the either conservation actions or of the additional storage feature at Laurance Lake (raising the dam height by 3 feet), provides some attenuation of the MW/D (driest) climate change scenario's impact in the middle of the summer, but it is minimal.

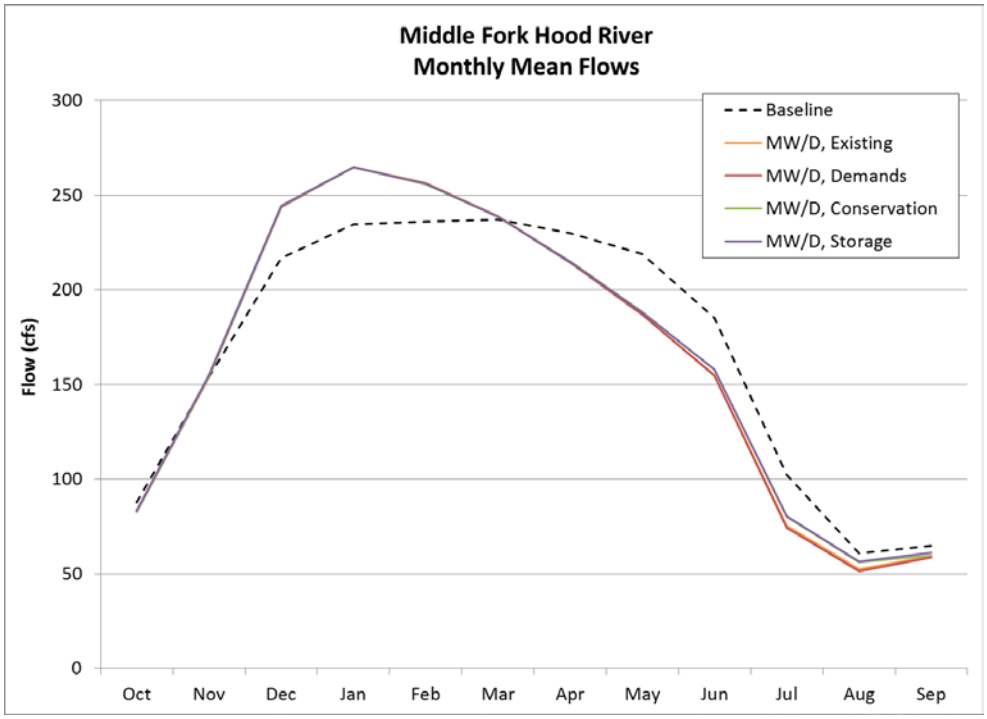


Figure 44. Mean monthly flow on the Middle Fork Hood River for the MW/D climate change scenario.

For a closer inspection of the potential impacts of the MW/D climate change scenario summer months at the Middle Fork Hood River location, Figure 45 shows the distribution of flow for each adaptation option for July, August, and September. At low flows (below the median, or 50th percentile), the simulated increase in consumptive use resulted in decreased flow in the Middle Fork when compared to the historical condition.

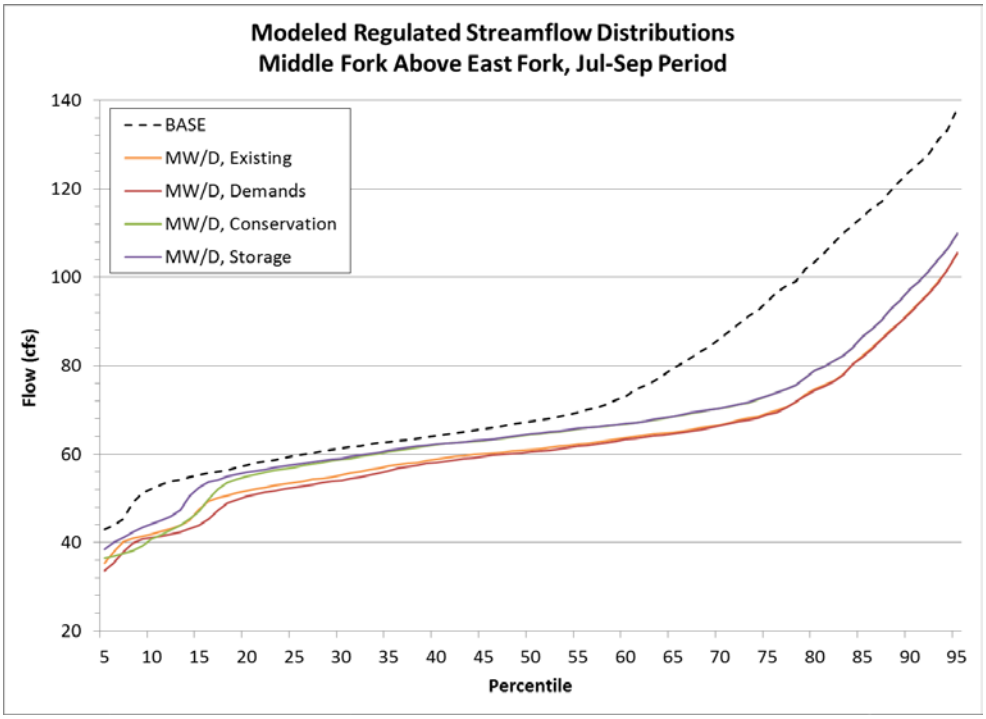
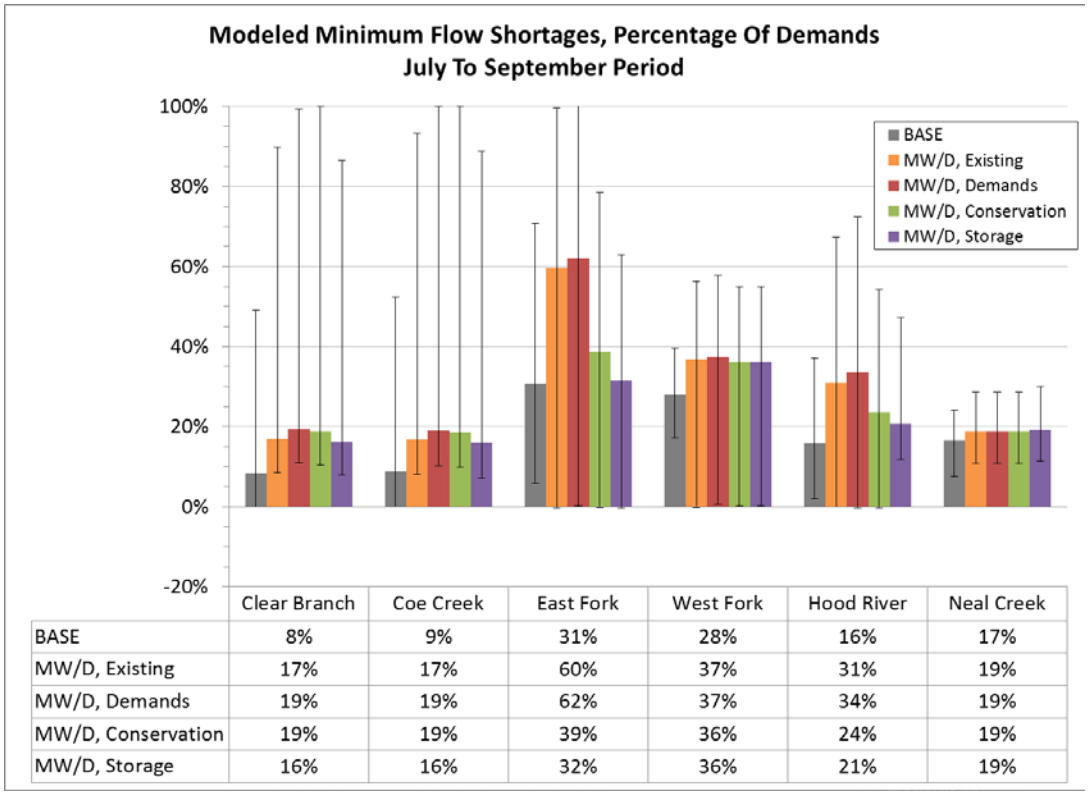


