RECLAMATION
Managing Water in the West

Hood River Basin Study:
Water Resource Management Model Technical Memorandum

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

August 2014

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Mission of the Bureau of Reclamation

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

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1.0 INTRODUCTION

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

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

In 2011, Hood River County submitted a proposal to conduct a basin study in the Hood River basin and was awarded funding in 2012. Hood River County and Reclamation will collaborate on addressing four main components, including:

1. Define current and future basin water supply and demands, with consideration of potential climate change impacts.
2. Determine through analysis the potential impacts of climate change on the performance of current water delivery systems (e.g., infrastructure and operations).
3. Develop structural and non-structural options to maintain viable water delivery systems for adequate water supplies in the future.
4. Conduct a tradeoff analysis of the options developed, summarize the findings, and make recommendations on preferred options.

1.1 Purpose and Scope

The purpose of this Technical Memorandum is to document the development and utilization of a water resources management (WRM) model that was constructed to simulate historical and projected future regulated streamflows across the basin, as part of the Hood River Basin Study (Basin Study). For both the simulated historical period (water years 1980 through 2009) and the simulated future period (water years 2030 through 2059), the model accounts for all existing major flow diversions, reservoir operations, and minimum flow requirements. For the simulated future period, the model also simulates the potential impacts of several water resources alternatives, including additional water demands, water conservation practices, and supplemental storage volumes.

Due to a general lack of observed data for constructing and constraining the WRM model, some key simplifications of the Hood River basin's water management features were implemented. Limitations of the WRM model likely arise from these simplifications, and possibly include the inability to completely distinguish the impacts of climate change on modeled reservoir volumes/releases and dependent downstream demands. However, simulated future changes (relative to historical conditions) and general trends are largely consistent with anticipated future impacts, and should be informative for planning purposes.

Results of the model simulations were used to estimate the timing and quantities of water at many locations throughout the Hood River basin to support stream habitat analyses, which are being conducted by Normandau Associates, Incorporated (Normandau 2014). The model results were also used to develop adaptation and mitigation strategies, which are reported in the Basin Study Report.

1.2 Hood River Basin Description

The Hood River basin is located in northwestern Oregon, is approximately 480 square miles, and drains predominantly northwards directly into the Columbia River (Figure 1). There are three primary forks to the mainstem Hood River: the West Fork Hood River, the Middle Fork Hood River, and the East Fork Hood River (Figure 1). The West Fork Hood River subbasin accounts for 30 percent of the total basin area. The Middle Fork and East Fork combine to form the East Fork Hood River subbasin, which accounts for approximately 45 percent of the total basin area. As shown in Figure 2, the headwaters of this subbasin are fed in part by the glaciers along the northern and eastern sides of Mount Hood. The remaining subbasin is located downstream of the confluences of the three forks, and accounts for 25 percent of the total basin area.

Water management in the Hood River basin has many components, some of which are illustrated in Figure 2. As shown, there are five irrigation districts that, cumulatively, draw water from all three forks, as well as the mainstem Hood River and its lower tributaries (WPN 2013a). The largest diversion in the basin is the Main Canal (Figure 1), which diverts water from the East Fork Hood River and serves both the East Fork Irrigation District (EFID) and the Mount Hood Irrigation District (MHID). Although not shown in Figure 2, there are also six potable water districts that provide water for domestic uses to several municipalities within and near the basin (WPN 2013a). Each water district is responsible for delivering water to and keeping account of water used within its boundaries.

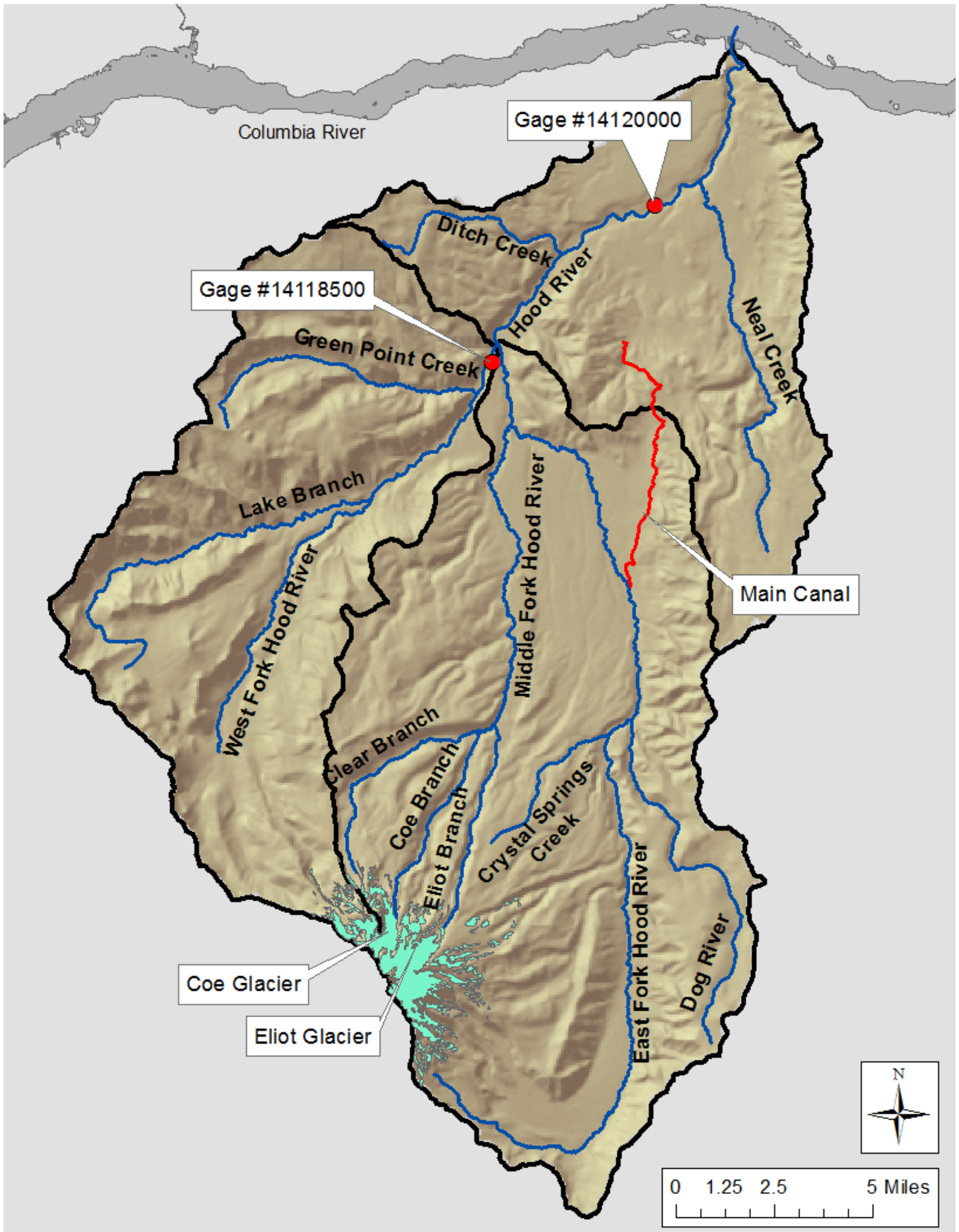

Figure 1. Shaded relief map of the Hood River basin, with some key features notated.

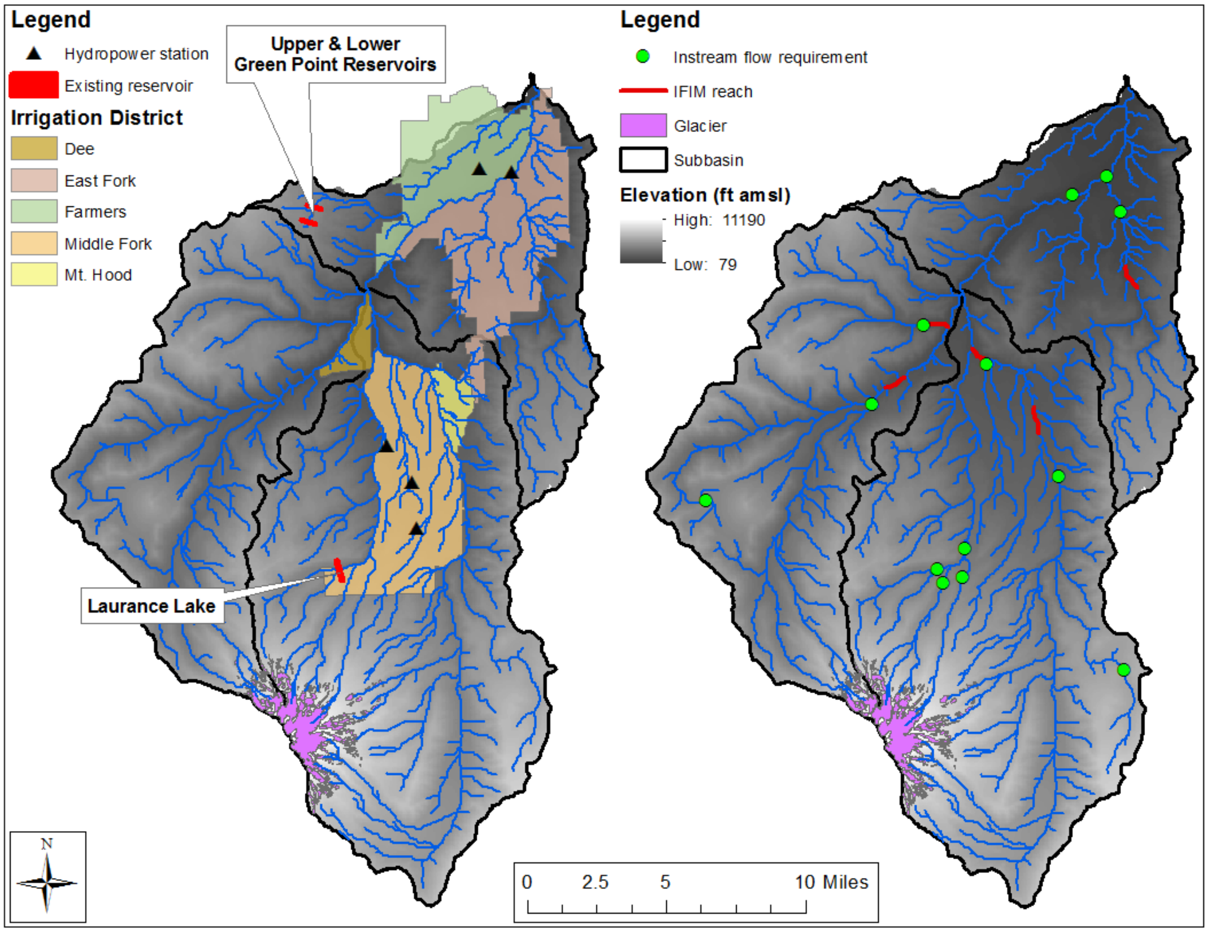

Figure 2. Modeled stream network and water management features of the Hood River basin.

There are two primary reservoir systems in the Hood River basin: Laurance Lake located on Clear Branch (which drains into the Middle Fork Hood River), and Upper and Lower Green Point Reservoirs on Ditch Creek (which are partially fed by water diverted from the neighboring West Fork Hood River subbasin) which drains to the mainstem Hood River. In addition to supporting agriculture, instream flows, and recreation, Laurence Lake helps supply the basin's 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 plants 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.

The State of Oregon abides by the principal of prior appropriation to govern the use of both surface and subsurface waters. In contrast to the riparian doctrine adopted by most states in the eastern U.S. where landowners have inherent rights to water flowing through their property, prior appropriation allows for public ownership of water (OWRD 2014a). In general, individuals, farms, businesses, and municipalities in Oregon are not automatically granted the right to use water without first obtaining a permit through the Oregon Water Resources Department (OWRD 2014a). The granted permit, or water right, specifies how much water can be used and for what purpose(s); where and when water can be obtained and delivered; and the priority date of the right, which is usually the date when the application for permit is filed (OWRD 2014a). Under prior appropriation, water right holders with the most senior rights (i.e., those with the oldest priority dates) are the first to be provided with water during water scarce periods, regardless of their physical location in the hydrologic system. For example, upstream users with more junior rights may have to allow water to pass downstream to more senior users.

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2.0 MODEL DESCRIPTION

Reclamation collaborated with Watershed Professionals Network (WPN) to characterize and simulate water management throughout the Hood River basin using MODSIM-DSS software (MODSIM), a network flow modeling platform and river basin management decision support system developed by Colorado State University. The MODSIM-based water resources management (WRM) model was constructed with representations of the basin's detailed stream network and all major water management features and activities (see Section 1.2). Additionally, the WRM model handles water rights accounting, via the robust MODSIM solver, to optimally distribute water across the Hood River basin based on priority dates. The WRM model was configured for and runs on a daily time step.

2.1 Input Data

Discussed in the *Surface Water Modeling Technical Memorandum* (Reclamation 2014a), the physically-based surface water model was used to generate the natural streamflows for input to the WRM model. The *Hood River Basin Water Use Assessment* (WPN 2013a) was referenced for average diversion amounts, reservoir characteristics and typical operations, average hydropower demands, minimum flow requirements, and water rights quantities and priorities. Additionally, project partners and stakeholders were consulted with on several occasions to ensure model features reasonably represent on-the-ground water management facilities and activities. Descriptions of the input data for the WRM model are provided in the sections that follow.

2.1.1 Streamflows

There are three types of streamflow data inputs to the WRM model: inflows, gains, and losses. Inflows correspond to natural streamflows along headwater reaches, which are those located upstream of all water management facilities and activities. Inflow data was imported to the WRM model directly from the surface water model. Gains and losses correspond to local contributions to natural streamflows along incremental reaches, which are those located downstream of one or more water uses. Gains are positive contributions to streamflows, and losses are negative contributions. Gains and losses were calculated by comparing the natural streamflows at upstream and downstream surface water model flow locations. Refer to the *Surface Water Modeling Technical Memorandum* (Reclamation 2014a) for a list and descriptions of the locations selected for surface water model streamflow locations.

Table 1 lists all of the streamflow data inputs to the WRM model. As shown, every inflow has an "in" prefix succeeded by a location-specific descriptive name. Gains and losses are preceded by "gain" and "loss", respectively. The names of gains and losses are less descriptive than inflows, but still indicate the relevant stream reach and the relative location along each reach. For example, *gainMFa* and *gainMFc* are the furthest upstream and downstream gains, respectively, along the Middle Fork Hood River.

Table 1. Streamflow data input nodes in the WRM model.

Inflows		Gains		Losses
inClearBrAtLaurance		gainDitch		lossDitch
inCoeCkAbvMouth		gainDog		lossDog
inColdSpringCkAtMouth		gainEFa		lossEFa
inDeadPtCkAtMouth		gainEFb		lossEFb
inDogRvAbvPuppy		gainEFc		lossEFc
inEliotBrAbvMouth		gainEFd		lossEFd
inEmilCkAtMouth		gainEFe		lossEFe
inEvansCkAbvGriswell		gainEFf		lossEFf
inGreenPtUppRes		gainGPres		lossGPres
inGriswellCkAtMouth		gainGreen		lossGreen
inIndianCkAbvMouth		gainHooda		lossHooda
inLakeBrBlwLost		gainHoodb		lossHoodb
inNealCkAbvWFNeal		gainHoodc		lossHoodc
inNGreenPtCkAtStanley		gainLB		lossLB
inOdellCkAtMouth		gainMFa		lossMFa
inPineCkAtMouth		gainMFb		lossMFb
inRogersCkAtMouth		gainMFc		lossMFc
inTonyCkAbvMouth		gainNeal		lossNeal
inTroutCkAtMouth		gainWFa		lossWFa
inWestFkAbvLakeBr		gainWFb		lossWFb
inWFNealCkAbvLateral				
inWisehartCkAtMouth				

In the WRM model, losses primarily arise from the absence of streamflow routing estimation routines in the model structure. The MODSIM platform is capable of modeling streamflow routing; however, due to time constraints and a lack of observed data, this was not pursued for the WRM model. In reality, the travel time of water between two locations is dependent upon many physical factors, including the travel distance, slope, and channel roughness (Dingman 2002). The surface water model incorporates linear reservoir routing, a simplified representation of streamflow routing, to estimate the travel times of water throughout the stream network (Wigmosta et al. 2002). Thus, whereas the surface water model streamflows account for time lags between upstream and downstream locations, the WRM model assumes that the travel time of water between any two points, regardless of the distance or flow path between them, is equal to the model time step of one day. Thus, the WRM model uses losses as accounting tools to ensure that a basin-wide water balance is met at every time step. Future efforts could investigate implementing streamflow routing in the WRM model. Doing so could provide insight into physical losses across the stream network (i.e., losing reaches, where streamflows seep into the ground). In the current state of the WRM model, any physical losses are confounded by the manner in which the model calculates the incremental streamflows.

Figure 3 illustrates the WRM model streamflow input scheme for Neal Creek. The two inflow data points, *inNealCkAbvWFNeal* and *inWFNealCkAbvLateral*, represent the headwaters of Neal Creek. The *gainNeal* and *lossNeal* inputs account for the incremental flow between the confluence of the headwaters and the mouth of Neal Creek, *NealCkAtMouth*. All nodes labeled with an abbreviated but descriptive name represent locations where natural flows are available from the surface water model. Other nodes, such as *Neal1*, simply account for WRM model structure, such as confluences. The *minNeal* and *minHood2* nodes correspond to minimum flow requirements, which are discussed in Section 2.1.3.

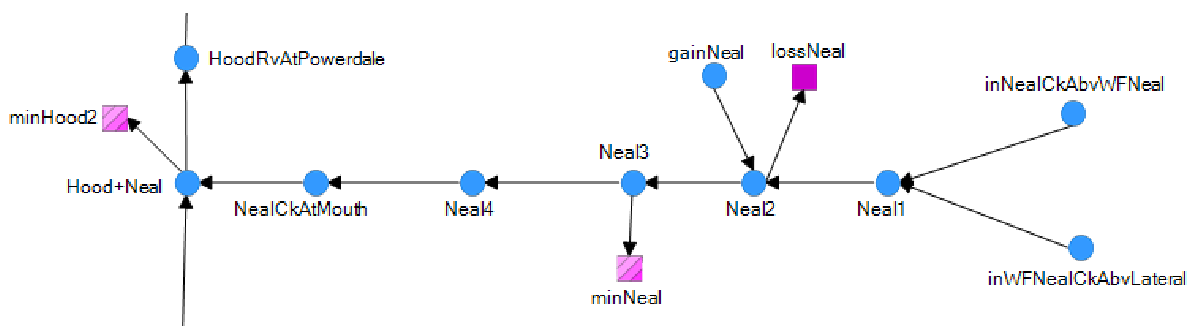


Figure 3. Model representation of Neal Creek.

Streamflow input data for two locations in the Hood River basin were adjusted to match historical observations. The headwaters of the East Fork Hood River (i.e., the *gainEFa* node) were reduced during the spring months based on streamflow observations along the East Fork above the Main Canal. Inflows to Laurance Lake (i.e, the *inClearBrAtLaurance* node) were adjusted such that the average timing and shape of the simulated inflow hydrograph matched inflow calculations provided by the MFID. The adjustments, or bias corrections, applied to these two locations are discussed in the context of the historical results presented in Section 3.1.

2.1.2 Consumptive Uses

Consumptive uses of water for agricultural and municipal purposes are modeled as demands where water is diverted from the stream network and not returned, at least not in full. Each consumptive use demand node, which represents the general point of diversion for all associated water rights, is symbolized by a solid purple square named with a "div" prefix. Monthly average reported deliveries to each consumptive use demand, as well as the decreed flow and priority date of each water right contributing to each demand, were obtained from the *Hood River Basin Water Use Assessment* (WPN 2013a), which contains compilations of approximately the last 10 years of water use reports from OWRD for all local water districts in the basin.

With the exception of EFID, on-farm infiltration and canal seepage are generally minimized across the Hood River basin because of the prevalence of efficient sprinkler systems and piped diversions (N. Christensen, personal communication, November 21, 2013), so the majority of water diverted for consumptive uses is assumed to not return to the stream network in the WRM model. The few exceptions to this are locations where irrigation districts have indicated that seepage is known to occur, and have provided estimates of when this occurs and to what extent. EFID's approximately 50 overflow points primarily return to the mainstem Hood River downstream Tucker gauge, which is below the lowest node evaluated in the model. Refer to Appendix A for details on these locations, as well as for a complete list of consumptive uses and associated water rights incorporated into the WRM model.

Figure 4 illustrates the upper West Fork Hood River section of the WRM model. The *divHoodRiver* node represents the potable demands for the Hood River Water District, and the *divDC* node represents the agricultural demands served by the Dee Canal. The double lines linking the DeeCanal node to the *divDC* demand signify that multiple water rights are "calling" for water to satisfy the *divDC* demand. Each water right in the model is tied to its legal priority date. Thus, older (or more senior) water rights have higher priority when the model is run and the solver distributes flow across the entire network.

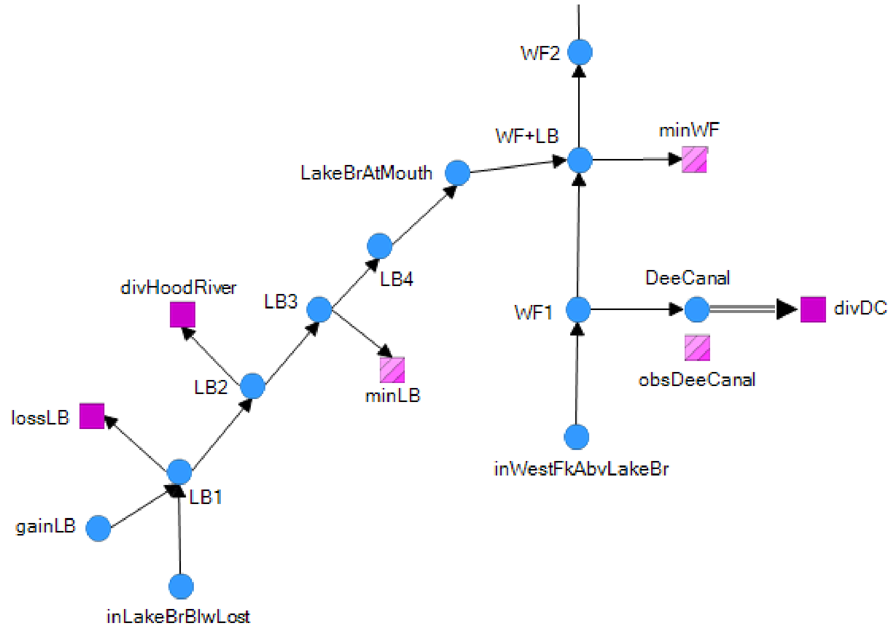


Figure 4. Model representation of Lake Branch and the headwaters of the West Fork Hood River.

2.1.3 Minimum Flows

As mentioned above, and portrayed in Figure 3 and Figure 4, minimum flow requirements (instream flow rights and agreements) are symbolized in the WRM model by hashed purple square nodes named with a "min" prefix. The monthly required flows for each minimum flow requirement, as well as the priority dates of each, were obtained from the *Hood River Basin Water Use Assessment* (WPN 2013a) and OWRD (R. Wood, OWRD Watermaster, personal communication, November 25, 2013).

Minimum flow requirements are represented in the model using flow-through demand nodes, which effectively maintain the demanded flows in the stream channel. Technically, the flow-through demands divert water from the stream channel, but then immediately return the same quantity directly downstream (and upstream of any other diversions). Analogous to the consumptive use demands, each flow-through demand is tied to one or more water rights (each of which is populated with its legal priority date). Therefore, in terms of how the solver distributes water, minimum flow requirements are treated identically to consumptive uses except that all water diverted returns to the stream channel in the same time step (and thus no water is consumed by the diversion). Refer to Appendix A for a complete list of minimum flow requirements, including the associated water rights, incorporated into the WRM model.

2.1.4 Hydropower Demands

Because water is passed through hydropower facilities, rather than consumed, the Hood River basin's hydropower demands are also modeled with flow-through demand nodes. Each hydropower flow-through demand is named with a "to" prefix followed by the managing irrigation district and name of the powerplant. For example, the demand for Powerplant No. 1 in the MFID is named *toMFIDPP1*. 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, were obtained from the Hood River Basin Water Use Assessment (WPN 2013a).

Figure 5 displays the WRM model section corresponding to a portion of FID that encompasses the district's two hydropower facilities, symbolized by red triangles. Powerplant No. 2 is along the Low Line (LL) Pipeline and Powerplant No. 3 is downstream of where Farmers Canal (FC) joins the LL Pipeline. As mentioned above, each powerplant has an associated flow-through demand that specifies the average monthly flows through each. Again, the relevant water rights and priority dates are tied to each flow-through demand, which limit the flow that the powerplants can legally receive. Refer to Appendix A for a complete list of hydropower demands and associated water rights incorporated into the WRM model.

Due to time constraints, and initial technical issues with the MODSIM software, the modeling effort focused on reporting flows and changes in flows through all hydropower plants. MODSIM is capable of translating flow to power generation. However, this requires calibrating each power facility's physical characteristics and efficiencies. Future work could carry this forward, if desired.

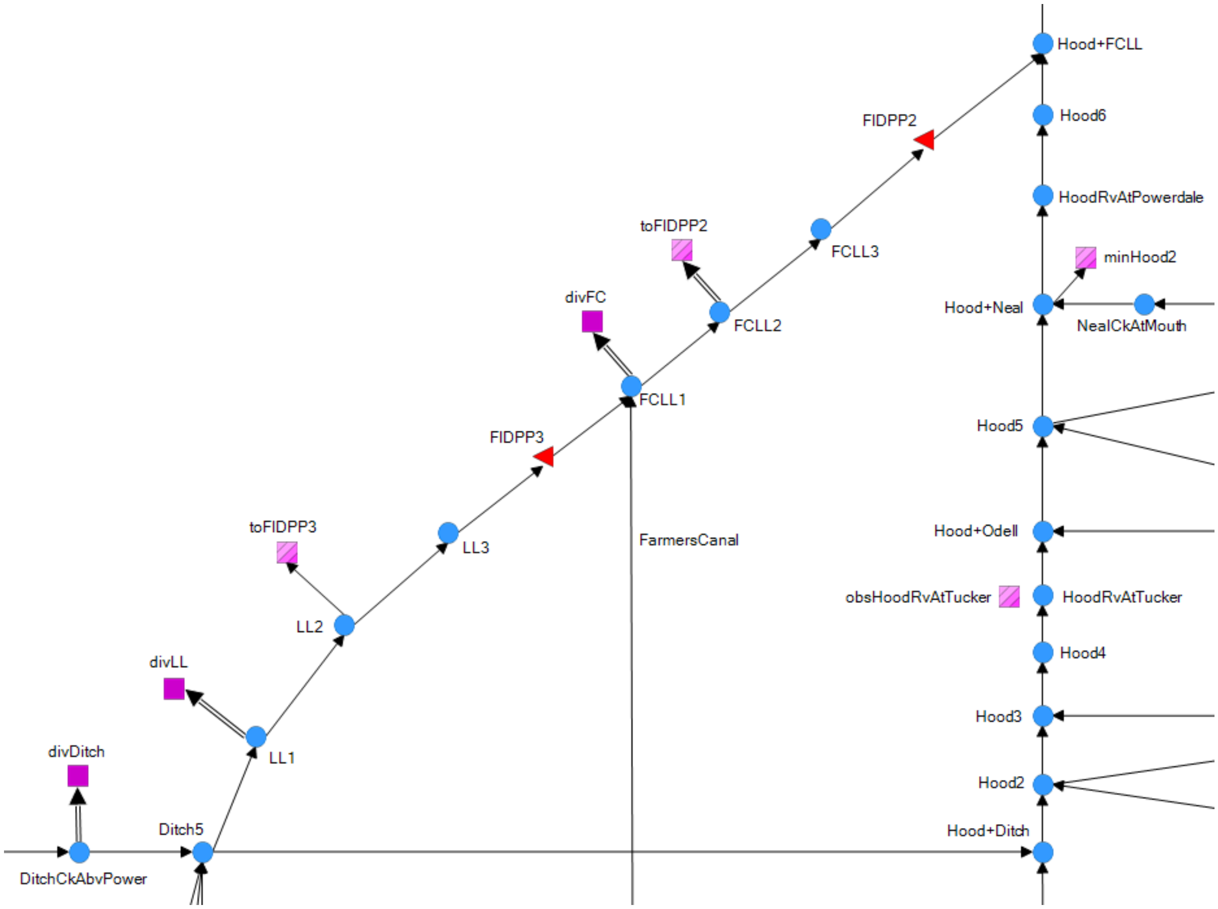


Figure 5. Model representation of the lower portions of FID and the mainstem Hood River.

