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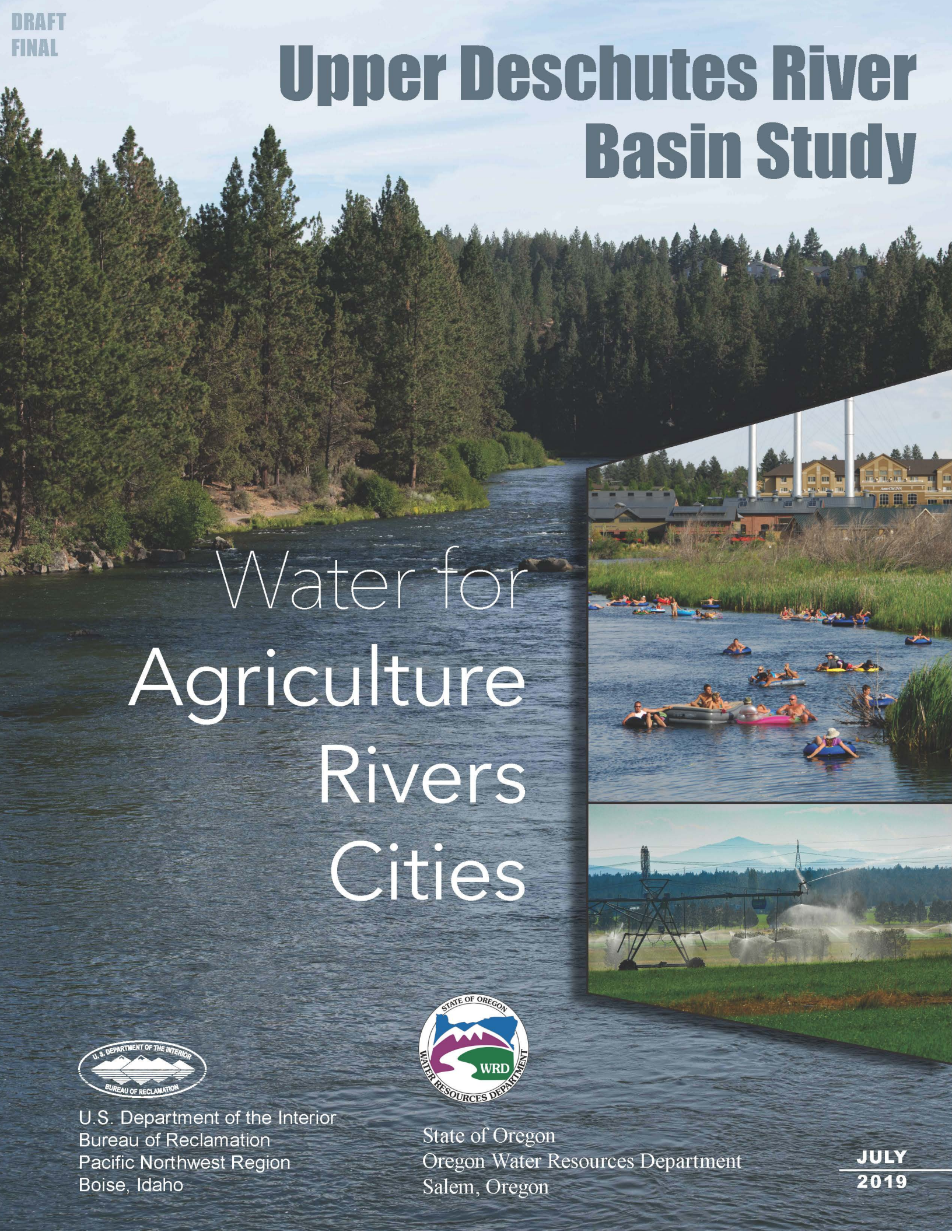
Upper Deschutes River Basin Study



Water for Agriculture Rivers Cities

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

State of Oregon
Oregon Water Resources Department
Salem, Oregon

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Disclaimer

The Upper Deschutes River Basin Study was funded jointly by the Bureau of Reclamation (Reclamation) and the State of Oregon Water Resources Department (OWRD) and is a collaborative product of the Upper Deschutes River Basin Study Work Group (BSWG). The purpose of the study is to assess current and future water supply and demand in the Upper Deschutes River Basin and to identify a range of potential strategies to address projected imbalances. The study is a technical assessment and does not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or OWRD. The study does not propose or address the feasibility of any specific project, program, or plan. Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of Federal funds. All cost estimates included in this study are preliminary and intended only for comparative purposes.

Mission Statements

U.S. Department of the Interior

PROTECTING AMERICA'S GREAT OUTDOORS AND POWERING OUR FUTURE

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

Bureau of Reclamation

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

Oregon Water Resources Department

The Department's mission is to serve the public by practicing and promoting responsible water management through two key goals:

- To directly address Oregon's water supply needs
- To restore and protect streamflows and watersheds in order to ensure the long-term sustainability of Oregon's ecosystems, economy, and quality of life

Acronyms and Abbreviations

Acronym or Abbreviation	Definition
Basin Study	Upper Deschutes River Basin Study
C	Celsius
cfs	Cubic feet per second
COID	Central Oregon Irrigation District
DBBC	Deschutes Basin Board of Control
DRC	Deschutes River Conservancy
DWPI	Deschutes Water Planning Initiative
F	Fahrenheit
FWS	United States Fish and Wildlife Service
GCM	Global Climate Model
HCP	Habitat Conservation Plan
LWD	Less Warming - Dry
LWW	Less Warming - Wet
MWD	More Warming - Dry
MWW	More Warming - Wet
NUID	North Unit Irrigation District
ODFW	Oregon Department of Fish and Wildlife
OWRD	Oregon Water Resources Department
Reclamation	Bureau of Reclamation
Scenario	Hypothetical water management scenario for modeling
TSID	Three Sisters Irrigation District
USGS	United States Geological Survey
WUA	Weighted Usable Area