Figure 45. Distribution of mean monthly flow on the Middle Fork Hood River for the MW/D climate change scenario during the summer months.

6.4 Minimum Flows Evaluation

The evaluation of climate change impacts on minimum flow requirements was conducted at several locations in the basin, including Clear Branch and Coe Branch on the Middle Fork Hood River, the East Fork above the Middle Fork, the West Fork below Lake Branch, Neal Creek at the mouth, and Hood River at Tucker Bridge. Instream water rights and agreements are generally junior to other water rights in the basin and because of that, these rights may potentially be more impacted in the future than consumptive use and hydropower rights. Figure 46 shows the average changes in minimum flow shortages during the summer at each location for all the increased demands, conservation, and storage alternatives in the MW/D climate change scenario during the critical summer months. These results were developed from the simulated historical averages for the instream rights and agreements in the basin.



	Clear Branch	Coe Creek	East Fork	West Fork	Hood River	Neal Creek
BASE	8%	9%	31%	28%	16%	17%
MW/D, Existing	17%	17%	60%	37%	31%	19%
MW/D, Demands	19%	19%	62%	37%	34%	19%
MW/D, Conservation	19%	19%	39%	36%	24%	19%
MW/D, Storage	16%	16%	32%	36%	21%	19%

Figure 46. Average modeled minimum flow shortages as a percentage of average demands from July to September for the MW/D climate change scenario.

On the Middle Fork tributaries (Coe Branch and Clear Branch), if no adaptation action is taken, shortages occur 20 percent or less of the time (error bars represent the 10th and 90th percentiles of simulated values) regardless of the alternative selected. Increasing the storage capacity of Laurance Lake near the headwaters of the Middle Fork Hood River attenuates these minimum flow shortages, but by very little due to their junior water right status.

On the East Fork Hood River, if no alternative is implemented (existing conditions) or if demands are increased, minimum instream flow shortages increase 30 percent above average historical conditions. However, with the Neal Creek Reservoir alternative implemented, releases from that proposed reservoir allow an additional 10 cfs to remain in the East Fork during the summer months by reducing the amount diverted by the Main Canal. This results in more than a 20 percent decrease in the projected shortage under the first two alternatives.

On the West Fork Hood River, increases in minimum instream shortages were projected to increase approximately 12 percent above historical conditions if no alternative is implemented (existing conditions), but the driest change in climate occurs. Implementing the conservation alternative shows generally negligible results. No reservoir alternative is proposed on the West Fork Hood River so no impact is observed from that alternative.

Neal Creek minimum flow shortages were not projected to increase above historical conditions under any future climate change scenario or option evaluated. This suggests that the reservoir releases from the proposed Neal Creek Reservoir may effectively augment flows along the East Fork without significantly impacting minimum flows on Neal Creek. The MW/D climate scenario simulations suggest that implementing both the conservation measures and the new storage along Neal Creek could not only mitigate the effects of climate change, but may actually result in more streamflows down the East Fork when compared to the historical period.

6.5 Hydropower Demands Evaluation

While hydropower production was not evaluated in this Basin Study, the water supply demand by the powerplant facilities was modeled. Simulated changes in flows through hydropower facilities were generally not significant (Table 14). Although hydropower water rights are senior to minimum flow requirements and may impact some of these results, the primary reason for the tempered impact of projected climate change on hydropower operations in the basin was likely due to the timing of peak power production versus the timing of peak consumptive water use. As described in Section 4.4.1, the average total hydropower production in all of the powerplants show that peak hydropower demands occur in the early to late spring, when consumptive use demands are low. The streamflows remain relatively high throughout the future period.

Table 14. Simulated future departures from simulated historical hydropower flows (annual and quarterly averages) for FID and MFID in the MW/D climate change scenario.

FID	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)
MW/D Scenario	Annual	0	0	0	0
	Oct-Dec	0	0	0	0
	Jan-Mar	0	0	0	0
	Apr-Jun	0	0	0	0
	Jul-Sep	0	0	0	0
MED Scenario	Annual	0	0	0	0
	Oct-Dec	0	0	0	0
	Jan-Mar	0	0	0	0
	Apr-Jun	0	0	0	0
	Jul-Sep	0	0	0	0
LW/W Scenario	Annual	1	0	0	0
	Oct-Dec	0	0	0	0
	Jan-Mar	0	0	0	0
	Apr-Jun	0	0	0	0
	Jul-Sep	0	0	0	0

MFID	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)
MW/D Scenario	Annual	0	0	1	2
	Oct-Dec	0	0	0	0
	Jan-Mar	0	0	0	1
	Apr-Jun	0	1	2	2
	Jul-Sep	-1	0	3	4
MED Scenario	Annual	0	0	2	2
	Oct-Dec	0	0	0	0
	Jan-Mar	0	0	1	1
	Apr-Jun	0	1	2	2
	Jul-Sep	0	0	4	4
LW/W Scenario	Annual	0	1	2	2
	Oct-Dec	0	0	0	0
	Jan-Mar	0	0	1	1
	Apr-Jun	0	1	2	2
	Jul-Sep	0	1	5	5

6.6 Groundwater Options

Three groundwater options were evaluated in this Basin Study that included increased pumping under current conditions, increased pumping under climate change conditions, and aquifer injection under both current and future conditions. These results are reported in this section.

6.6.1 Increased Pumping under Current Conditions

The modeled impacts that result from this scenario are directly due to the methodology for adding wells described in Section 5.5 that impacts would change, depending on how and where additional wells are added to the model. The metrics used for reporting the impacts under this scenario were changes in water levels and groundwater-contributed stream gains (baseflow).