2.1.5 Storage

In the WRM model, red triangles symbolize both hydropower plants and reservoirs. In contrast to the powerplant nodes; however, the reservoirs nodes in the WRM model are informed with physical/structural characteristics and operational constraints, such as storage capacities and targets. The modeled reservoirs also incorporate legal storage rights, which compete for water in the same manner as all other water rights in the Hood River basin (i.e., based on priority dates). Flows into a reservoir can only be stored if there is physical space available (i.e., the reservoir is not full), the storage right is in priority (i.e., storing does not conflict with the demands of more senior downstream users), and there is accrual storage available (i.e., the annual volume of the storage right has not been reached). Reservoir characteristics and associated storage rights were obtained from the *Hood River Basin Water Use Assessment* (WPN 2013a). Refer to Appendix A for a list of reservoir characteristics and associated storage rights incorporated into the WRM model.

Due to a general lack of long-term observed data and fixed operating rule curves for the reservoir system, some key simplifications for constructing and constraining the WRM model were implemented. Limitations of the WRM model likely arise from these simplifications, and possibly include the inability to completely distinguish the impacts of climate change on modeled reservoir volumes/releases and dependent downstream demands. However, as will be discussed in Section 4.0, simulated future changes (relative to historical conditions) and general trends are largely consistent with anticipated future impacts, and should be informative for planning purposes.

Upper and Lower Green Point Reservoirs were combined into a single reservoir (Green Point Reservoir system), with a total storage capacity equal to the sum of the capacities of the two physical reservoirs (938 acre-feet). Additionally, whereas in traditional water resources management models (based on much more robust records of observed data) where reservoir releases are determined by downstream demands (primarily), the releases from the Green Point Reservoir system and Laurance Lake were explicitly specified in the WRM model as demands. A 100 percent of the demanded flows directly downstream of the reservoirs in the WRM model (note that the flows are actually piped). Lastly, the modeled storage right accrual volumes (Appendix A) were increased above the physical capacities of the Green Point Reservoir system and Laurance Lake to account for the apparent lack of separation of storage right releases and reservoir bypass releases in the average monthly reservoir release numbers reported in the OWRD water use reports summarized in the *Hood River Basin Water Use Assessment* (WPN 2013a).

For the Green Point Reservoir system, the release demand (5 cubic feet per second [cfs]) was determined by iteratively comparing average monthly simulated storage volumes to observed (2005 through 2009) volumes (WPN 2013a). The model was configured to restrict the reservoir system to fill during March through June and to release for irrigation during June through September, which are the general operating criteria provided by FID (J. Camarata, FID manager, personal communication, February 11, 2014). Flows for downstream hydropower demands are passed through the reservoir system in other months. For Laurance Lake, the release demand was populated with observed (2008 through 2012) average monthly reservoir release rates (WPN 2013a). No seasonal restrictions in storing inflow were specified for Laurance Lake.

Figure 6 displays the model section corresponding to the portion of FID just upstream of that displayed in Figure 5. As shown, water is diverted from the headwaters of Green Point Creek through the Stanley-Smith Pipeline to feed the *GPres* node, which represents Upper and Lower Green Point Reservoirs combined. There are two additional sources of flow to *GPres*: *inGreenPtUppRes,* which represents the inflows to the physical Upper Green Point Reservoir, and *gainGPres,* which represents the local contributions to flows between the physical reservoirs. The structure of the links to, from, and seemingly bypassing *GPres* may seem counterintuitive; however, the WRM model directs all flows through the modeled reservoir. The bypass link going from nodes *GPres2* to *Ditch1* simply represents the portion of flow that is effectively passed through the reservoir without contributing to a storage right. The *outGPres* demand is populated with simulated combined average releases from Upper and Lower Green Point Reservoirs for irrigation, along with the same priority date as that assigned to the storage right.

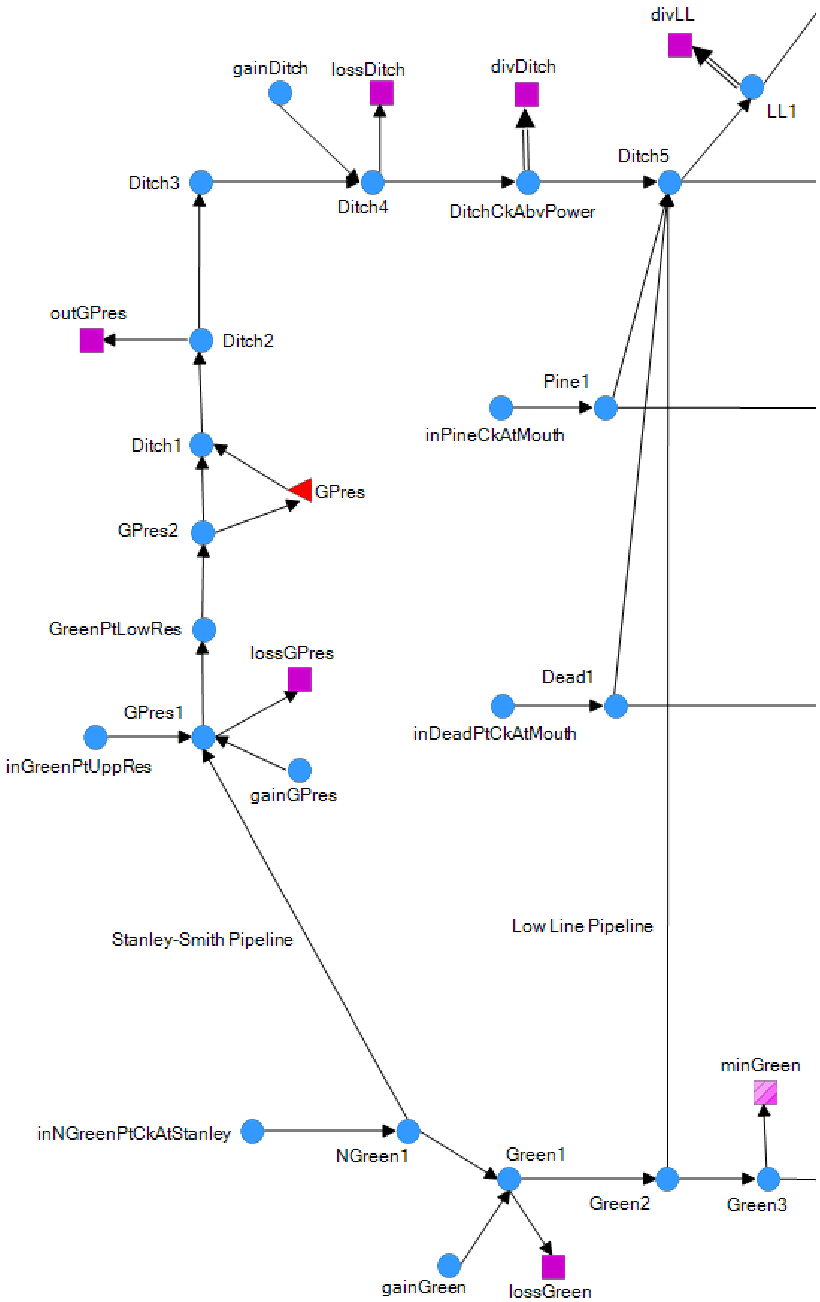


Figure 6. Model representation of the upper portion of FID.

2.1.6 Other Data

The WRM model is structured so that average historical demands, along with corresponding legal water right constraints, drive water allocation across the Hood River basin. Historical observations of flow are incorporated into the model to enable comparisons between simulated and observed flow through various “links”, which represent stream reaches and canals. Historical observations data were obtained from the U.S. Geological Survey (USGS) surface water data portal (USGS 2014) and OWRD historical streamflow data portal (OWRD 2014b). Refer to Appendix A for a complete list of historical observation data locations incorporated into the WRM model.

Each observation data point is represented with a flow-through demand node named with an “obs” prefix. The observation flow-through demands are not linked to the rest of the WRM model network to prevent the simulations from being inappropriately guided by observations, which would hinder confidence in future period simulations where observations are not available. For example, the *obsDeeCanal* node in Figure 4 represents historically observed flows through the Dee Canal. It is not linked to other nodes so as to prevent the model from forcing the observed values to flow through the modeled Dee Canal.

3.0 HISTORICAL RESULTS

The performance of the WRM model was gauged by Reclamation and WPN according to how well the simulated historical (water years 1980 through 2009) results aligned with observed (including calculated or estimated, and anecdotal) information for the key features, or metrics, listed in Table 2.

Table 2. Metrics for the WRM model.

Metric	Observed Standards	Source(s)
Streamflows	Daily stream gage data	USGS 2014, OWRD 2014b
Consumptive uses	Average annual and monthly delivered volumes by water district	OWRD 2014b, WPN 2013a
Minimum flows	Monthly minimum flow requirements	OWRD 2014b, WPN 2013a
Hydropower demands	Average annual and monthly delivered volumes through powerplants	WPN 2013a
Storage	Average monthly reservoir volumes	WPN 2013a, MFID*, FID*

*Indicates calculated, estimated, or anecdotal information

To ensure that model inputs and outputs were representative of historical conditions, many quality control checks of the modeled water management features and input data were performed by Reclamation and WPN. For the WRM model, it was critical to distinguish whether differences between simulated and observed data were the result of misrepresented water use(s), inaccurate inflows and/or gains and losses, or simply variability in human behavior that cannot be simulated. On several occasions, Reclamation and WPN coordinated with local irrigation district managers, OWRD personnel, and project stakeholders to validate modeled water management features, and to obtain additional data to support maintaining or changing model representations. Summaries of the agreements between simulated historical and observed metrics are provided in the sections that follow.

3.1 Streamflows

Two stream gage locations (Figure 1) were identified with sufficient observed data to measure the performance of streamflow simulations throughout the historical period: Hood River at Tucker Bridge (#14120000), and West Fork Hood River near Dee (#14118500). Figure 7 illustrates the simulated historical and observed streamflows through the mainstem Hood River at Tucker Bridge for water years 2000 to 2009 (the first 20 years of the historical period are excluded for clarity). The WRM model appears to capture the observed timing and quantity of runoff relatively well, considering the multitude of upstream water uses that affect the simulated streamflow at this location. However, a low bias during the late summer is slightly apparent from the plots.

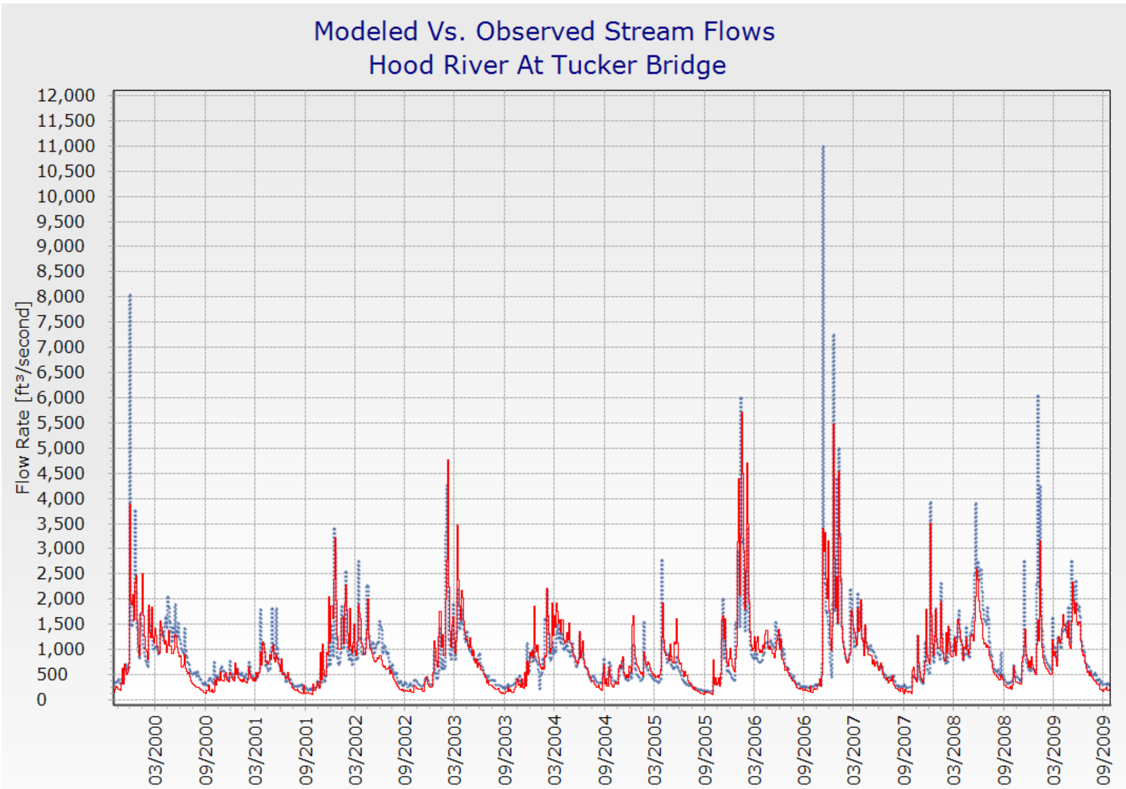


Figure 7. Daily hydrographs of modeled (red solid line) and observed (blue dashed line) streamflows for the Hood River at Tucker Bridge for water years 2000 through 2009.

A statistical treatment of the model calibration is provided in Figure 8, which displays the percentile distributions of simulated historical and observed flows for the entire historical period (water years 1980 through 2009). For streamflow values greater than the median (50th percentile), the WRM model over-estimates the observed flows by approximately 5 percent, and throughout the lower quartile (below the 25th percentile), the WRM model under-simulates the observed flows by approximately 20 percent or 50 cfs. This is likely the result of a combination of factors, including errors in modeled upstream water management activities and limitations of the surface water model used to provide natural flows to the WRM model.

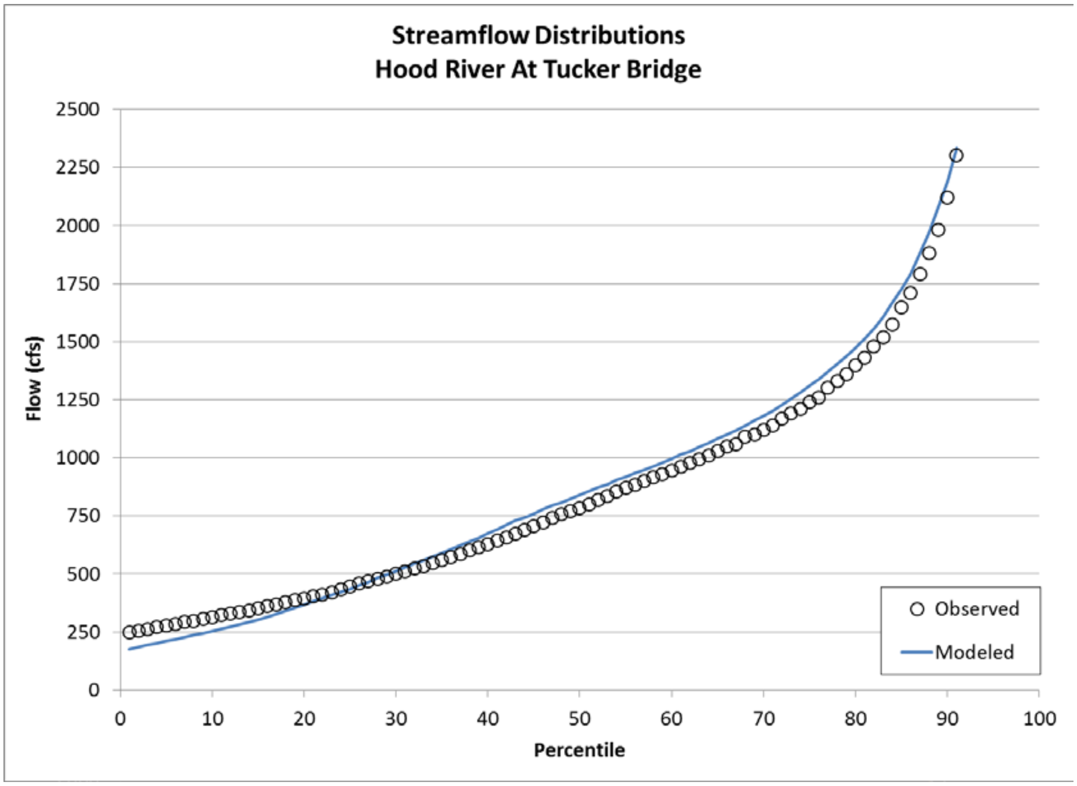


Figure 8. Statistical comparison of simulated historical and observed streamflows for the Hood River at Tucker Bridge.

The surface water model is not equipped with a physical groundwater modeling component, but the lower Hood River basin does interact with the aquifer system that underlies it (Reclamation 2014b). As mentioned in the *Surface Water Modeling Technical Memorandum* (Reclamation 2014a), the simulated natural streamflows are, on average, approximately 100 cfs lower than the naturalized observed streamflows along the mainstem Hood River at Tucker Bridge during the summer months. The less dramatic under-simulations of the WRM model (50 cfs), which more accurately accounts for upstream water usage than the naturalized flow calculations, suggest that some of the surface water model's low bias could be related to errors in the naturalized flow estimates. However, the results of both the surface water and WRM models suggest that contributions to the mainstem Hood River from stream-aquifer interactions may not be accurately accounted for.

Figure 9 and Figure 10 illustrate results analogous to those described above for the West Fork Hood River. Although the highest observed peaks are again under-simulated (which is a function of the surface water model), the simulated low flows align well with the corresponding observed values. In contrast to the Hood River at Tucker Bridge stream gage, relatively little water management activities occur upstream of the calibration point along the West Fork Hood River (and all are included in the WRM model). Thus, the potential for cumulative model differences between simulated and observed streamflows is much lower at this location. The strong agreements in Figure 9 and Figure 10 also suggest that groundwater contributions to streamflows are likely smaller along the West Fork Hood River than along the mainstem Hood River.

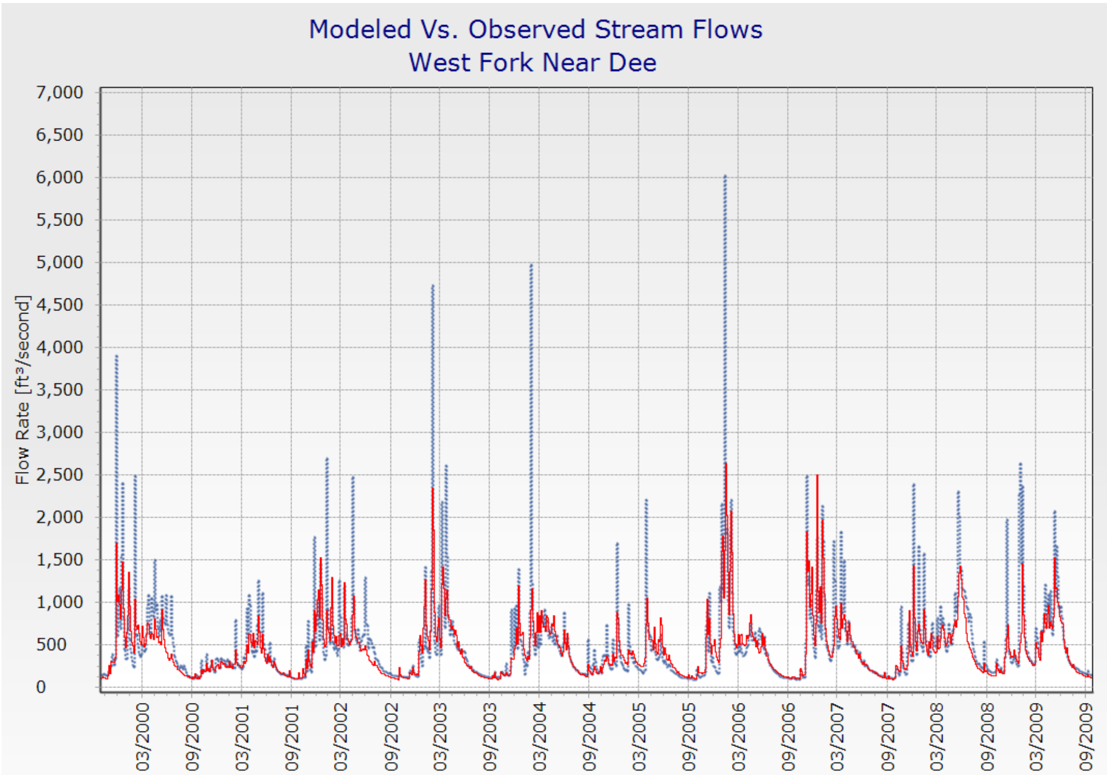


Figure 9. Daily hydrographs of modeled (red solid line) and observed (blue dashed line) streamflows for the West Fork Hood River near Dee for water years 2000 through 2009.

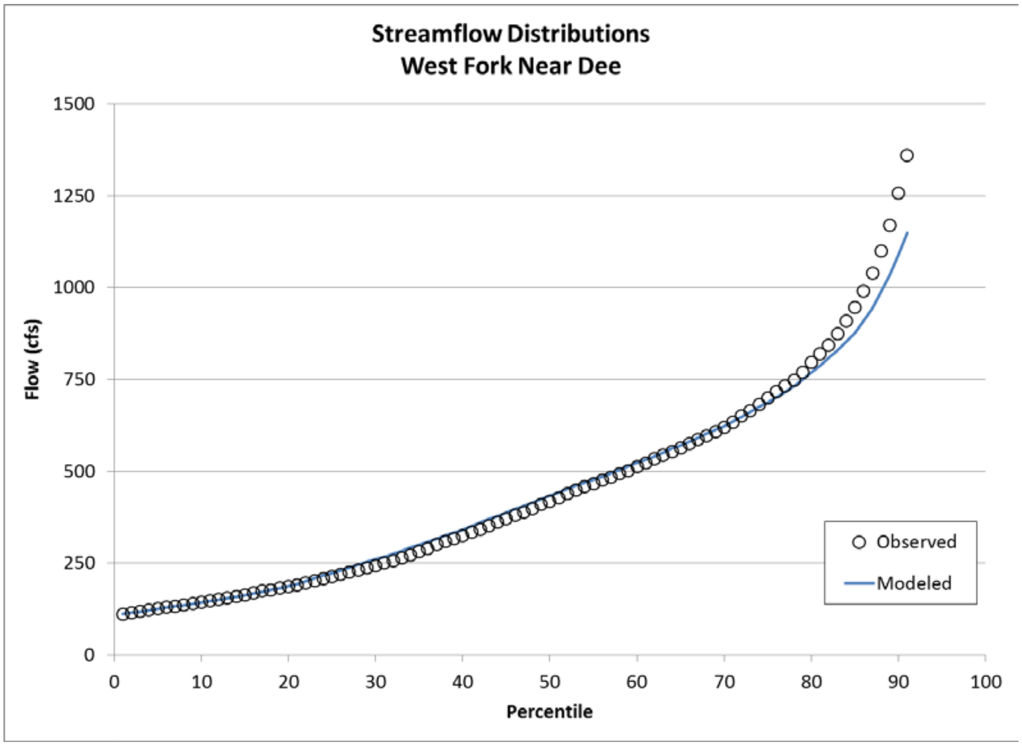


Figure 10. Statistical comparison of simulated historical and observed streamflows for the West Fork Hood River near Dee.

Additional stream gage data obtained through OWRD (OWRD 2014b) were considered during calibration of the WRM model. These include approximately 8 years of discontinuous daily data (2002 to 2009) for the Middle Fork Hood River above its confluence with the East Fork Hood River and for the East Fork Hood River above the Main Canal POD, as well as 14 years of discontinuous daily data (1996 to 2009) for the East Fork Hood River above the Middle Fork. All comparisons between simulated historical and observed values at these locations include only those simulated values where observations were available, which generally coincided with spring and summer months. Thus, the higher values in the statistical distributions of flow (Figure 11 to Figure 13) are not representative of the full flow regimes along the Middle Fork and East Fork because the late fall and winter months have been excluded.

The spring/summer-truncated streamflow results for the Middle Fork Hood River are provided in Figure 11. Whereas the median simulated flow value is very similar (within 5 percent) to the corresponding observed value, there appears to be both negative and positive biases along the low and high flow regimes, respectively. For the purposes of this study, positive high flow bias is not especially troublesome, since flood control is not a priority in the Basin Study. However, the negative low flow bias, of approximately 20 percent or 20 cfs at the 25th percentile, is potentially significant, since the majority of water uses occur during the summer months when flows are lower. Discussed in Section 3.2, modeled demand shortages in the MFID are neither prevalent nor significant. However, the modeled negative low flow bias along the Middle Fork Hood River contributes to the late summer under-simulations along the mainstem Hood River (Figure 7 and Figure 8).

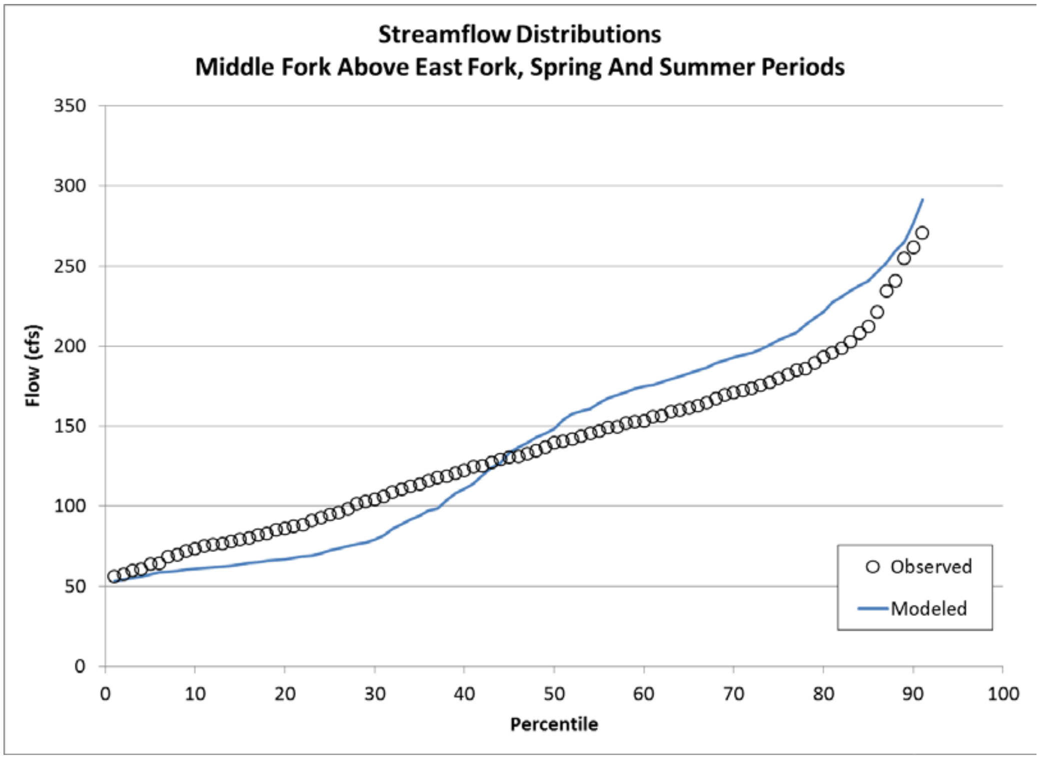


Figure 11. Statistical comparison of simulated historical and observed streamflows for the Middle Fork Hood River above the East Fork.

