Technical Memorandum

Hydrologic Evaluation of Alternatives for the Deschutes Basin Habitat Conservation Plan

Deschutes Project, Oregon
Columbia Pacific Northwest Region

U.S. Department of the Interior

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Mission Statements

The Department of the Interior conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

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

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Acronyms and Abbreviations

Acronym or Abbreviation	Definition
AF	acre-feet
AID	Arnold Irrigation District
cfs	cubic feet per second
COID	Central Oregon Irrigation District
DRC	Deschutes River Conservancy
DBHCP	Deschutes Basin Habitat Conservation Plan
EIS	Environmental Impact Statement
LPID	Lone Pine Irrigation District
MWRV	Minimum Winter Release Volume
NCAO	North Canal (part of COID)
NEPA	National Environmental Policy Act
NUID	North Unit Irrigation District
OID	Ochoco Irrigation District
OSF	Oregon Spotted Frog
SID	Swalley Irrigation District
TID	Tumalo Irrigation District
TSID	Three Sisters Irrigation District
OWRD	Oregon Water Resources Department
Reclamation	Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service

Preface

The Draft Environmental Impact Statement (EIS) relied on model assumptions and results published in a technical memorandum published in August 2019. This preface describes changes that were made to the model assumptions between the Draft EIS and the Final EIS based on public comment; the table also indicates the sections in this report where details about the new assumptions can be found.

Location	Alternative	Assumption Change	Section
Wickiup	All	Change to minimum flow calculation so that minimums are set based on Wickiup storage triggers rather than equation used in DEIS.	2.2.2 3.2.2
Wickiup	Alternative 2	A maximum flow rate was set for irrigation season outflow.	3.2.2
Wickiup	Alternative 2	Limitations were placed on the rate of outflow change in April and September.	3.2.2
Crescent	Alternative 2	Minimum outflow set to 10 cfs and a volume of water was reserved and used to augment spring outflows and reduce the rate of decrease in the fall.	3.2.3
Crescent	All	The 1911 storage right was allowed to fill a new 35,000 acre-feet each year rather than counting existing storage toward that right.	2.2.3
NUID	All	Added planned Central Oregon Irrigation District (COID) conservation where 29.4 cfs diverted under COID's existing water rights will be diverted at the Pilot Butte canal and delivered to North Unit Canal via pipeline. North Unit Irrigation District's (NUID's) diversion is reduced by 29.4 cfs.	2.4
NUID	All	Daily Wickiup storage demand request was adjusted to reflect real time operations. Demand request was reduced based on April 1 storage in Wickiup.	2.4
Prineville	No Action, Alternative 2, and Alternative 3	Summer outflows from the uncontracted account were capped at 50 cfs.	2.3 3.3
Prineville	Alternative 4	Summer outflows from the uncontracted account were capped at 80 cfs.	3.4
All	All	Dataset extended to include inflows through September 30, 2018.	2.0

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1. Introduction

The Bureau of Reclamation (Reclamation) is cooperating with the U.S. Fish and Wildlife Service (USFWS) on the Environmental Impact Statement (EIS) for the Deschutes Basin Habitat Conservation Plan (DBHCP) on the Deschutes River in central Oregon. As part of that study, Reclamation used a RiverWare model of the river, distribution, and reservoir system to simulate the alternatives for the EIS. This technical memorandum documents the model representation of the alternatives and summarizes a selection of the results.

2. Reference RiverWare Model

The water resources modeling for the DBHCP EIS was conducted using a daily time-step RiverWare® ver. 7.5 model of the Deschutes Basin above the Pelton Round Butte reservoir complex. A short summary of the model is presented here. The model development is described in-depth in a separate document (Reclamation 2017a).

Unregulated hydrology is input to the model and represents river flows, stream gains (springs or small tributaries), and losses without reservoir operations or diversions. The model then applies rules to operate the system with different configurations of logic and instream and consumptive demands. The unregulated hydrology is mean daily flows from water years 1981 to 2018 (October 1980 through September 2018). Additional Reclamation reports (Reclamation 2017c and 2020) document how these data were developed.

The RiverWare model represents the Upper Deschutes River (excluding Crescent Creek, Little Deschutes River, Tumalo Creek, Whychus Creek, Crooked River, and Ochoco Creek). Figure 1 shows a map of the Deschutes River and Crooked River basins, along with the included tributaries.

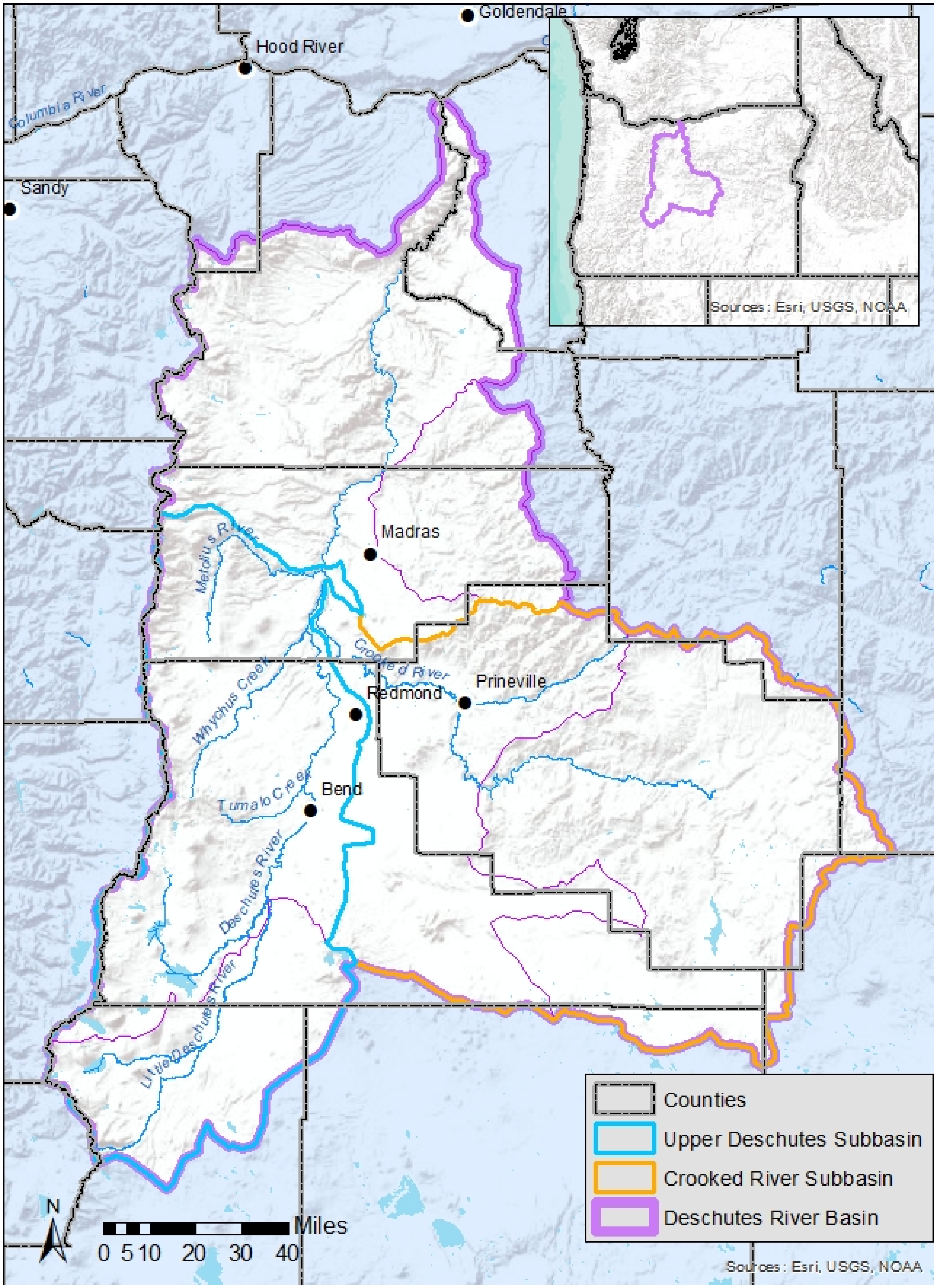

Figure 1. Deschutes River and Crooked River basins

RiverWare is a general rules-based modeling platform that requires full definition of the physical layout of a river system and logic to define operation of the system. The model is constructed using RiverWare objects that define reservoirs, diversions, river reaches, control points (which monitor instream flow locations), and river gages. Figure 2 and Figure 3 diagram the layout of the RiverWare model for the Upper Deschutes and the Crooked River subbasins, respectively. The red circles indicate water users (representing diversions) and are labeled with the acronym for the irrigation district or other water user group that they serve. The yellow boxes indicate stream gages and are named with their four-letter acronym from the Hydromet program (https://www.usbr.gov/pn/hydromet/), with the exception of the Highway 126 gage on the Crooked River. The green triangles represent locations where gains and losses are input into the model. The blue diamonds represent control points (i.e., locations where flow is monitored in the model to ensure minimum flow criteria are maintained). While the model itself has more detail than these schematics, the figures illustrate the most relevant features of the model.

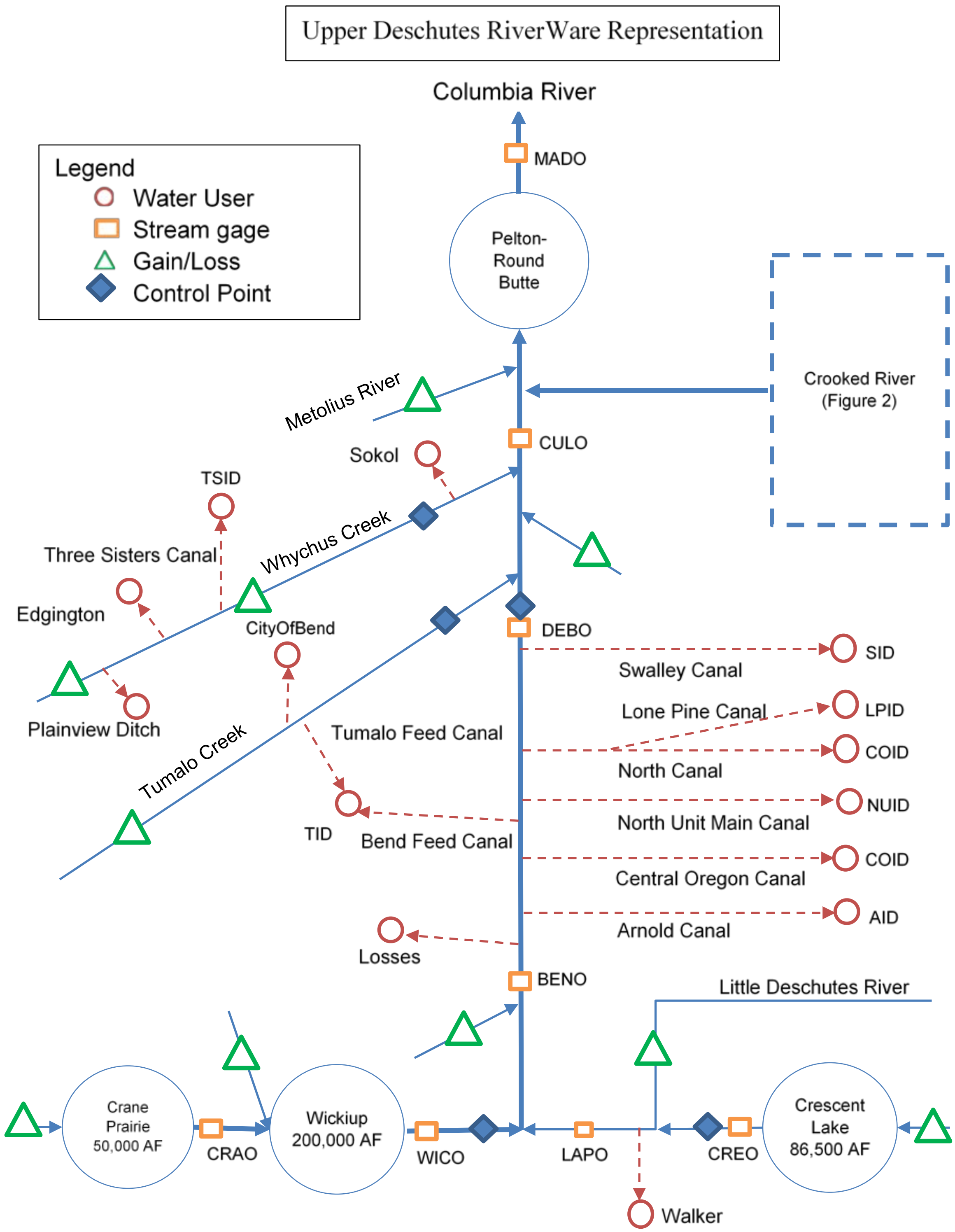

Figure 2. Schematic of RiverWare representation of Upper Deschutes River

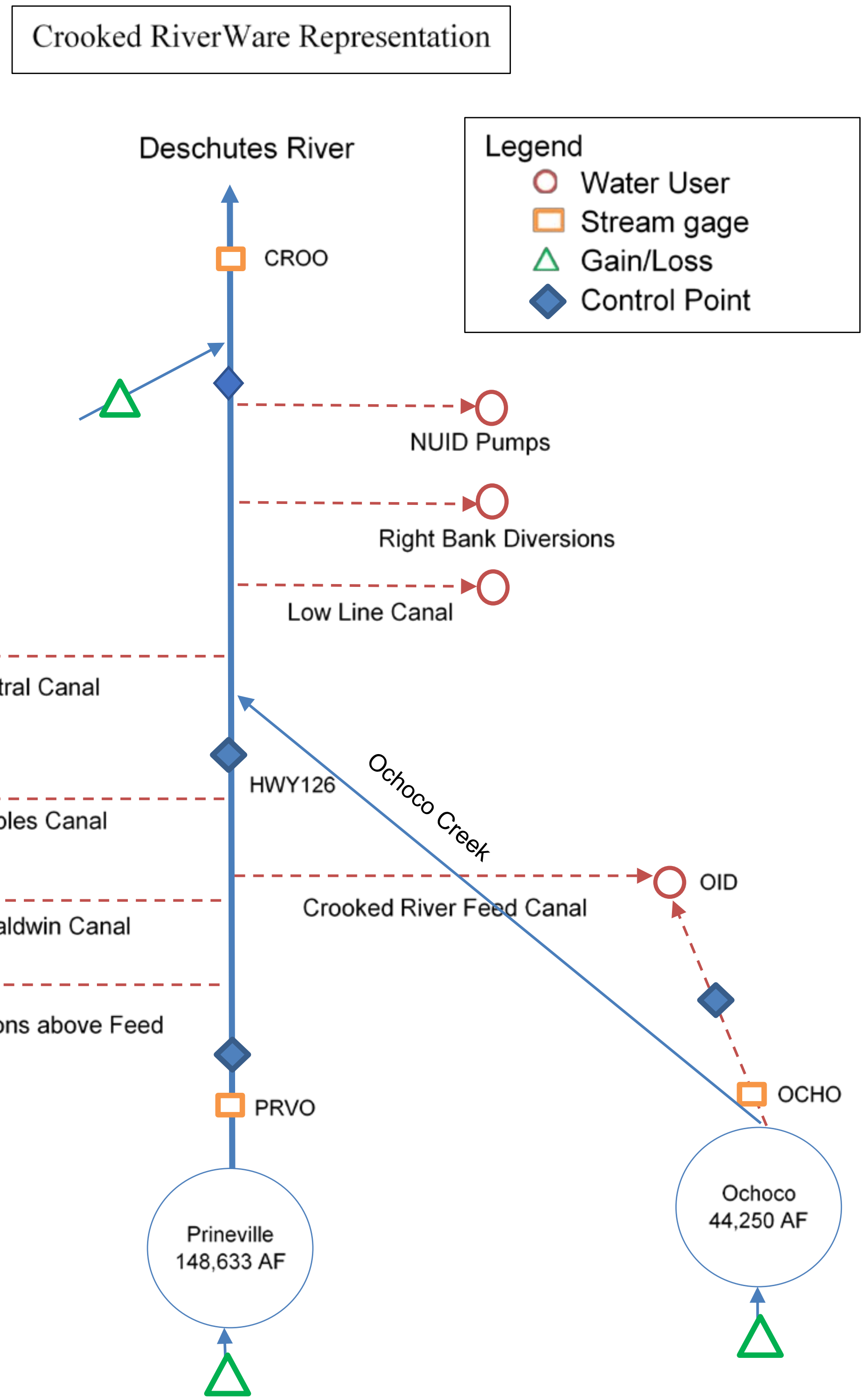

Figure 3. Schematic of RiverWare representation of Crooked River

Operating rule logic was first developed to simulate historical operations from 1984 through 2009[1], the years in which measured data could be compared to model output to ensure proper operation. The model used water rights, diversion patterns, and inflow hydrology representative of the time period. Detailed information about the inputs and calibration quality is described in Reclamation 2017a. The operating logic was then updated to incorporate recent changes in the basin, including the Oregon Spotted Frog (OSF) Biological Assessment (Reclamation 2017b) and the Crooked River Collaborative Water Security and Jobs Act of 2014. The details of those operations are described in Section 2.2 and Section 2.3.

It is important to recognize that there are many assumptions and simplifications that are required when developing a model. The data and operating logic attempt to simulate realistic conditions and water management as closely as possible, but it is likely there will be some operations that are handled differently in real time. The operations described in this report are relatively new and are still undergoing changes as real-time experience informs operations.

Some of the operations described in this report were developed based on the best available information and assumptions about how they would be implemented in real time. It is possible that these will be adaptively changed through time within the constraints of the National Environmental Policy Act (NEPA).

2.1. Irrigation Demand Pattern

For scenario-based studies, it is common to develop a version of the model that simulates current conditions (baseline model). This model is meant to indicate the response of a system, using the current operation definition, to historical inflow hydrology. For the baseline model, diversions were changed from the historical daily time series (that varies from year to year) to a single daily pattern that repeats annually (representing average irrigation diversions calculated from measured data for recent years). By using a single year pattern for diversion, the effects of management changes can be examined more easily because they are not combined with the effects of changing demands. Figure 4 shows the daily diversion pattern that is repeated every year for the model simulation period for the eight DBHCP applicant irrigation districts. Table 1 shows the year ranges and total average annual volume for each district.

[1] Measured data were available for most locations in the basin starting in 1984. Model development began shortly after 2010, so 2009 was used as the end year for calibration.

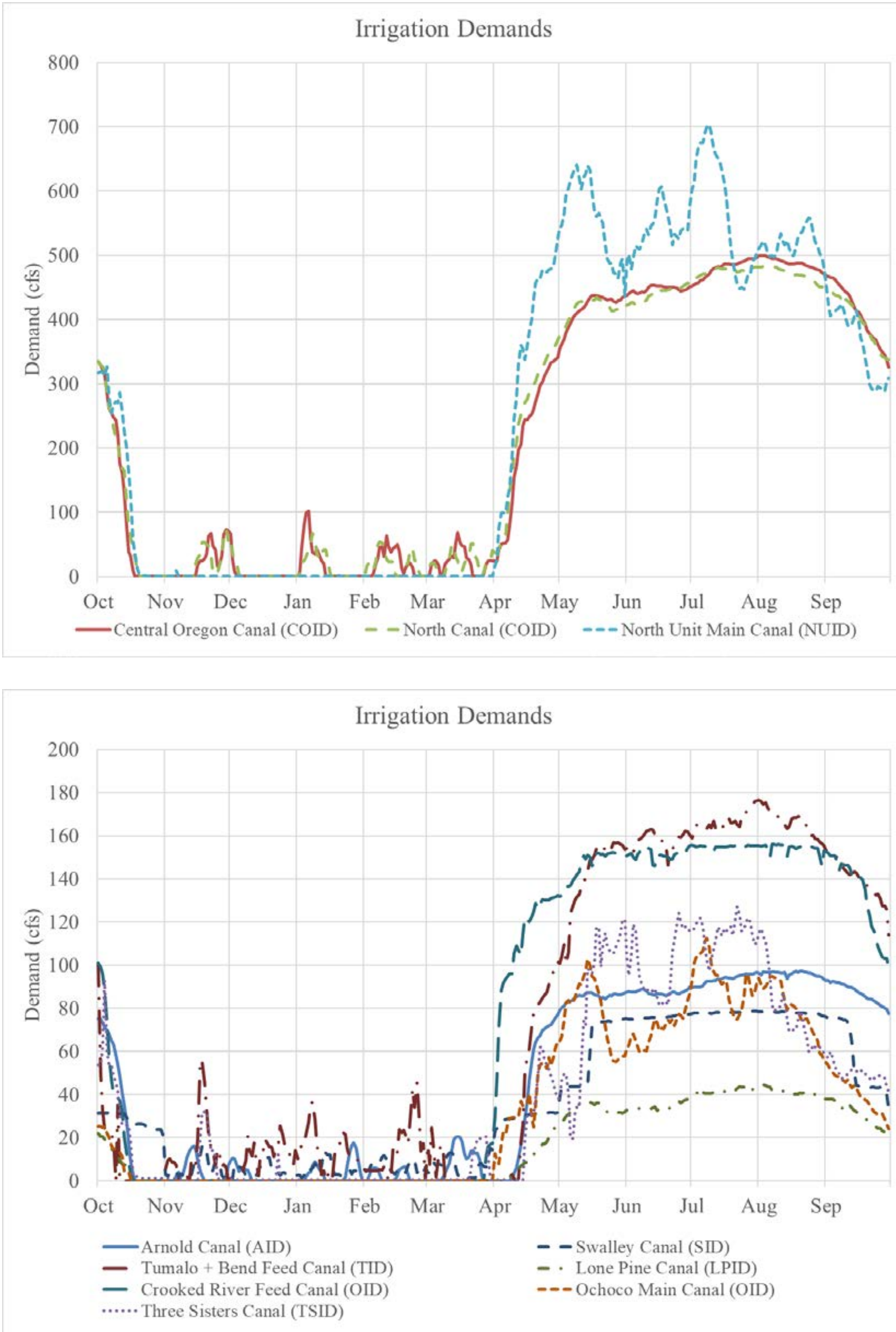

Figure 4. Daily diversion pattern that is repeated for every year in the model simulations; the top plot is for larger diversions for COID and NUID and the bottom plot is for smaller diversions for remaining districts

Table 1. Total annual demand used in modeling and years used to calculate demand[2]

District*	Years Used in Average	Total Annual Demand (acre-feet)
AID	2010-2017	32,266
COID	2010-2017	303,703
LPID	2010-2017	16,017
NUID	2010-2017	196,788
OID	2010-2017	77,824
SID	2013-2017	26,372
TSID	2011-2016, with manual adjustments for recent operational changes outside the irrigation season	35,004
TID	2009, 2010, 2011, 2013, 2014	53,517

*AID = Arnold Irrigation District; COID = Central Oregon Irrigation District; LPID = Lone Pine Irrigation District; NUID = North Unit Irrigation District; OID = Ochoco Irrigation District; SID = Swalley Irrigation District; TSID = Three Sisters Irrigation District; TID = Tumalo Irrigation District.

2.2. Baseline Upper Deschutes River Operation

Baseline operating rules for the Upper Deschutes River reflect the operating criteria in the Oregon Spotted Frog Biological Assessment (Reclamation 2017b). Generally, the operation is intended to minimize elevation changes in Crane Prairie Reservoir and set a minimum outflow from Wickiup Reservoir. In addition, winter outflows from Crane Prairie Reservoir, Wickiup Reservoir, and Crescent Lake were all larger than historical releases to enhance habitat conditions in the downgradient stream network.

2.2.1. Crane Prairie Reservoir

Crane Prairie Reservoir is operated to minimize elevation changes throughout the year to maximize habitat for the OSF. The reservoir is operated between 35,000 acre-feet and 50,000 acre-feet. In the model, this is accomplished by including a storage account that is dedicated to the OSF with a senior priority date of August 30, 1899, which is one day earlier than the most senior water right on the system (Swalley). This approach ensures that the highest priority in the model is to maintain 35,000 acre-feet of storage in Crane Prairie Reservoir. Three other storage accounts represent 5,000 acre-feet of storage

[2] The total demand for COID was slightly larger in the modeling because the LPID diversion was not subtracted from the NCAO [North Canal (part of COID)] diversion. This will be updated in later versions.

each for Arnold Irrigation District (AID), Central Oregon Irrigation District (COID), and Lone Pine Irrigation District (LPID).

Because of the senior priority date of the OSF account (35,000 acre-feet), it is kept full unless evaporation or seepage reduce its volume and the reduction cannot be made up with inflows. The 15,000 acre-foot operating range is used to meet seasonal OSF habitat and irrigation needs according to the schedule outlined below.

- January 1 to March 15: Crane Prairie Reservoir begins to store water, if available, until the reservoir reaches 45,000 acre-feet.
- March 16 to May 1: Crane Prairie Reservoir passes inflow to hold the storage volume achieved on March 15. Ideally, this volume would be 45,000 acre-feet.
- May 2 to May 15: Crane Prairie Reservoir stores water up to 1.1 feet above the elevation achieved on March 15. Ideally, this volume would be 50,000 acre-feet.
- May 16 to July 15: Crane Prairie Reservoir passes inflow to hold the storage volume achieved on May 15.
- July 15 to October 1: Crane Prairie Reservoir releases water in the irrigation district's accounts to reduce the reservoir back down to 35,000 acre-feet.
- October 2 to December 30: Crane Prairie Reservoir passes inflow to maintain 35,000 acre-feet.

Outflows from Crane Prairie Reservoir are generally managed to release a maximum of 400 cubic feet per second (cfs) throughout the year. The minimum release varies depending on the time of the year, with 100 cfs released from December 1 through August 30 and 75 cfs released the remainder of the year. These flow criteria are considered less important than reaching and maintaining the elevations in Crane Prairie Reservoir. Therefore, there are times when the minimum outflow is allowed to decrease down to a minimum of 30 cfs in support of the higher priority criteria. Outflows are allowed to increase above 400 cfs when there is an elevation restriction and inflows exceed 400 cfs minus seepage.

Although the location and timing of returns from Crane Prairie Reservoir seepage is not fully understood, it is generally believed that seepage losses return to the stream network upstream of Wickiup Reservoir. This is based on physical observations and geological knowledge of the area, including: (1) the proximity of a major groundwater discharge area (approximately 300 cfs to Sheep Springs), (2) the change in the underlying geology to low-permeability sedimentary deposits of the La Pine sub-basin, (3) the location of a fault at Sheep Springs (a likely impediment to groundwater flow), and (4) the groundwater head gradient. All of these point to Wickiup Reservoir (Sheep Springs) being the location of returns from Crane Prairie Reservoir seepage (LaMarche 2018).

For the calibration/historical model, it was assumed that any returns from Crane Prairie Reservoir seepage would be captured in the gains between Crane Prairie Reservoir and Wickiup Reservoir. However, since the seepage is dependent on elevation, it is expected that seepage from the No Action operation would be different than historical. So, the change in potential seepage was calculated by taking historical seepage calculation and subtracting it from a new seepage calculation using the new reservoir elevations. Based on conversations with the Oregon Department of Water Resources, a 3-month lag time was assumed to route the change in seepage back to the reach above Wickiup Reservoir. This addition to the model was done with equations that use the current Crane Prairie Reservoir elevation as input, so any new changes to Crane Prairie Reservoir elevation would adjust the seepage return.

2.2.2. Wickiup Reservoir

Outflows from Wickiup Reservoir are managed to maintain a minimum of 100 cfs between September 16 and March 30. Between March 31 and September 15, a minimum outflow of 600 cfs is used, if possible. Once irrigation releases begin, outflows from Wickiup Reservoir often exceed 600 cfs to meet downstream irrigation demand. If required releases exceed 600 cfs prior to April 30, the outflow is not allowed to decrease more than 30 cfs in a single flow adjustment or cumulatively over the course of multiple flow adjustments. Maximum non-irrigation season outflows are kept below 800 cfs until April 15 unless the reservoir needs to make flood releases.

2.2.3. Crescent Lake

As long as there is enough inflow and stored water, outflows from Crescent Lake are managed to maintain minimum flows of 30 cfs from March 15 through November 30 and 20 cfs from December 1 through March 14. If the reservoir storage drops below 7,000 acre-feet, outflows are reduced to 6 cfs. Crescent Lake has two storage rights, a right for 35,000 acre-feet with a January 1, 1911 priority date and a right for 51,050 acre-feet with a priority date of January 1, 1961. Regardless of the storage in Crescent Lake, it is allowed to accrue a new 35,000 acre-feet each year under the January 1, 1911 priority date, not to exceed to the total storage capacity in the reservoir.

2.3. Crooked River Operation

Operating rules on the Crooked River, particularly at Prineville Reservoir, reflect changes that were made in the Crooked River Collaborative Water Security and Jobs Act of 2014 (also called Crooked River Legislation). Changes are still being made to the operations as real time implications are observed and discussed. As additional experience is gained, the model logic will continue to be refined, but, for the purpose of this study, the logic used is as described below.

Prineville Reservoir has seven storage accounts that fill in priority by the dates shown in Table 2. All of the accounts, except for the uncontracted account, fill in proportion to their space with equal priority. The uncontracted space fills last and is used to augment flows seasonally for fishery purposes as coordinated by USFWS and Reclamation.

Table 2. Prineville Reservoir storage rights from Crooked River legislation

Model Water Right Name	Priority Date	Maximum Storage Volume
CityOfPrineville	4/8/1914	5,100 acre-feet
LowLine	4/8/1914	330 acre-feet
Ochoco	4/8/1914	60,640 acre-feet
Others	4/8/1914	6,527 acre-feet
Peoples	4/8/1914	3,497 acre-feet
RentalNUID	4/8/1914	10,000 acre-feet
Uncontracted	4/9/1914	65,520 acre-feet
Total	--	***151,614 acre-feet***

Releases from the uncontracted account (also known as the fish and wildlife account) are calculated for the irrigation season (April 1 to October 15) and the non-irrigation season (October 16 to March 31) using the storage in the account on April 1. To calculate the irrigation season, the model first reserves a volume of water for the non-irrigation season equal to 50 cfs released each day from October 16 to March 30 or the volume of water in the uncontracted account on April 1, whichever is greater (Minimum Winter Release Volume [MWRV]). The remaining volume is then divided equally among the 365 days and that value is released each day (Irrigation Season Release) with a maximum release of 50 cfs. This approach intentionally reserves water for winter releases.

$$\text{MWRV} = \text{Max}\begin{cases} V * \frac{50\ \text{cfs} * 1.98\ \text{AF/d}}{\text{cfs}} \\ \text{UV} \end{cases}$$ where

MWRV = Minimum Winter Release Volume

V = Number of days between and October 15 current year and April 1 next year

UV = Storage in the uncontracted Account on April 1

$$\text{Irrigation Season Release} = \text{Min}\begin{cases} (\text{UV} - \text{MWRV}^{3})/(365\ \text{d} * \frac{1.98\frac{\text{AF}}{\text{d}}}{\text{cfs}}) \\ 50\ \text{cfs} \end{cases}$$

For the non-irrigation season, the irrigation season release flow rate is added to the minimum winter release flow rate and is released from the uncontracted account.

Non-Irrigation Season Release = Irrigation Season Release + MWRV

[3] This equation is limited to a positive result in the model.

Table 3 shows example irrigation season and non-irrigation season releases from the uncontracted account given April 1 storage volumes in the uncontracted account. These releases are added to irrigation season storage releases, runoff season flood releases, and other minimum flow requirements described below.

Table 3. Calculated irrigation and non-irrigation season releases based on April 1 uncontracted volume in Prineville Reservoir

Total Storage Prineville Reservoir (acre-feet)	Uncontracted Volume April 1 (acre-feet)	Irrigation Season Release (cfs)	Non-irrigation Season Release (cfs)
148,633	62,520	50	113
118,000	36,987	21	71
88,000	6,987	0	6
78,000	0	0	0

Other minimum releases include a 10 cfs release maintained from Bowman Dam and a 7 cfs release from the City of Prineville mitigation account. These releases are executed in the model using the following logic described below.

