RECLAMATION

Managing Water in the West

Hood River Basin Study

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

November 2015

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.

Study Limitations

The Hood River Basin Study was funded jointly by the Bureau of Reclamation (Reclamation) and Hood River County and is a collaborative product of the study participants as identified in Section 1.0 of this report. The purpose of the study is to assess current and future water supply and demand in the Hood River basin and adjacent areas that receive water from the basin, and to identify a range of potential strategies to address any projected imbalances. The study is a technical assessment and does not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or the funding partners (i.e. Hood River County). The study does not propose or address the feasibility of any specific project, program or plan. Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of Federal funds. All cost estimates included in this study are preliminary and intended only for comparative purposes.

Hood River Basin Study

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EXECUTIVE SUMMARY

Introduction

The Bureau of Reclamation (Reclamation), in partnership with Hood River County (County) and the Hood River County Water Planning Group (HRCWPG) conducted a Hood River Basin Study (Basin Study) and the results are documented in this final report. Reclamation selected the Basin Study in fiscal year 2011. The purpose of the Basin Study is to assess current and future water supply and demand in the Hood River Basin and adjacent areas that receive water from the basin. In addition, the study aims to identify a range of potential strategies to address any current or projected imbalances.

Currently, there is already a lack of adequate streamflow in the basin during the summer months to meet the competing demands for water. This imbalance is expected to be exacerbated by climate change. The basin's 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. Hood River basin streamflow relies heavily on snowmelt at the beginning of summer and Mount Hood glacial melt during August and September of each year. Warming temperatures in future years will increase the speed of snowpack and glacial melting. Also, glaciers and snowpack are projected to continue to decrease in size and volume. Currently, between 50 and 70 percent of flow during the critical water use period is provided from glacial melt. Once the Mount Hood glaciers fully recede, the basin will lose one of its largest water storage supplies.

Some of the primary demands placed on the basin's surface and groundwater supplies include potable water; irrigation needs; hydropower; protection of aquatic species, in particular Endangered Species Act (ESA)-listed fish; recreation; and scenic value. These demands are expected to increase as climate change and population growth impact water resources in the region. The County and the HRCWPG saw the need to prepare now to ensure reliable water deliveries and sufficient instream flows for threatened and endangered fish in the future.

The study developed 38 alternatives to address the basin's imbalances in water supply and demand. These alternatives identify risks posed to water supply and opportunities to mitigate those risks through developing water supplies, improving water management, and sustaining or improving environmental quality and ecological resiliency. From these 38 alternatives, six were more fully evaluated and grouped into three major categories: water conservation, groundwater recharge, and surface water storage. These alternatives are provided to stimulate potential further evaluation or implementation by Hood River County or their partners.

Basin Location

The Hood River basin is a 482-square-mile region located in northern Oregon. It 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 (Figure ES-1). The region includes the City of Hood River and many unincorporated communities, such as Odell and Parkdale, all of which are located in Hood River County. The county's approximate population is 23,000.

Basin Ecology

Since 1998, four species of fish residing in the Hood River basin have been listed as threatened under the ESA, including bull trout, resident cutthroat trout, steelhead, and Chinook. Modeling for this Basin Study showed that, without mitigation, fish habitat will continue to decrease compared to historical conditions.

Basin Economy

The economy of Hood River County is primarily dependent on agriculture, which is supplied with irrigated water. There are multiple water districts in the basin and five major irrigation districts that serve a total of 23,950 acres. In 2010, raw agricultural commodity sales in Hood River County were $87,598,000 (Oregon State University Extension 2010).

The basin has two major reservoir systems that deliver water in part for agricultural use. Those reservoirs are Laurance Lake, located on a tributary to the Middle Fork Hood River, and Upper and Lower Green Point Reservoir, located on Ditch Creek that drains into the mainstem Hood River (Figure ES-2). In addition to supporting agriculture, these reservoir systems also supply water for meeting instream flow requirements, recreation, and several hydropower facilities. Middle Fork Irrigation District (MFID) operates Laurance Lake and three powerplants, and Farmers Irrigation District (FID) operates the Green Point Reservoir system and two powerplants near the mouth of the Hood River. None of these facilities are Reclamation owned or operated.

Basin Study Process

This study sought to quantify current and potential future water supply and demand imbalances through 2060, and then develop adaptation and mitigation strategies to address them. The County and their consultants conducted efforts to quantify existing water use; water conservation; and fisheries spawning, rearing, and migrating habitat throughout the study process. In turn, this information was adjusted based on anticipated population growth, changes in land use, and subsequent changes in water use and supply, including supply changes due to climate change.

While the County was undertaking this work, Reclamation constructed hydrologic, groundwater, and water resource models and used its existing models to establish a baseline of historical conditions to compare with simulations of future conditions, including climate change impacts to streamflow. Once all data collection and modeling was completed, evaluation was conducted for the selected alternatives to identify gaps in water supply and demand, and to understand how the alternatives may offset future climate change impacts.

Basin Study Partners and Stakeholders

The primary partners on this basin study were the Bureau of Reclamation, Hood River County and the HRCWPG. The HRCWPG includes the County, Hood River Watershed Group, Columbia Gorge Fruit Growers Association, Hood River County Soil and Water Conservation District, multiple water districts, environmental groups, local resource specialists, MFID, East Fork Irrigation District (EFID), FID, Mount Hood Irrigation District (MHID), Dee Irrigation District (DID), Oregon Water Resources Department, Confederated Tribes of Warm Springs Oregon, Natural Resources Conservation Service, and various interested citizens of Hood River County. It is notable that the Confederated Tribes of the Warm Springs were pleased with the Basin Study process and the full spectrum of long-term alternatives presented, including water conservation.

Basin Study Funding Source

The Basin Study was funded through Reclamation's Basin Study Program which is under the Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program. For the Hood River Basin Study, Hood River County was Reclamation's non-Federal cost-share partner.

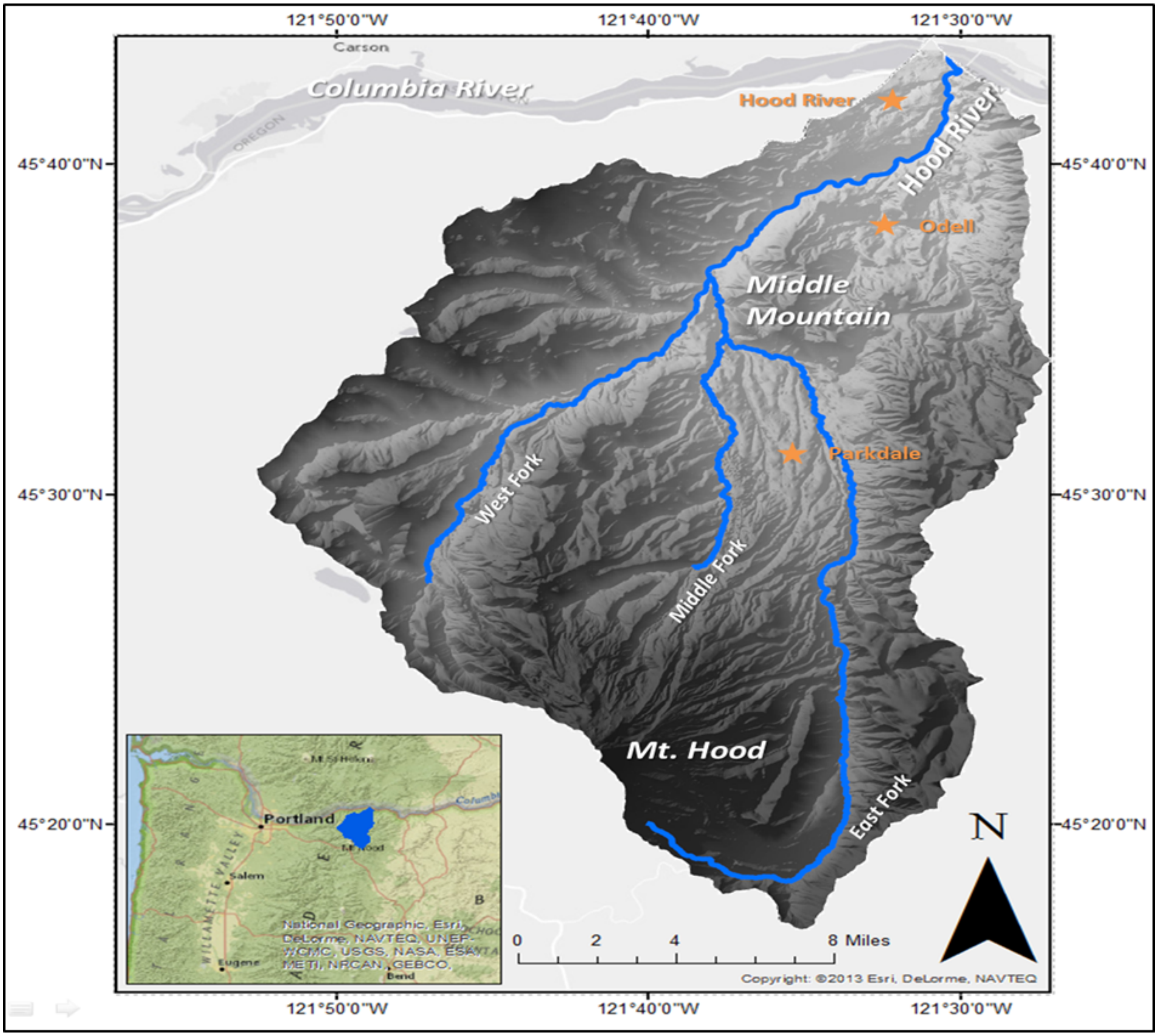

Figure ES-1. Shaded relief map of the Hood River basin study area.

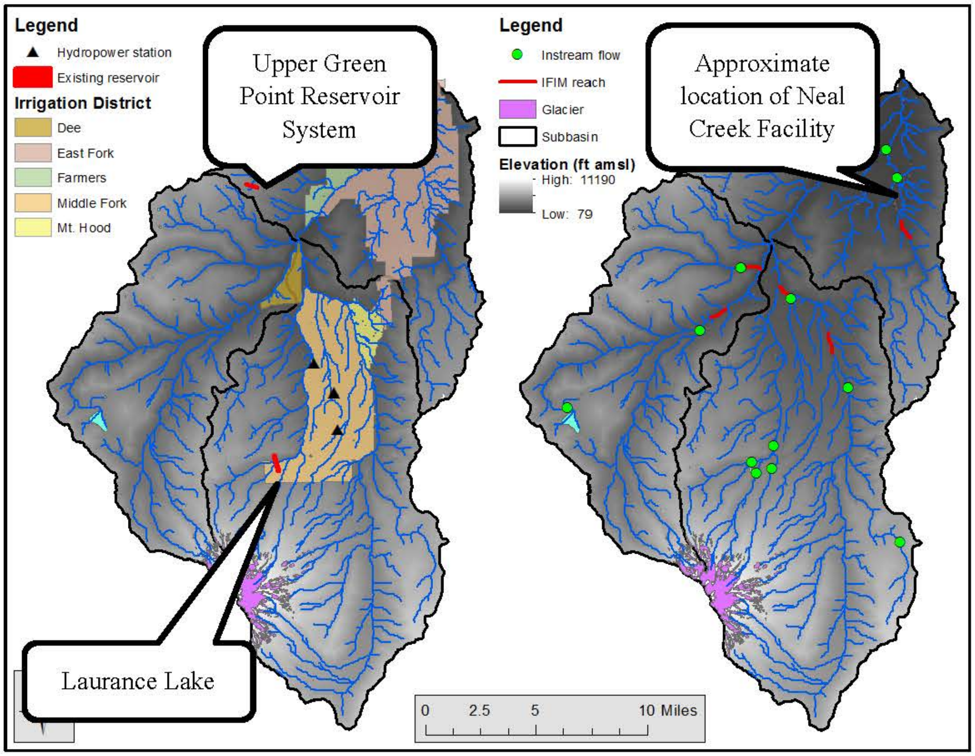

Figure ES-2. Hood River Basin irrigation districts, reservoir system, and stream network.

Results of Climate Change Analysis

Multiple climate change scenarios were developed and evaluated as part of the Basin Study. In an effort to capture the full range of potential future climate in the basin through 2060, Reclamation staff generated three climate change scenarios for use in the study—dry (More Warming/Drier or MW/D), median (MI), and wet (Less Warming/Wetter or LW/W). The study used these climate change scenarios to evaluate impacts on streamflow, the Mount Hood glaciers, and snowpack.

Analysis showed that future average temperatures increased between 0.7ºC in the spring in the LW/W scenario and 2.4ºC in the summer in the MW/D scenario. Also, modeling showed that future precipitation varied between a 33 percent decrease in the summer in the MW/D climate change scenario, to a 12 percent increase in the LW/W climate change scenario in the fall. These results indicate that the air temperature in the Hood River Basin will continue to increase in the future. Temperature increases will affect water supply (surface water, glacier melt, snow melt) volume and timing, and water use (e.g., irrigation, hydroelectric power).

All three climate change scenarios studied showed peak flow timing shifting to earlier in the year and peak flow volume rising higher than historical streamflow. Also, all three climate change scenarios project streamflow to be lower than historical averages in the summer. These changing patterns may result in increased flooding and sediment transport during high flow events, and decreased supply for demands of all types (e.g., irrigation, hydropower, minimum instream flows) during the summer months. Figure ES-3 depicts the streamflow resulting from analysis of the LW/W, MI, and MW/D future climate change scenarios as a difference from the historical streamflow, shown as the zero line in the plot.

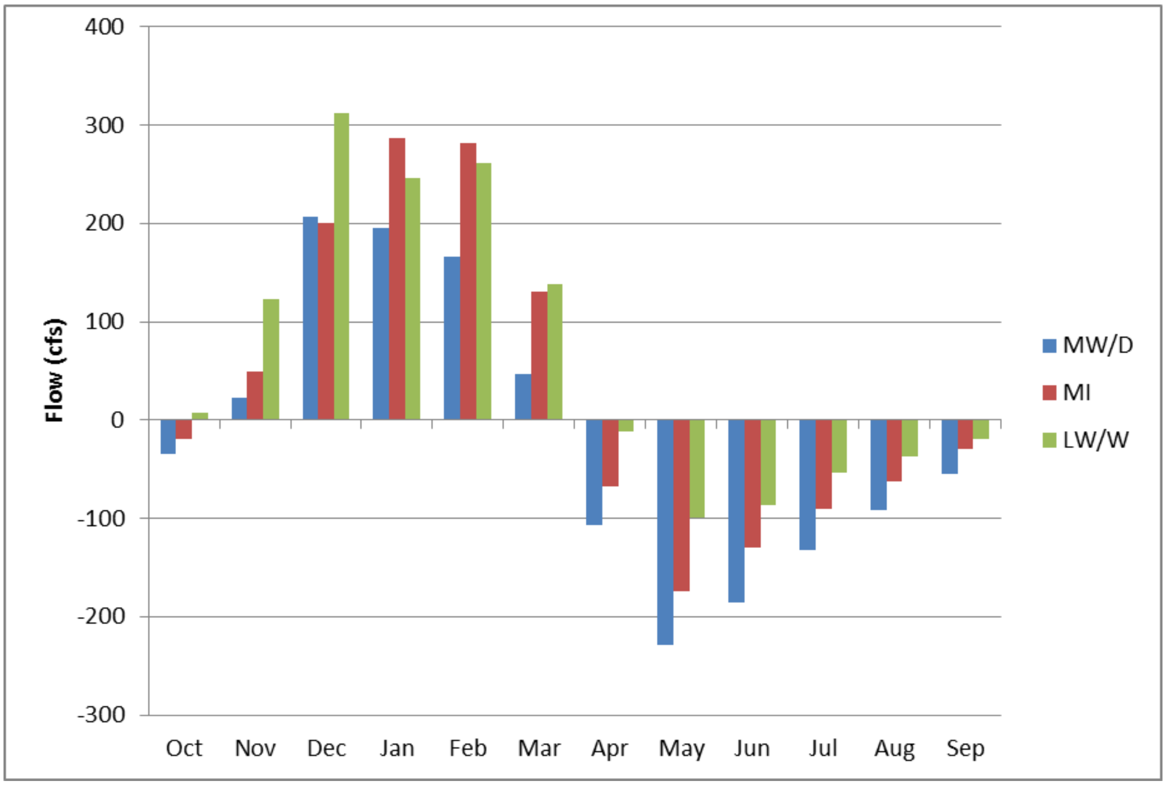

Figure ES-3. Average monthly streamflow difference from historical streamflow in the MW/D, MI, and LW/W climate change scenarios at the Hood River at Tucker Bridge gage near the City of Hood River.

Since the 1920s, the amount of snowpack in the Hood River Basin has decreased. This pattern of decline is expected to continue through 2060. This decrease in snowpack results in higher streamflow in the winter and lower streamflow runoff during the spring and summer months (Figure ES-3). 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.

In addition, the Mount Hood glaciers have a significant contribution to the basin's water supply and warming temperatures have been reducing their size and volume since the 1920s. The Middle Fork and East Fork of the Hood River are fed in part by the glaciers of Mount Hood (Figures ES-1 and ES-2). As such, these systems have a high percentage of glacier melt contribution to their overall total annual streamflow. Nolin (2007) reported that glacial melt contributed up to 74 percent of the streamflow in some tributaries to these forks during August, and slightly less in September. Depending on which climate change scenario is viewed, increasing temperatures will cause the size and volume of the glaciers to continue to shrink over time with a change of 1 to 4 percent. As air temperature warms, the contribution to the streams from the glacial melt is projected to increase slightly before decreasing as the glacier fully recedes. The timing of that shift is not known.

Summary Evaluations of Alternatives

Initially, Hood River County, HRCWPG and Reclamation identified 38 alternatives to address Hood River Basin water supply and demand gaps. The partners and stakeholders agreed that it was important to examine steps that could be taken to improve existing use of the basin's water resource. Since summer flow was already an issue, and was proved to be a larger concern due to the impacts of climate change, alternatives that could supply water during summer months were prioritized. Based on this direction, six alternatives were more fully evaluated and grouped into three major categories: water conservation, groundwater recharge, and surface water storage. These six alternatives are outlined in Table ES-1.

If no action is taken, potable and irrigation demands will continue to increase and exacerbate water imbalances in the future, particularly during the summer months. The expected increase of groundwater pumping to meet future agricultural needs will add to those imbalances as groundwater extracted for irrigation use would further deplete summertime flows. The conservation, groundwater recharge for either storage or augmentation, and surface water storage alternatives were evaluated against existing supply and demand imbalances, as well as future imbalances determined in the increased water demands and pumping scenarios.

The water conservation alternative included evaluating the possibility of irrigation districts converting sprinklers to micro- or drip-irrigation systems. Also, the study evaluated transitioning to more efficient potable water fixtures. However, these reductions were not included in the water management modeling because they were too minor to be captured by the model.

The groundwater recharge alternative was evaluated to determine if water pumped into the groundwater aquifers could be used later (considered groundwater recharge for storage alternative), or if groundwater could be used as recharge to streamflow during the summer months (considered the groundwater recharge for streamflow augmentation alternative).

The surface water 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 new facility on Neal Creek, a tributary to the mainstem Hood River.

None of these facilities are owned or operated by Reclamation so any actions taken would be implemented and funded by non-Federal partners. Cost estimates provided in this Basin Study report are relative, comparative, and preliminary and are not intended for budgeting.

Table ES-1. Alternatives analyzed in the Hood River Basin Study.

Alternatives	Type of alternative	Total Cost	Impact to Water Budget	How applied
Irrigation Water Conservation	Conservation	Varies by irrigation district	Up to 16.5 cfs (11,953 acre-feet/year) reduced use in sprinkler upgrades, and up to 23 cfs (16,652 acre-feet/year) reduced use for piping	Estimated reduction of water use based on converting 49 percent of existing impact sprinklers to micro- or drip-irrigation.
Aquifer injection; storage for future use	Groundwater	--	Location specific (around Middle Mountain)	Evaluated aquifer injection at various locations in the basin to determine potential benefits to aquifer storage.
Aquifer injection; streamflow augmentation	Groundwater	--	Unknown	Evaluated aquifer injection at various locations in the basin to determine potential benefits to streamflow augmentation.
Expansion of Laurance Lake	Reservoir Storage	$328,000	370 acre-feet additional storage	Evaluated the potential of installing a weir to raise the dam by 3 feet increasing storage from 3,565 to 3,935 acre-feet.
Expansion of Upper Green Point Reservoir	Reservoir Storage	$1,272,000 to $2,347,500 depending on location of construction material.	561 acre-feet additional storage	Evaluated the potential of raising the dam by 8 feet to increase storage from 988 to 1,549 acre-feet.
Construction of Neal Creek Facility	Reservoir Storage	$13,213,500 to $27,872,500 depending on location of construction material	2,557 acre-feet additional storage	Evaluated the potential of constructing a new facility with a storage volume of 2,557 acre-feet.

Overall, there is broad acceptance and support among stakeholders for water conservation alternatives (conversion of sprinkler systems to micro- or drip-irrigation and canal piping). Potable water conservation could be implemented where possible and where it helps a water district meet its reliability goals. However, it could not be used as a primary tool to increase summer streamflows because the quantity conserved relative to irrigation conservation was minor, so the focus on conservation was on irrigation efficiency improvements. More significant reductions in water use can be obtained by transitioning from water sprinklers to micro- or drip-irrigation, piping, or other water delivery changes. Costs associated with potable and irrigation water conservation varied depending on location and type of application.

Of the three storage alternatives, two appear to have more local acceptance and support than the others: Laurance Lake dam raise through the use of a new weir structure and Upper Green Point Reservoir dam raise. These had more stakeholder support in general because the cost per acre-foot was lower and environmental impacts were minimal when compared to other alternatives. However, the Laurance Lake dam raise alternative may have a greater effect on ESA species, such as the northern spotted owl, than the other surface storage alternatives because of the dam's proximity to their habitat.

The third storage alternative—construction of the Neal Creek facility—shows the most potential for improving water supply on the East Fork Hood River, but it comes with the highest potential for environmental impacts, the highest cost, and the greatest negative response from the participants. This proposed facility would reduce the volume of water that is currently diverted from the East Fork to the Main Canal to irrigate the EFID and MHID. Ultimately, the Neal Creek facility benefits irrigation and leaves more water in the East Fork Hood River during summer months when flows are most critical for meeting minimum instream flow requirements. However, the storage facility would alter flow on Neal Creek which creates concerns for that system as operations, minimum instream flows, and other uses would need to be worked out.

Of the two groundwater alternatives, the aquifer injection for storage around Middle Mountain showed the greatest benefit for water supply. Based on the model, almost half of the water injected was still available during the spring and summer. However, streamflow augmentation had minimal usefulness given that most of the water returned to the stream too quickly to help the summer low flow period when instream flow requirements are of issue. In general, groundwater recharge alternatives, either for flow augmentation or for additional storage, would require additional analyses and significant improvements on data collection activities in the basin. No cost estimates were generated for the groundwater alternatives as there was not enough information at this time.

Conclusions

While this final report does not include recommendations and is not intended to be a decision document, it meets the requirements of the Basin Study program, including an assessment of the water supplies, demands, and climate change risks; an analysis of how existing infrastructure and operations will perform in response to changing water realities; identification and evaluation of viable adaptation strategies to improve operation and infrastructure to supply adequate water supply in the future; and a comparison analysis of all viable adaptation strategies identified (comparison of cost, environmental impacts, risks, contribution to meeting water needs, stakeholder response, or other attributes).

As an agency, Reclamation benefited from this Basin Study by (1) refining its modeling processes, (2) gaining a better understanding of glacial contribution and the water resources of the region, (3) meeting its mission to help others manage their water resources, and (4) cultivating relationships with Hood River County water users. In addition, this Basin Study helped Reclamation meet the aims of the Secure Water Act (SWA). The SWA states that research is needed to improve understanding of the variability of the water cycle in the United States; to mitigate for the challenges of climate change; to efficiently manage water resources; and to identify new supplies of water. This effort was deemed necessary to ensure water resources management in the United States is sustainable and will continue to provide adequate quantities of water. As part of the SWA, Congress found that adequate and safe water supplies are fundamental to the health, economy, security and ecology of the United States.

While each of the alternatives presented has the potential to decrease the gap between water demand and supply in the Hood River basin, no single alternative will satisfy all of the water resource needs. However, due to the projection that summer streamflows are expected to get lower, a priority could be given to projects in the basin that have the ability to increase summer streamflow. Project permitting, planning, and design will vary and may be simple for sprinkler conversion efforts or improvements to water delivery mechanisms; however, a new storage alternative may be considerably more complex and take more time and effort. Public acceptability, funding, legal issues such as water rights, and regulatory and environmental compliance issues would need to be resolved before moving any of these alternatives toward implementation.

Obtaining sufficient funding for a publicly acceptable action would be a necessary initial step toward implementation. Depending on the total cost, an interested stakeholder could move forward with funding on its own or seek partnerships with state and local entities. A number of funding sources may be required to implement any action.

The path forward from the Hood River Basin Study requires additional data collection, monitoring, and evaluation of the alternatives identified. Hood River County will continue to investigate installation of a weir to raise the volume of Laurance Lake during high water runoff and to implement other conservation measures vetted through this process. The County will also likely pursue additional funding from outside sources to continue work on the sprinkler conversion and piping projects. Reclamation will provide Hood River County the physical and water resource models developed for this Basin Study so they can be used to continue to address water related issues in the basin.