The additional wells result in a decrease in groundwater levels as compared to the baseline current condition model run. The decrease in groundwater level is shown spatially in Figure 47. The figure also shows a maximum possible decline of several tens of feet within the EFID boundaries at the end of the fifth year of increased pumping. The location of the additional pumping wells that were added play a large part in the resulting modeled decrease. Different configurations of wells would result in different magnitudes and locations of groundwater level decrease.

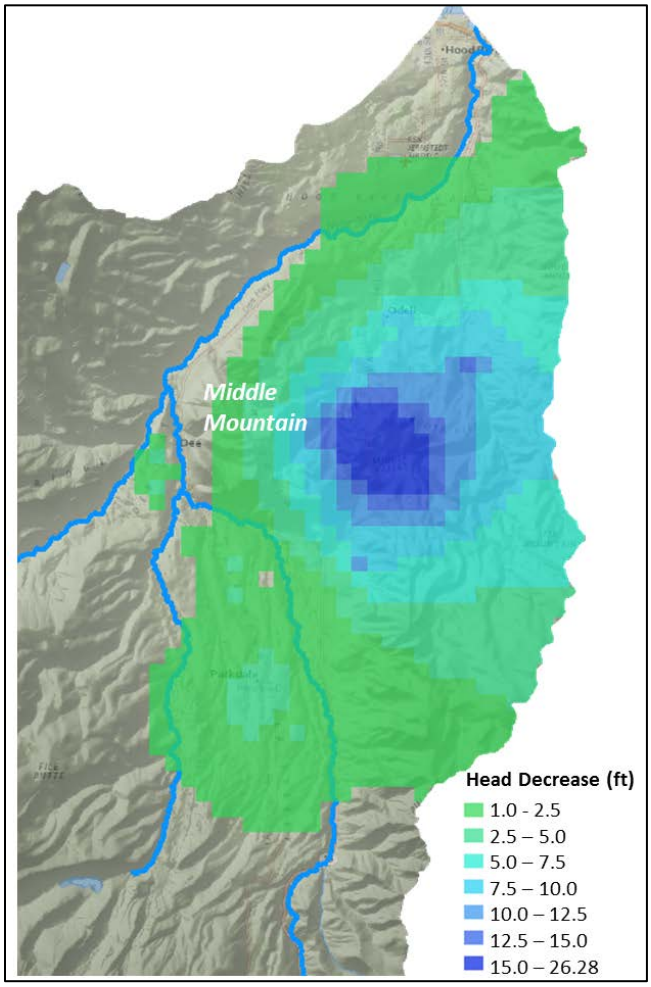


Figure 47. Water level change due to increased pumping under current conditions.

The average change in baseflow that the model simulates in this particular scenario is shown in Figure 48. The figure shows the pronounced effects of the increased pumping scenario to the April-through-September timeframe when the increased pumping is active. From a volumetric standpoint, the additional demand imposed by the increased pumping scenario is approximately 8,200 acre-feet per year while the annual average decrease in baseflow volume from the scenario is approximately 7,100 acre-feet per year. This suggests that roughly 80 to 90 percent of groundwater pumping is captured from the Hood River and its tributaries. The remainder of the impacts in terms of volume is seen at the Columbia River model boundary.

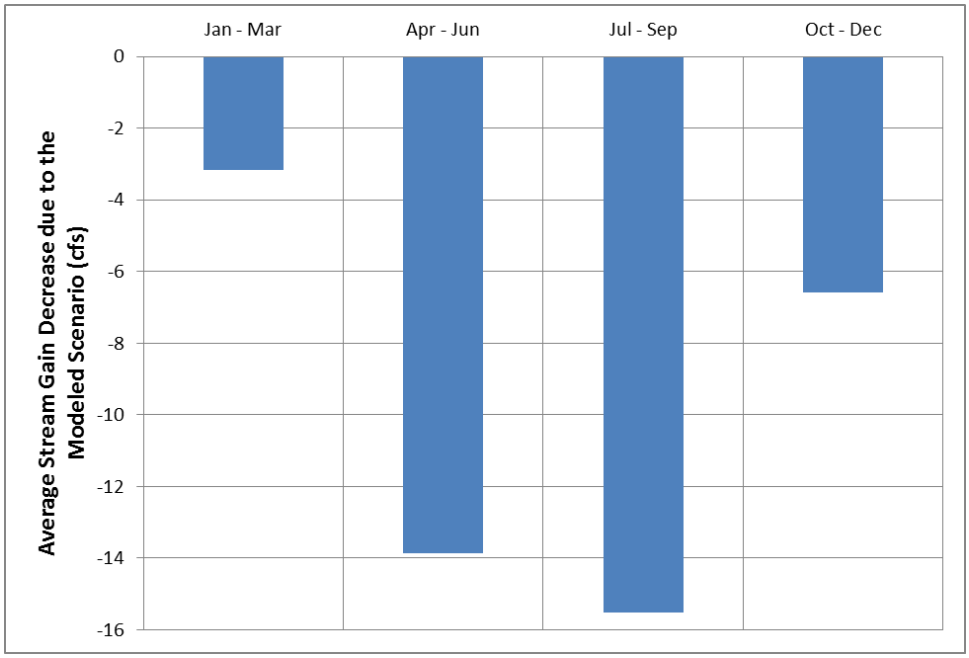


Figure 48. Baseflow change due to the current conditions, increased pumping scenario.

6.6.2 Increased Pumping under Climate Change Conditions

Increases in groundwater pumping due to climate change conditions were formulated differently than those under current conditions. Assuming that evapotranspiration needs for crops would increase and that late summer streamflow would be less available with climate change, pumping rates were increased to reflect the projected change in potential evapotranspiration using output from the hydrologic modeling (see Section 4.2) that was accomplished in support of the Basin Study.

Changes in groundwater levels due to projected climate change conditions and estimated increases in groundwater use due to modeled irrigation and evapotranspiration demand are shown in Figure 49. The water level differences represent the 30-year average for each climate condition per quarter at select locations in the Hood River basin. The MW/D climate conditions result in the greatest decrease while the LW/W climate conditions result in the least decrease with respect to modeled groundwater levels. Water level decreases are greatest near the northern part of the model domain due to estimated pumping increases and the clustering of irrigation wells in this region.