If releases from Bowman Dam are less than 10 cfs, then:

1. The first 7 cfs will be released from the City of Prineville mitigation account, if available. If the City of Prineville mitigation account did not fill, the release will be the amount of storage in the account on April 1 divided by 365 days.
2. The remainder will be made up with water from the uncontracted/fish and wildlife account.
3. If the uncontracted/fish and wildlife account is empty, the remainder will be made up with live flow.
4. If there is insufficient live flow, the remainder will be made up with stored water from the first fill accounts in proportion to their storage.

2.4. Special Diversion Operations

TID, OID, and NUID divert water from multiple streams to satisfy demand for their districts. All three of these diversions require unique model constructs and rules to ensure the correct amount of water is diverted from the appropriate tributary.

TID diverts water from Tumalo Creek and supplements with water from Crescent Lake via the Upper Deschutes. It also has a live flow of 9.5 cfs directly from the Deschutes. TID first tries to satisfy its demand using natural flow rights, the majority of which are on Tumalo Creek. If there is still shortage, TID will request stored water from Crescent Lake via the Upper Deschutes.

OID diverts from both the Crooked River and Ochoco Creek and first tries to satisfy the demand based on recent historical diversion rates from each tributary, Crooked River and Ochoco Creek, using both natural flow and stored water rights. If there is still a shortage, OID will divert additional water from Prineville Reservoir.

NUID diverts water from both the Upper Deschutes River and the Crooked River. On the Upper Deschutes, NUID can divert water under its 1913 live flow water right and can request stored water from Wickiup Reservoir. On the Crooked River, it can divert under its 1955 live flow right and request rental water from Prineville Reservoir [4]. When the model is running, it will first try to satisfy the total demand for the district using historical diversion rates for each tributary. If it is a year when Wickiup did not fill, the initial request from the Upper Deschutes at the North Unit Main Canal [NUID.divReq] is reduced from its historical daily average [NUID.divReqHistAvg] using an equation that scales the demand to storage in Wickiup [Wic.Storage] on April 1. 20,000 acre-feet is added to the numerator to estimate the diversions from live flow. This equation is intended to replicate the behavior of NUID demand in drier years.

$$NUID.divReq = NUID.divReqHistAvg * \frac{Wic.Storage[April\ 1, current\ year] + 20{,}000\ AF}{150{,}000\ AF}$$

If there are shortages when compared to the NUID.divReqHistAvg, additional water will be diverted from the Crooked River to satisfy the demand limited by the pump capacity, the amount of water in the rental account on Prineville Reservoir, and the requirement to leave live flow instream per an agreement between Deschutes River Conservancy and NUID (called the DRC agreement [OWRD 2013]). This agreement, signed in 2013, requires that NUID allow flow to bypass its pumps; however, NUID is not required to release stored water to meet this minimum flow requirement. The amount of flow varies depending on water year conditions and month (Table 4). A dry year is defined if the storage in Prineville Reservoir is less than 135,000 acre-feet after March 30, or if the outflow from the reservoir is less than 75 cfs for the previous 30 days.

Lastly, a conservation option was implemented in the model where COID will line a portion of their canal and transfer the savings (approximately 29.4 cfs or 9,388 acre-feet, annually) during the irrigation seasons from the North Canal (also sometimes referred to as the Pilot Butte Canal) to the North Unit Main Canal via a pipeline. When the model is running, the North Canal diversion request remains the same and the first 29.4 cfs diverted is transferred to satisfy NUID's total diversion request. NUID's diversion request is reduced by 29.4 cfs since they will be getting that water via the pipeline rather than from the river.

[4] NUID also has a 1968 priority water right that it does exercise in some years. However, the maximum diversion rate for the 1955 water right is 200 cfs, which is the maximum physical pump capacity. For simplicity, the model only simulates the 1955 right since there is no case when the other right would be used for the purposes of this model.

Table 4. Deschutes River Conservancy bypass flows for dry and non-dry years[5]

Month	Dry Year (flow in cfs)	Non-Dry Year (flow in cfs)
Jan	0	0
Feb	0	0
Mar	0	0
Apr	120.617	181.417
May	50	95.598
Jun	54.381	86.081
Jul	51.451	61.451
Aug	56.846	68.146
Sep	57.599	114.219
Oct	121.874	151.574
Nov	0	0
Dec	0	0

3. Scenario Descriptions

The RiverWare model assumptions were adjusted for each of the four alternatives evaluated for the DBHCP EIS.

3.1. Alternative 1: No Action

The No Action model is the baseline model described in Section 2. No additional changes were made to the model for the No Action alternative.

[5] For May in dry years, the agreement allowed flows to drop to 43.798 cfs. Negotiations between NUID and FWS have made 50 cfs the minimum flow past the pumps. This was modeled in No Action and the Alternatives, though it is not a required action in No Action. This resulted in similar shortages to NUID in No Action and Alternative 2A; in reality, the shortages in No Action would be lower.

3.2. Alternative 2 (Preferred): Districts' DBHCP Proposal

The Alternative 2 model includes the assumptions defined in the Districts' DBHCP proposal. Alternative 2 starts with all of the assumptions in Alternative 1 and then adds to them. The primary changes include changes to Crane Prairie, Wickiup, Crescent, and Crooked River operations. Three versions of this alternative were run to simulate implementation through time: Alternative 2A represents the first 7 years of implementation, Alternative 2B represents years 8 through 12, and Alternative 2C represents years 13 through 30.

3.2.1. Crane Prairie Reservoir

Crane Prairie Reservoir is operated to minimize elevation changes throughout the year to maximize habitat for the OSF and the operations are the same for all three implementation phases. The reservoir is operated between 38,000 acre-feet and 48,000 acre-feet, which is different from the No Action operating range of 35,000 to 50,000 acre-feet. In the model, this is accomplished by including a storage account that is dedicated to the OSF with a senior priority date of August 30, 1899; this date is one day earlier than the most senior water right on the Deschutes River downstream of Crane Prairie Reservoir, which belongs to Swalley Irrigation District. This ensures that the highest priority in the model is to maintain 38,000 acre-feet of storage in Crane Prairie. Three other storage accounts represent 10,000 acre-feet of storage for AID (3,500 acre-feet), COID (3,000 acre-feet), and LPID (3,500 acre-feet)[6].

Due to the senior priority date of the OSF account, it is kept full unless evaporation or seepage reduce its volume and it cannot be made up with inflows. The 10,000 acre-feet of active storage that results from operation of the reservoir for OWF is utilized as summarized below.

- November 1 to March 14: Crane Prairie Reservoir begins to store water, if available, until the reservoir reaches 48,000 acre-feet.
- March 15 to July 15: Crane Prairie Reservoir passes inflow to hold the storage volume achieved on March 15. Ideally, this volume would be between 46,800 and 48,000 acre-feet.
- July 16 to July 31: Crane Prairie Reservoir storage is reduced at a maximum rate of 225 acre-feet per day.
- July 31 to October 31: Crane Prairie Reservoir storage is reduced at a maximum rate of 450 acre-feet per day until storage in Crane Prairie is 38,000 acre-feet, then 38,000 acre-feet is maintained until November 1.

Outflows from Crane Prairie Reservoir are generally managed to maintain a minimum release of 75 cfs, if possible. If flows cannot be maintained at 75 cfs, the model will allow flows to drop to a minimum of 30 cfs.

[6] The distribution of the accounts is still being negotiated; these were the distributions used for modeling purposes.

3.2.2. Wickiup Reservoir

Minimum outflow requirements will change as Alternative 2 is implemented through time. Outflows from Wickiup Reservoir are managed to maintain a minimum between September 16 and March 30 as shown in Table 5. Between March 30 and September 15, a minimum outflow of 600 cfs is used, if possible. Once irrigation releases begin, outflows from Wickiup Reservoir often exceed 600 cfs to meet downstream irrigation demand. If required releases exceed 600 cfs prior to April 30, the outflows cannot subsequently decrease more than 30 cfs in a single flow adjustment or cumulatively over the course of multiple flow adjustments. Maximum non-irrigation season outflows are kept below 800 cfs until April 15 unless the reservoir needs to make flood releases. Maximum irrigation season outflows are shown in Table 5; these outflow limitations are applied just to the outflow, not the downstream demand request. NUID, being the junior user on the system and the primary user of Wickiup outflow, is therefore the most affected by this outflow reduction.

Table 5. Non-irrigation season minimum and irrigation season maximum Wickiup outflows based on implementation years

Alternative	Implementation Years	Non-Irrigation Season Minimum	Irrigation Season Maximum
2A	First 7 years	100 cfs	Amount needed to satisfy downstream demand (as much as 1,800 cfs)
2B	Years 8 through 12	300 cfs	1,400 cfs
2C	Years 13 to 30	400 cfs and will increase to 500 cfs if Wickiup has more than 100,000 acre-feet on November 1 each year.	1,200 cfs

3.2.3. Crescent Lake

TID is setting aside a volume of water in Crescent Lake to be used for minimum flows as they reduce demand through conservation in their district. They intend to increase the size of the volume and the minimum outflows through time as they implement conservation. The timing of their implementation is not exactly aligned with the year ranges defined in Alternatives 2A, 2B, and 2C, so an approximation of the volumes and minimum flows was used in the model (Table 6). The volumes are determined based on April 1 storage in Crescent Lake and (like Wickiup) the volumes and minimum outflow will change through time as Alternative 2 is implemented. Crescent Lake is operated to ensure minimum outflows as shown in Table 6. The minimum outflows from Crescent Lake are lower than for No Action because it was determined that it was more important to shape the outflows at critical times of the year for the species than to maintain a higher flow throughout the winter storage season.

Table 6. Non-irrigation season minimum outflows from Crescent for each alternative version

Alternative	Non-Irrigation Season Minimum	Volume Reserved for Minimum Flows based on Crescent Storage on April 1		
		Crescent below 45,000 acre-feet on April 1	Crescent between 45,000 and 75,000 acre-feet on April 1	Crescent above 75,000 acre-feet on April 1
2A	10 cfs	5,264 acre-feet	7,264 acre-feet	8,764 acre-feet
2B	10 cfs	6,464 acre-feet	8,464 acre-feet	9,964 acre-feet
2C	12 cfs	8,864 acre-feet	10,864 acre-feet	12,364 acre-feet

In real time, a portion of this reserved volume will be used to provide a buffer during the fall when irrigation deliveries are turning off and to augment flows in the spring. Both of these operations will be managed in real time based on weather and flow conditions in critical habitat locations and may result in different flows seasonally and annually. In order to understand how this operation might work, the model simulates a fall reduction in flows starting on October 1 and a spring increase in flows starting on April 20. It should be noted that typical irrigation season releases start around July 1, however flows were simulated to start earlier to demonstrate an example of releases to assist OSF life history needs. If October 1 outflows are greater than 50 cfs, they are reduced by 10 cfs a day down to 50 cfs and held at 50 cfs through October 15. After October 15, outflows are reduced 10 cfs a day down to the minimum and held through the winter. If outflows are less than 50 cfs on October 1, they are reduced by 10 cfs a day down to the minimum and held through the winter. On April 20, flows begin increasing in even increments to a spring minimum that starts on May 1. The May 1 minimum is calculated by dividing the volume remaining for minimums on March 31 by 61 days. The volume on March 31 is used because it represents the remaining volume after the fall reduction and winter minimums are used before the volume is adjusted on April 1 to account for the volume to be used in the upcoming year.

3.2.4. Crooked River

OID will supplement winter flows on the Crooked River up to 50 cfs if outflows from Prineville Reservoir are less than 50 cfs. Water from the City of Prineville Mitigation Account will be released only in the months of December and January, and the daily release quantity will be the volume on November 30 divided by 61 days. This operation is the same for all three implementation phases.

3.3. Alternative 3

The Alternative 3 model is the same as the No Action and Alternative 2 model, except that it uses different non-irrigation season minimum and irrigation season maximum outflows from Wickiup, and that the outflow from the uncontracted account in Prineville Reservoir is protected from being diverted. Three versions of this alternative were run to simulate implementation through time: Alternative 3A represents the first 5 years of implementation, Alternative 3B represents years 6 through 10, and Alternative 3C represents after years 11 through 30. Results are shown only for Alternative 3C.

3.3.1. Wickiup Reservoir

Wickiup releases are the same as described in Alternative 2 with the exception of the non-irrigation season minimums and the irrigation season maximums. In Alternative 3C, the non-irrigation season minimum outflows are determined using the storage in Wickiup on October 1 and December 1 as summarized below.

- If October 1 Wickiup storage is less than 75,000 acre-feet, minimum outflow is 400 cfs.
- If October 1 Wickiup storage is greater than 75,000 acre-feet, minimum outflow is 500 cfs.
- If December 1 Wickiup storage is greater than 75,000 acre-feet, minimum outflow can increase by 100 cfs, up to 500 cfs.

3.3.2. Crescent Lake

Crescent Lake is operated to ensure minimum outflows are 20 cfs throughout the year. In July through September, the minimums are kept to 50 cfs if there is enough water in the reservoir.

3.3.3. Crooked River

The Crooked River has a difference in operations because uncontracted releases are assumed to be bypassed by the NUID pumps in this alternative (in other words, the water is "protected" from diversion). Specifically, the NUID pumps were modeled to bypass the larger of minimum requirements from the DRC agreement or the release from the uncontracted account. The maximum irrigation season release from the uncontracted account is 80 cfs.

3.4. Alternative 4

The Alternative 4 model is the same as Alternative 3 except that the variable outflow requirements were modified slightly for Wickiup Reservoir and the minimum winter requirement from the uncontracted account on Prineville Reservoir was increased to 80 cfs. Two versions of this alternative were run to simulate implementation through time: Alternative 4A represents the first 5 years of implementation and Alternative 4B represents years 6 through 30. Results are shown only for Alternative 4B.

3.4.1. Wickiup Reservoir

Wickiup releases are the same as described in Alternative 3 with the exception of the non-irrigation season minimums. In Alternative 4B, the non-irrigation season minimum outflows are determined using the storage in Wickiup on October 1 and December 1 as summarized below.

- If October 1 Wickiup storage is less than 75,000 acre-feet, minimum outflow is 400 cfs.
- If October 1 Wickiup storage is greater than 75,000 acre-feet but less than 125,000 acre-feet, minimum outflow is 500 cfs.
- If October 1 Wickiup storage is greater than 125,000 acre-feet, minimum outflow is 600 cfs.
- If December 1 Wickiup storage is greater than 75,000 acre-feet, minimum outflow can increase by 100 cfs, up to 600 cfs.

3.4.2. Crooked River

Releases from the uncontracted account (also known as the fish and wildlife account) are calculated for the irrigation season (April 1 to October 15) and the non-irrigation season (October 16 to March 30) using the storage in the account on April 1. To calculate the irrigation season, the model first reserves a volume of water for the non-irrigation season equal to 80 cfs released each day from October 16 to March 30 or the volume of water in the uncontracted account on April 1, whichever is greater (Minimum Winter Release Volume). The remaining volume is then divided equally among the 365 days and that value is released each day (Irrigation Season Release). This approach intentionally reserves water for the winter.

$$\text{MWRV} = \text{Max}\begin{cases} V * \frac{80\ \text{cfs} * 1.98\ \text{AF/d}}{cfs} \\ \text{UV} \end{cases} \text{where}$$

M = Minimum Winter Release Volume

V = Number of days between April 1 next year and October 15 current year

UV = Storage in the uncontracted account on April 1

$$\text{Irrigation Season Release} = \text{M}in\begin{cases} (\text{UV} - \text{MWRV}[7])/(365\ \text{d} * \frac{1.98\frac{\text{AF}}{\text{d}}}{\text{cfs}}) \\ 80\ \text{cfs} \end{cases}$$

For the non-irrigation season, the irrigation season release flow rate is added to the minimum winter release flow rate and is released from the uncontracted account.

Non- Irrigation Season Release = Irrigation Season Release + MWRV

The uncontracted releases are assumed to be bypassed by NUID in this alternative. Specifically, the NUID pumps were modeled to bypass the larger of the minimum requirements from the DRC agreement or the release from the uncontracted account.

[7] This equation is limited to a positive result in the model.

4. Scenario Results

The RiverWare model produces many different types of output that can be used to interpret the implications of the alternatives, including reservoir storage, flow at gages, and water delivered to water users. The reservoir storage and flow at gages were primarily used to determine if the model was performing as expected under the defined scenario. Shortages were calculated by subtracting the amount of water delivered to water users from the amount of water that was requested. In the years where NUID's irrigation request from Wickiup was reduced to reflect real-world operations, the shortage was still calculated with respect to the total demand. The shortages were used to determine the potential impacts of the various scenarios and to determine the volume of water that would be required to satisfy all of the objectives in the scenario.

Alternative results are displayed in a number of formats. Summary hydrographs are used to show the potential range of reservoir storage, reservoir outflow, and flow at gages. The summary hydrographs show the median value (the daily flow or storage value achieved in 50 percent of the years) as a colored line and include a shaded area showing the daily range of 20 to 80 percent exceedance.[8] Reservoir storage and outflow are shown together so that the relationship between storage and outflow can be observed. Irrigation deliveries are shown as annual exceedance graphs where total annual irrigation volumes are sorted in order of largest to smallest to indicate the frequency of delivering a particular volume. The ability to meet instream and out-of-stream model flow objectives is shown using shortage graphs, where the shortage represents the difference between a model objective and the modeled output. Shortages are summed annually and shown in exceedance graphs similar to irrigation deliveries.

4.1. Alternative 1: No Action

Results for No Action are displayed to establish a baseline against which to compare the other alternatives. Only the locations that experience a change in the alternatives are shown in the No Action section.

4.1.1. Upper Deschutes

Figure 5 shows summary hydrographs of the simulated storage (top) and outflow (bottom) from Crane Prairie Reservoir for No Action (Alternative 1). The storage graph shows the summary of the 20 to 80 percent range of storage for the scenario. The intended operation at Crane Prairie Reservoir was as shown below.

1. To be at or above 35,000 acre-feet for the entire year.

[8] The 20% exceedance value shows the value where only 20% of the values are larger; the 80% exceedance value shows the value where 80% of the values are larger. For example, the 20% exceedance storage in Crane Prairie Reservoir on June 1 is 49,000 acre-feet and the 80% exceedance storage is 47,500 acre-feet.

2. Increase from 35,000 acre-feet to 45,000 acre-feet by March 15.
3. Maintain 45,000 acre-feet from March 15 through May 1.
4. Increase from 45,000 to 50,000 acre-feet from May 1 to May 15, if possible.
5. Maintain the storage achieved on May 15 through July 15.
6. Release storage down to 35,000 acre-feet by November 1.

Figure 5 shows that these operational objectives can be achieved. The relationship between changes in storage and outflow can also be seen in these graphs. For example, on January 1, outflows decrease to fill Crane Prairie Reservoir to 45,000 acre-feet by February 15. The model shows abrupt changes in outflows because storage objectives are prioritized in the model. Real-time operations may be different than the model output because the model logic is based on rules that may turn on and off suddenly as conditions change, whereas real time operations may be able to smooth out the operational changes.

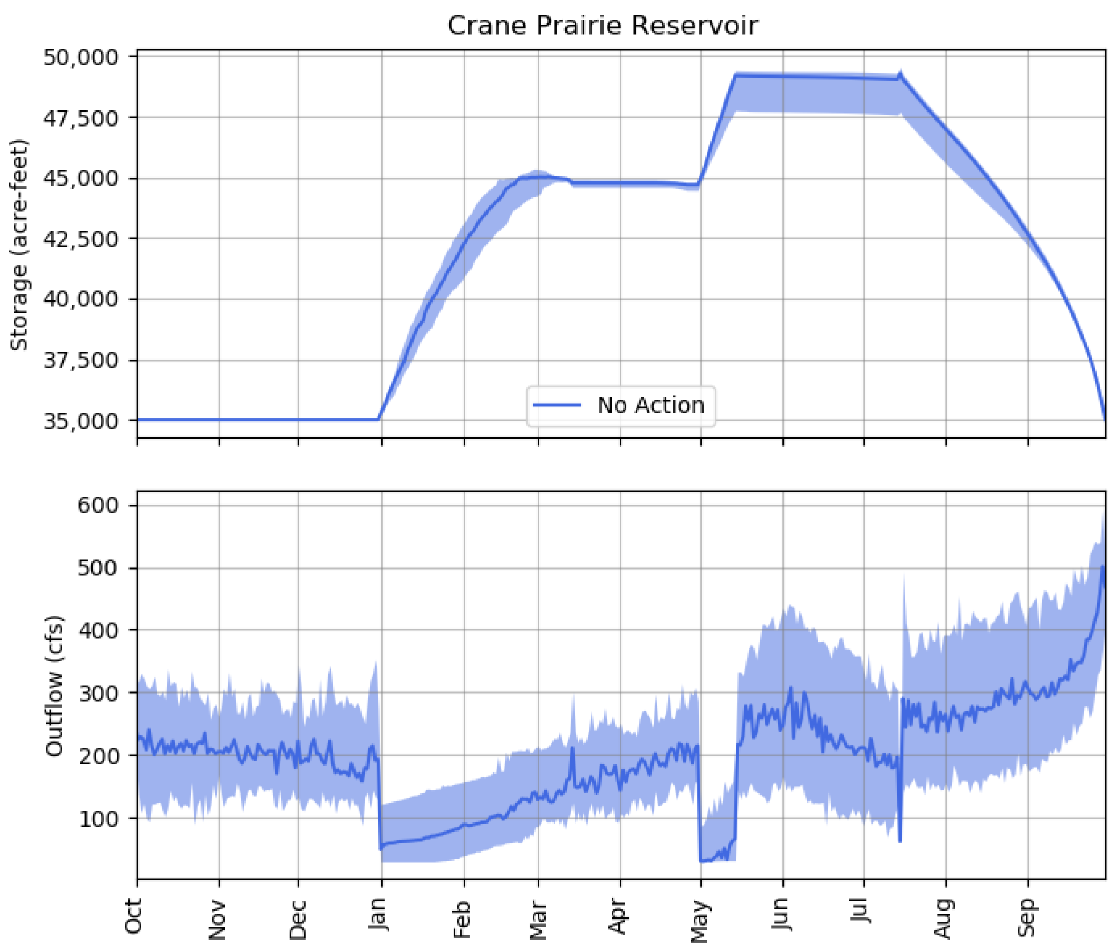

Figure 5. Summary hydrographs of simulated storage (top) and outflow (bottom) from Crane Prairie Reservoir for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 6 shows summary hydrographs of the simulated storage and outflow from Wickiup Reservoir for No Action. Recall that the intended operation at Wickiup Reservoir was to maintain a minimum of 100 cfs outflow year-round and to meet downstream irrigation requests. From this graph, it can be seen that the model objectives were met. In addition, the figure shows the storage in Wickiup Reservoir that results from the upstream operation at Crane Prairie Reservoir and the outflow requirements. The summertime outflow pattern reflects Wickiup Reservoir releases to meet downstream irrigation demands, particularly for the NUID.

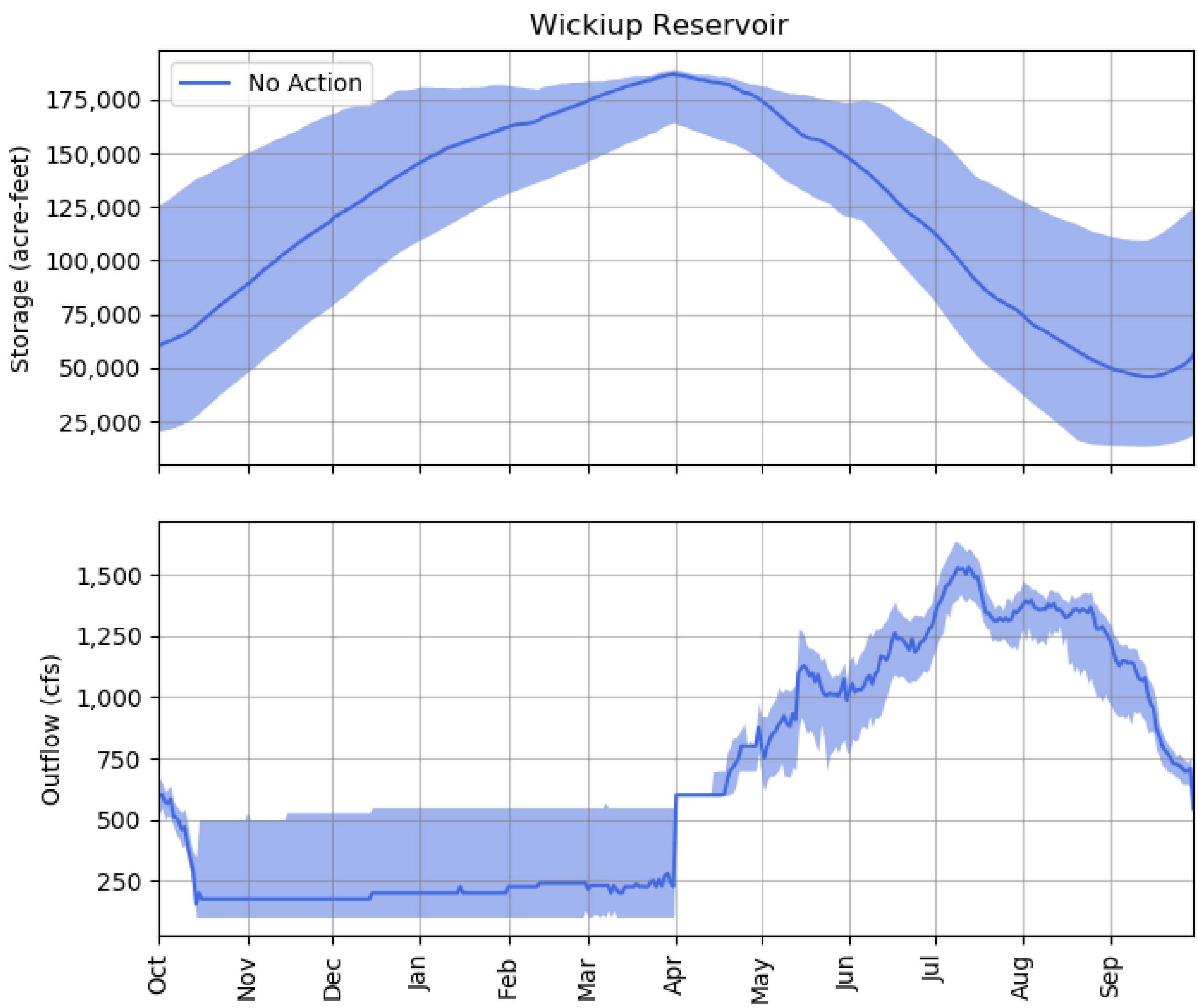

Figure 6. Summary hydrographs of simulated storage (top) and outflow (bottom) from Wickiup Reservoir for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 7 shows summary hydrographs for the storage and outflow from Crescent Lake for No Action. Recall that the intended operation for Crescent Lake was to maintain a minimum outflow of 30 cfs from March 15 to November 30 and 20 cfs from December 1 to March 14. The outflow graph shows that this operation is achievable in all years above the 80 percent flow exceedance, and the storage graph shows the statistical range of storage on any given day during the year for the simulation period. While mode summary hydrographs generally show the annual pattern of storage or flow, that is not the case for Crescent Lake storage. This is because the reservoir capacity exceeds the typical annual inflows to the reservoir, so the reservoir can store water for multiple irrigation seasons. As a result, the annual storage pattern can be very different from year to year. The increased outflow in the higher flow years in February are due to flood releases required to prevent the reservoir from overtopping.

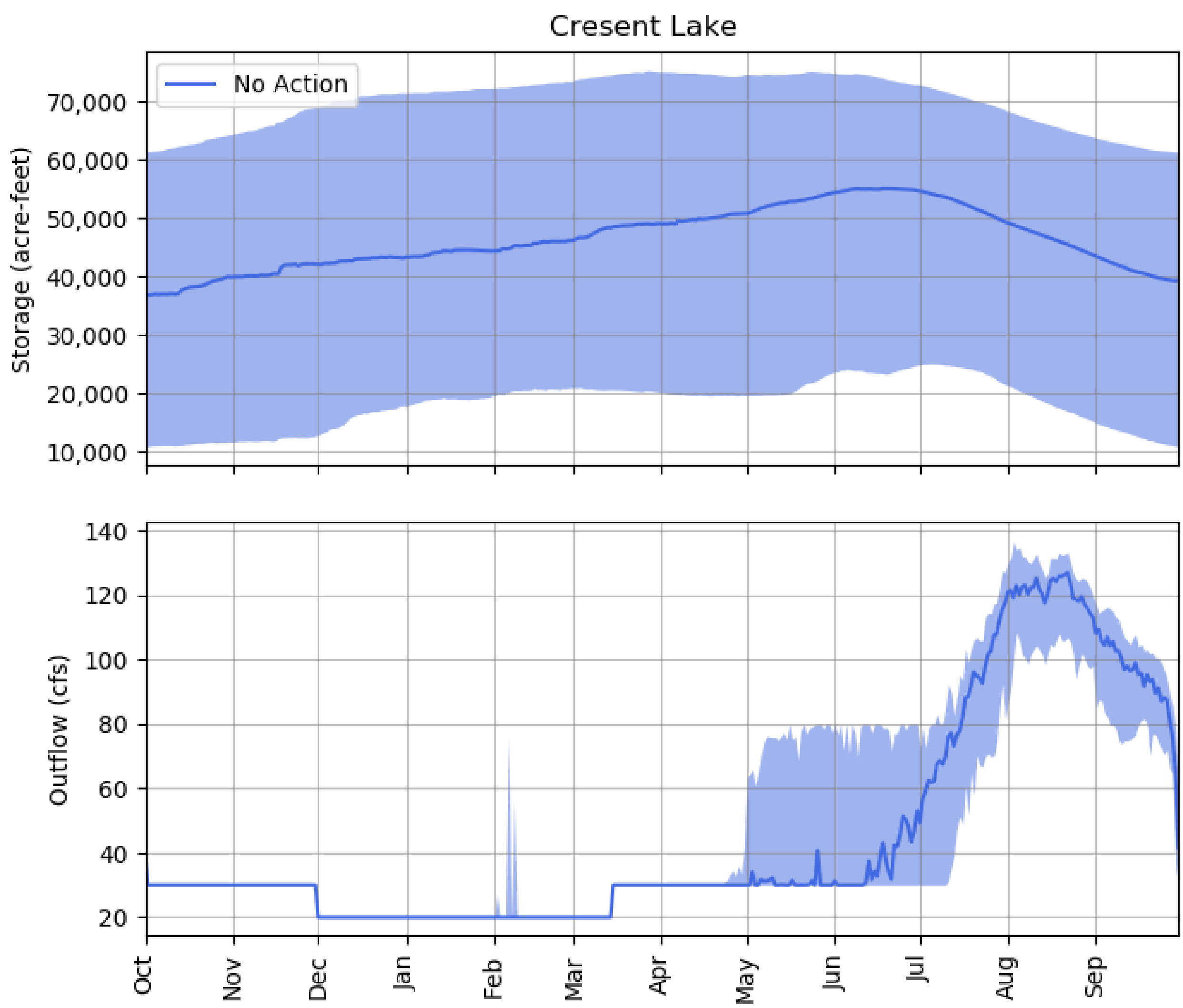

Figure 7. Summary hydrographs of simulated storage (top) and outflow (bottom) from Crescent Lake for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 8 shows a summary hydrograph of the simulated flow in Little Deschutes River at La Pine for the No Action Alternative. The flow at this gage is largely unregulated, with only a small contribution from Crescent Creek and Crescent Lake in the spring but a larger contribution in the summer and fall.