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Acronyms	
Basin Study	Hood River Basin Study
Basin Study Report	Hood River Basin Study Report
CMIP	Coupled Model Inter-comparison Project
DHSVM	Distributed Hydrologic Soil Vegetation Model
DID	Dee Irrigation District
EFID	East Fork Irrigation District
ESA	Endangered Species Act
FID	Farmers Irrigation District
GCM	Global Circulation (or Climate) Model
GHG	Greenhouse gases
HRCWPG	Hood River County Water Planning Group
IFIM	Instream Flow Incremental Methodology
LW/D	Less Warming/Drier climate scenario
LW/W	Less Warming/Wetter climate scenario
MED, C, MI	Median, Central, or Middle climate scenario
MODSIM-DSS	Water Resource Management Model
MFID	Middle Fork Irrigation District
MW/D	More Warming/Drier climate scenario
MW/W	More Warming/Wetter climate scenario
MW-hr	Megawatt-hour
MHID	Mount Hood Irrigation District
MODFLOW	Groundwater Management Model
OWRD	Oregon Water Resources Department

Acronyms	
OWRD Storage Study	Hood River Basin Surface Water Supply and Storage Feasibility Assessment
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	Soil and Water Conservation District
TM	Technical Memorandum
USGS	U.S. Geological Survey
WaterSMART Program	Sustain and Manage America's Resources for Tomorrow Program
WPN	Watershed Professionals Network
WRIS	Water Rights Information System
WUR	Water user reports

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1.0 INTRODUCTION

In 2009, Congress enacted the Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act, which authorizes the Bureau of Reclamation (Reclamation) to determine the impacts of climate change on water supply, demands, and reservoir evaporation and to work with non-Federal partners to develop adaptation strategies. 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. Reclamation initiated the Basin Study Program as part of the WaterSMART Program in which a Basin Study would be conducted with a non-Federal partner. Four main components of a Basin Study are:

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.

Non-Federal partners contribute at least 50 percent of the total costs as cash or in-kind services as this is not a financial assistance program. Reclamation's share of the study costs can only be used to support work done by Reclamation or its contractors.

Reclamation selected the Hood River Basin Study (Basin Study) in fiscal year 2011 with Hood River County as the study partner (Figure 1). 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 is provided in Section 3.3.2.

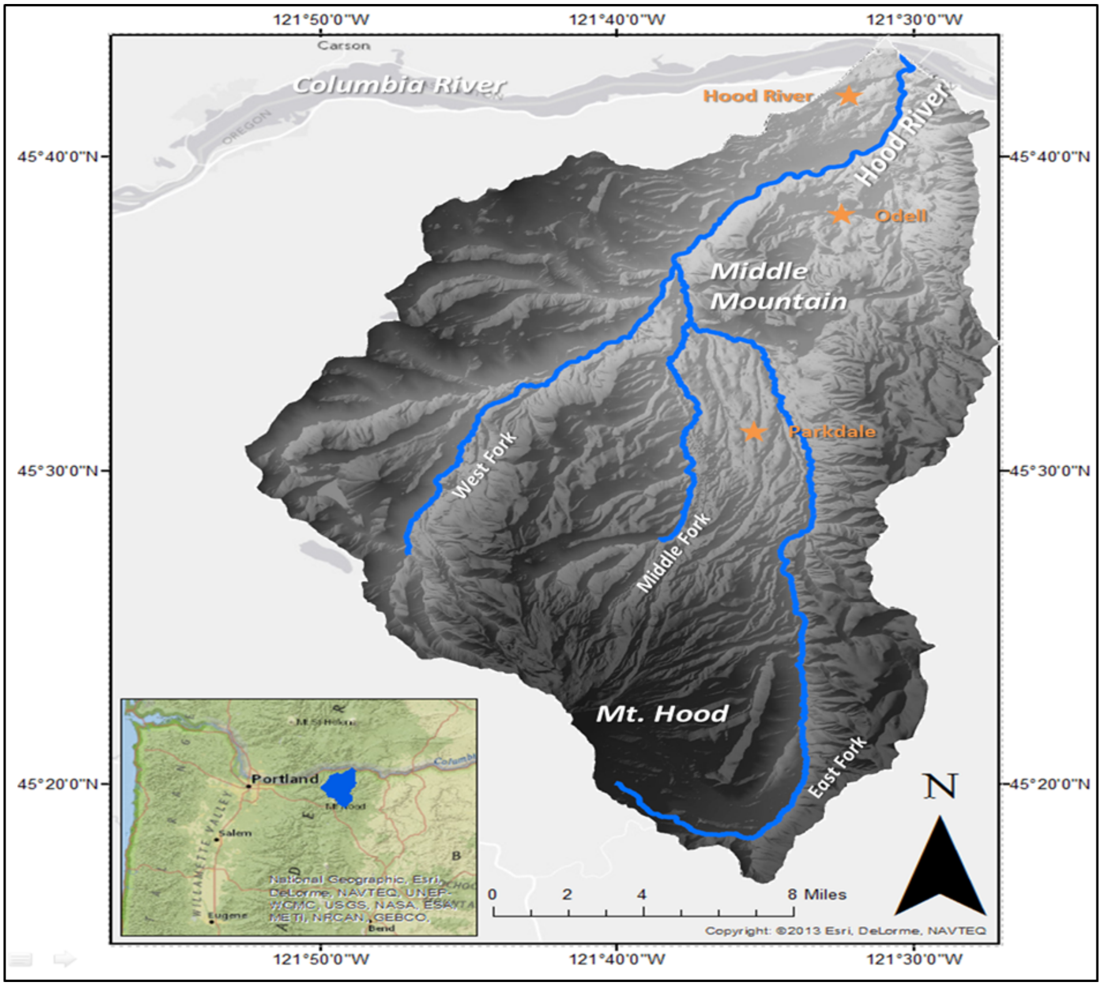

Figure 1. Shaded relief map of the Hood River basin study area.

1.1 Study Approach

The Plan of Study, completed by Reclamation in 2011, outlined the overall Basin Study strategy and management approach. In addition, concurrent activities were conducted by Watershed Professionals Network (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 to 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. This team met weekly initially, then reduced the frequency of 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). The HRCWPG includes the County, Hood River Watershed Group, Columbia Gorge Fruit Growers Association, Hood River County Soil and Water Conservation District, multiple water districts, environmental groups, local resource specialists, Middle Fork Irrigation District (MFID), East Fork Irrigation District (EFID), Farmers Irrigation District (FID), Mount Hood Irrigation District (MHID), Dee Irrigation District (DID), Oregon Water Resources Department, Confederated Tribes of Warm Springs Oregon, Natural Resources Conservation Service, and various interested citizens of Hood River County. This team 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 members of the HRCWPG, 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 or enhanced 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 subteam conducted the climate change analyses, and discussed and documented results.
    - The Groundwater Modeling Subteam included Reclamation staff in addition to groundwater experts from the U.S. Geological 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, and discussed 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, and 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* (Normandeau 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:[1]

- *Technical Memorandum 1 - Potential Reservoir Storage Locations* provides an overview of the geology and describes the potential of using pre-selected areas as 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* 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 simulate 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 and Coordination

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 committee seat openings to the public and solicited representatives of irrigation districts, municipal water suppliers, the watershed group, the local water master, the local Soil and Water Conservation

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

District (SWCD), and County Planning Department. The group had its first official meeting in January 2009.

Since then, the HRCWPG 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 in the Basin Study Program.

The Basin Study was conducted in collaboration with stakeholders throughout the basin. Interest was broad and included the County, Hood River Watershed Group, Columbia Gorge Fruit Growers Association, Hood River County Soil and Water Conservation District, multiple water districts, environmental groups, local resource specialists, irrigation districts, Oregon Water Resources Department, Confederated Tribes of Warm Springs Oregon, Natural Resources Conservation Service, and various interested citizens of Hood River County. Regular updates on the status of tasks and findings 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.[2] Reclamation established a webpage to share draft technical memorandums and other documents that needed to be reviewed by stakeholders.[3] 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.

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

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

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2.0 BACKGROUND

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. The City of The Dalles 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 2). 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 the 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 area.

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 27 and 45 inches per year (Oregon Climate Service 2014) 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.

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.

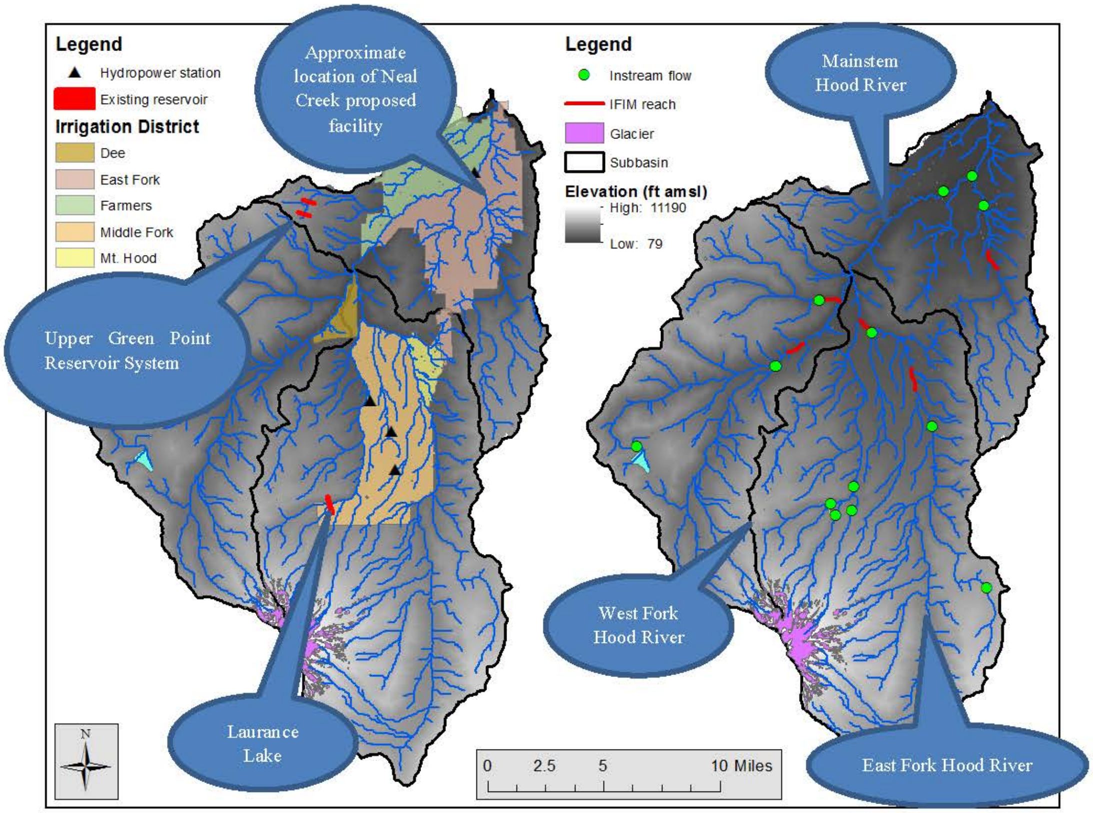


Figure 2 Hood River Basin irrigation districts, reservoir system, and stream network.

2.1 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. In 2010, raw agricultural commodity sales in Hood River County were $87,598,000 (Oregon State University Extension 2010). 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 140 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. Severe drought years have resulted in a complete lack of water for some water users for the latter part of the irrigation season. 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), produce electricity through hydropower facilities. This hydropower production has provided valuable income to the districts, which has allowed them to improve operational efficiencies and reduce environmental impacts.

Since 1998, four species of fish residing in the Hood River basin have been listed as threatened under the Endangered Species Act (ESA) including bull trout, resident cutthroat trout, steelhead, and Chinook. 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.

2.2 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. As part of this Basin Study, significant actions were taken to collect new well data and compile existing hydrogeologic data to include in the physical modeling. Of the six domestic water districts, only one, Crystal Springs, has completed a detailed analysis of the area of contribution for the source water (Yinger 2003).

In 2008 ECONorthwest completed the Hood River County Population Forecast study in which the projected population growth through 2040 was almost 30 percent higher than in 2010 (County-wide average annual growth rate of 1.29 percent). The demand for domestic water supplies for areas where growth could occur will increase with that increased population.

2.3 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 developed by the State of Oregon (Sceva 1960) and a 1983 Water Resources Investigations Report published by the U.S. Geological Survey (Grady 1983). Geologic understanding in the basin was improved considerably in 2012 with the completion of 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. Surface 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. An increase in wells tapped for irrigation could conceivably affect existing domestic wells in addition to surface water flows.

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.

3.1 Water Use Assessment

In June 2013, WPN completed the *Hood River Basin Water Use Assessment* (WPN 2013a). The Water Use Assessment is divided into 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[4] (WRIS), water user reports,[5] and geospatial database.[6] Individual districts provided access to past reports, 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

[4] See http://www.oregon.gov/owrd/pages/wr/wris.aspx.
[5] See http://www.oregon.gov/owrd/pages/wr/water_use_report.aspx.
[6] See http://www.oregon.gov/owrd/Pages/maps/index.aspx.

described above were downloaded, assembled into tables, and all non-cancelled water rights (those still being used) 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 Hood River County for inclusion in their web map server.[7]

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.[8] 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, and Parkdale Water District (Figure 3). Also included but not shown on the map are Mount Hood Meadows Resort, Port of Hood River, and the City of The Dalles.

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

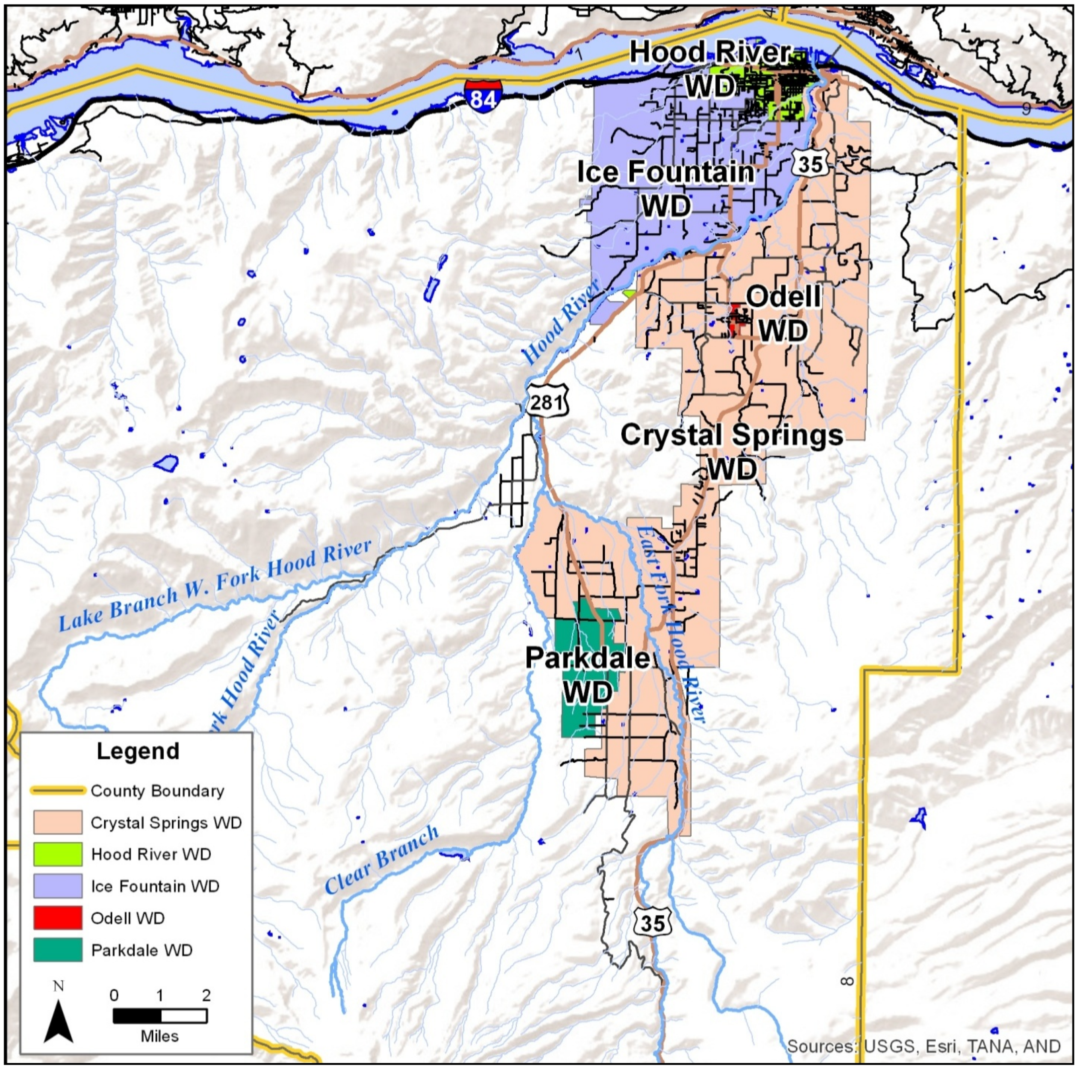


Figure 3. Geographic boundaries of the potable water districts in Hood River County, Oregon.

Annual water use varies significantly by water district. Figure 4 shows the annual water use for major potable water districts (note that Mount Hood and other smaller users are not shown). The Dalles, Crystal Springs, and the City of Hood River are the three highest consumers of average monthly water (Figure 5). 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 because their water use is minimal compared to the major water users documented here.

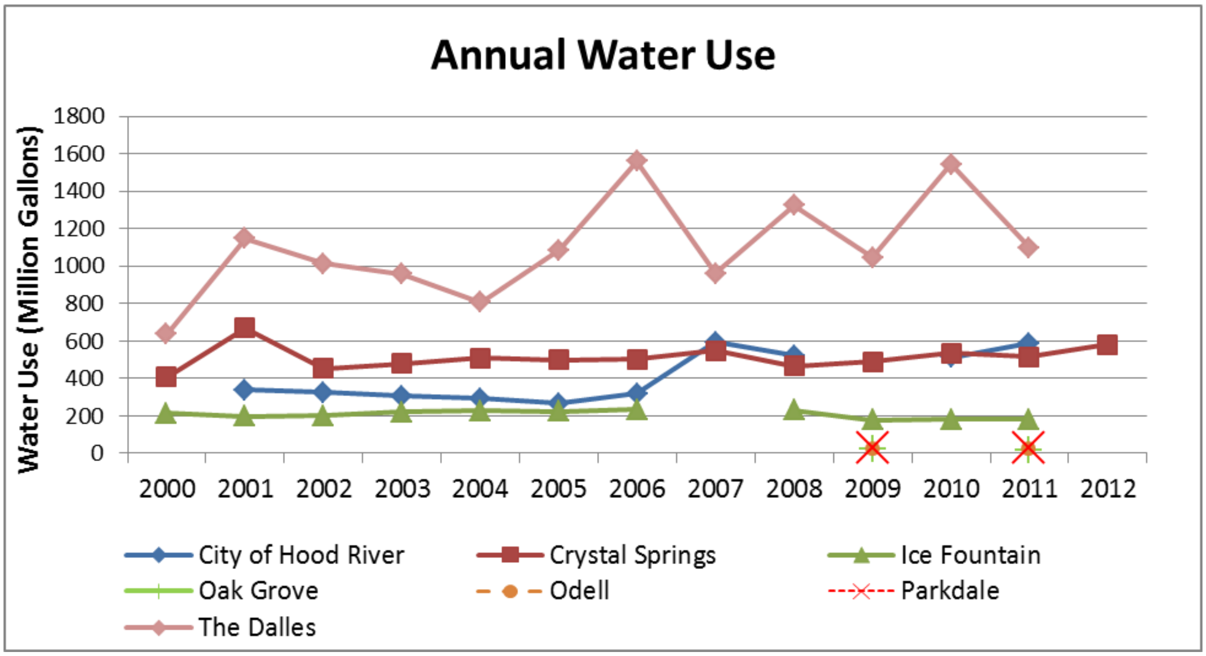


Figure 4 Annual water use for major potable water districts in the Hood River basin, Oregon.

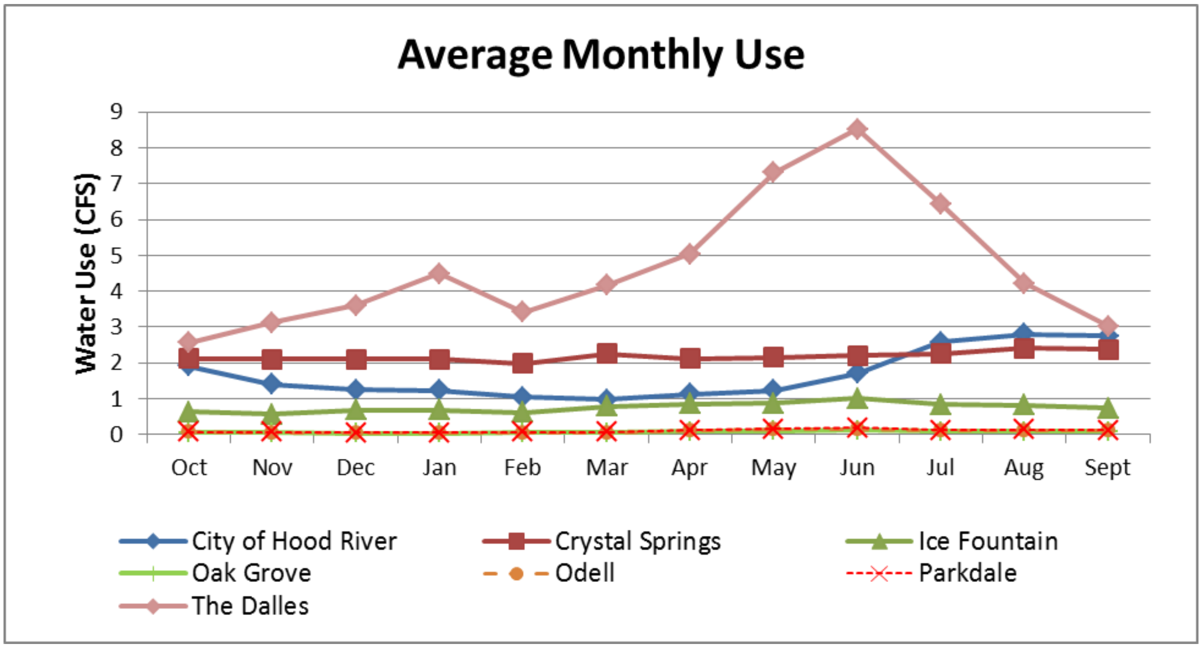


Figure 5 Average monthly water use for major potable water districts in the Hood River basin, Oregon.

Table 1 Summary of potable water right and use.

Water Company	Source	Use
City of Hood River	Springs	1.67 cubic feet per second per year (cfs/year). Average use per month ranged from 0.98 in March to 2.8 in August.
Crystal Springs Water District	Springs	2.18 cfs/year. Average use per month ranged from 1.98 in February to 2.41 in August.
Ice Fountain Water District	Springs (plus intertie with City of Hood River for backup)	0.76 cfs/year Average use per month ranged from 0.57 cfs in November to 1.01 cfs in June.
Oak Grove Water Company	Spring	No records. Values were estimated at approximately 0.08 cfs/year.
Odell Water Company	Springs that are tributaries to McGuire Creek	0.09 cfs No records of monthly use so values were estimated Average use per month ranged from 0.05 cfs in December to 0.16 cfs in June.
Parkdale Water Company	Spring	0.11 cfs/year Average use per month ranged from 0.06 cfs in December to 0.19 cfs in June.
The Dalles	Dog River	Average of 4.7 cfs/year. The water right is for all streamflow at diversion Average use per month ranged from 2.6 cfs in October to 8.5 cfs in June.

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 Hood River, and MFID on the Middle Fork (Figure 6). 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.

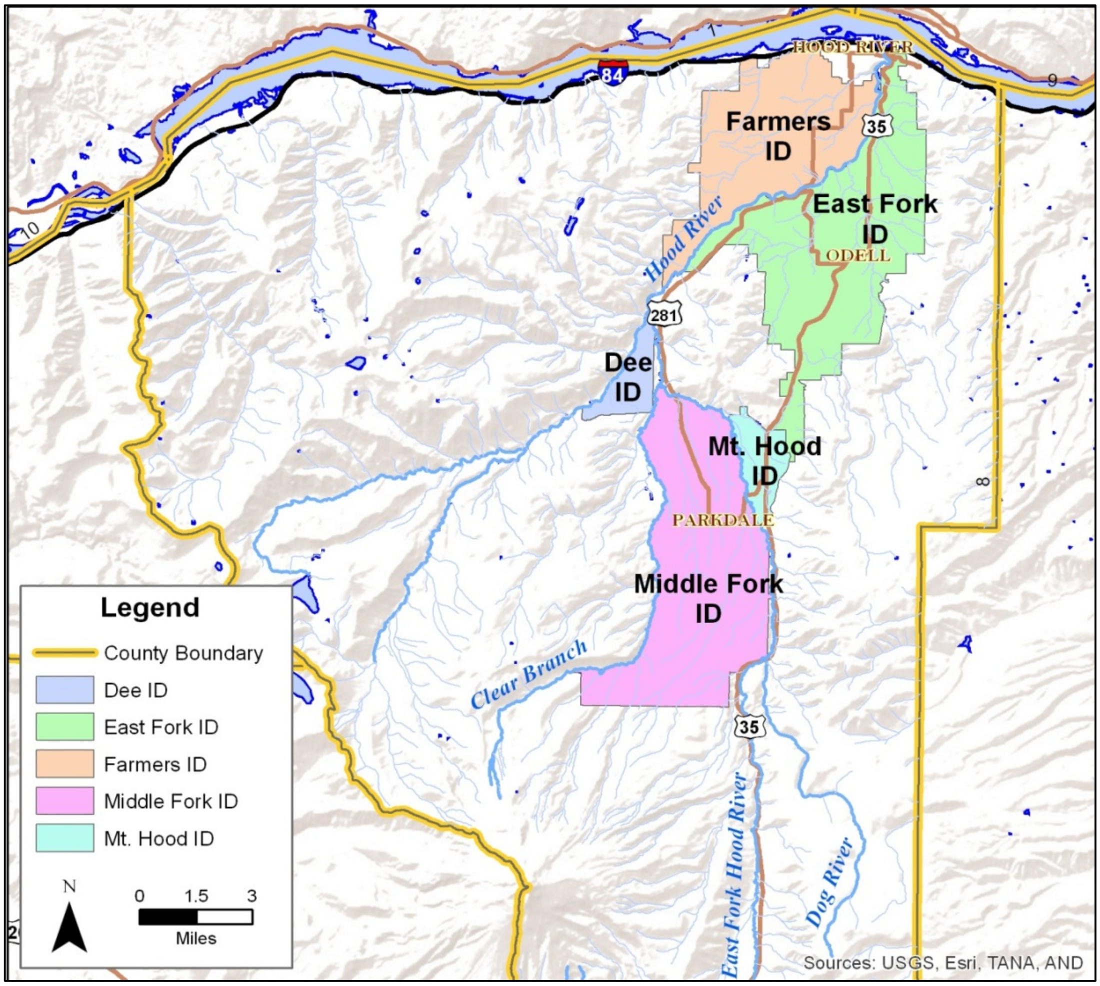


Figure 6 Irrigation district boundaries in Hood River County, Oregon.