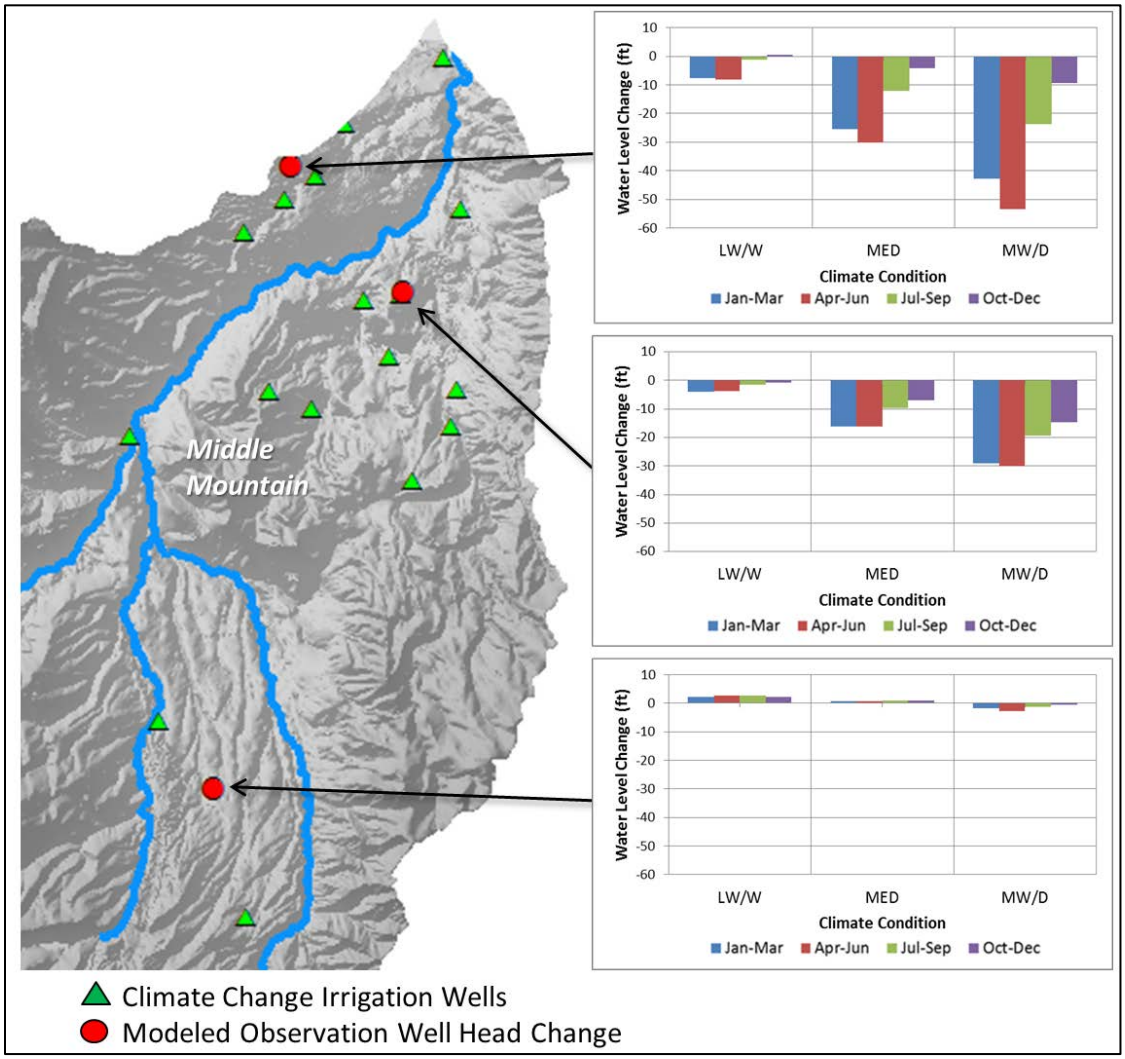


Figure 49. Climate change impacts on groundwater levels, modeled pumping increase scenario.

Impacts to baseflows as a result of climate change and the simulated increase in pumping due to streamflow decreases and potential evapotranspiration increases are shown in Figure 50. Negative values in this figure indicate a large decrease in baseflows due to the increased pumping scenario under climate change conditions. The magnitude of the baseflow decrease is greatest for the dry condition (MW/D) and is the least for the wet condition (LW/W). This result is expected since the increased pumping due to climate change was defined as 50 percent of the DHSVM modeled streamflow decrease in addition to the potential evapotranspiration increase.

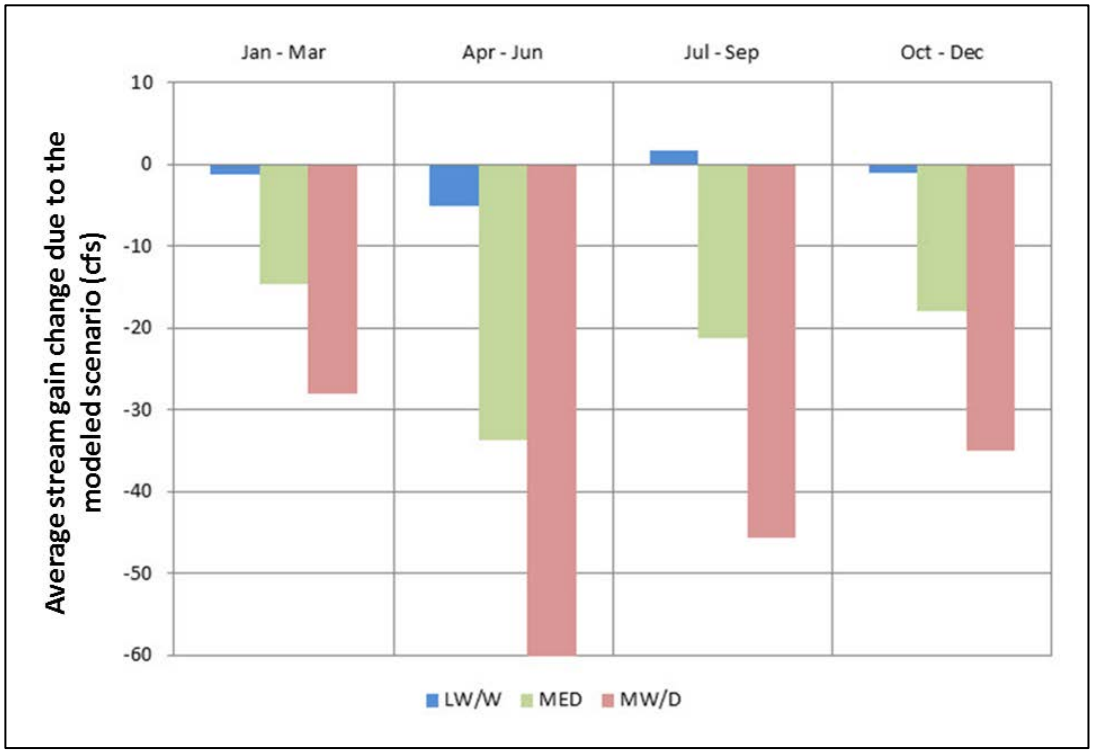


Figure 50. Baseflow change due to the climate change conditions, increased pumping scenario.

6.6.3 Aquifer Injection under Current and Climate Change Conditions

As described in Section 5.5, a continuous 10 cfs flow rate is injected into the model cells for two consecutive seasons (fall and winter) and the model response for the seasons and years that follow was evaluated. The model response that occurred in the spring and summer that immediately follows injection were of greatest importance because these were the periods when irrigation withdrawal and streamflow augmentation would be most needed.