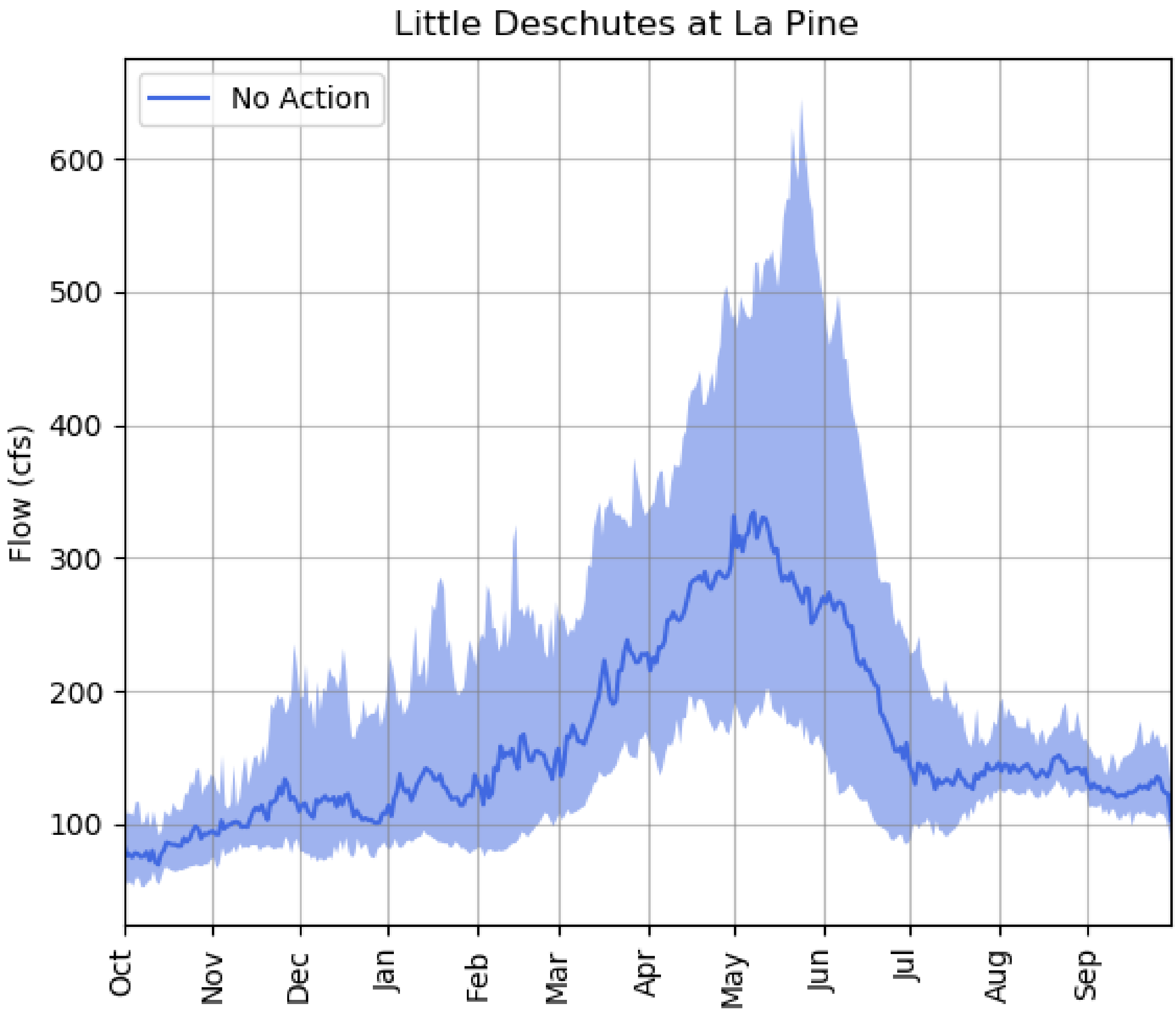

Figure 8. Summary hydrograph of simulated flow in the Little Deschutes River at La Pine for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 9 shows a summary hydrograph of the simulated flow in the Deschutes River at Benham Falls for No Action. This gage is upstream of the major diversions but downstream of the reservoirs. It is heavily influenced by the outflow from Wickiup Reservoir and the flow from the Little Deschutes.

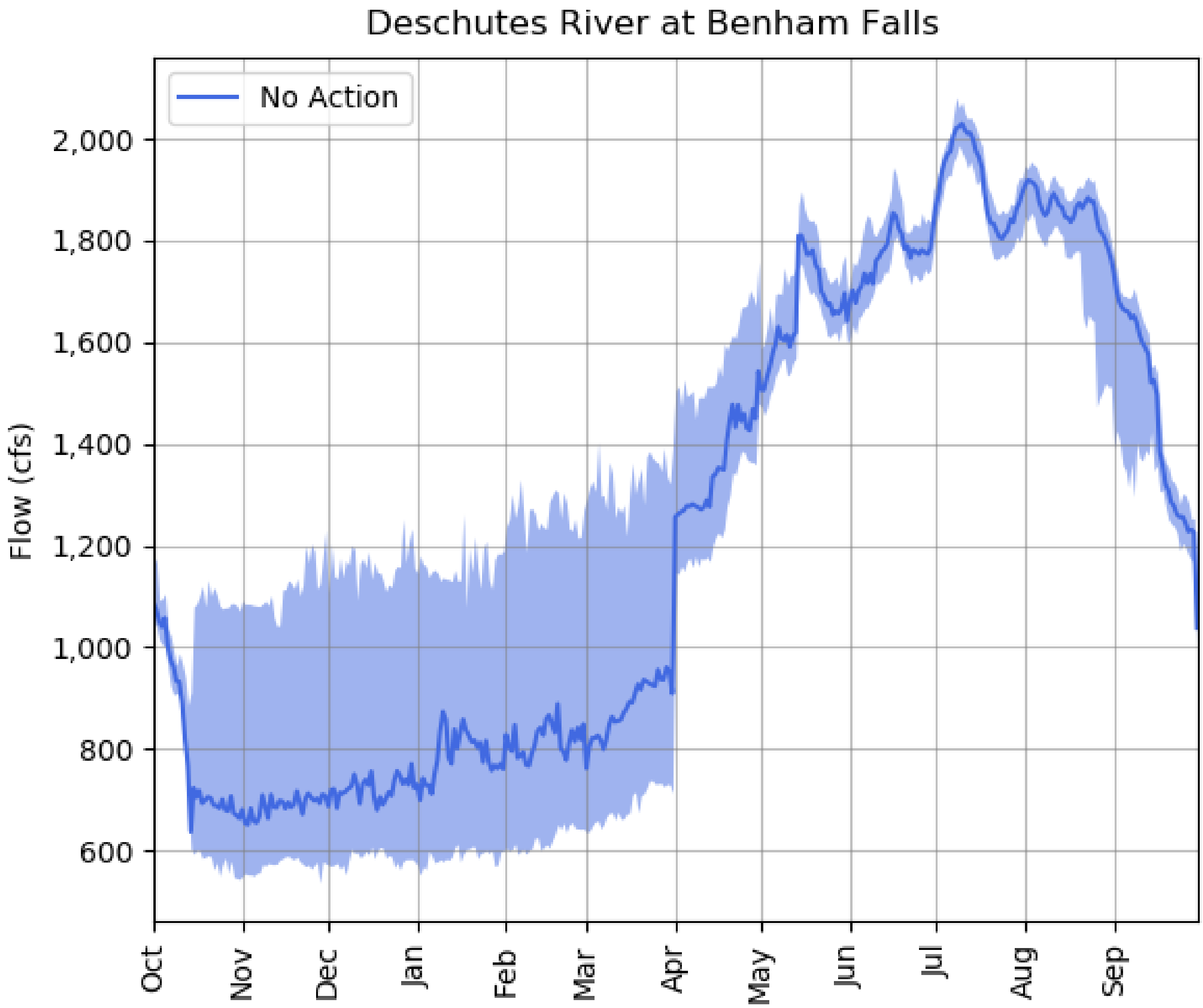

Figure 9. Summary hydrograph of simulated flow in the Deschutes River at Benham Falls for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 10 shows a summary hydrograph of the simulated flow in the Deschutes River below Bend for No Action. The gage is located downstream of all of the major irrigation diversions; therefore, it is representative of the lowest flow between Bend and the Pelton-Round Butte dam complex.

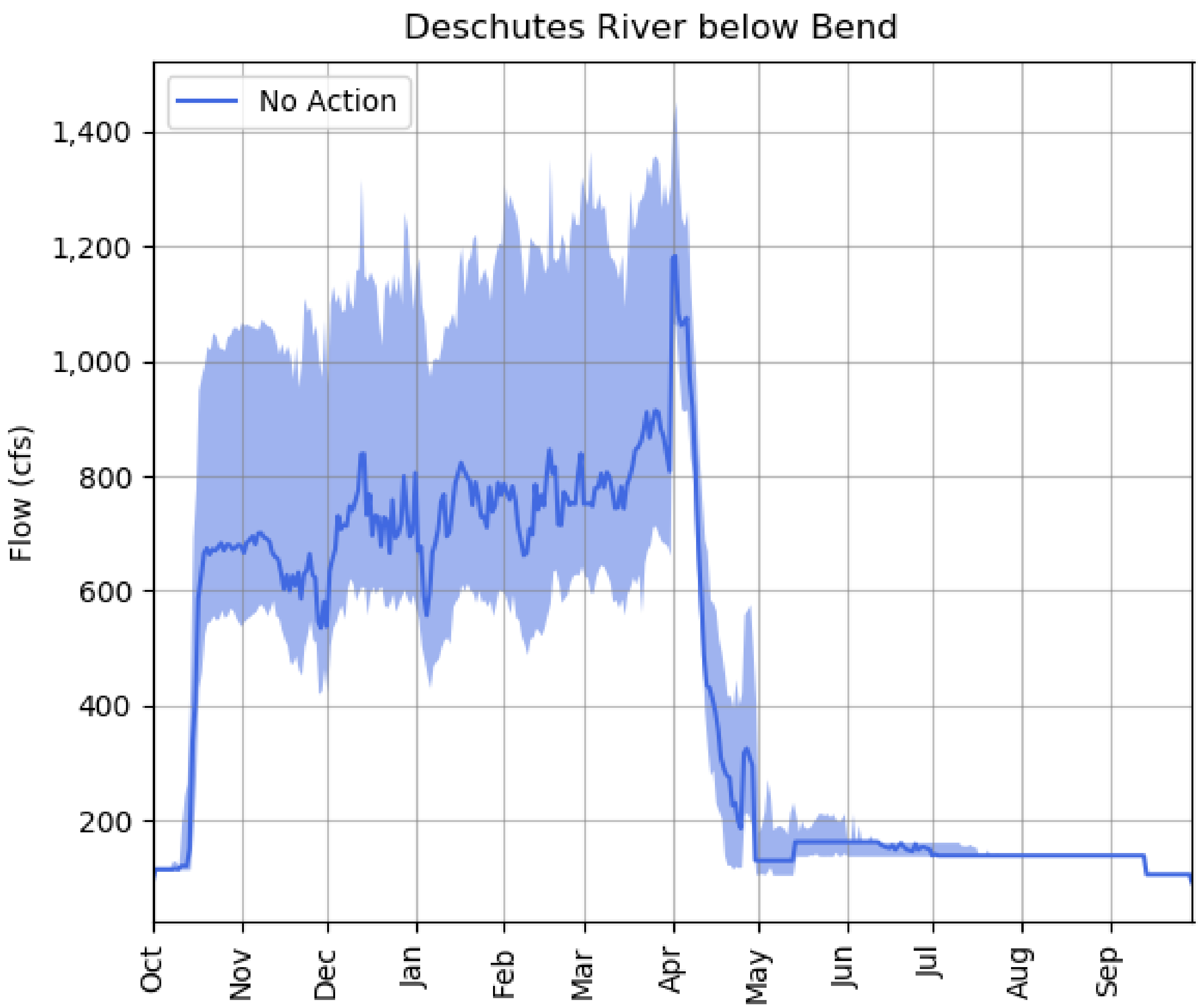

Figure 10. Summary hydrograph of simulated flow in the Deschutes River below Bend for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

4.1.2. Tumalo Creek

Figure 11 shows a summary hydrograph of the simulated flow in Tumalo Creek below the TID diversion for the No Action alternative. Tumalo Creek is a tributary to the Upper Deschutes; it does not have any on-channel storage and supplies water for the City of Bend and TID. The hydrograph represents the lowest flow on the creek below all diversions.

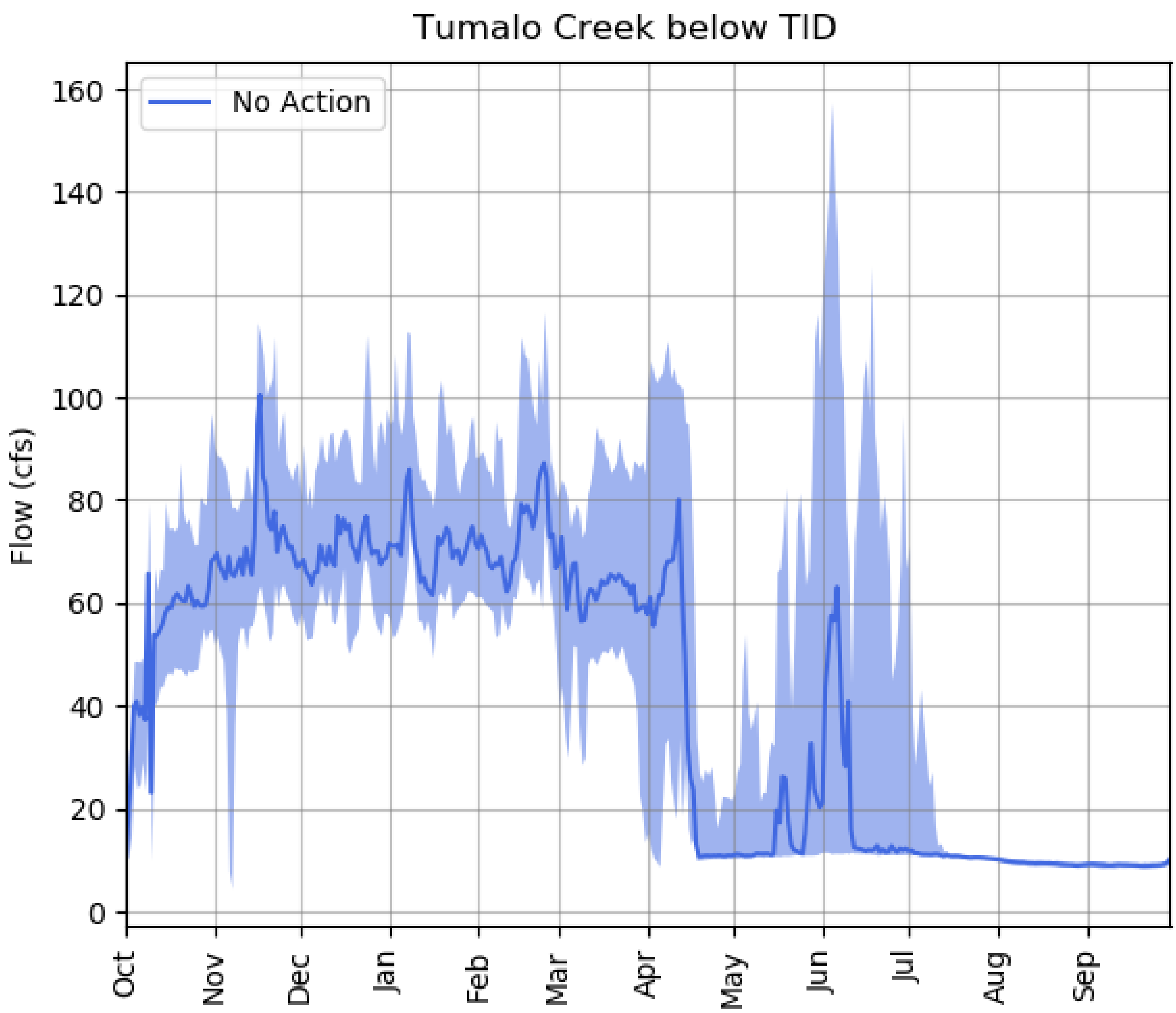

Figure 11. Summary hydrograph of simulated flow in Tumalo Creek below the TID diversion for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

4.1.3. Whychus Creek

Figure 12 shows a summary hydrograph of the simulated flow in Whychus Creek at Sisters for the No Action alternative. Whychus Creek is a tributary to the Upper Deschutes River; it does not have any on-channel storage and supplies water for three small irrigation districts (Edgington, Sokol, and Plainview), along with the much larger Three Sisters Irrigation District (TSID). Output at this control point represents the lowest flow on the creek.

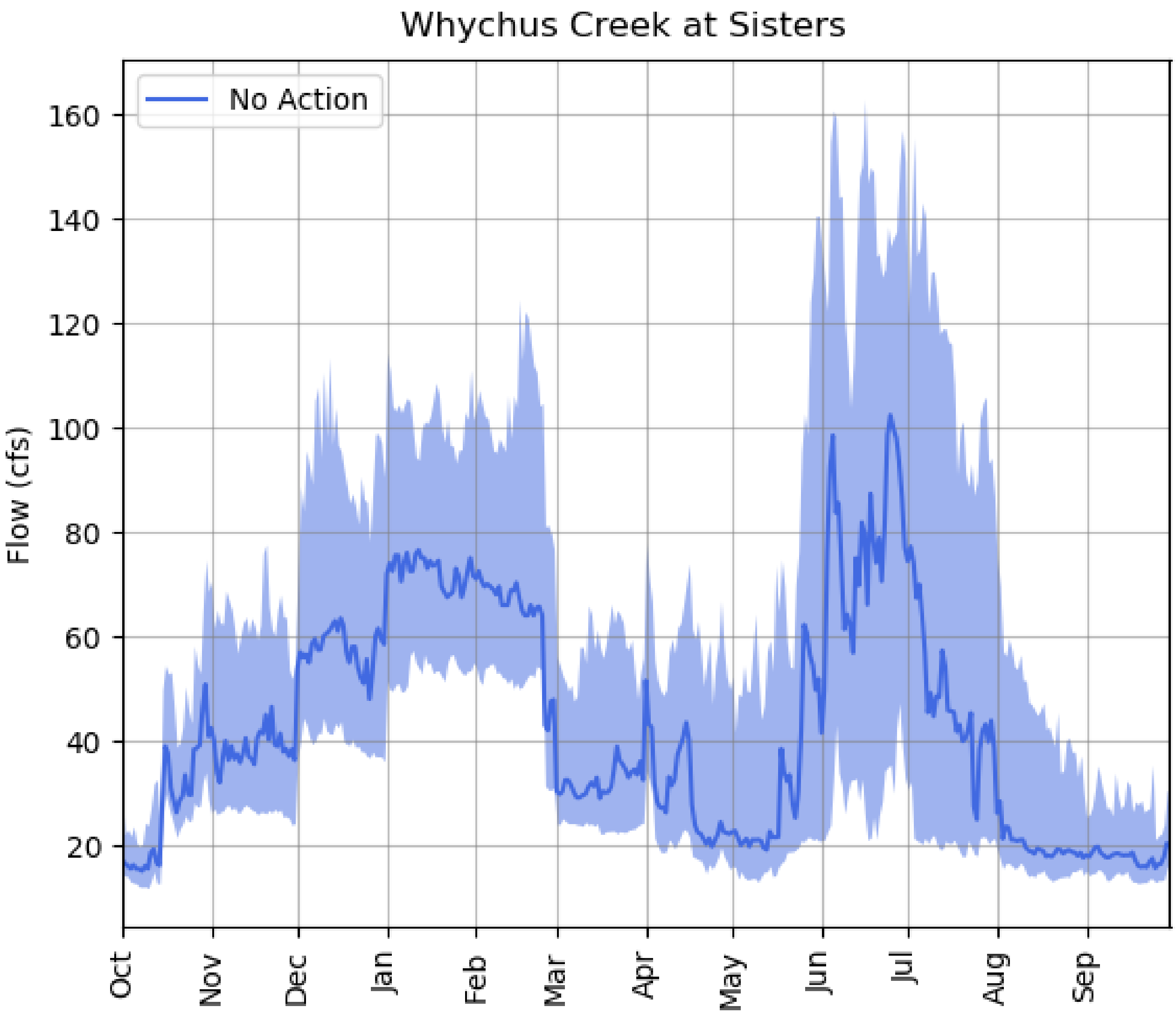

Figure 12. Summary hydrograph of simulated flow in Whychus Creek at Sisters for the No Action Alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

4.1.4. Crooked River

Figure 13 shows summary hydrographs for simulated storage and outflow from Prineville Reservoir for No Action. Prineville Reservoir typically reaches its peak storage volume between April and June and releases water throughout the irrigation season to meet downstream demand and ecological flow objectives, all of which were met in this scenario. During the fall and winter, it releases water as necessary to make space in the reservoir to capture spring runoff and prevent flooding downstream of the dam. In the winter, it releases flows based on the uncontracted flow equations described in Section 2.3. The release pattern in November, December, and January for higher outflows is a result of the model attempting to maintain storage at or below the flood rule curve, which is adjusted on a monthly basis.

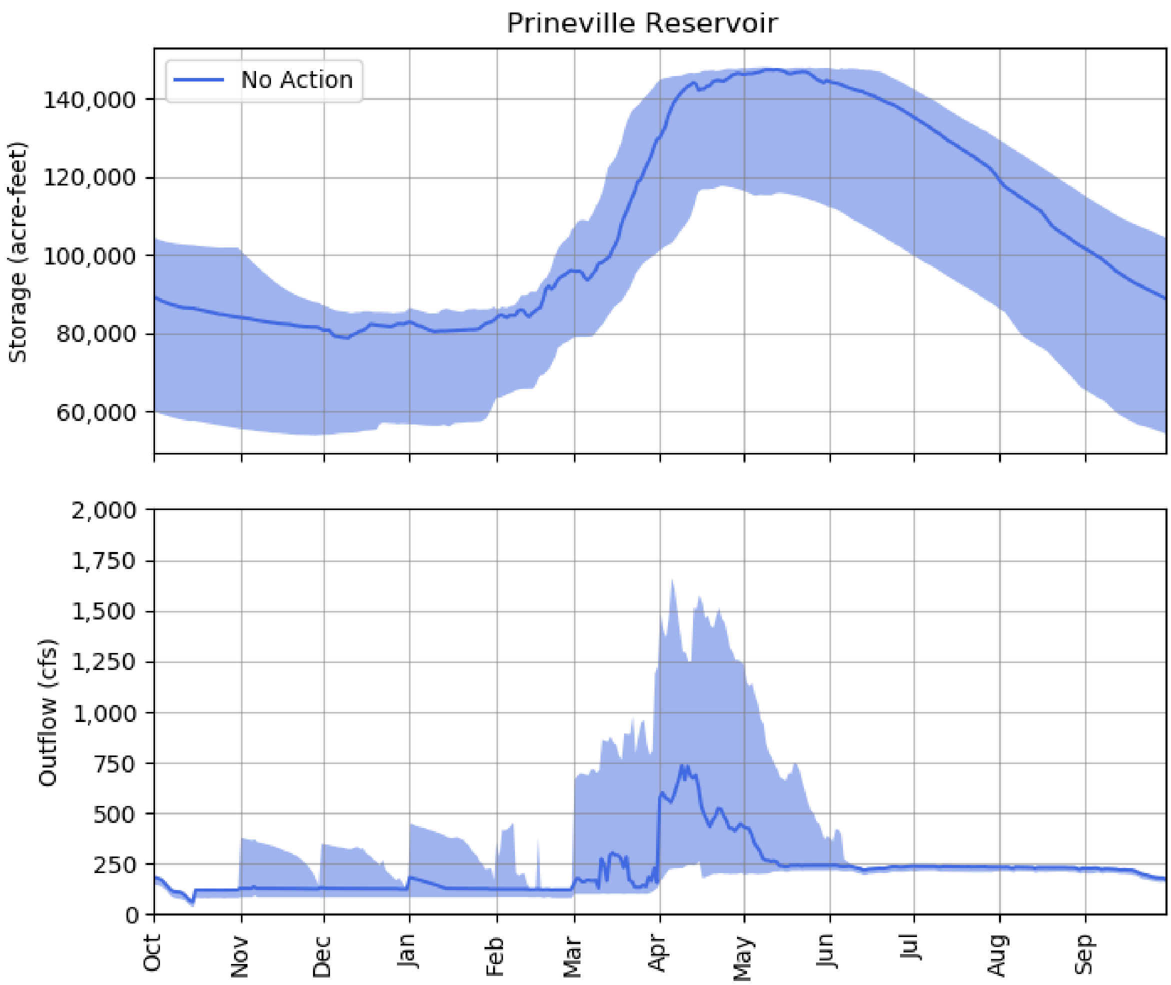

Figure 13. Summary hydrographs of simulated storage (top) and outflow (bottom) from Prineville Reservoir for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 14 shows summary hydrographs for simulated storage and outflow from Ochoco Reservoir for No Action. Like Prineville Reservoir, Ochoco Reservoir typically reaches its peak storage volume between April and June and releases water throughout the irrigation season to meet downstream demand and ecological flow objectives. During the fall and winter, water is released to make space in the reservoir as necessary to capture spring runoff and prevent flooding downstream of the dam. During the winter, enough water is released to maintain 5 cfs in the creek.

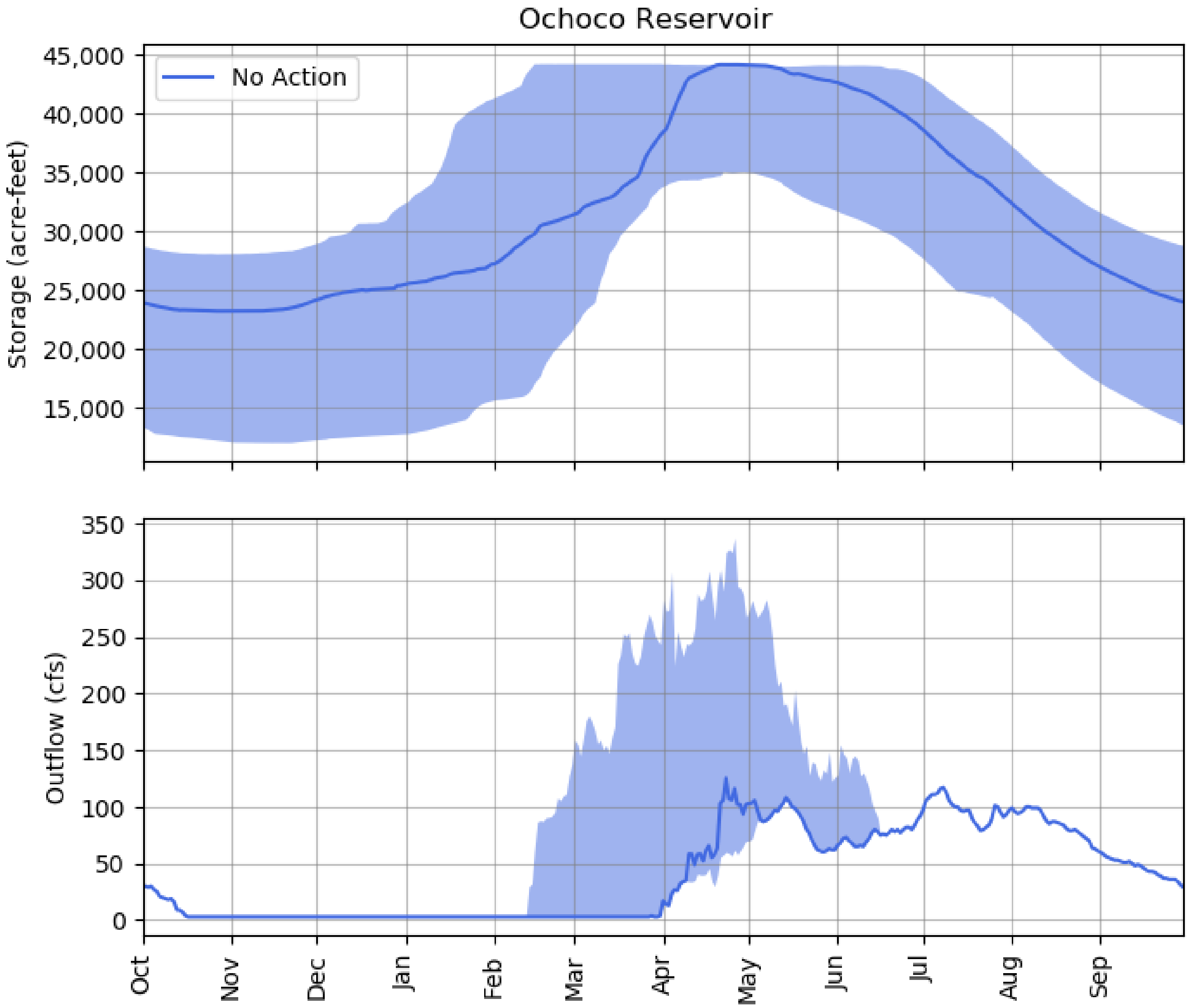

Figure 14. Summary hydrographs of simulated storage (top) and outflow (bottom) from Ochoco Reservoir for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 15 shows a summary hydrograph of the simulated flow in the Crooked River at Highway 126 for No Action. The flow at this gage generally represents a low flow point in the river below some of the major diversions and above most return flows; the minimum flow requirements at this gage were met with this scenario. It is largely influenced by the outflow from Prineville Reservoir in the winter and by the upstream diversions and contracted reservoir releases in the summer.

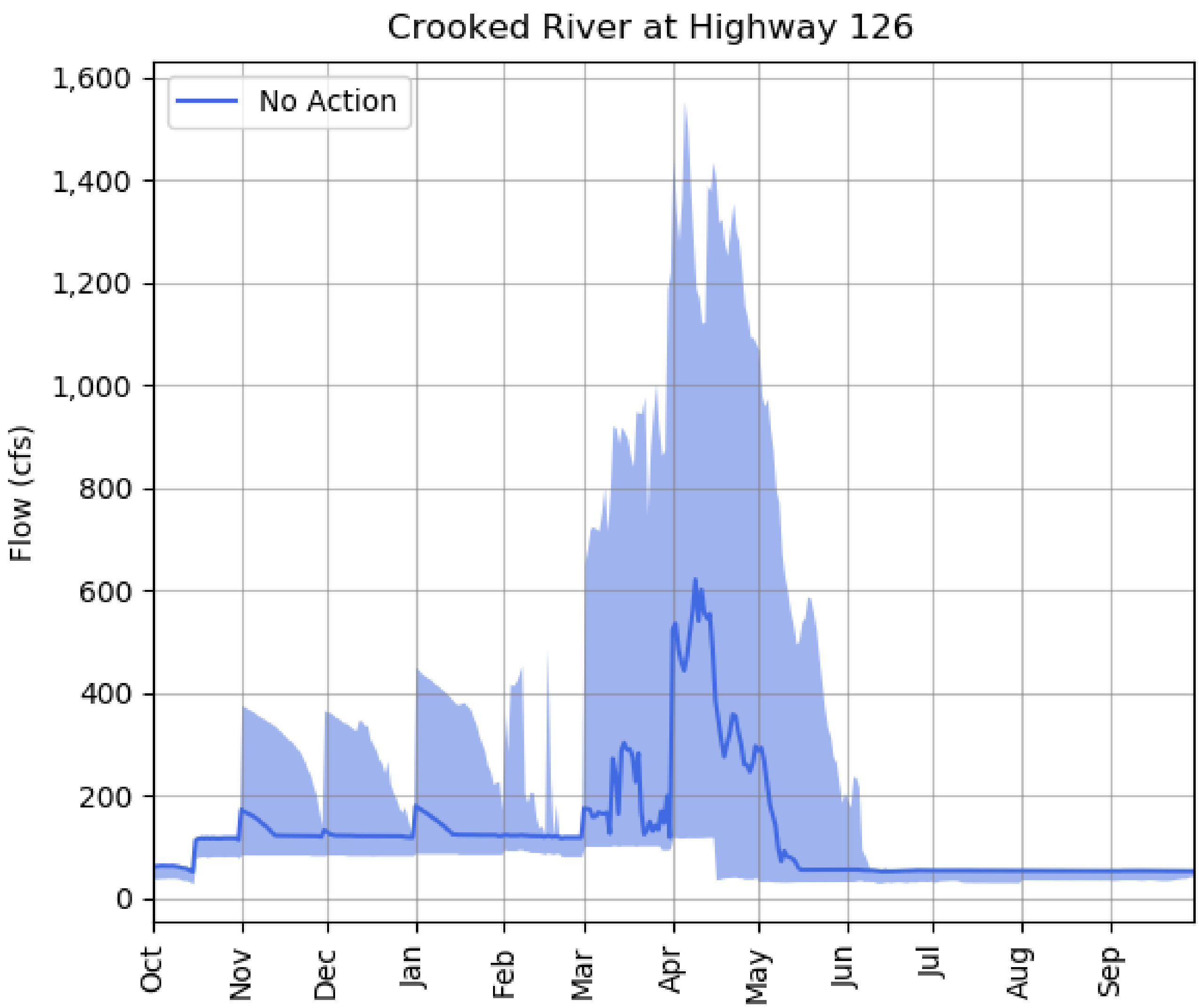

Figure 15. Summary hydrograph of simulated flow in the Crooked River at Highway 126 for the No Action alternative. The dark blue line represents the median and the shaded blue areas represent the 20 to 80 percent exceedance.