The source of the low bias along the Middle Fork Hood River is not entirely clear. However, given the diligence of UW in modeling glacier dynamics in the Hood River basin, as well as the scale of modeled melt contributions to streamflows (Reclamation 2014a), this discrepancy is likely not attributable to grossly inaccurate glacier modeling. Under-represented snow melt and/or groundwater inputs, however, could factor into this low bias.

Analogous results for the East Fork Hood River are provided in Figure 12 though modeled and observed data for both the upper (above the Main Canal) and lower (above the Middle Fork) locations are plotted. Whereas the simulated values below the 50^{th} percentile generally agree very well with the corresponding observed values for the upper location, the WRM model again under-simulates the low flow values at the lower location, by approximately 20 percent or 20 cfs at the 25^{th} percentile. In contrast to the low bias along the Middle Fork Hood River, which could be due to model inaccuracies in the headwaters (i.e., from snow melt) and lower reaches (i.e., from groundwater) of the Middle Fork system, the negative bias at the lower East Fork Hood River location is only attributable to model inaccuracies in the lower reaches of the East Fork system because a bias correction was applied to the East Fork headwaters.

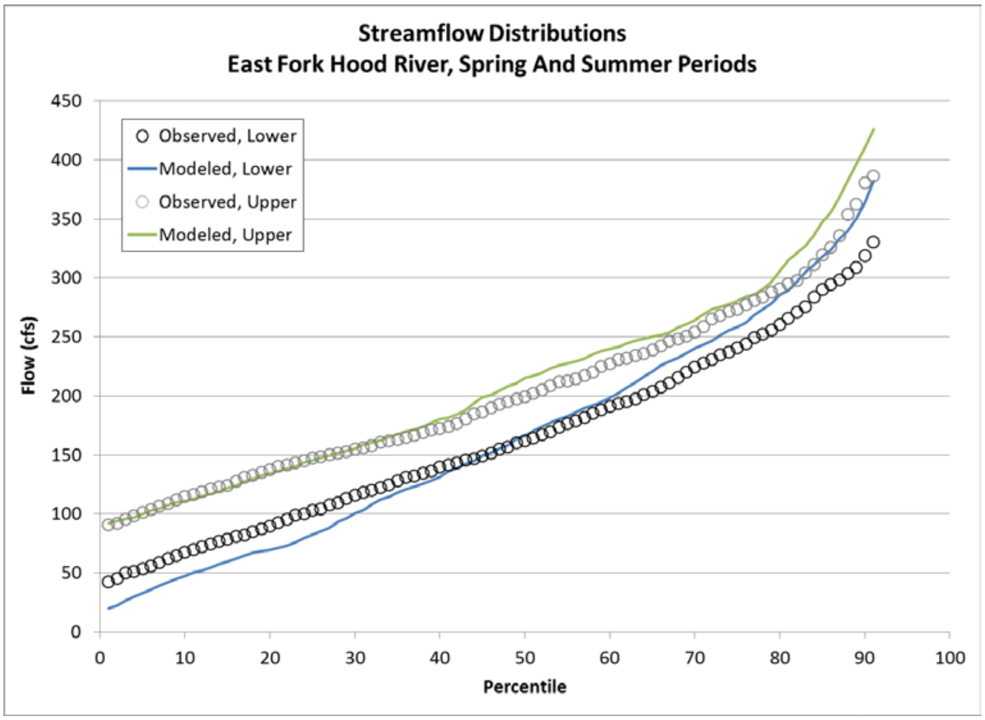


Figure 12. Statistical comparison of simulated historical and observed streamflows for the East Fork Hood River above the Main Canal (upper) and above the Middle Fork (lower).

Figure 13 shows the statistical distribution of modeled flow for the upper East Fork Hood River prior to the aforementioned bias correction. As shown, the simulated distribution diverges from the observed distribution above the 25th percentile. To arrive at the simulated distribution for the upper location plotted in Figure 12, the daily values of the raw simulation (for the *gainEFa* node at the most upstream location along the East Fork) were multiplied by the factors summarized in Table 3. To avoid sharp changes in daily flows, the monthly factors were smoothed via 15-day centered moving average. For example, for the month of April, rather than multiplying all daily values by 0.64, the daily factors ranged from 0.60 to 0.79, reflecting the contributions of the preceding March factor of 0.97 and the succeeding May factor of 0.58. During this process, priority was placed on aligning the simulated and observed flows during the late summer, with less concern for the higher flows during the spring and early summer.

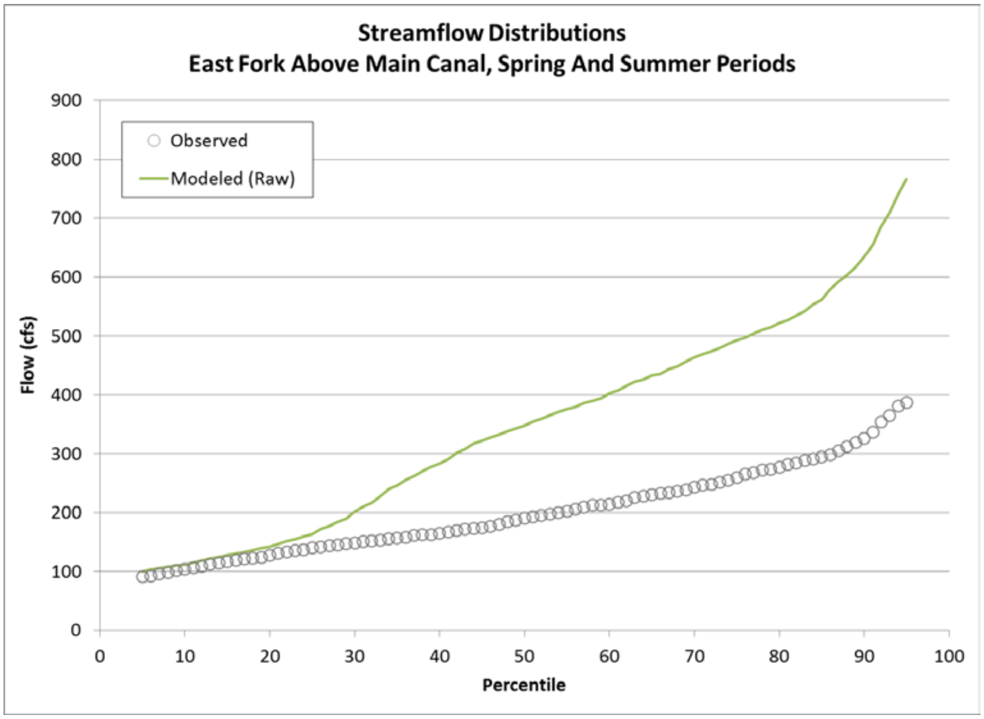


Figure 13. Statistical comparison of uncorrected simulated historical and observed streamflows for the East Fork Hood River above the Main Canal.

Table 3. Bias correction factors applied to headwaters of the East Fork Hood River ("gainEFa" node).

Month	Monthly Factor	Daily Factor Range
January	1.00	1.00-1.00
February	1.00	1.00-1.00
March	0.97	0.82-1.00
April	0.64	0.60-0.79
May	0.58	0.57-0.59
June	0.50	0.50-0.57
July	0.49	0.49-0.55
August	0.78	0.57-1.00
September	1.00	1.00-1.00
October	1.00	1.00-1.00
November	1.00	1.00-1.00
December	1.00	1.00-1.00

From the discussion provided previously, the under-simulations of late summer flows along the mainstem Hood River may be mostly attributable to corresponding under-simulations along the Middle Fork and East Fork and lack of long-term consistent observed data. Of the approximate 50 cfs shortage at the mainstem location, up to 40 cfs can be traced to the upstream under-simulations. However, assuming that modeled water management activities and processes across the Hood River basin are accurate, these data suggest that approximately 10 cfs may be contributed by lower basin groundwater, which the model does not physically account for, to the mainstem Hood River during the late summer. Additionally, the corresponding 20 cfs under-simulation along the East Fork Hood River may be attributable to unrepresented groundwater contributions. The case for groundwater inputs to the Middle Fork Hood River is not as strong, however, since headwater gage data were not available to help discern the potential source(s) of the under-simulation at this location.

In summary, based on the simulated historical streamflow results provided by the WRM model, it may be reasonable to ascribe approximately 10 to 30 cfs (up to 10 percent) of flow in the Hood River system during the late summer period to groundwater sources. This is based on several assumptions, including the accuracies of the structure of and data within the WRM and surface water models. Future work is needed to support or improve this estimate, specifically incorporating a physical groundwater modeling component into the surface water model.

3.2 Consumptive Uses

A summary of the simulated historical results for all major consumptive uses in the Hood River basin is provided in Table 4 by water district on an annual basis. The average reported delivery volumes, which include reservoir releases, were summarized from the *Hood River Basin Water Use Assessment* (WPN 2013a). The average modeled demand volumes are all within 5 percent of the reported volumes. The slight differences arise from simplifications applied to the physical water management features and activities in order to model them using the MODSIM software. For example, multiple water rights at multiple points of diversion may be assigned exclusively to one demand node.

The average modeled percent shortages represent the relative volumes that are demanded but not delivered in the model. These discrepancies may be due, at least in part, to the low streamflow biases discussed above. However, because average monthly reported deliveries were used to populate the consumptive use demands in the model, the modeled shortages may also arise from low water years where, in reality, demands were scaled back to conserve water.

For each water district, the sum of the relative difference between the modeled demands and reported deliveries (column four in Table 4) and the modeled percent shortage (column five in Table 4) provides an estimate of overall model performance during the historical period. On an average annual basis, the simulated historical demands meet the reported deliveries within 9 percent (includes some hydrology data).

Table 4. Summary statistics for consumptive uses in the WRM model during the historical period (includes some hydrology data).

Water District	Average Reported Delivery (kaf)	Average Modeled Demand (kaf)	Percent Difference Between Modeled And Reported	Average Modeled Percent Shortage
Dee Irrigation	3.3	3.3	0%	0%
East Fork Irrigation	30.1*	29.9	-1%	-1%
Farmers Irrigation	69.6	70.2	1%	-2%
Middle Fork Irrigation	32.9	31.4	-5%	-4%
Mount Hood Irrigation	2.0	2.0	0%	-3%
All Potable	3.6	3.6	0%	-1%

*Average of watermaster measurements.

Note: reservoir release demands included in results for Farmers and Middle Fork Irrigation Districts.

Figure 14 displays the simulated historical shortages in consumptive uses on an annual basis and for each quarter of the water year. The shortages represent the differences between demanded and delivered water in the model. For ease of comparison across water districts, the shortages are reported as percentages of demanded volumes. The spread in model results (10^{th} and 90^{th} percentiles) are illustrated by the error bars. As shown, the average simulated historical shortages are less than 5 percent of the demanded volumes for all water districts. However, during some years, the shortages in MHID exceed 10 percent on an annual basis and approach 20 percent during the late summer period. Because the WRM model is populated with average reported consumptive uses, during drier years there is simply not enough simulated water in the Hood River basin to satisfy all of the demands.

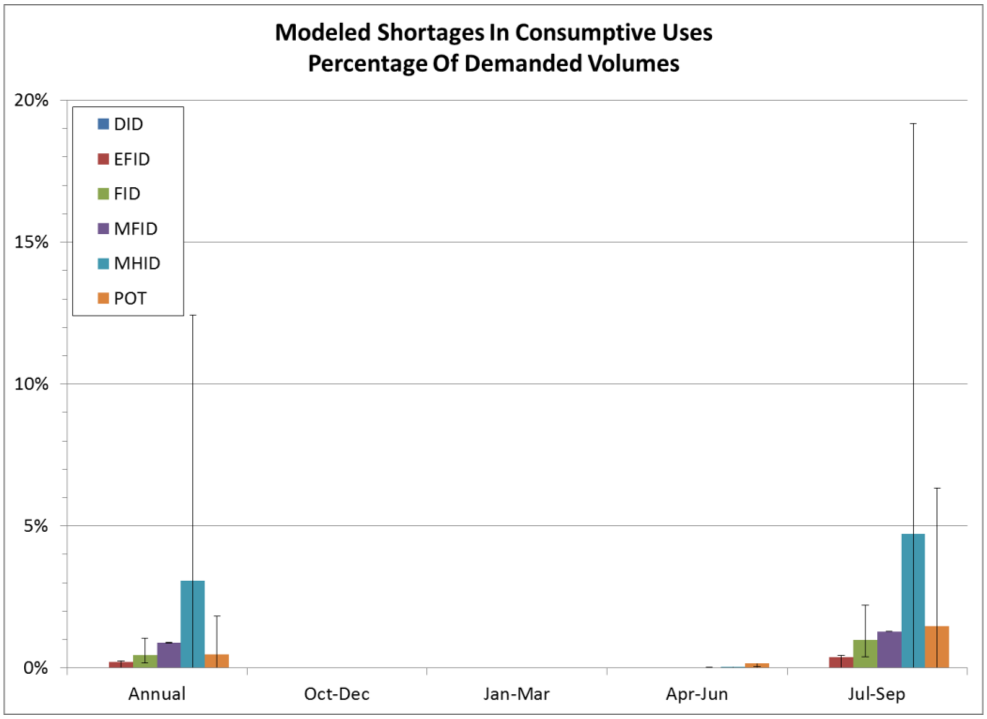


Figure 14. Comparison of average modeled consumptive use shortages, as percentages of demanded volumes, for the historical period. Modeled 10th and 90th percentiles indicated by error bars.

3.3 Minimum Flows

Figure 15 illustrates the simulated historical shortages in minimum flows across the Hood River basin as percentages of required flows. The Hood River minimum flow requirement listed in Figure 15 corresponds to the Tucker Bridge location, and the East Fork requirement corresponds to the reach just upstream of the confluence with the Middle Fork. All other locations listed are self-explanatory as they represent the only requirements on those streams.

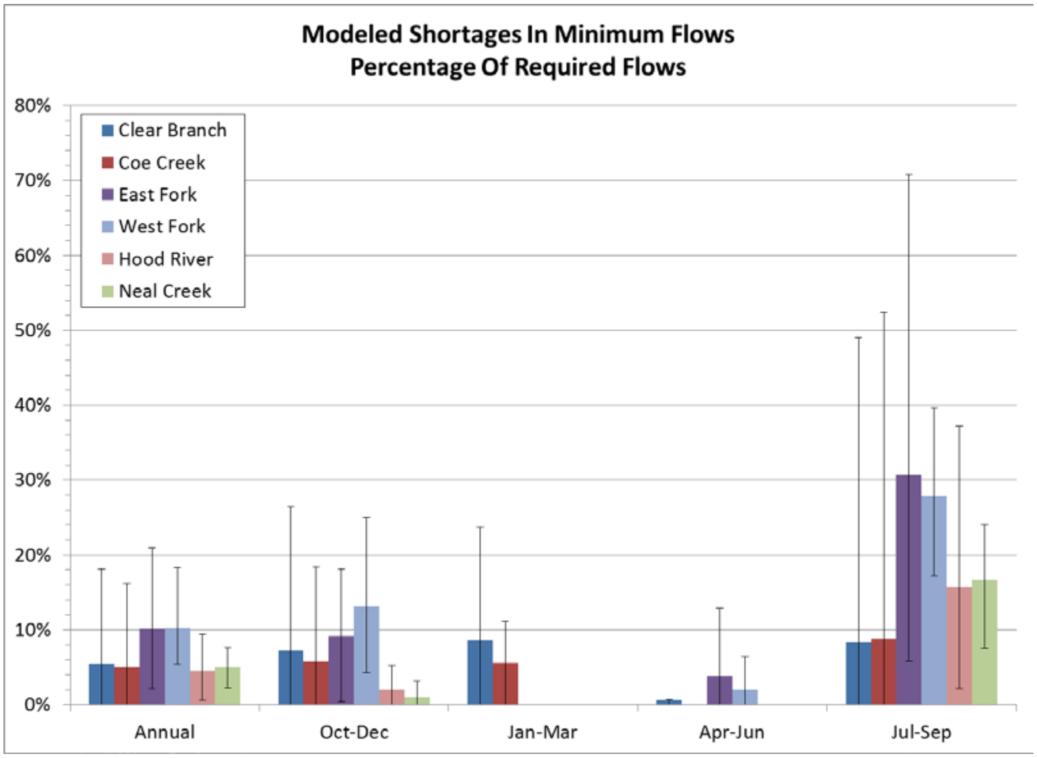


Figure 15. Comparisons of average modeled minimum flow shortages, as percentages of required flows, for the historical period. Modeled 10th and 90th percentiles indicated by error bars.

Five minimum flow requirements are not listed in Figure 15. The simulated historical results for the instream rights/agreements along Green Point Creek and Hood River at Powerdale Dam indicated no shortages at these locations.

The shortage results for the Middle Fork Hood River and Dog River are provided in Table 5. In contrast to those shown above, the instream rights for these locations are rarely satisfied during the simulated historical period. Results for Middle Fork Hood River and Dog River were not included in Figure 15 to prevent detraction from the results for the other locations.

Table 5. Shortage results for instream requirements on the Middle Fork Hood River and Dog River.

Location	Period	Percentage of Required Flows			Percentage of Time
		Average	Low (10th Percentile)	High (90th Percentile)	
Middle Fork	Annual	67%	59%	74%	97%
	Oct-Dec	75%	65%	87%	96%
	Jan-Mar	60%	35%	78%	93%
	Apr-Jun	63%	55%	71%	99%
	Jul-Sep	71%	63%	86%	99%
Dog River	Annual	33%	20%	45%	67%
	Oct-Dec	30%	10%	59%	65%
	Jan-Mar	27%	05%	51%	59%
	Apr-Jun	24%	11%	42%	48%
	Jul-Sep	72%	61%	82%	94%

In conjunction with the observed flow distribution of the Middle Fork Hood River (Figure 11), the results listed in Table 5 suggest that this instream right attempts to over-allocate the Middle Fork system. The right calls for a minimum of 255 cfs during June and 100 cfs during September. As Figure 11 shows, during the spring and summer months, the Middle Fork Hood River is often observed to dip below 100 cfs and rarely exceeds 250 cfs. Thus, the streamflows along the Middle Fork cannot be expected to meet the instream right, except perhaps during wetter years.

The Dog River instream right is similarly problematic because the primary water right for the City of the Dalles allows for all flow in the Dog River to be diverted from approximately midway between the mouth and headwaters of the system (WPN 2013a). Thus, it is unlikely that streamflows along the Dog River meet the instream right, except again during wetter years when local contributions below the point of diversion are sufficiently high.

3.4 Hydropower Demands

Table 6 provides results for the hydropower demands that are analogous to those listed in Table 5. As shown, the WRM model effectively serves all average reported hydropower demands in the Hood River basin. The modeled flows available and priorities of the hydropower demands are such that effectively no shortages are simulated during the historical period.

Table 6. Summary statistics for hydropower demands in the WRM model during the historical period.

Water District	Average Reported Delivery (kaf)	Average Modeled Demand (kaf)	Percent Difference Between Modeled And Reported	Average Modeled Percent Shortage
Middle Fork Irrigation	78.3	78.4	0%	0%
Farmers Irrigation	65.5	65.3	0%	0%

3.5 Storage Volumes

Observed reservoir elevation/storage and release data were obtained from the *Hood River Basin Water Use Assessment* (WPN 2013a) and/or provided by FID and MFID. Figure 16 displays the simulated historical and observed (2005 through 2009) average monthly storage volumes in the Green Point Reservoir system. Overall, the simulated volumes agree with those observed within 4 percent. The slight low bias during March through July may be attributed to the model not allowing the reservoir system to begin filling earlier during lower water years (Section 2.1.5), unlike how FID actually operates the reservoirs when needed (N. Christensen, personal communication, April 10, 2014). Conversely, the slight high bias during August and September is likely due to the modeled constant release rate, whereas more than 5 cfs is often released by FID during these months.

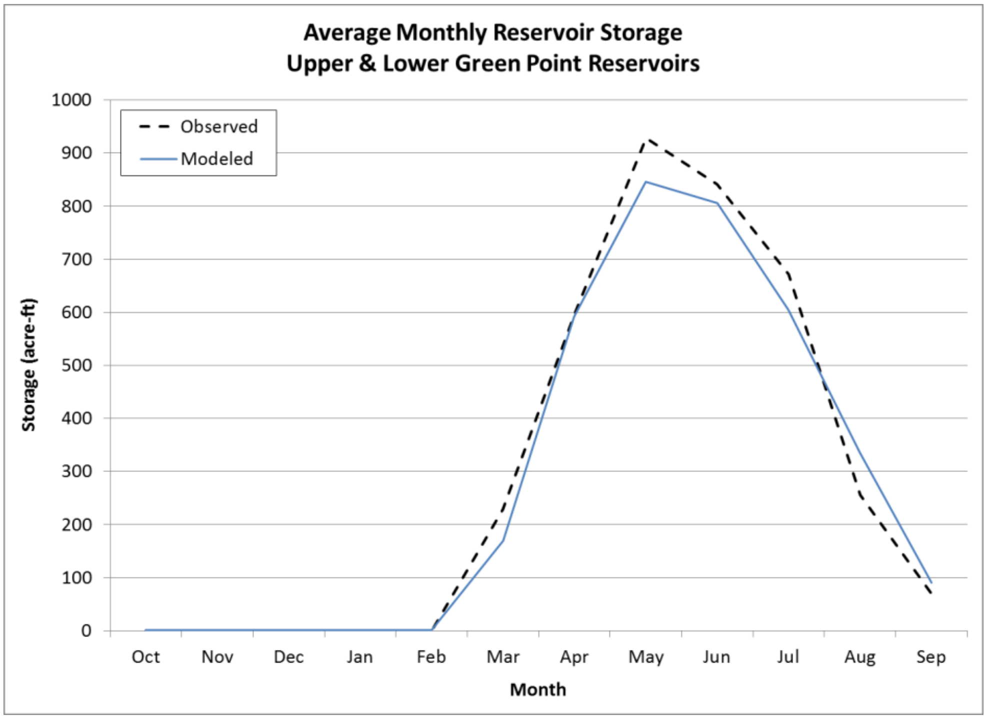


Figure 16. Comparison of simulated historical and observed average monthly storage volumes in the Green Point Reservoir system.

A comparison of simulated historical average monthly inflow volumes to those estimated by MFID (based on measured storages and releases, notated as Observed*) for Laurance Lake is displayed in Figure 17. Although the average annual volumes of the two data sets are not vastly different (simulated is approximately 15 percent lower than Observed*), the inaccurate timing and shape of the simulated inflows impacted how Laurance Lake stored and delivered water during initial model runs. Thus, in a manner similar to that described above for the upper East Fork Hood River, a bias correction was applied to Laurance Lake inflows (*inClearBrAtLaurance* node). The bias correction factors are summarized in Table 7. The corrected average monthly inflow volumes, also shown in Figure 17, align very well with the Observed* volumes.

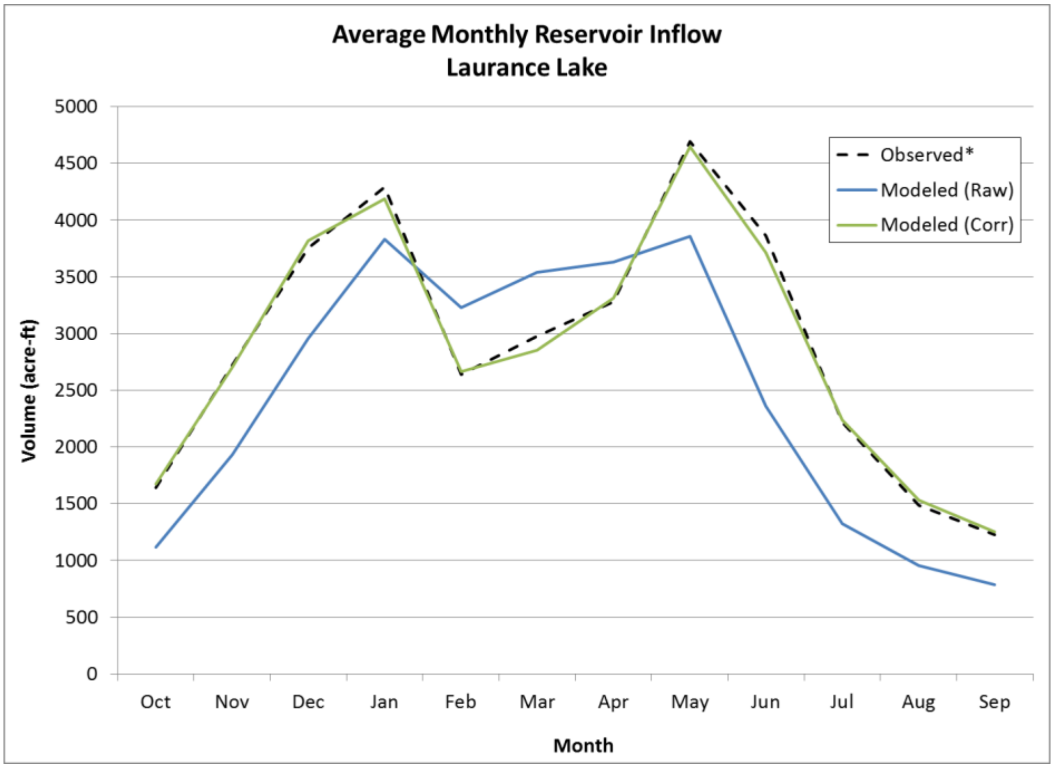


Figure 17. Comparison of corrected and uncorrected simulated historical and observed* average monthly inflow volumes for Laurance Lake. *Indicates that information was estimated by MFID based on measured storage volumes and release rates.

Table 7. Bias correction factors applied to inflows of Laurance Lake (*inClearBrAtLaurance* node).

Month	Monthly Factor	Daily Factor Range
January	1.1	0.96-1.19
February	0.8	0.80-0.94
March	0.8	0.80-0.85
April	0.9	0.85-1.04
May	1.2	1.06-1.39
June	1.6	1.41-1.65
July	1.7	1.65-1.70
August	1.6	1.60-1.65
September	1.6	1.55-1.60
October	1.5	1.45-1.55
November	1.4	1.35-1.45
December	1.3	1.21-1.35

The simulated historical average monthly storage volumes for Laurance Lake, generated using the bias corrected inflows described above and average releases from the *Hood River Basin Water Use Assessment* (WPN 2013a), are provided in Figure 18 along with observed (1999 to 2009) averages. Although, overall, the model difference is less than 6 percent, the simulations appear to under-estimate peak storage and are slightly temporally shifted. Given that inflows were adjusted to match MFID data, the source of these discrepancies is likely the simulated release rates. Whereas MFID scales back reservoir releases during dry years or to balance aesthetics and recreation with irrigation (C. DeHart, MFID Manager, personal communication, February 18, 2014), the WRM model attempts to release the average amounts regardless of conditions. The only driver for retaining versus releasing (or passing) water in the WRM model is the relative priority of the storage/release water right to the water rights of the downstream demands. Thus, if water is available in the reservoir, and the release demand is calling for water, then the WRM model discharges water from the reservoir. However, despite the appearance of the simulated values in Figure 18, the model does fill Laurance Lake during most years. Figure 19 shows that the modeled reservoir is effectively full in June throughout the majority of the historical period. This result is in good agreement with observations except at low percentiles, which are indicative of dry years.