Two metrics were defined to evaluate the effectiveness of each model cell for either storage or streamflow augmentation. The metric used for storage was the percentage of injected water retained within the model boundaries for all stress periods that follow injection. This metric compared the difference in the baseline water budget and the injection water budget for the entire model domain repeated for each model cell. In effect, the storage metric calculated how much of the injected water left the model domain through any of the modeled boundary conditions. Conversely, this resulted in the injected water that remained within the model domain that was available for withdrawal. This metric was reported as a fraction of the injected volume.

The metric used for streamflow augmentation was the difference between the baseline and the simulated baseflows at the Hood River at Tucker Bridge gage. This metric was reported as a flow rate. A comparison of the injection metric results for two cells is shown in Figure 51. The plots next to the map show the modeled metric value on the vertical axis and the modeled time represented by a MODFLOW stress period (SP) on the horizontal axis. Each SP represents an annual quarter with SP0 spanning the months from October through December, SP1 spanning January through March, and so on. Aquifer injection occurs during the first fall and winter, SP0 and SP1 respectively, with a continuous injection rate of 10 cfs. The cell's spatial location has a direct effect on whether injections were conducive for aquifer storage and withdrawal or for streamflow augmentation.

In general, cells located near the river were more conducive for streamflow augmentation while cells that were farther away were better suited for aquifer storage and withdrawal. The red cell (red curve), located near the river, had most of the injected water returning to the river much earlier than the blue cell (blue curve). Figure 51 shows the difference in modeled and baseline groundwater-contributed baseflows at Tucker Bridge. In contrast, the blue cell, located on Middle Mountain, may be better suited for aquifer storage and withdrawal as shown by the blue bars on Figure 51. These show that the blue cell's injection location allowed the aquifer to retain more of the injected volume as opposed to the red cell that quickly lost the injected water to the modeled boundary conditions.

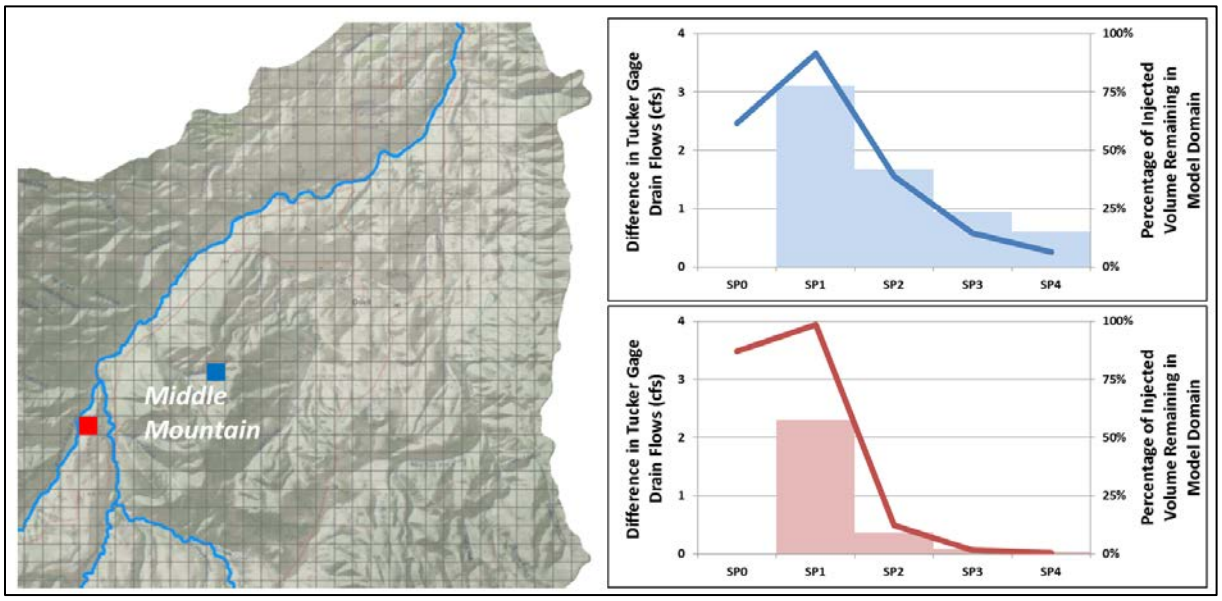


Figure 51. Cell-by-cell injection metric results comparison.

Figure 52 shows the geographic distribution of values shown in graphs on Figure 51 for the fall and winter when injection occurs, and the spring and summer that directly follow. Each cell is colored based on the modeled metric value at different stress periods for each cell. Of

particular interest is the modeled result for the spring and summer because this is when benefits for irrigation withdrawals and streamflow augmentation are most needed.

Figure 52 is comprised of maps that show the remaining fraction of the injected water within the model domain that results from the cell-by-cell injection analysis. Cells located near the river are shown to be ineffective in terms of storage and withdrawal during the irrigation season with less than 10 percent of the injected volume remaining in aquifer storage during the spring and summer. A location where aquifer injection for aquifer storage and recovery might be feasible is the area directly southeast of Middle Mountain where roughly 40 to 50 percent of the injected volume is retained during the spring and summer. The area northeast of Middle Mountain is another location that shows potential for aquifer storage and recovery.