Figure 16 shows a summary hydrograph of the simulated flow in the Crooked River below the NUID pumps for No Action. The flow at this gage generally represents another low flow point in the river below major diversions and above irrigation return flows. It is largely influenced by the outflow from Prineville Reservoir in the winter and by the upstream diversions in the summer. The minimum flows as described in the Deschutes River Conservancy Bypass Flow agreement were met in all years (note that the lowest modeled bypass flow was 50 cfs, though the agreement allows for a lower value, 43.798 cfs, in May in dry years).

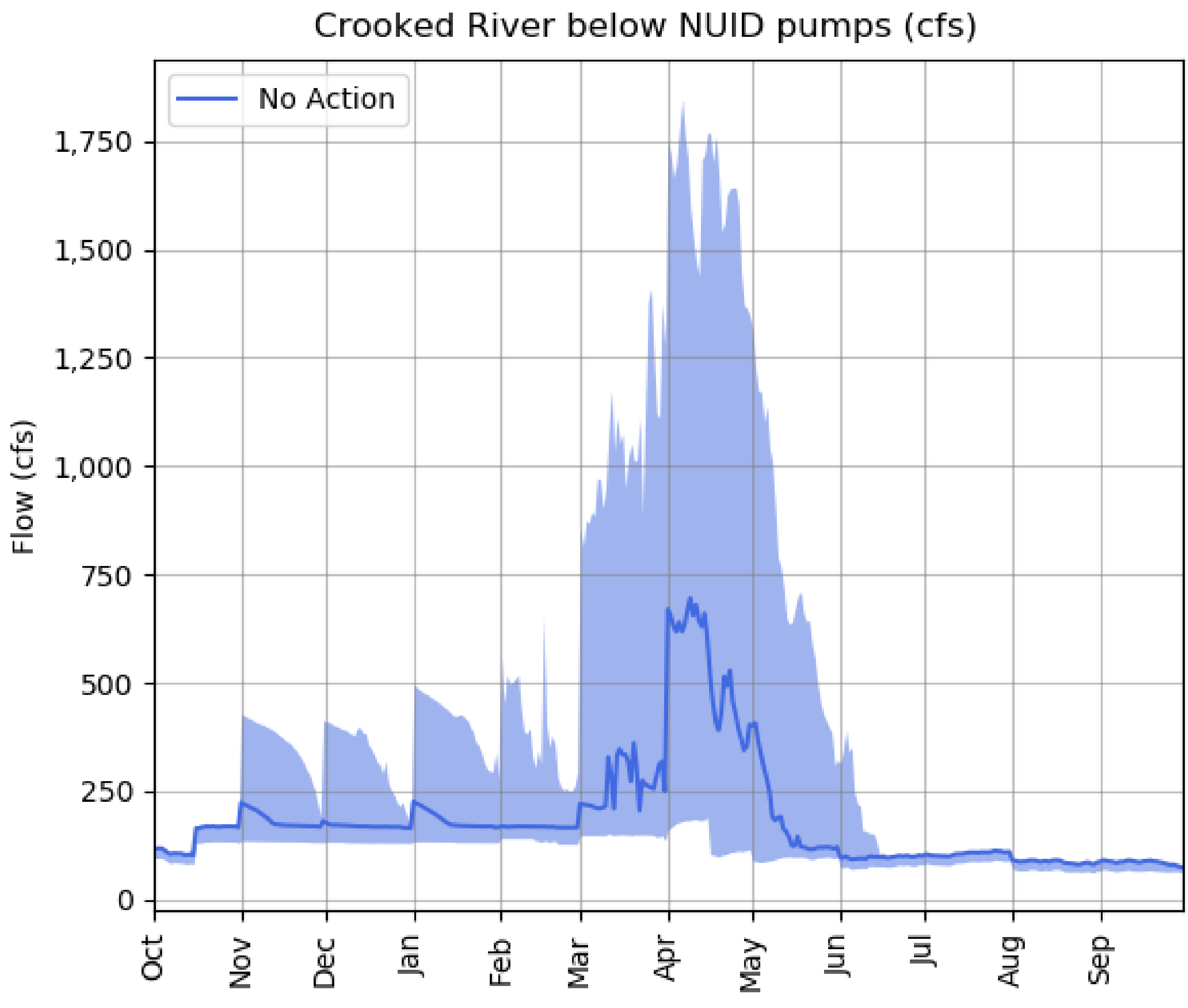

Figure 16. Summary hydrograph of simulated flow in the Crooked River below the NUID pumps for the No Action alternative. The dark blue line represents the median and the shaded blue area represents the 20 to 80 percent exceedance.

4.1.5. Irrigation Shortages

Irrigation shortages are calculated every model year and are the difference between the requested demand and the amount of water delivered to each district. The total annual shortages for the No Action alternative are ranked and shown in Figure 17. NUID has the largest shortage in the No Action alternative because it is the junior water user on the system.

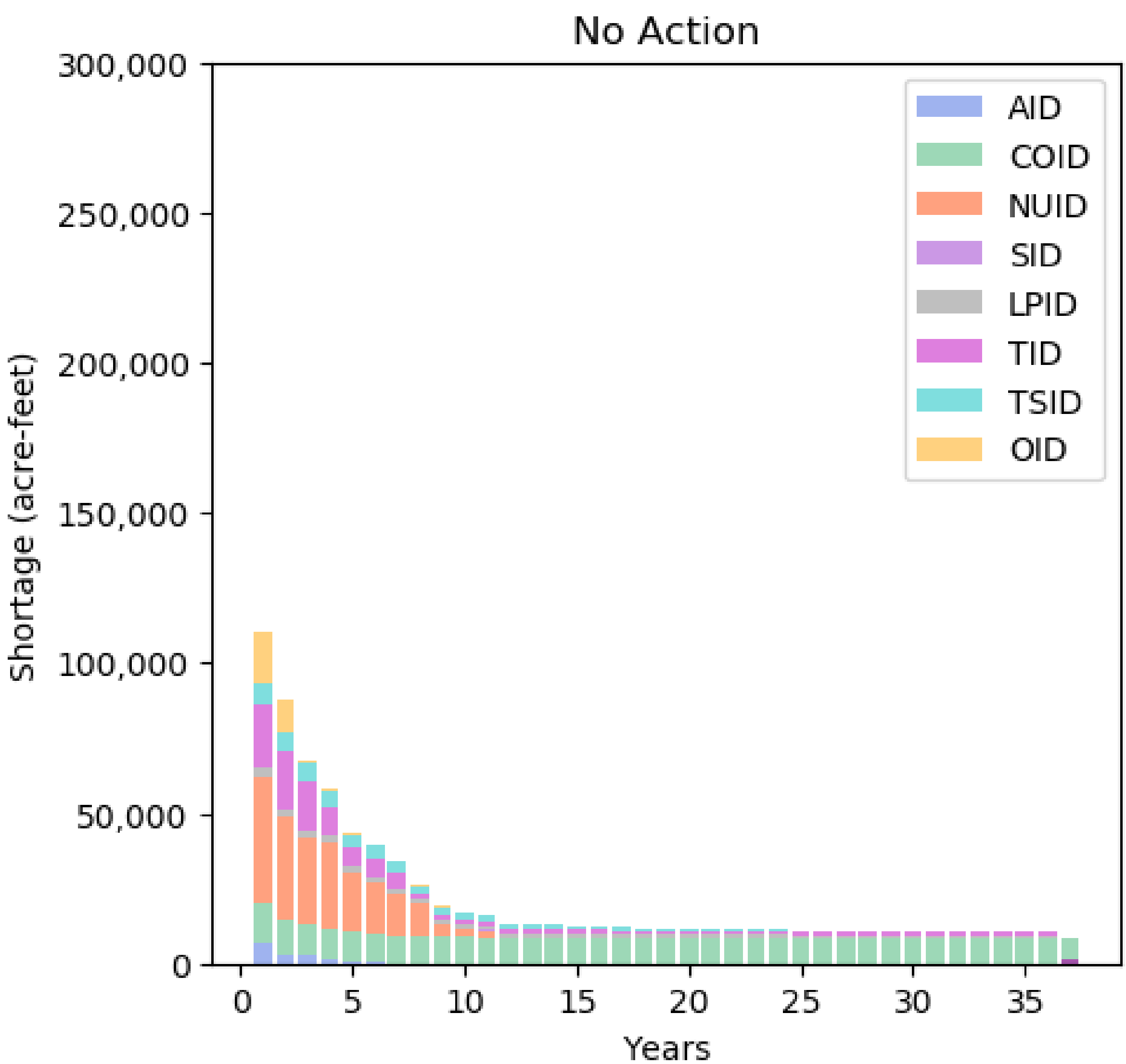

Figure 17. Irrigation shortages for the eight major districts in the basin for No Action

Table 7 shows the minimum, median, and maximum shortages from the total annual diversion for No Action. These are also shown as percent of total demand for each entity in order to illustrate the significance of the shortage.

Table 7. Minimum, median, and maximum shortages for No Action, reported both in volume (acre-feet) and as percent of total annual demand

District	No Action Alternative					
	Minimum		Median		Maximum	
	acre-feet	percent	acre-feet	percent	acre-feet	percent
AID	-	0%	-	0%	6,800	21%
COID	6,000	0.4%	6,200	0.4%	10,700	1%
NUID	-	0%	-	0%	42,100	21%
SID	-	0%	-	0%	-	0%
LPID	300	2%	1,300	8%	2,900	18%
TID	1,500	3%	1,500	3%	20,800	39%
TSID	-	0%	1,000	3%	6,400	18%
OID	-	0%	-	0%	15,600	20%

4.2. Alternative 2: Districts' DBHCP Proposal

The Alternative 2 results are displayed along with the No Action results for comparison. Only the locations that experienced a change from the No Action results are shown in this section. The DBHCP will be implemented in three major phases over time and the results shown reflect those time periods where Alternative 2A is years 0 to 7, Alternative 2B is years 8 to 12, and Alternative 2C is years 13 to 30.

4.2.1. Upper Deschutes

Figure 18 shows summary hydrographs of the simulated storage (top) and outflow (bottom) from Crane Prairie Reservoir for No Action Alternative (blue) compared to Alternative 2 (green). Recall that the intended operation for Crane Prairie Alternative 2 was as described below.

1. Store water from November 1 to March 14 to reach 48,000 acre-feet.
2. Pass inflow from March 15 to July 15 to maintain between 46,800 and 48,000 acre-feet.
3. Release storage at a maximum rate of 225 acre-feet per day from July 16 to July 31.
4. From July 31 to October 31, release up to 450 acre-feet per day until 38,000 acre-feet and then maintain 38,000 acre-feet until October 31.
5. Outflows are managed to maintain a minimum release of 75 cfs, if possible, and an absolute minimum of 30 cfs.

Figure 18 shows that this operation can be maintained through all three implementation phases. The difference between the Alternative 2 operation and the No Action operation is primarily due to the change in operating rules. However, the fill period between November 1 and March 14 also varies due to changes in inflow to the reservoir. Outflows from the reservoir are generally more consistent using the operation in Alternative 2 and show less dramatic changes than for No Action.

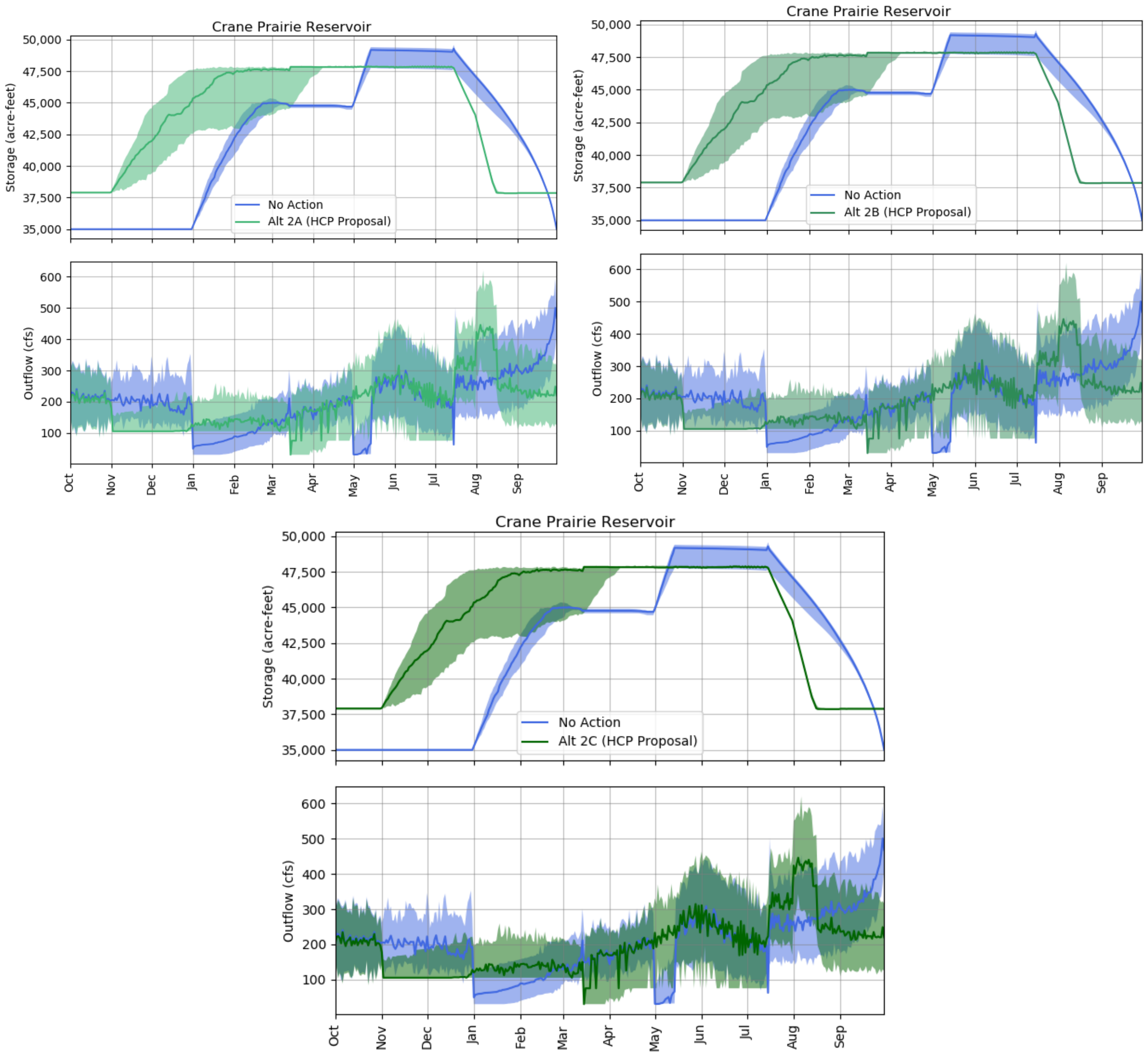

Figure 18. Summary hydrographs of simulated storage (top) and outflow (bottom) from Crane Prairie Reservoir for No Action (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B at the top right, and 2C at the bottom. The dark blue or green line represents the median and the shaded blue or green areas represent the 20 to 80 percent exceedance.

Figure 19 shows summary hydrographs of the simulated storage and outflow from Wickiup Reservoir for No Action (blue) compared to Alternative 2 (green) with the three implementation phases. For all three implementation phases, Wickiup was able to meet the outflow objectives of Alternative 2; however, the reservoir has lower storage volumes than No Action, particularly in the later implementation phases, due to the higher outflows. For Alternative 2A, Wickiup maintains a minimum of 100 cfs in all years and does not have a maximum irrigation season outflow. This outflow results in similar storage to No Action. For Alternative 2B, Wickiup maintains a minimum storage season outflow of 300 cfs in all years and a maximum irrigation season outflow of 1,400 cfs. Storage in Wickiup is lower than No Action primarily due to the increase in winter flows. For Alternative 2C, Wickiup maintains a minimum storage season outflow of 400 cfs and a maximum irrigation season outflow of 1,200 cfs in all years.

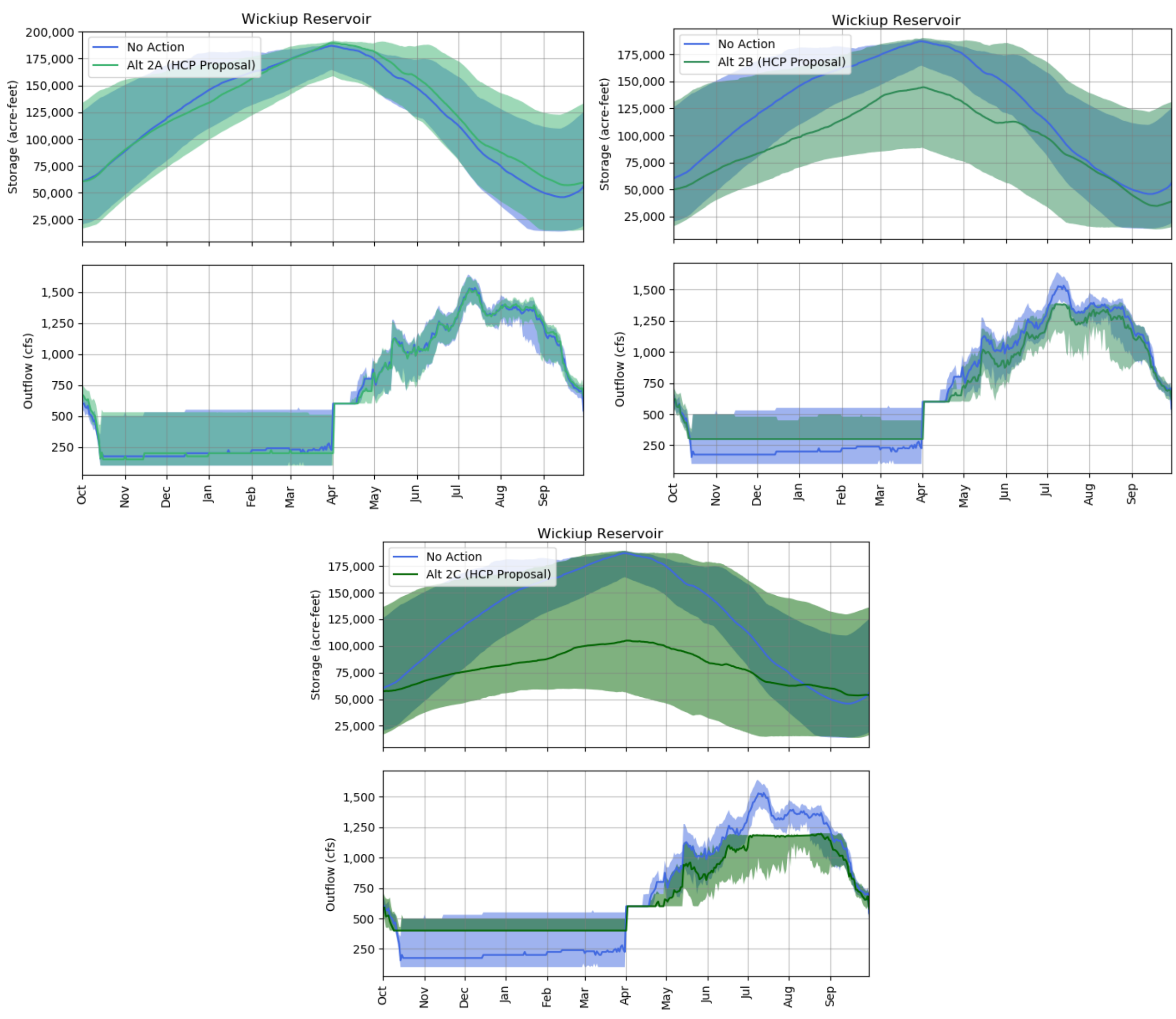

Figure 19. Summary hydrographs of simulated storage (top) and outflow (bottom) from Wickiup Reservoir for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B at the top right, and 2C at the bottom. The dark blue or green line represents the median and the shaded blue or green areas represent the 20 to 80 percent exceedance.

Figure 20 shows summary hydrographs for the storage and outflow from Crescent Lake for No Action (blue) compared to Alternative 2 (green) for all three implementation phases. Recall that the intended operation for Crescent Lake in Alternative 2 was to maintain a minimum of 10 cfs in the non-irrigation season (increased to 11 cfs in Alternative 2C), and then use a reserved portion of stored water to increase spring flows and reduce flows more slowly at the end of the irrigation season. These graphs indicate that the minimum can be maintained in all years and provide an example of how the spring and fall operation may occur, though this will be managed in real time based on weather and flow conditions in critical habitat locations which may result in flow that look different from these graphs. As noted in the scenario description, the minimum outflows from Crescent are lower than No Action because it was determined to be more important to shape the outflows at critical times of the year for the species than to maintain a higher flow throughout the year.

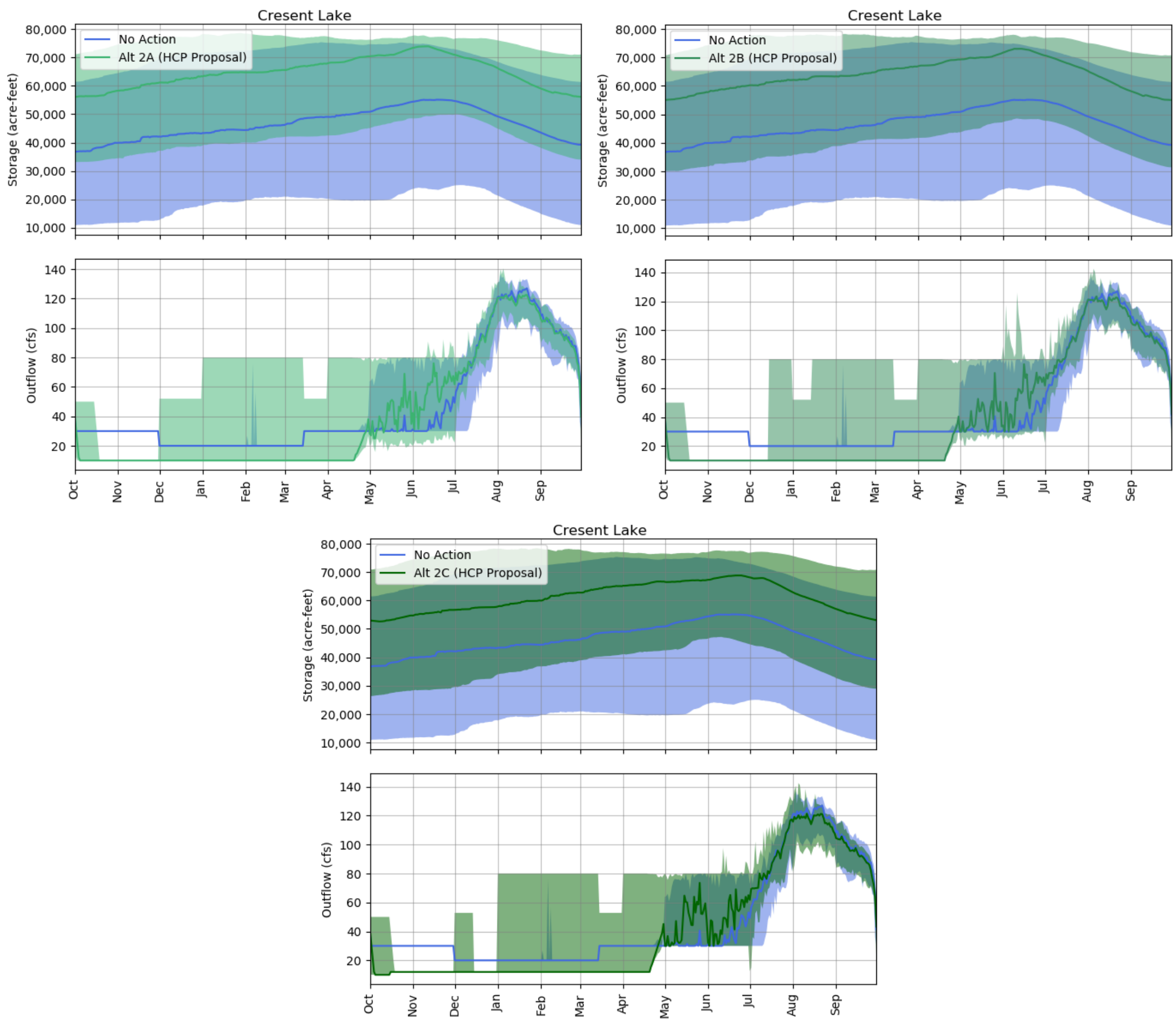

Figure 20. Summary hydrographs of simulated storage (top) and outflow (bottom) from Crescent Lake for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B is shown at the top right, and 2C at the bottom. The dark blue or green line represents the median and the shaded blue or green areas represent the 20 to 80 percent exceedance.

Figure 21 shows a summary hydrograph of the simulated flow in the Little Deschutes River at La Pine for No Action (blue) compared to Alternative 2 (green) for all three implementation phases. As mentioned previously, the flow at this gage is largely unregulated, with a small contribution from Crescent Creek and Crescent Lake in the spring and a larger contribution in the summer and fall. The changes in the releases from Crescent Lake can be seen primarily in the fall months, but, overall, the flow is relatively similar at this gage for both alternatives.

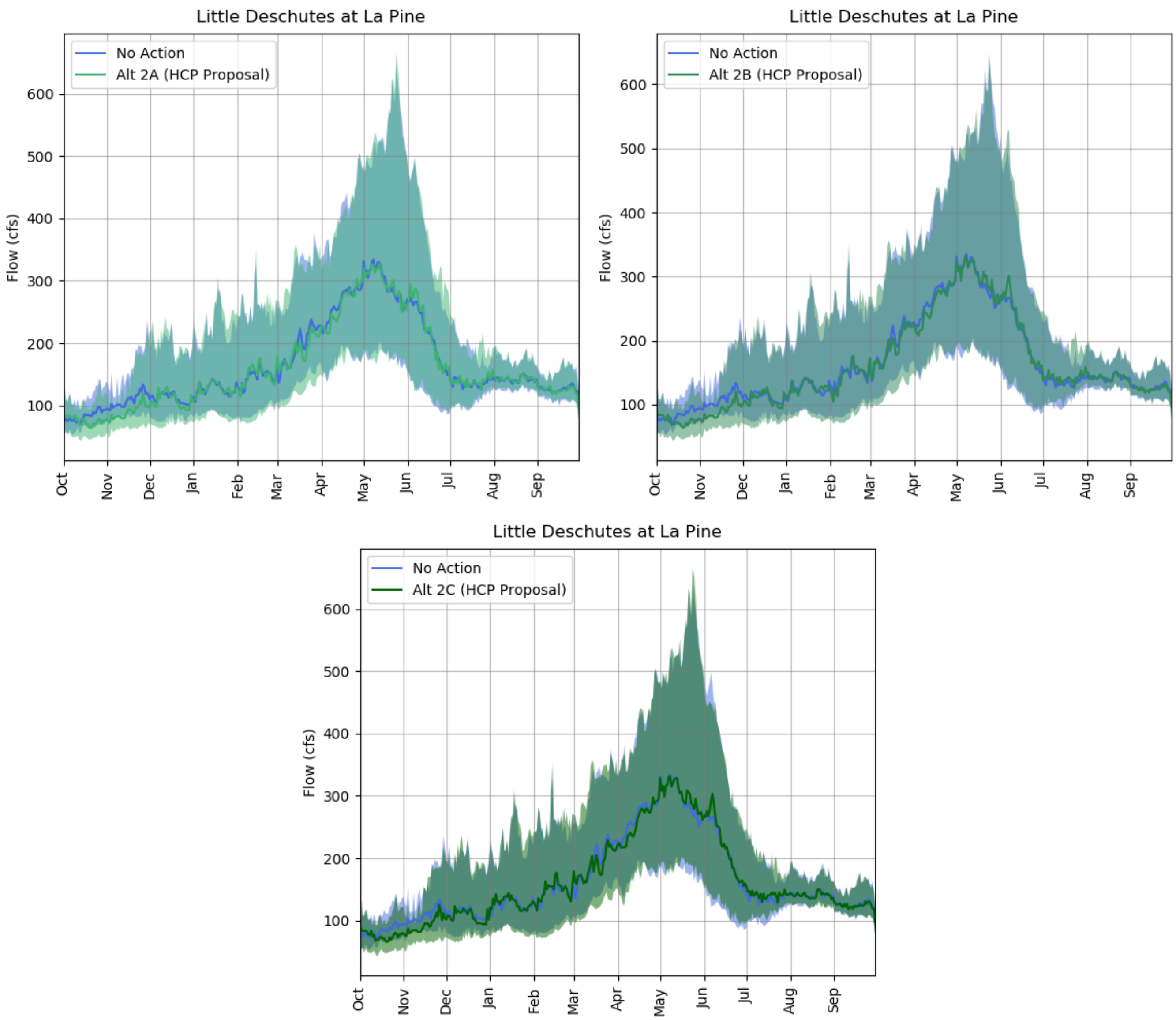

Figure 21. Summary hydrograph of simulated flow in the Little Deschutes River at La Pine for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left), 2B at the top right, and 2C at the bottom. The dark blue and green lines represent the median and the shaded area represents the 20 to 80 percent exceedance.

Figure 22 shows a summary hydrograph of the simulated flow in the Deschutes River at Benham Falls for No Action (blue) compared to Alternative 2 (green) for all three implementation phases. This gage is heavily influenced by the outflow from Wickiup Reservoir. Consequently, the changes from No Action mimic the changes at Wickiup Reservoir.