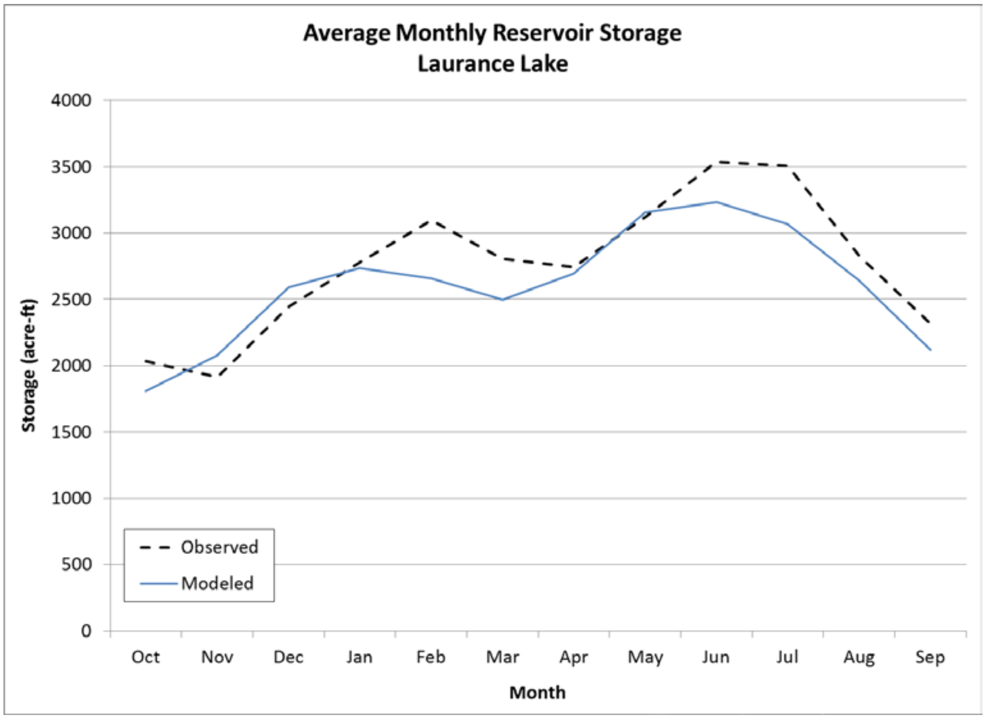


Figure 18. Comparisons of simulated historical and observed average monthly storage volumes in Laurance Lake.

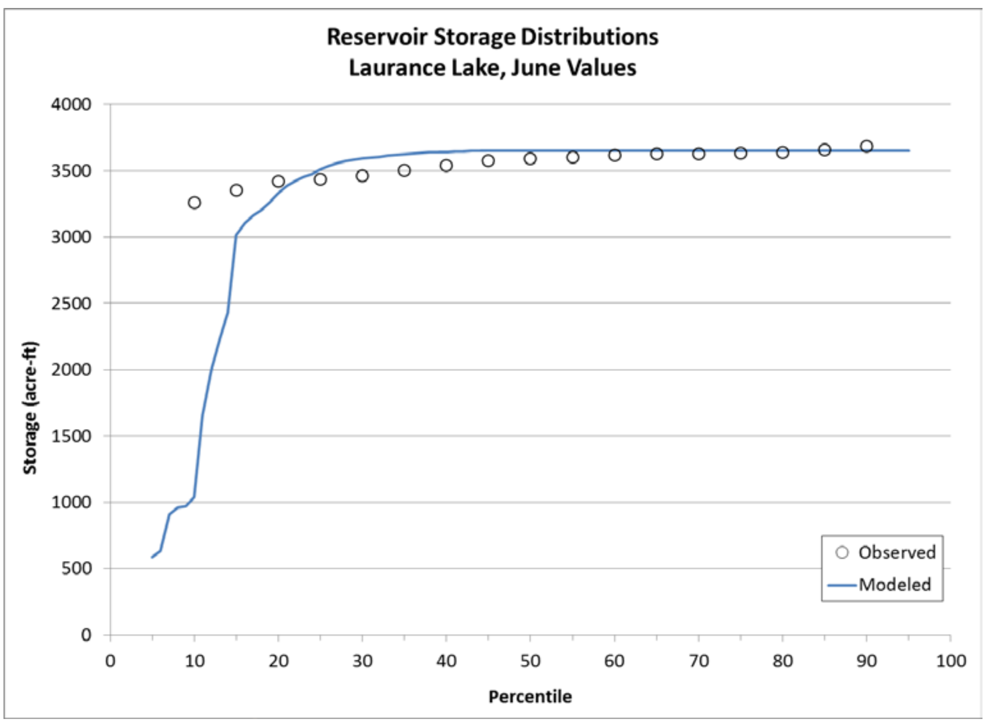


Figure 19. Statistical comparison of simulated historical and observed June storage volumes in Laurance Lake.

4.0 FUTURE CLIMATE CHANGE RESULTS

The WRM model was used to simulate potential future (water years 2030 through 2059) regulated streamflows and water uses in the Hood River basin using the climate change scenario streamflows from the surface water model. A description of the potential future natural streamflows generated for this Basin Study can be found in the *Surface Water Modeling Technical Memorandum* (Reclamation 2014a). Information on selecting the climate change scenarios can be found in the *Climate Change Analysis Technical Memorandum* (Reclamation 2014c).

Figure 20 illustrates a summary of the climate change scenarios selected for this Basin Study. Three scenarios were chosen for hydrologic modeling to represent more warming and dry (MW/D) conditions, less warming and wet (LW/W) conditions, and median (MED) conditions. This naming convention indicates that adjustments in precipitation are both greater than and lower than historical precipitation and that adjustments in temperature are all greater than historical temperature. The MED scenario simply represents the statistical center of the adjustments. The MW/D, LW/W, and MED scenarios were selected over other potential scenarios based on the ability to provide the largest range of future hydrologic conditions.

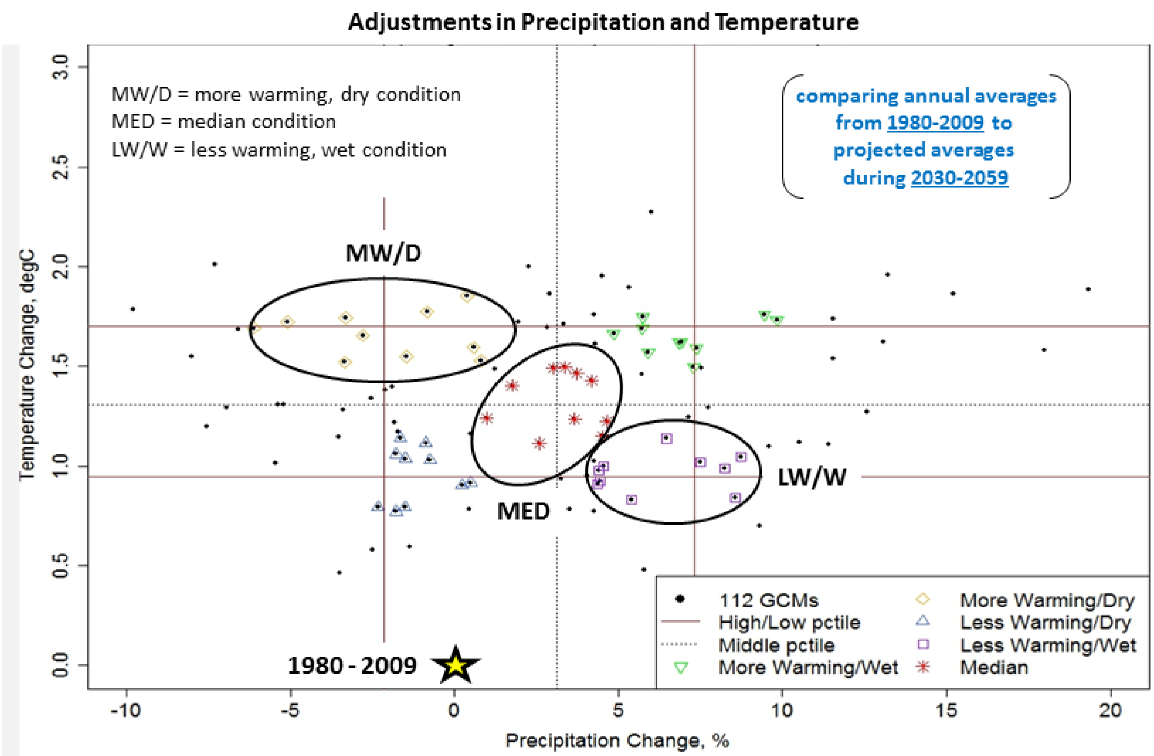


Figure 20. Summary of climate change projection selection results for the Hood River Basin Study.

The natural flows generated by the surface water model for each climate change scenario (MW/D, MED, LW/W) were utilized in the WRM model in the exact same manner as the natural flows for the historical period. Specifically, the bias corrections discussed in Sections 3.1 and 3.5 were also applied to the climate change scenario flows.

For the future period simulations, the natural flows for each climate change scenario were applied to the existing water management/use scheme across the Hood River basin, as well as to three alternative schemes of water management/use: 1) more demands, 2) more demands, more conservation, and 3) more demands, more conservation, and more storage. For simplicity, these alternatives are referred to as the Demands, Conservation, and Storage alternatives, respectively. Descriptions of each simulation, along with corresponding labels for the figures that follow, are provided in Table 8.

Table 8. Summary of WRM model simulations.

Period	Climate Scenario	Alternative	Label
Historical	N/A	Existing	BASE
Future	MW/D	Existing	MW/D, Existing
Future	MED	Existing	MED, Existing
Future	LW/W	Existing	LW/W, Existing
Future	MW/D	More demands	MW/D, Demands
Future	MED	More demands	MED, Demands
Future	LW/W	More demands	LW/W, Demands
Future	MW/D	More demands, more conservation	MW/D, Conservation
Future	MED	More demands, more conservation	MED, Conservation
Future	LW/W	More demands, more conservation	LW/W, Conservation
Future	MW/D	More demands, more conservation, more storage	MW/D, Storage
Future	MED	More demands, more conservation, more storage	MED, Storage
Future	LW/W	More demands, more conservation, more storage	LW/W, Storage

The Demands Alternative represents consumptive uses increasing according to projected increases in population (for potable water districts) or increases in temperature-driven evapotranspiration (for irrigation water districts). The potable water use increases are based on a recent Hood River County population forecast (ECONorthwest 2008). This forecast predicts a 2.0 percent average annual growth rate within Hood River city limits, and a 0.8 percent growth rate within rural areas. Since development in the Hood River basin predominantly occurs through subdividing existing lots or developing agricultural land, only indoor water use is scaled up to account for increases in population. See the *Hood River Basin Water Conservation Assessment* (WPN 2013b) for details on the methodology used in developing the potable water use factors (Table 9).

Table 9. Factors applied to modeled consumptive uses to account for future increases in temperature and population.

Irrigation District	Factor	Potable District	Factor
Dee	1.06	City of Hood River	1.31-1.88
East Fork	1.04	City of The Dalles	1.00-1.74
Farmers	1.08	Crystal Springs	1.23-1.24
Middle Fork	1.03	Ice Fountain	1.22-1.24
Mount Hood	1.04	Oak Grove	1.13-1.31
		Odell	1.17-1.27
		Parkdale	1.17-1.29

The factors used to account for increased consumptive use by the irrigation districts (Table 9) are based on a study by Oregon State University College of Agricultural Sciences, which predicts a 10 percent increase in demand per 1 degree Celsius (°C) increase in temperature (Coakley et al. 2010). Under the MED climate scenario, the average increase in April through September temperature is 1.4 °C. However, because a portion of each district is supplying more water than current crop demand (i.e., impact sprinklers), only the part of each district using micro- or rotator sprinklers is scaled up to account for temperature change. Please see the *Hood River Basin Water Conservation Assessment* (WPN 2013b) for details.

The Conservation Alternative represents the consumptive use increases from the Demands Alternative combined with decreases in irrigation demands from planned water conservation measures, such as converting to more efficient sprinkler systems. Table 10 lists the multiplicative factors used to decrease irrigation uses by water district. These factors are based on surveys of the types of sprinklers in each district, and then converting 49 percent of the existing area using impact sprinklers to micro sprinklers. A study by the Hood River Soil and Water Conservation District (SWCD) found that impact sprinklers use between 2.4 and 3.0 feet of water per year, while micro sprinklers use closer to 1.5 feet per year (HRSWCD

2013). In addition to the reduction in use to account for sprinkler conversion, an additional 21.5 cfs is subtracted from historical EFID use to account for eliminating overflows and canal seepage (i.e., assumes all EFID conveyance losses are eliminated) plus 1.5 cfs is subtracted from historical DID use to account for a recent piping of their diversion system and 1 cfs to account for MHID spill.

Table 10. Factors applied to modeled consumptive uses to account for future water conservation measures.

Water District	Factor
Dee Irrigation District	0.76
East Fork Irrigation District	0.67
Farmers Irrigation District	0.97
Middle Fork Irrigation District	0.87
Mount Hood Irrigation District	0.83

The Storage Alternative incorporates the measures of the Demands and Conservation alternatives combined with additional storage capacity, either in existing facilities or in a new facility. This alternative investigates increasing storage capacities of the Green Point Reservoir system and Laurance Lake by 561 acre-feet and 370 acre-feet, respectively. Additionally, this alternative also examines adding a new reservoir with the capacity of 2,557 acre-feet along the West Fork of Neal Creek. Refer to the *Hood River Basin Surface Water Storage Feasibility Assessment Report* (OWRD and HRC 2014) for details on these potential storage additions.

As mentioned in Sections 2.1.5 and 3.5, historically reported monthly average reservoir releases were specified in the WRM model for the Green Point Reservoir system and Laurance Lake for the historical simulation. These average historical releases were also used in the future period simulations for the Existing Alternative. To foster transparency and consistency, for the Demands Alternative the releases were scaled upwards by the appropriate factors used to estimate consumptive use increases (Table 9). For the Conservation and Storage alternatives, the upwardly scaled releases used in the Demands Alternative were maintained. This was done to investigate whether any water savings through consumptive use conservation measures could benefit hydropower production (N. Christensen, personal communication, January 17, 2014).

To highlight the effects of climate change, the results and discussions that follow include comparisons between the simulated historical results and those from each climate scenario under the existing water management scheme (Existing Alternative). To illustrate the potential upper limits of climate change impacts, the results and discussions that follow also focus on the various alternative simulations under the MW/D climate scenario. For a complete summary of results for all climate scenario-alternative combinations, please refer to Appendix B.

4.1 Streamflows

Although on an annual basis runoff volumes are not projected to change significantly, the potential future climate conditions were found to alter the timing and character of seasonal runoff across the Hood River basin (discussed in the *Surface Water Modeling Technical Memorandum* [Reclamation 2014a]). Because of more precipitation and warmer temperatures relative to historical conditions, which are modeled to result in more rain versus snow and melting snowpack, natural runoff is expected to increase during the fall and winter months. However, during the spring and summer months when water uses are greater, natural runoff is expected to decrease from relatively less precipitation and reduced snowpack. The results from the WRM model simulations indicate that these seasonal shifts in natural runoff translate directly into seasonal shifts in regulated streamflows.

Figure 21 illustrates the monthly difference hydrograph for the mainstem Hood River at Tucker Bridge for the Existing Alternative under each climate scenario. The differences are from the simulated historical (or BASE) results. As shown, the increases in December range from approximately 200 to 300 cfs, and the decreases in May range from approximately 100 to 200 cfs. However, as Figure 22 shows, perhaps the most significant impacts to mainstem streamflows in terms of water use occur during the months of July and August, when the decrease in streamflows exceeds 30 percent under the MW/D climate scenario.

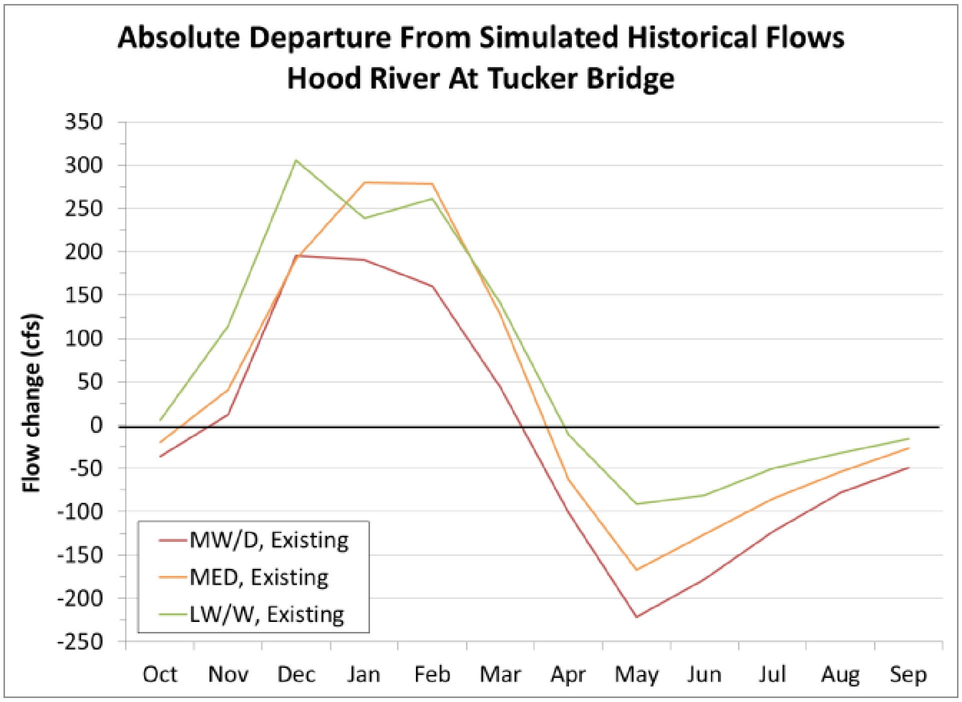


Figure 21. Comparison of absolute average monthly changes in streamflows along the Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

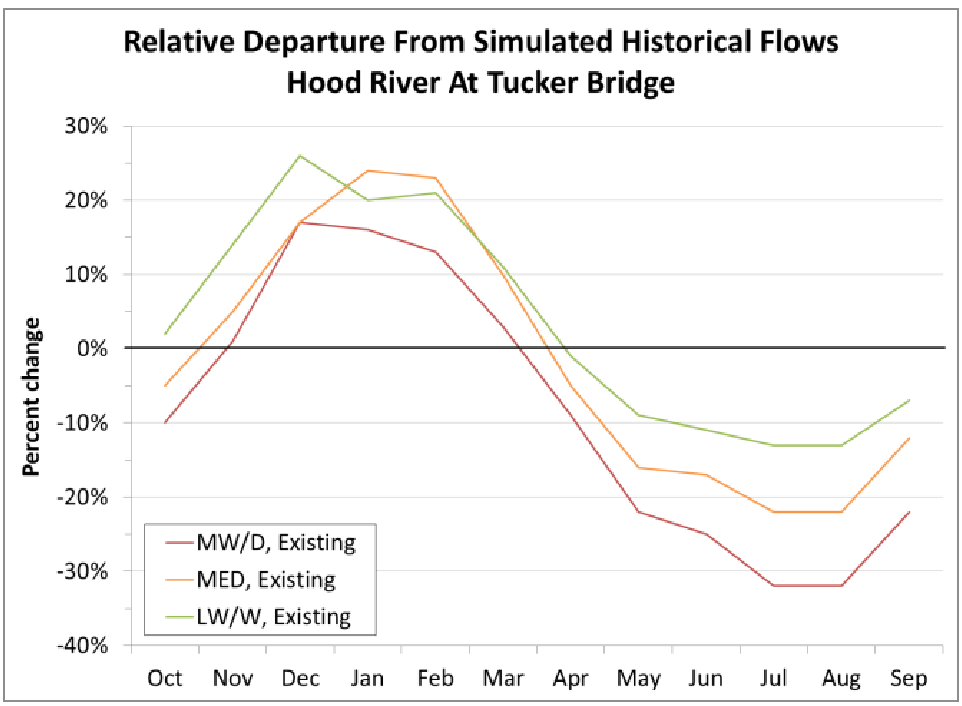


Figure 22. Comparison of relative average monthly changes in streamflows along the Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

To illustrate the effects of the water resource alternatives along the mainstem Hood River, the percentile distributions of July to September streamflows are plotted for the BASE condition and under each MW/D climate scenario-alternative combination in Figure 23. Consistent with the results presented in Figure 21 and Figure 22, the Existing Alternative yields decreases throughout the full range of streamflows during the summer months. Additional consumptive use decrease the streamflows further, by approximately 10 cfs. Implementing conservation measures and additional storage increases streamflows by approximately 30 and 40 cfs, respectively, from those under the Demands Alternative. However, regardless of the modeled alternatives, under the MW/D climate scenario streamflows remain lower than simulated historical. The results in Figure 24 are also consistent with the previous figures, with MW/D streamflows simulated higher than historical during the January through March period. As might be expected, the modeled alternatives have no positive or negative effect during the winter months.

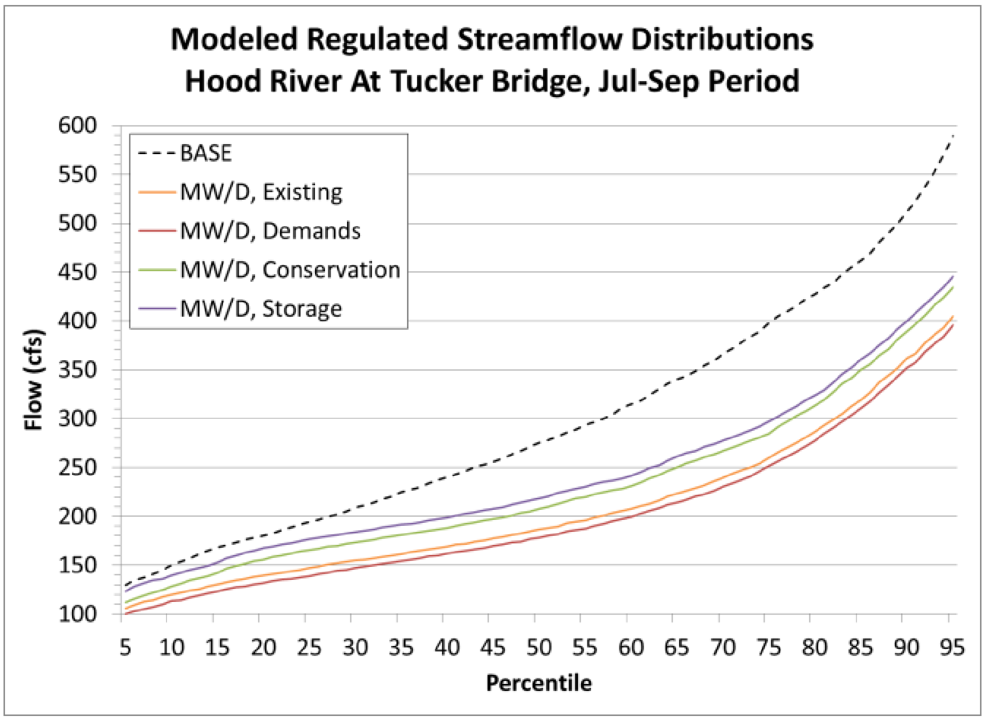


Figure 23. Statistical comparison of summer and winter streamflows along the Hood River (July-September) for the MW/D climate scenario under each water resource alternative.

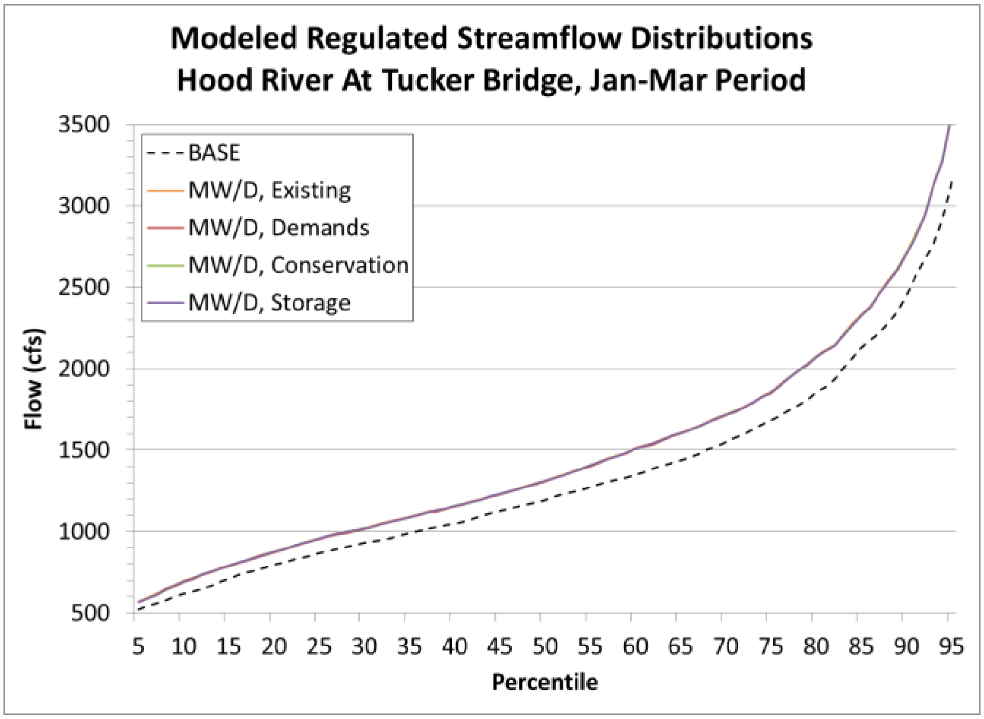


Figure 24. Statistical comparisons of summer and winter streamflows along the Hood River (January-March) for the MW/D climate scenario under each water resource alternative.

Results analogous to those presented in Figure 21 and Figure 22 are provided for the West Fork Hood River near Dee (Figure 25 and Figure 26), the Middle Fork Hood River above the East Fork (Figure 27 and Figure 28), and the East Fork Hood River above the Middle Fork (Figure 29 and Figure 30). The same patterns observed along the mainstem Hood River generally apply to the results along all three forks: increases in streamflows nearing 30 percent of historically simulated during the fall and winter months, and decreases nearing 30 percent of historically simulated during the spring and summer months.

The one stand-out to these general patterns is along the East Fork Hood River, where late summer streamflows exhibit decreases of more than 50 percent for the MED and MW/D climate scenarios. This suggests that the East Fork may be more vulnerable to climate change. 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 ability to temper the late summer disparity of having to satisfy the greatest annual water demands with the lowest annual flows.