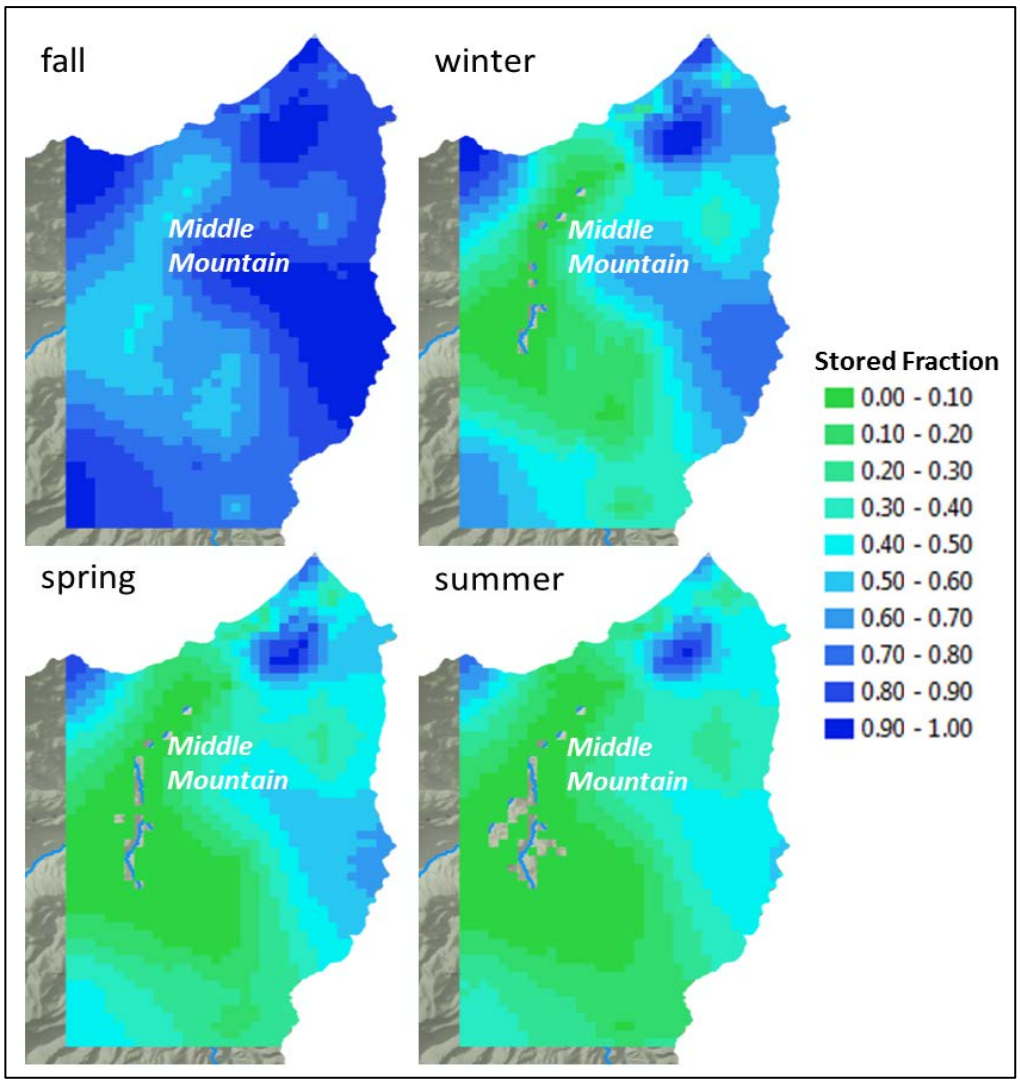


Figure 52. Cell-by-cell injection effects on aquifer storage volume, current conditions.

Figure 53 shows the increase in baseflows at Tucker Bridge resulting from injection at individual model cells. A direct injection into the aquifer shows that the injected volume leaves the aquifer relatively quickly for cells near the river. These cells stop contributing to baseflows as early as the spring that directly follows aquifer injection.

None of the evaluated cells appear to be effective in augmenting baseflows at Tucker Bridge during the summer. Figure 53 shows that even among cells that are still contributing to a baseflows increase in the summer, the increase is relatively small at a maximum of 1 cfs out of the injected 10 cfs during the fall and winter. This results in a baseflow increase equivalent to a maximum of 10 percent of the injected flow rate.

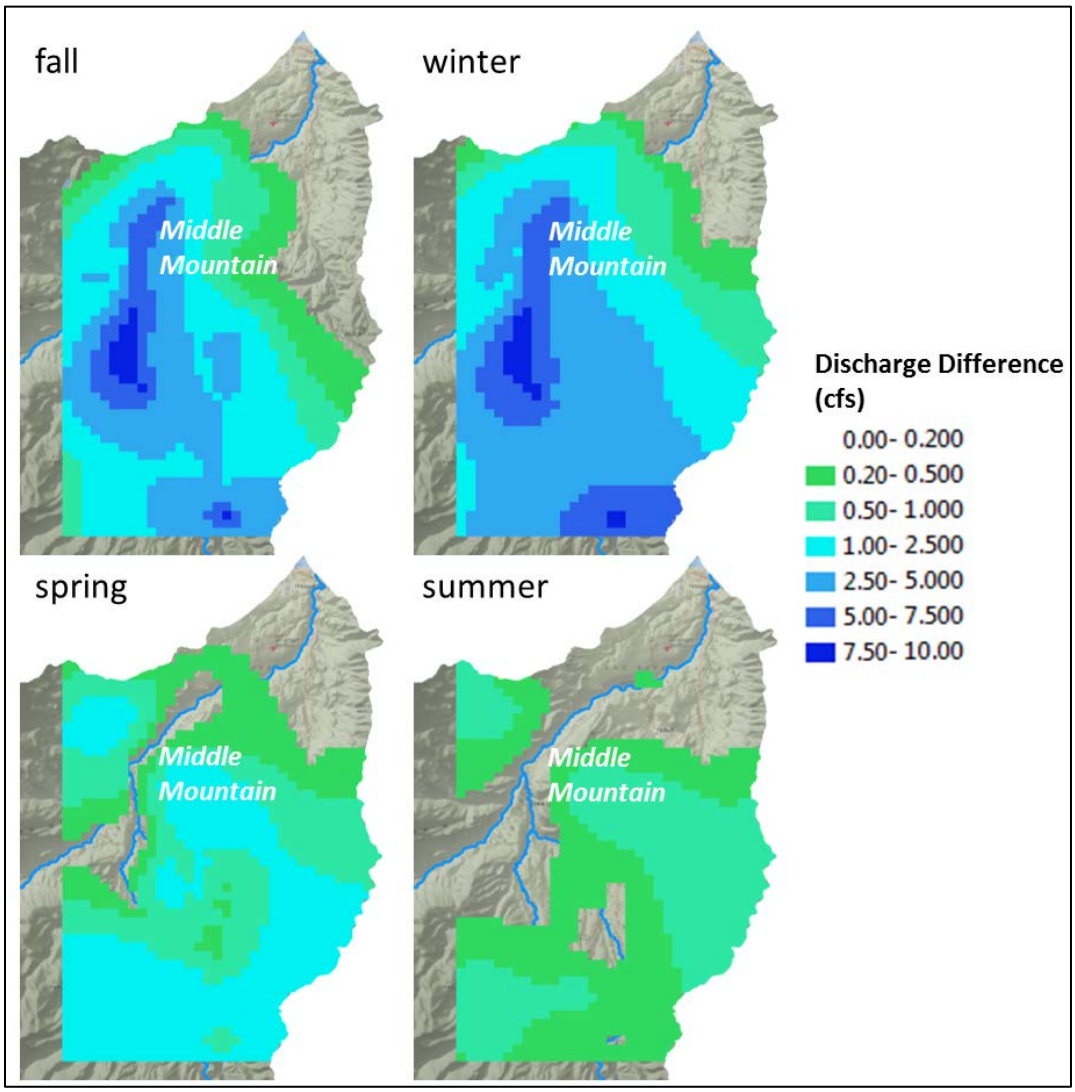


Figure 53. Cell-by-cell injection effects on Tucker Bridge streamflows, current condition.

The aquifer injection modeling for aquifer storage under climate change conditions resulted in very similar results as those under current conditions. This is not surprising given that the defined metric that quantifies benefits under the aquifer injection scenario relies on a relative change from a baseline condition. Figure 54 displays the benefit maps for the MED climate change condition that shows the remaining fraction of the injected water within the model domain which results from the cell-by-cell injection analysis.