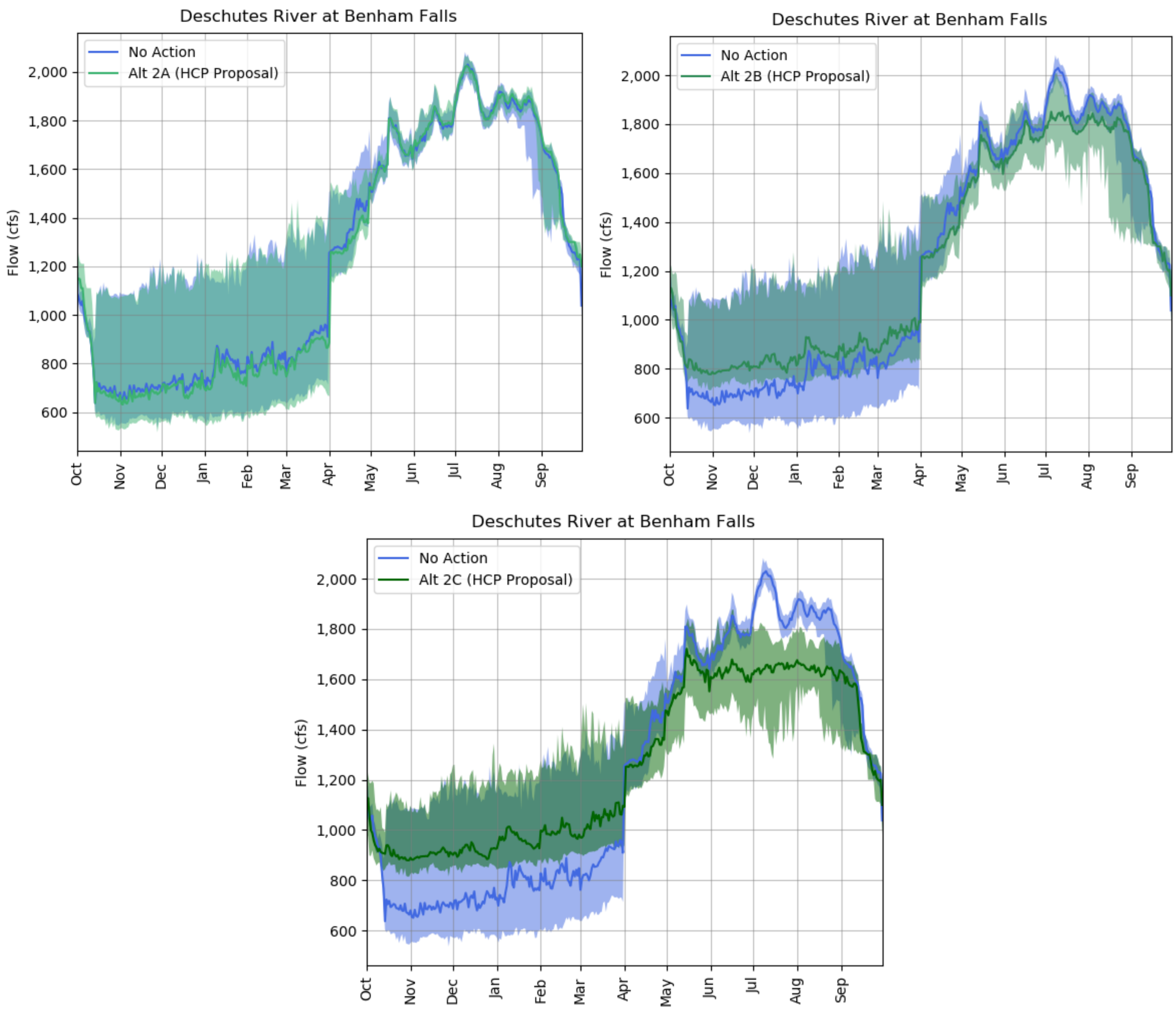

Figure 22. Summary hydrograph of simulated flow in the Deschutes River at Benham Falls for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B at the top right, and 2C at the bottom). The dark blue and green lines represent the median and the shaded area represents the 20 to 80 percent exceedance.

Figure 23 shows a summary hydrograph of the simulated flow in the Deschutes River below Bend for the No Action alternative (blue) compared to Alternative 2 (green) for all three implementation phases. The minimum flow targets are able to be met in all implementation phases. The effects of the increased releases from Wickiup Reservoir can be seen in the winter months when the range and median of flow is incrementally larger than for No Action. The summer flows at this location are similar for both alternatives. The effects of the minimum outflow requirements below Wickiup Reservoir in April and the rate of outflow reduction at the end of the irrigation season can be seen in these graphs, which show there is flow passing Bend that is not being diverted for irrigation. These additional releases are over and above irrigation demand but could be diverted in real time if the districts had a need for the water.

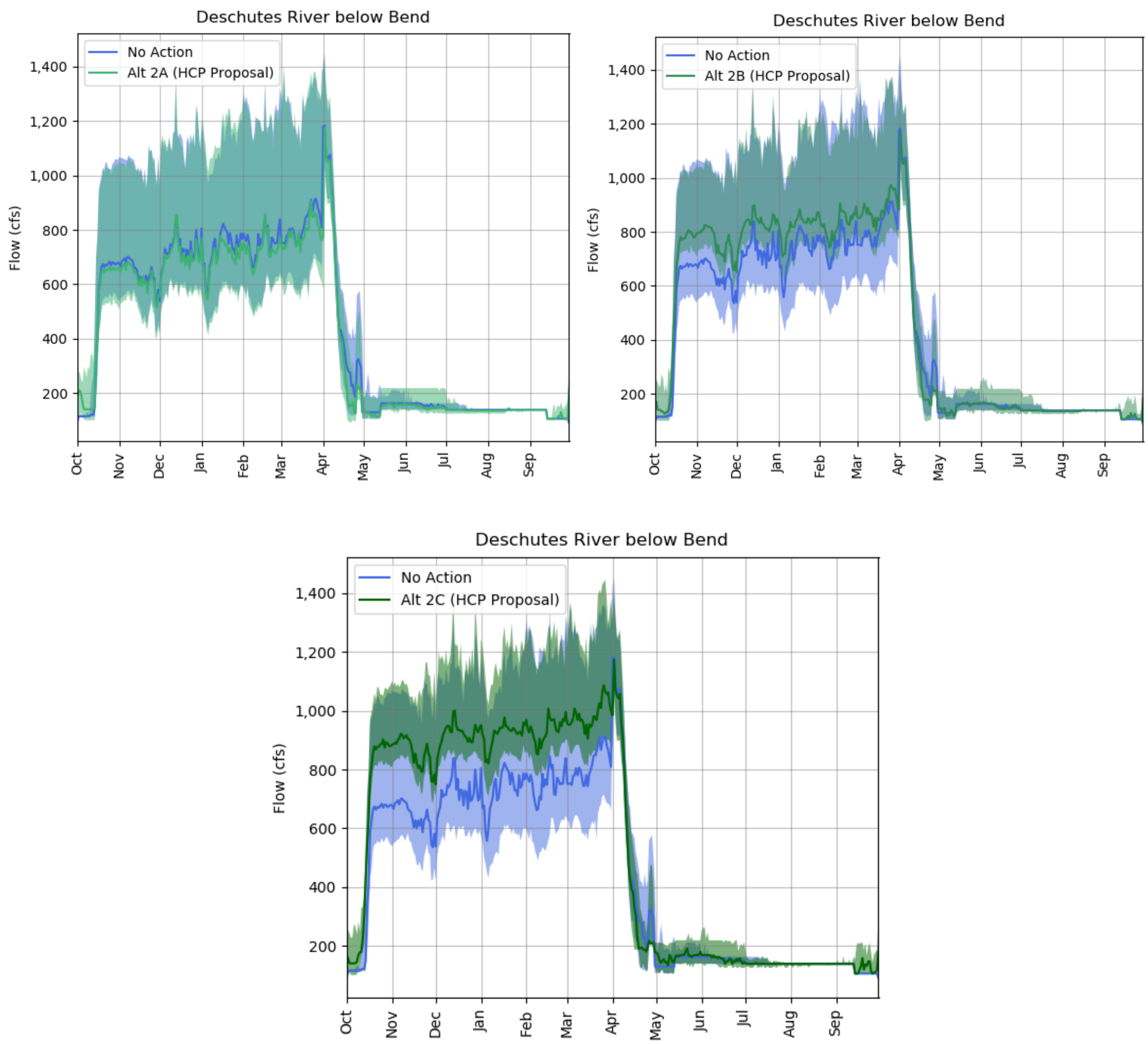

Figure 23. Summary hydrograph of simulated flow in the Deschutes River below Bend for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left), 2B at the top right, and 2C at the bottom. The dark blue or green lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

4.2.2. Tumalo Creek

There are no changes in Tumalo Creek flows from No Action to Alternative 2.

4.2.3. Whychus Creek

There are no changes in Whychus Creek flows from No Action to Alternative 2.

4.2.4. Crooked River

Figure 24 shows summary hydrographs for simulated storage and outflow from Prineville Reservoir for No Action (blue) compared to Alternative 2 (green) for all three implementation phases. Prineville Reservoir's operation in Alternative 2 reflects the changes in the Upper Deschutes. As more water is released from Wickiup Reservoir for minimum flows, there is less available for NUID during the irrigation season. This causes Prineville Reservoir to release more water from NUID's rental account, resulting in higher outflows and lower reservoir storage.

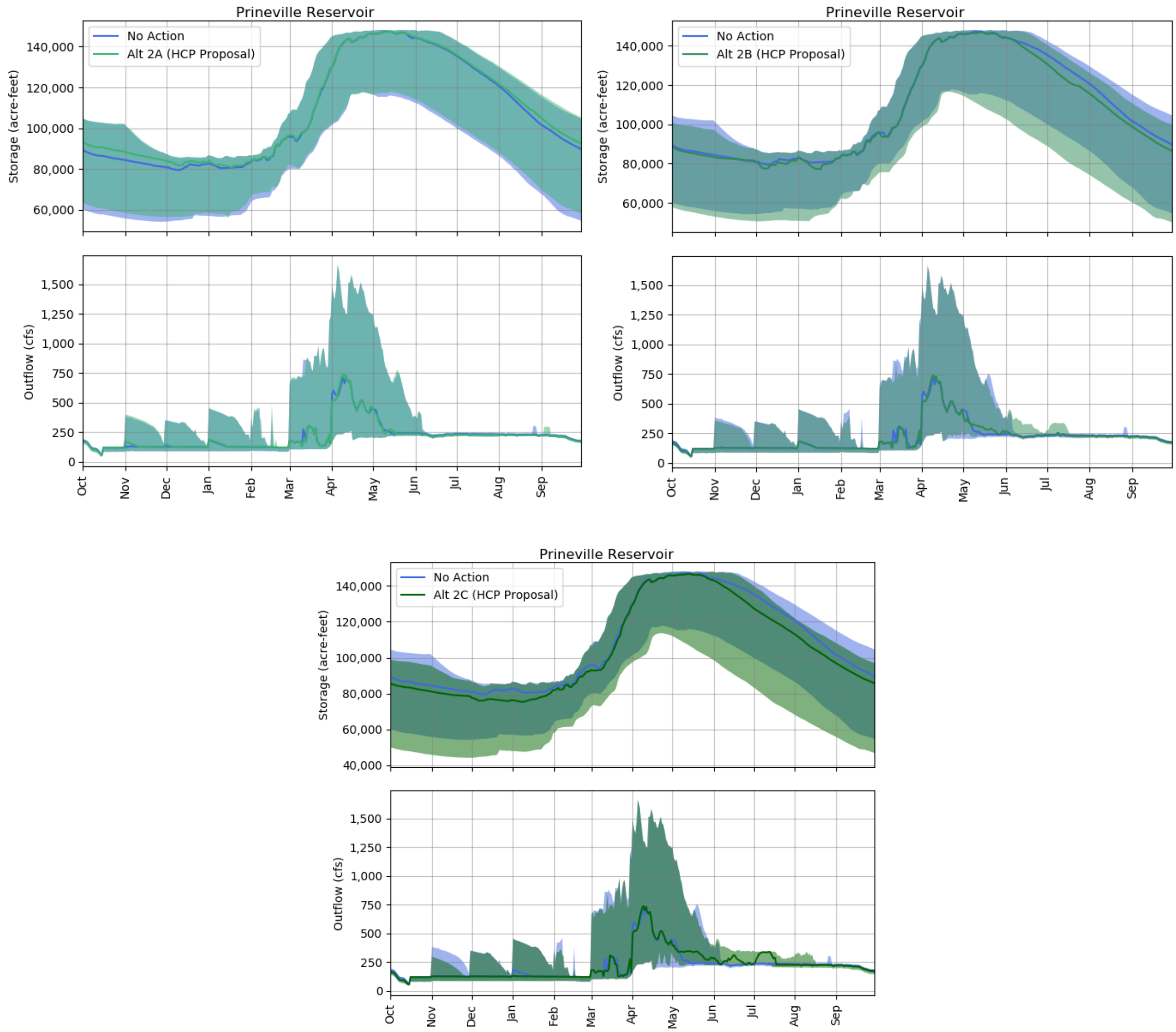

Figure 24. Summary hydrographs of simulated storage (top) and outflow (bottom) from Prineville Reservoir for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B at the top right, and 2C at the bottom. The dark blue or green line represents the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 25 shows a summary hydrograph of the simulated flow in the Crooked River at Highway 126 for No Action (blue) compared to Alternative 2 (green). The effects of the change in Prineville Reservoir releases can be seen at this location, where the minimum flow objectives are able to be met in all years.

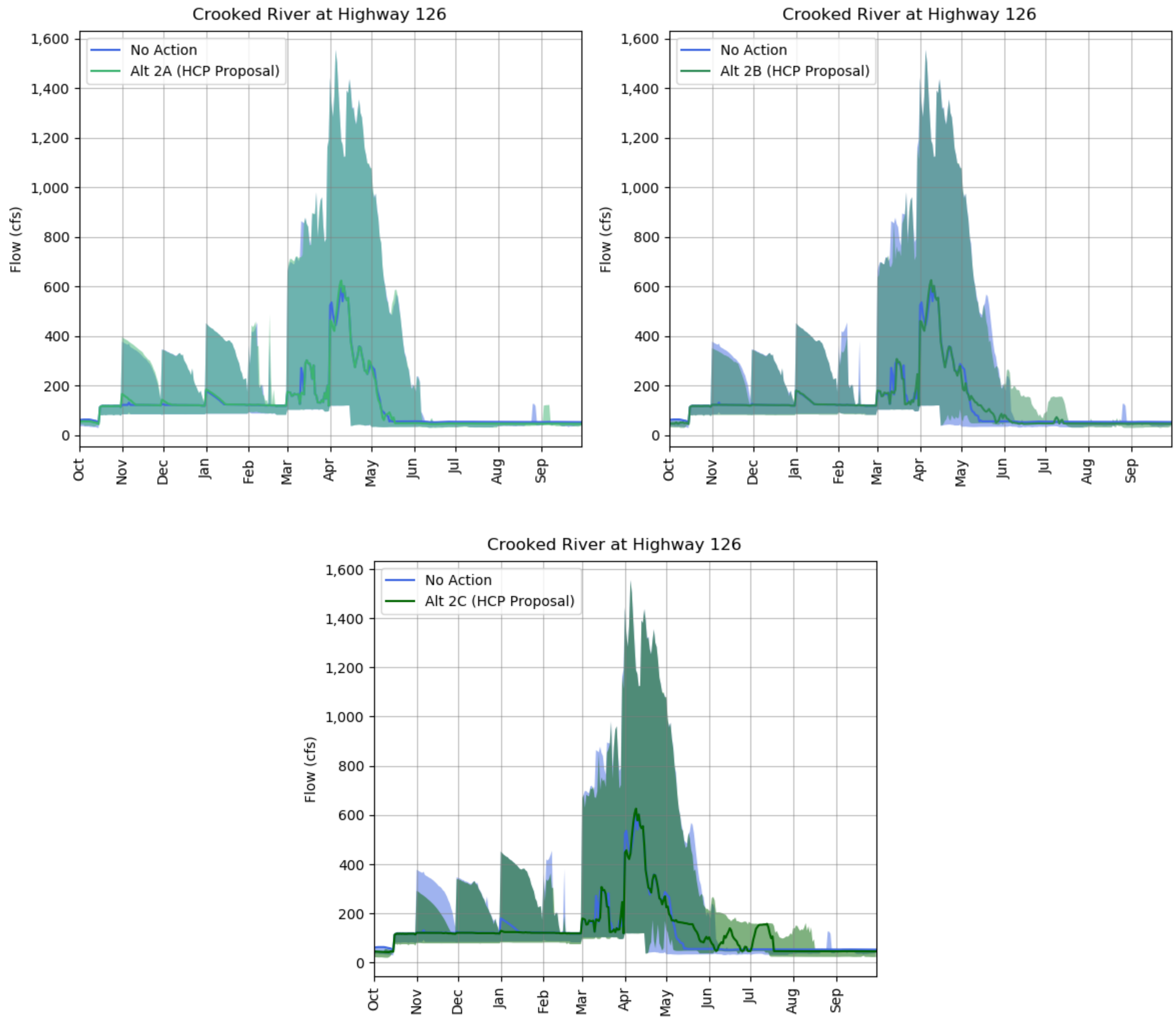

Figure 25. Summary hydrograph of simulated flow in the Crooked River at Highway 126 for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B at the top right, and 2C at the bottom. The dark blue or green lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 26 shows a summary hydrograph of the simulated flow in the Crooked River below the NUID pumps for No Action (blue) compared to Alternative 2 (green). The effects of the change in Prineville Reservoir releases can be seen at this location. The minimum flows as described in the Deschutes River Conservancy Bypass Flow agreement were met in all years.

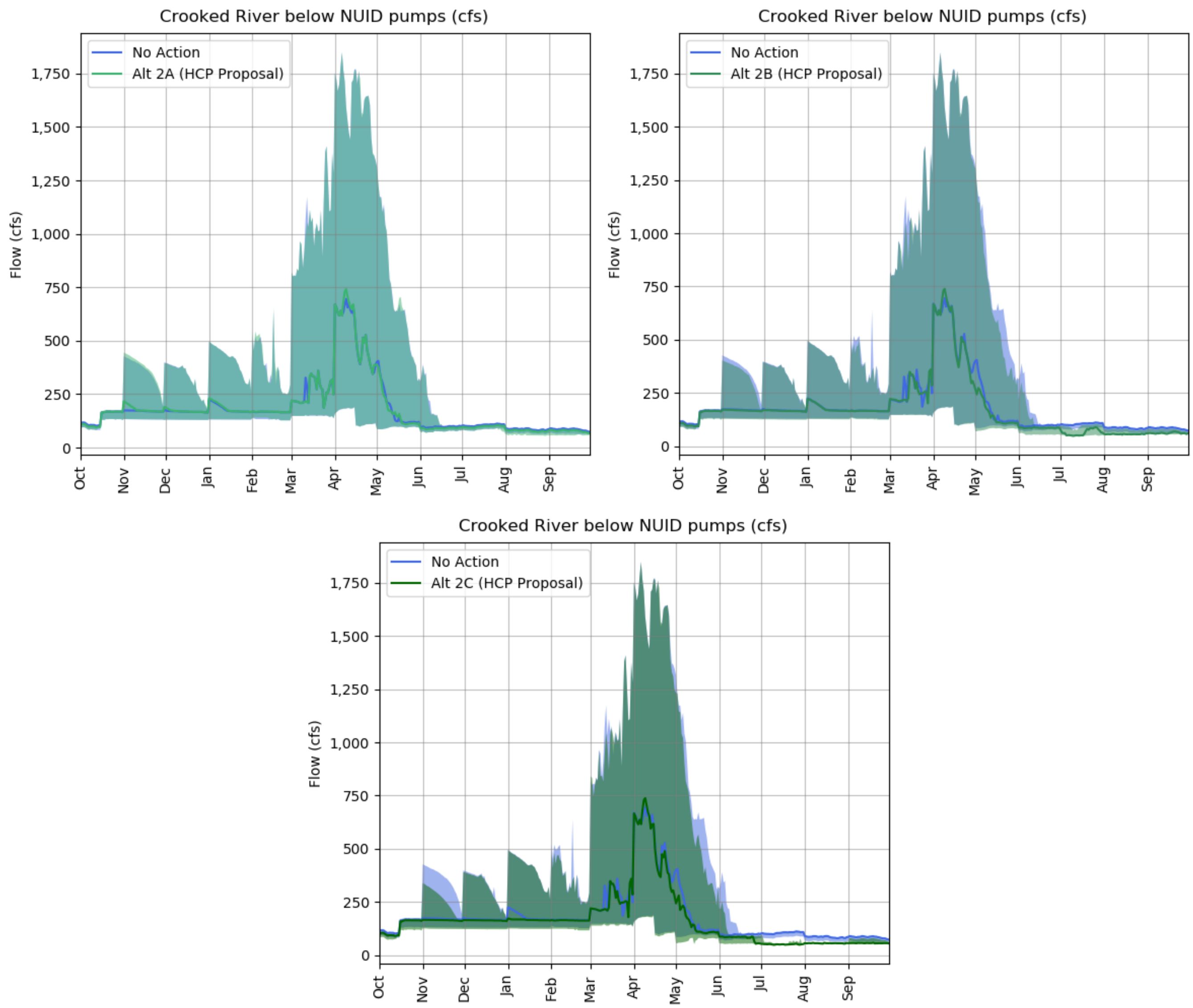

Figure 26. Summary hydrograph of simulated flow in the Crooked River below NUID pumps for the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left), 2B at the top right, and 2C at the bottom. The dark blue or green lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

4.2.5. Irrigation Shortages

Irrigation shortages are calculated every model year and are the difference between the requested demand[9] and the amount of water delivered to each district through the implementation phases. Even though there are three implementation phases with different lengths, each phase is modeled for the entire model run period (1980 through 2018) to get the best assessment of potential effects under different hydrologic conditions. The years indicated on the graphs are the years of the run period, not the years of the implementation phase.

The total annual shortages for Alternatives 2A, 2B, and 2C are ranked and shown in Figure 27. NUID has the largest shortage in Alternative 2 because it is the junior water user on the system. This shortage increases as Alternative 2 is implemented because the increased non-irrigation season flows out of Wickiup Reservoir reduce the amount of stored water available for NUID. Other districts also experience increased shortage because of the increased non-irrigation season flow requirement, and, in the case of LPID and AID, because their storage allocation in Crane Prairie was smaller than for No Action.

Table 8 shows the minimum, median, and maximum shortages from the total annual diversion for No Action, Alternative 2A, Alternative 2B, and Alternative 2C. The shortages are also shown as percent of total demand for each entity to illustrate the significance of the shortage.

[9] Even if model demand was reduced to respond to hydrologic conditions, the total shortage was still calculated using the full, non-reduced annual demand.

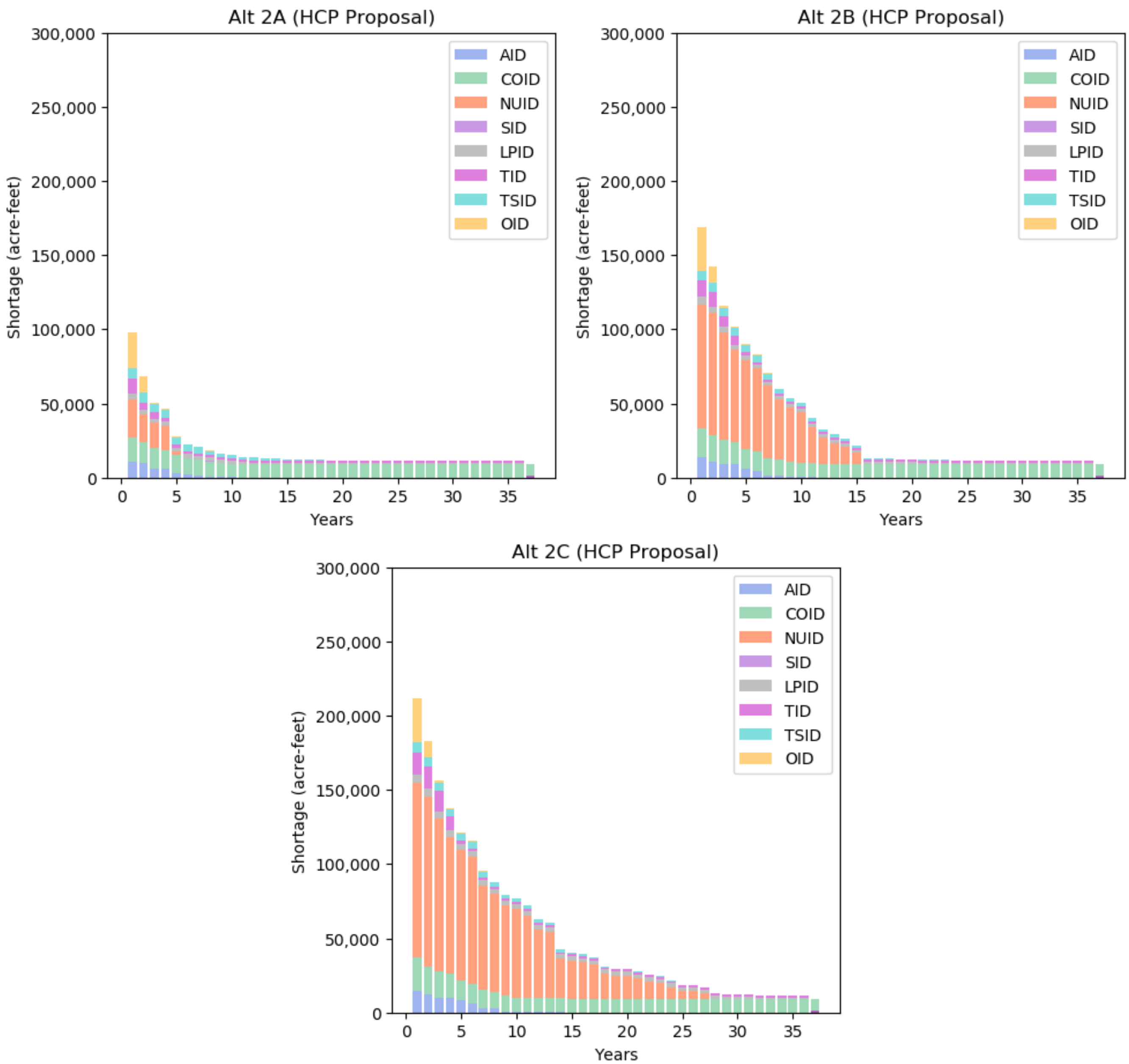

Figure 27. Irrigation shortages for the eight major irrigation districts for Alternative 2

Table 8. Minimum, median, and maximum shortages for No Action, Alternative 2A, Alternative 2B, and Alternative 2C, reported both in volume (acre-feet) and as percent of total annual demand

Alternative	District	Minimum Shortage		Median Shortage		Maximum Shortage	
		Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent
No Action	AID	-	0%	-	0%	6,800	21%
	COID	6,000	0.4%	6,200	0.4%	10,700	1%
	NUID	-	0%	-	0%	42,100	21%
	SID	-	0%	-	0%	-	0%
	LPID	300	2%	1,300	8%	2,900	18%
	TID	1,500	3%	1,500	3%	20,800	39%
	TSID	-	0%	1,000	3%	6,400	18%
	OID	-	0%	-	0%	15,600	20%
Alternative 2A	AID	-	0%	-	0%	10,900	34%
	COID	6,600	0.5%	6,600	0.5%	12,800	1%
	NUID	-	0%	-	0%	35,200	18%
	SID	-	0%	-	0%	-	0%
	LPID	200	1%	900	6%	4,000	25%
	TID	1,500	3%	1,500	3%	9,900	19%
	TSID	-	0%	1,000	3%	6,400	18%
	OID	-	0%	-	0%	23,100	30%
Alternative 2B	AID	-	0%	-	0%	13,800	43%
	COID	6,600	0.5%	6,600	0.5%	15,400	1%
	NUID	-	0%	8,000	4%	92,900	47%
	SID	-	0%	-	0%	-	0%
	LPID	900	6%	1,700	11%	5,200	32%
	TID	1,500	3%	1,500	3%	11,000	21%
	TSID	-	0%	1,000	3%	6,400	18%
	OID	-	0%	-	0%	27,900	36%
Alternative 2C	AID	-	0%	-	0%	14,700	46%
	COID	6,600	0.5%	6,700	0.5%	17,100	1%
	NUID	-	0%	25,700	13%	126,000	64%
	SID	-	0%	-	0%	-	0%
	LPID	900	6%	2,600	16%	5,500	34%
	TID	1,500	3%	1,500	3%	15,500	29%
	TSID	-	0%	1,000	3%	6,400	18%
	OID	-	0%	-	0%	28,000	36%

As a consequence of using more Wickiup flows for winter releases, there is less water available during the irrigation season for NUID; therefore, there is more reliance on flow from the Crooked River. Table 9 shows the percent of NUID deliveries that are from the Crooked River in the various stages of the alternative.

Table 9. Maximum, median, and minimum percent contributions of the Crooked River to NUID total delivery

Percent Contribution	Alternative			
	No Action	Alternative 2A	Alternative 2B	Alternative 2C
Minimum	7%	7%	7%	7%
Median	7%	7%	7%	17%
Maximum	14%	15%	34%	45%

4.3. Alternative 3

This section presents results for Alternative 3, along with the results for No Action and Alternative 2C for comparison. Only the locations that experienced a change from the No Action alternative are shown, and results are shown only for the final phase of Alternative 3, i.e., Alternative 3C.

4.3.1. Upper Deschutes

Figure 28 shows summary hydrographs of the simulated storage and outflow from Wickiup Reservoir for No Action (blue) compared to Alternative 3C (purple), and for Alternative 2C (green) compared to Alternative 3C (purple). The graphs show the results of the scenario where minimums between 400 and 500 cfs were maintained and defined by November 1 Wickiup Reservoir storage contents, as compared to the No Action alternative where minimum outflows were 100 cfs and to Alternative 2C where outflows ranged from 400 to 500 cfs. The graphs show that the ranges of flows are achievable for each of the alternatives. However, Wickiup Reservoir storage for Alternative 3C is lower than for both No Action and Alternative 2C.

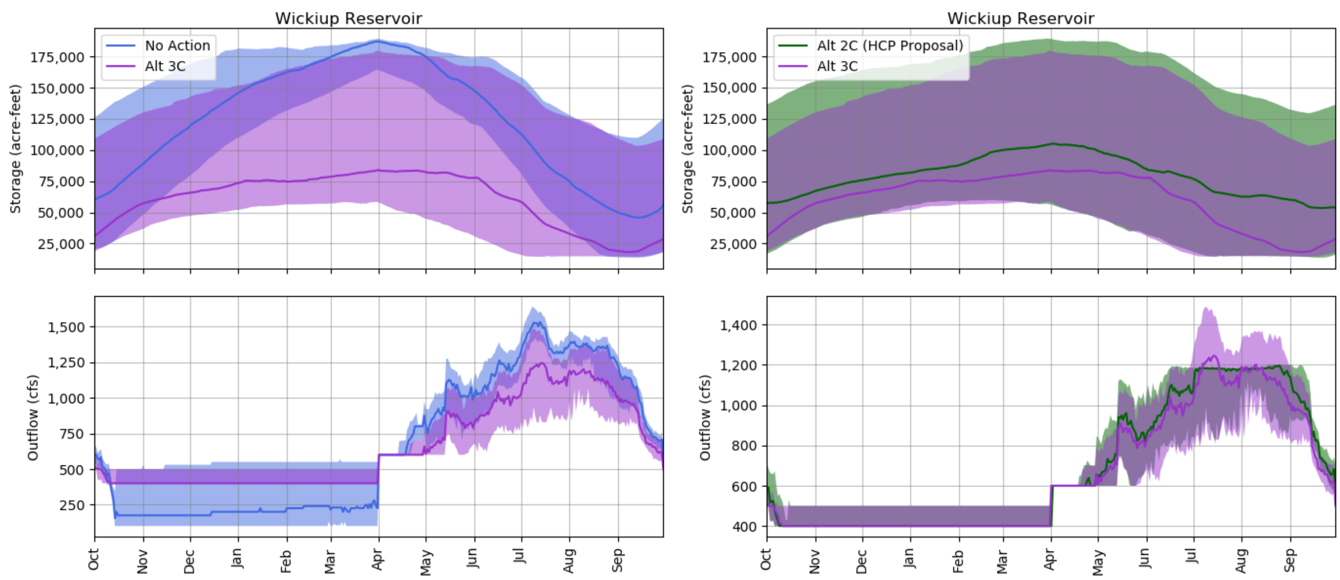

Figure 28. Summary hydrographs of simulated storage (top) and outflow (bottom) from Wickiup Reservoir. The graph on the left shows No Action (blue) compared to Alternative 3 (purple). The graph on the right shows Alternative 2C (green) compared to Alternative 3C (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 29 shows summary hydrographs for the storage and outflow from Crescent Lake for No Action (blue) compared to Alternative 3 (purple), and for Alternative 2C (green) compared to Alternative 3C (purple). Recall that the intended operation for Crescent Lake in Alternative 3 was to maintain a minimum of 20 cfs throughout the year and 50 cfs from July 1 through September 30, if there is enough water in the lake; this operation was able to be achieved in all modeled years. The storage in Crescent Lake is slightly higher than for No Action because the outflow requirements are lower in Alternative 3C, which is largely due to the reduced minimum outflow requirements from Alternative 3C compared to No Action. When compared to Alternative 2C, Alternative 3C storage is lower because the minimum outflow requirement for Alternative 3C is higher than Alternative 2C.