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 cfs 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 988 acre-feet) fed by Gate Creek and Cabin Creek via pipeline	73 cfs hydropower water right from the mainstem; 40 cfs irrigation water right, and 30 cfs for orchard spraying. The hydroelectric plants generate about 25,000 MW-hours/year combined Reservoirs are drained at the end of each irrigation season.
Middle Fork Irrigation District (6,362 acres)	Eleven major points 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 7. FID operates two facilities while the MFID operates a total of three. Water diverted for irrigation by FID cannot be used to generate power, therefore, as irrigation season ramps up in May, there is a significant decrease in the amount of water available for hydropower production. As shown in Figure 8, annual combined power production has increased slightly (ranging from 18,200 Megawatt-hours (MW-hr) in 2005 to 25,700 MW-hr in 2010), some of which is attributed to improved operational efficiencies.

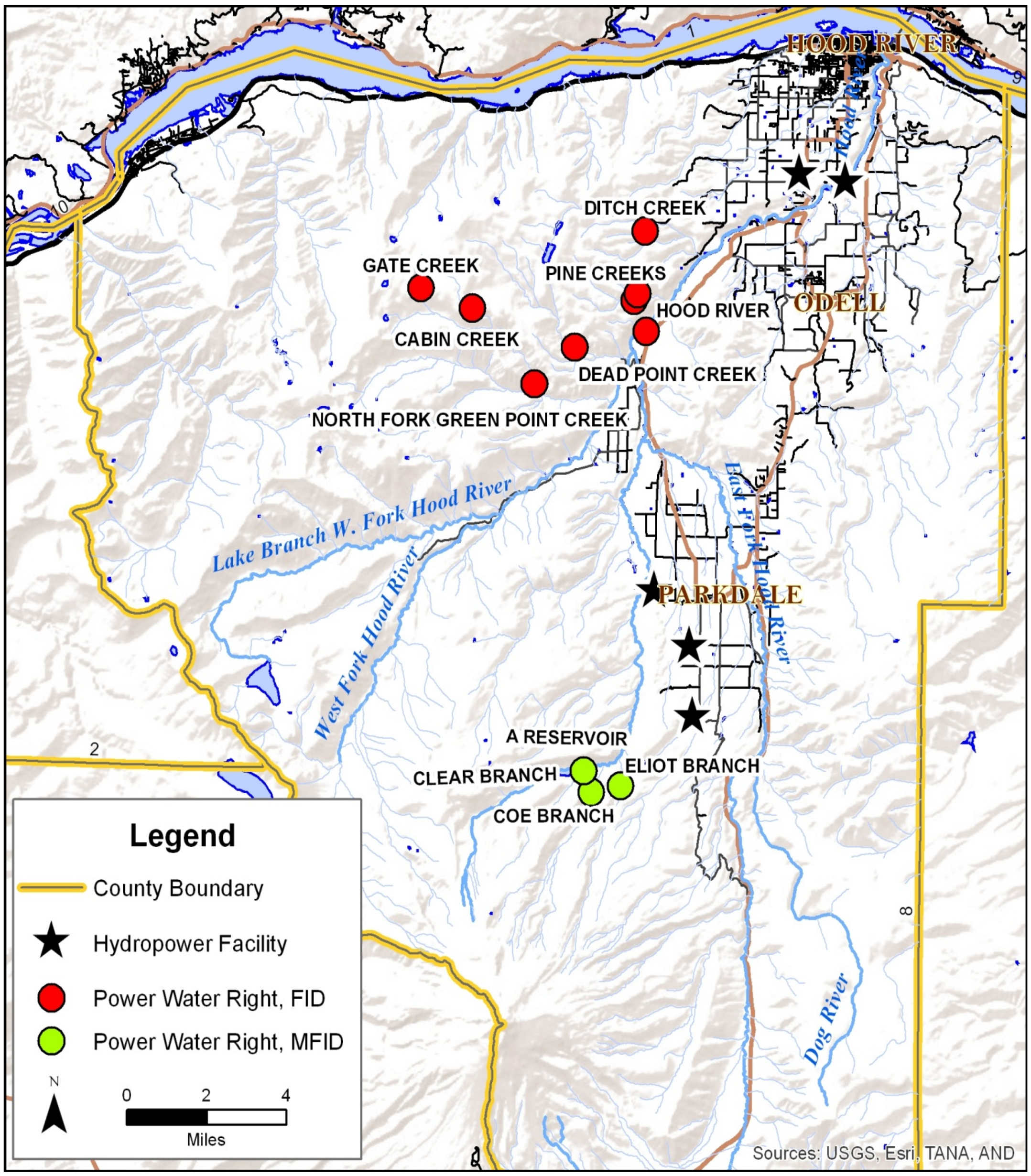


Figure 7 Hydropower facilities in the Hood River basin, Oregon.

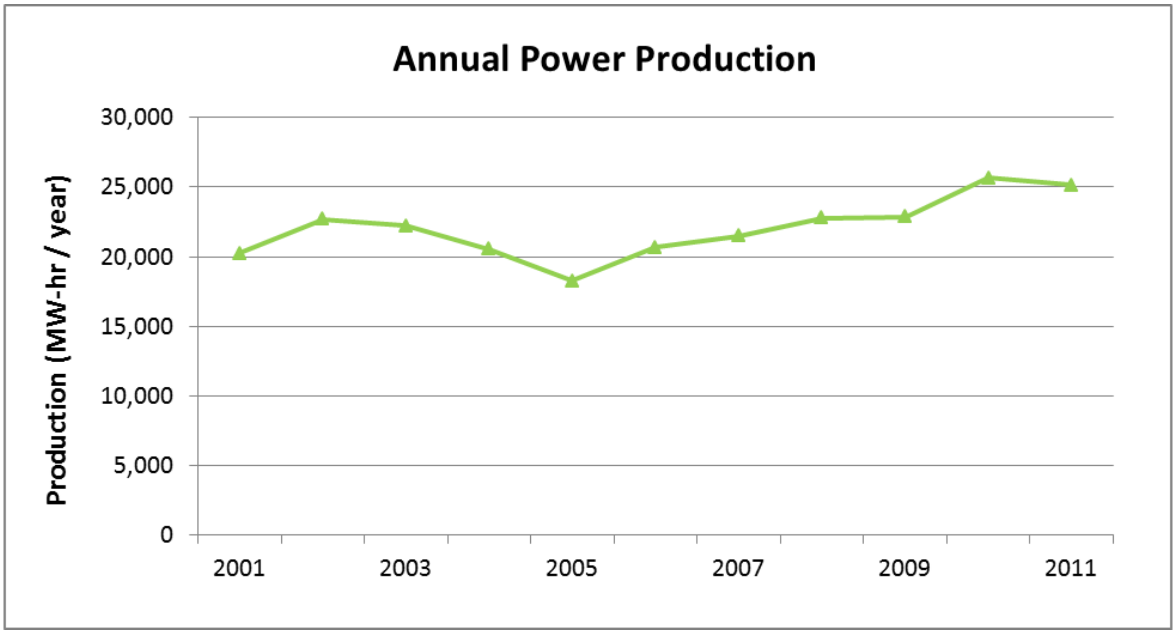


Figure 8 Annual combined power production for Farmers Irrigation District.

The MFID operates three hydropower facilities that are situated in a series. 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 9).

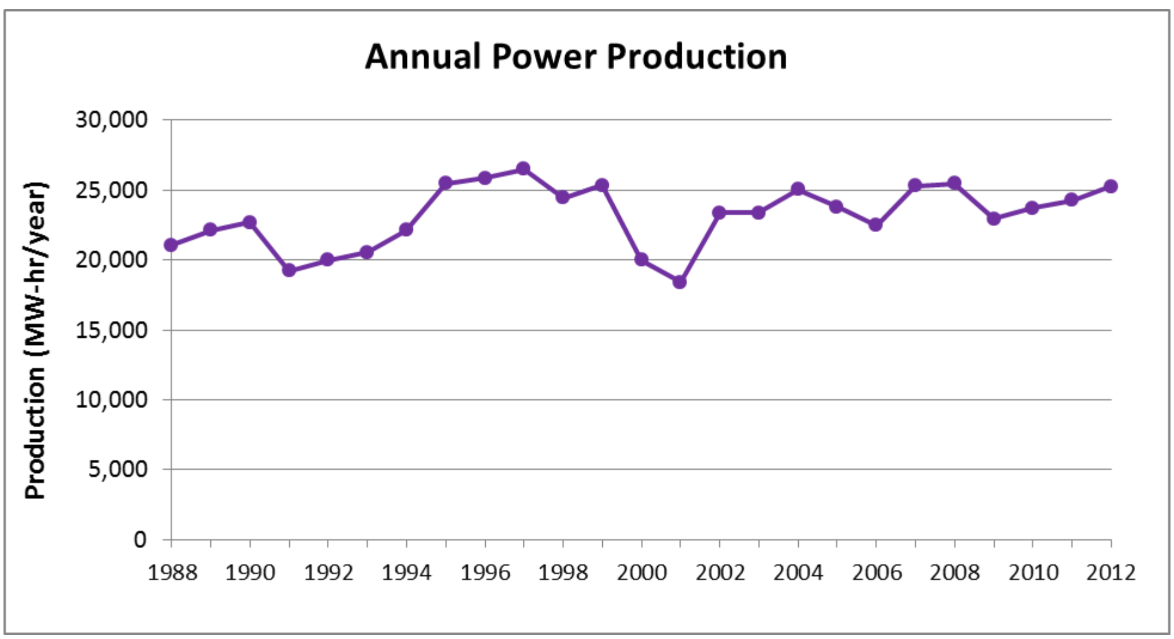


Figure 9 Annual combined power production for Middle Fork Irrigation District.

Instream Water Use

There are seven major instream water rights in the Hood River basin held in trust by OWRD for the people of Oregon (Figure 10) that vary between 5 and 250 cfs/month (Water Use Assessment 2013). There are also three smaller instream water rights (typically a few cfs) that are the result of conserved water agreements; an agreement that ensures 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 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.

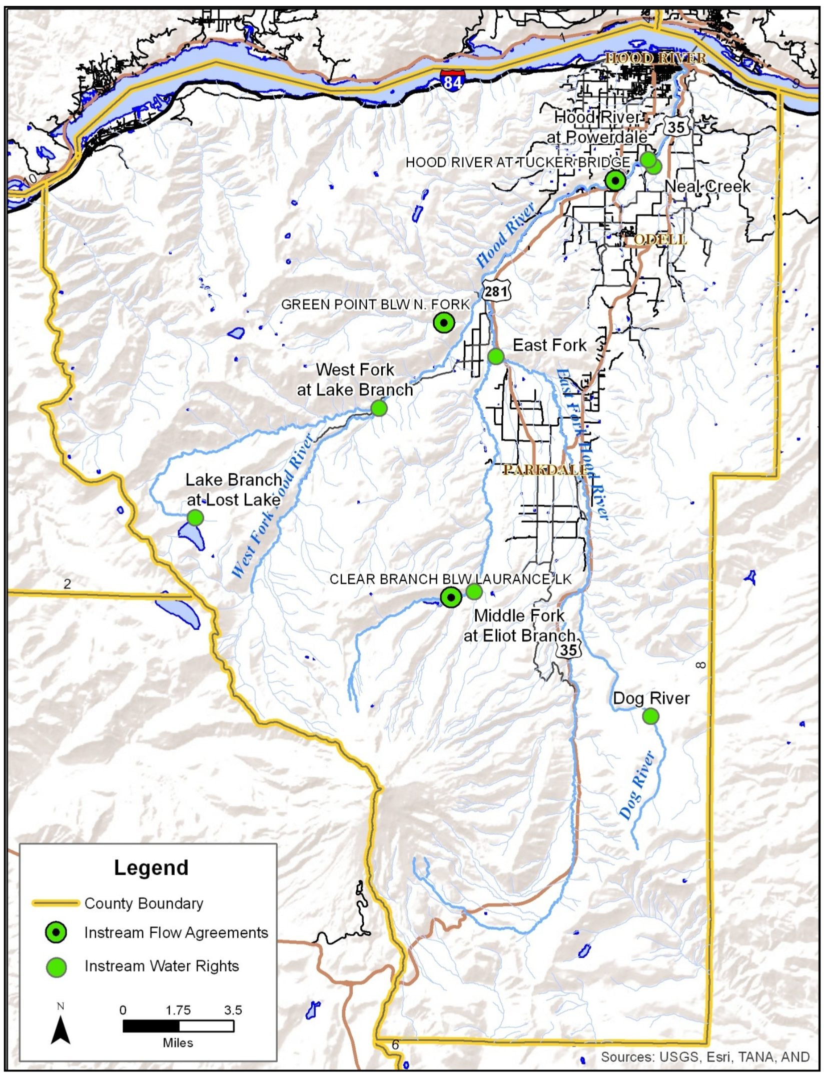


Figure 10 Location of instream water rights and flow agreements in the Hood River basin, Oregon.

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, most industrial water use in the Hood River basin is quite small and is often also served by other sources. Permitted water use rates varying between less than 1 cfs to 2.5 cfs (Hood River Water Use Assessment 2013). Figure 11 reflects the locations of the most significant commercial water rights. Most of the industrial water rights, as well as most of the industrial use in the basin, can be categorized into one of the following groups from which they can be analyzed: 1) cold storage/packing houses, 2) lumber mill, or 3) other/small use from which they can be analyzed.

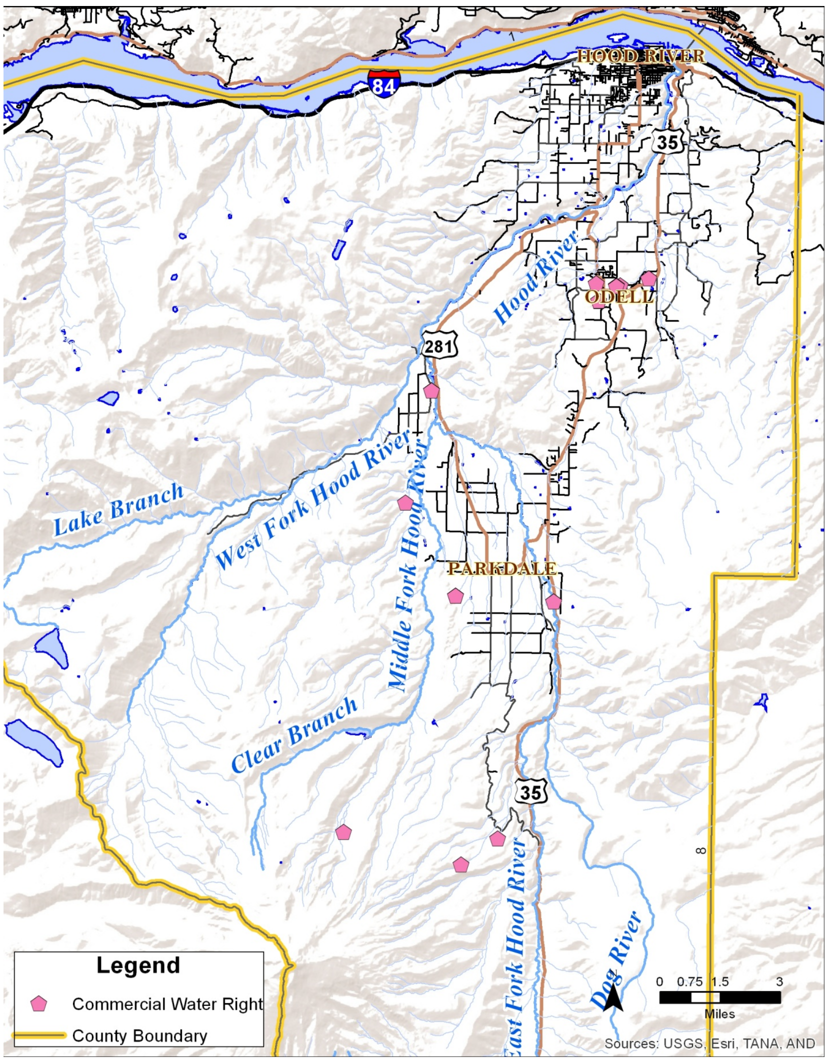


Figure 11 Location of all industrial water rights in the Hood River Basin, Oregon.

Water Resource Modeling Data

Data to support Reclamation's hydrologic and water resource modeling included analyzing 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.

The Distributed Hydrologic Soil and Vegetation Model (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 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, which are also 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. In addition, sedimentation impacts, which are significant in the basin due to the 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, reducing outdoor water use 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, The Dalles has less economic and political will to implement conservation measures. 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 1.3 percent over the basin including the City of The Dalles). With this population increase between 2010 and 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 1,000 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 water 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. This percentage of savings was selected because it was at the high end of what has been achieved in other areas (Water Conservation Assessment 2013b). By reducing use of water for outdoor purposes, more than 50 million gallons of water can be saved each year in the 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.

Irrigation Water

Irrigation diversions occur from April 15 through September 30 peaking at 15 times that of the potable water use peak. Therefore, 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 systems would reduce irrigation use up to 23 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 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 has been increasing in recent years. From 1960 to 1995, one or two debris flows of record occurred, and since 1995, there has been one almost every other year (McMahan 2011). 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 could help increase the number of growers willing to convert to more efficient systems and decrease operation and maintenance costs at hydropower facilities. 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 connecting the Coe Creek diversion to the settling basin.

3.3 Reservoir Storage Studies

This section describes the results of Reclamation's 2-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, Hood River County 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 2-day site visit to the basin to evaluate 17 reservoir alternatives that were under consideration for either new or expanded water storage sites (Figure 12). 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 3 feet and Upper Green Point Reservoir dam by 8 feet, which were selected to be evaluated in more detail by Hood River County.

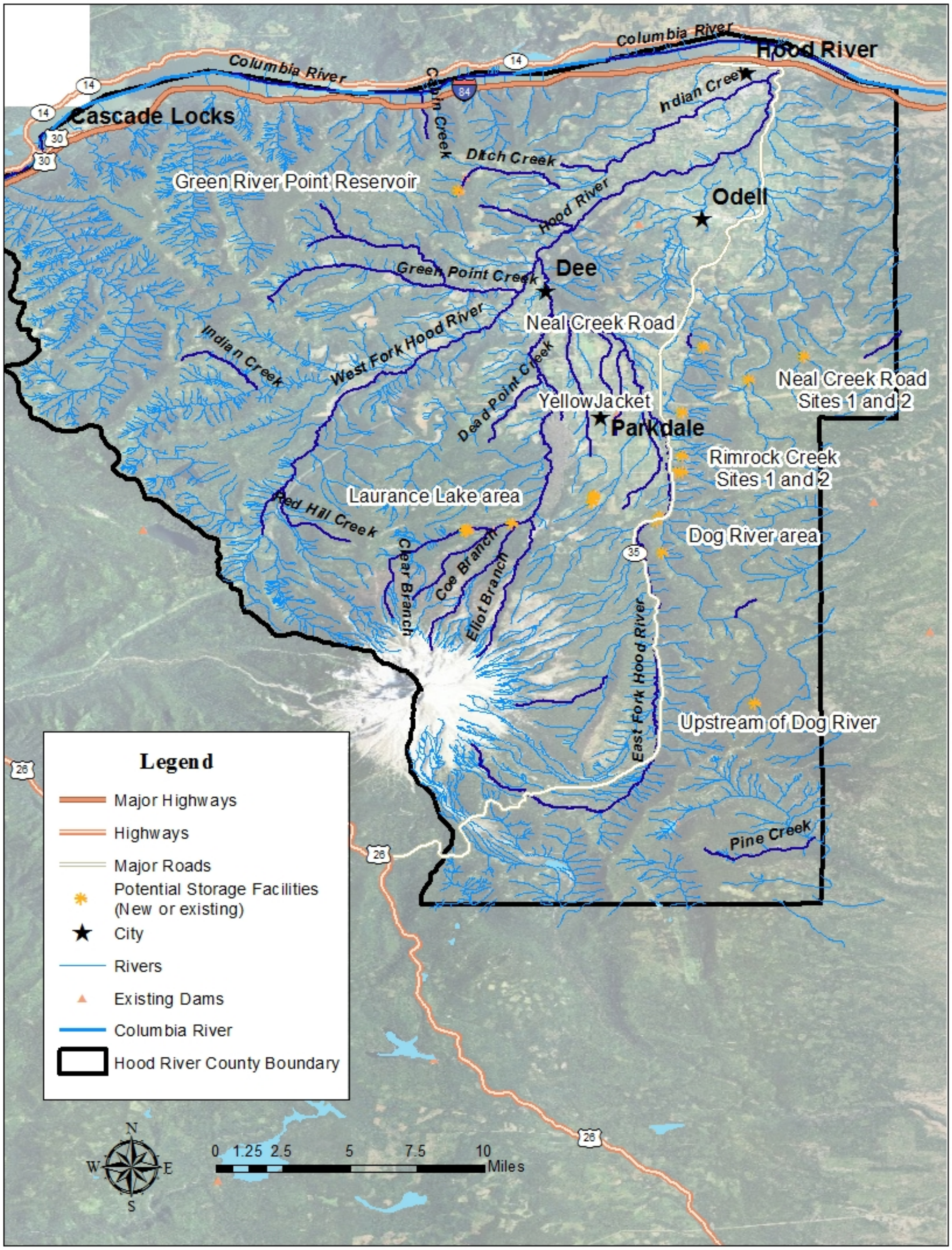


Figure 12 Potential locations (approximate) for additional storage as identified by Hood River County (for the specific list, see Table 3).

Reclamation staff qualitatively evaluated 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. 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 6.2.3 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 Smullin 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	2,557	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

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 NW of Dog River - Site 2	60	2540	592	11.6	261	1,093	0.05
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 3 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 8 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 the Hood River Basin Surface Water Storage Feasibility Assessment (OWRD Storage Study) funded through the OWRD Water Conservation, Storage, and Reuse grant program. The OWRD Storage Study leveraged the initial data that Reclamation had developed through the Federal appraisal-level reservoir storage analysis conducted as part of this Basin Study (see Section 3.3.1). The OWRD grant program funds were used primarily to assess: 1) current and future instream flow requirements in the Hood River Basin, 2) the current agricultural, potable, industrial, and hydroelectric water uses in the Hood River Basin, and 3) future conservation and storage alternatives in the Hood River Basin.

Of the 17 storage options in Reclamation's preliminary investigation, three 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 sites 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 three reservoir storage alternatives selected for further analysis. These three alternatives include expanding 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 561 acre-feet of storage capacity, increasing the total capacity to 1,549 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 listed northern spotted owl habitat exists near or within the project area and may be affected.

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 million, respectively.

Laurance Lake

The Laurance Lake storage alternative considers raising the dam at 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 3,935 acre-feet. Most of the dam is on glacial moraine, alluvium, 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 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 National Forest, which contains northern spotted owl habitat. If releases from the weir system affect downstream flow patterns, bull trout and steelhead habitat may be affected by the change in flow regime.

Total capital costs were estimated at $328,000, 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 2,557 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, reduced diversions to the Main Canal from the East Fork Hood River would benefit that system by leaving additional water instream. 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 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 assumed materials were sourced onsite and the other assumed materials were not. Total capital costs were $13.2 million and $27.9 million, respectively. In addition to capital costs, annual operation and maintenance costs were estimated between $1.24 million and $2.43 million.

Details on the evaluation of each option are provided in Section 5.2.2. The analysis of the storage options including impacts to water supply, operations, and demand benefits are provided in Section 6.1.2.

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. These flows are used in subsequent modeling efforts to understand the potential impacts of climate change.

Figure 13 shows schematically how the physical models incorporate climate or hydrology developed by the climate change process. The three models used in this Basin Study include:

1. MODSIM is a water resource model used to simulate reservoir operations, irrigation diversions, and minimum instream 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).

Generating climate change data is a process in which climate change forecasts are selected and processed into meteorological data (e.g., temperature, precipitation). Meteorological data are then used as input to a hydrologic model, such as DHSVM, to generate streamflow at locations of interest. 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.