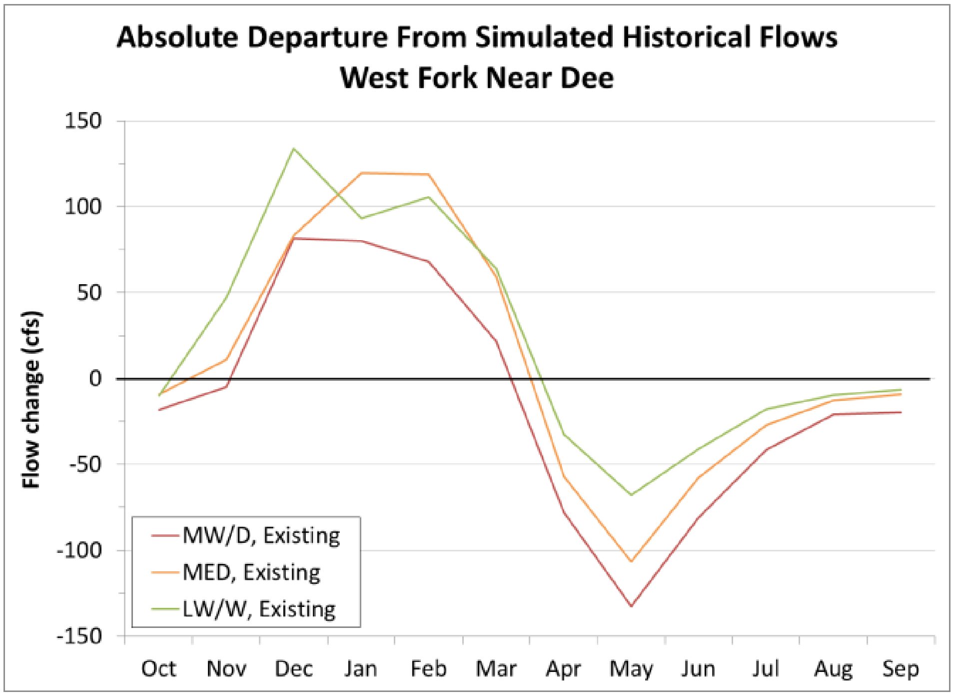


Figure 25. Comparison of absolute average monthly changes in streamflows along the West Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

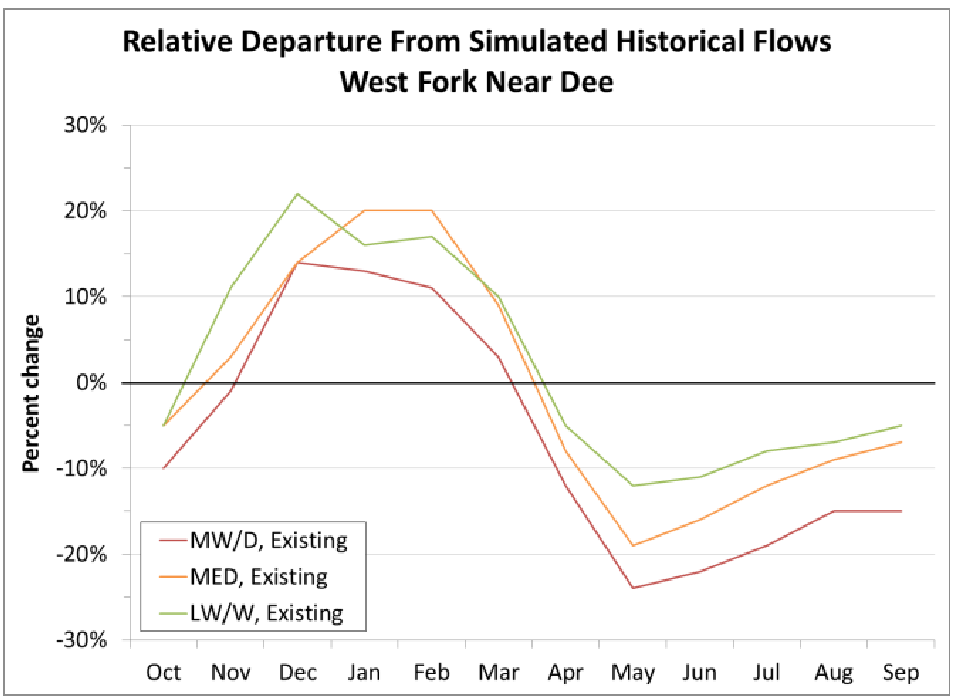


Figure 26. Comparison of relative average monthly changes in streamflows along the West Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

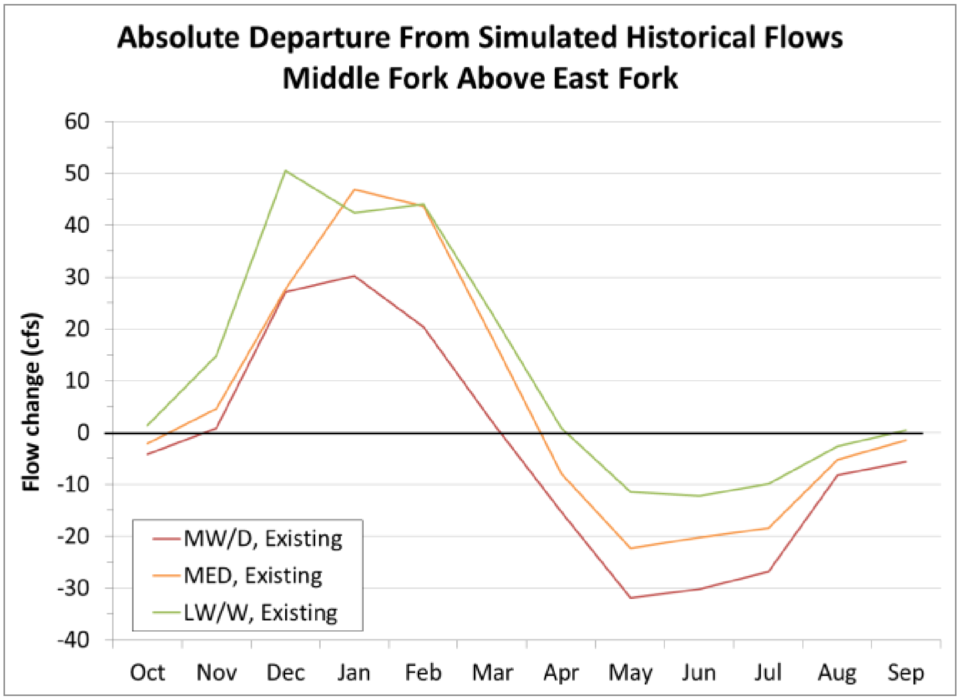


Figure 27. Comparison of absolute average monthly changes in streamflows along the Middle Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

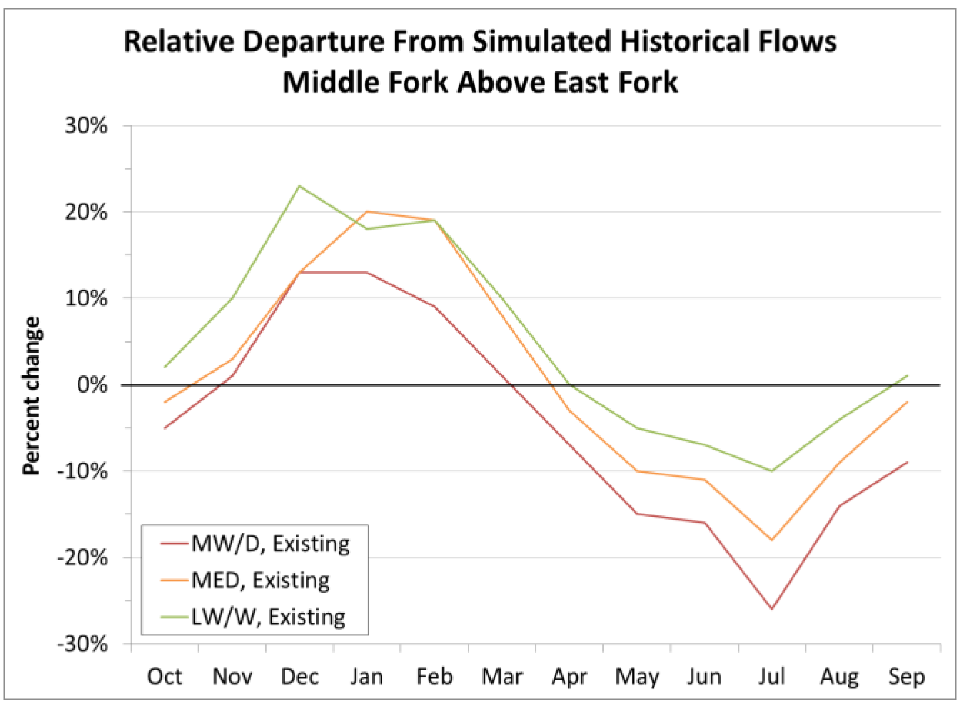


Figure 28. Comparisons of relative average monthly changes in streamflows along the Middle Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

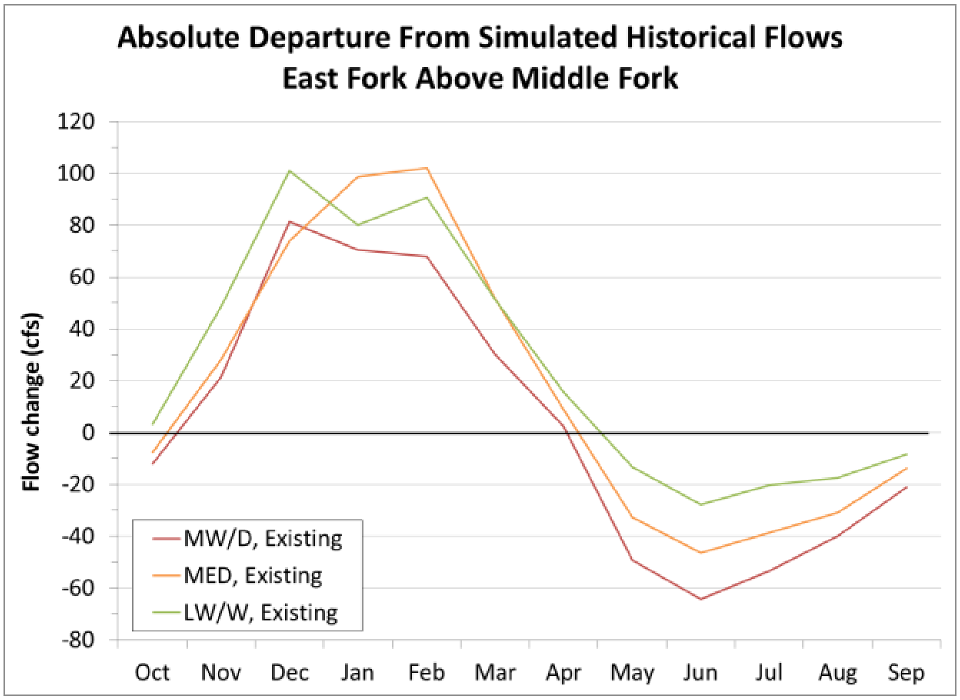


Figure 29. Comparisons of absolute average monthly changes in streamflows along the East Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

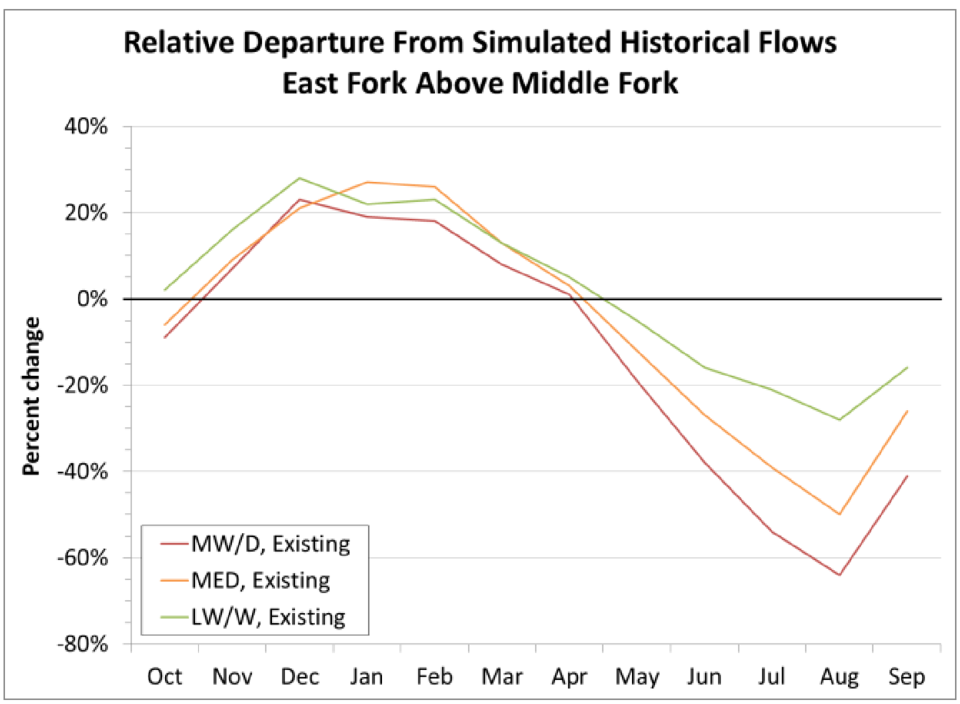


Figure 30. Comparison of relative average monthly changes in streamflows along the East Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

Figure 31 through Figure 33 contain the percentile distributions of July to September streamflows along the three forks under the BASE condition and under each MW/D climate scenario-alternative combination. The results in Figure 31 show that because relatively little water use occurs along the West Fork Hood River, and no additional storage was modeled along this fork, the water resource alternatives have little impact to streamflows. However, it is clear that the MW/D climate scenario is simulated to decrease flows along the West Fork during the summer months.

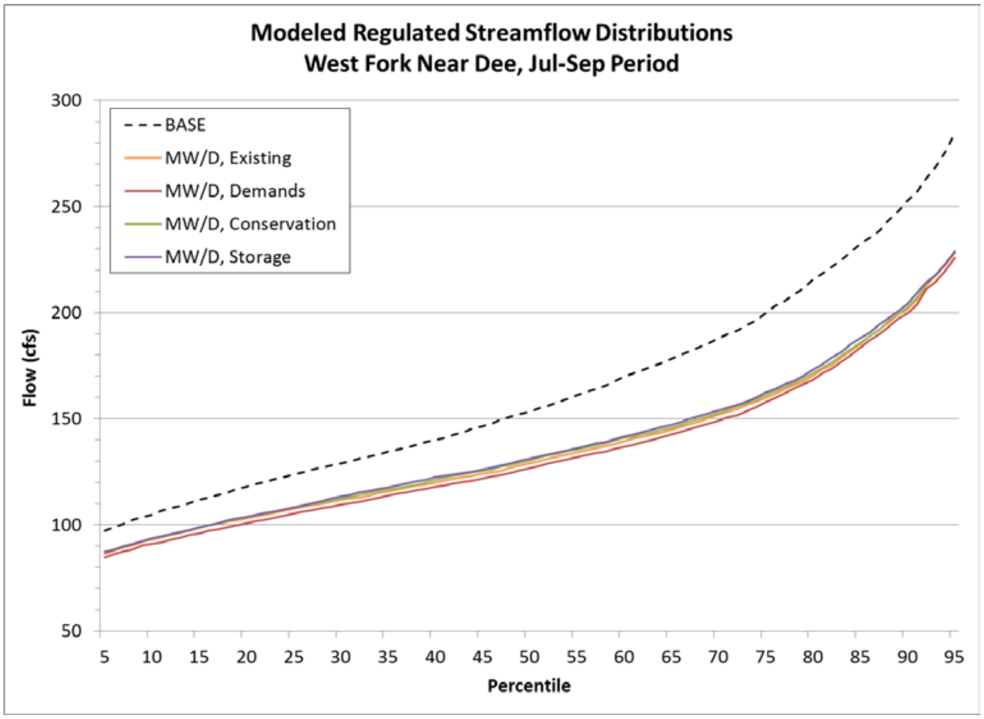


Figure 31. Statistical comparisons of summer streamflows along the West Fork Hood River for the MW/D climate scenario under each water resource alternative.

The effects of the alternatives along the Middle Fork Hood River during the summer months, shown in Figure 32, are more discernable. At low flows (below the median, or 50th percentile), the modeled increases in consumptive use (Table 9) result in departures between the Existing and Demands alternative. This is likely due to the minimum flow requirement along Middle Fork being outcompeted by other demands in MFID. When streamflows are high enough, Laurance Lake is able to follow its average release schedule and all demands (i.e., consumptive uses, hydropower demands, and minimum flow requirements) are satisfied. However, as water becomes scarce the more senior irrigation and hydropower water rights are satisfied before water is allowed to flow downstream to meet the instream agreement. Refer to Appendix A for complete lists of consumptive use, hydropower demand, and minimum flow priority dates.

The results for the Conservation Alternative indicate that when flows are high enough the decreases in consumptive use (Table 10) supplement streamflows by approximately 4 cfs, or 7 percent, as compared to the Demands Alternative. However, again, demand shortages arise at low flows, and the more senior irrigation and hydropower rights are delivered water before additional flows are allowed to pass downstream.

Lastly, the results for the Storage Alternative, which entailed increasing the capacity of Laurance Lake by 370 acre-feet, show that the additional storage water does not supplement streamflows above the 20th percentile, indicating that demand shortages in MFID are not present when streamflows are above this threshold. However, the additional storage does supplement streamflows below this threshold by approximately 5 cfs, or 10 percent, as compared to the Conservation Alternative. The MW/D climate scenario simulations suggest that implementing both the conservation measures and the additional storage in Laurance Lake could mitigate the effects of climate change along the Middle Fork, to the extent that future streamflows, demands, and instream flows during the critical summer months are only impacted during very low flow periods. As will be discussed in Section 4.5, however, there may also be the potential during these very low flow periods to release additional storage water without significantly drawing down Laurance Lake.

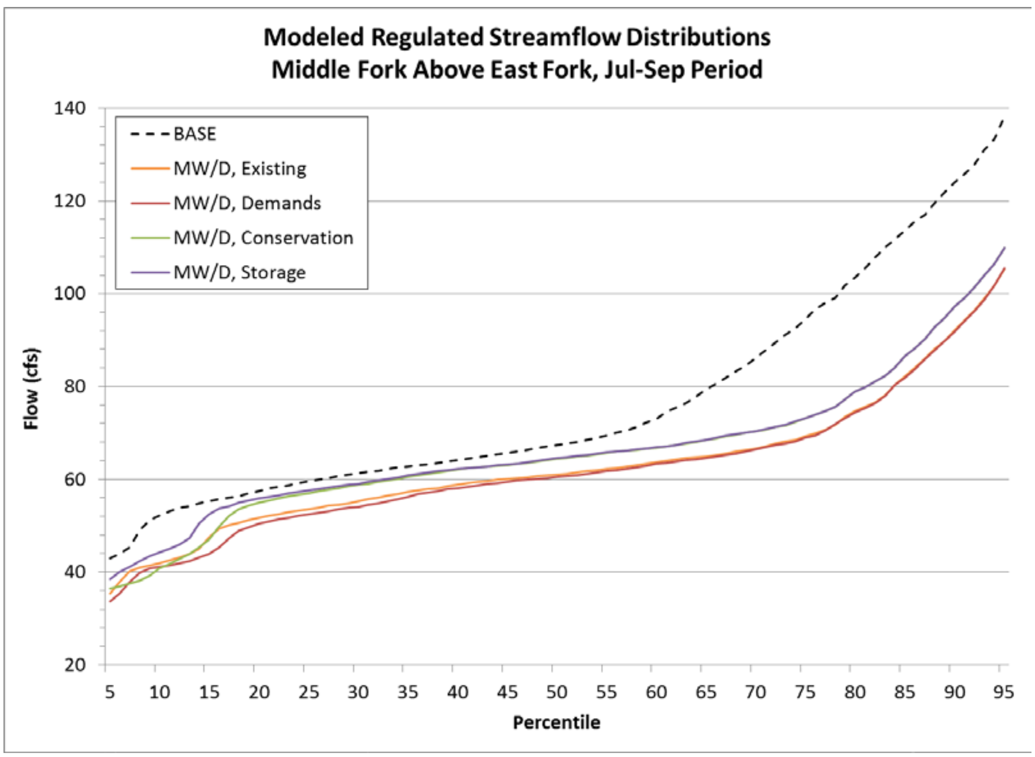


Figure 32. Statistical comparisons of summer streamflows along the Middle Fork Hood River for the MW/D climate scenario under each water resource alternative.

The effects of the alternatives along the East Fork Hood River during the summer months are shown in Figure 33. In contrast to the results along the Middle Fork, the Demands Alternative reduces streamflows along the East Fork during all but the lowest flow periods. Because there is currently no storage capacity along the East Fork to help balance demands with inflows, the additional consumptive use (Table 9) directly reduces streamflows. As Figure 33 illustrates, the exception to this is during very low flow periods. Unlike the Middle Fork instream agreement, the instream water right along the East Fork just below the Main Canal point of diversion is a senior right. Refer to Appendix A for complete lists of consumptive use and minimum flow priority dates. When water is scarce, the East Fork instream right is satisfied even before any shortages in irrigation demands are compensated. The instream right calls for just 2 cfs; however, tributary inflows and local gains downstream of the Main Canal point of diversion supplement the minimum flow requirement to yield approximately 10 cfs in the East Fork during the lowest flow periods.

The effects of implementing conservation measures along the East Fork are notable. Reducing the irrigation demands of EFID and MHID (Table 10) decreases the amount diverted through the Main Canal by up to 40 cfs during the summer months. This is clearly evident in Figure 33, by comparing the Conservation and Demands curves, except during very low flows when the conserved water is needed to meet irrigation demand shortages.

The potential reservoir along the West Fork Neal Creek was modeled with releases of 10 cfs to supplement EFID. As Figure 33 shows, 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. Because no shortages along Neal Creek were simulated (under any climate scenario-alternative combination), the reservoir releases effectively augment flows along the East Fork under all summer flow conditions. 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 relative to historical conditions.

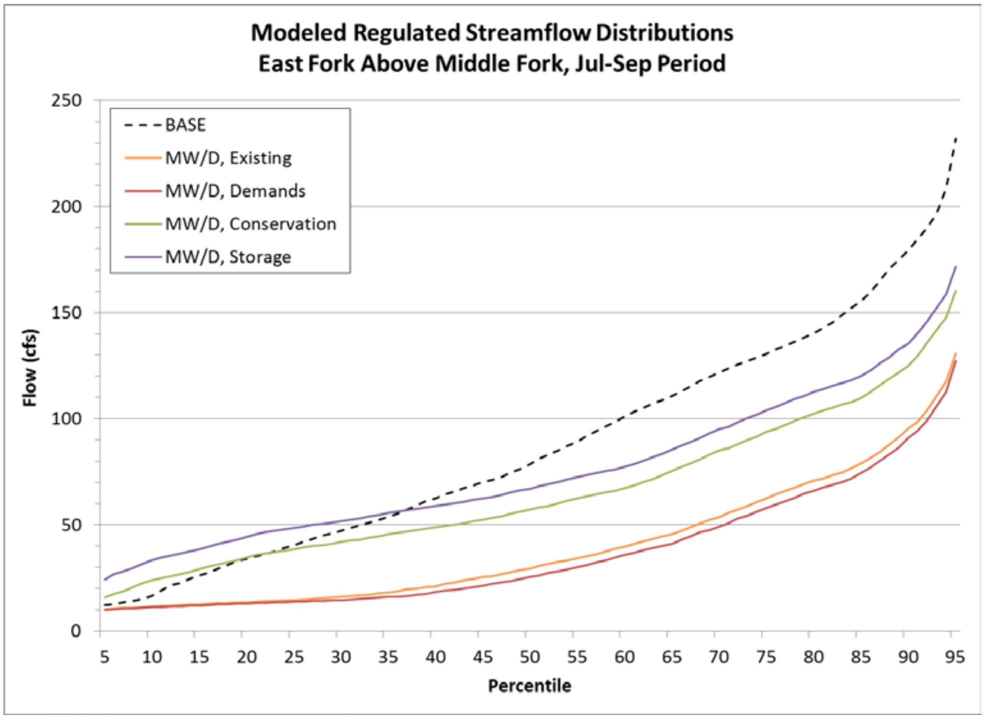


Figure 33. Statistical comparisons of summer streamflows along the East Fork Hood River for the MW/D climate scenario under each water resource alternative.

4.2 Consumptive Uses

Figure 34 through Figure 36 summarize the changes in simulated consumptive use shortages, displayed as percentages of demanded volumes, between the climate change scenarios (using the Existing Alternative) and the historical period. Results for districts where no changes were simulated under the Existing Alternative (DID, FID, and MFID) are not shown; however, results for all districts in the Hood River basin are provided in Appendix B. Because streamflows in the basin are projected to decrease during the summer months under future climate change, and water uses are greatest during this period, the impacts to consumptive uses are generally most notable during the months of July to September. However, with the exception of the MHID, summarized in Figure 34, the impacts to consumptive uses are moderated because of their senior water rights relative to minimum flow requirements.

Figure 34 and Figure 35 display results for the MHID and EFID, respectively. Whereas the EFID is simulated to be largely unaffected by climate change under the Existing Alternative, relatively significant impacts are projected for the MHID during the summer months, namely under the MW/D climate scenario. This disparity stems from the relative priorities of the MHID, EFID, and the instream right along the East Fork below the Main Canal point of diversion, along with the total volumes diverted for the MHID and EFID. The instream right of 2 cfs has a priority date of January 1, 1895, and the most senior rights of EFID and MHID have priority dates of November 25, 1895 and November 27, 1895, respectively (see Appendix A). Thus, during water scarce periods, the instream right is satisfied first, followed by EFID, and then MHID. Further, although 2 cfs is a small quantity relative to EFID consumptive use, which exceeds 100 cfs during the summer (WPN 2013a), it represents at least 20 percent of MHID consumptive use, which reaches a maximum of just 10 cfs (WPN 2013a). Therefore, when streamflows are low, the consumptive uses of MHID are among the first demands to be curtailed to satisfy the instream right, and the curtailment (or shortage) can be a relatively significant quantity.

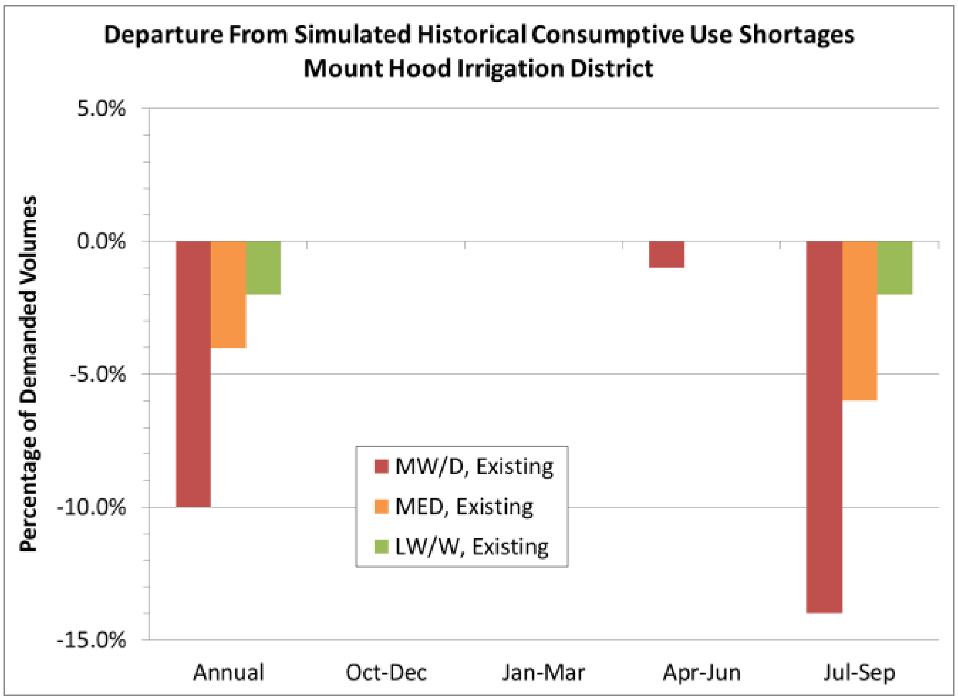


Figure 34. Changes in average consumptive use shortages in MHID and EFID from the simulated historical averages, as percentages of demanded volumes, for each of the climate scenario simulations, based on the existing water management scheme.