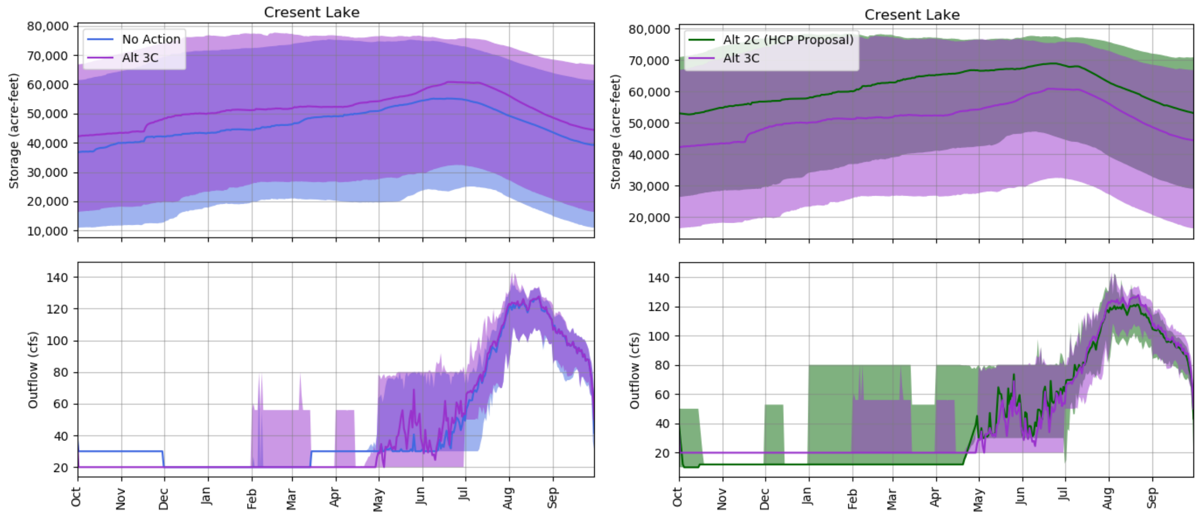

Figure 29. Summary hydrographs of simulated storage (top) and outflow (bottom) from Crescent Lake. The graph on the left shows the No Action alternative (blue) compared to Alternative 3C (purple). The graph on the right shows Alternative 2C (green) compared to Alternative 3C (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 30 shows summary hydrographs of the simulated flow in the Little Deschutes River at La Pine for No Action (blue) compared to Alternative 3C (purple), and for Alternative 2C (green) compared to Alternative 3C (purple). As mentioned previously, the flow at this gage is largely unregulated, with a small contribution from Crescent Creek and Crescent Lake in the spring and larger contributions in the summer and fall. The changes in the releases from Crescent Lake can be seen primarily in the summer months, but, overall, the flow is relatively similar at this gage for both alternatives. Note that the flow changes between Alternatives 2C and 3C are small relative to the total flow.

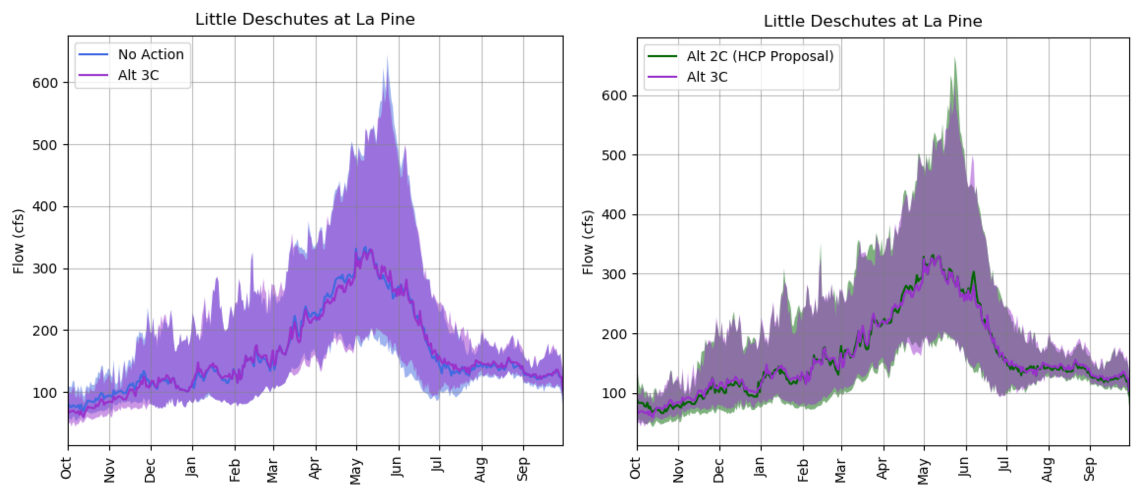

Figure 30. Summary hydrographs of simulated flow in the Little Deschutes at La Pine pumps. The graph on the left shows the No Action Alternative (blue) compared to Alternative 3C (purple). The graph on the right shows Alternative 2C (green) compared to Alternative 3C (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 31 shows summary hydrographs of the simulated flow in the Deschutes River at Benham Falls for No Action (blue) compared to Alternative 3C (purple), and for Alternative 2C (green) compared to Alternative 3C (purple). This gage is heavily influenced by the outflow from Wickiup Reservoir, so the changes from No Action mimic those changes at Wickiup Reservoir. Note that the differences between Alternative 2C and Alternative 3C are small, except for the irrigation season outflow limit from Wickiup that can be seen at Benham Falls.

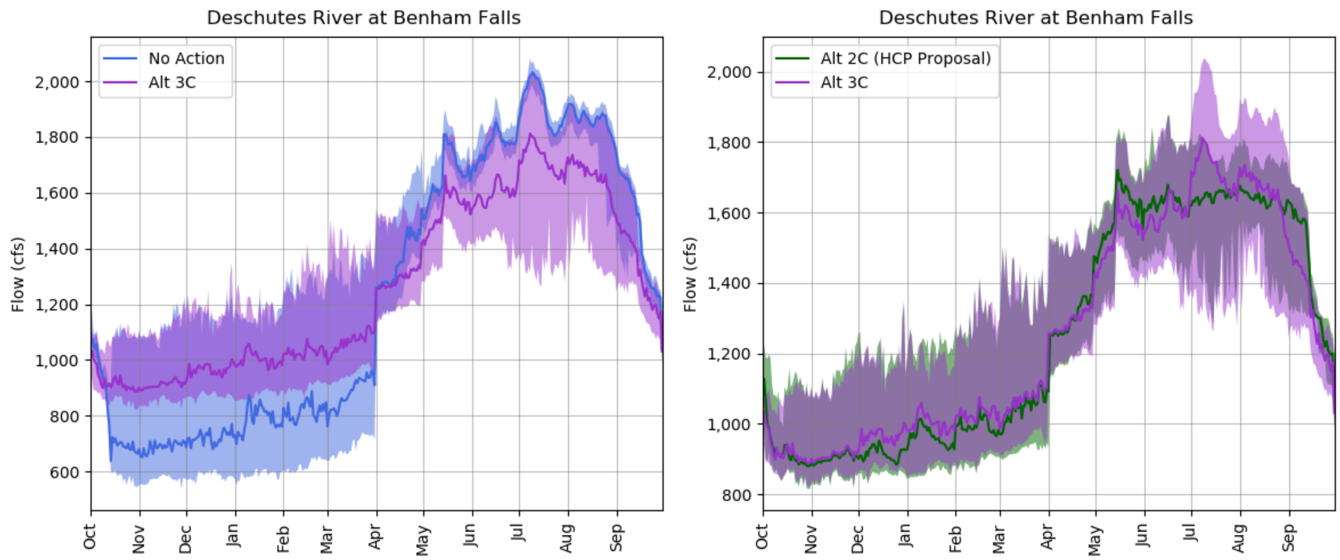

Figure 31. Summary hydrographs of simulated flow in the Deschutes River at Benham Falls. The graph on the left shows No Action (blue) compared to Alternative 3C (purple). The graph on the right shows Alternative 2C (green) compared to Alternative 3C (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 32 shows summary hydrographs of the simulated flow in the Deschutes River below Bend for No Action (blue) compared to Alternative 3C (purple), and for Alternative 2C (green) compared to Alternative 3C (purple). The effects of the increased release from Wickiup Reservoir can be seen in the winter months when the range and median of flow is larger than for No Action. The summer flows are similar for all three alternatives.

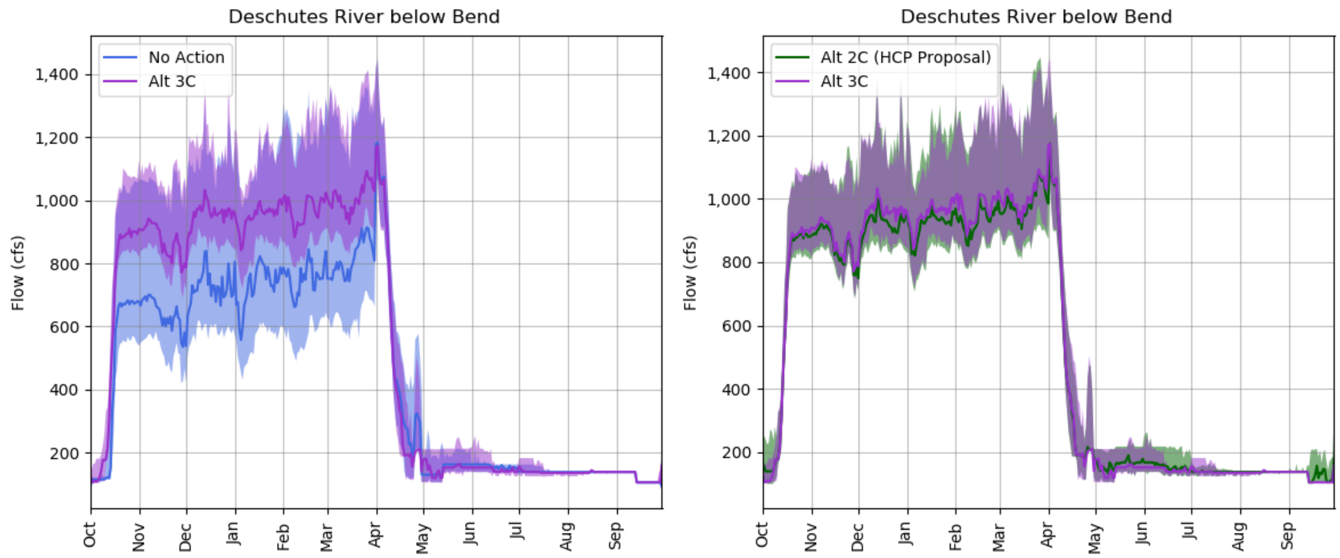

Figure 32. Summary hydrographs of simulated flow in the Deschutes River below Bend. The graph on the left shows No Action (blue) compared to Alternative 3C (purple). The graph on the right shows Alternative 2C (green) compared to Alternative 3C (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

4.3.2. Tumalo Creek

There are no changes in Tumalo Creek flows from No Action to Alternative 3.

4.3.3. Whychus Creek

There are no changes in Whychus Creek flows from No Action to Alternative 3.

4.3.4. Crooked River

The Crooked River has a difference in operation because the uncontracted releases are assumed to be bypassed by NUID in this Alternative (in other words, the water is “protected” from diversion). This is modeled by requiring NUID to bypass either the minimum flows required by the DRC agreement or the releases out of the uncontracted account, whichever is larger.

Figure 33 shows the storage and outflow from Prineville Reservoir for No Action compared to Alternative 3C (left), and for Alternative 2C compared to Alternative 3C (right). In Alternative 2, NUID could divert any uncontracted water over and above the DRC agreement flows. Under Alternative 3, they can no longer divert as much water in the river because they need to bypass the larger of the uncontracted release or the DRC agreement. To make up the difference, they request more from their rental account. This causes Prineville Reservoir storage to be slightly lower at the end of the irrigation season and, in some years, reduces storage on April 1. Since the uncontracted account is last to fill, it takes the shortage when Prineville Reservoir does not fill; this affects the amount it can release the following year. The overall effects are slightly different outflows and lower reservoir storage in Alternative 3.

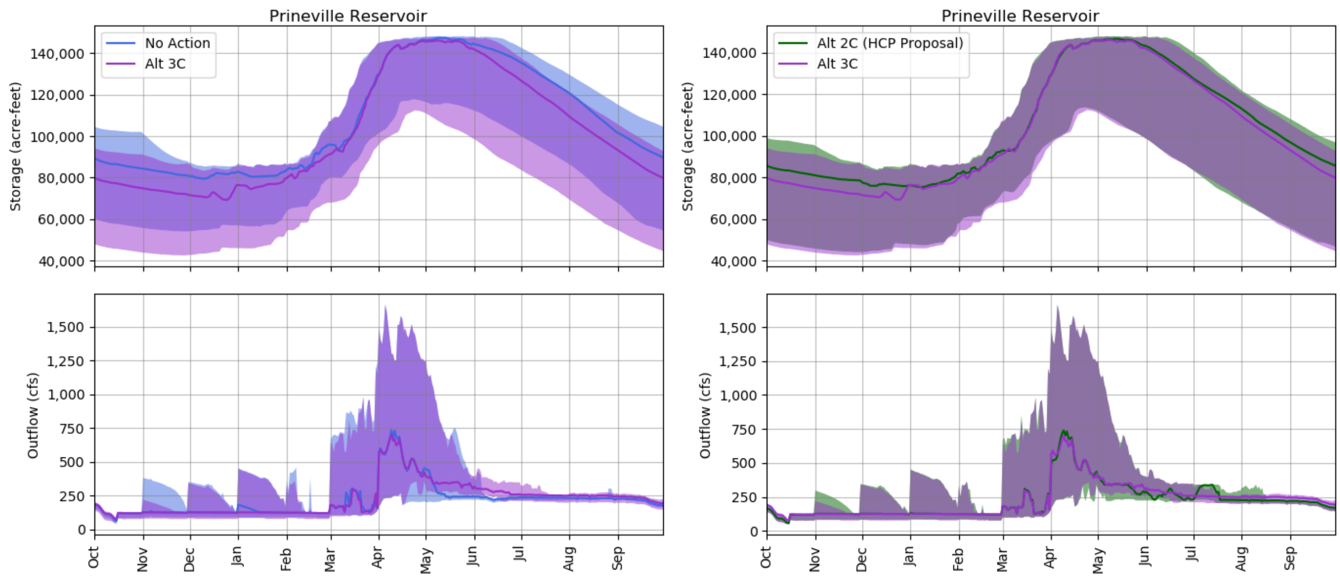

Figure 33. Summary hydrographs of simulated storage (top) and outflow (bottom) from Prineville Reservoir. The graphs on the left show No Action (blue) compared to Alternative 3C (purple). The graphs on the right show Alternative 2C (green) compared to Alternative 3C (purple). In all graphs, the colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

In the most extreme years from the simulation period, NUID used approximately 3,500 acre-feet more water from its rental account in Alternative 3C versus Alternative 2C. The effect on the uncontracted account was a reduction in storage of 3,400 acre-feet. This ultimately results in lower outflows from the uncontracted account.

Figure 34 shows summary hydrographs of the simulated flow in the Crooked River at Highway 126 for No Action (blue) compared to Alternative 3C (purple) (left), and for Alternative 2C (green) compared to Alternative 3C (purple) (right). The effects of the change in Prineville Reservoir releases can be seen at this location, where the minimum flows could be maintained in all model years.

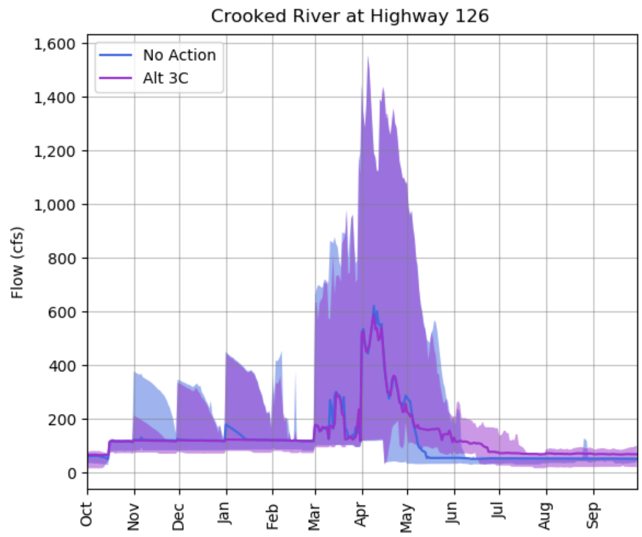

Figure 34. Summary hydrographs of simulated flow in the Crooked River at Highway 126. The graph on the left shows No Action (blue) compared to Alternative 3C (purple). The graph on the right shows Alternative 2C (green) compared to Alternative 3C (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 35 shows summary hydrographs of the simulated flow in the Crooked River below the NUID pumps for No Action (blue) compared to Alternative 3C (purple), and for Alternative 2C (green) compared to Alternative 3C (purple). Note that Alternative 3C shows slightly higher median flows than Alternative 2C in the summer. The effects of the change in Prineville Reservoir releases can be seen at this location, where the minimum flows as described in the Deschutes River Conservancy Bypass Flow agreement were met in all years with additional water supplied from the uncontracted account.

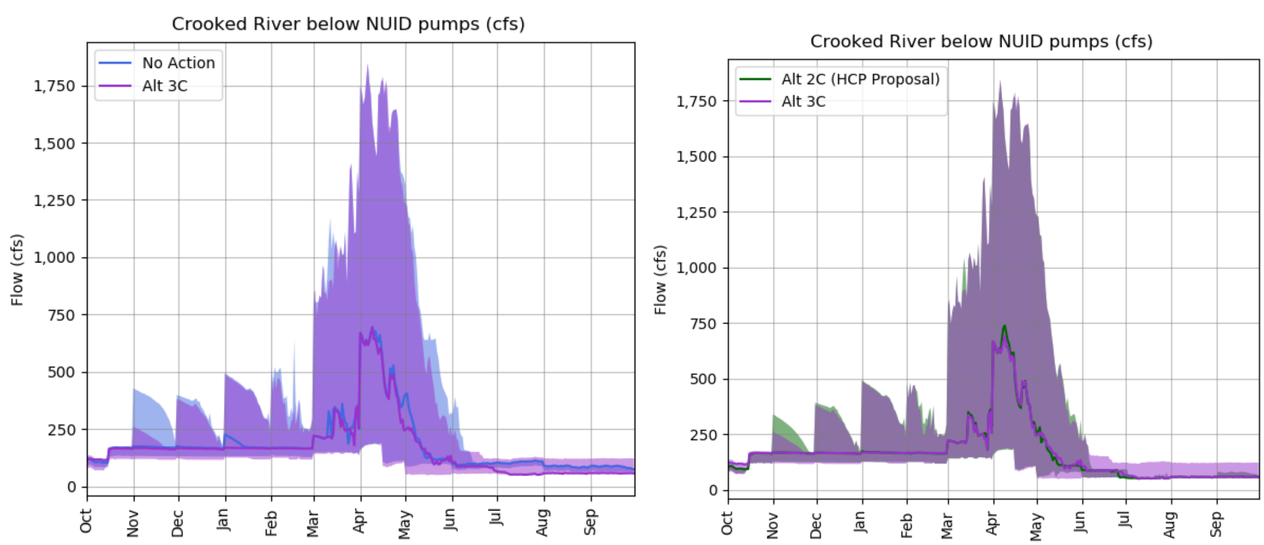

Figure 35. Summary hydrographs of simulated flow in the Crooked River below NUID pumps. The graph on the left shows the No Action Alternative (blue) compared to Alternative 3C (purple). The graph on the right

shows Alternative 2C (green) compared to Alternative 3C (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

4.3.5. Irrigation Shortages

Irrigation shortages are calculated every model year and are the difference between the requested demand[10] and the amount of water delivered to each district. Even though there are three implementation phases with different lengths, each phase is modeled for the entire model run period (1980 through 2018) to get the best assessment of potential effects under different hydrologic conditions. The years indicated on the graphs are the years of the run period, not the years of the implementation phase.

The total annual shortages for Alternative 3C are ranked and shown in Figure 36. NUID has the largest shortage in Alternative 3C because it is the junior water user on the system. This shortage is slightly larger than Alternative 2C in the median years because the uncontracted water out of Prineville Reservoir is bypassed the NUID pumps. Other districts also experience increased shortage because of the increased non-irrigation season flow requirement, and, in the case of LPID and AID, because their storage allocation in Crane Prairie was smaller than for No Action.

[10] Even if model demand was reduced to respond to hydrologic conditions, the total shortage was still calculated using the full non-reduced annual demand.

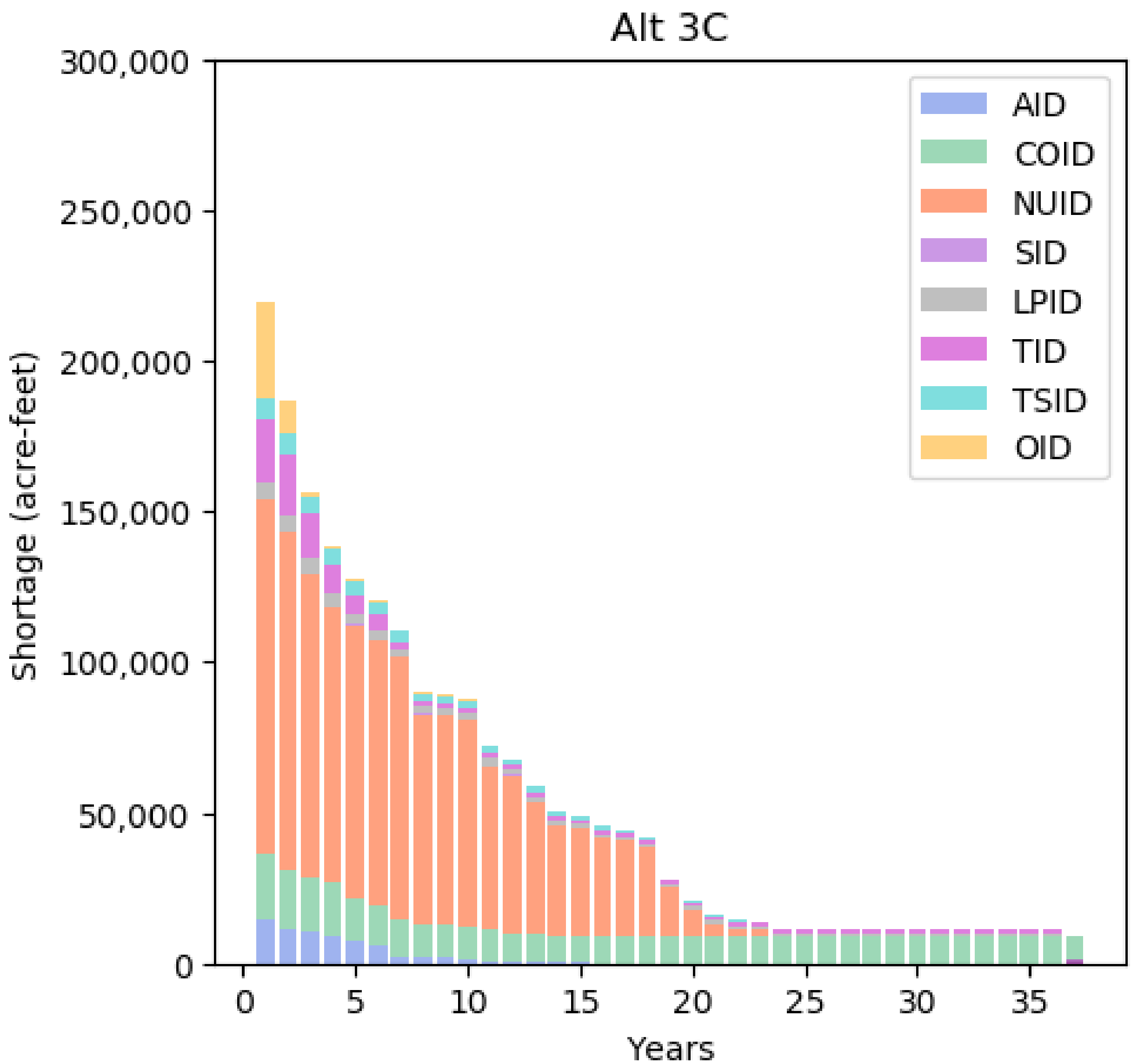

Figure 36. Irrigation shortages for the eight major irrigation districts for Alternative 3.

Table 10 shows the minimum, median, and maximum shortages from the total annual diversion for No Action and for Alternative 3C. The shortages are also shown as percent of total demand for each entity in order to indicate in the significance of the shortage.

Table 10. Minimum, median, and maximum shortages for No Action and Alternative 3C, reported both in volume (acre-feet) and as percent of total annual demand

District	No Action Alternative						Alternative 3C					
	Minimum		Median		Maximum		Minimum		Median		Maximum	
	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent
AID	-	0%	-	0%	6,800	21%	-	0%	-	0%	14,500	45%
COID	6,000	0.4%	6,200	0.4%	10,700	1%	6,600	0.5%	6,600	0.5%	17,100	1%
NUID	-	0%	-	0%	42,100	21%	-	0%	33,200	17%	126,000	64%
SID	-	0%	-	0%	-	0%	-	0%	-	0%	-	0%
LPID	300	2%	1,300	8%	2,900	18%	700	5%	900	6%	5,400	34%
TID	1,500	3%	1,500	3%	20,800	39%	1,500	3%	1,500	3%	20,700	39%
TSID	-	0%	1,000	3%	6,400	18%	-	0%	1,000	3%	6,400	18%
OID	-	0%	-	0%	15,600	20%	-	0%	-	0%	31,100	40%

A consequence of using more Wickiup flows for winter releases is there is less water available during the irrigation season for NUID; therefore, there is more reliance on flow from the Crooked River. Table 11 shows the percent of NUID deliveries that are from the Crooked River in the various stages of the alternative.

Table 11. Maximum, median, and minimum percent contributions of the Crooked River to NUID total delivery

Percent Contribution	Alternative	
	No Action	Alternative 3C
Minimum	7%	7%
Median	7%	18%
Maximum	14%	47%

4.4. Alternative 4

Alternative 4B results are displayed in this section, along with results from the No Action alternative and Alternative 2C for comparison. Only the locations that experienced a change from the No Action results are shown, and results are shown only for the final phase of Alternative 4 (Alternative 4B).

4.4.1. Upper Deschutes

Figure 37 shows summary hydrographs of the simulated storage and outflow from Wickiup Reservoir for the No Action alternative (blue) compared to Alternative 4B (orange-red), and for Alternative 2C (green) compared to Alternative 4B (orange-red). The graphs show the results of the scenario where minimums between 400 and 600 cfs were maintained and defined by November 1 Wickiup Reservoir storage contents, as compared to No Action (where minimum outflows were 100 cfs) and Alternative 2C (where outflows ranged from 400 to 500 cfs). The graphs show that the ranges of flows are achievable for each of the alternatives. However, Wickiup Reservoir storage in Alternative 4B is lower than both No Action and Alternative 2C.

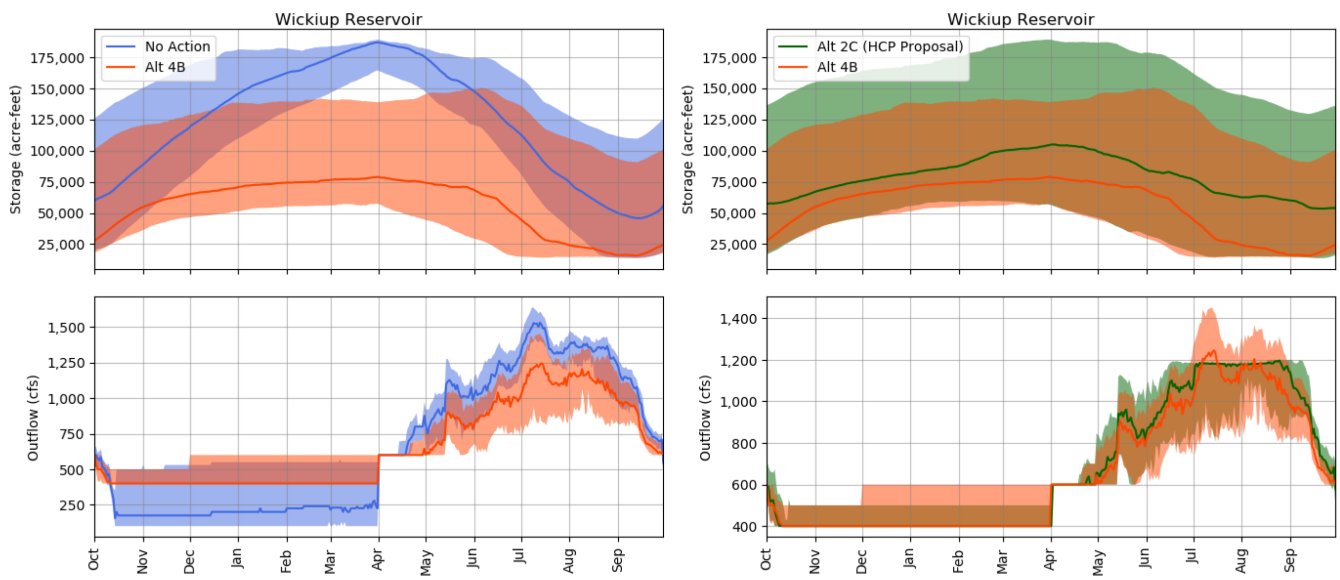

Figure 37. Summary hydrographs of simulated storage (top) and outflow (bottom) from Wickiup Reservoir. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (orange-red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 38 shows summary hydrographs for the storage and outflow from Crescent Lake for No Action (blue) compared to Alternative 4 (orange-red), and for Alternative 2 (green) compared to Alternative 4B (orange-red). Recall that the intended operation for Crescent Lake in Alternative 4 was to maintain a minimum of 20 cfs throughout the year and 50 cfs from July 1 through September 30, if there is enough water in the lake. The storage in Crescent Lake is slightly higher than for No Action because the outflow requirements are lower in Alternative 4B, largely due to the reduced minimum outflow requirement for Alternative 4B when compared to No Action. When compared to Alternative 2C, Alternative 4B storage is lower also because the minimum outflow requirement for 4B is higher than Alternative 2C, resulting in lower storage in Alternative 4B.