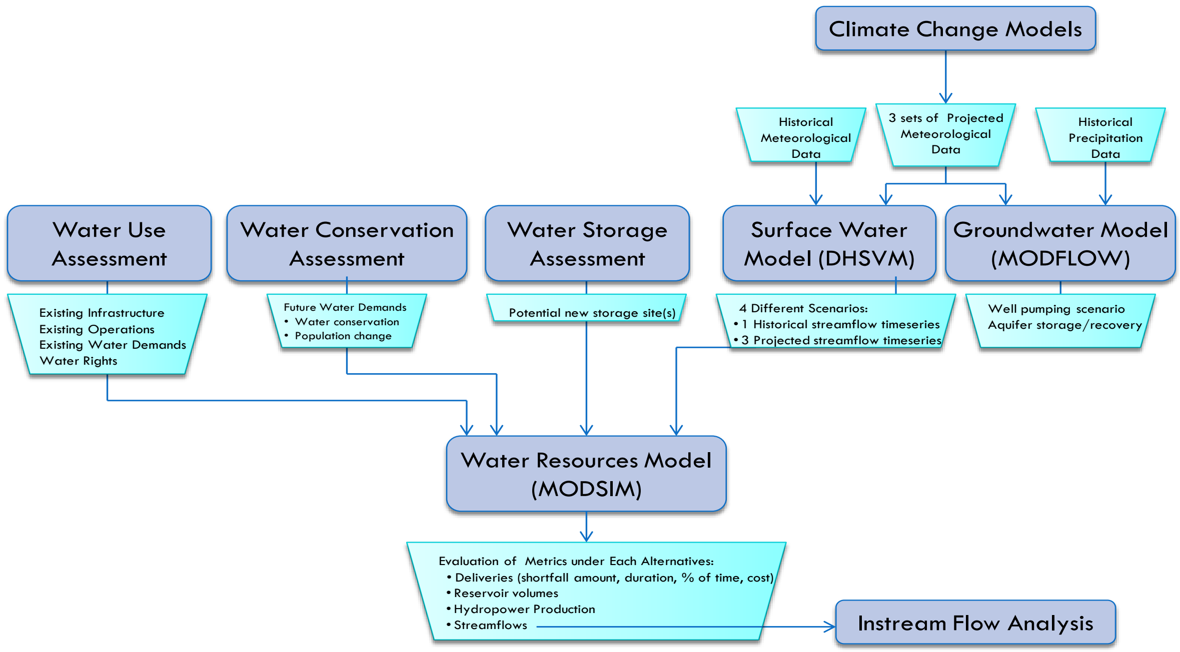


Figure 13 Schematic of climate change analysis and modeling interaction.

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 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 Warming/Drier (MW/D) 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 scenarios selected for analysis in this Basin Study were the MW/D, MED, and the LW/W. Results for each climate change scenario are shown in Table 5 with the corresponding change in precipitation and temperature for each season. 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.

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/ Drier (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/ Wetter (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, precipitation generally decreased below historical conditions.

4.2 Hydrologic Analysis

4.2.1 Approach

The Distributed Hydrologic Soil and Vegetation Model (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 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. The period of record in the model was 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 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 due to 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.

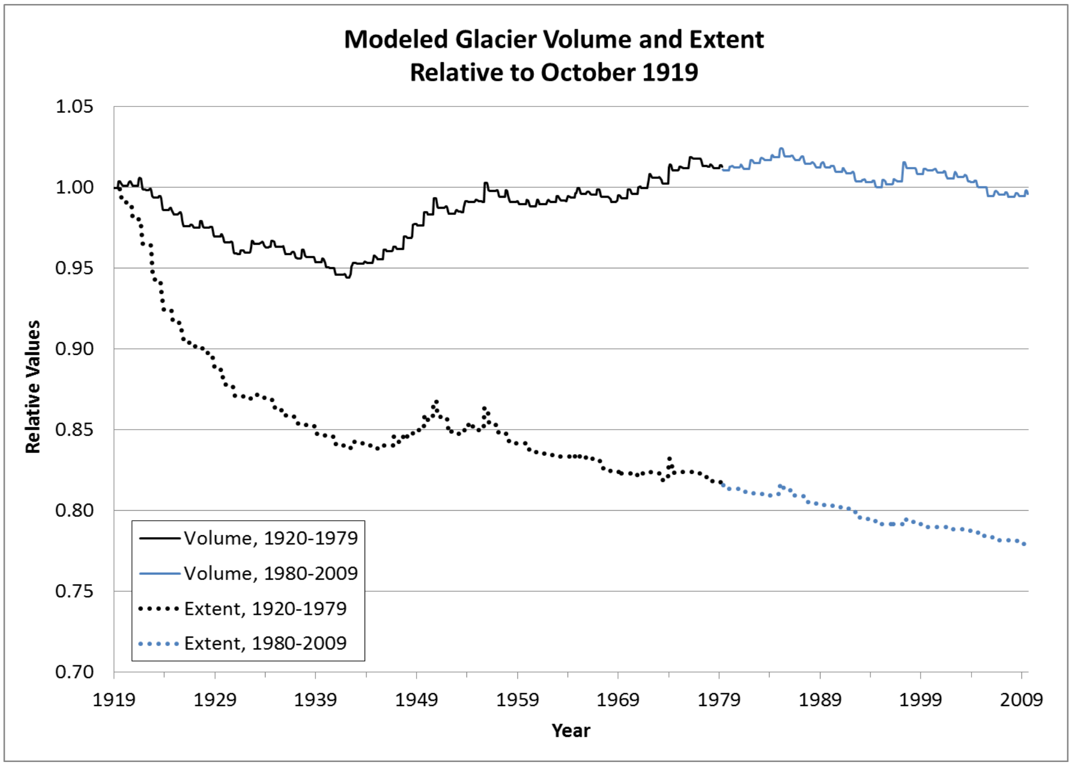


Figure 14 Simulated historical volume and extent of glaciers on Mount Hood from water years 1920 through 2009.

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 for water years 2030 through 2059. 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 due to increasing temperatures. In addition, the volume of the glaciers decreases between 3 and 10 percent depending on the climate change scenario, which is in contrast to the base simulation which remained effectively unchanged (Figure 14).

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 15). 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.

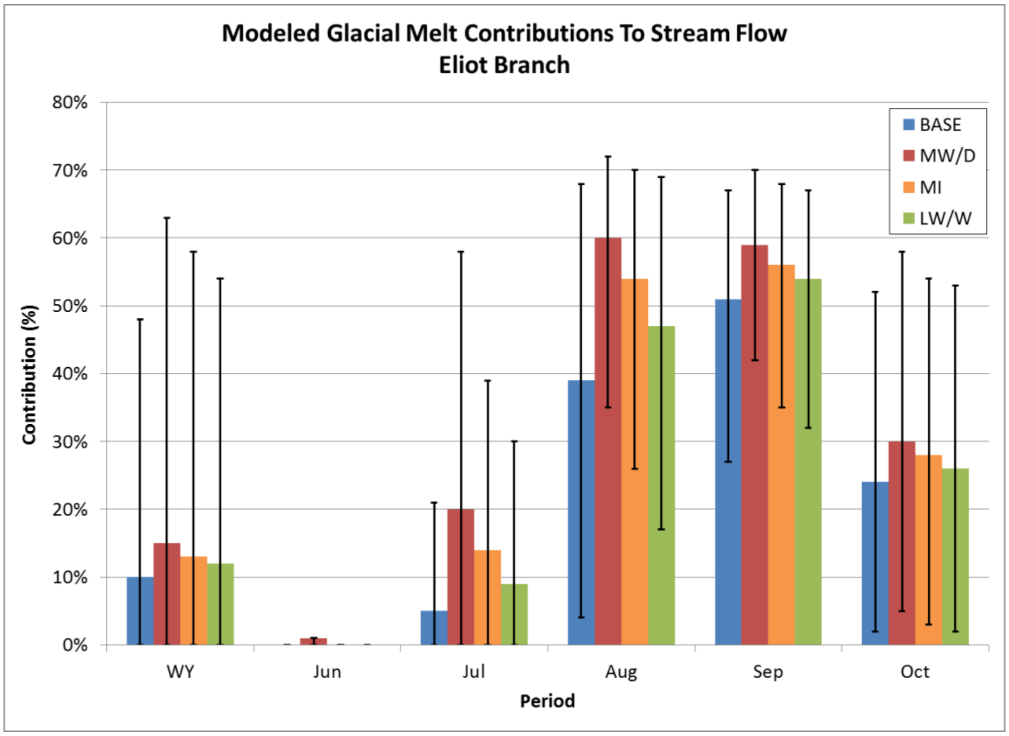


Figure 15 Comparison of simulated historical glacier melt contributions (base) shown as percent of total streamflow with simulated future glacier melt contributions under the three climate scenarios for Eliot Branch.

Snowpack

In general, a decrease of roughly 5 percent of snowpack every 30 years is evident in simulated historical records. In Figure 16, 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.

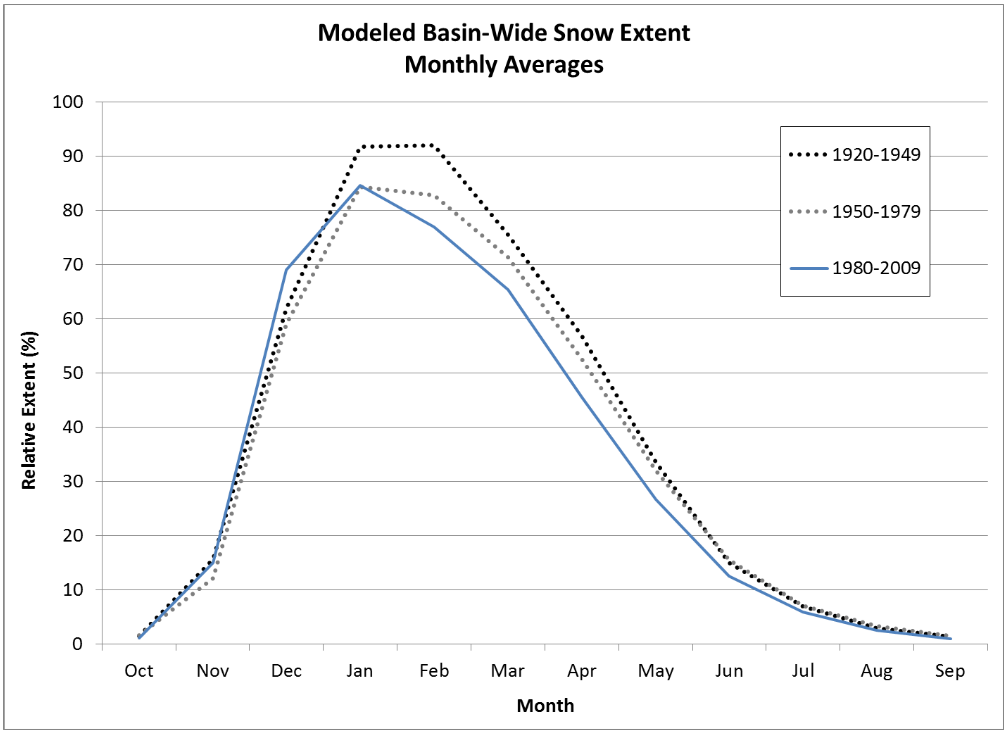


Figure 16 Simulated historical monthly snow extent values, averaged across the Hood River basin.

As shown in Figure 17, 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 16), 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 continue to experience less snowmelt-driven streamflow in the future. Impacts of glacier melt and snowpack contributions on streamflow are provided in the next section and in Section 6.2.3.

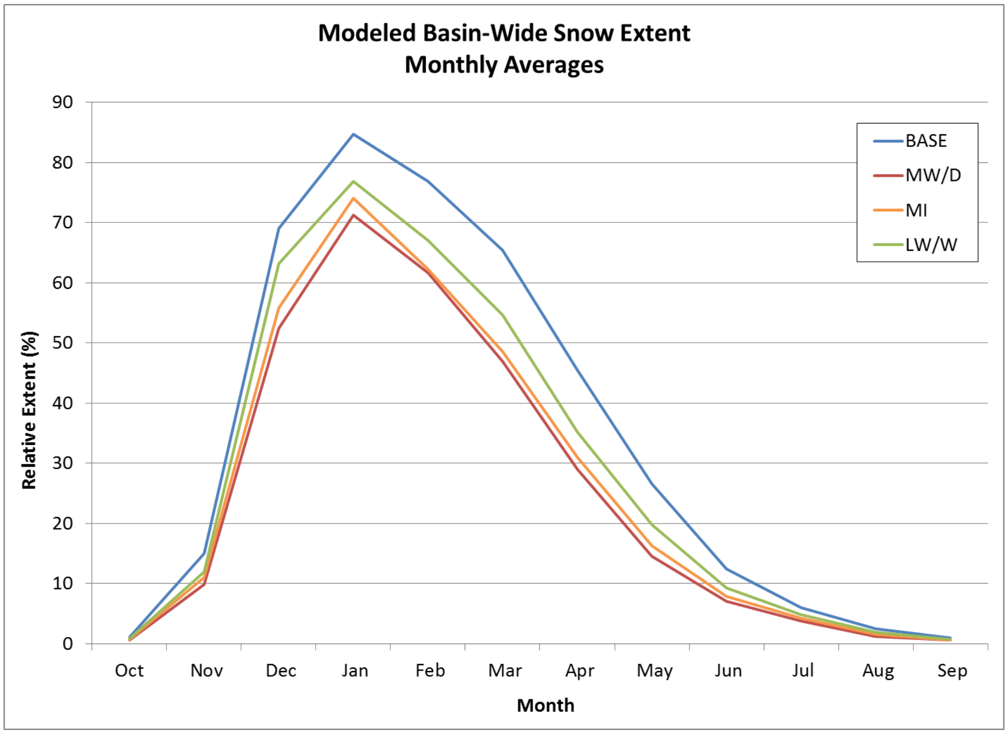


Figure 17 Comparison of simulated historical snow extents with simulated future snow extents under each climate scenario for the entire basin.

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 mainstem Hood River (Figure 18). 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. The simulated historical and the simulated future climate change flow results were also compared to better understand future water supply changes in the basin.

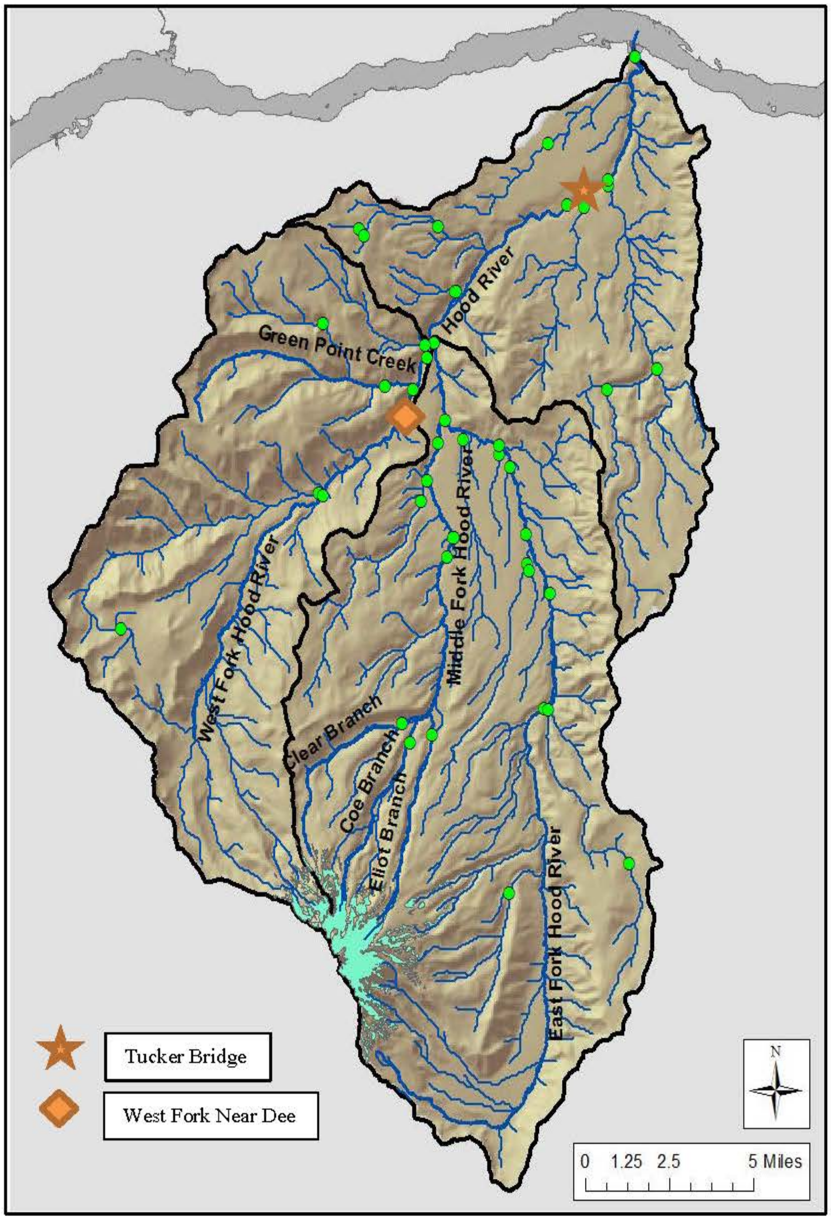
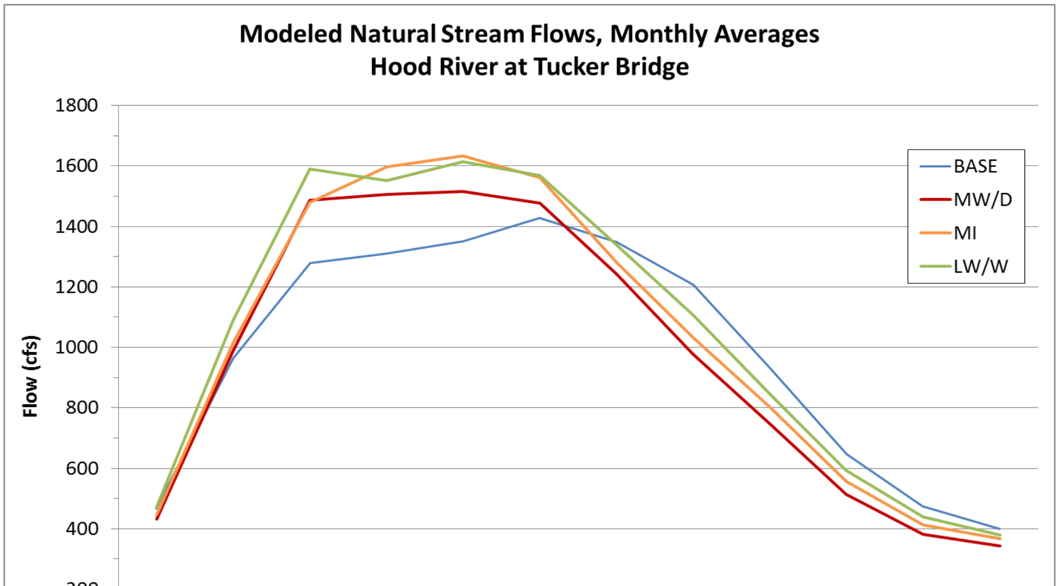


Figure 18 Locations specified for DHSVM model streamflow outputs.

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 are 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 whether biases existed in the streamflow at a particular location (Risley et al. 2009). Biases occur when 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 19 shows the results of this comparison for the Hood River at Tucker Bridge gage. Consistent with other studies in the Pacific Northwest (Reclamation 2008; Reclamation 2011), 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 period between October and December is steeper and begins earlier than the historical timing. The period between April and September 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 19 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

The 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.

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. Figure 20 has two panels; the top panel shows annual average precipitation from 1928 to 2005 and the bottom panel reflects the groundwater elevation range based on that precipitation. 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 2-month lag in comparison with monthly peak precipitation. For example, the peak on the top panel (annual average precipitation) occurs in December at almost 6 inches while the water level elevation peak occurs 2 months later in February at just above 755 feet at the HOOD372 station. However, the water level elevation does start rising from 750 feet to its peak in February when precipitation starts falling.

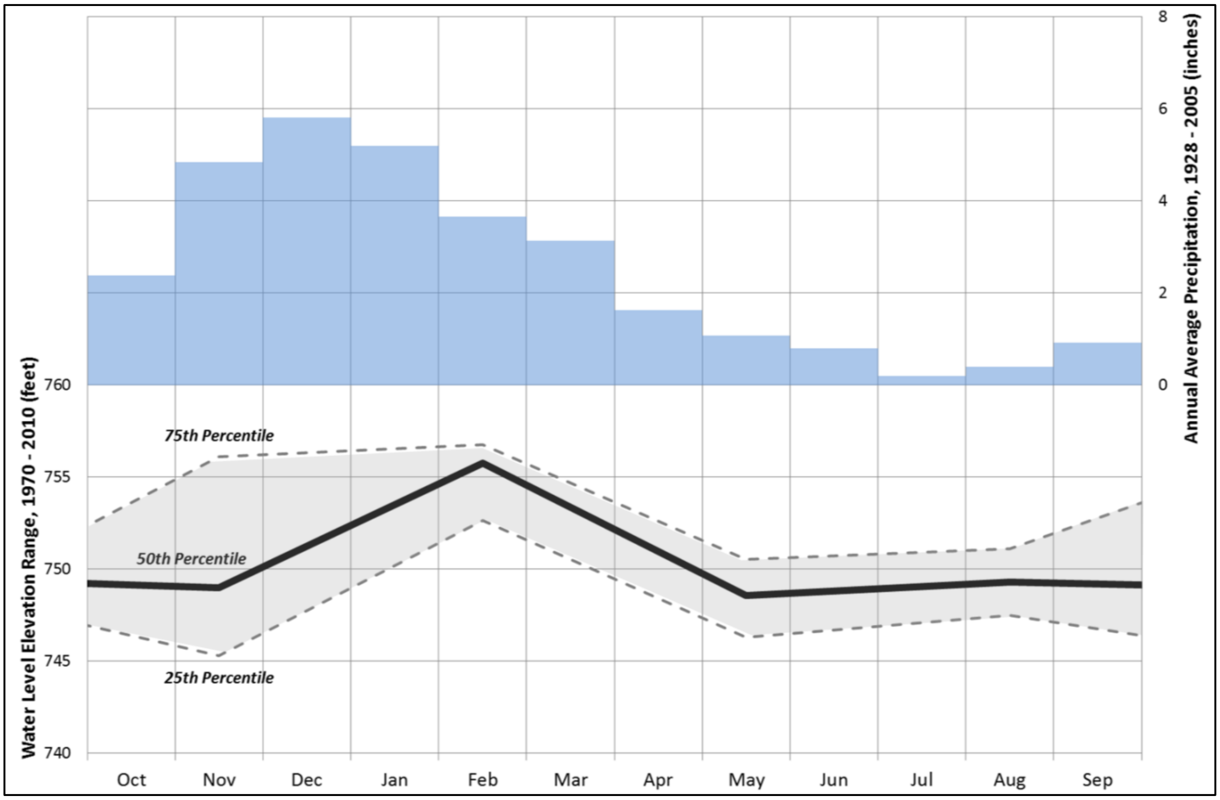


Figure 20 HOOD372 (Section 4, T2N, R10E). Water level elevation range and Hood River Experiment Station annual average precipitation.

The USGS MODFLOW-2000 model (Harbaugh et al. 2000) was used to simulate groundwater patterns in the Hood River basin. The model was calibrated by adjusting parameters of interest such as hydraulic conductivity. 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 was beyond the scope of this Basin Study. The model uses a small amount of data and basic understanding of the hydrogeological setting, so results are interpreted on a qualitative and not quantitative basis.[9]

[9] 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 21 shows the modeled and observed average baseline of the average water level conditions in the Hood River Basin for the years 1980 through 2010.

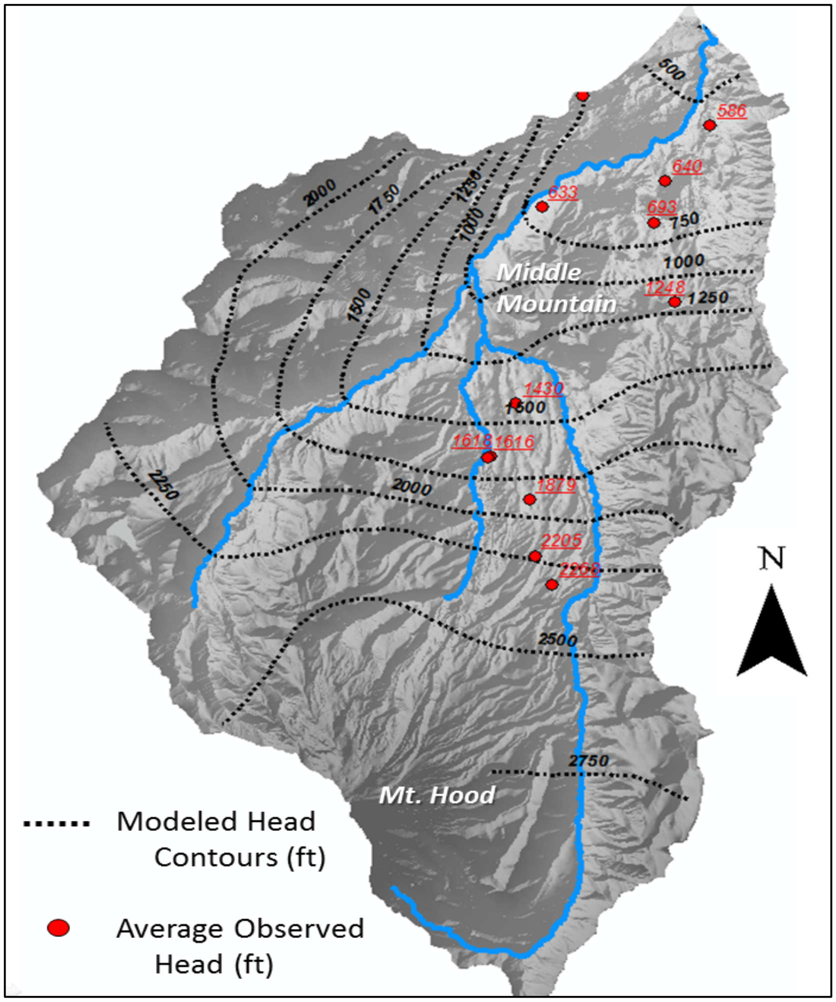


Figure 21 Modeled versus observed groundwater levels.