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Executive Summary

Introduction

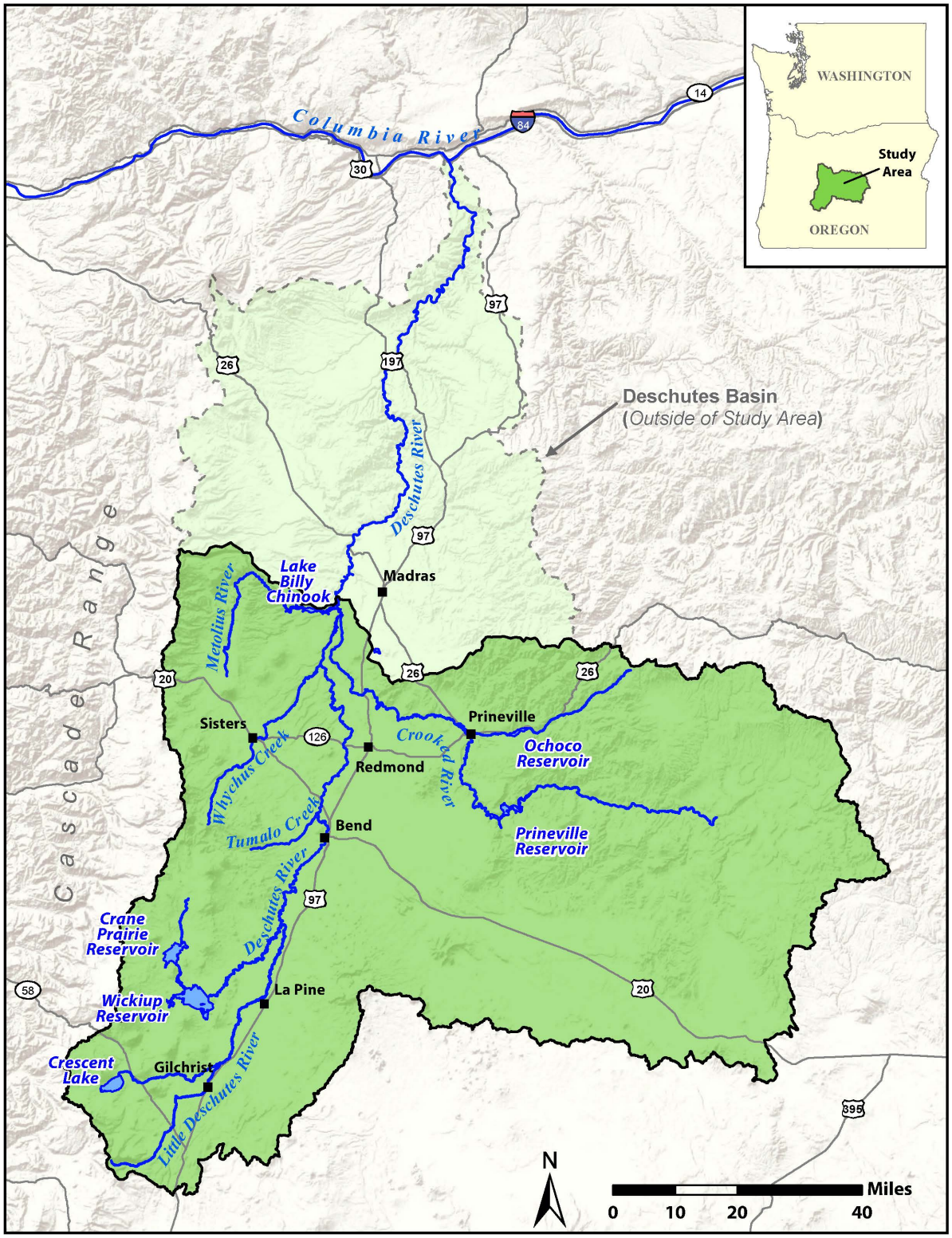
The Bureau of Reclamation (Reclamation), in partnership with the Oregon Water Resources Department (OWRD) and the Basin Study Work Group (BSWG), conducted the Upper Deschutes River Basin Study (Basin Study) and the results are documented in this report. Reclamation selected the Basin Study in fiscal year 2014. The purpose of the Basin Study is to assess current and future water supply and demand in Oregon's Upper Deschutes River basin and to identify a range of potential strategies to address current or projected imbalances. Key water supply needs in the basin involve agricultural, instream, and municipal objectives.

Agricultural water uses include diversions from rivers and streams by eight irrigation districts. Water stored in reservoirs during winter months is released during irrigation season for use by some of these irrigation districts. Districts with junior water rights are relatively less secure in their water supply.

Instream water needs for ecological objectives are affected by low and altered streamflows that result from storage of water and diversions for agricultural uses. At various locations in the basin, species of concern include redband trout, summer steelhead, Chinook salmon, and the Oregon spotted frog.

Municipal water users and similar non-municipal water suppliers generally rely on groundwater sources for water supplies. New water rights for groundwater use in the basin require water to be dedicated instream for mitigation per OWRD rules, and there is a projected shortfall of mitigation credits to meet anticipated groundwater demand.

The Basin Study identified a range of potential water management options for addressing water supply imbalances and evaluated opportunities, relative costs, and challenges associated with each option. This information, along with the water resource models developed for the Basin Study, provides an updated, refined, and shared foundation to support future water management in the Upper Deschutes River basin.



Upper Deschutes River Basin Study Area

Water Supply and Demand

Under current flow conditions in the Upper Deschutes River, water stored in reservoirs during the winter for irrigation use during the summer has resulted in lower winter streamflows and higher summer streamflows, affecting instream conditions relative to ecological needs. For areas farther downstream below Bend, summer irrigation diversions reduce flows in the Deschutes River. Tumalo Creek and Whychus Creek naturally experience low flows in the summer and fall that are exacerbated by irrigation withdrawals. In the Crooked River basin, reservoir storage and related water operations also affect instream flow conditions.

The Basin Study developed water resource models reperesentative of current conditions to evaluate and help quantify water supply shortages for agricultural and instream needs. These shortages represent the difference between a modeled objective, such as an instream flow value or a particular agricultural demand, and the modeled water deliveries. For municipal water suppliers and similar non-municipal suppliers, needs were estimated based on urban growth considerations and new groundwater right information. Basin Study assessments of supply and demand for the Upper Deschutes basin overall indicate median annual shortages totaling 135,000 acre-feet, increasing to 350,000 acre-feet for dry years.

Beyond current conditions, a range of available climate change models was used to evaluate climate conditions approximately 10 to 50 years in the future. Those models indicate that future annual precipitation in the basin is projected to increase by approximately 5 percent for median projections, with a potential range from a 3 percent decrease to an 11 percent increase. Future average temperatures may increase by 2.8° C (4.9° F) based on climate change models for median projections. Climate models also indicate that the timing patterns for precipitation may change in the future. The changes in timing of precipitation may result in increased precipitation in the winter and, coupled with higher temperatures, could shift runoff to earlier in the year on average.

Water Management Options

The Basin Study uses the term *options* to indicate broad categories of water management approaches, while the term *tool* is used to indicate specific water management approaches within the options. Three main water management options and related tools were evaluated for addressing identified water shortages:

Water Conservation (Irrigation) – The water conservation option considered specific tools for reducing agricultural demands, including piping district canals, piping privately owned laterals, and on-farm infrastructure upgrades (e.g., flood-to-sprinkler shifts in irrigation). Water conservation can decrease irrigation demand in particular areas, making water available to meet other needs in the basin and possibly increasing water supply security for other users.

Market-Based Approaches – The market-based option considered the use of price incentives to promote efficient water use and reallocation of supply. Tools relevant to agricultural uses include temporary lease of water rights (fallowing acres on an annual basis), voluntary duty reduction (incentives to reduce water use per acre), and permanent sale of water rights (moving irrigation water rights permanently off acres). Market-based approaches can also decrease irrigation demand in one area, making water available to meet other needs in the basin and possibly increasing water supply security for other users. For example, market transactions can be used to move water from one irrigator to another or to keep water instream to improve streamflow and create mitigation for groundwater users.

Enhanced/New Storage – For the mainstem Deschutes River system, enhanced and/or new storage facilities could potentially support improved streamflows by relocating existing storage farther downstream. This approach could also help irrigation district operations. In the Crooked River system, restoring water storage capacity lost to sedimentation in the existing Prineville Reservoir could provide additional flexibility in water operations to the benefit of multiple uses.

The evaluations of water management options developed planning-level estimates of potential water supply volumes and relative costs, as summarized in the table below. The Basin Study report includes important additional information on assumptions and limitations associated with assessment of these options.