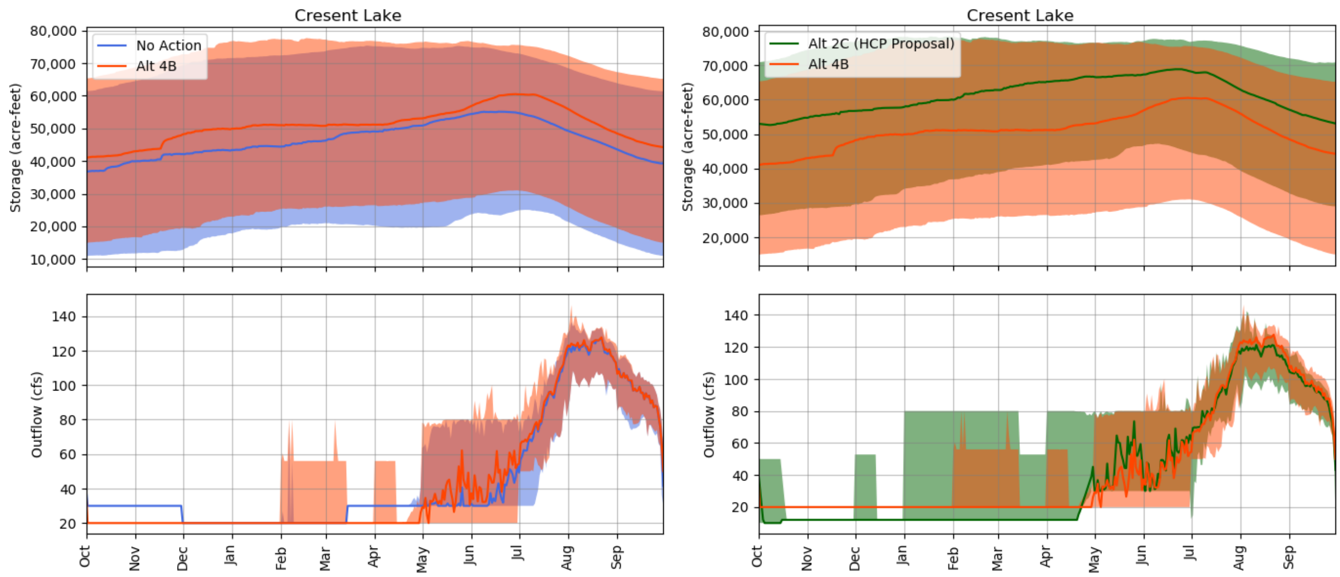

Figure 38. Summary hydrographs of simulated storage (top) and outflow (bottom) from Crescent Lake. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (orange-red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 39 shows summary hydrographs of the simulated flow in the Little Deschutes River at La Pine for the No Action alternative (blue) compared to Alternative 4B (orange-red), and for Alternative 2C (green) compared to Alternative 4B (orange-red). As mentioned previously, the flow at this gage is largely unregulated, with a small contribution from Crescent Creek and Crescent Lake in the spring and a larger contribution in the summer and fall. The changes in the releases from Crescent Lake can be seen primarily in the summer months, but, overall, the flow is relatively similar at this gage for both alternatives. Note that the flow changes between Alternatives 2C and 4B are small relative to the total flow.

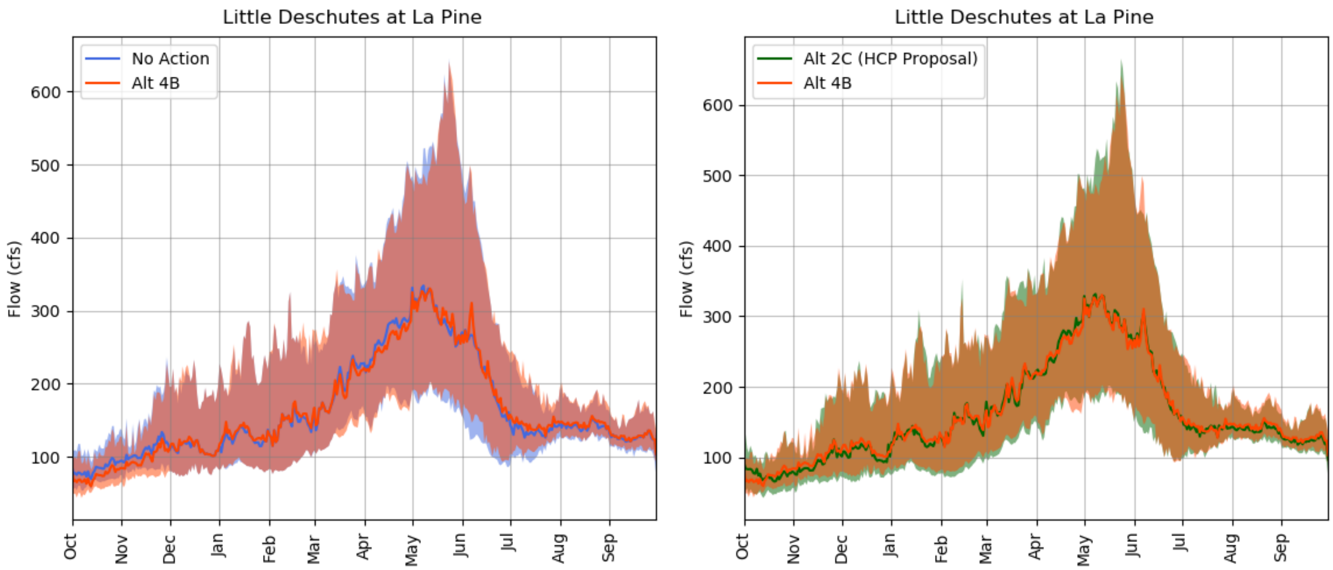

Figure 39. Summary hydrographs of simulated flow in the Little Deschutes at La Pine pumps. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (orange-red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 40 shows summary hydrographs of the simulated flow in the Deschutes River at Benham Falls for the No Action alternative (blue) compared to Alternative 4B (orange-red), and for Alternative 2C (green) compared to Alternative 4B (orange-red). This gage is heavily influenced by the outflow from Wickiup Reservoir, so the changes from No Action mimic those changes at Wickiup Reservoir. Note that the differences between Alternative 2C and Alternative 4B are small.

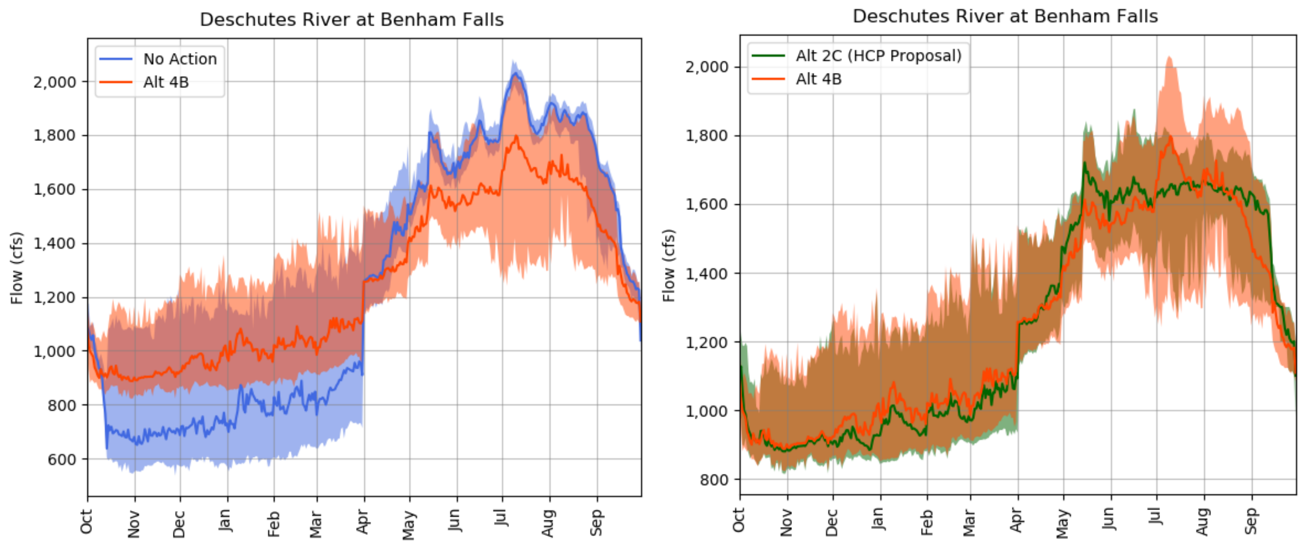

Figure 40. Summary hydrographs of simulated flow in the Deschutes River at Benham Falls. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 41 shows summary hydrographs of the simulated flow in the Deschutes River below Bend for No Action (blue) compared to Alternative 4B (orange-red), and for Alternative 2C (green) compared to Alternative 4B (orange-red). The effects of the increased release from Wickiup Reservoir can be seen in the winter months, when the range and median of flow is larger than for No Action. The summer flows are similar for all three alternatives.

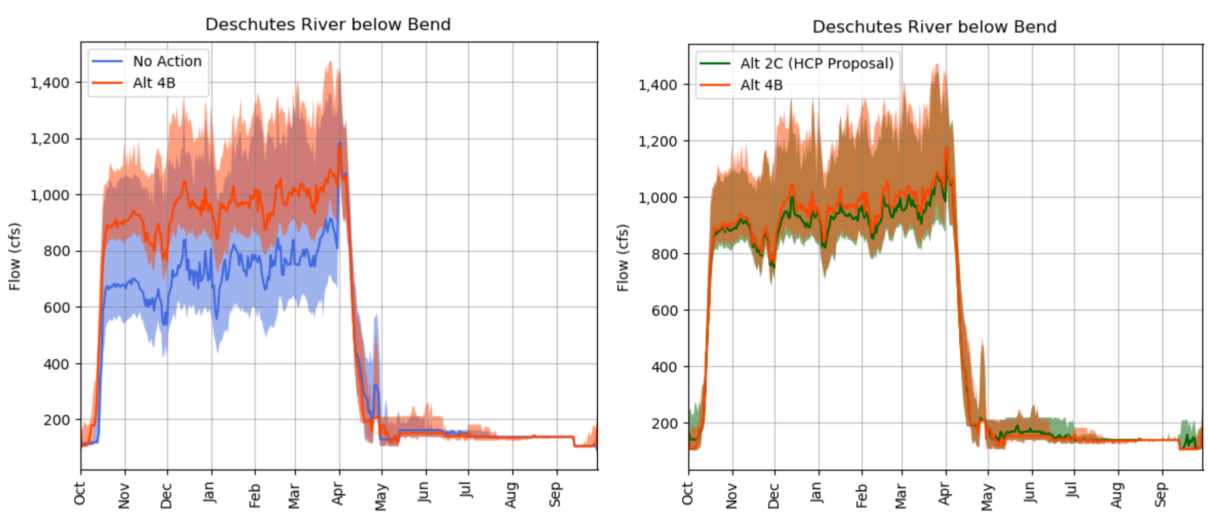

Figure 41. Summary hydrographs of simulated flow in the Deschutes River below Bend. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

4.4.2. Tumalo Creek

There are no changes in Tumalo Creek flows from No Action to Alternative 4.

4.4.3. Whychus Creek

There are no changes in Whychus Creek flows from No Action to Alternative 4.

4.4.4. Crooked River

The Crooked River has a difference in operations because the uncontracted releases from Prineville Reservoir are protected from diversion for irrigation. This is modeled by requiring NUID to bypass the larger of the minimum flows required by the DRC agreement and the releases out of the uncontracted account. In addition, the Crooked River is affected by the changes in Wickiup Reservoir outflow.

Figure 42 shows the storage and outflow from Prineville Reservoir for No Action and Alternative 4B. In Alternative 4B, the uncontracted flows are assumed to be bypassed by the NUID pumps, similar to Alternative 3C. In addition, higher winter outflows from Wickiup Reservoir reduce the Upper Deschutes supply to NUID, so the district requests additional rental water from Prineville Reservoir. Overall, the effect is slightly different outflows and lower reservoir storage in Alternative 4B.

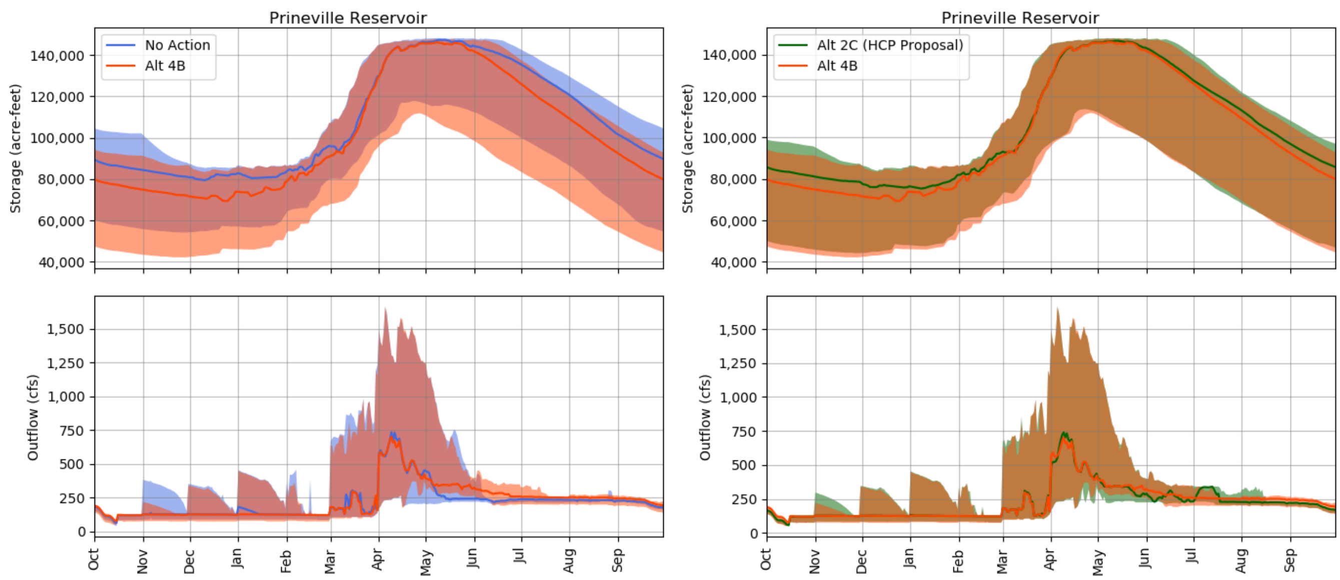

Figure 42. Summary hydrographs of simulated storage (top) and outflow (bottom) from Prineville Reservoir. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (orange-red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

The change in Wickiup Reservoir outflows has a much larger effect on NUID shortages in Alterative 4B than in Alternative 3C; in the most extreme years, it uses almost the entire 10,000 acre-feet in the account. The effect on the uncontracted account is a reduction in storage by 28,000 acre-feet, which results in lower outflows from the uncontracted account.

Figure 43 shows summary hydrographs of the simulated flow in the Crooked River at Highway 126 for the No Action alternative (blue) compared to Alternative 4B (red), and for Alternative 2C (green) compared to Alternative 4B (orange-red). The effects of the change in Prineville Reservoir releases can be seen at this location, where minimum flows can be achieved in all modeled years.

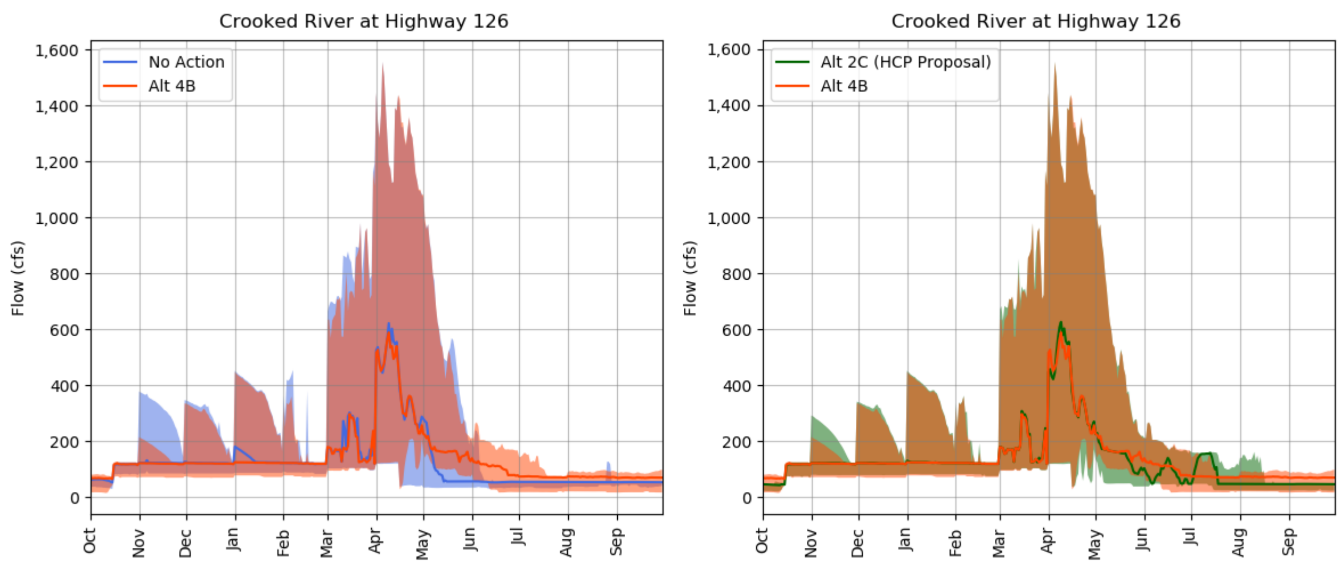

Figure 43. Summary hydrographs of simulated flow in the Crooked River at Highway 126. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

Figure 44 shows summary hydrographs of the simulated flow in the Crooked River below NUID pumps for No Action (blue) compared to Alternative 4B (orange-red), and for Alternative 2C (green) compared to Alternative 4B (orange-red). The effects of the change in Prineville Reservoir releases can be seen at this location, where the minimum flows as described in the Deschutes River Conservancy Bypass Flow agreement were met in all years with additional water supplied from the uncontracted account.

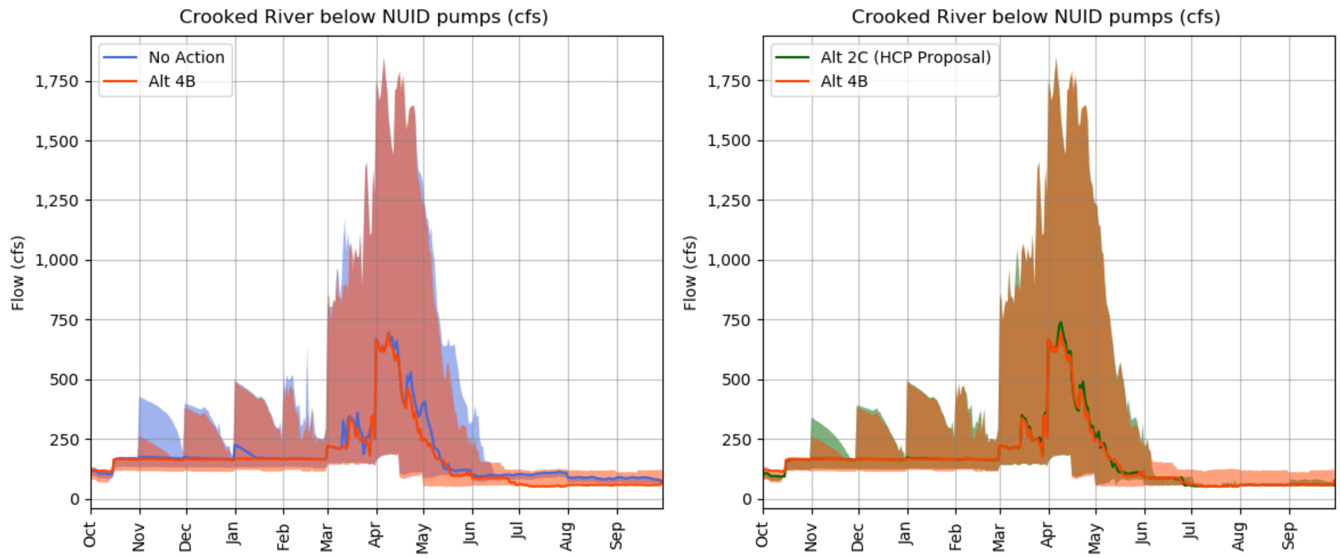

Figure 44. Summary hydrographs of simulated flow in the Crooked River below NUID pumps. The graph on the left shows the No Action alternative (blue) compared to Alternative 4B (red). The graph on the right shows Alternative 2C (green) compared to Alternative 4B (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance.

4.4.5. Irrigation Shortages

Irrigation shortages are calculated every model year and are the difference between the requested demand[11] and the amount of water delivered to each district. Even though there are three implementation phases with different lengths, each phase is modeled for the entire model run period (1980 through 2018) to get the best assessment of potential effects under different hydrologic conditions. The years indicated on the graphs are the years of the run period, not the years of the implementation phase.

The total annual shortages for Alternative 4B are ranked and shown in Figure 45. As for the No Action alternative, NUID has the largest shortage in Alternative 4B because it is the junior water user on the system. This shortage is increased because the non-irrigation season flows out of Wickiup Reservoir reduce the amount of stored water available for NUID. Other districts also experience increased shortages because of the increased non-irrigation season flow requirement, and, in the case of LPID and AID, because their storage allocation in Crane Prairie was smaller than for No Action.

[11] Even if model demand was reduced to respond to hydrologic conditions, the total shortage was still calculated using the full non-reduced annual demand.

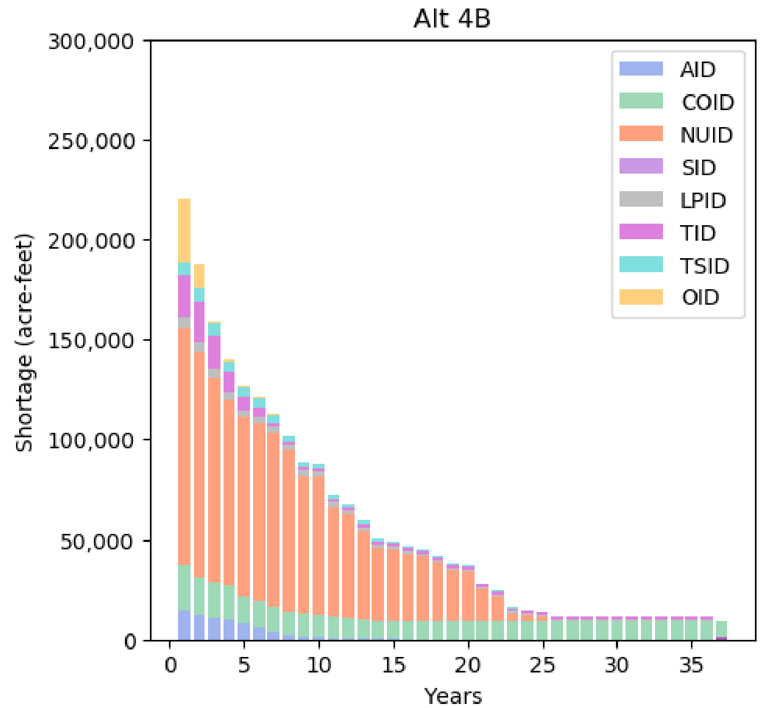

Figure 45. Irrigation shortages for the eight major irrigation districts for Alternative 4

Table 12 shows the minimum, median, and maximum shortages from the total annual diversion for No Action and Alternative 4B. These are also shown as percent of total demand for each entity to illustrate the significance of the shortage.

Table 12. Minimum, median, and maximum shortages for No Action and Alternative 4B, reported both in volume (acre-feet) and as percent of total annual demand

District	No Action Alternative						Alternative 4B					
	Minimum		Median		Maximum		Minimum		Median		Maximum	
	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent	Acre-feet	Percent
AID	-	0%	-	0%	6,800	21%	-	0%	-	0%	14,600	45%
COID	6,000	0.4%	6,200	0.4%	10,700	1%	6,600	0.5%	6600	0.5%	17,500	1%
NUID	-	0%	-	0%	42,100	21%	-	0%	37,500	19%	126,000	64%
SID	-	0%	-	0%	-	0%	-	0%	-	0%	-	0%
LPID	300	2%	1,300	8%	2,900	18%	900	6%	900	6%	5,400	34%
TID	1,500	3%	1,500	3%	20,800	39%	1,500	3%	1,500	3%	20,700	39%
TSID	-	0%	1,000	3%	6,400	18%	-	0%	1,000	3%	6,400	18%
OID	-	0%	-	0%	15,600	20%	-	0%	-	0%	31,100	40%

A consequence of using more Wickiup flows for winter releases is there is less water available during the irrigation season for NUID, and therefore, there is more reliance on flow from the Crooked River. Table 13 shows the percent of NUID deliveries that are from the Crooked River in the various stages of the alternative.

Table 13. Maximum, median, and minimum percent contributions of the Crooked River to NUID total delivery

Percent Contribution	No Action	Alternative 3C
Minimum	7%	7%
Median	7%	21%
Maximum	14%	46%

5. Limitations and Uncertainty

River-reservoir models, such as the one used in this study, are designed to replicate current operating criteria along with potential future operating criteria to test potential changes in operations. They use assumptions and simplifications that are required to develop repeatable logic and a suitable test environment for potential future conditions. They are not intended to be predictive in nature, nor are they intended to exactly replicate future operations on a day-to-day basis. Rather, they are intended to be used to understand trends and effects from plausible operations using a range of historical inflow hydrology. Therefore, selecting individual years, months, or days for analysis is not recommended. In addition, statistics from the model output should be used as a guideline for potential future conditions, but it should be recognized that changes to future inflow hydrology or variations in real time operations could affect the performance of those statistics in the future.

The output from the models presented in this analysis show the effects of specific operating criteria on key metrics such as reservoir outflow and storage, irrigation deliveries, and gage flows. The uncertainty in the results is captured in a range of outputs presented in the hydrographs and tables.

Due to the adaptive nature of some of the measures in the EIS, some of the operations described and modeled for this study represent the best assessment of the implementation of those measures. However, as more information is learned through implementation, the real-time operations may be different than the information presented in this report. The operations will be continuously monitored to ensure they remain within the constraints defined in the NEPA analysis.

6. Summary

Four alternatives were simulated for the DBHCP EIS using RiverWare. The major results from all of the alternatives are summarized below.

- Crane Prairie Reservoir can achieve the storage requirements in most years.
- Crescent Lake can achieve minimum flow requirements, resulting in:
  - Higher storage when compared to No Action.
- Higher winter outflows from Wickiup Reservoir can be achieved, resulting in:
  - Higher winter flows below Wickiup Reservoir, at Benham Falls, below Bend, and at Madras. The increase in flows depends on the flow range defined in the scenario.
  - Decreased winter storage in Wickiup Reservoir. This leads to less water available for irrigation releases in the summer.
  - Lower summer flows below Wickiup Reservoir and at Benham Falls, but not below Bend or at Madras. Lower summer flows below Wickiup Reservoir and at Benham Falls are also due to irrigation season maximum outflow limits.
  - Decreased storage in Crescent Lake due to additional live flow needed for downstream diversion.
  - Increased irrigation shortages, with NUID being the most impacted. Since NUID can also receive water from the Crooked River, storage in Prineville Reservoir is also affected.
- The combination of increasing fish and wildlife (uncontracted) releases from Prineville Reservoir during the irrigation season and bypassing the water by the NUID pumps (in other words, "protecting" the water from diversion) results in:
  - Increased use of NUID's rental account. The amount of water needed is dependent on minimum releases from Wickiup Reservoir.
  - Increased shortage to NUID.
  - Decreased uncontracted water in some years. This results in lower releases in the following year.

7. Literature Cited

Parenthetical Reference	Bibliographic Citation
LaMarche 2018	LaMarche, J. 2018., personal communication. Conversation and emails between Jonathan LaMarche, Hydrologist (Oregon Water Resources Department, Salem, Oregon) and Jennifer Johnson, Hydraulic Engineer, (U.S. Bureau of Reclamation, Boise, Idaho). Subject: The seepage processes between Crane Prairie and Wickiup Reservoirs. August 2018.
OWRD 2013	Oregon Department of Water Resources (OWRD). 2013. Agreement between North Unit Irrigation District and Deschutes River Conservancy regarding minimum stream flows in the Crooked River. Attachment 3 to Conserved Water Application CW-75. Signed September 18, 2013.
Reclamation 2017a	Bureau of Reclamation. 2017a. *Development of a Daily Water Management Model of the Deschutes River, Oregon, using RiverWare*. March 2017.
Reclamation 2017b	Bureau of Reclamation. 2017b. *Hydrologic Evaluation of Baseline and Proposed Management of the Deschutes Project for Oregon Spotted Frog (OSF Proposal)*. January 2017.
Reclamation 2017c	Bureau of Reclamation. 2017c. *Unregulated Flows in the Upper Deschutes Basin, Oregon*. October 2017.
Reclamation 2020	Bureau of Reclamation. 2020. DRAFT *Development of 2020 Level Modified Flows for the Deschutes River Basin*. June 2020.

8. Appendix – Logarithmic Graphs of Crooked River Flows

Since a large emphasis is placed on the low flows in the Crooked River, logarithmic graphs were developed to better portray the model output.