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 13, the meteorological data generated in the climate change analysis (i.e., precipitation and temperature data), as opposed to the hydrologic results (i.e., streamflow), 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 22 shows the combined potable water shortage as a percentage 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 from July through September.

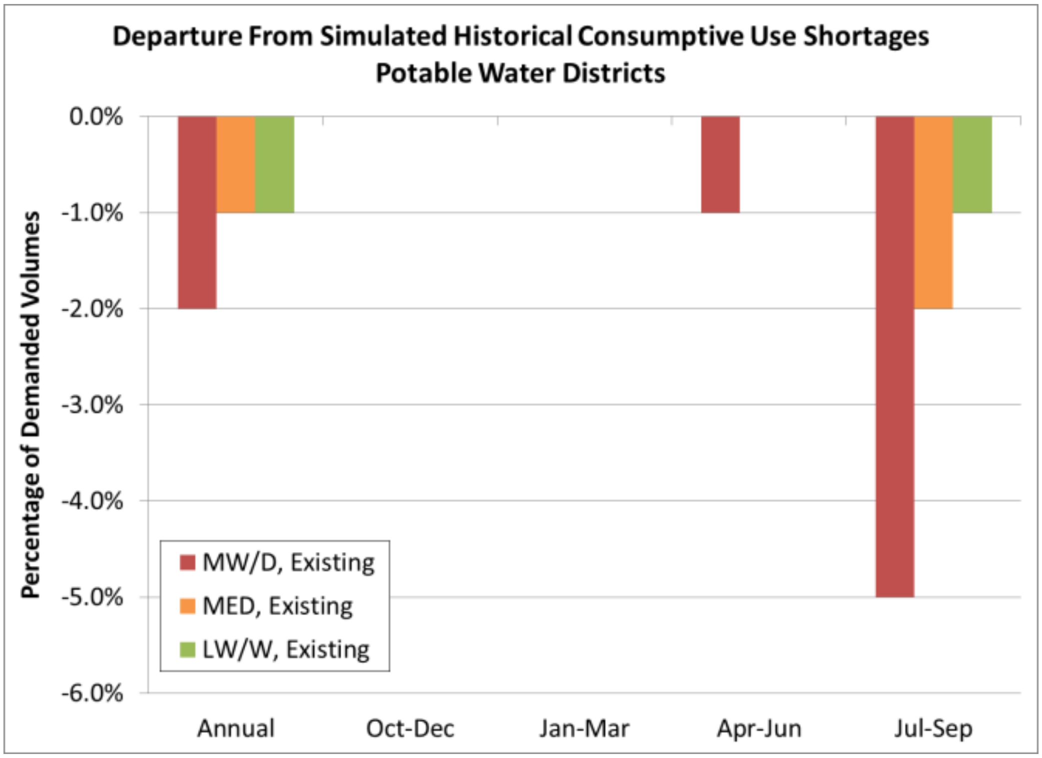


Figure 22 Average annual and quarterly shortages of existing potable water demands projected using the MW/D, MED, and LW/W future climate change scenarios.

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 10 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 Sections 3.1 and 3.2 of this Basin Study Report, the primary irrigation districts in 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 23. Figure 23 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.

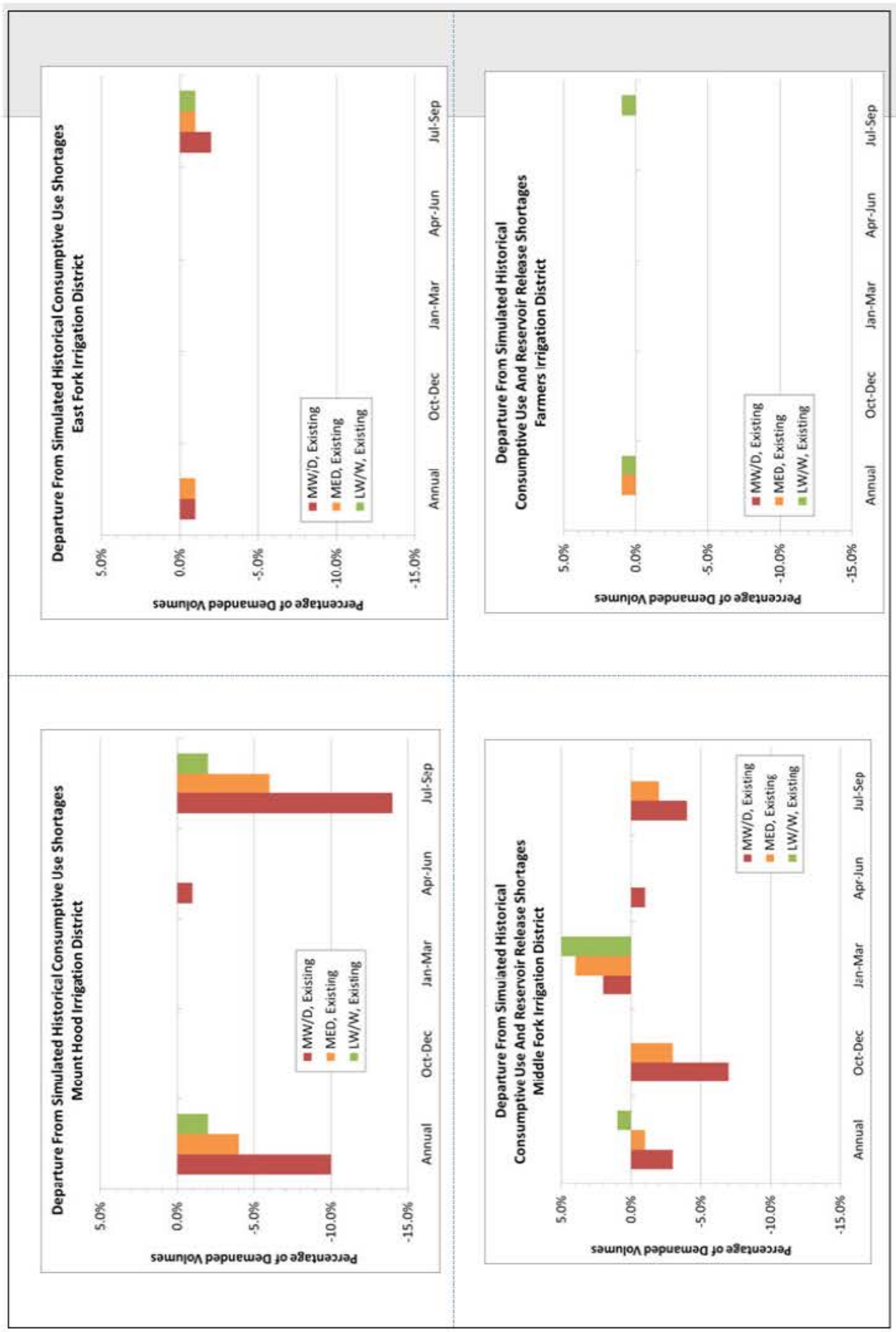


Figure 23. Future consumptive use shortages evaluated using existing conditions for major irrigation districts in the Hood River basin.

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 correspond to when irrigation occurs in MFID. The releases from Laurance Lake that occur in the fall and winter months support hydropower operations.

In the MW/D climate change scenario, 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 24 and Figure 25, 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.

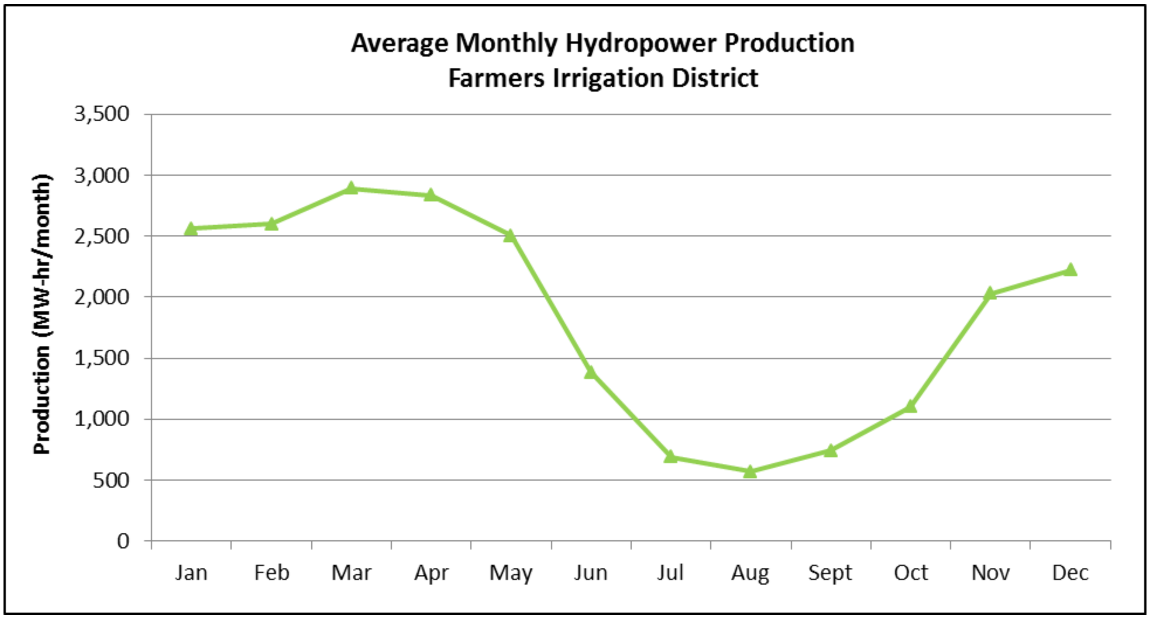


Figure 24 Average monthly hydropower production for Farmers Irrigation District.

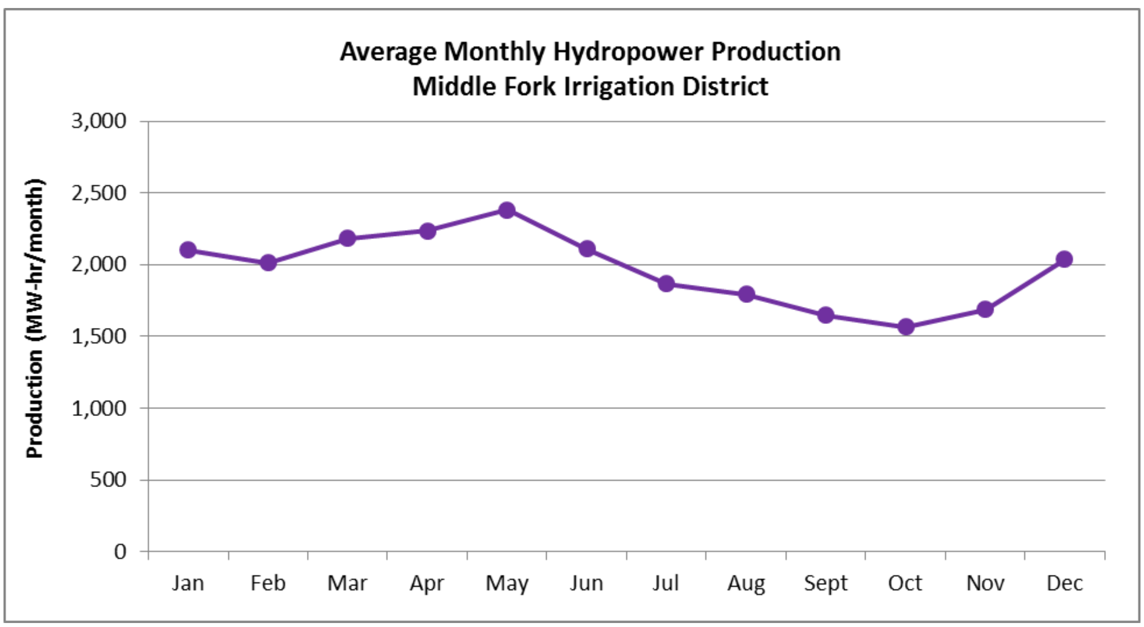


Figure 25 Average monthly hydropower production for Middle Fork Irrigation District.

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

Hood River County considered 17 new or enhanced storage options as described in Section 0. These sites had been identified through the HRCWPG in meetings prior to the start of the Basin Study. Reclamation provided more details on each site including geology, storage volume potential, and general topography information. Hood River County narrowed the reservoir storage alternatives to three, one each in FID, EFID, and MFID to evaluate using the Hood River MODSIM-DSS water resource management model. These three 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 2013a) 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 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 year 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 26 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 scenario. Peak volume in the MED and LW/W climate change scenarios are approximately 200 acre-feet more than in historical conditions indicating that the reservoir would likely not have issues filling to 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.

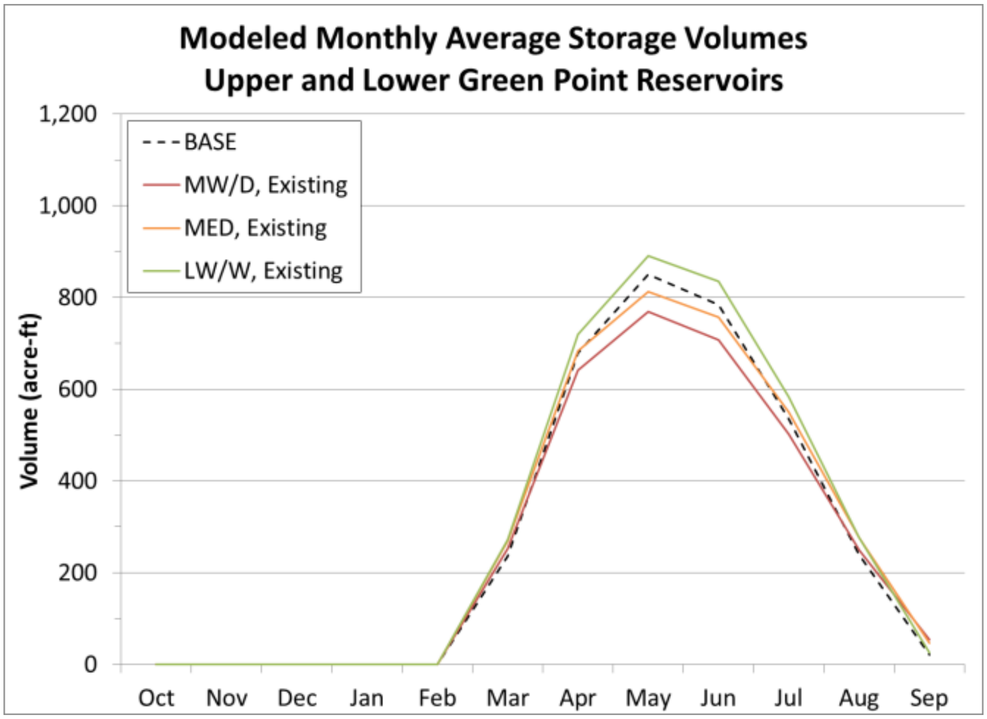


Figure 26 Future climate change impacts on existing storage volume at Upper and Lower Green Point Reservoir.

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 27). 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.

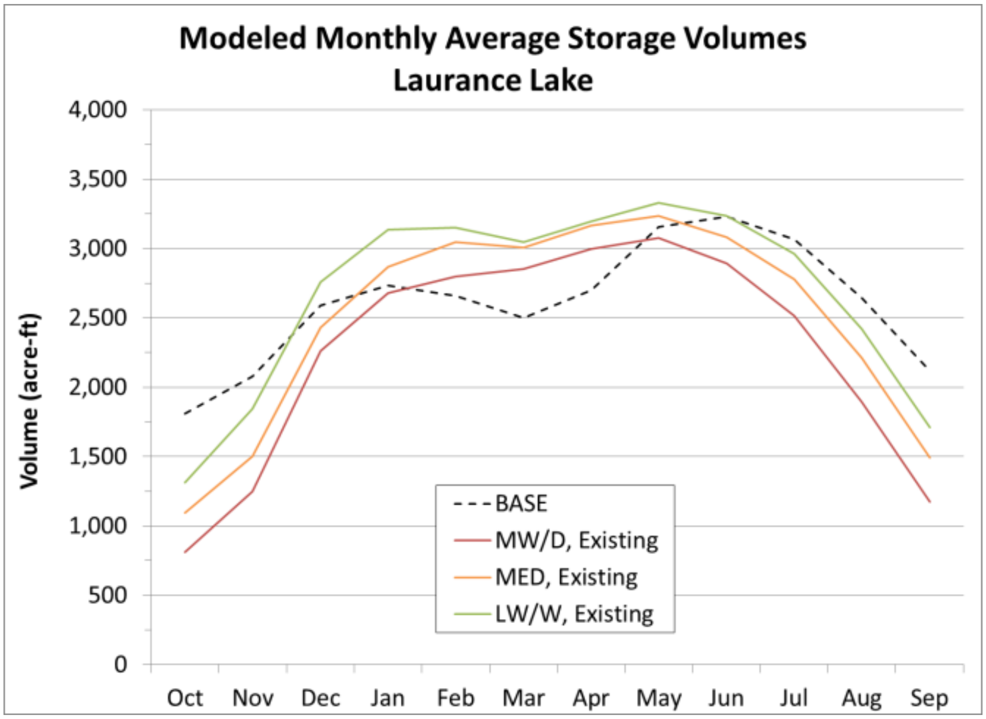


Figure 27 Future climate change impacts on existing storage volume at Laurance Lake.

4.4.3 Streamflow

Naturalized 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 28 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.

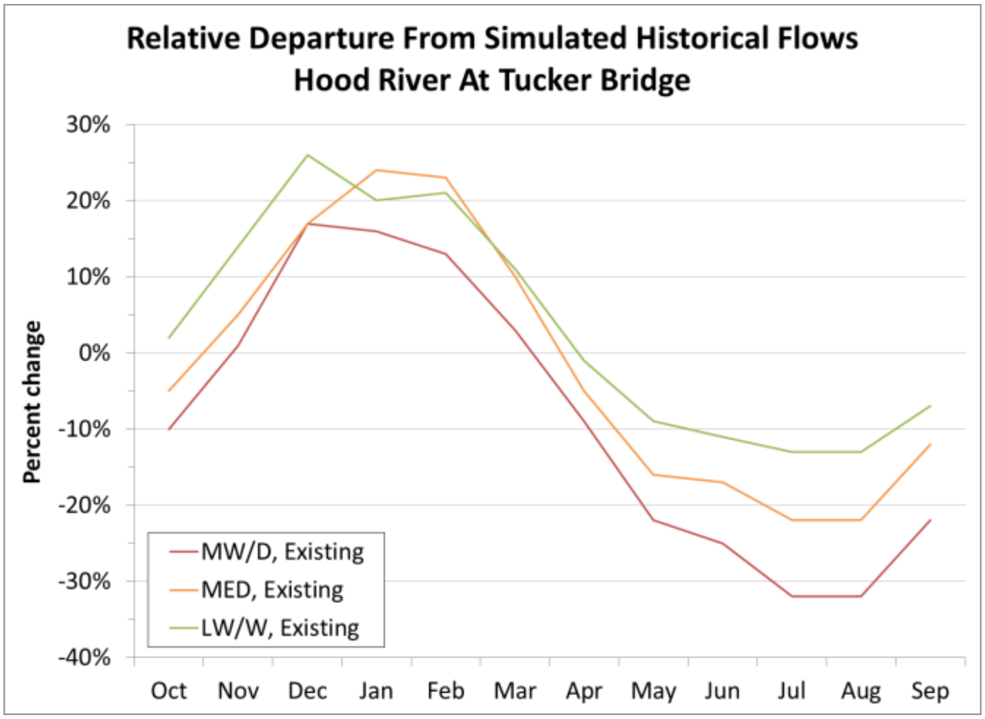


Figure 28 Departure of the MW/D, MED, and LW/W climate change scenarios from simulated historical streamflow at Hood River at Tucker Bridge gage.

Flow from the three climate change scenarios compared to historical streamflow at the West Fork near Dee gage is shown in Figure 29. 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.

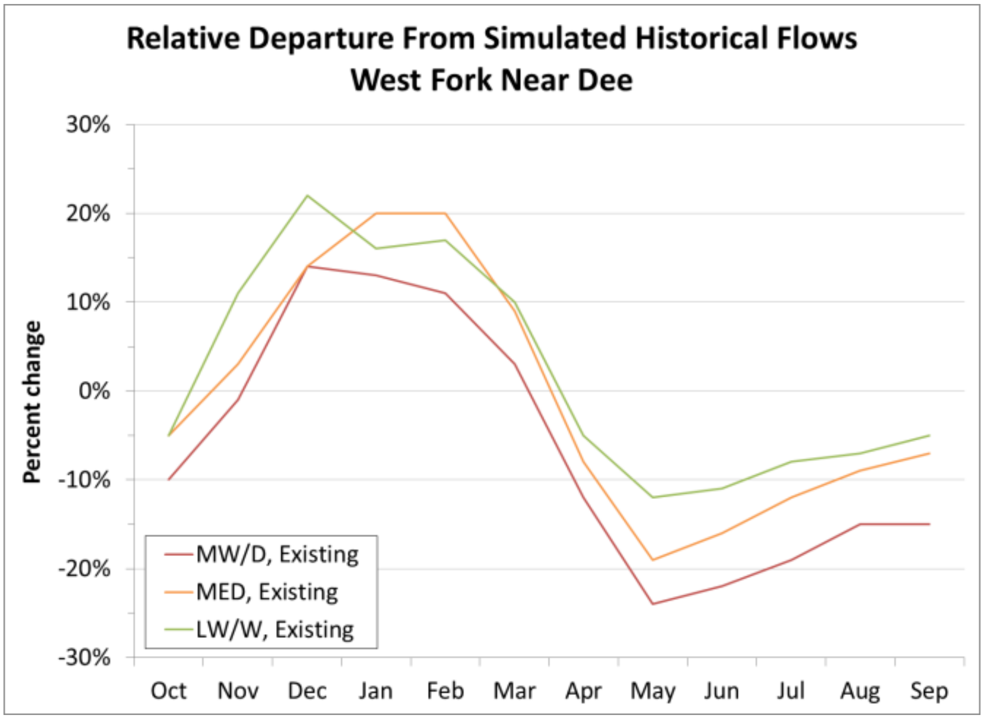


Figure 29 Departure of the MW/D, MED, and LW/W climate change scenarios from simulated historical streamflow at West Fork near Dee gage.

5.0 DEVELOPMENT OF SCENARIOS AND ALTERNATIVES

Almost 40 potential surface water and groundwater alternatives were developed to address the water supply and demand imbalances in the basin (Table 7). These alternatives were considered by Hood River County, the HRCWPG, Reclamation, and other participants for their costs and effect to the water budget to identify which alternatives should be considered for further evaluation. These alternatives included specific potable and irrigation water conservation actions, sediment management, and power production. These alternatives included consideration of 17 potential storage sites or enhancements to existing ones. Sediment management and power production were not further evaluated in this Basin Study because it was beyond the scope of the effort, but the County may pursue these alternatives in the future.

Table 7 Summary table of alternatives evaluated 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
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

Potential Alternatives Considered	Type of alternative	Cost, if applicable ($)	Effect to Water Budget
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
Middle Fork 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 Smullin Road	Reservoir Storage	--	493 acre-feet
Rimrock Creek Site 1	Reservoir Storage	--	170 acre-feet
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

Potential Alternatives Considered	Type of alternative	Cost, if applicable ($)	Effect to Water Budget
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 Laurance Lake Reservoir	Reservoir Storage	328,000	370 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
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

From these nearly 40 alternatives, the field was narrowed to six alternatives including one conservation action, three storage facility sites, and two groundwater management alternatives (Table 8). The conservation alternative evaluated reduction in water use due to changes in sprinkler conversion in the future. The reservoir storage capacity alternatives evaluated improvements to two existing facilities (Green Point and Laurance Lake) and a proposed new storage facility (Neal Creek). Two groundwater management alternatives were also developed and investigated. In addition, cost estimates were developed for each of the conservation and storage alternatives. No cost estimates were generated for the groundwater alternatives as there was not enough information at this time.

Table 8 Summary table of alternatives evaluated in the Hood River Basin Study.

Alternatives Selected	Type of alternative	How applied
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 8 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 3 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.
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 Scenarios

In addition to the six alternatives selected for further analyses, three scenarios in which surface water and groundwater use were increased were evaluated (Table 9). These scenarios assume that demand for surface water and groundwater increased above current levels and were evaluated using both existing and future climate conditions. These increases in water use were estimated based on future population growth, increases in agriculture land development and use, and potable water use as cities in Hood River County continue to grow. All future uses were projected through 2050 by Hood River County to align with the estimation in population growth assessed in the Hood River County Coordinated Population Forecast, 2008-2028 Study (ECONorthwest 2008). Water use estimates were calculated by irrigation district and evaluated as the "Existing" scenario in Section 6.0. The same approach was used to estimate water use by water districts (Table 9 in the "How applied" column).