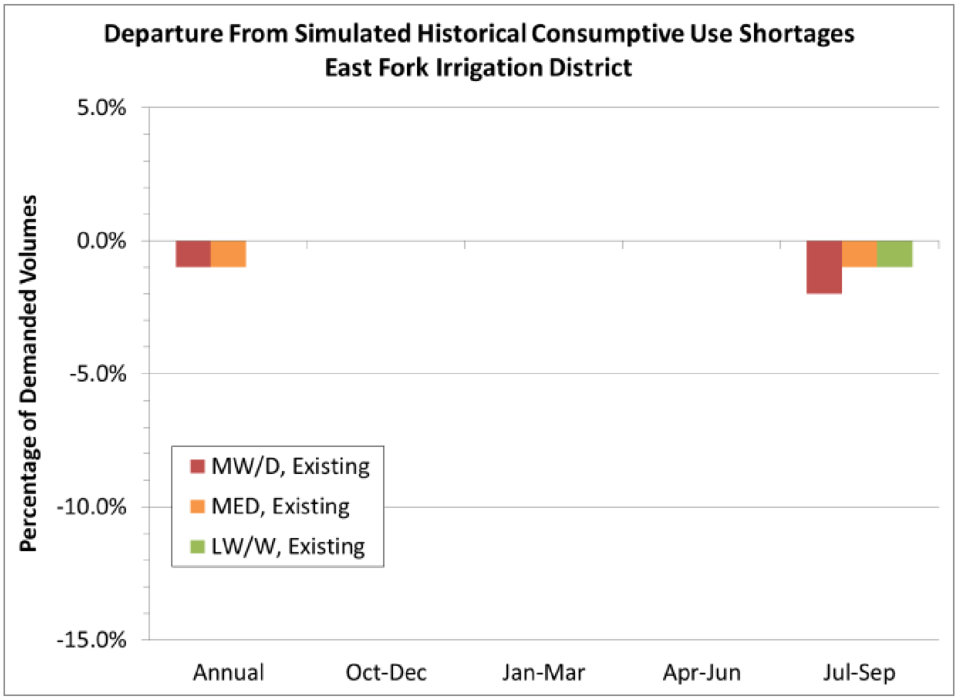


Figure 35. Changes in average consumptive use shortages in MHID and EFID from the simulated historical averages, as percentages of demanded volumes, for each of the climate scenario simulations, based on the existing water management scheme.

A summary of results for all potable water districts in the Hood River basin is provided in Figure 36. For clarity, the results of all potable water districts were summarized together. These results indicate that, under the Existing Alternative, the projected climate change impacts to potable water districts are generally negligible. The exception to this may be during the July to September period under the MW/D climate scenario. However, only the City of The Dalles and Crystal Springs diversions, located along tributaries to the upper East Fork Hood River exhibit any shortages during the future period. Although the City of The Dalles water right is the most senior in the Hood River basin (August 1, 1870), the Dog River is unable to satisfy average historical demands of this water district under the climate scenarios during low water years. The Crystal Springs water rights, in contrast, are junior to the instream right along the East Fork below the Main Canal and to the EFID and MHID rights. Thus, the WRM model simulates curtailment of the Crystal Springs diversion during low water years to serve the more senior downstream rights.

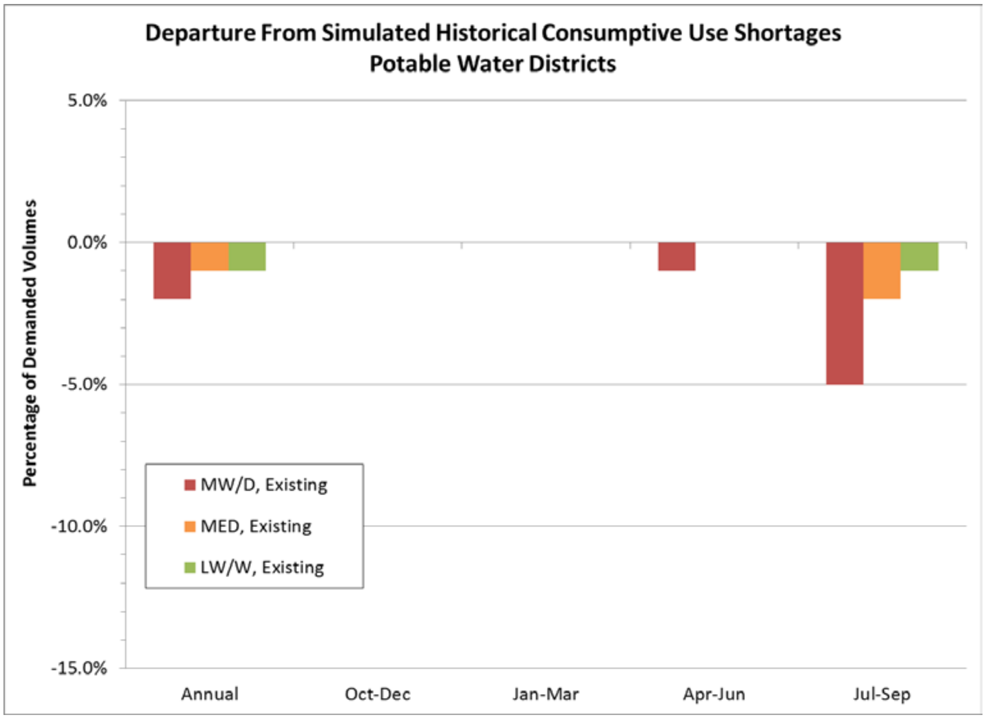


Figure 36. Changes in average consumptive use shortages in potable districts from the simulated historical averages, as percentages of demanded volumes, for each of the climate scenario simulations, based on the existing water management scheme.

A summary of the effects of the water resource alternatives on consumptive uses is provided in Figure 37, according to relative (percent) shortages by historical delivered volumes, for each water district. Consistent with the discussions above, the MW/D climate scenario simulations indicate that the MHID is the primarily water district impacted. Again, this is largely an artifact of the model ensuring that the instream right along the East Fork below the Main Canal is always satisfied. However, the results also indicate that implementing water conservation measures in EFID and MHID, and adding new storage along Neal Creek, essentially eliminates the MHID shortages. As mentioned earlier, because the modeled potable district shortages occur entirely along East Fork Hood River tributaries, the same conservation and storage measures benefit the potable districts, as well.

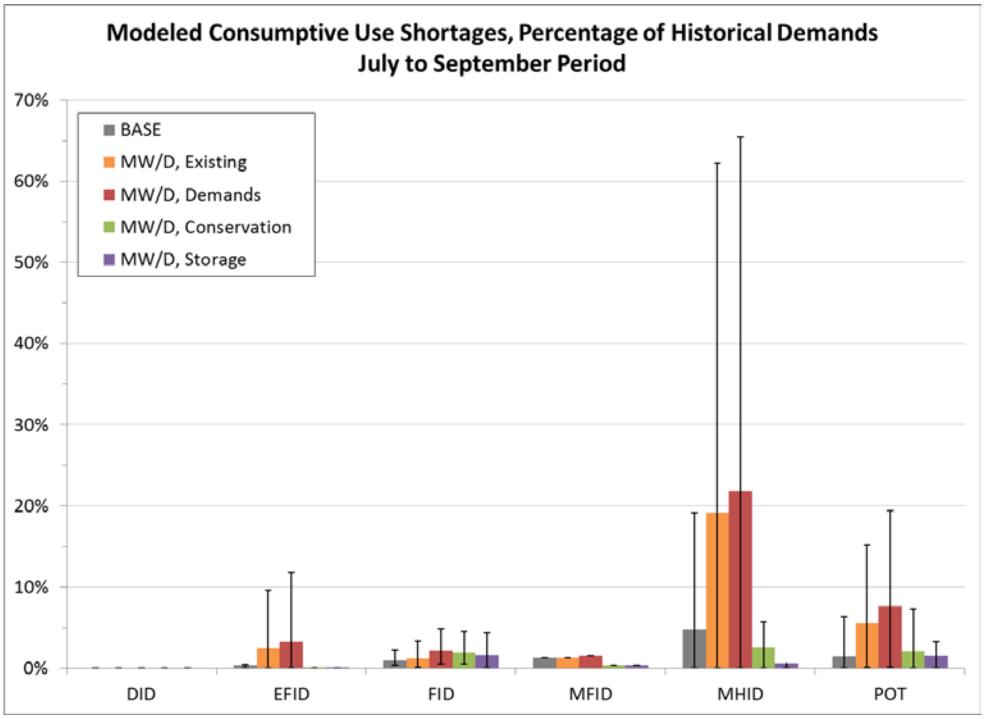


Figure 37. Comparison of average modeled summer consumptive use shortages, as percentages of demanded volumes, for the MW/D climate scenario under each water resources alternative. Modeled 10th and 90th percentiles indicated by error bars.

4.3 Minimum Flows

As mentioned in Section 4.2, because the instream water rights and agreements are mostly junior to other water rights (refer to Appendix A), the projected strains on streamflows during the summer months are generally simulated to impact the Hood River basin's minimum flow requirements more so than the consumptive use and hydropower rights. Figure 38 displays the absolute (cfs) changes in simulated minimum flow shortages between the climate change scenarios (using the Existing Alternative) and the historical period for the Hood River at Tucker Bridge. Due to climate change alone (i.e., no additional consumptive use demands), during the July to September period, the Hood River at Tucker Bridge instream right is simulated to experience additional shortages of approximately 10 to 40 cfs.

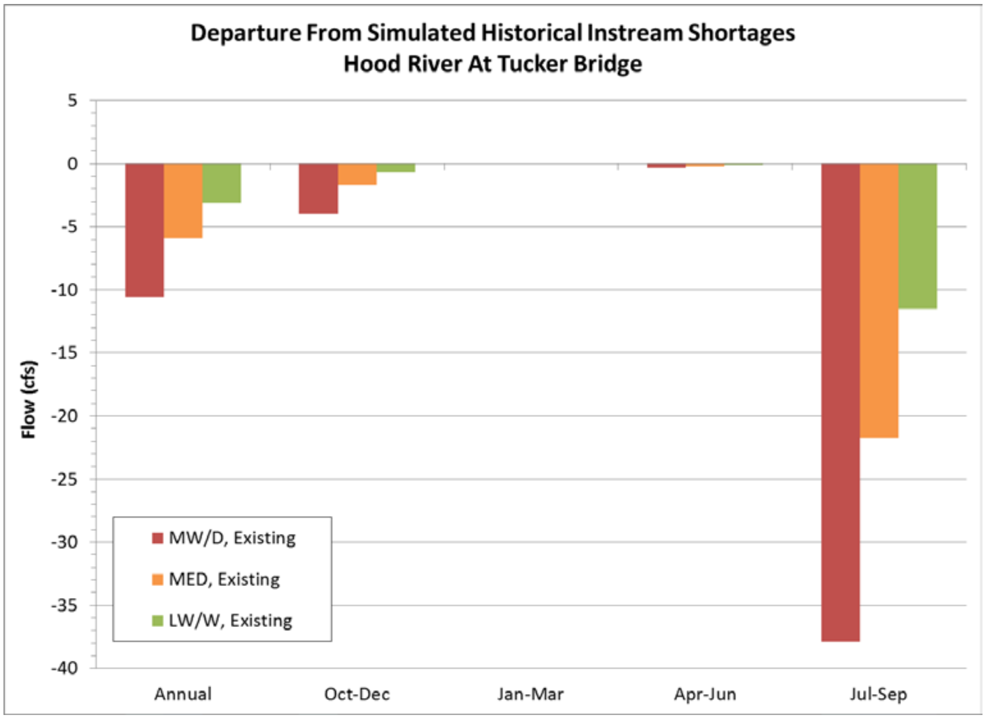


Figure 38. Changes in average minimum flow shortages along the Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

The analogous results for the instream rights along the West Fork Hood River below Lake Branch and the East Fork Hood River above the Middle Fork are presented in Figure 39 and Figure 40, respectively. As mentioned in Section 3.3, the instream right along the Middle Fork Hood River is rarely met during the historical period. Figure 40 suggests that the majority of the summer impact along the mainstem Hood River is related to strains along the East Fork. Because consumptive use shortages are not simulated along the West Fork during the future period, the simulated increases in shortages for the minimum flow requirement below Lake Branch are due solely to simulated impacts of climate change on natural streamflows. However, irrigation demands are relatively large along the East Fork; thus, the simulated increases in shortages for the minimum flow requirement above the Middle Fork are exacerbated by the demands of more senior consumptive use rights competing for limited water availability. Because the instream right is senior to the EFID and MHID irrigation rights, and the flow requirement is relatively small, no minimum flow shortages are simulated along the East Fork Hood River below the Main Canal.

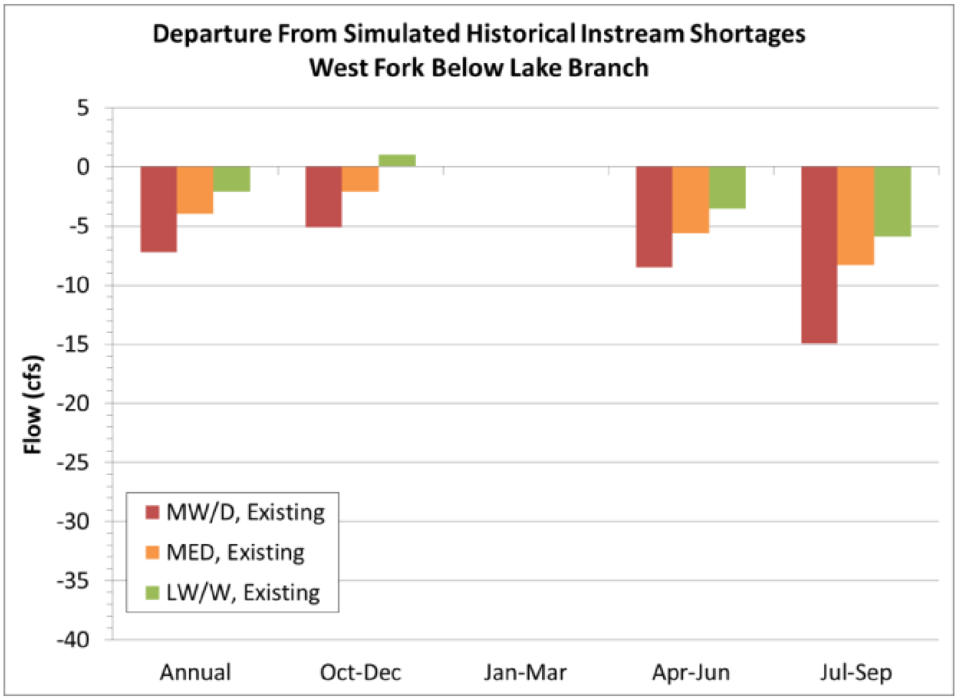


Figure 39. Changes in average minimum flow shortages along the West Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

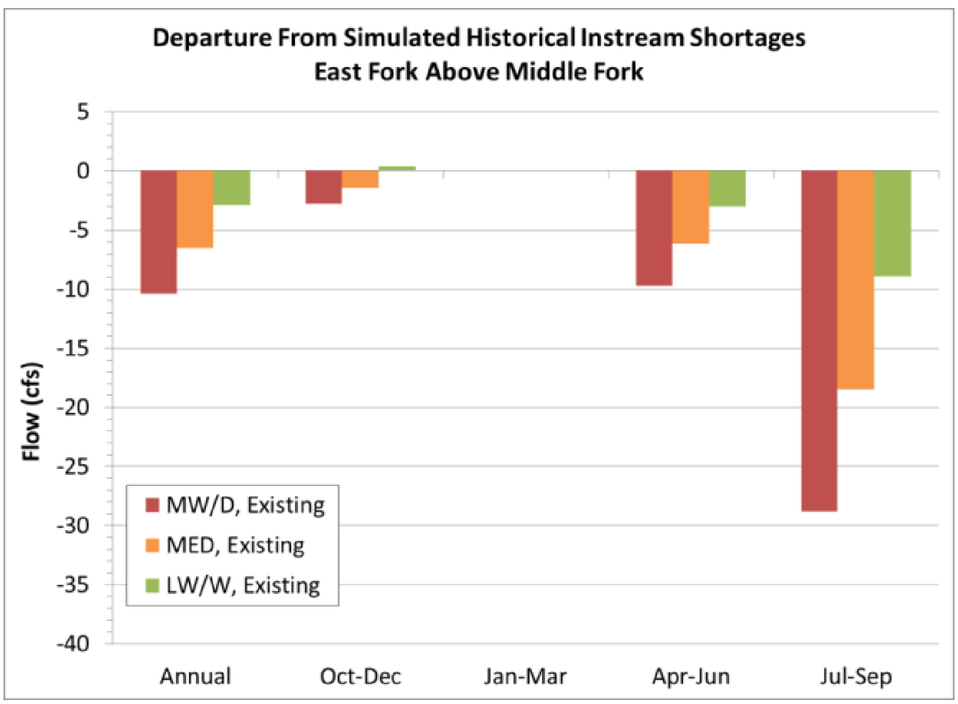
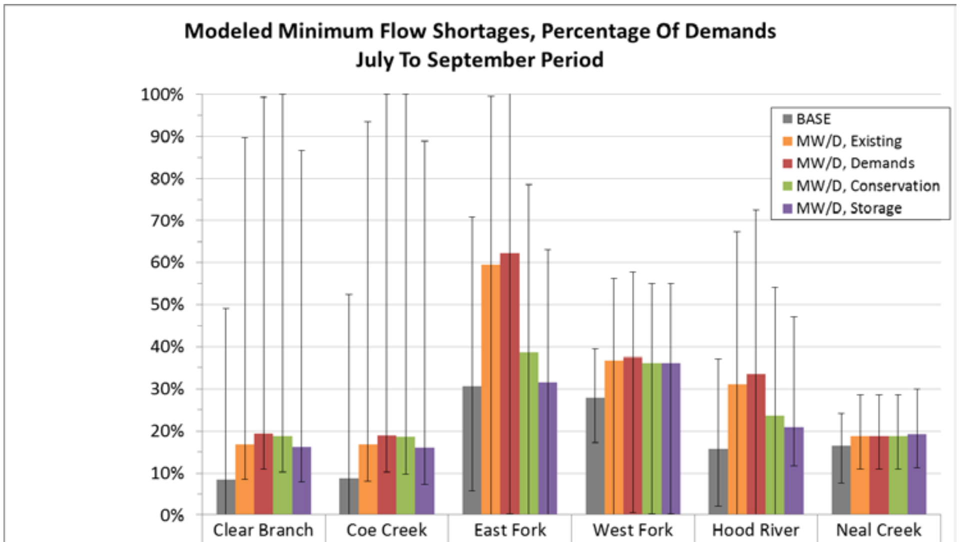


Figure 40. Changes in average minimum flow shortages along the East Fork Hood River from the simulated historical averages for each of the climate scenario simulations, based on the existing water management scheme.

Not all minimum flow requirements in the Hood River basin exhibit large shortages under the future climate scenarios. These include the five instream rights or agreements excluded from the results of Section 3.3, as well as the instream right along Neal Creek and the instream agreements along Clear Branch and Coe Creek. To maintain consistency with the results presented in Section 3.3, these latter three minimum flow requirements were included in Figure 41 along with the instream rights listed in Figure 38 through Figure 40.

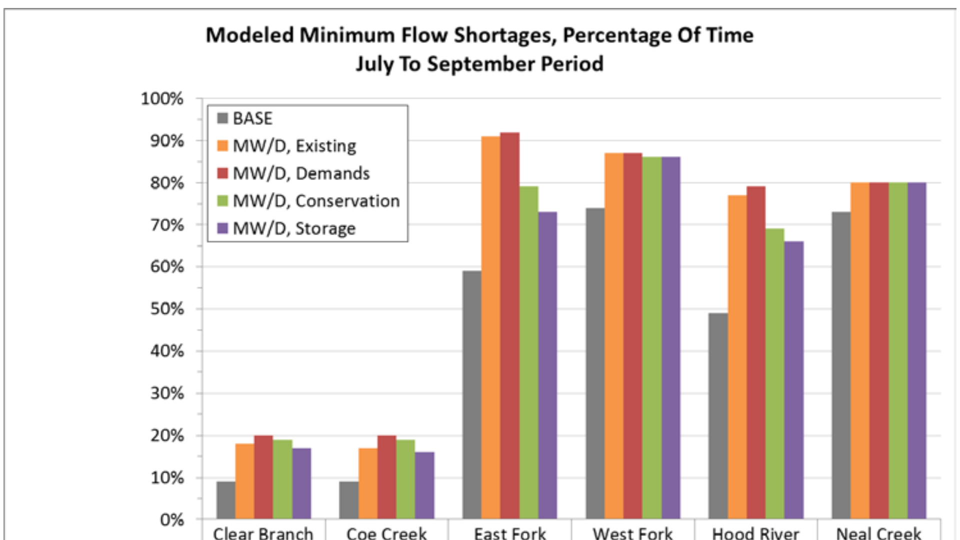
Figure 41 and Figure 42 compare the simulated relative (percent) shortages according to average required flows and occurrences, respectively, during the summer months. Results for the historical period and for the MW/D climate scenario are shown. Although shortages in the requirements along Clear Branch and Coe Creek are simulated to account for significant proportions of the required flows during some years (indicated by the error bars in Figure 41, which represent the 10^{th} and 90^{th} percentiles of simulated values), these shortages occur only 20 percent or less of the time (Figure 42). Conversely, the shortages along Neal Creek generally only account for less than 20 percent of the required flows (Figure 41), though these shortages are simulated to occur often (Figure 42). However, the changes in shortages under the MW/D climate scenario for these three instream rights and agreements are not significant.

Perhaps the most notable results illustrated in Figure 41 and Figure 42 are the simulated decreases in shortages along the East Fork Hood River above the Middle Fork and Hood River at Tucker Bridge upon implementation of the water conservation and additional storage schemes. Scaling back the Main Canal diversion and adding the Neal Creek storage facility may reduce the East Fork minimum flow shortages by over 20 percent according to required flows. These water savings carry down to the mainstem Hood River, where the reduction in shortages at Tucker Bridge could reach 10 percent of required flows.



	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 41. Comparisons of average modeled summer minimum flow shortages, as percentages of required flows, for the MW/D climate scenario under each water resources alternative. Modeled 10th and 90th percentiles indicated by error bars.



	Clear Branch	Coe Creek	East Fork	West Fork	Hood River	Neal Creek
BASE	9%	9%	59%	74%	49%	73%
MW/D, Existing	18%	17%	91%	87%	77%	80%
MW/D, Demands	20%	20%	92%	87%	79%	80%
MW/D, Conservation	19%	19%	79%	86%	69%	80%
MW/D, Storage	17%	16%	73%	86%	66%	80%

Figure 42. Comparisons of average modeled summer minimum flow shortages, as percentages of time, for the MW/D climate scenario under each water resources alternative.

4.4 Hydropower Demands

Average relative (percent) changes in flows through hydropower facilities (grouped by irrigation district) under each climate scenario-alternative combination from the simulated historical averages are provided in Table 11 for MHID (FID had minimal changes). For clarity, the changes are summarized on an annual (water year) basis and by quarter. The red and blue hues represent decreases and increases, respectively, from the simulated historical average shortages, with the darker colors corresponding to greater differences.

Table 11. Simulated future departures from simulated historical hydropower flows (annual and quarterly averages) for Middle Fork Irrigation District.

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

Akin to the future period results of consumptive uses in the Hood River basin, simulated changes in flows through hydropower facilities are generally not significant. Although the seniorities of the hydropower water rights relative to those of minimum flow requirements (see Appendix A) factor into these results, the primary reason for the tempered impact of projected climate change on hydropower operations in the basin is perhaps the timing of peak power production versus the timing of peak consumptive water use. Figure 43 and Figure 44, adapted from the *Hood River Basin Water Use Assessment* (WPN 2013a), illustrate the average total hydropower production in FID and MFID, respectively, over the course of approximately 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 the future period (see Section 4.1).

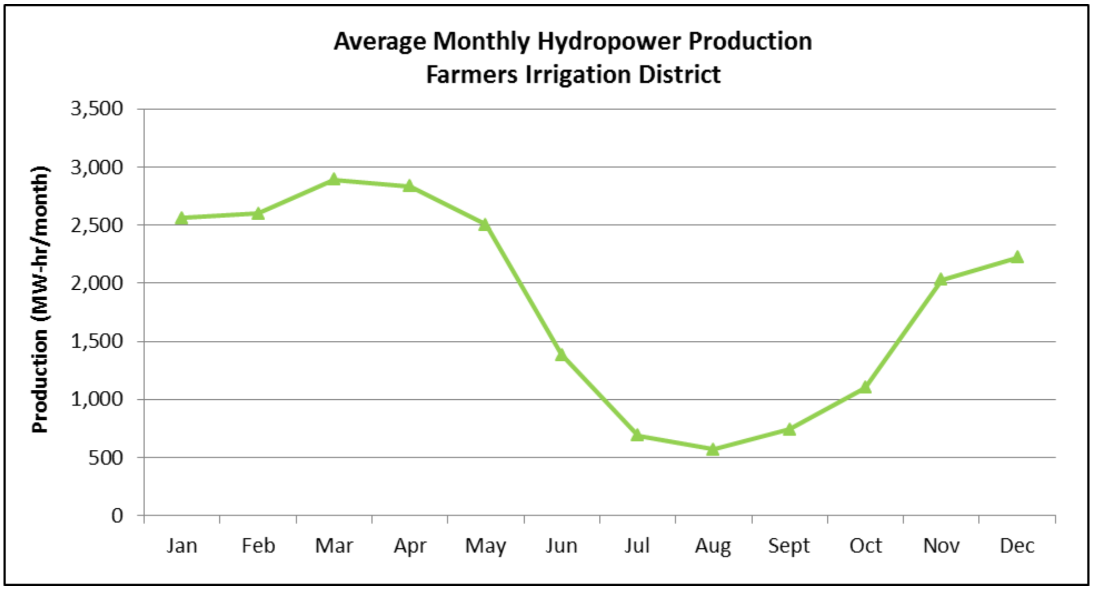


Figure 43. Historically observed average monthly hydropower production in FID (WPN 2013a).

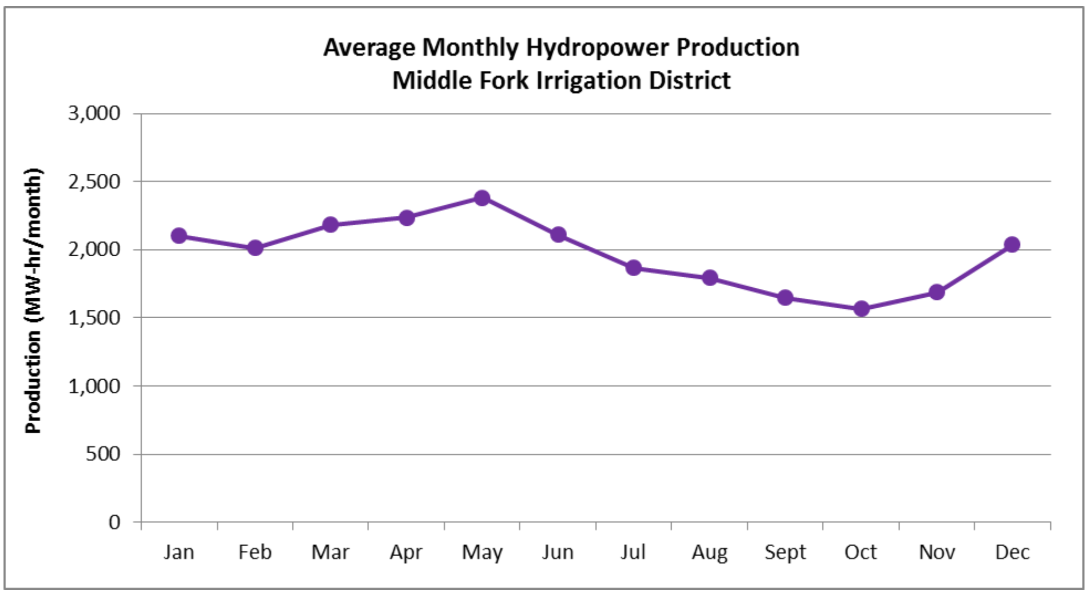


Figure 44. Historically observed average monthly hydropower production in MFID (WPN 2013a).