Summary of Water Management Options

Water Management Option	Estimated Potential Opportunity (acre-feet)	Estimated Cost	Estimated Average Cost per Acre-foot	Benefits and Challenges
Water Conservation Infrastructure (Irrigation)	185,000	$990 million	$5,000	Benefits: proven tool; infrastructure upgrades also improve operations without affecting number/location of irrigated acres; piping can increase opportunities for water marketing Challenges: piping canals is expensive and can face opposition to changing the nature of open canals; land use policies and historic designations can affect some canals; some approaches require action and/or agreement by numerous parties
Market-based Incentives	160,000	$65 million	$400	Benefits: temporary leasing and permanent transfers are tested and effective approaches; temporary approaches are flexible and can be scaled for dry years; could make water available at relatively low cost

Water Management Option	Estimated Potential Opportunity (acre-feet)	Estimated Cost	Estimated Average Cost per Acre-foot	Benefits and Challenges
				Challenges: costs may increase due to coordination needs among multiple parties; legal and irrigation district policy changes may be required; district operational issues limit viability in some locations
Enhanced/New Storage	40,000	$200 million	$5,000	Benefits: could help improve instream flow conditions while adding operational flexibility for irrigation districts Challenges: extensive studies would be required to assess feasibility, environmental impacts; implementation would be expensive and take many years

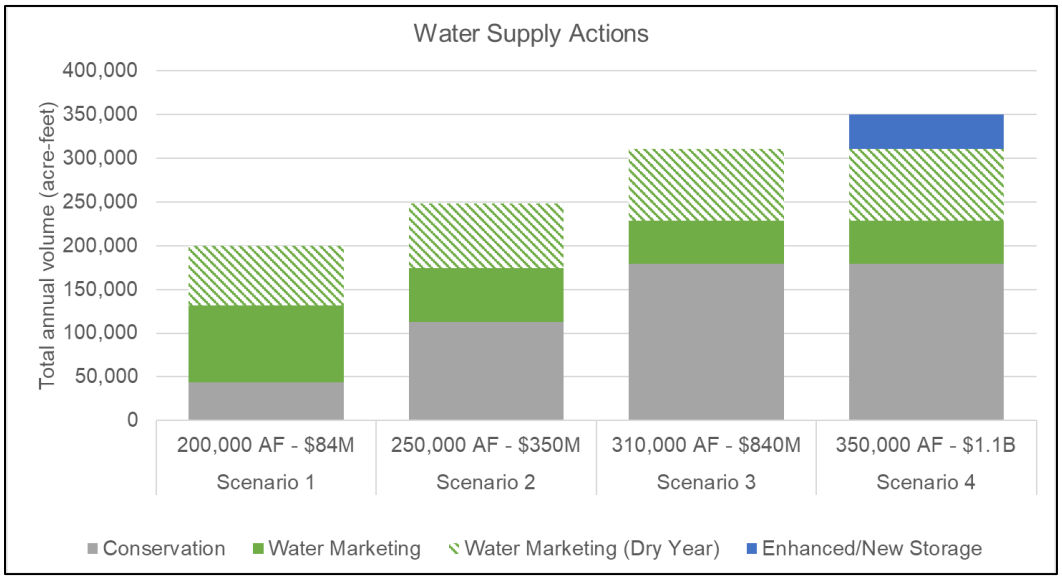
Assessment of Water Management Options

Water resources modeling completed for the Basin Study included evaluation of the options and tools described above. Specific water management tools within each option were combined in four hypothetical water management scenarios. These scenarios were designed to help illustrate the features of different water supply strategies and provide information about how various tools might interact if applied in combination. The BSWG acknowledged that legal, technological, and/or financial impediments may exist and that the demand reductions assumed in the scenarios should be viewed only as hypotheticals for exploring "what if" conditions.

Modeling objectives for all four of the water management scenarios included the objectives of attempting to meet irrigation demands and attempting to meet increased instream flow objectives. The specified irrigation demands were reduced in each scenario by assuming the use of a combination of the identified water management tools; some of the tools assumed in the scenarios could be relevant for establishing mitigation for groundwater users.

The integration of different assumed water management tools in the hypothetical scenarios allowed actions to be scaled for dry years. The combinations of tools and the associated total estimated water supply opportunities for each scenario are illustrated in the figure below. Modeled instream flow objectives were increased from Water Management Scenarios 1 and 2 to Water Management Scenarios 3 and 4 to provide information on both shorter-term, lower-cost combinations of strategies and longer-term, higher-cost combinations of strategies. Representative relative costs for the suite of water management tools assumed for each hypothetical scenario were estimated as $84 million for Scenario 1, $350 million for Scenario 2, $840 million for Scenario 3, and $1.1 billion for Scenario 4. Additional

information on the hypothetical water management scenarios is provided in Section 4.1 of the Basin Study report.



Hypothetical Water Management Scenarios

The outcomes of the scenario modeling provide information about water management strategies relevant primarily to four specific areas of the basin: the mainstem Upper Deschutes River, Tumalo Creek, Whychus Creek, and the Crooked River.

Mainstem Upper Deschutes: For the mainstem Upper Deschutes River above Bend, the assumed hypothetical water supply tools involved water conservation, water leasing, water transfers, and (for Scenario 4) enhanced/new storage. Outcomes indicate that for the assumed demand reductions, modeled instream flow objectives (300 cubic feet per second (cfs) winter flows for Scenarios 1 and 2; 600 cfs winter flows for Scenarios 3 and 4) could often be met in the Upper Deschutes River while still meeting irrigation needs. These results are predicated on the assumption of a signficant demand reduction using a variety of market-based and infrastructure-based tools, focused on irrigation districts with senior water rights, and carry a very high price tag – particularly for the higher modeled flow objective. Estimated costs for the scenarios increase as the proportion of infrastructure-based options increases.

Tumalo Creek: The scenario modeling results for Tumalo Creek indicate that the assumed water supply actions (water conservation and water leasing), if successfully implemented, could produce significant benefits in many years. Such potential benefits include flows in excess of the modeled instream flow objective (33 cfs summer flows) and increasing Tumalo Creek's contribution to cold-water inputs in the Deschutes River. Additional dry-year management options could be considered.

Whychus Creek: Scenario modeling for Whychus Creek assumed water management tools involving water conservation, water leasing, and water transfers. The outcomes suggest that

if those actions were successfully implemented, modeled instream flow objectives (33 and 45 cfs summer flows) could be met or exceeded in wet/average years but would not be met in dry years. For the assumed reduction in irrigation demands, the results indicate that those reduced demands could be met in wet and average years, with some shortages in dry years. Under current conditions, water conservation opportunities are close to being fully capitalized upon in the Three Sisters Irrigation District; a robust annual leasing program and dry-year leasing could be useful tools to further enhance flow restoration.

Crooked River: Scenario modeling for the Crooked River indicates that water supply options in the Crooked River basin could consider addressing the less frequent but significant-in-magnitude shortages identified for dry years. Results relative to the assumed instream model flow objectives (80 and 140 cfs summer flows) suggest that there could be opportunities for achieving higher flows in wet years, if desired. Irrigation shortages could largely be avoided if all of the hypothetical reductions in irrigation demand could be achieved. Tools assumed in the scenarios included water conservation, water leasing, and (for Scenario 4) enhanced storage. The Basin Study also developed a temperature model for Prineville Reservoir that could help inform future water management through assessing relationships between streamflow, air temperature, water temperature, and reservoir levels.

Groundwater Mitigation Needs: All four water management scenarios include water supply options that could potentially be used to generate groundwater mitigation relevant to future needs of municipal and similar non-municipal water suppliers. While permanent instream transfers are a proven tool for addressing these objectives, current irrigation district policies are generally oriented toward keeping their water rights available for irrigation use. Instream leasing provides temporary mitigation, but municipalities generally require permanent transactions that provide long-term assurances due to the large investments associated with water supply infrastructure. Storage releases, as considered in the hypothetical water management scenarios, have been used in the Crooked River basin to generate groundwater mitigation, but the potential for wider use has not been fully tested. While the overall volume of water needed to meet the mitigation demand is relatively small compared to the total water budget in the basin, stakeholders will need to continue to work toward reliable, predictable, and cost-effective means for addressing this demand.