Table 9 Summary table of increased potable and irrigation water use evaluated in the Hood River Basin Study if no alternatives were implemented.

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.
Increased pumping due to increased agricultural need	Groundwater	Evaluated increased pumping due to increased agricultural need under existing and climate change conditions.

5.1.1 Surface Water Demand Scenarios under Existing and Future Climate Change Conditions

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) were 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 result in overwatering. Many of these irrigators are expected to transition to micro- or drip-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). This value was estimated based on anticipated evapotranspiration, various crop types, and general crop mix in the valley (WPN 2013b). 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.

5.1.2 Groundwater Demand Scenarios under Existing and Future Climate Change Scenarios

Increased Pumping under Current Conditions

The increased pumping scenario was defined based on the groundwater demand that would result from irrigating the remainder of the irrigable acres within the Hood River basin irrigation district boundaries. A report authored by the Hood River Soil and Water Conservation District enumerates the amount of irrigable acreage and irrigated lands within each irrigation district's boundaries (Hood River SWCD 2002). The increased pumping scenario relies on the addition of wells within each irrigation district based on the amount of irrigable land that is 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 results in an average pumping demand of 1 cfs per well during the irrigation season.

Increased Pumping under Future Conditions

Increases in groundwater pumping due to climate change conditions were formulated differently than those under current conditions. Pumping rates under climate change conditions were adjusted based on outputs from the hydrologic modeling that was accomplished in support of the larger Hood River Basin Study.

Increases in current pumping rates for irrigation demand due to climate change were calculated based on increases in the modeled potential evapotranspiration (PET) or the amount of evaporation that would occur assuming that there is a sufficient water source available. Under future conditions, the average increase in PET was determined by quarter for each future climate change condition (January – March, April – June, July – September, and October – December). That percent increase was then used to adjust the groundwater modeled pumping rates and results reported.

5.2 Alternatives

5.2.1 Water Conservation Alternatives

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

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 in use per household likely to 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. Since The Dalles has such a high percentage of the total potable water use and is outside the Hood River basin, it has less economic and political will to implement conservation measures, which reduces the amount likely to be conserved.

Irrigation Water Conservation

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

In addition to conversion of impact sprinklers to micro-sprinklers, piping or other water delivery changes were evaluated. Table 10 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 10 Water conservation achieved through piping and conveyance changes.

District	Reduction in 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 Includes eliminating overflows as well.
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 10. 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- or drip-irrigation 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 11 and Table 12. 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 11 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 12 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	$28,000,000	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.

5.2.2 Reservoir Storage Alternatives

As described in Section 0 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. This section briefly describes the three alternatives selected for further analysis that was completed in the OWRD Storage Study.

Reservoir Alternative 1 – Expansion of the Upper Green Point Reservoir

Green Point Reservoirs have a capacity estimated at 988 acre-feet (Wy' East Surveys 2002). This alternative evaluated the potential of raising the upper dam by 8 feet which includes 2 feet of freeboard, adding 561 acre-feet resulting in a new total storage capacity of 1,549 acre-feet (Figure 12). There may be some constraints on the amount of water available to store because of natural flow and water rights currently held by others on the streams surrounding the Upper Green Point Reservoir. The OWRD Storage Study has more information 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 13 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. For more information on annual operational costs, please refer to the OWRD Storage Study (2014).

Table 13 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

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 flow into the reservoir: Clear Creek and Pinnacle Creek (Figure 12). 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 glacial moraine, alluvium, and possibly lake bed materials found downstream of the dam. The amount of water available to store is constrained by instream and out-of-stream uses held on Clear and Pinnacle creeks. This alternative should not affect wetlands, but ESA habitat may be affected, including the northern spotted owl.

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

Estimated Costs for Alternative 2

Table 14 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 operating and maintenance costs were estimated as 1.5 percent of the total project. Costs associated with the environmental 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 14 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

Reservoir Alternative 3 – Neal Creek Reservoir

This alternative includes construction of a new 2,557-acre-foot reservoir on the West Fork of Neal Creek to serve irrigation needs, instream flow augmentation, and recreational purposes (Figure 12). The amount of water available for storage is likely constrained by water rights held by others. No wetlands are delineated in the potential impact area; however, ESA-listed species and their habitat 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 15. Two alternatives are presented, of which 3A represents the assumption that fill material for construction of the dam is nearby and 3B assumes it is not. The unit storage costs are extremely high in either case. For more information on annual operational costs, please refer to the OWRD Storage Study (2014).

Table 15 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-September period to enable supplementing streamflows during temporary, critical low water situations.

5.2.3 Groundwater Alternatives

Two future groundwater alternatives were evaluated to understand the potential benefit of aquifer injection for groundwater storage or for streamflow augmentation. 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 aquifer storage and recovery and streamflow augmentation alternatives 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 aquifer storage and recovery and streamflow augmentation alternatives, 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. More detailed information on the process can be found in the Groundwater Technical Memorandum.

6.0 EVALUATION OF SCENARIOS, SELECTED ALTERNATIVES AND OTHER METRICS

This section summarizes the results of the evaluation of the selected surface water and groundwater alternatives under existing and future climate change that include water conservation actions, and three reservoir storage alternatives and aquifer injection for either storage or streamflow augmentation. Also, 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.

In addition to these alternatives, three groundwater and surface water scenarios were evaluated in which water demands continued to increase in the future, but no alternative was implemented.

Each section contains plots depicting results for alternatives or scenarios under the existing and future climate change conditions. The existing conditions scenario, labeled "existing," reflects results of the potential impact of climate change on the metric presented assuming no alternatives were implemented, but climate change occurs. The simulation labeled as "demands" is representative of increased demands (as described in Section 5.0) for potable and irrigation water demands under the climate change scenario identified. Information for conservation, labeled as "conservation," is representative of a combination of the increased demands scenario and implementation of the conservation alternative. The reservoir storage alternatives (labeled "storage") include implementation of the increased demands scenarios, conservation alternatives, and storage alternatives. Additional information is provided on streamflow and minimum flow at key locations in the basin.

Section 6.2.3 provides the results for the two groundwater alternatives that included aquifer injection for streamflow augmentation and aquifer injection for storage. In addition to these alternatives, increased pumping assuming no actions are taken by the county is also evaluated.

6.1 Scenarios

6.1.1 Increased Surface Water Demand Scenario

Results for the increased water demand scenario 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.[10]

Figure 30 depicts the average July-September consumptive use shortages for irrigation water in each major irrigation district 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 30.

In the driest future climate change scenario, all but DID experience shortages regardless of which adaptation action is pursued. MHID experiences the greatest relative shortage under 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, MHID experiences the greatest reduction in future shortages. A slightly better result occurred if demands increased and the Neal Creek storage facility alternative was implemented in conjunction with conservation actions.

[10] 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.

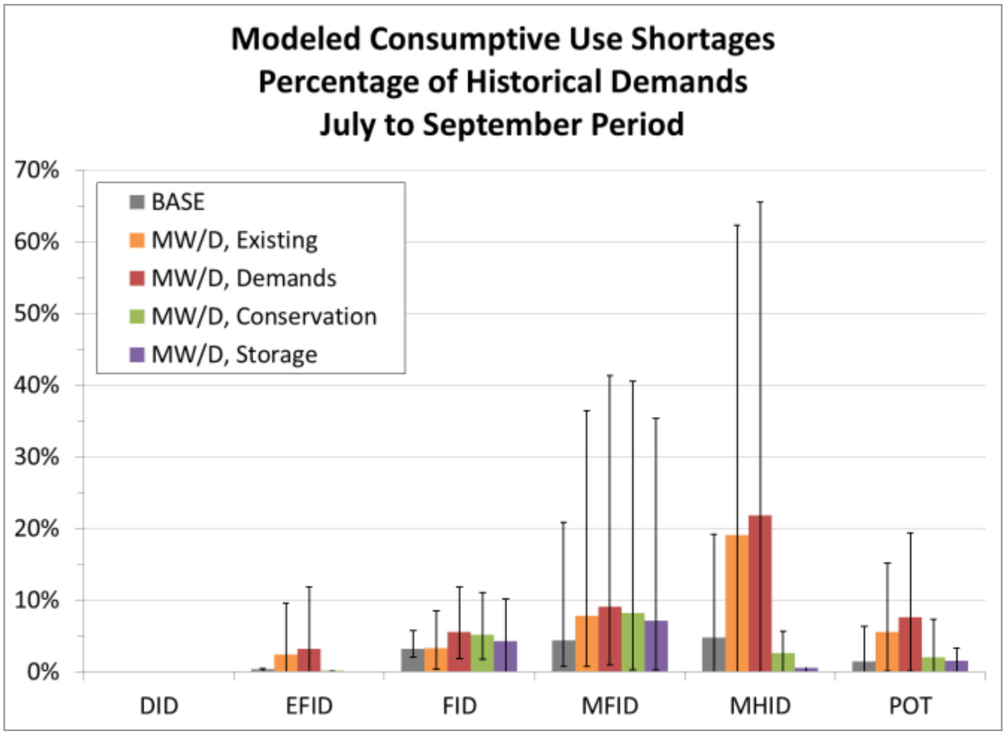


Figure 30. Average July to September consumptive use shortages as a percent of historical demands for the five major irrigation districts in the MW/D climate change scenario The error bars reflect the 10th and 90th percentile ranges for each result.

6.1.2 Increased Groundwater Demand Scenarios

Pumping Scenario under Current Conditions

The impacts under this scenario were reported as changes in water levels and groundwater-contributed stream gains (baseflow).

The additional wells result in decreased groundwater levels as compared to the baseline current condition model run. The decrease in groundwater level is shown spatially in Figure 31. 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 play a large part in the resulting modeled decrease. Different configurations of wells would result in different magnitudes and locations of groundwater level decrease.

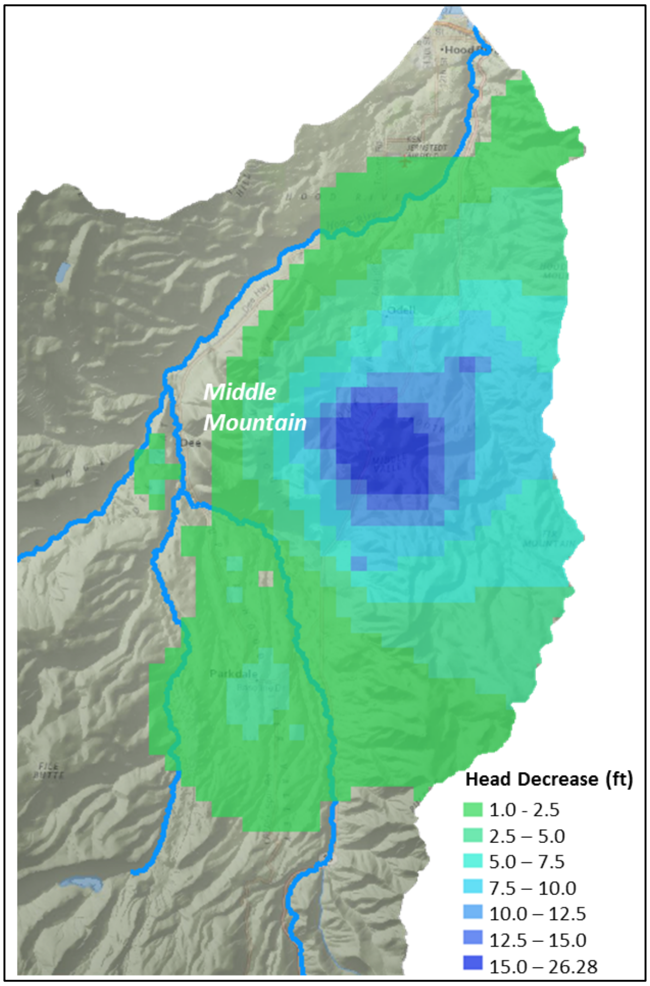


Figure 31 Water level change due to increased pumping under current conditions.

The average change in baseflow that the model simulates in this particular scenario is shown in Figure 32. The figure shows the pronounced effects of the increased pumping scenario in the April to September timeframe when the increased pumping is active.

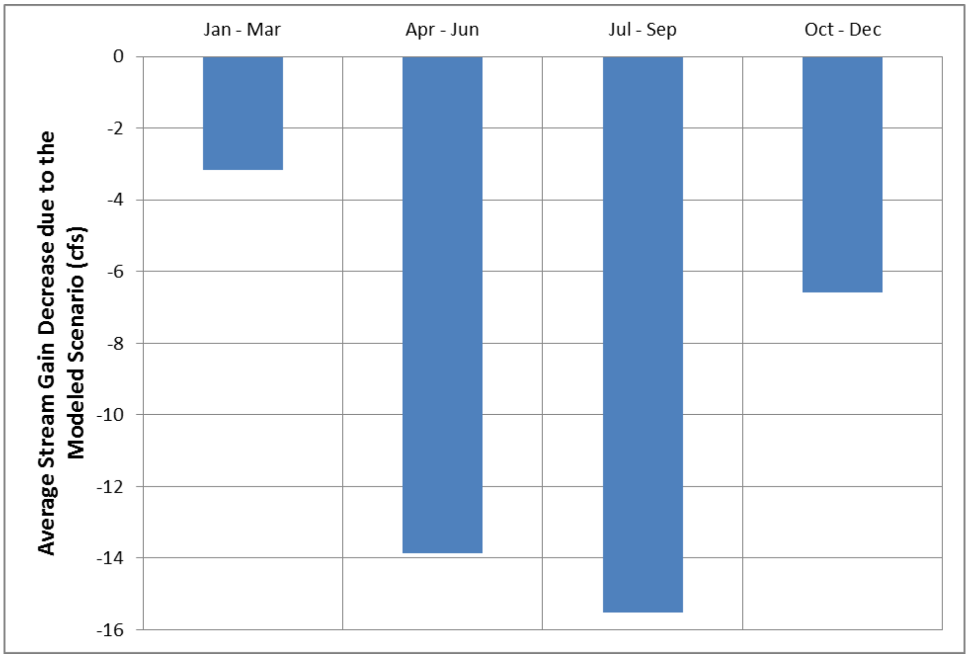


Figure 32 Baseflow change due to the current conditions, increased pumping scenario.

Increased Pumping Scenario 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 and the potential decrease in natural streamflow (see Section 4.2). Recharge was adjusted to reflect the changes in precipitation from climate change.

Impacts to baseflows from this scenario are shown in Figure 33. 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.

Additional results can be found in the Groundwater Technical Memorandum.

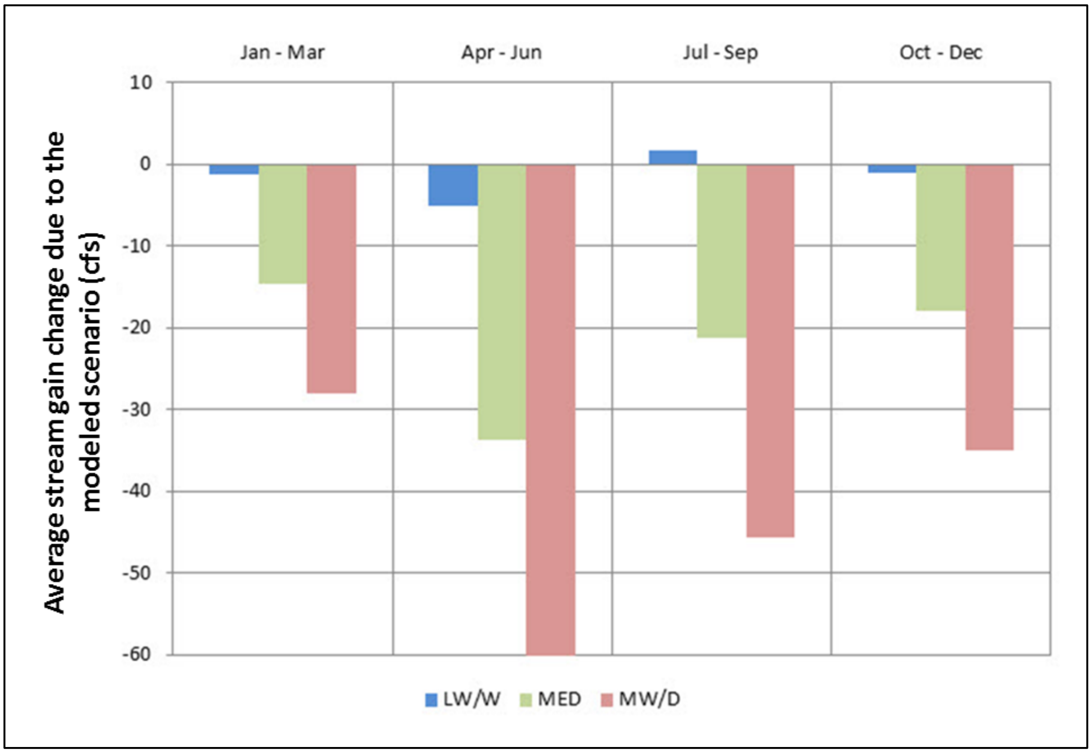


Figure 33 Baseflow change due to the climate change conditions, increased pumping scenario.

6.2 Alternatives

6.2.1 Conservation

Conservation alternatives were reported relative to the storage alternatives in the following section.

6.2.2 Reservoir Storage Alternatives

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 8 feet, with 2 feet of freeboard resulting in a new total storage capacity of 1,549 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 2013a). This reservoir system supports water use needs primarily for the FID.

Figure 34 and Figure 35 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 34, 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. However, as shown in Section 4.0, no shortages were projected for FID under the demands scenario so it may be that the projected inability to fill under the driest future is insignificant.

Implementation of conservation actions do not resolve the shortage resulting from increased demands scenario significantly in the driest future climate. In addition, lower volumes of water are projected throughout the summer and early fall. Only when the conservation and storage alternatives are implemented is the Green Point Reservoir system 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.

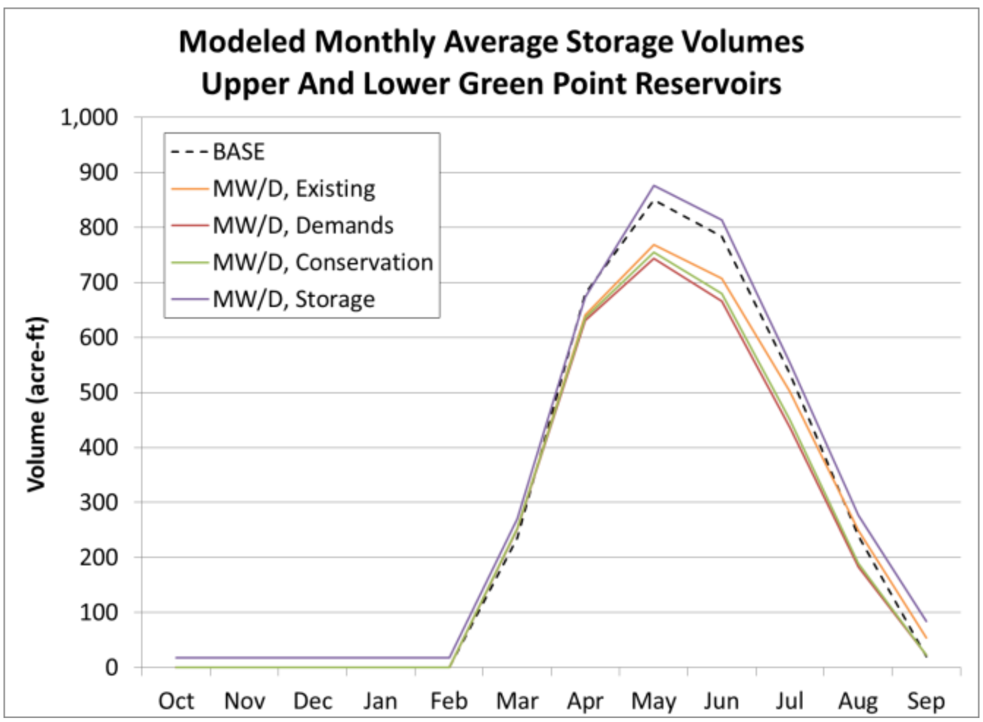


Figure 34 Change from simulated historical storage capacity for the MW/D climate change scenario in the Upper and Lower Green Point reservoirs.

Figure 35, 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.

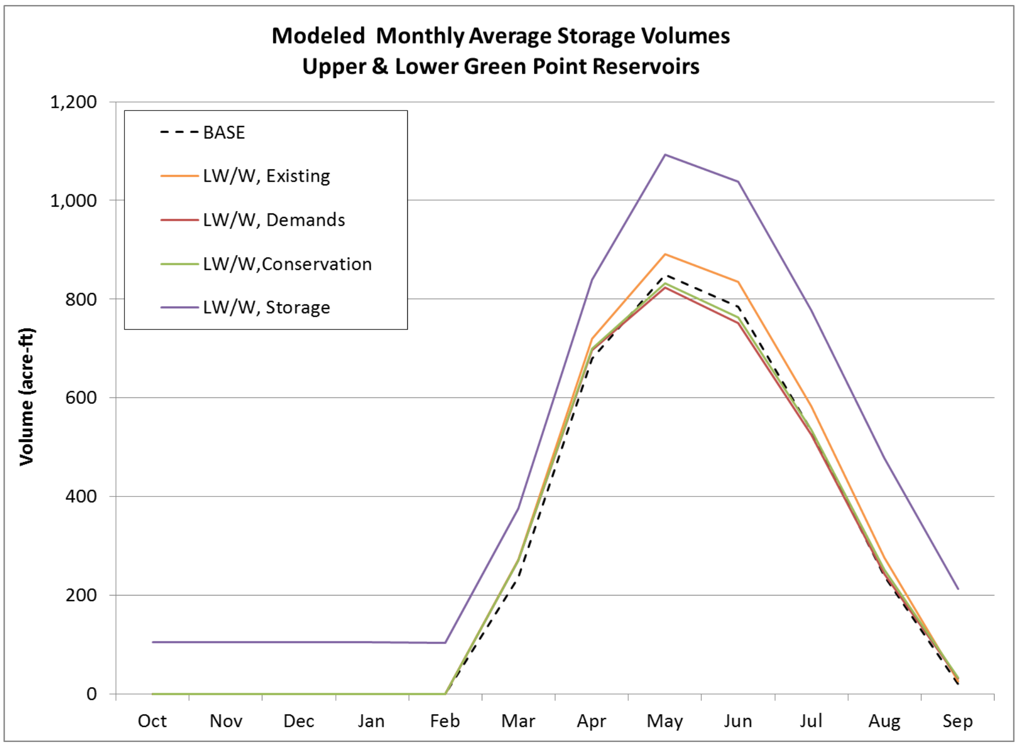


Figure 35 Change from simulated historical storage capacity for the LW/W climate change scenario in the Upper and Lower Green Point Reservoir system.

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 peaks 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.

Figure 36 depicts the MW/D future climate change scenario impacts on Laurance Lake. In the MW/D climate change scenario, the summary hydrograph suggests that the timing of the average inflow to the reservoir between October and January is significantly less than historical inflow. The second peak in June is projected to shift earlier in the year to May in the future, but no impact is observed in timing of 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.

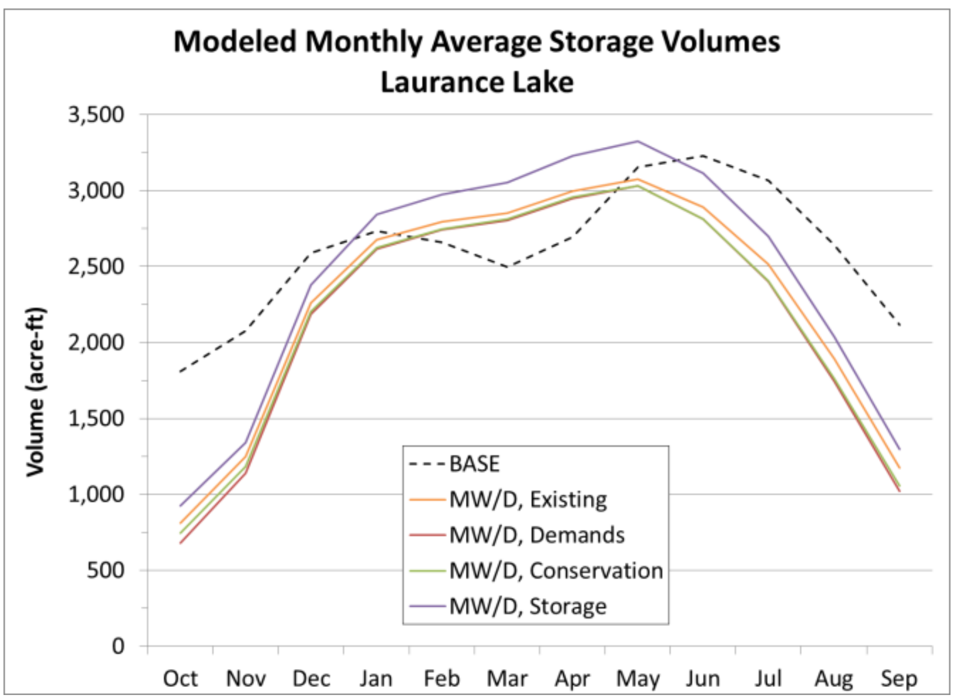


Figure 36 Change from simulated historical storage capacity for the MW/D climate change scenario in Laurance Lake.

Figure 37 depicts Laurance Lake inflow, releases, and peak volume during the wetter, LW/W climate change scenario. The October, November, and December storage volume is slightly below existing conditions, but 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.