4.5 Storage Volumes

The simulated monthly average storage volumes for the Green Point Reservoir system and Laurance Lake under the Existing Alternative are provided in Figure 45 and Figure 46, respectively. As shown, the effects of projected climate change on water volumes in the Green Point Reservoir system appear somewhat muted. Under the MW/D climate scenario, the average peak volume (in May) is reduced by just 10 percent. Under the LW/W climate scenario, the average peak volume is simulated to increase by 5 percent. These results are controlled by the Green Point Reservoir system's relatively small capacity and the manner in which it is operated in the WRM model (see Section 3.5).

The Green Point Reservoir system is configured to fill during the months of March through June, but, as Figure 16 shows, the majority of inflows needed to fill the system occur between March and May when consumptive uses are low and streamflows remain relatively high throughout the future period (see Section 4.1). Based on the existing capacity of the Green Point Reservoir system (938 acre-feet), an average of just 5.2 cfs are needed during the months of March through May to fill the system. Under the BASE conditions, average inflows of 6.3 cfs occur during this period. Average inflows decrease to 5.7 cfs under the MW/D climate scenario, a reduction of just 10 percent (which coincides with the peak volume reduction apparent in Figure 45). Thus, the effects of climate change alone on water volumes in the Green Point Reservoir system fill ability are not expected to be dramatic, but with reduced summer inflow, maintaining reservoir volume through the end of the irrigation season may be more difficult.

For Laurance Lake, the effects of climate change on storage volumes are more notable (Figure 46). Although the peak volumes are not reduced excessively, but are shifted to earlier in the year, the minimum average monthly storage volumes (in October) are simulated to decrease by approximately 500 to 1000 acre-feet, or by 28 to 55 percent. These results are indicative of how the runoff regime in the Hood River basin is expected to change under future climate change: greater streamflows in the winter but lower streamflows in the summer (see Section 4.1). These impacts are apparent in the storage volumes of Laurance Lake because the reservoir receives inflows and releases outflows continuously throughout the year (see Section 3.5).

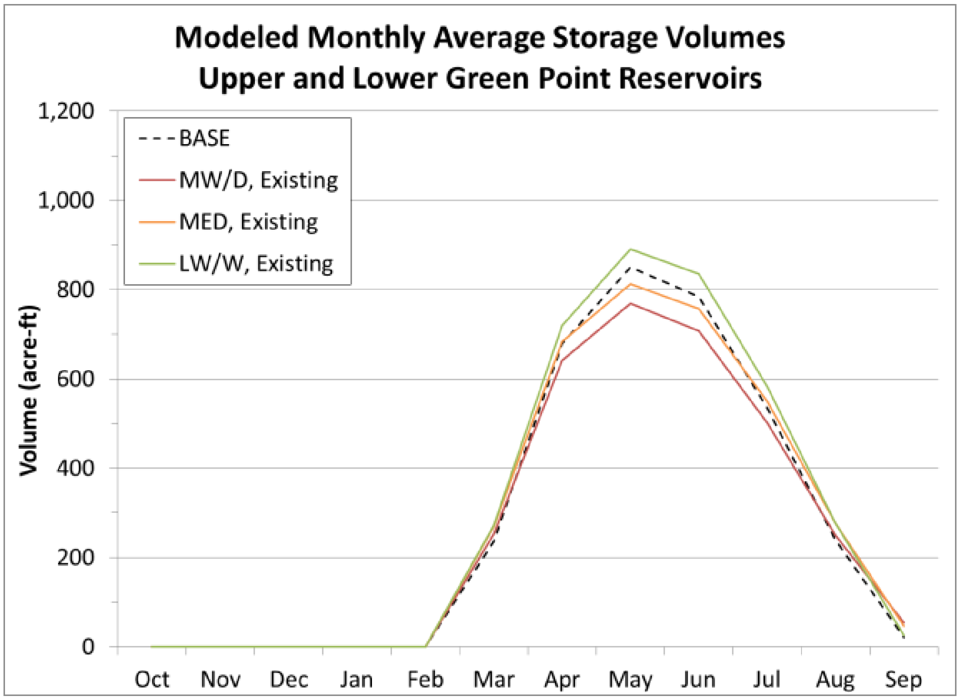


Figure 45. Comparisonsof average monthly storage volumes in the Green Point Reservoir system for each of the climate scenario simulations, based on the existing water management scheme.

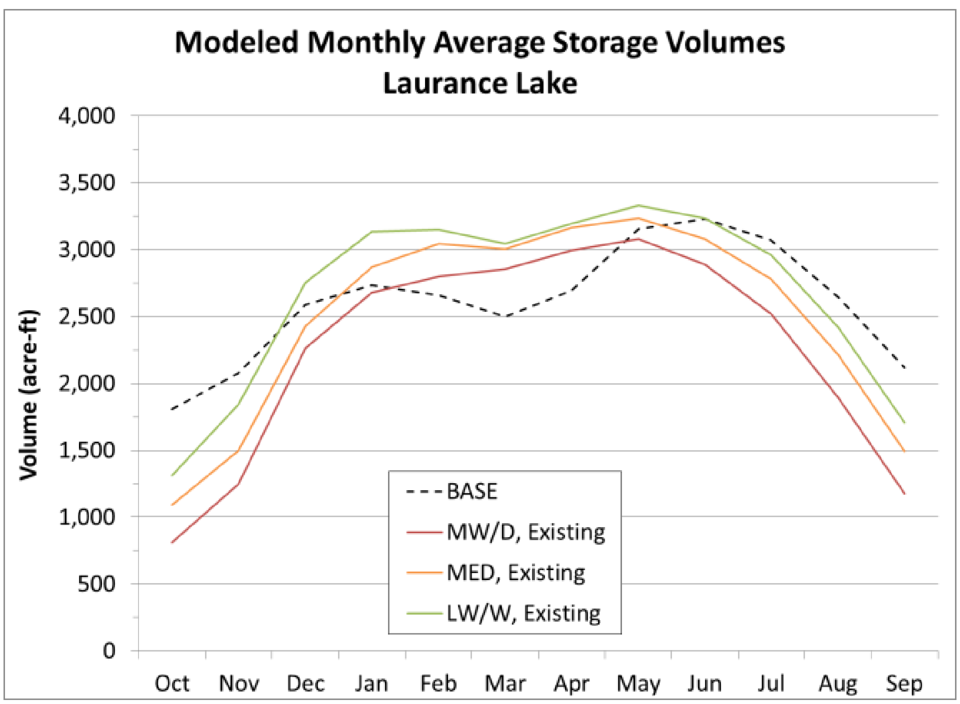


Figure 46. Comparison of average monthly storage volumes in the Laurance Lake for each of the climate scenario simulations, based on the existing water management scheme.

Figure 47 and Figure 48 illustrate the differences in average storage volumes in the Green Point Reservoir system under the alternative simulations for the MW/D climate scenario. Although the future increases in consumptive use in FID could be significant (Table 9), no significant demand shortages are simulated in FID under the Existing or Demands alternatives (Figure 37). Thus, the simulated impacts to storage volumes in the Green Point Reservoir system under the Demands Alternative are not significant. Further, because future water conservation measures are not expected to substantially scale back irrigation demands in FID (Table 10), the simulated impacts to storage volumes under the Conservation Alternative are also negligible.

As Figure 48 shows, increasing the storage capacity in the Upper Green Point Reservoir (to a system total of 1,499 acre-feet) is simulated to increase the average stored volumes by approximately 80 acre-feet (compared the Conservation Alternative) throughout the July to September period. This assumes that the way the system is operated currently remains the same. If the reservoir storage is increased, there would be potential to fill earlier and store flow from the increased runoff during the winter and early spring. Although this represents just 5 percent of the total capacity, this additional volume could be reserved for augmenting streamflows during critical low flow periods. For example, an additional 3 cfs could be released continuously throughout a two-week window.

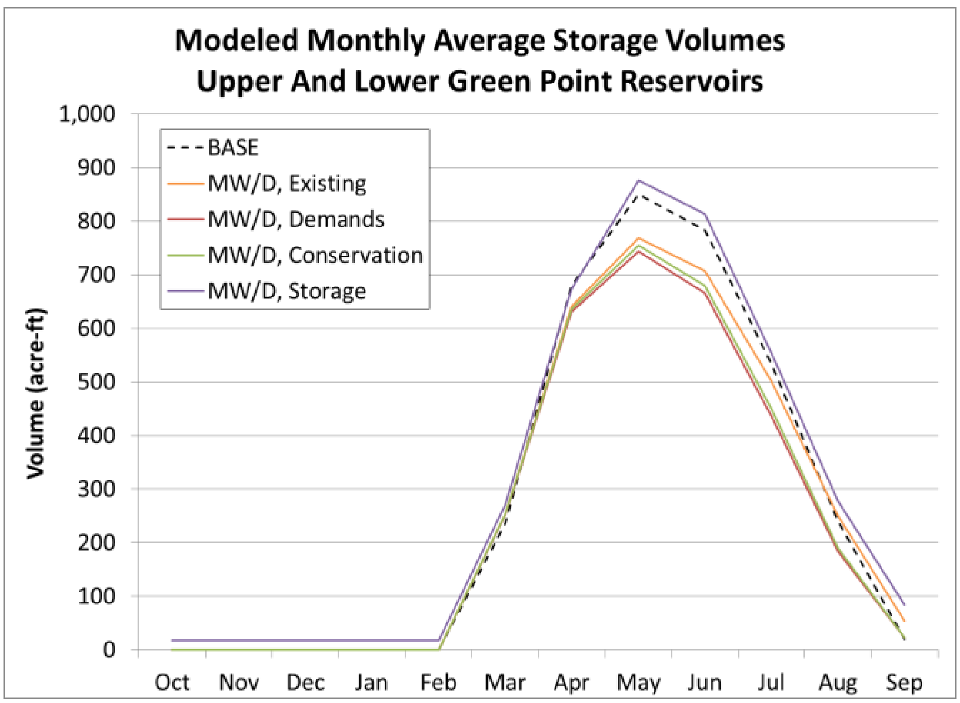


Figure 47. Comparisons of modeled average monthly storage volumes and simulated changes in average storage volumes in the Green Point Reservoir system for the MW/D climate scenario under each water resource alternative.

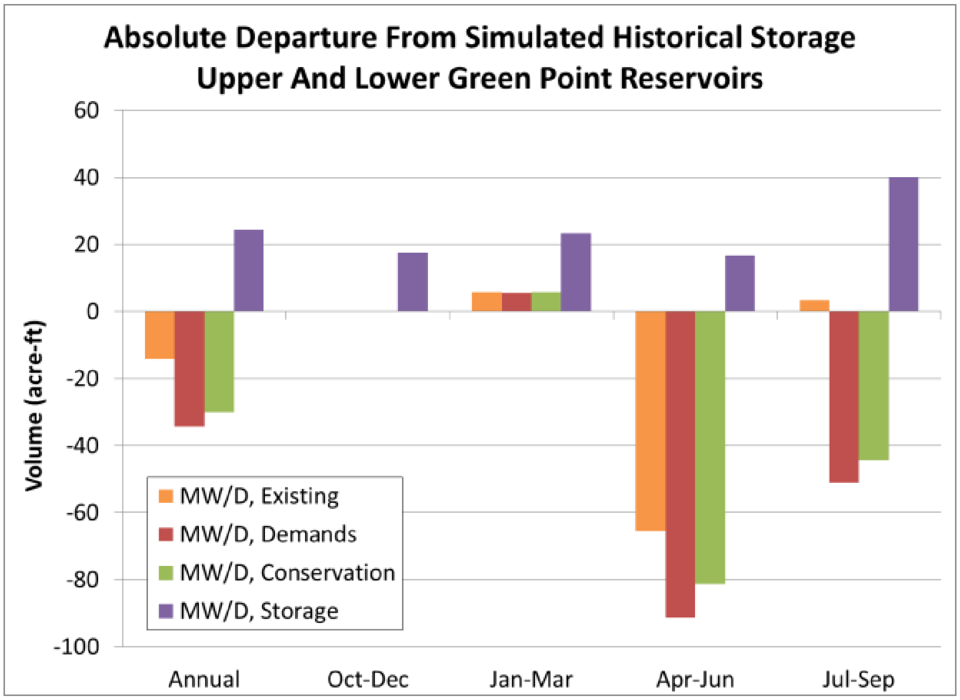


Figure 48. Comparisons of absolute average monthly storage volumes and simulated changes in average storage volumes in the Green Point Reservoir system for the MW/D climate scenario under each water resource alternative.

Figure 49 and Figure 50 illustrate the differences in average storage volumes in Laurance Lake under the alternative simulations for the MW/D climate scenario. These results are synonymous with those discussed above for the Green Point Reservoir system, with only small impacts simulated under the Demands and Conservation alternatives. However, again, the results indicate that the additional storage capacity (to a total of 3,935 acre-feet) could allow for supplemental streamflows during critical low flow periods. The average additional 270 acre-feet of storage during the July to September period could provide 10 cfs continuously throughout a two-week period.

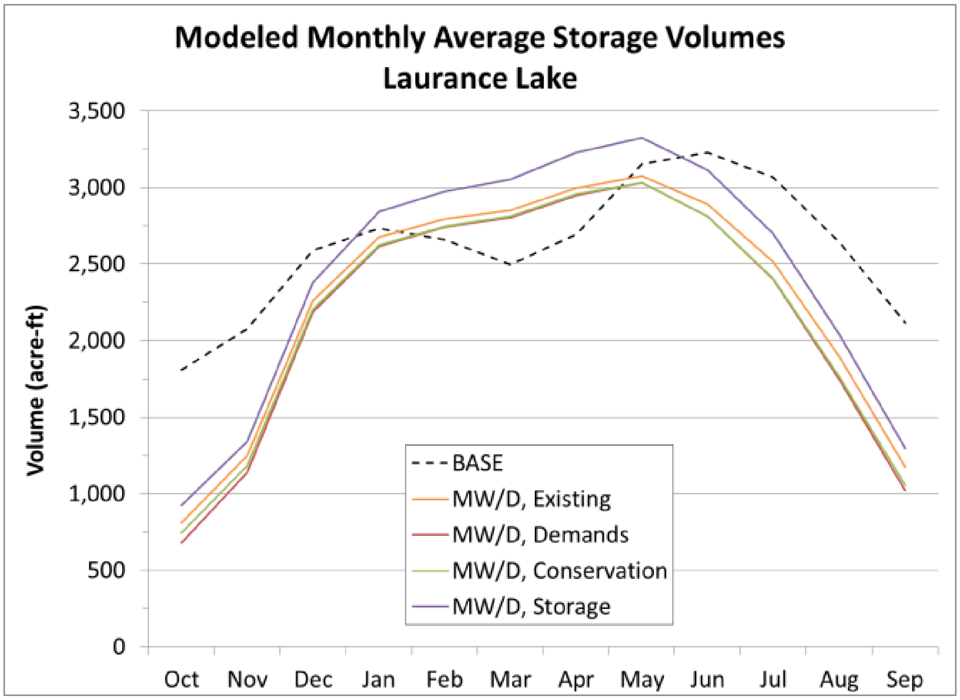


Figure 49. Comparison of average monthly storage volumes and simulated changes in average storage volumes in Laurance Lake for the MW/D climate scenario under each water resource alternative.

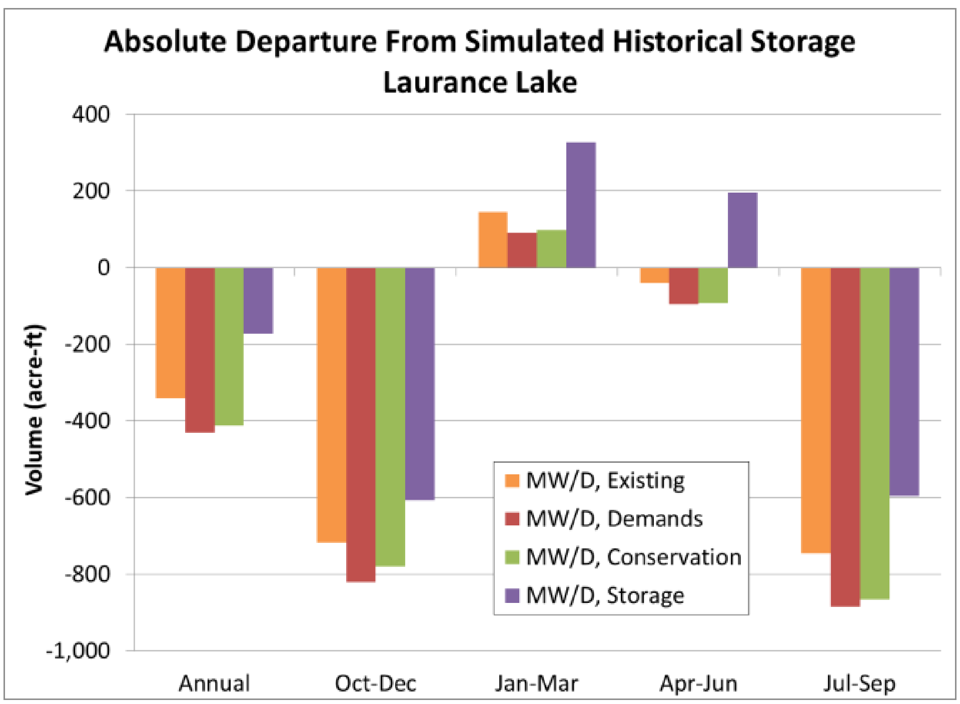


Figure 50. Comparison of absolute average monthly storage volumes and simulated changes in average storage volumes in Laurance Lake for the MW/D climate scenario under each water resource alternative.

The remaining component of the Storage Alternative entails a new reservoir along the West Fork of Neal Creek with a capacity of 2,557 acre-feet. As mentioned in Section 4.1, the potential reservoir was modeled with releases of 10 cfs during the months of June through September to supplement EFID. As Figure 51 shows, on average, inflows during the months of January through April nearly fill the reservoir throughout the future period under the more dramatic MW/D climate scenario. Although not shown, the potential reservoir does fill during all but two (very dry) future years. Also mentioned in Section 4.1, 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. Because no shortages along Neal Creek were simulated (under any climate scenario-alternative combination), the reservoir releases effectively augment flows along the East Fork under all summer flow conditions.

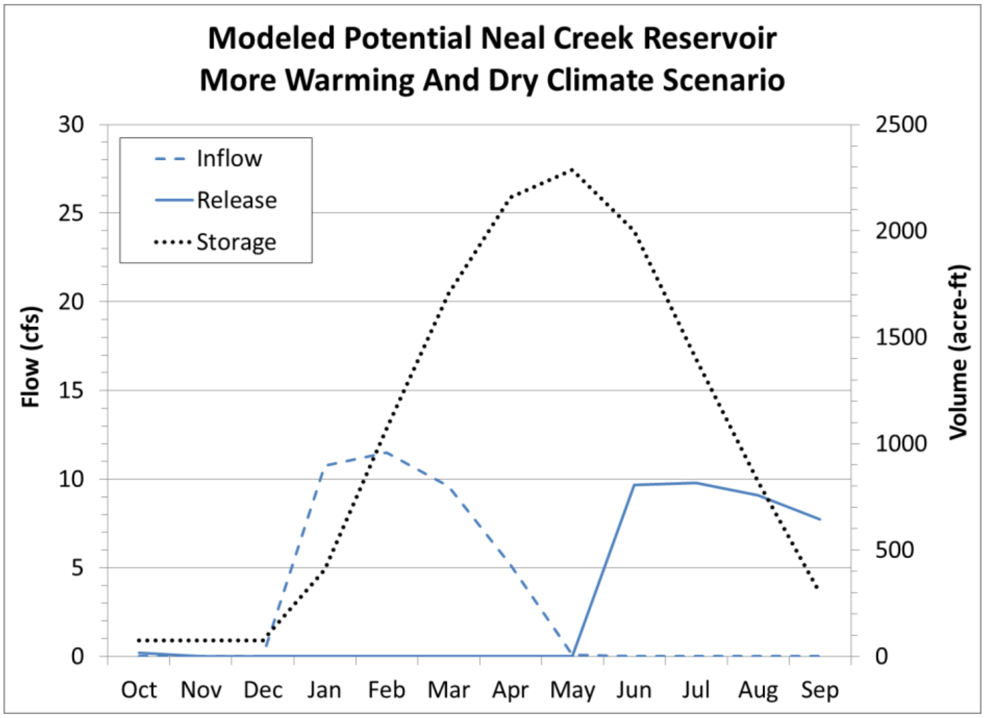


Figure 51. Modeled average monthly inflows to, storage volumes of, and releases from the potential Neal Creek Reservoir for the MW/D climate scenario.

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5.0 CONCLUSIONS

For the historical period (water years 1980 through 2009), the WRM model appears to capture the observed timing and quantity of regulated streamflows relatively well. There is, however, a low flow bias of approximately 50 cfs along the mainstem Hood River at Tucker Bridge during the late summer. This may be due to errors in modeled upstream water management activities, or simply a function of the limitations of the surface water model used to provide natural flows to the WRM model.

The under-simulations of late summer flows along the mainstem may be mostly attributable to under-simulations along the Middle Fork and East Fork. Up to approximately 40 cfs of the low bias along the mainstem can be traced to the upstream under-simulations. Assuming that modeled water management activities and processes across the Hood River basin are accurate, these data suggest that approximately 10 cfs of the low bias may be linked to lower basin groundwater contributions to the mainstem Hood River. Additionally, the corresponding 20 cfs under-simulation along the East Fork Hood River may be attributable to unrepresented groundwater contributions. The case for groundwater inputs to the Middle Fork Hood River is not as strong; however, since headwater gage data were not available to help discern the potential source(s) of the under-simulation at this location. In summary, it may be reasonable to ascribe approximately 10 to 30 cfs (up to 10 percent) of flow in the Hood River system during the late summer period to groundwater sources. Of course, this is based on several assumptions, including the accuracies of the structure of and data within the WRM model and the surface water model.

Because the surface water model is not equipped with a physical groundwater modeling component, but the lower Hood River basin does interact with the aquifer system that underlies it, gains to the mainstem Hood River from stream-aquifer interactions are not explicitly accounted for in the WRM model. Future efforts should include incorporating a physical groundwater modeling component into the surface water model, and assessing whether the enhanced natural streamflows, once applied to WRM model, better capture the late summer flow regime in the lower Hood River basin.

The potential climate conditions of the future period (water years 2030 through 2059) are simulated to alter the timing and character of seasonal runoff across the Hood River basin. Increases in both precipitation and temperature during the fall and winter months produce greater streamflows during these months. However, less precipitation and snowpack during the spring and summer months yield lower streamflows when demands for water are greatest. Along the mainstem Hood River, under the existing water management scheme, modeled climate change scenarios yield decreases in summer streamflows of approximately 10 to 30 percent. Similar streamflow reductions are simulated along the West Fork and Middle Fork.

However, along the East Fork, where irrigation demands are relatively high and no significant storage facility currently exists, the simulated summer reductions in streamflows approach 60 percent.

Under the existing water management scheme, the modeled climate scenarios show the largest streamflow impacts during the months of July through September, when demands for water are greatest, thus further reducing low streamflows. The impacts are scaled by the relative seniorities of water rights across the Hood River basin, generally with consumptive use and hydropower demands given priority over minimum flow requirements. Instream shortages along the lower East Fork Hood River are shown to increase during the summer quarter, as are instream shortages along the mainstem Hood River at Tucker Bridge. However, the seniority of the instream right along the upper East Fork relative to irrigation rights results in additional simulated shortages in MHID during low water years.

The modeled climate change impacts to the Upper and Lower Green Point Reservoirs under the existing water management scheme were difficult to accurately simulate in the WRM model because of the small individual contributing areas. Also these results may be due to the lack of simulated demand shortages in FID, the small storage capacities relative to simulated inflows, and perhaps the general reservoir operating criteria. However, future simulations of Laurance Lake exhibit increased storage during the winter months and significantly decreased storage during the summer months. Given the simplifications applied to these reservoirs in the WRM model, the future results should be viewed qualitatively. Subsequent efforts should include a more rigorous approach to modeling the Hood River basin's reservoirs and dependent downstream demands.

The modeled future increases in consumptive demands do not significantly reduce deliveries to irrigation or potable water rights, satisfying instream rights or agreements, hydropower operations, or storage volumes. However, meeting these additional demands basin-wide does result in an approximate reduction of 10 cfs in the simulated streamflows along the mainstem Hood River during the summer months.

The largest impacts of modeled future water conservation measures occur along the East Fork Hood River and the irrigation districts that are served by the Main Canal. Reducing the flows diverted through the Main Canal (by up to 40 cfs during the summer) mitigates the projected reductions in streamflows along the East Fork and mainstem. This helps satisfy the instream requirements along these reaches. Coupled with the modeled releases of the potential Neal Creek Reservoir, the conservation actions effectively eliminate the simulated future shortages in MHID.

Of the potential storage options investigated, the Neal Creek Reservoir option provides more consistent benefits to streamflows and demands. The modeled reservoir fills nearly every year during the winter and spring months, and is able to supplement EFID with up to 10 cfs throughout the summer without significantly impacting streamflows along Neal Creek. The reservoir releases reduce the amount diverted through the Main Canal by up to an additional 10 cfs, thus improving streamflows along the lower East Fork and mainstem Hood River during the summer months.

Increasing the storage capacity of the Upper Green Point Reservoir or Laurance Lake did not consistently or significantly benefit streamflows or demands. However, additional capacity in these reservoirs may provide enough additional storage to allow for short-term releases during very low flow periods. The MW/D climate scenario simulations suggest that implementing both the conservation measures and the additional storage in Laurance Lake could mitigate the effects of climate change along the Middle Fork, to the extent that future streamflows, demands, and instream flows during the critical summer months are only impacted during very low flow periods. Under the more extreme MW/D climate scenario, the average additional storage in these reservoirs could provide continuous 3 cfs to Ditch Creek and 10 cfs to Clear Branch during a critical two week window.

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APPENDIX A

Table A1. Consumptive use water rights incorporated into the WRM model.