Conclusions

This Basin Study identified and evaluated a broad range of water management options to assess opportunities, costs, and challenges for their potential use in addressing imbalances in water supply and demand. Water conservation tools and market-based approaches are proven in the Upper Deschutes River basin and can complement each other. In addition, temporary market-based tools provide near-term, flexible approaches that can be scaled to addresss dry-year conditions. Challenges for implementation of water conservation and market-based options involve high costs for some approaches, legal and policy barriers, and practical limitations related to coordination among numerous parties. The Basin Study evaluation of new or enhanced water storage facilities showed that these concepts have the

potential to further reduce water-supply shortages in the longer term but involve high costs and significant uncertainties.

The BSWG's pursuit and completion of the Basin Study incorporated a collaborative approach to identify and evaluate water management issues affecting multiple interests. The cooperative work in an open venue supported broadly shared understandings of basin hydrology and potential benefits and costs of water management strategies. Water resources modeling tools that have been developed for the Basin Study provide an updated, refined, and accepted technical basis to support future water management efforts.

While the Basin Study does not propose or recommend any particular approach or plan, basin stakeholders can use the outcomes to inform projects that address imbalances between water supply and demand. Funding sources may be leveraged to support large-scale piping projects and complementary on-farm improvements and market-based programs. Such funding opportunities may exist via Reclamation's WaterSMART Program Water and Energy Efficiency Grants, Water Marketing Strategy Grants, drought resiliency projects under the Drought Response Program, and the Water Management Options Pilots Selection Process. Additional sources include programs managed by the U.S. Department of Agriculture Natural Resources Conservation Service. The BSWG recognized that the ongoing development of the Deschutes River Basin Habitat Conservation Plan will inform permitting under the Endangered Species Act and may provide opportunities for complementary water management initiatives.

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1. Introduction

In 2009, Congress enacted the Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act, which authorizes the Bureau of Reclamation (Reclamation) to work with non-Federal partners to evaluate water supply and demand and water management strategies. To implement the SECURE Water Act, the U.S. Department of the Interior established the Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program in 2010. Reclamation initiated the Basin Study Program as part of the WaterSMART Program. Basin Studies are conducted with non-Federal partners contributing at least 50 percent of the total costs as cash or in-kind services. Reclamation selected the Upper Deschutes River Basin Study (Basin Study) in fiscal year 2014.

The Upper Deschutes River Basin Study was completed by Reclamation and the Deschutes Basin Study Work Group (BSWG) in 2019. The $1.5 million study was funded on a 50/50 cost-share basis by the WaterSMART Program and the Oregon Water Resources Department (OWRD) Water Supply Development Fund.

1.1 Uncertainty

The information presented in this report was developed in collaboration with basin stakeholders and was peer reviewed in accordance with Reclamation and Department of the Interior polices. This report is intended to inform and support planning for the future by identifying potential future scenarios. The analyses provided in this report reflect the use of best available datasets and methodologies at the time of the study.

Water resources studies are developed in collaboration with basin stakeholders to evaluate potential future scenarios to assess risks and potential actions that can be taken to minimize impacts, including supply-and-demand imbalances. These types of studies support a proactive approach to water resources management, using the best available science and information to develop scenarios of future conditions within the watershed. This positions communities to take steps now to mitigate the impacts of future water supply management issues, including water shortages, impacts of droughts and floods, variations in water supply, and changing water demands for water for new or different uses.

Because every water resources planning study requires the study partners to make assumptions about future conditions, addressing the uncertainties in those assumptions is an essential component of the planning process. For example, there are uncertainties associated with the characterization of future water supply and demand, demographics, environmental and other policies, economic projections, climate conditions, and land use, to name a few. Moreover, projections are often developed using modeling techniques that themselves are only potential representations of a particular process or variable, therefore introducing additional uncertainties into characterizations of the future. The cumulative, interacting uncertainties are not well known in the scientific community and, therefore, are not presented

within this study. By recognizing this at each process step, uncertainties are adjusted for and reduced when possible, allowing Reclamation and its stakeholders to use the best available science to create a range of possible future risks that can be used to help identify appropriate adaptation strategies, which is fundamental to the planning process. Importantly, scenarios of future conditions should not be interpreted as a prediction of the future, nor is the goal of any water resources planning study to focus on a singular future. Rather, the goal is to plan for a range of possible conditions, thereby providing decision support tools for water managers.

Of significant interest are projections of future climate, which ultimately drive many assumptions of water supplies and demands through their influence on the water cycle. Projections of future climate are developed using the scientific community's best assessment of potential future conditions as characterized by global climate models (GCMs). GCM projections are based upon initial model states, assumptions of future greenhouse gases in the atmosphere, and internal as well as external forcings, such as solar radiation and volcanic activity, to name a few. Changes in land surface, atmosphere, and ocean dynamics, as well as how such changes are best modeled in GCMs, continue to be areas of active research. Depending on these and other uncertainties, projected future conditions, such as the magnitude of temperature and precipitation changes, may vary. Observed climatic data and GCM simulations show warming trends over recent decades. However, the degree to which the magnitude of GCM-simulated warming agrees with historic observations, where some studies find more GCM warming (Santer et al., 2017) while others show warming rates more in line with observations (Lin and Huybers, 2016; Richardson et al., 2016), varies based on the data, methods, and time periods used for making such comparisons. The evaluation and refinement of GCM performance is an ongoing area of research and includes methods to characterize model outputs and observations and how measurement errors, internal variability, and model forcings can be improved to enhance future performance (Lin and Huybers, 2016).

Further, it is important to recognize that these models perform better at global rather than regional or watershed-level scales. Accordingly, techniques must be employed to downscale, or localize, GCM output for applications such as basin-specific water resources planning studies. These downscaled projections of climate are used as inputs to hydrologic models to produce projected streamflows, which are then used to assess impacts to the water resource system in question. Uncertainties at each of the steps necessary to translate GCM output to water resources impacts can be characterized and adjusted for, yet uncertainties remain in the downscaling process that can result in variations, depending on the modeling technique used.

Ultimately, future conditions at any particular time or place cannot be known exactly, given the current scientific understanding of potential future conditions. Likewise, it is important to recognize that the risks and impacts are the result of collective changes at a given location. Warming and increased carbon dioxide may increase plant water-use efficiency and lengthen the agricultural growing season, but may also have adverse effects on snowpack and water availability. These complex interactions underscore the importance of using a planning

approach that identifies future risks to water resources systems based on a range of plausible future conditions, and working with stakeholders to evaluate options that minimize potential impacts in ways most suitable for all stakeholders involved.

1.2 Background

The Basin Study was designed to consider long-standing water management issues in the Upper Deschutes River basin. The study area includes the Upper Deschutes River system, as well as the Crooked River, Whychus Creek, and Tumalo Creek drainages (Figure 1).