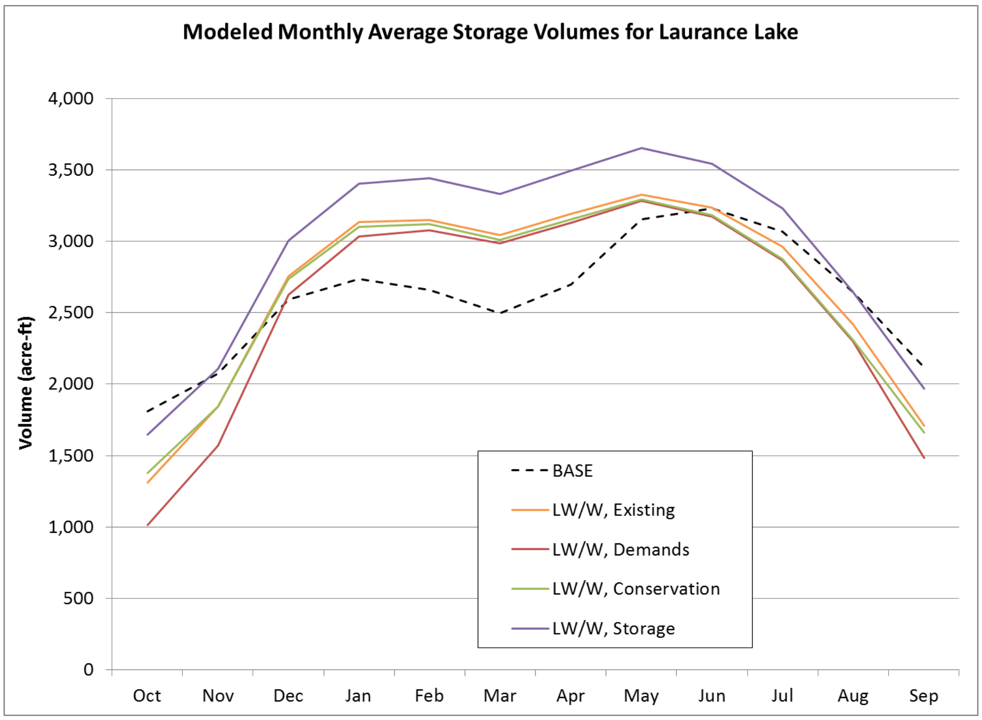


Figure 37 Change from simulated historical storage capacity for the LW/W climate change scenario in Laurance Lake.

Storage Reservoir Alternative 3 – Neal Creek Reservoir

Storage Reservoir Alternative 3 consists of the construction of a new reservoir on the West Fork of Neal Creek with a total capacity of 2,557 acre-feet to help meet irrigation needs and instream flow augmentation (Figure 12). 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 38 shows, reservoir inflow and releases are 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. This suggests that minimum instream flow requirements in the East Fork Hood River could be met with the Neal Creek facility.

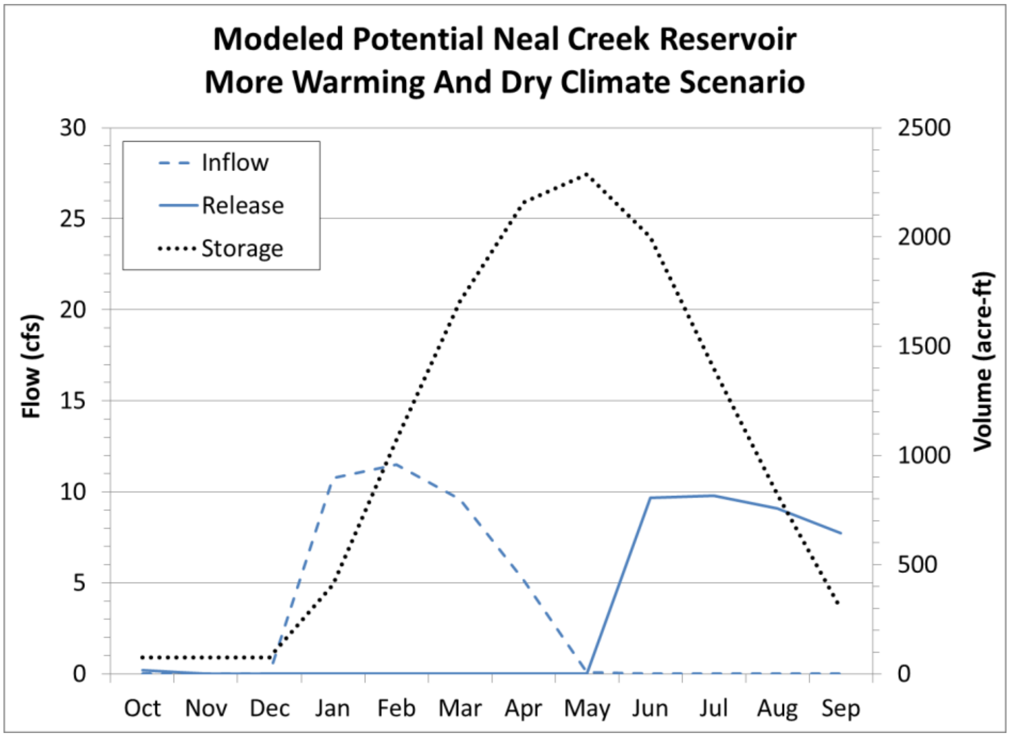


Figure 38 Simulation of inflow, release and storage patterns for the proposed Neal Creek Reservoir.

6.2.3 Groundwater Alternatives

Two groundwater alternatives were evaluated in this Basin Study that included aquifer injection for either groundwater storage or for streamflow augmentation under both current and future conditions. In addition to these alternatives, this section describes the increased pumping scenario under current and future conditions.

In an effort to understand the potential for aquifer storage and streamflow augmentation, a continuous 10 cfs flow rate was injected into individual model cells for two consecutive seasons (fall and winter) and the model response for the seasons and years that follow was evaluated (described in Section 5.2.3).

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. The metric used for streamflow augmentation was the difference between the baseline and the simulated baseflows at the Hood River at Tucker Bridge gage. 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.

Figure 39 shows the geographic distribution of values 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. 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. 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.

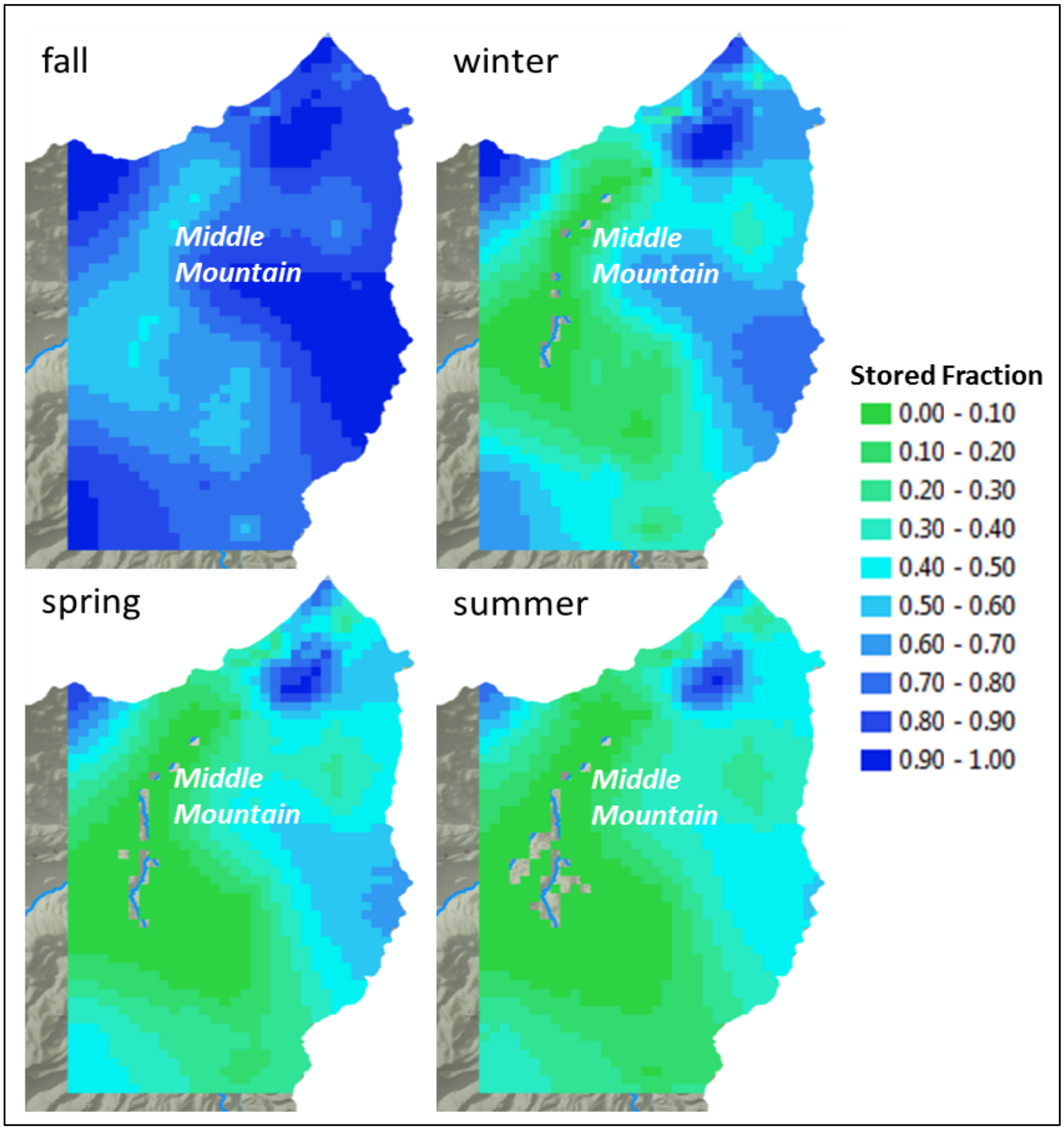


Figure 39 Cell-by-cell injection effects on aquifer storage volume, current conditions.

Figure 40 shows the increase in baseflows at Tucker Bridge resulting from groundwater injection at specific locations. The injected volume of water leaves the aquifer relatively quickly near the river and stops contributing to baseflows as early as spring.

None of the evaluated cells appear to be effective in augmenting baseflows at Tucker Bridge during the summer. Figure 40 shows that even among cells that are still contributing to a baseflow 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.

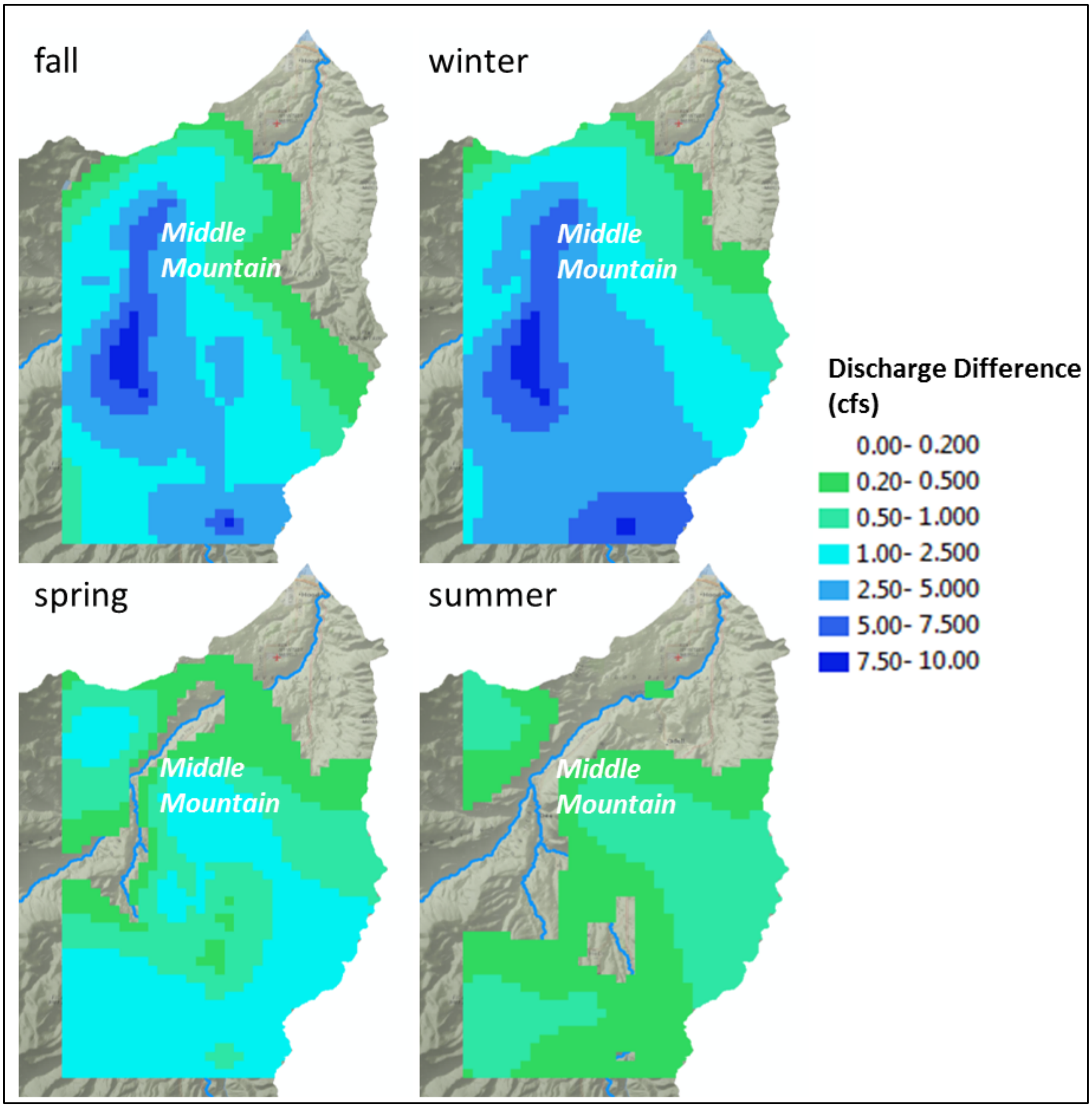


Figure 40 Cell-by-cell injection effects on Tucker Bridge streamflows, current condition.

Both scenarios resulted in similar impacts under climate change 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.

6.3 Other Metrics Evaluated

6.3.1 Streamflow

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 41).

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 precipitation will fall in the form of rain as opposed to snow, and warmer temperatures will increase the speed of 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.

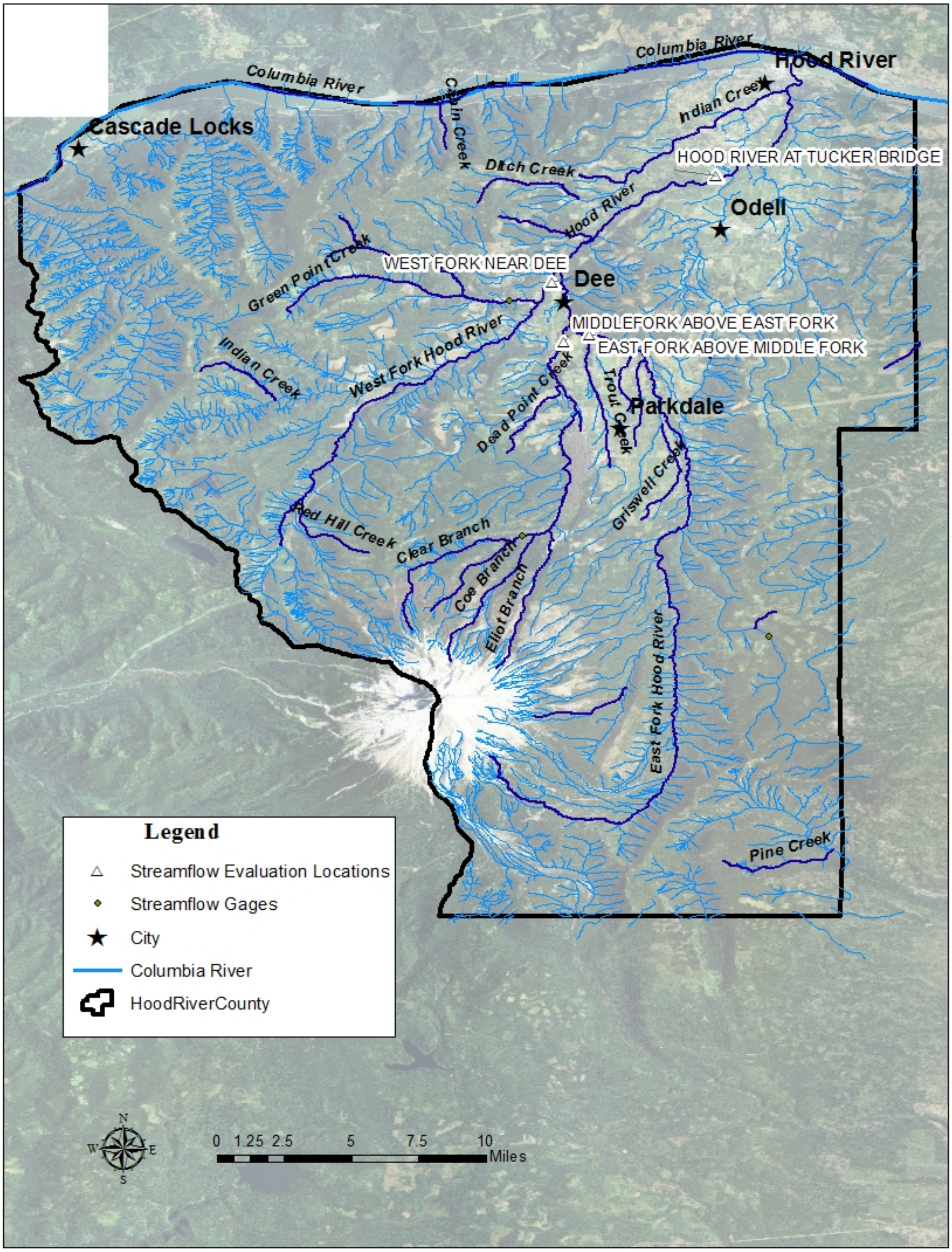


Figure 41 Location of streamflow evaluation points on the East Fork, Middle Fork, West Fork, and mainstem of the Hood River.

Hood River at Tucker Bridge

Figure 42 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.

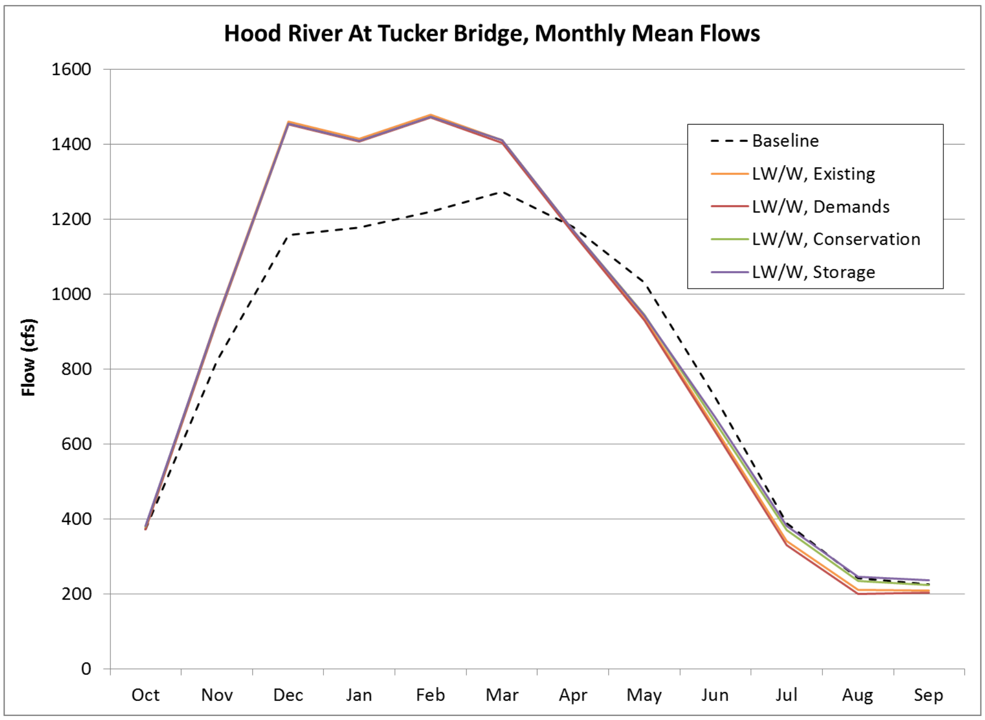


Figure 42 Average monthly regulated streamflow for the LW/W climate change scenario at the Hood River at Tucker Bridge.

In Figure 43, 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 the 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 scenario.

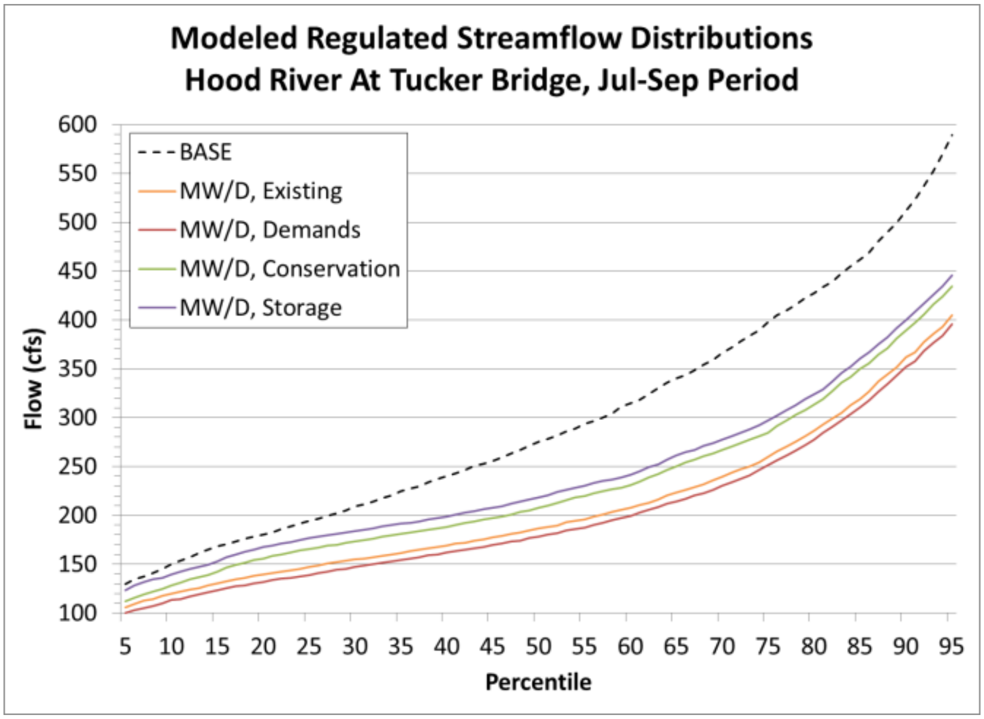


Figure 43 Distribution of average regulated streamflow at the Hood River at Tucker Bridge gage for the July through September period in the MW/D climate change scenario.

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 44 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.

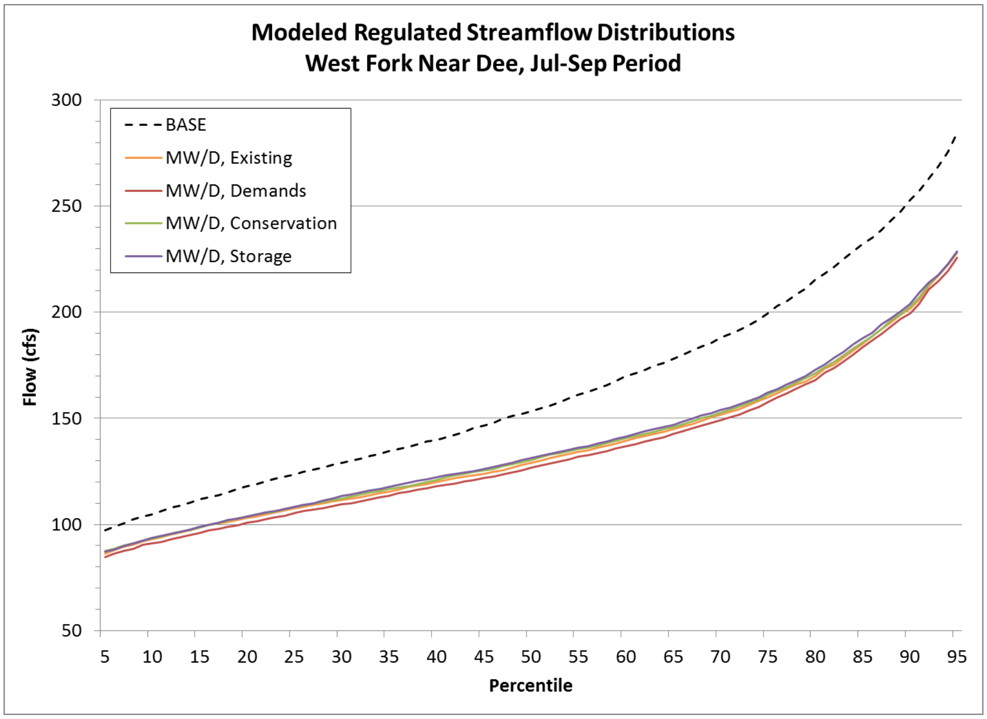


Figure 44 Distribution of average regulated streamflow at the West Fork near Dee gage for the July through September period in the MW/D climate change scenario.

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 41).

Figure 45 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.