Local Water District	Model Demand	Purpose	Amount (cfs)	Priority Date
Dee Irrigation District	divWF	irrigation	9.22	9/13/1909
		multiple	12.50	2/10/1978
		supplemental	6.00	3/7/1931
East Fork Irrigation District	divEFID	irrigation	104.45	11/25/1895
		irrigation	5.99	3/13/1964
		irrigation	4.45	8/8/1977
		multiple	25.00	2/23/1977
		multiple	12.10	8/15/1978
Farmers Irrigation District	divDitch	irrigation	5.00	12/31/1874
		irrigation	1.25	12/31/1891
		irrigation	10.00	10/6/1902
	divFC	irrigation	39.85	5/7/1906
		multiple	26.00	7/28/1977
		spraying	30.00	12/5/1974
		supplemental	7.50	7/16/1969
	divLL	irrigation	15.00	12/19/1892
		supplemental	5.00	12/31/1899
		supplemental	25.00	12/1/1905
		supplemental	10.00	12/1/1905
Middle Fork Irrigation District	divEmil	supplemental	0.55	4/2/1965
	divEvans	irrigation	1.06	12/31/1894
		irrigation	0.95	12/31/1896
		irrigation	0.38	12/31/1900
		irrigation	0.36	12/31/1901
		temperature	5.47	2/20/1981
	divGriswell	irrigation	0.87	6/16/1924
	divMLa	irrigation	75.00*	1/2/1962
	divMLb	irrigation		
	divMLc	irrigation		
	divMLd	irrigation		
	divRogers	irrigation	1.54	1/19/1910

Local Water District	Model Demand	Purpose	Amount (cfs)	Priority Date
		irrigation	3.63	3/30/1972
	divTrout	irrigation	0.22	12/31/1892
		irrigation	0.16	12/31/1897
		irrigation	0.19	12/31/1898
		irrigation	3.63	3/30/1972
	divWisehart	irrigation	1.00	8/9/1915
Mount Hood Irrigation District	divMHID	irrigation	10.65	11/27/1895
		irrigation	0.90	11/27/1895
		multiple	8.00	4/22/1977
		multiple	14.26	8/8/1978
		supplemental	1.10	3/2/1964
City of Hood River	divHoodRiver	potable	19.00	9/13/1923
City of The Dalles	divTheDalles	potable	All flowƗ	8/1/1870
Crystal Springs Water District	divCrystalSprings	potable	1.00	6/7/1930
		potable	2.65	1/22/1964
		potable	3.50	3/3/1969
Ice Fountain Water District	divIceFountain	potable	3.00	7/25/1984
Oak Grove Water Company	divOakGrove	potable	0.25	11/8/1929
		potable	0.08	3/6/1963
		potable	0.09	3/2/1994
Odell Water Company	divOdell	irrigation	0.66	12/31/1882
		potable	0.25	3/3/1927
		potable	1.00	5/31/1929
Parkdale Water Company	divParkdale	potable	1.50	3/26/1971

*Based on conversations with MFID and the Hood River Basin Water Use Assessment (WPN 2013a), water right modeled as follows: 10 percent of average monthly mainline consumptive use to divMLa (0 to 5 cfs), 10 percent of mainline consumptive use to divMLb (0 to 5 cfs), average monthly differences in flows through powerplants No. 1 and No. 2 to divMLc (0 to 4 cfs), and average monthly differences in flows through powerplants No. 2 and No. 3 to divMLd (0 to 32 cfs). ƗModeled with monthly average reported uses (WPN 2013a).

Table A2. Consumptive use water rights incorporated into the WRM model.

Model Demand	Return Location	Return Fraction	Reference
divMLb	MFID mainline	0.20	MFID
divEvans	MFID mainline	0.20	MFID
divMHID	East Fork	0.20	WPN
divEFID	East Fork	0.20 (Oct-Mar)	WPN
		0.50 (Apr-Jun)	WPN
		0.20 (Jul-Aug)	WPN
		0.35 (Sep)	WPN

Table A3. Instream water rights in the Hood River Basin (values in cfs) incorporated into the WRM model (WPN 2013a).

Priority Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
East Fork Hood River above Middle Fork												
11/31983	100	100	100	150	150	150	100	100	100	150	150	150
Hood River at Powerdale Dam												
11/3/1983	170	270	270	270	170	170	130	100	100	100	100	170
Hood River at Powerdale Dam												
10/8/1998					250	250	250	250	250	220		
Neal Creek above Hood River												
11/3/1983	13	13	13	20	20	20	13	13	5	20	20	13
Middle Fork Hood River below Eliot Branch												
8/12/1991	150	150	150	255	255	255	150	150	100	255	255	150
West Fork Hood River below Lake Branch												
12/6/1991	150	150	150	255	255	255	150	180	176	195	255	180
Lake Branch below Lost Lake												
12/6/1991	67	67	67	168	113	66.9	44.8	38.6	37.1	35.7	67	67
Dog River above East Fork												
12/6/1991	12	12	20	20	20	20	12	7.01	6.05	7.79	14.7	12
East Fork Hood River below Main Canal												
1/1/1895	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1

Table A4. Instream flow agreements in the Hood River Basin (values in cfs) incorporated into the WRM model (WPN 2013a).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Green Point Creek above West Fork											
40	40	40							20	20	20
Hood River at Tucker Bridge											
250	250	250	250	250	250	250	250	250	250	250	250
Clear Branch below Laurance Lake											
20	20	20	20	20	3	3	3	3	8.5	18.7	20
Coe Creek below diversion											
5	5	5	5	5	5	5	5	5	5	5	5
Eliot Branch below diversion											
5	5	5	5	5	5	5	5	5	5	5	5

Notes: Green Point Creek requirement of 40 cfs extends to April 4th, and requirement of 20 cfs begins October 16th. Requirement along Hood River was simplified for the WRM model (WPN 2013a). Clear Branch requirement of 3 cfs begins June 10th and extends to October 7th; the agreement was simplified for the WRM model (WPN 2013a). All instream agreements were assigned junior priorities (January 1, 2007).

Table A5. Hydropower water rights incorporated into the WRM model.

Local Water District	Model Demand	Purpose	Amount (cfs)	Priority Date
Farmers Irrigation District	toFIDPP2	power	73.00	2/11/1981
	toFIDPP2 toFIDPP3	power	35.00	2/11/1981
Middle Fork Irrigation District	toMFIDPP1 toMFIDPP2 toMFIDPP3	power	20.00	1/26/1981
	toMFIDPP1 toMFIDPP2 toMFIDPP3	power	20.00	1/26/1982

Table A6. Reservoir characteristics incorporated into the WRM model.

Reservoir	Capacity (acre-feet)	Storage Right (acre-feet)	Priority Date	Modeled Storage Right (acre-feet)
Green Point Reservoir system	938	1,003	11/22/1933	1,500
Laurance Lake	3,565	3,550	4/6/1967	25,000

Note: The modeled storage right (accrual) volumes were increased above the legal storage rights (and physical capacities) to account for the apparent lack of separation of storage right releases and reservoir bypass releases in the average monthly reservoir release numbers reported in the OWRD water use reports (WPN 2013a).

Table A7. Historical daily observational data incorporated into the WRM model.

Location	Period of Record*	Continuous
Hood River at Tucker Bridge	10/1/1979-9/30/2009	Yes
West Fork Hood River near Dee	10/1/1979-9/30/2009	Yes
East Fork Hood River above Middle Fork	8/2/1996-9/30/2009	No
East Fork Hood River above Main Canal	6/5/2001-9/30/2009	No
Middle Fork Hood River above East Fork	10/2/2001-9/30/2009	No
Tony Creek	10/2/2001-11/26/2007	No
Clear Branch below Laurance Lake	10/1/2001-9/30/2009	Yes
Farmers Canal	10/1/1979-9/30/1989	No
Dee Canal	10/2/1979-9/30/2009	Yes
Main Canal	10/1/1979-9/30/2009	Yes
Mount Hood Canal	10/1/1979-9/28/1989	Yes

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APPENDIX B

Average changes in streamflows under each climate scenario-alternative combination from the simulated historical averages for the mainstem Hood River and all three forks are provided in Tables B1 through B4. For clarity, the changes are summarized on an annual (water year) basis and by quarter. The red and blue hues represent decreases and increases, respectively, from the simulated historical streamflow averages, with the darker colors corresponding to greater differences. Both the relative (percent) differences and absolute (flow) differences are provided.

Table B1. Simulated future departures from simulated historical flows (annual and quarterly averages) for the Hood River at Tucker Bridge.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-10	-12	-8	-6	-69	-80	-52	-43
	Oct-Dec	2	1	2	2	16	9	16	17
	Jan-Mar	11	10	10	10	131	125	127	128
	Apr-Jun	-19	-19	-17	-17	-178	-185	-167	-162
	Jul-Sep	-29	-32	-22	-17	-80	-88	-60	-48
MED Scenario	Annual	-3	-5	-1	1	-23	-33	-4	4
	Oct-Dec	5	4	5	5	36	28	35	37
	Jan-Mar	19	18	18	18	227	221	226	224
	Apr-Jun	-13	-14	-12	-12	-127	-134	-115	-111
	Jul-Sep	-19	-22	-11	-7	-52	-61	-29	-19
LW/W Scenario	Annual	2	1	5	6	16	6	34	43
	Oct-Dec	13	12	13	14	94	87	95	95
	Jan-Mar	17	17	17	17	210	203	207	206
	Apr-Jun	-7	-8	-6	-6	-69	-76	-59	-54
	Jul-Sep	-11	-14	-3	2	-30	-39	-7	5

Table B2. Simulated future departures from simulated historical flows (annual and quarterly averages) for the West Fork Hood River above the East Fork.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-7	-8	-7	-7	-27	-29	-26	-26
	Oct-Dec	0	0	0	0	1	0	1	0
	Jan-Mar	9	9	9	9	56	55	56	55
	Apr-Jun	-19	-20	-19	-19	-100	-102	-100	-100
	Jul-Sep	-16	-18	-16	-15	-26	-28	-25	-24
MED Scenario	Annual	-2	-3	-2	-2	-7	-9	-6	-6
	Oct-Dec	4	3	3	3	13	11	12	12
	Jan-Mar	16	16	16	16	99	98	99	98
	Apr-Jun	-15	-15	-14	-15	-75	-77	-75	-75
	Jul-Sep	-10	-11	-9	-9	-15	-18	-14	-14
LW/W Scenario	Annual	1	1	2	2	4	4	7	7
	Oct-Dec	9	11	11	11	31	38	39	39
	Jan-Mar	14	14	14	14	87	88	88	88
	Apr-Jun	-9	-9	-9	-9	-49	-48	-46	-46
	Jul-Sep	-7	-9	-7	-6	-11	-14	-10	-10

Table B3. Simulated future departures from simulated historical flows (annual and quarterly averages) for the Middle Fork Hood River above the East Fork.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-5	-6	-4	-4	-8	-9	-6	-6
	Oct-Dec	3	2	2	3	4	3	3	4
	Jan-Mar	7	7	7	7	17	17	17	17
	Apr-Jun	-13	-13	-12	-12	-27	-27	-25	-25
	Jul-Sep	-17	-18	-13	-12	-12	-13	-9	-9
MED Scenario	Annual	0	-1	1	1	0	-1	2	2
	Oct-Dec	4	4	4	5	6	5	6	7
	Jan-Mar	15	15	15	15	36	35	36	36
	Apr-Jun	-8	-8	-8	-8	-17	-18	-16	-16
	Jul-Sep	-10	-10	-6	-6	-7	-8	-4	-4
LW/W Scenario	Annual	4	4	5	5	6	6	8	8
	Oct-Dec	11	11	11	12	16	15	16	16
	Jan-Mar	15	15	15	15	36	36	36	36
	Apr-Jun	-4	-4	-3	-3	-8	-9	-7	-7
	Jul-Sep	-5	-5	-1	-1	-3	-4	-1	-1

Table B4. Simulated future departures from simulated historical flows (annual and quarterly averages) for the East Fork Hood River above the Middle Fork.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-18	-21	-2	3	-36	-42	-4	5
	Oct-Dec	6	4	7	7	15	11	18	18
	Jan-Mar	15	14	14	14	56	52	54	54
	Apr-Jun	-20	-22	-10	-7	-47	-52	-23	-17
	Jul-Sep	-54	-58	-17	-2	-37	-40	-12	-1
MED Scenario	Annual	-9	-12	7	12	-17	-23	14	23
	Oct-Dec	7	6	9	9	18	14	21	21
	Jan-Mar	22	21	22	22	83	79	82	82
	Apr-Jun	-13	-15	-3	-1	-31	-35	-8	-2
	Jul-Sep	-39	-44	4	20	-27	-30	3	14
LW/W Scenario	Annual	0	-3	15	20	0	-6	30	39
	Oct-Dec	15	13	16	16	37	32	40	40
	Jan-Mar	19	18	19	19	73	69	72	72
	Apr-Jun	-6	-8	4	6	-13	-18	9	14
	Jul-Sep	-22	-28	24	41	-15	-19	17	28

Average changes in consumptive use shortages (and reservoir release shortages, where indicated) under each climate scenario-alternative combination from the simulated historical averages for the main irrigation and potable water districts in the Hood River basin are provided in Tables B5 through B10. For clarity, the changes are summarized on an annual (water year) basis and by quarter. The red and blue hues represent decreases and increases, respectively, from the simulated historical average shortages, with the darker colors corresponding to greater differences. Both the relative (percent) differences and absolute (volume) differences are provided.

Table B5. Simulated future departures from simulated historical consumptive use shortages (annual and quarterly averages) for the Dee Irrigation District.

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

Table B6. Simulated future departures from simulated historical consumptive use and reservoir release shortages (annual and quarterly averages) for the Farmers Irrigation District.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (af)	Demands (af)	Conservation (af)	Storage (af)
MW/D Scenario	Annual	-1	-1	-1	-1	-17	-96	-75	-51
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	-1	-1	-1	-17	-96	-75	-51
MED Scenario	Annual	0	-1	-1	0	8	-53	-45	9
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	-1	0	0	8	-53	-45	9
LW/W Scenario	Annual	0	-1	-1	0	23	-29	-14	26
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	0	0	0	23	-29	-14	26

Table B7. Simulated future departures from simulated historical consumptive use shortages (annual and quarterly averages) for the East Fork Irrigation District.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (af)	Demands (af)	Conservation (af)	Storage (af)
MW/D Scenario	Annual	-1	-2	0	0	-352	-483	44	66
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	-4	-7	0	0
	Jul-Sep	-2	-3	0	0	-347	-476	44	66
MED Scenario	Annual	-1	-1	0	0	-140	-215	62	66
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	-1	-2	0	0
	Jul-Sep	-1	-2	0	0	-139	-214	62	66
LW/W Scenario	Annual	0	-1	0	0	-51	-99	65	66
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-1	-1	0	0	-51	-99	65	66

Table B8. Simulated future departures from simulated historical consumptive use and reservoir release shortages (annual and quarterly averages) for the Middle Fork Irrigation District.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (af)	Demands (af)	Conservation (af)	Storage (af)
MW/D Scenario	Annual	0	0	1	1	0	-22	73	73
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	-1	1	1	0	-22	73	73
MED Scenario	Annual	0	0	1	1	0	-22	73	73
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	-1	1	1	0	-22	73	73
LW/W Scenario	Annual	0	0	1	1	0	-22	73	73
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	-1	1	1	0	-22	73	73

Table B9. Simulated future departures from simulated historical consumptive use shortages (annual and quarterly averages) for the Mount Hood Irrigation District.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (af)	Demands (af)	Conservation (af)	Storage (af)
MW/D Scenario	Annual	-10	-11	1	3	-195	-231	29	55
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	-1	-1	0	0	-5	-6	0	0
	Jul-Sep	-14	-16	2	4	-190	-225	28	55
MED Scenario	Annual	-4	-5	2	3	-85	-104	46	62
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	-2	-3	0	0
	Jul-Sep	-6	-7	4	5	-83	-101	46	62
LW/W Scenario	Annual	-2	-2	3	3	-37	-52	57	63
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	-1	-2	0	0
	Jul-Sep	-2	-3	5	5	-36	-50	57	63

Table B10. Simulated future departures from simulated historical consumptive use shortages (annual and quarterly averages) for the Hood River basin's potable (municipal) water districts.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (af)	Demands (af)	Conservation (af)	Storage (af)
MW/D Scenario	Annual	-2	-2	-1	-1	-89	-152	-40	-29
	Oct-Dec	0	-1	-1	-1	0	-20	-20	-20
	Jan-Mar	0	0	0	0	0	-2	-2	-2
	Apr-Jun	-1	-1	0	0	-9	-10	-7	-7
	Jul-Sep	-5	-6	-1	0	-80	-121	-11	0
MED Scenario	Annual	-1	-1	0	0	-39	-78	-13	-7
	Oct-Dec	0	-1	-1	-1	0	-15	-15	-15
	Jan-Mar	0	0	0	0	0	-1	-1	-1
	Apr-Jun	0	0	0	0	-4	-5	-3	-3
	Jul-Sep	-2	-3	0	0	-35	-56	7	13
LW/W Scenario	Annual	-1	-1	0	0	-18	-44	0	4
	Oct-Dec	0	-1	-1	-1	0	-12	-12	-12
	Jan-Mar	0	0	0	0	0	-2	-2	-2
	Apr-Jun	0	0	0	0	-2	-3	-2	-2
	Jul-Sep	-1	-1	0	1	-15	-27	15	19

Average changes in minimum flow shortages under each climate scenario-alternative combination from the simulated historical averages for the instream rights and agreements in the Hood River basin are provided in Tables B11 through B23. For clarity, the changes are summarized on an annual (water year) basis and by quarter. The red and blue hues represent decreases and increases, respectively, from the simulated historical average shortages, with the darker colors corresponding to greater differences. Both the relative (percent) differences and absolute (flow) differences are provided.

Table B11. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Clear Branch below Laurance Lake.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-1	-2	-1	-1	0	0	0	0
	Oct-Dec	-6	-7	-7	-5	-1	-1	-1	-1
	Jan-Mar	3	2	2	2	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-9	-11	-11	-8	0	0	0	0
MED Scenario	Annual	1	1	1	1	0	0	0	0
	Oct-Dec	-3	-4	-4	-2	0	-1	-1	0
	Jan-Mar	4	4	4	4	1	1	1	1
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-4	-5	-5	-4	0	0	0	0
LW/W Scenario	Annual	2	2	2	3	0	0	0	0
	Oct-Dec	0	0	0	1	0	0	0	0
	Jan-Mar	6	6	6	6	1	1	1	1
	Apr-Jun	1	1	1	1	0	0	0	0
	Jul-Sep	-1	-3	-2	0	0	0	0	0

Table B12. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Coe Creek below diversion.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-3	-4	-4	-3	0	0	0	0
	Oct-Dec	-5	-6	-6	-5	0	0	0	0
	Jan-Mar	1	1	1	1	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-8	-10	-10	-7	0	-1	-1	0
MED Scenario	Annual	-1	-2	-1	-1	0	0	0	0
	Oct-Dec	-2	-3	-3	-2	0	0	0	0
	Jan-Mar	3	2	2	2	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-3	-4	-4	-2	0	0	0	0
LW/W Scenario	Annual	1	0	0	1	0	0	0	0
	Oct-Dec	0	0	0	0	0	0	0	0
	Jan-Mar	4	4	4	4	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	-2	-1	1	0	0	0	0

Table B13. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Dog River above East Fork.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-3	-9	-11	-11	0	-1	-2	-2
	Oct-Dec	0	-11	-11	-11	0	-1	-1	-1
	Jan-Mar	12	2	2	2	2	0	0	0
	Apr-Jun	-16	-19	-19	-19	-3	-4	-4	-4
	Jul-Sep	-2	1	-13	-14	0	0	-1	-1
MED Scenario	Annual	-1	-6	-8	-8	0	-1	-1	-1
	Oct-Dec	1	-10	-10	-10	0	-1	-1	-1
	Jan-Mar	14	5	5	5	2	1	1	1
	Apr-Jun	-11	-14	-14	-14	-2	-3	-3	-3
	Jul-Sep	-3	0	-10	-11	0	0	-1	-1
LW/W Scenario	Annual	1	-4	-5	-5	0	-1	-1	-1
	Oct-Dec	4	-6	-6	-6	1	-1	-1	-1
	Jan-Mar	12	2	2	2	2	0	0	0
	Apr-Jun	-5	-8	-8	-8	-1	-2	-2	-2
	Jul-Sep	-3	-2	-8	-8	0	0	-1	-1

Table B14. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for East Fork Hood River above Main Canal.

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

Table B15. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for East Fork Hood River above Middle Fork.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-8	-9	-3	-1	-10	-12	-3	-1
	Oct-Dec	-2	-3	-1	-1	-3	-4	-2	-2
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	-6	-7	-2	0	-10	-11	-3	-1
	Jul-Sep	-29	-31	-8	-1	-29	-32	-8	-1
MED Scenario	Annual	-5	-6	0	1	-7	-8	0	2
	Oct-Dec	-1	-2	-1	-1	-1	-2	-1	-1
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	-4	-4	0	1	-6	-7	-1	1
	Jul-Sep	-18	-21	1	8	-19	-21	1	7
LW/W Scenario	Annual	-2	-3	2	3	-3	-4	3	4
	Oct-Dec	0	0	1	1	0	0	1	1
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	-2	-2	1	2	-3	-4	1	2
	Jul-Sep	-9	-11	8	13	-9	-12	8	13

Table B16. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Eliot Branch above diversion.

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

Table B17. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Green Point Creek above West Fork.

Scenario	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	0	0	0	0	0	0	0	0
	Oct-Dec	-1	-1	-1	-1	0	0	0	0
	Jan-Mar	1	1	1	1	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	0	0	0	0	0	0	0
MED Scenario	Annual	1	0	0	0	0	0	0	0
	Oct-Dec	-1	-1	-1	-1	0	0	0	0
	Jan-Mar	1	1	1	1	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	0	0	0	0	0	0	0
LW/W Scenario	Annual	-1	1	1	1	0	0	0	0
	Oct-Dec	-7	0	0	0	-1	0	0	0
	Jan-Mar	1	1	1	1	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	0	0	0	0	0	0	0	0

Table B18. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Hood River at Tucker Bridge.

Scenario	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-5	-5	-3	-2	-11	-13	-6	-4
	Oct-Dec	-2	-2	-1	-1	-4	-5	-4	-4
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-15	-18	-8	-5	-38	-44	-20	-13
MED Scenario	Annual	-3	-3	-1	-1	-6	-8	-2	0
	Oct-Dec	-1	-1	-1	0	-2	-2	-1	-1
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-8	-11	-2	1	-22	-27	-5	1
LW/W Scenario	Annual	-2	-2	0	0	-3	-5	1	2
	Oct-Dec	0	0	0	0	-1	-1	0	0
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	0	0	0	0	0	0	0	0
	Jul-Sep	-4	-6	2	4	-12	-17	3	9

Table B19. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Hood River at Powerdale Dam.

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

Table B20. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Lake Branch below Lost Lake.

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

Table B21. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Middle Fork Hood River below Eliot Branch.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-2	-2	-2	-2	-3	-3	-3	-3
	Oct-Dec	1	1	1	1	4	3	3	4
	Jan-Mar	7	7	7	7	11	10	10	10
	Apr-Jun	-5	-5	-5	-5	-12	-12	-12	-12
	Jul-Sep	-9	-9	-9	-8	-12	-13	-12	-12
MED Scenario	Annual	0	0	0	0	2	1	2	2
	Oct-Dec	2	2	2	2	5	4	5	5
	Jan-Mar	10	10	10	10	16	16	16	16
	Apr-Jun	-2	-3	-2	-3	-6	-7	-6	-7
	Jul-Sep	-6	-5	-6	-6	-8	-8	-8	-8
LW/W Scenario	Annual	2	2	2	2	5	4	5	5
	Oct-Dec	4	4	4	4	9	8	9	9
	Jan-Mar	10	10	10	10	15	15	15	15
	Apr-Jun	0	-1	0	-1	-1	-2	-1	-2
	Jul-Sep	-3	-2	-3	-3	-4	-4	-5	-4

Table B22. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for Neal Creek above Hood River.

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

Table B23. Simulated future departures from simulated historical minimum flow shortages (annual and quarterly averages) for West Fork Hood River below Lake Branch.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (cfs)	Demands (cfs)	Conservation (cfs)	Storage (cfs)
MW/D Scenario	Annual	-4	-4	-4	-4	-7	-8	-7	-7
	Oct-Dec	-3	-3	-3	-3	-5	-6	-5	-5
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	-3	-4	-3	-3	-9	-9	-8	-8
	Jul-Sep	-9	-9	-8	-8	-15	-16	-14	-14
MED Scenario	Annual	-2	-3	-2	-2	-4	-5	-4	-4
	Oct-Dec	-1	-1	-1	-1	-2	-3	-2	-2
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	-2	-2	-2	-2	-6	-6	-5	-5
	Jul-Sep	-5	-6	-4	-4	-8	-10	-7	-7
LW/W Scenario	Annual	-1	-2	-1	-1	-2	-3	-2	-2
	Oct-Dec	0	0	0	0	1	1	1	1
	Jan-Mar	0	0	0	0	0	0	0	0
	Apr-Jun	-1	-2	-1	-1	-4	-4	-3	-3
	Jul-Sep	-3	-4	-3	-3	-6	-7	-5	-5

Average changes in storage volumes under each climate scenario-alternative combination from the simulated historical averages for the existing reservoirs in the Hood River basin are provided in Tables B24 and B25. For clarity, the changes are summarized on an annual (water year) basis and by quarter. The red and blue hues represent decreases and increases, respectively, from the simulated historical averages, with the darker colors corresponding to greater differences. Both the relative (percent) differences and absolute (volume) differences are provided.

Table B24. Simulated future departures from simulated historical average storage volumes for Upper and Lower Green Point Reservoirs.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (af)	Demands (af)	Conservation (af)	Storage (af)
MW/D Scenario	Annual	-5	-12	-11	9	-14	-34	-30	24
	Oct-Dec	0	0	0	0	0	0	0	18
	Jan-Mar	7	7	7	29	6	6	6	23
	Apr-Jun	-8	-12	-11	2	-65	-91	-81	17
	Jul-Sep	1	-19	-17	15	3	-51	-44	40
MED Scenario	Annual	2	-5	-5	57	4	-14	-13	159
	Oct-Dec	0	0	0	0	0	0	0	115
	Jan-Mar	14	14	14	155	11	11	11	126
	Apr-Jun	-3	-6	-5	23	-21	-45	-36	181
	Jul-Sep	10	-8	-10	80	26	-22	-26	215
LW/W Scenario	Annual	8	0	1	60	22	0	4	167
	Oct-Dec	0	0	0	0	0	0	0	105
	Jan-Mar	15	15	15	144	13	12	12	117
	Apr-Jun	6	-2	-1	28	44	-14	-6	219
	Jul-Sep	12	1	3	84	31	2	9	225

Table B25. Simulated future departures from simulated historical average storage volumes for Laurance Lake.

	Period	Existing (%)	Demands (%)	Conservation (%)	Storage (%)	Existing (af)	Demands (af)	Conservation (af)	Storage (af)
MW/D Scenario	Annual	-13	-17	-16	-7	-341	-431	-413	-173
	Oct-Dec	-33	-38	-36	-28	-716	-821	-780	-607
	Jan-Mar	6	3	4	12	147	91	99	328
	Apr-Jun	-1	-3	-3	6	-39	-96	-93	196
	Jul-Sep	-28	-34	-33	-23	-745	-885	-866	-596
MED Scenario	Annual	-4	-9	-6	5	-117	-229	-156	137
	Oct-Dec	-22	-31	-22	-11	-483	-678	-485	-244
	Jan-Mar	13	10	12	23	341	274	309	598
	Apr-Jun	4	3	3	14	132	86	94	420
	Jul-Sep	-17	-22	-20	-8	-446	-584	-531	-214
LW/W Scenario	Annual	3	-2	1	13	66	-64	31	347
	Oct-Dec	-9	-20	-8	4	-187	-422	-172	95
	Jan-Mar	18	15	17	29	479	402	447	761
	Apr-Jun	7	6	6	18	225	168	183	534
	Jul-Sep	-9	-15	-12	0	-244	-390	-326	8

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