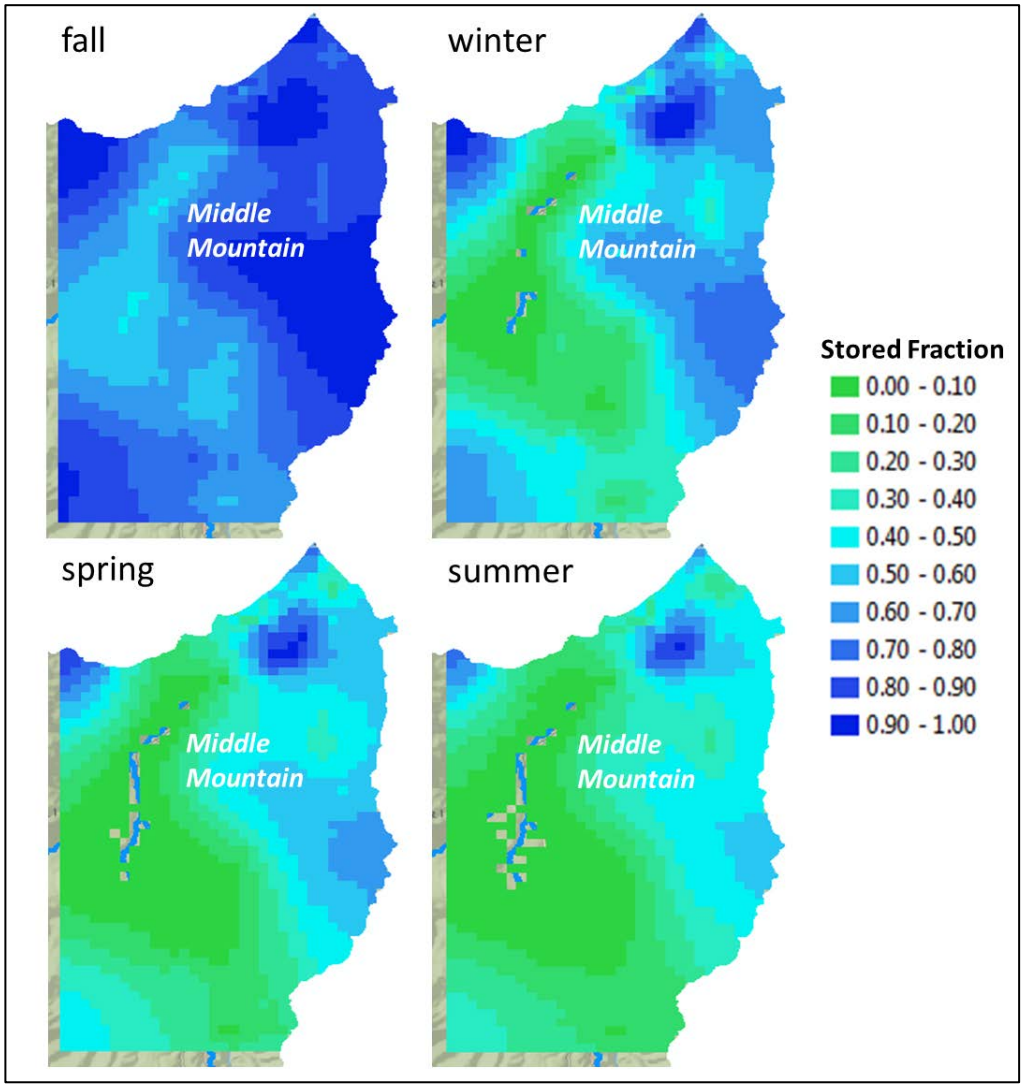


Figure 54. Cell-by-cell injection effects on aquifer storage volume, median climate change condition.

The aquifer injection modeling for streamflow augmentation under climate change conditions resulted in very similar results as those under current conditions for the same reasons mentioned in the previous section. Figure 55 shows the difference between modeled and baseline groundwater-contributed baseflows at Tucker Bridge that result from the cell-by-cell

injection analysis. A direct injection into the aquifer shows that the injected volume leaves the aquifer relatively quickly for cells near the river. These cells stop contributing to groundwater-contributed baseflows as early as the spring that directly follows aquifer injection.

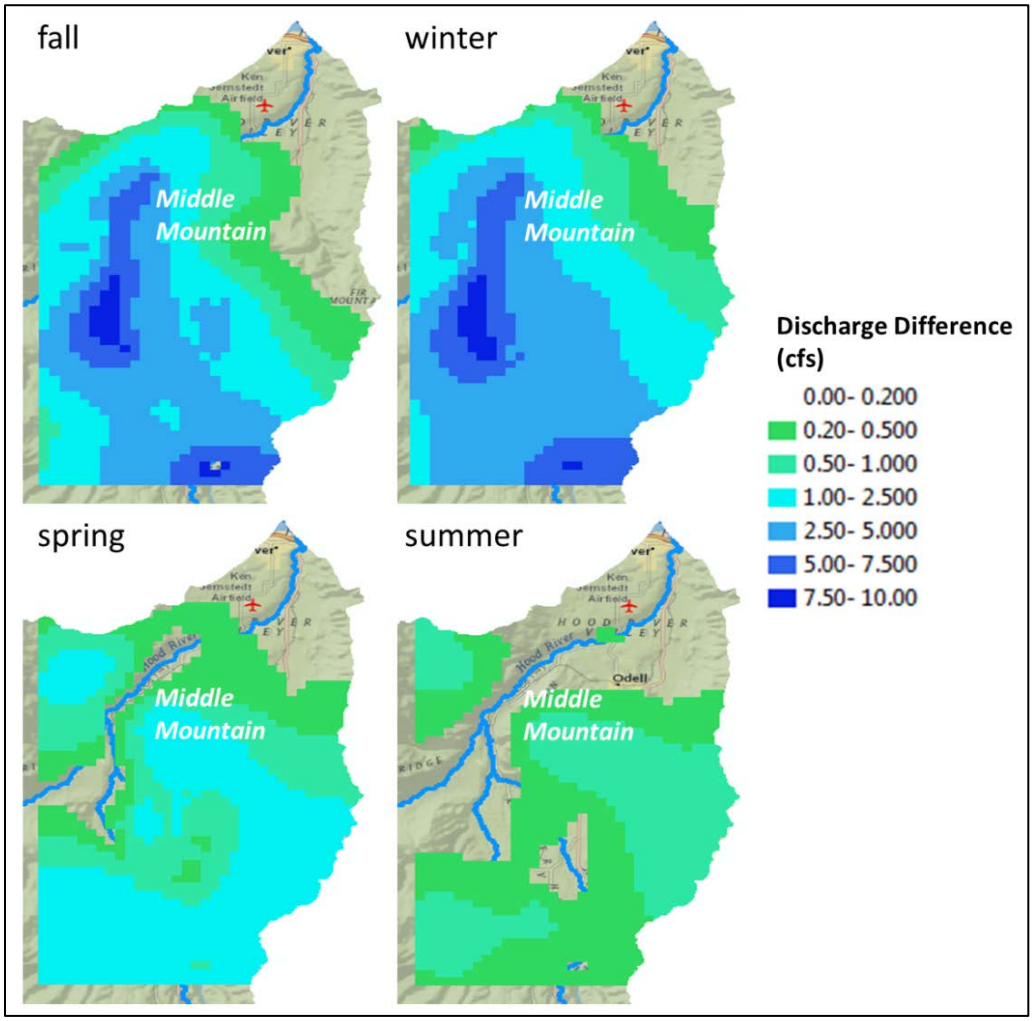


Figure 55. Cell-by-cell injection effects on Tucker Bridge streamflows, median climate change condition.