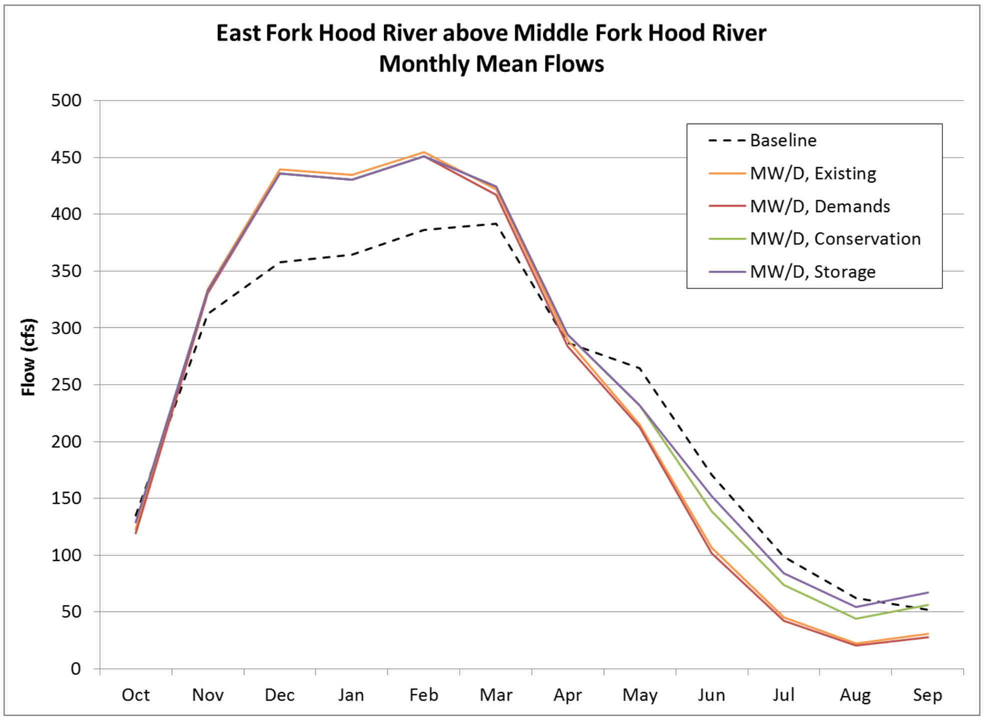


Figure 45 Mean monthly flow on the East Fork Hood River above the Middle Fork Hood River for the MW/D climate change scenarios.

Figure 46 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 alternative implemented, some benefits to the East Fork were projected. The storage facility, while on Neal Creek, increases the flow in East Fork Hood River because the facility reduces the water diversion to the Main Canal during the summer. This results in more flow remaining in the East Fork below the Main Canal.

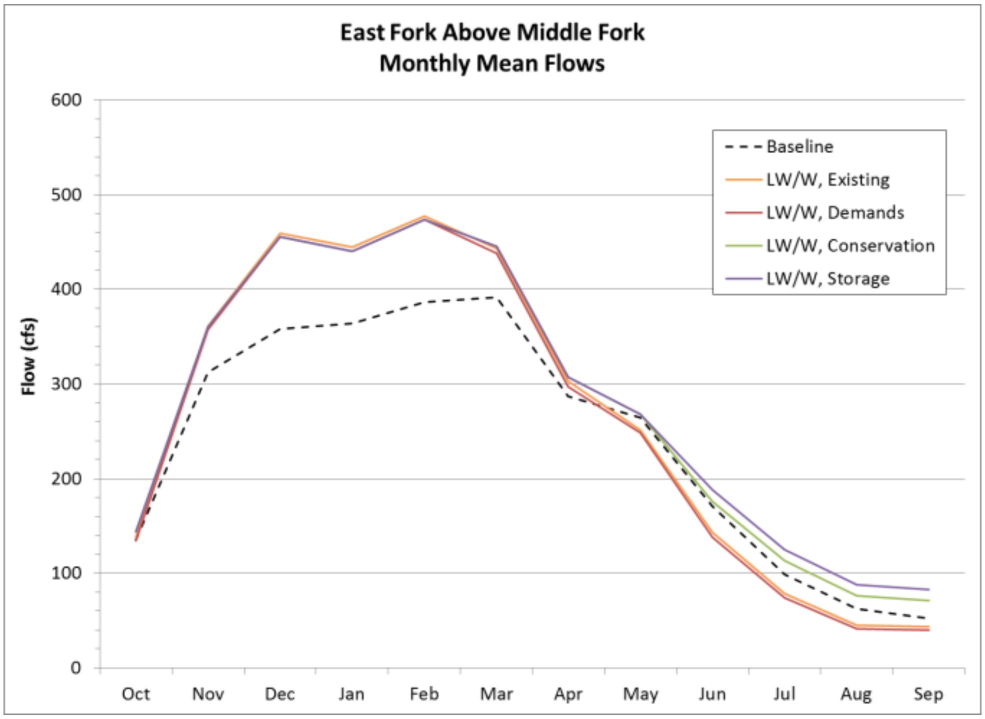


Figure 46 Mean monthly flow on the East Fork Hood River above the Middle Fork Hood River for the LW/W climate change scenarios.

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 where the peak of the flow is 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 47). Implementation of either the conservation or additional storage alternative 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.

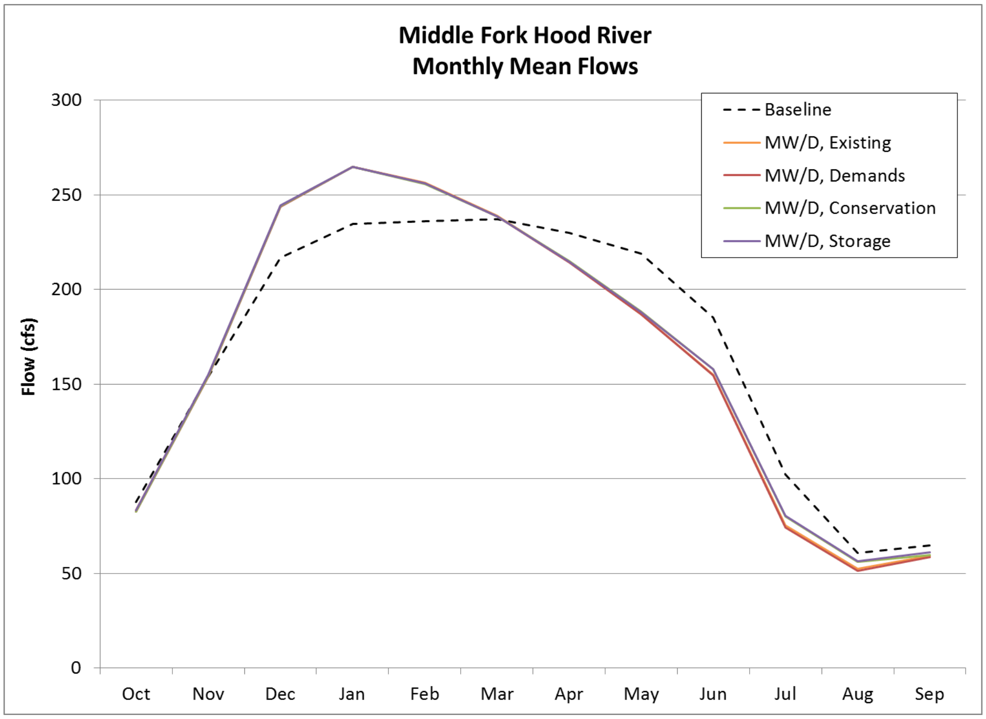


Figure 47 Mean monthly flow on the Middle Fork Hood River for the MW/D climate change scenario.

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 48 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.

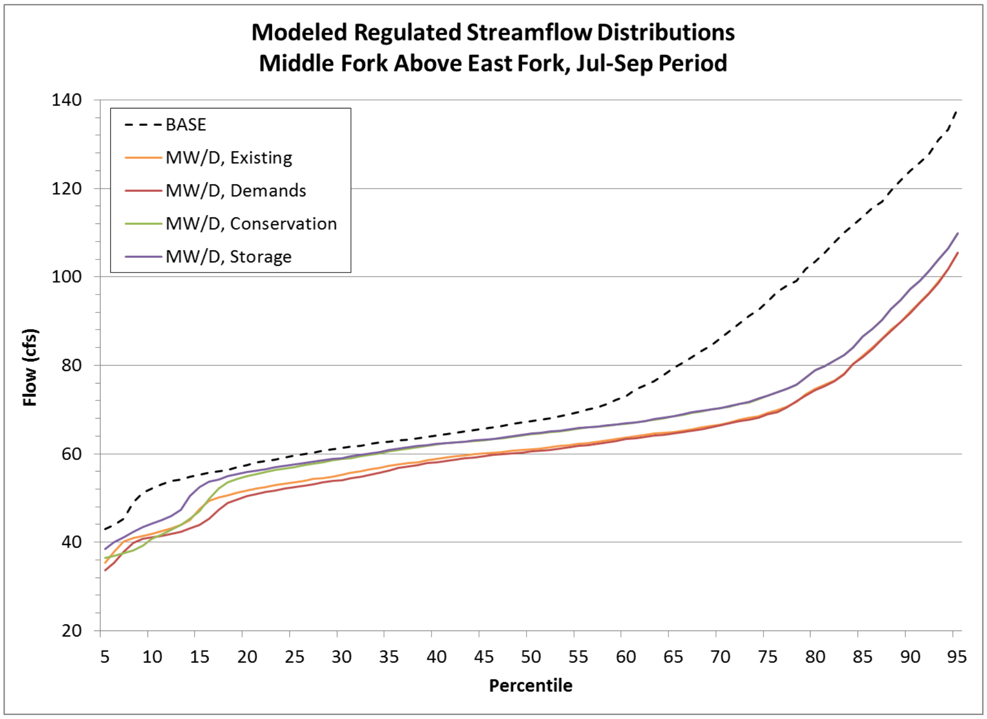
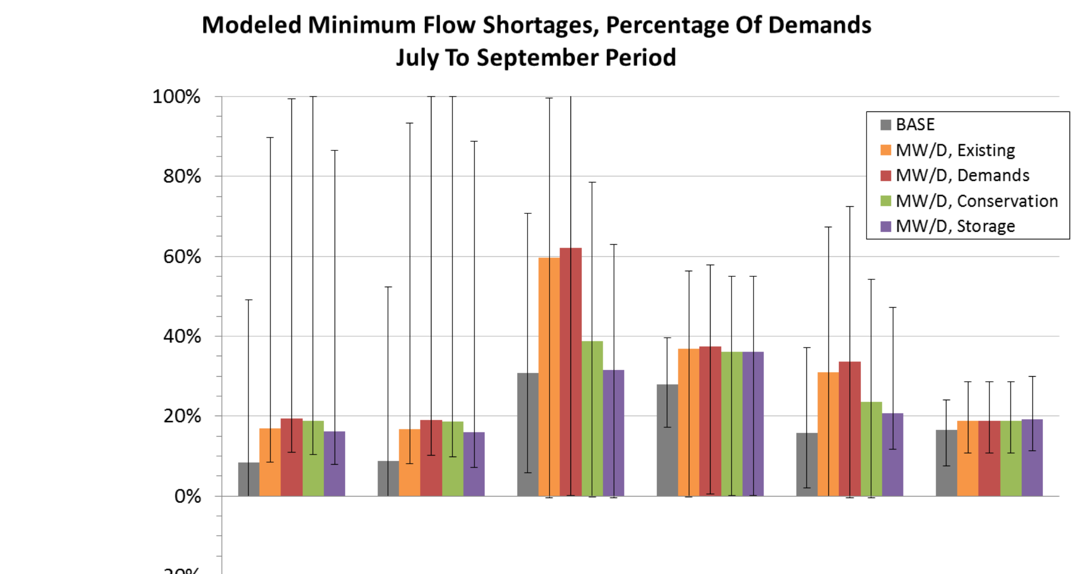


Figure 48 Distribution of mean monthly flow on the Middle Fork Hood River for the MW/D climate change scenario during the summer months.

6.3.2 Minimum Instream Flows Evaluation

The evaluation of climate change impacts on minimum instream flow requirements was conducted at several locations in the basin, including Clear Branch and Coe Creek 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 49 shows the average changes in minimum flow shortages during the summer at Clear Branch, Coe Creek, East Fork Hood River, West Fork Hood River, Hood River, and Neal Creek for the increased demands scenario and the conservation and storage alternatives in the MW/D climate change scenario during July, August, and September. Error bars represent the 10th and 90th percentiles of simulated values.



	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 49 Average modeled minimum flow shortages as a percentage of average demands from July to September for the MW/D climate change scenario The error bars reflect the 10th and 90th percentile ranges for each result.

Figure 49 shows that Clear Branch and Coe Creek (Middle Fork tributaries) experience shortages 20 percent or less of the time regardless of which simulation was run. 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 (Hood River Water Use Assessment 2014).

On the East Fork Hood River, if an extremely dry climate occurs in the future under existing conditions or under the increased demands scenario, minimum instream flow shortages increase to almost 60 percent. However, with the Neal Creek Reservoir alternative implemented (shown as the "Storage" alternative), releases from that proposed reservoir allow an additional 10 cfs to remain in the East Fork during the summer months because that water no longer needs to be diverted through the Main Canal. This results in more than a 20 percent decrease in the projected shortage under existing conditions or increased demands scenarios.

On the West Fork Hood River, increases in minimum instream shortages were projected to increase approximately 9 percent above base (historical) conditions. Implementing the conservation or storage alternative shows generally negligible results.

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.

6.3.3 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. 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.

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7.0 CONCLUSIONS AND SUGGESTED ACTIONS

Of the three storage alternatives, two appear to have more local acceptance and support than the others: Laurance Lake dam raise and Upper Green Point Reservoir dam raise. There is also broad acceptance and support for water conservation alternatives (conversion of sprinkler systems to micro- or drip-irrigation and canal piping). Recharge, either for flow augmentation or for additional storage, would require additional analyses and significant improvements on data collection activities in the basin.

The highest overall costs are for new surface water storage development. The highest estimate was for the proposed Neal Creek facility. The total capital cost assuming fill material was onsite was $13,213,500 or $6,653 per acre-foot of storage. If fill material is obtained offsite, capital costs were estimated at $27,872,500 or over $14,000 per acre-foot of storage. The lowest capital costs are associated with storage increase at Laurance Lake. Total capital costs were estimated at $328,000 or $886 per acre-foot of storage. Annual operation and maintenance costs were also estimated at roughly $5,000 per year. Finally, the dam raise and embankment retrofit at the Upper Green Point Reservoir was also estimated assuming material onsite and material offsite. Costs were $1,272,000 and $2,347,500 respectively. Cost per acre-foot was $2,267 if material was onsite and $4,184 if it was offsite.

Potable and irrigation water conservation costs varied. Minimal reductions in water use can be achieved through installation of high efficiency flow fixtures and reduction in outdoor water use. More significant reductions in water use can be obtained by transitioning from water sprinklers to micro- or drip-irrigation, piping, or other water delivery changes. With the exception of EFID, there are minimal water conservation benefits to converting open channel to a piped system. However, EFID could reduce per acre use by 21.50 cfs, but at a cost of $16,108,000. These costs include piping the remaining 22 miles of the EFID system. DID and MHID could achieve minor reductions of 2.5 cfs per acre combined at costs of $1,436,000 and $134,426, respectively.

Water conservation through conversion of sprinklers to micro- or drip-irrigation systems does have significant promise, but at a cost. Reductions in water use range between 155 per year per acre foot for DID to 2,297 per year per acre foot for EFID. However, the cost is expensive for the districts varying between $217,200 and $634,385 for DID and FID, respectively. For EFID, an estimated $2,950,312 (assuming $195,000 for a settling basin) would be needed to convert to a more efficient irrigation system. For MHID, costs were estimated at $2,515,200.

The surface storage alternative with the fewest environmental impacts would be either dam raise alternative, although the Laurance Lake dam raise may have a greater effect on ESA species. The Neal Creek facility shows the most potential for improving water supply on the

East Fork Hood River, but comes with the highest potential for environmental impacts. This proposed facility reduces the volume of water that has to be diverted off the East Fork to the Main Canal to irrigate the EFID and MHID. As a result, more water remains in the East Fork Hood River during summer-time when critical flows are needed the most. While the other storage facilities offer potential as well, the Upper Green Point Reservoir system is emptied each year and there are limitations on how the water from the facility can be used. Laurance Lake provides some potential as well, particularly during the January through June refill period.

Of the two groundwater alternatives, groundwater storage showed the greatest benefit around Middle Mountain in which almost half of the water injected into the model was still available during the spring and summer. Flow augmentation had minimal benefit given that most of the water returned to the stream too quickly to benefit the summer low flow period.

Table 16. Summary Trade-Off Analysis table of all alternatives evaluated in this Basin Study and others being considered by Hood River County outside of this effort.

Alternative	Alternative Description	Benefit (in general and to water budget)	Applicable Irrigation District	Environmental Impact	County and Stakeholder Response	Cost
Conservation	***Implement irrigation efficiency upgrades (convert sprinkler to micro-sprinkler)***					
		Reduction of 13.1 % of on-farm use for 1,800 acre-feet/year	MFID	Positive benefit to streamflow	Generally supported	$2,515,200
		Reduction of 12.0 % of on-farm use for 2,297 acre-feet/year	EFID	Positive benefit to streamflow	Generally supported	$2,950,312
		Reduction of 9.5 % of on-farm use for 155 acre-feet/year	DID	Positive benefit to streamflow	Generally supported	$217,200
		Reduction of 6.7 % of on-farm use for 163 acre-feet/year	MHID	Positive benefit to streamflow	Generally supported	$227,506
		Reduction of 3.5 % of on-farm use for 401 acre-feet/year	FID	Positive benefit to streamflow	Generally supported	$634,385

Alternative	Alternative Description	Benefit (in general and to water budget)	Applicable Irrigation District	Environmental Impact	County and Stakeholder Response	Cost
Conservation	***Reduce or eliminate overflows and canal seepage***					
		Limited/no potential available.	MFID	Minimal	Generally supported	$0
		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.	EFID	Positive benefit to streamflow	Generally supported	$16,108,000
		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.	DID	Positive benefit to streamflow	Generally supported	$1,436,000
		Eliminates 50 percent of overflow where MHID receives water from EFID.	MHID	Positive benefit to streamflow	Generally supported	$134,426
		Limited/no potential available.	FID	Minimal	Generally supported	$0

Alternative	Alternative Description	Benefit (in general and to water budget)	Applicable Irrigation District	Environmental Impact	County and Stakeholder Response	Cost
Storage	***Expand Storage in Laurance Lake***					
		Add weir to dam resulting in a 3 feet raise in pool during the spring for a total of 370 acre-feet	MFID	Likely positive (increases summer streamflow). Should not affect wetlands; ESA habitat may be affected (including northern spotted owl); IFIM results show no negative impact to fisheries from increased winter and spring fill rates	Generally supported	$328,000 or 886/ac-foot with O&M at $5,000 per year

Alternative	Alternative Description	Benefit (in general and to water budget)	Applicable Irrigation District	Environmental Impact	County and Stakeholder Response	Cost
Storage	***Collect data to analyze EFID potential reservoir (Neal Creek)***					
		Determine potential benefit of new facility on Neal Creek for a total of 2,557 acre-feet	EFID	Likely positive to streamflow; Decreases Neal Creek winter flow; increases East Fork summer stream flow; Significant environmental; Need to gather more information and better understand potential impacts	Not supported at this time.	Between $13.2 and $27.9 million or $6,653 to $14,000 per acre-foot

Alternative	Alternative Description	Benefit (in general and to water budget)	Applicable Irrigation District	Environmental Impact	County and Stakeholder Response	Cost
Storage	***Expand Storage in Upper Green Point Reservoir System***					
		Raise dam by 8 feet (plus freeboard) for a total of 561 acre-feet	FID	May affect wetlands; ESA habitat may be affected (including northern spotted owl)	Not supported at this time. Shortages are generally not experienced at this time.	Between $1.3 and $2.3 million or $2,267 to $4,184 per acre-foot
Groundwater	***Aquifer injection for groundwater storage***	Potential benefit near Middle Mountain.	EFID	More information is needed.	More information is needed.	Unknown
	Aquifer injection for streamflow augmentation	Generally no benefit at the evaluated sites because water returns too quickly to the stream.	Varies	More information is needed.	More information is needed.	Unknown

While each of the alternatives has the potential to decrease the gap between demand and supply for water in the Hood River basin, no single alternative will satisfy all of the water resource needs. The degree of complexity varies among the alternatives as does the obstacles that exist for implementation. Permitting, planning, and design may be simple for sprinkler conversion efforts or improvements to water delivery mechanisms while a new storage alternative may be considerably more complex and take more time and effort. Public acceptability, funding, legal ramifications, and regulatory compliance issues would need to be resolved before moving any of these alternatives toward implementation.

7.1 Suggested Actions

Summer is a critical period identified as a limiting factor for the fisheries in terms of insufficient streamflow. Because the Hood River basin is snowmelt dominated and expected to have significantly lower summer streamflow in the future, staffing and funding resources could be allocated towards adapting and mitigating for future climate change impacts. Agriculture is the largest user of water in the summer period; therefore, staffing and funding resources could be allocated to water conservation upgrades, operational efficiencies, and potentially a new or expanded storage site. Potable water conservation could be implemented where possible, especially where it helps a water district meet its reliability goals. However, potable water conservation could not be used as a primary tool to increase summer streamflows. Additionally, because irrigation water rights are typically senior to instream rights and the actions above are primarily aimed at increasing instream flow, further evaluation of optimal instream flows could be conducted. Based on the analyses in this Basin Study Report, specific actions that could be implemented or evaluated further include:

- Implement irrigation efficiency upgrades. Any conversion of impact sprinklers to micro-irrigation will increase summer streamflow in Hood River. An estimate of effectiveness is that converting 49 percent of existing impact sprinklers to micro sprinklers could increase streamflow (varies by irrigation district). Additional analysis could be conducted to evaluate which stream reaches could benefit most from increased streamflow and then target sprinkler conversion in those areas.

- Reduce or eliminate overflows and canal seepage in EFID. EFID has 60 overflow points and 20 miles of open canal that lose water to seepage. Overflow rates, locations, and potential approaches to resolving overflows varies throughout EFID so loss measurements should be performed throughout the district to quantify where and at what rate water is exiting the system. It is estimated that during irrigation season EFID loses 21.5 cfs to overflows and seepage, and during spring herbicide spray season, this loss is roughly 50 percent greater. Eliminating these losses through piping, which may address some overflows as well, could be one of the highest priorities in the basin.

- Expand existing storage at Laurance Lake. Expanding this storage site increases both water resource reliability and summer instream flow. Although this would need to be evaluated further before being implemented, this Basin Study combined with the IFIM Study conducted shows no negative impact to fisheries from the increased winter and spring fill needs.

- Collect data that can be used in a future analysis of reservoir storage in EFID. Due to the significant cost and EFID Optimization Plan that will be conducted over the next few years, it is not suggested to pursue the EFID storage site on the West Fork of Neal Creek at this time. However, it is possible that at some point in the future this site could be beneficial to instream flow and irrigation supply; therefore, steps should be taken now that could make evaluating this possible. The two highest priority items are to install continuous streamflow gauges on Neal Creek and East Fork Hood River.

- Collect and use additional data in evaluating optimal streamflows for aquatic habitat. The IFIM study conducted was based on the suitability of depth and velocity for certain species and life stages. Although suggestions from this are scientifically sound, further data could be used to evaluate optimal streamflow levels. This could include items such as redd surveys.

- Expand groundwater data collection. The groundwater modeling conducted as part of this study concluded that groundwater cannot be used as a viable source for large scale supply without drawdown of the aquifer and decreased streamflow. However, groundwater modeling was based on a limited number of wells and, as such, this well network could be expanded to facilitate more robust groundwater modeling in the future.

- Implement projects that can increase summer streamflow. Due to the projection that summer streamflows are expected to get lower, a priority could be given to projects in the basin that have the ability to increase summer streamflow. The Hood River Soil and Water Conservation District completed the Hood River Watershed Action Plan (2002) in collaboration with the Hood River Watershed Group. Actions such as connecting the channel to the floodplain and reforestation were being considered and could continue in the basin in the future.

- Refine modeling that was done as part of this Basin Study. The Basin Study consisted of a series of modeling steps, each model with its own simplifications and uncertainties. Although these are inherent in all modeling, due to the appraisal level of this initial Basin Study, additional resources could be spent to refine any one of the models used. This may take the form of any of the following: analyzing additional climate scenarios, adding additional streamflow routing points in the hydrologic model (e.g., for Kingsley Reservoir diversion), analyzing when the increased streamflow due to glacial melt will stop, or modeling additional scenarios or refining operations in the water resource model.

8.0 STUDY LIMITATIONS

This section describes the limitations with the various efforts completed in this Basin Study and identifies several additional actions that could be taken to refine the results presented. 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.

8.1 Climate Change

8.1.1 Global Climate Forcing

This Report summarizes results from the Basin Study in which historical and future climate change 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, but the uncertainties associated with these pathways are not explored in this 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 Coupled Model Inter-comparison Project 5 (CMIP5) set of Global Circultation (Climate) Models (GCMs) runs.

8.1.2 Global Climate Simulation

The activity presented in this Basin Study Report considers climate projections produced by the 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.

8.1.3 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.

8.1.4 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 impact studies (e.g., Van Rheenan et al. 2004; Maurer et al. 2007; Reclamation 2008; Reclamation 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.

8.2 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 updated 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 Mount Hood 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.

8.3 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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