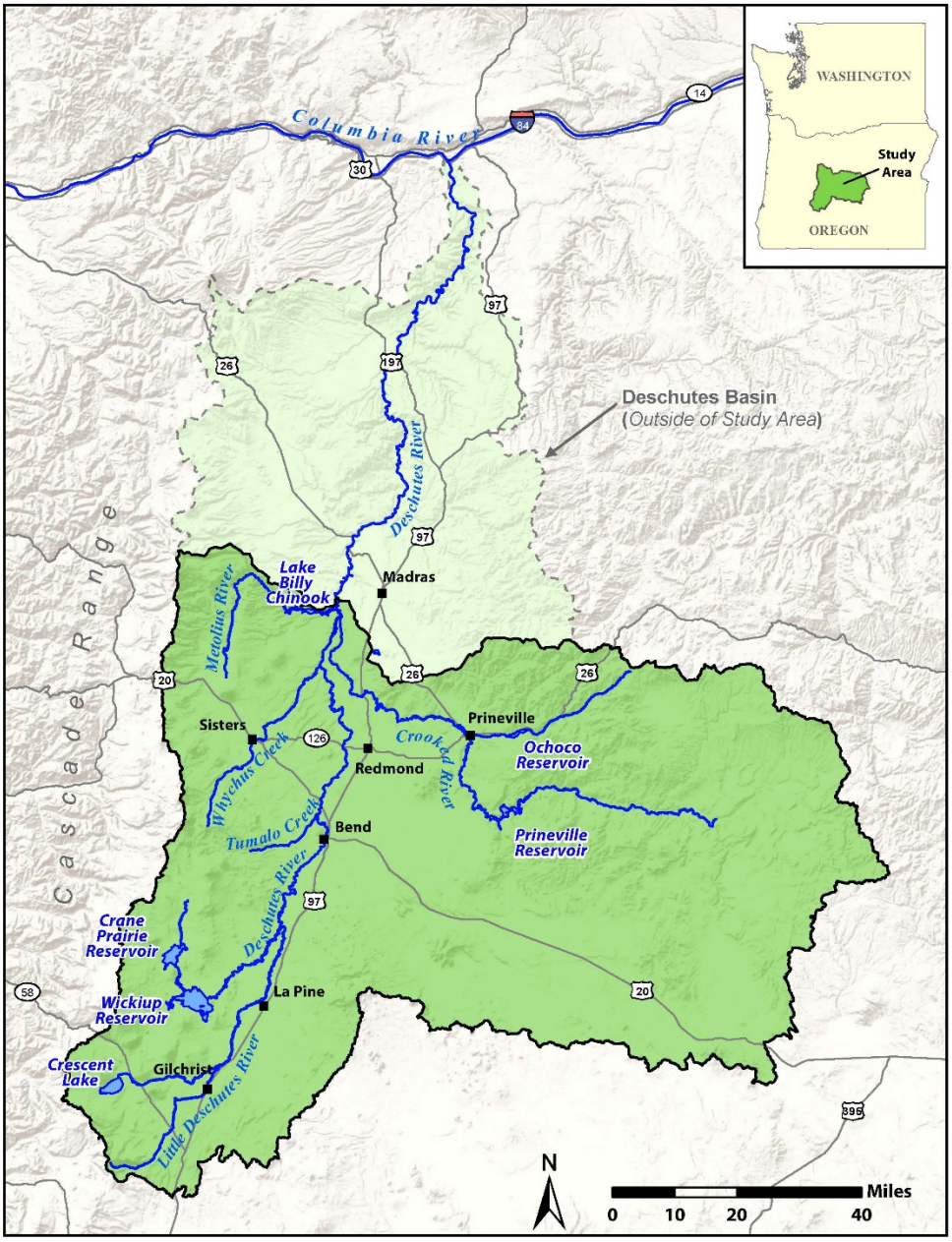

Figure 1. Upper Deschutes River Basin study area.

More than 100 years ago, Federal and state policies encouraged the settlement of central Oregon's high desert by facilitating access to land and irrigation water. This water has made possible the diverse agricultural sector that has helped shape the region. However, as a result of this water development, many rivers and streams were left with low or altered flows.

As the region grew, the Upper Deschutes River basin experienced increased demand for water for people, cities, farms, and fish and wildlife. Over the past two decades, irrigation districts, governmental entities, and conservation groups have worked together to address these issues. Basin stakeholders have collaborated to implement water conservation and water marketing projects that restored significant flows to basin rivers and streams and that aided groundwater uses (by establishing groundwater mitigation). The history of stakeholders working together in the Deschutes River basin is illustrated by the following milestones:

- 1996 – Tribal, irrigation, and environmental interests formed the Deschutes River Conservancy (DRC) with the goal of restoring streamflow and water quality in the basin using proactive, collaborative, and market-based approaches.
- 2002 – Irrigation districts in central Oregon formed the Deschutes Basin Board of Control (DBBC) to coordinate on efforts to conserve water, improve services for farm and ranch families, and enhance river conditions for wildlife species and recreational opportunities.
- 2004 – The Deschutes Water Alliance (DWA) was formed with support from a Reclamation grant. DWA goals were to meet water supply needs for instream, irrigation, and municipal interests through development of a regional water management plan. A formal Memorandum of Understanding was completed in 2010, and work completed under the grant resulted in a robust set of water supply-and-demand studies and potential water management measures.
- 2012 – Recognizing a need for even more comprehensive planning, many of the same partners involved with the DWA launched the Deschutes Water Planning Initiative (DWPI) to focus specifically on how to restore flows in the Upper Deschutes River while meeting irrigation and municipal/quasi-municipal needs.
- 2014 – The DWPI group evolved and expanded to form the Basin Study Work Group (BSWG). The BSWG pursued the Basin Study as a way to more comprehensively evaluate water supply and demand and identify how interconnected actions could be used to address water issues in the basin (BSWG 2014).

BSWG member entities are listed below:

Arnold Irrigation District	Avion
Bend Paddle Trail Alliance	Bureau of Reclamation
Central Oregon Flyfishers	Central Oregon Irrigation District
City of Bend	City of La Pine
City of Madras	City of Prineville
City of Redmond	Coalition for the Deschutes

Crooked River Watershed Council	Department of Environmental Quality
Deschutes County	Deschutes River Conservancy
Deschutes Soil and Water Conservation District	Deschutes Water Alliance
Lone Pine Irrigation District	Native Reintroduction Network
North Unit Irrigation District	Ochoco Irrigation District
Oregon Department of Agriculture	Oregon Land and Water Alliance
Portland General Electric	Sunriver Anglers
Swalley Irrigation District	Three Sisters Irrigation District
Trout Unlimited	Tumalo Irrigation District
U.S. Fish and Wildlife Service	Upper Deschutes Watershed Council
U.S. Department of Agriculture Forest Service	WaterWatch of Oregon
Oregon Water Resources Department	Confederated Tribes of the Warm Springs

The BSWG and Reclamation jointly developed a Memorandum of Agreement and Plan of Study (Reclamation 2015a; Reclamation 2015b) to define the scope and approach for the Basin Study. The objectives of the Basin Study were as follows:

- Evaluate and quantify current and future water supply and demand, considering future climate conditions (for the Basin Study, demands involved both instream and out-of-stream demands).
- Develop and analyze potential tools that could address identified imbalances in supply and demand.
- Evaluate potential water management tools, and combinations of tools, in terms of effectiveness, cost, environmental impact, risk, stakeholder response, and other factors.

The BSWG also defined broad goals for water management strategies in the basin and framed them as "the three legs of the stool" required to support achievable and sustainable actions that could secure and maintain the following:

- Increased streamflows and improved water quality for the benefit of fish, wildlife, and people.
- A reliable and affordable water supply to sustain agriculture.
- A safe, affordable, and high-quality water supply for municipal and quasi-municipal water users.

The BSWG endorsed the concept that all three of these broad goals should be valued and pursued in parallel.

The Basin Study is not an implementation plan, as it does not propose, recommend, or endorse any particular action or plan. It does provide a foundation for water management planning and related project implementation by the basin stakeholders. While this Basin Study report presents the overall outcomes of the study, additional and more-detailed technical information relevant to potential future planning efforts is available in Technical Memoranda and related documents identified in Table 1.