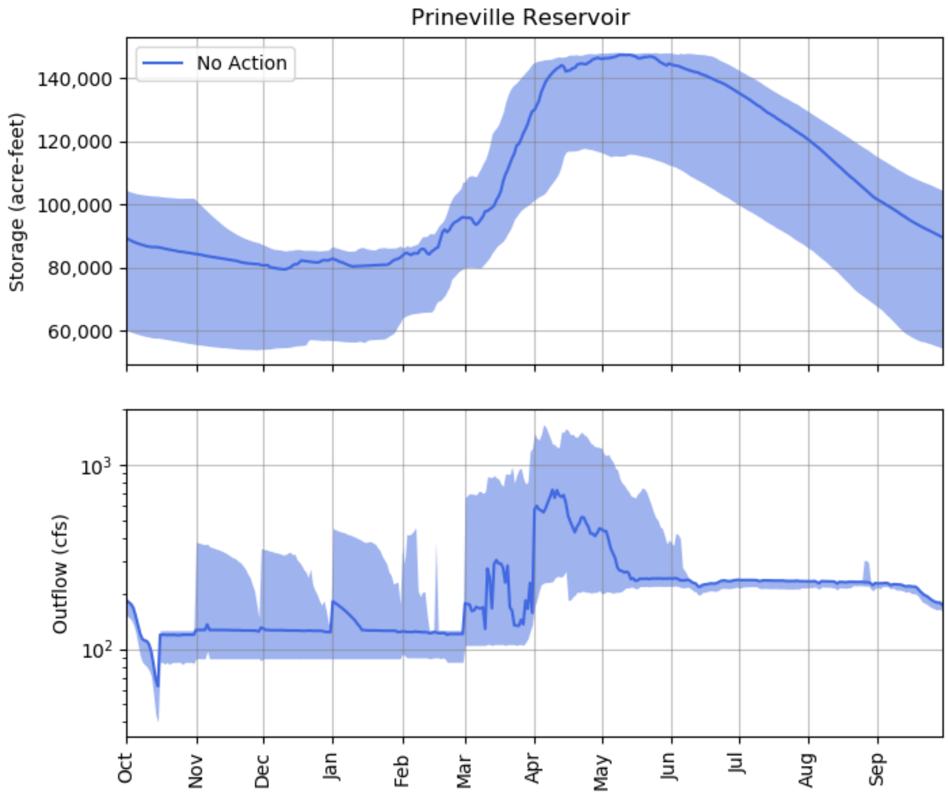

Figure 46. Summary hydrograph of simulated storage (top) and outflow (bottom) from Prineville Reservoir showing the No Action alternative. The dark blue line represents the median and the shaded blue area represents the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

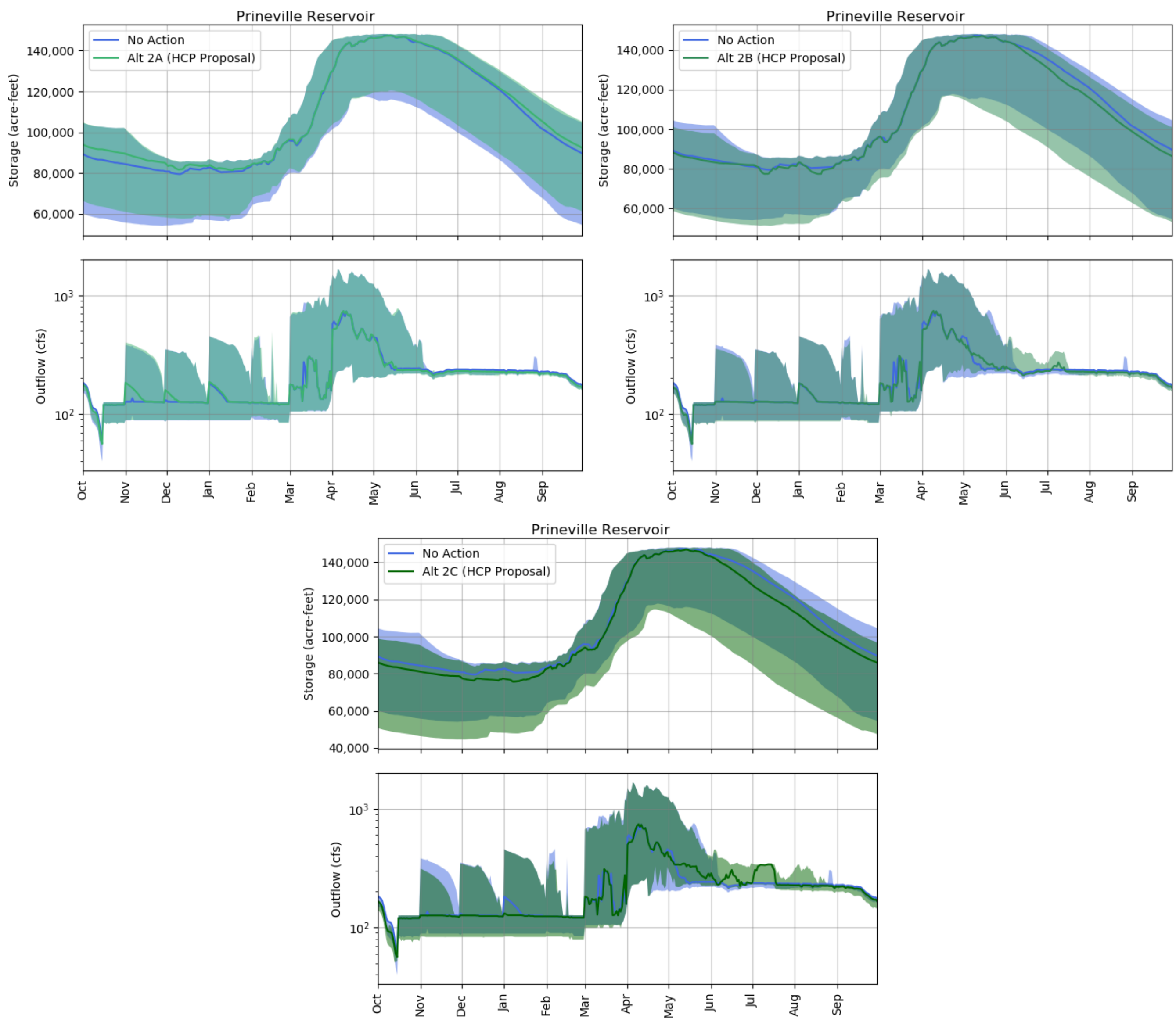

Figure 47. Summary hydrographs of simulated storage (top) and outflow (bottom) from Prineville Reservoir. The graphs show the No Action alternative (blue) compared to Alternative 2 (green); Alternative 2A is shown in the top left, 2B in the top right, and 2C at the bottom. The dark blue or green line represents the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

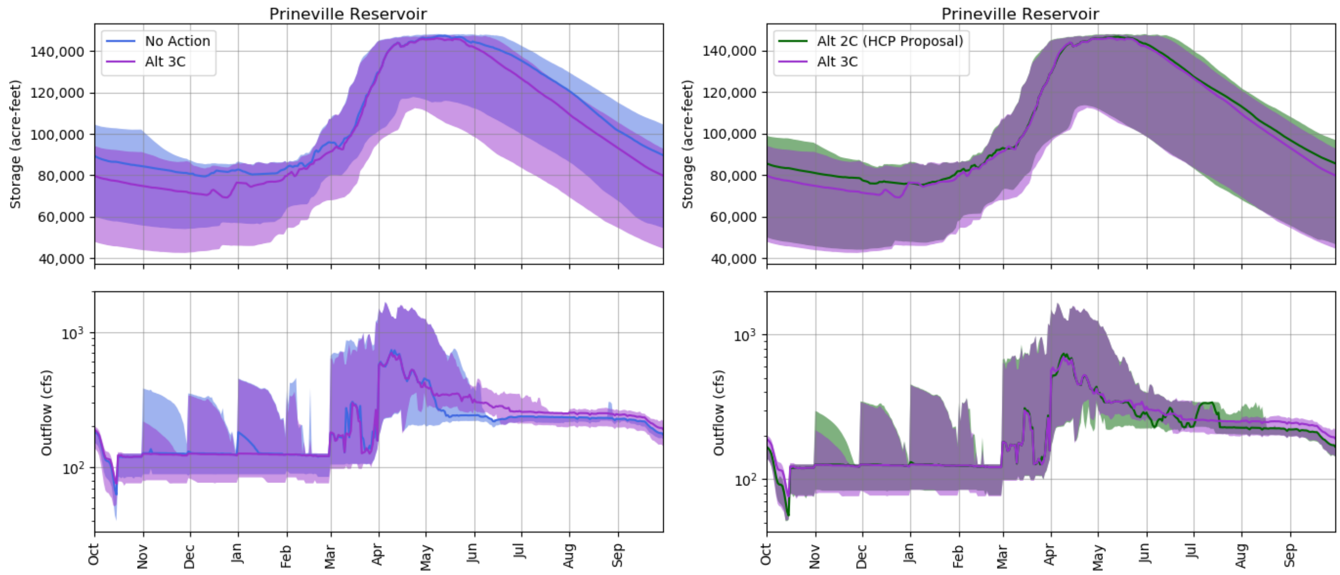

Figure 48. Summary hydrographs of simulated storage (top) and outflow (bottom) from Prineville Reservoir. The graphs on the left show the No Action alternative (blue) compared to Alternative 3 (purple). The graphs on the right show Alternative 2 (green) compared to Alternative 3 (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

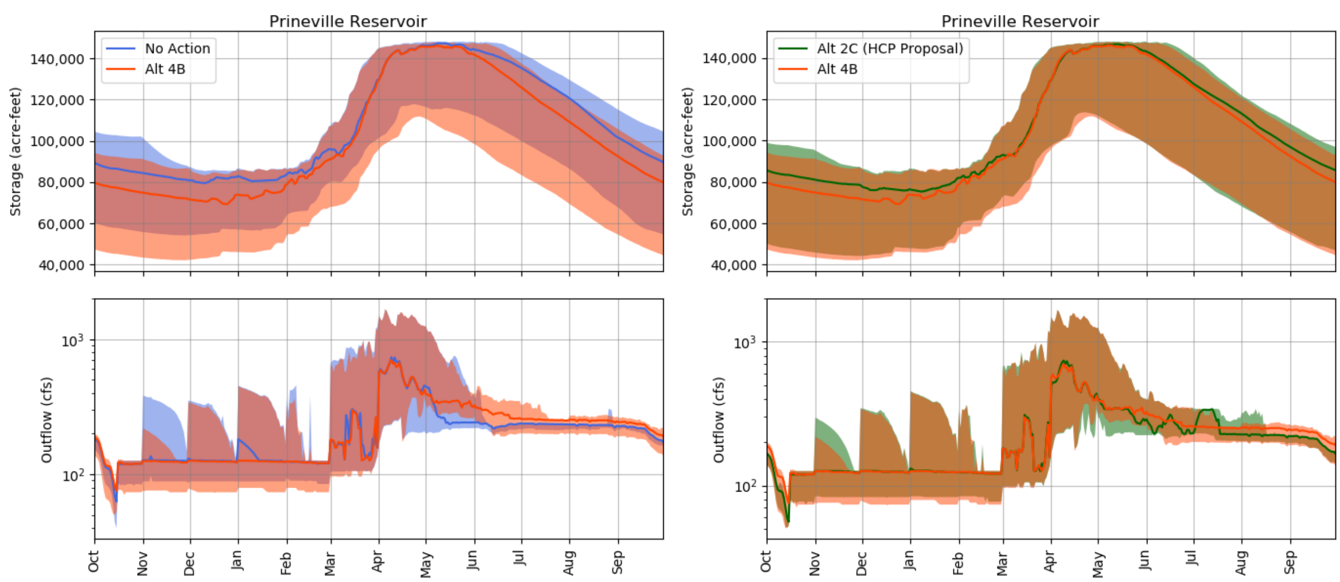

Figure 49. Summary hydrographs of simulated storage (top) and outflow (bottom) from Prineville Reservoir. The graphs on the left show the No Action alternative (blue) compared to Alternative 4 (orange-red). The graphs on the right show Alternative 2 (green) compared to Alternative 4 (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

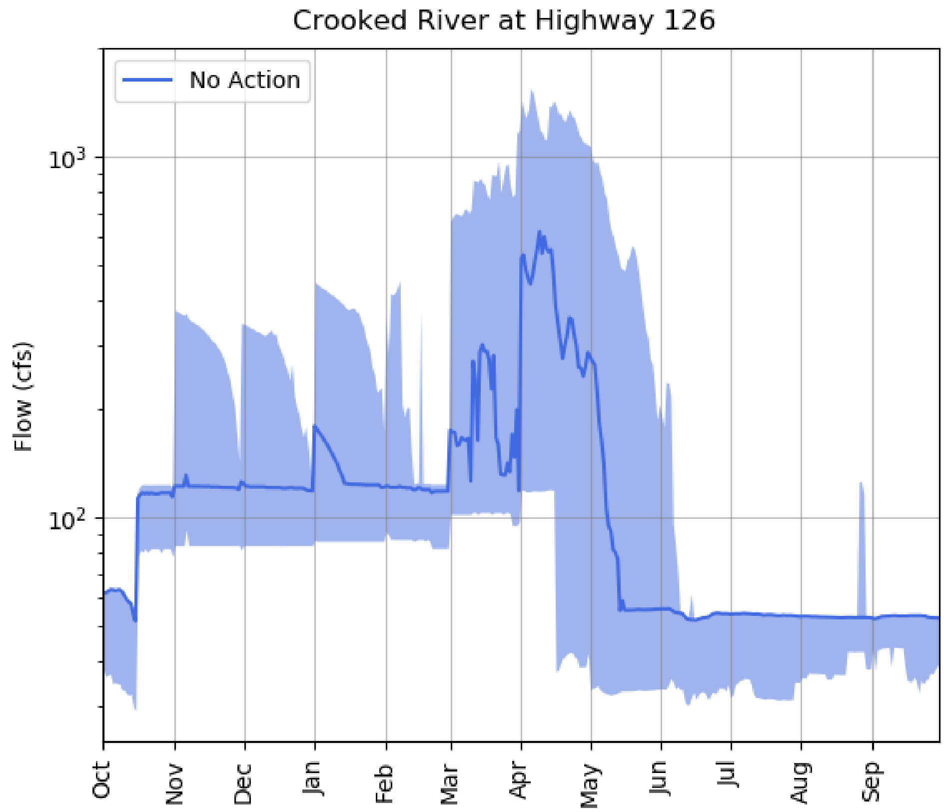

Figure 50. Summary hydrograph of simulated flow in the Crooked River at Highway 126 showing the No Action alternative. The dark blue line represents the median and the shaded blue area represents the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

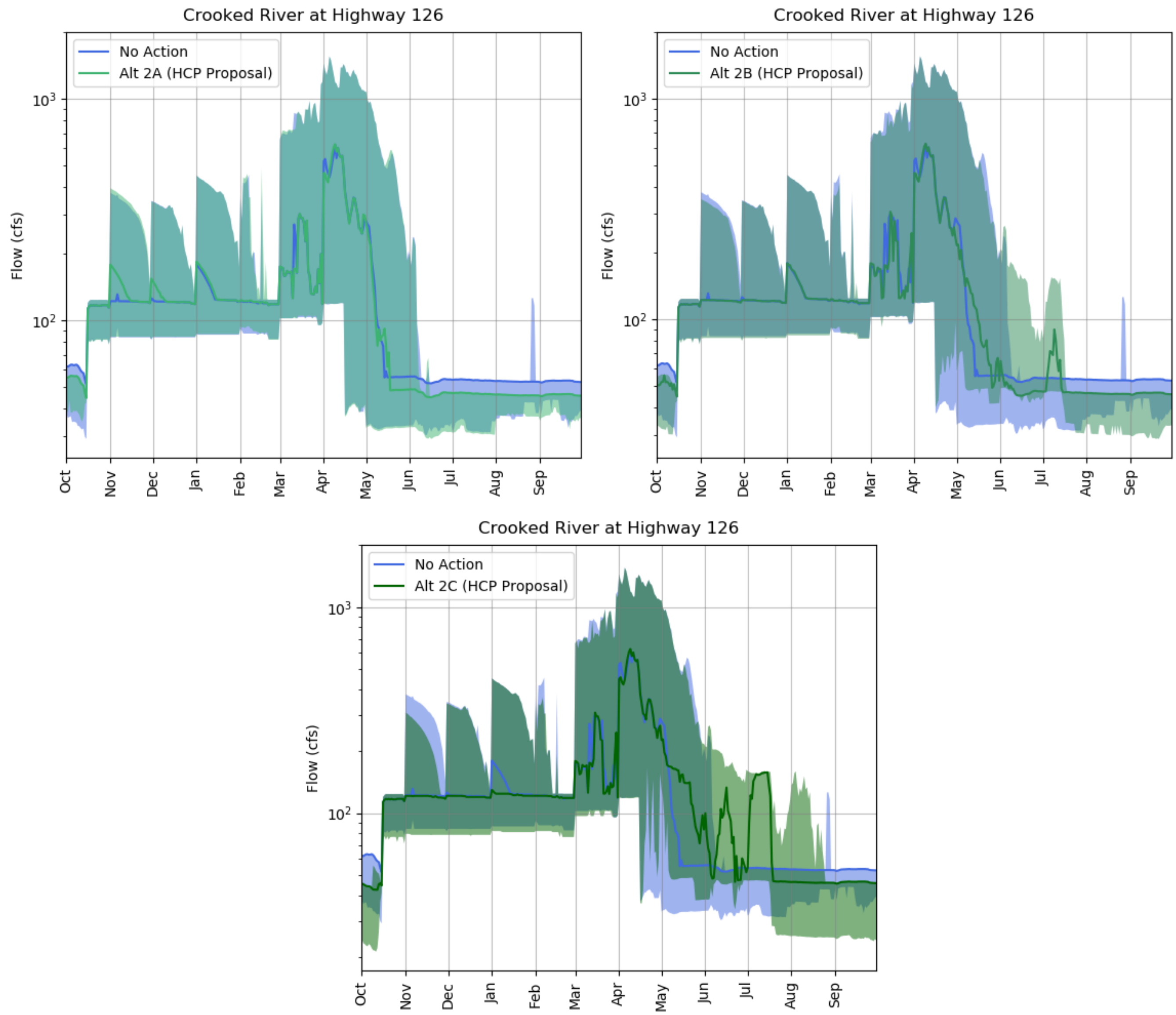

Figure 51. Summary hydrograph of simulated flow in the Crooked River at Highway 126. The graph shows the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B at the top right, and 2C at the bottom). The dark lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

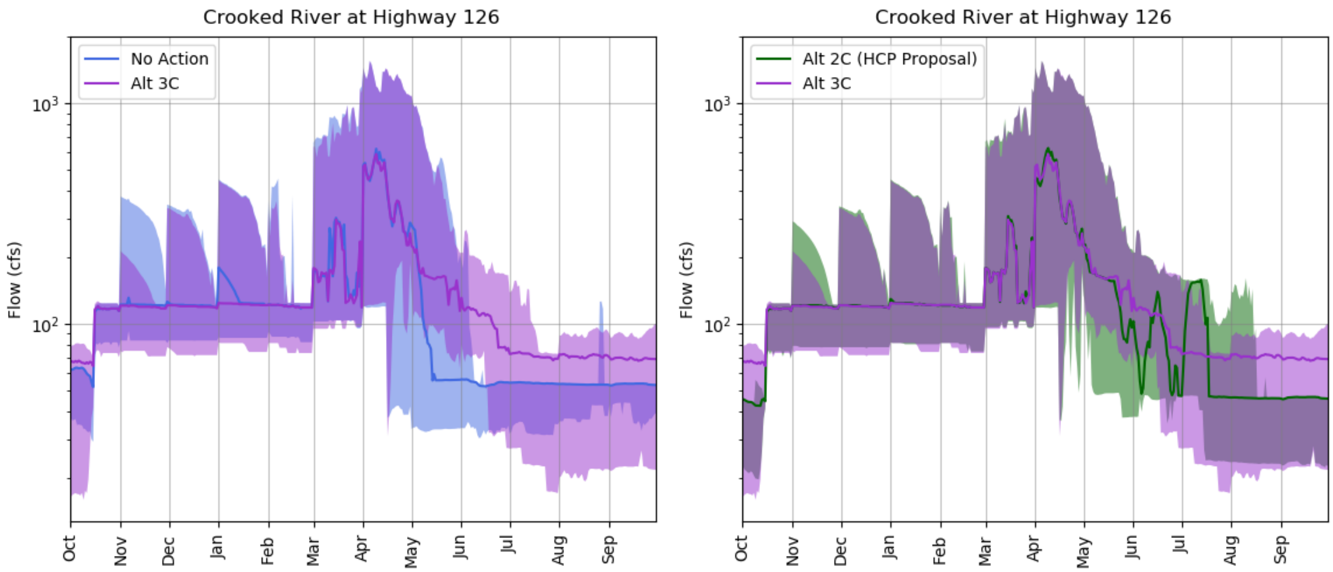

Figure 52. Summary hydrographs of simulated flow in the Crooked River at Highway 126. The graph on the left shows the No Action alternative (blue) compared to Alternative 3 (purple). The graph on the right shows Alternative 2 (green) compared to Alternative 3 (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

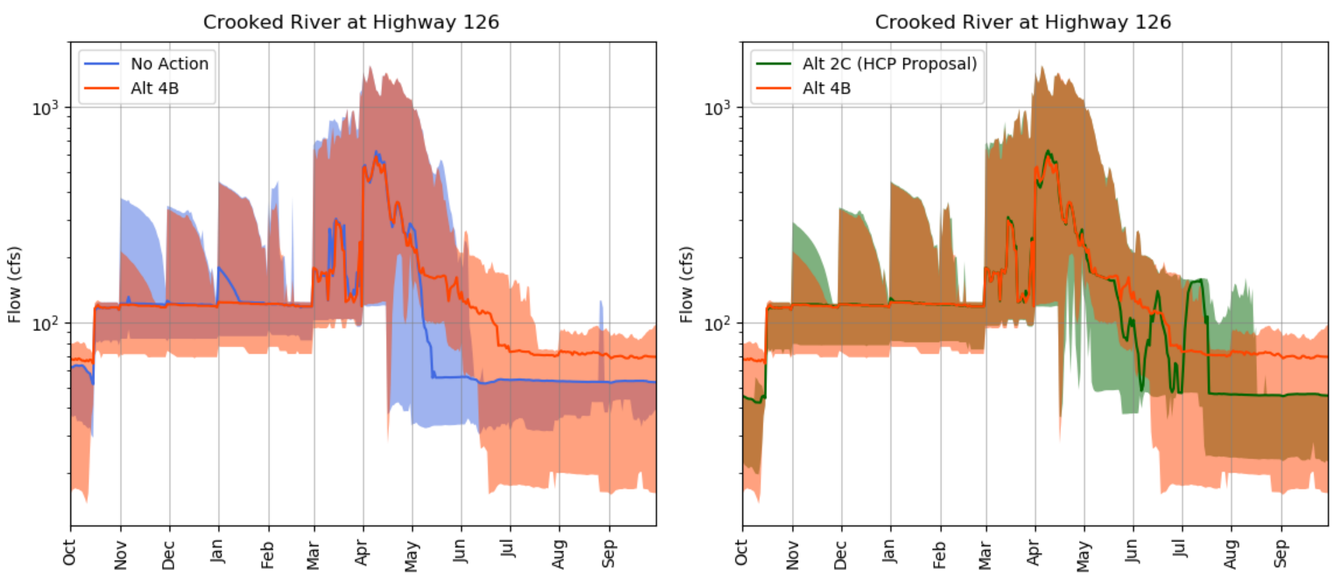

Figure 53. Summary hydrographs of simulated flow in the Crooked River at Highway 126. The graph on the left shows the No Action alternative (blue) compared to Alternative 4 (red). The graph on the right shows Alternative 2 (green) compared to Alternative 4 (red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

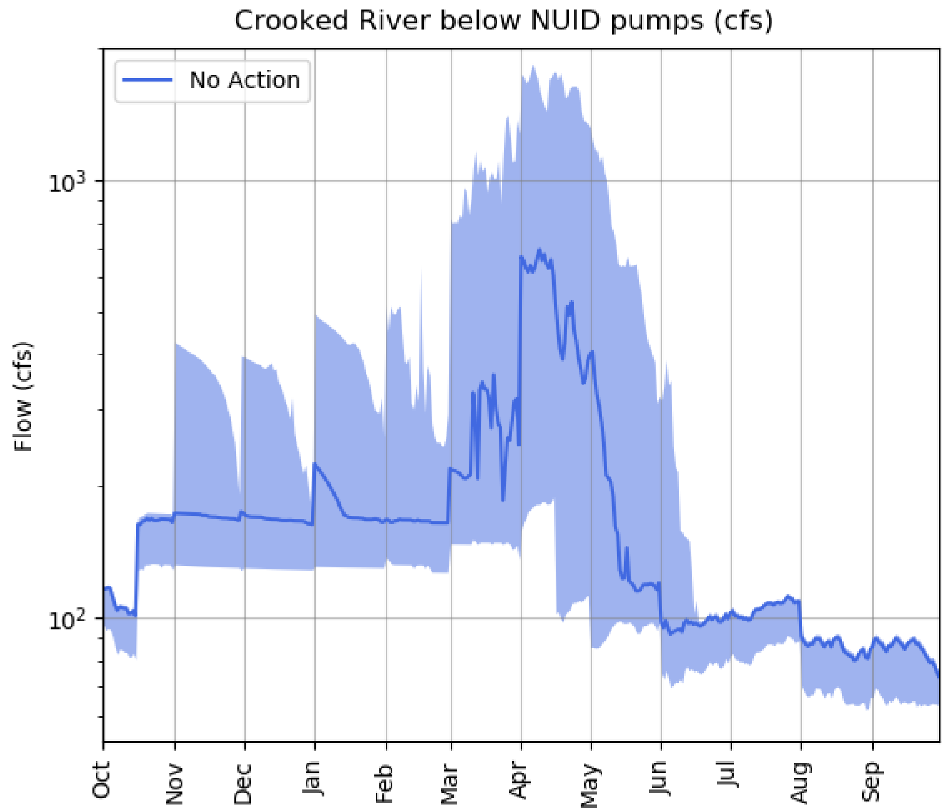

Figure 54. Summary hydrograph of simulated flow in the Crooked River below the NUID pumps showing the No Action alternative. The dark blue line represents the median and the shaded blue area represents the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

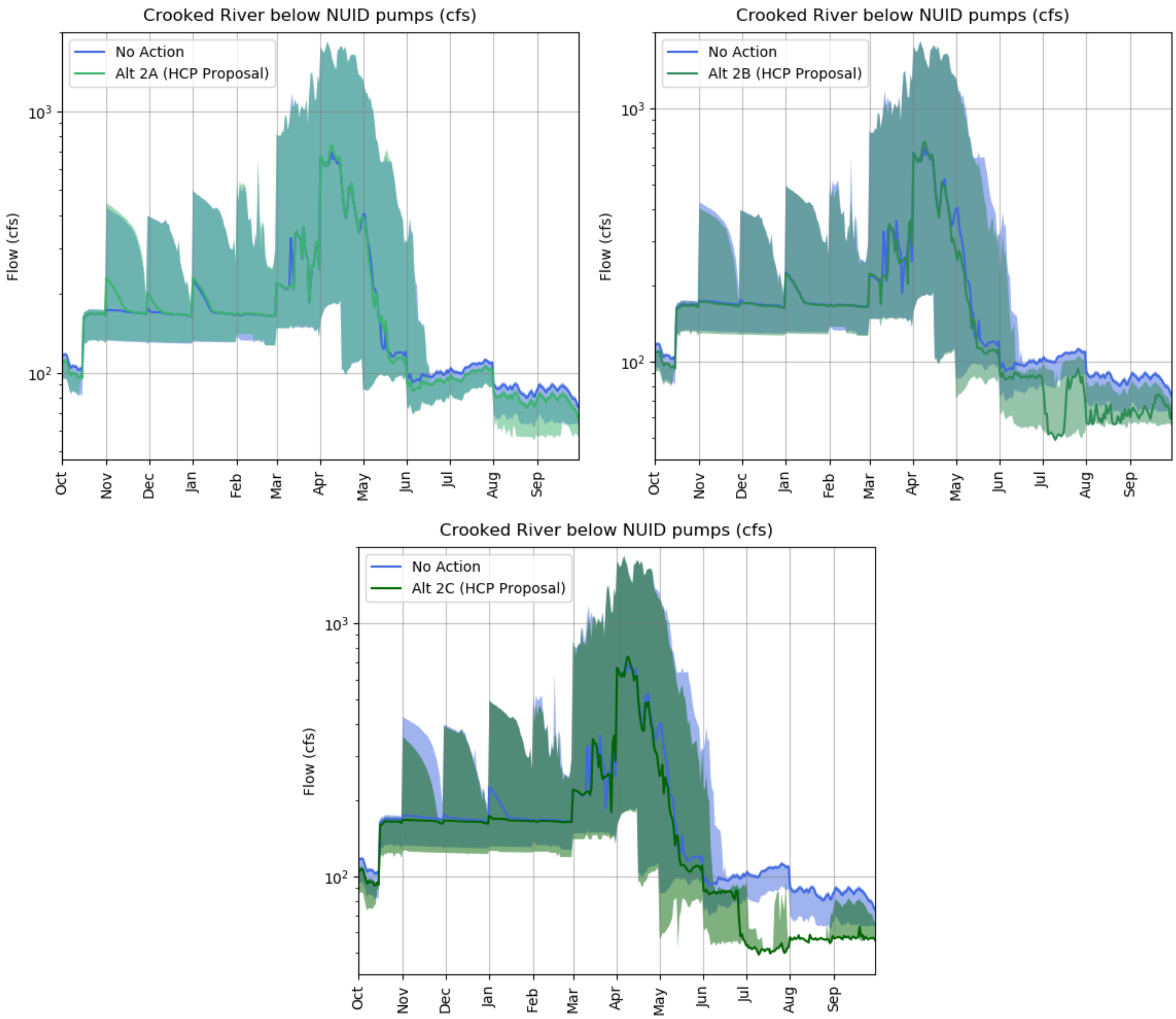

Figure 55. Summary hydrograph of simulated flow in the Crooked River below NUID pumps. The graph shows the No Action alternative (blue) compared to Alternative 2 (green); 2A is shown at the top left, 2B at the top right, and 2C at the bottom. The dark blue and green lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

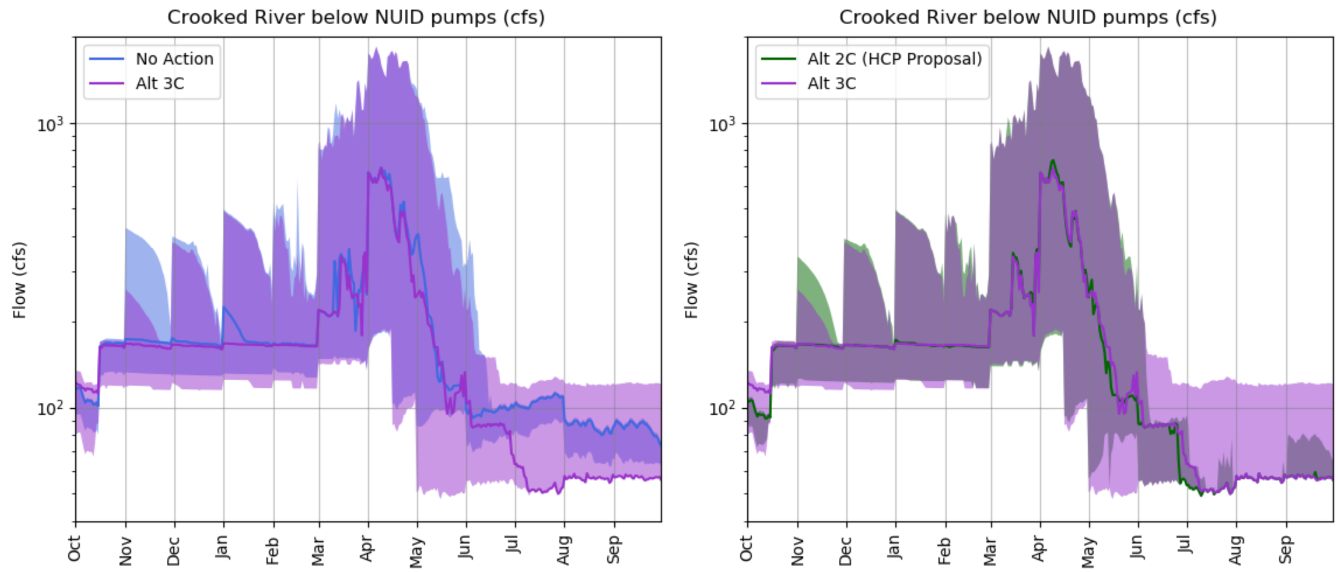

Figure 56. Summary hydrographs of simulated flow in the Crooked River below NUID pumps. The graph on the left shows the No Action alternative (blue) compared to Alternative 3 (purple). The graph on the right shows Alternative 2 (green) compared to Alternative 3 (purple). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.

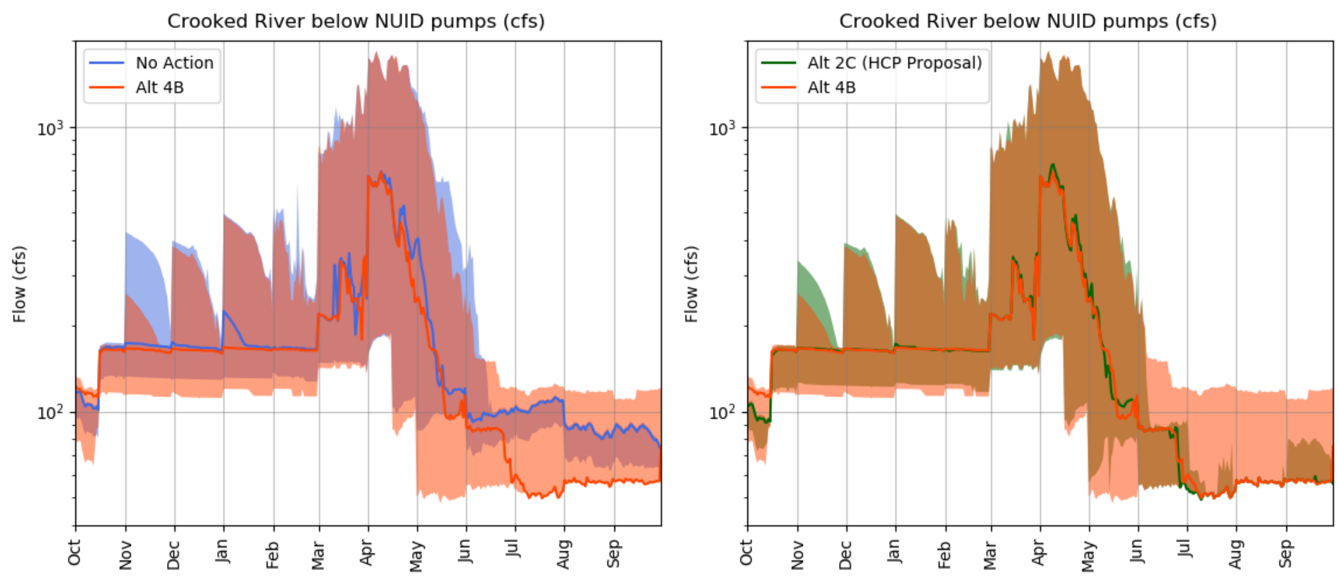

Figure 57. Summary hydrographs of simulated flow in the Crooked River below NUID pumps. The graph on the left shows the No Action alternative (blue) compared to Alternative 4 (red). The graph on the right shows Alternative 2 (green) compared to Alternative 4 (orange-red). The colored lines represent the median and the shaded areas represent the 20 to 80 percent exceedance. The y-axis for flows is shown in logarithmic scale.