7.0 STUDY LIMITATIONS AND FUTURE CONSIDERATIONS

This section describes the limitations with the various efforts in completed as well identifies several additional actions that could be taken to refine the results presented in this Basin Study Report. These actions include collecting additional data and making adjustments in the physical and network models Reclamation constructed to conduct the analyses presented in this Basin Study Report.

7.1 Climate Change

7.1.1 Global Climate Forcing

This Basin Study Report summarizes results from the Hood River Basin Study in which historical and future climate change climate and hydrology were evaluated using multiple models and approaches. The Basin Study considers future climate projections representing a range of future greenhouse gas (GHG) emission paths, the uncertainties associated with these pathways are not explored in this Basin Study Report. These uncertainties include:

- Those introduced by assumptions about technological and economic developments, globally and regionally.
- How those assumptions translate into global energy use involving greenhouse gas emissions.
- Biogeochemical analysis to determine the fate of GHG emissions in the oceans, land, and atmosphere.

Also, not all of the uncertainties associated with climate forcing are associated with GHG assumptions. Considerable uncertainty remains associated with natural forcings, with the cooling influence of aerosols being regarded as the most uncertain on a global scale (e.g., figure SPM-2 in IPCC 2007). This uncertainty will continue to exist even with the new sets of emissions pathways such as the representative concentration pathways used in the CMIP5 set of GCM runs.

7.1.2 Global Climate Simulation

The activity presented in this Basin Study Report considers climate projections produced by most up-to-date climate models. Even though these models have shown an ability to simulate the influence of increasing GHG emissions on global climate (IPCC 2007), there are still

uncertainties about the scientific understanding of physical processes that affect climate, how to represent such processes in climate models (e.g., atmospheric circulation, clouds, ocean circulation, deep ocean heat uptake, ice sheet dynamics, sea level change, land cover effects from water cycle, vegetative and other biological changes), and how to do so in a mathematically efficient manner given computational limitations.

7.1.3 Climate Projection Bias Correction

GCMs are biased toward being too wet, too dry, too warm, or too cool when compared to historical climate. These biases are identified and accounted for using bias-corrected climate projections data prior to incorporation into follow-on efforts. This step corrects for disparities in scale and climate between the global, regional, and local scales. Bias correction of climate projections to local weather stations was especially important since major irrigation demands and reservoir simulation processes are temperature and precipitation dependent.

7.1.4 Climate Projection Spatial Downscaling

The analyses for the Basin Study used global scale climate projections that were empirically downscaled, using spatial disaggregation on a monthly time step (following GCM bias correction on a monthly time step). Although this technique has been used to support numerous water resources impacts studies (e.g., Van Rheenan et al. 2004; Maurer 2007; Anderson et al. 2008; Reclamation 2008; Reclamation 2010; McGuire et al. 2010), uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies require historical reference information on spatial climatic patterns, at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which presumably could change somewhat with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption where the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have statistical stationarity. However, it is possible that such stationarity will not hold at various space and time scales, over multiple locations, and for various climate variables. The significance of potential non-stationarity in empirical bias correction and downscaling methods, and the need to utilize alternative downscaling methodologies, remains to be established.

7.2 Surface Water

Surface water was evaluated using the DHSVM model, which was calibrated by the University of Washington. Several key pieces of data used in the model could be improved to improve the calibration and ultimately, the results it produced, including:

1. The National Land Cover Database classifications for the DHSVM model grid cells corresponding to SNOTEL sites could be updated to be more representative of the physical locations (i.e., change from forested to grassland). This update would enable a more direct comparison between simulated historical and observed snow-water equivalent, but would maintain the integrity of the existing calibration.

2. Determine if recalibrating the DHSVM model with modified snow-relevant parameters (and deforested SNOTEL site grid cells) could improve the snow-water equivalent simulations and/or the regulated flow simulations along the Middle Fork and East Fork.

The glacier component should be run continuously from 1920 through the selected future window of time for results to be more realistic. The projected data between 2010 and 2029 were not estimated for inclusion at the time of this Basin Study. Because of that the potential impacts of climate change on the Hood River glaciers during that period is unknown and how those potential impacts might affect the glacier's volume and extent in 2030 is not known. To fill this void in information would require obtaining the historical climate forcing data (e.g., temperature and precipitation) and adjusting future climate forcing data between 2010 and 2029. In addition, results from this effort would need to be used as input to the DHSVM hydrologic model. This step would enable the DHSVM model with the glacier component to run continuously from October 1979 through September 2059 and would thus provide more physically appropriate initial state of the modeled glaciers for the future climate scenario simulations.

The Hood River DHSVM model has a groundwater component that was not available for use in this analysis. Additional analysis could be conducted to incorporate the groundwater component into the hydrologic model, and recalibrate a "coupled" DHSVM surface water and groundwater model to generate simulated historical natural flows across the basin. Once the coupled model is calibrated and results produced, these data could then be used in the MODSIM model constructed to evaluate Hood River water resources. In addition to potentially improving the calibrations of both the DHSVM and MODSIM models, these efforts could also shed some light on the significance of groundwater to the basin's overall hydrology and water resources management schemes.

Finally, the physical characteristics and efficiencies of each hydropower facility in the basin were not evaluated due to lack of data. Efforts should be made to model the hydropower

production component in MODSIM. This would enable the MODSIM model to translate flow through each facility into power generation, which could then be evaluated using the future climate change scenarios.

7.3 Groundwater

The MODFLOW model is successful in simulating groundwater levels and the seasonality of estimated stream gains. Although the model cannot simulate absolute heads and stream gains with a large degree of certainty, the model is useful in estimating relative changes in these same values given a particular groundwater management scenario.

Given the lack of hydrogeologic data in the basin, multiple approximations and assumptions were made in constructing the model, and as such, the potential for uncertainty is inherent in the modeled results. Every known parameter within the model domain depends on the approximations and assumptions made during the water budget calculation, model construction, and calibration process. This work was the first step towards a more comprehensive model and as data become available, the model should be modified and recalibrated accordingly. The model provided insight by identifying locations where additional data should be collected, which was also useful for identifying locations that may benefit from further investigation. Evaluating specific cells or groups of cells in the MODFLOW model on a location-by-location basis and evaluating hydrogeological conditions to account for both aquifer storage and streamflow augmentation would be appropriate for a more detailed effort.

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