Table 1. Upper Deschutes River Basin Study documentation

Topic	Document	Information Provided	Reference
Documentation of the Basin Study Process			
Basin Study Work Group	Basin Study Work Group Charter	Defines the purpose, structure, and processes for the BSWG as agreed to by the BSWG Steering Committee.	BSWG 2014
Basin Study Administration	Memorandum of Agreement: Deschutes Basin Board of Control and Reclamation	Establishes the terms guiding performance of the Basin Study and the associated cost-share responsibilities between the Deschutes Basin Board of Control (acting as the fiscal agent for the BSWG) and Reclamation.	Reclamation 2015a
Study Scope, Schedule, and Budget	Plan of Study	Sets forth the planned scope, schedule, and budget for the Basin Study; tasks to be addressed within the fixed budget were evaluated and agreed upon by the BSWG.	Reclamation 2015b
Technical Sufficiency Review	Technical Memorandum: Summary of Technical Sufficiency Reviews, Upper Deschutes River Basin Study	Provides comments received from technical reviewers on Basin Study technical documentation; includes descriptions of how comments are addressed in the Basin Study report.	Reclamation 2018a
Technical Analyses to Inform Modeling and Related Assessments			
Hydrology and Water Supply	Technical Memorandum: Analysis of Regulated River Flow in the Upper Deschutes Basin using Varying Instream and Out-of-Stream Conditions	Describes modeling studies of river flows, incorporating ranges of hydrologic conditions based on recorded data, current water usage patterns and water rights, and hypothetical water management scenarios; identifies estimated shortages in water supplies for assumed conditions.	Reclamation 2018b
Future Climate Conditions	Technical Memorandum: Compilation and Analysis of Climate Change Information in the Deschutes Basin	Presents models used to project potential future variability in precipitation and temperature; discusses applications relative to Basin Study objectives.	Reclamation 2018c
Instream Ecological Needs	Technical Memorandum: Oregon Spotted Frog and Deschutes Redband Trout Habitat Modeling and Riparian Analysis at Two Sites on the Upper Deschutes River	Instream flow study at two sites on the Upper Deschutes River below Wickiup Reservoir; evaluates relationships between streamflow and both instream and adjacent riparian wetland habitats.	River Design Group 2017

Topic	Document	Information Provided	Reference
Stream Temperature	Technical Memorandum: Prineville Reservoir and Crooked River Temperature Model	Development of a temperature model of Prineville Reservoir and the Crooked River; explores the effects of potential water management approaches on water temperatures.	Portland State University 2017
	Technical Memorandum: Whychus Creek and Middle Deschutes River Temperature Assessments	Assessment of relationships between stream temperature, streamflow, and air temperature at three sites (Whychus Creek, Middle Deschutes River, and Tumalo Creek); regression analyses used to assess potential predictors of stream temperatures.	Upper Deschutes Watershed Council 2016
Exploration of Water Management Tools			
Irrigation District Infrastructure and Water Use	Technical Memoranda: Literature Reviews (individual working drafts) for Arnold, Central Oregon, Lone Pine, North Unit, Ochoco, Swalley, Three Sisters, and Tumalo Irrigation Districts	Compilations of available data on irrigation systems including supply, storage, distribution, water use, and water conservation.	Anderson Perry & Associates 2016
Water Conservation Tools (Irrigation)	Technical Memorandum: Water Conservation Assessment	High-level summary estimates of water conservation potential and associated costs for the eight irrigation districts in the study area; addresses piping district-owned canals, piping private laterals, and on-farm conservation.	Watershed Professionals Network 2017
Market-Based Tools	Technical Memorandum: Market-Based Approaches as a Water Supply Alternative (LPE Task 7)	Evaluates the potential for market-based approaches as a water supply option; addresses price incentives to promote efficient water use and reallocation of existing supply relative to potential water management objectives.	Summit Conservation Strategies 2017
Enhanced/New Storage	Technical Memorandum: Assessment of Potential Enhanced or New Storage Opportunities	Provides information about potential approaches, additional storage volumes, and possible cost ranges for new water storage opportunities; helps inform evaluations of storage options as a possible element of future water management strategies.	Reclamation 2018d

Topic	Document	Information Provided	Reference
Hydrologic Forecasting Improvements	Technical Memorandum: Current Hydrologic Forecasting, Potential Improvements, and Next Steps	Evaluation of opportunities for improvements in hydrologic forecasting approaches that could enhance water management operations in the Upper Deschutes and Crooked River basins.	Watershed Professionals Network 2016
	Technical Memorandum: Upper Crooked River Basin SNOTEL	Evaluates potential opportunities for improving hydrologic forecasting that could enhance water management operations; explores possible sites for additional snow telemetry stations in the Upper Crooked River basin.	Reclamation 2018e
Improved Gaging of Diversions	Technical Memorandum: Crooked River – Diversion Gaging	Evaluates potential opportunities for improving water management by installing additional gaging on Crooked River diversions below Prineville Reservoir.	Reclamation 2018f
Potential Storage Enhancement through Flood Control Operations	Technical Memorandum: Prineville Reservoir – Operating Rule Curve	Evaluates the potential for enhancing storage at Prineville Reservoir via modifications to the rule curve guiding flood control operations.	Reclamation 2018g
Clarification of Critical Issues			
Legal & Policy Factors	Technical Memorandum: Water Right Assessment: Historical Diversions and Instream Water Rights in the Deschutes Basin (Task 1A)	Summary of existing information on water rights and water use (irrigation, municipal, quasi-municipal, and instream) in the Upper Deschutes basin.	GSI Water Solutions, Inc. 2018a
	Technical Memorandum: Water Right, Legal and Policy Opportunities and Impediments for Stored Water, Forbearance, Instream Flow Protection, and Mitigation (Task 2, Part 2)	Evaluates potential water right opportunities for managing reservoirs to increase streamflow in the Upper Deschutes outside of irrigation season and to establish mitigation credits (note: Task 2, Part 1 was not implemented, per BSWG decision, as additional information became available).	GSI Water Solutions, Inc. 2018b
	Technical Memorandum: Water Right, Legal and Policy Opportunities and Impediments Associated with Options for Water Movement (Task 4)	Explores potential ways to move water rights and/or water supply to meet various needs.	GSI Water Solutions, Inc. 2018c

Topic	Document	Information Provided	Reference
	Technical Memorandum: Water Right Opportunities and Impediments for New or Expanded Reservoir Storage (Task 5)	Identifies opportunities and impediments for new or expanded water storage from a water rights/legal perspective.	GSI Water Solutions, Inc. 2018d
	Technical Memorandum: Groundwater Mitigation under the Deschutes Basin Groundwater Mitigation Program; A Summary of Projected Supply and Demand (Task 6)	Evaluates the projected supply of, and demand for, mitigation credits for allowing new uses of groundwater.	GSI Water Solutions, Inc. 2018e
	Technical Memorandum: Evaluate Water Right, Legal and Policy Opportunities and Impediments Associated with Several Potential Actions in Whychus Creek (Task 3)	Considers potential groundwater-surface water exchanges and below-ground storage opportunities in the Whychus Creek basin.	GSI Water Solutions, Inc. 2018f
Evaluations of Water Management Tools and Scenarios			
Hydrology and Water Supply	Technical Memorandum: Analysis of Regulated River Flow in the Upper Deschutes Basin using Varying Instream and Out-of-Stream Conditions	Describes modeling studies of river flows, incorporating ranges of hydrologic conditions based on recorded data, current water usage patterns and water rights, and hypothetical water management scenarios; identifies estimated shortages in water supplies for assumed conditions.	Reclamation 2018c
Multi-Criteria Evaluations	Technical Memorandum: Multi-Criteria Evaluation of Alternatives and Scenarios	Summarizes criteria developed by the BSWG for evaluation of potential water resource management tools; evaluates potential water management tools and hypothetical scenarios relative to the identified criteria.	Summit Conservation Strategies 2018

2. Water Needs and Study Approach

This section describes the key water needs in the Upper Deschutes River basin and outlines the approach taken in the Basin Study to evaluate water management strategies for addressing those needs. The BSWG determined that integrated solutions involving multiple tools are needed to address water needs for "the three legs of the stool" required to support achievable and sustainable water management in the Upper Deschutes River basin, i.e., agricultural needs, instream/ecological needs, and municipal/quasi-municipal water users. These three categories of water needs are described below.

- Agricultural water uses include diversions from rivers and streams by eight irrigation districts in the basin. Water stored in reservoirs during winter months is released during irrigation season for use by some of these irrigation districts. Districts with junior water rights, such as North Unit Irrigation District (NUID), are relatively less secure in their water supply. Figure 2 illustrates the locations of irrigation districts, reservoirs, and other key features of the study area.
- Instream water needs for ecological objectives are affected by low and altered streamflows that result from storage of water and diversions for agricultural uses. Species of concern relative to ecological objectives include redband trout throughout the basin, summer steelhead and Chinook salmon in Whychus Creek and the lower Crooked River system, and the Oregon spotted frog in the Upper Deschutes River, Little Deschutes River, and Crescent Creek. Locations of the Deschutes River, Tumalo Creek, Whychus Creek, the Crooked River, and other waterways in the study area are shown in Figure 2.
- Municipal and quasi-municipal water users generally rely on groundwater sources. Since 2002, new water rights for groundwater use in the basin require mitigation credits per the Deschutes Basin Groundwater Mitigation Program (Oregon Administrative Rules Chapter 690, Division 505) and there is a projected shortfall of mitigation credits to meet projected groundwater demand. The locations of key cities in the study area are shown in Figure 2.

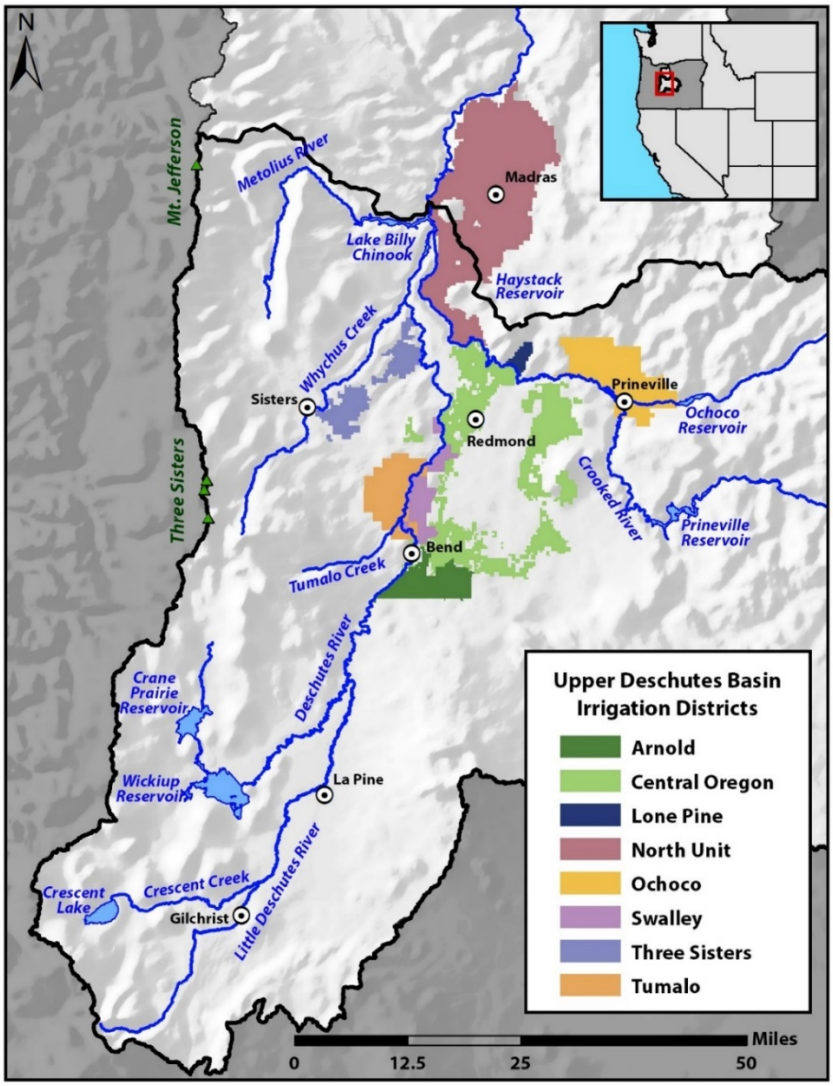

Figure 2. Upper Deschutes Basin irrigation districts, waterways, cities, and reservoirs.

Water rights affect how water may be used for different objectives. For the purposes of the Basin Study, existing water rights and historical water diversion information provided data for irrigation and municipal/quasi-municipal water users. For instream uses, existing water rights developed by the State of Oregon serve as a reference for instream demand. These state instream water rights were based on several different methodologies but generally reflect flows to support specific species and life cycles of fish. State scenic waterway flows and other studies, documents, and legislation may articulate other demands for water instream. In general terms, irrigation water rights account for the majority of the surface flow in the basin; instream rights, where they exist, are junior to most irrigation rights and frequently go unmet (Figure 3).

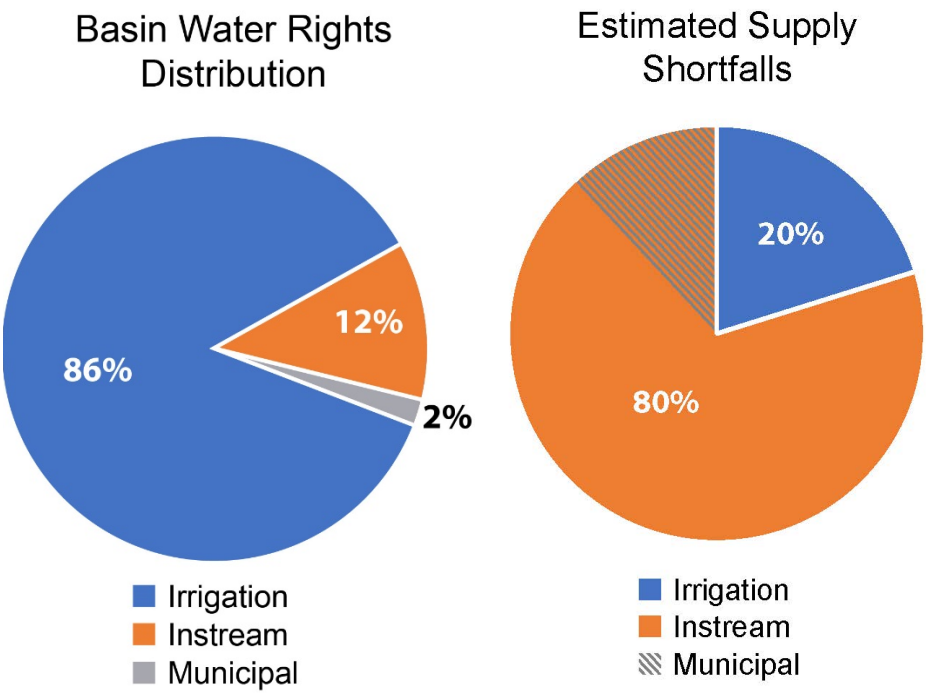

Figure 3. Water rights and estimated shortfalls for the Upper Deschutes River basin. Total demand for water (approximately 1,900,000 acre-feet per year) was calculated by summing daily requested volumes over the year, accounting for seasonal variability of instream flow and irrigation flow rights. The total median irrigation and instream shortage is approximately 135,000 acre-feet per year. Estimated projected municipal and quasi-municipal water supplier needs (16,000 acre-feet) are shown as an overlay related to instream shortages because water for mitigating groundwater pumping is dedicated instream.

Each of the three main water uses has distinct water needs in terms of location, quantity, and timing. The Basin Study was designed to advance understandings of these water needs and evaluate water management options for addressing identified imbalances in supply and demand. For the Upper Deschutes basin, this generally involves ways to address low and altered streamflows to benefit ecological conditions while maintaining or improving water supply reliability and/or financial security for irrigated agriculture, and while planning to meet future groundwater mitigation needs for municipal, industrial, and commercial uses.

2.1 Hydrology Overview

In the Upper Deschutes River basin, the geologic setting results in significant infiltration of precipitation and large groundwater contributions to river flows that, absent reservoir storage and operations, tend to moderate seasonal variations in flows relative to other rivers in the western United States (Reclamation 2018b). Despite the moderating influence of large groundwater contributions, variations in weather and other factors contributed to varying flows in the Upper Deschutes River even prior to reservoir construction and operations. Figure 4 depicts the seasonal and inter-annual variability in calculated unregulated flows (i.e., flows without storage or diversions) at the Deschutes River below the Wickiup gage, with blue showing calculated daily flow and orange showing average monthly flow

(Reclamation 2018b). Calculated unregulated summer flows range from approximately 200 to 900 cfs, depending on hydrologic conditions.

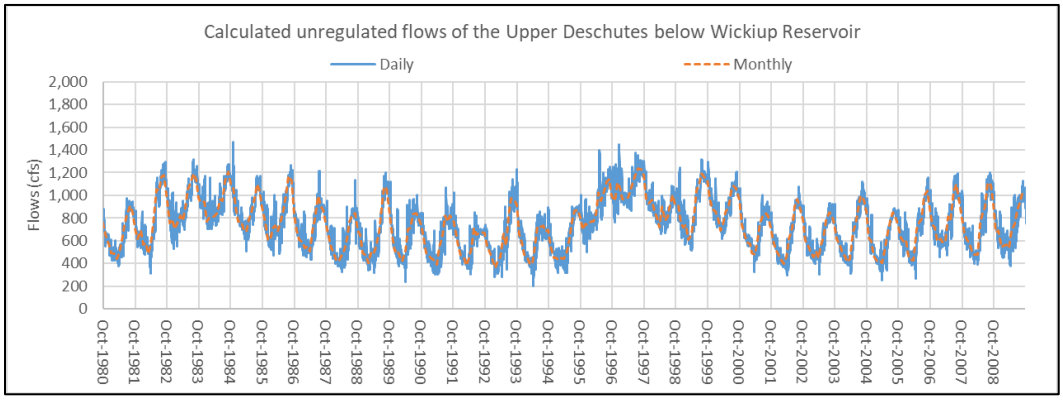

Figure 4. Seasonal and inter-annual variability for unregulated flows in the Deschutes River below Wickiup Reservoir (Reclamation 2018b).
This figure illustrates calculated variability in unregulated flows for the Upper Deschutes River (i.e., flows in the absence of reservoir storage and operations). The flows shown on the figure vary seasonally and from year to year. Data shown are 5-day moving averages for daily flows (blue) and monthly averages (orange).

Under current regulated flow conditions, water stored in reservoirs during the winter for irrigation use during the summer has resulted in lower winter streamflows and higher summer streamflows compared to natural or unregulated conditions in the Upper Deschutes River between Wickiup Reservoir and the City of Bend. The plot in Figure 5 illustrates calculated unregulated mean daily flow (blue) and modeled regulated mean daily flow (grey/black) at the Deschutes River at the Wickiup gage and is representative of current operating conditions in the Deschutes Basin. The shaded areas indicate the 20th to 80th percentile range of daily flow, and the solid blue and black lines show the medians.

Farther downstream below the City of Bend (about 60 river miles downstream of Wickiup Reservoir), summer irrigation diversions reduce flows in the Middle Deschutes River (which extends to Lake Billy Chinook; Figure 1); groundwater inputs then add to flows as the river nears the downstream limit of the study area. Tumalo Creek and Whychus Creek naturally experience low flows in the summer and fall that are accentuated by irrigation withdrawals.

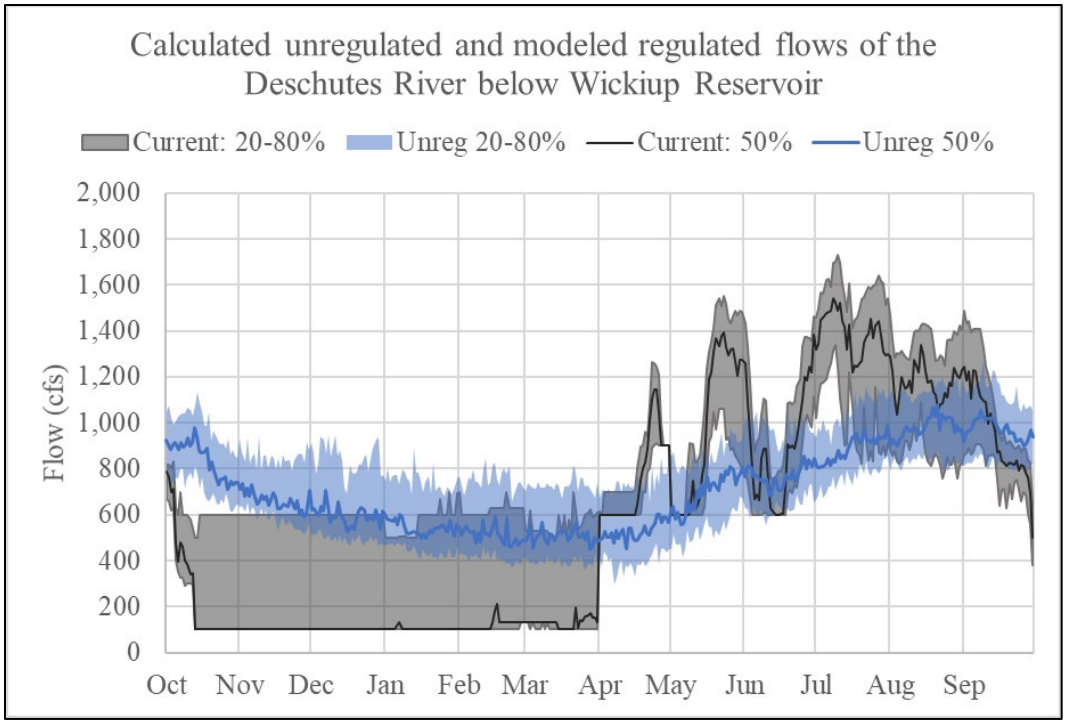

Figure 5. Effects of storage on Upper Deschutes River flows (Reclamation 2018b).
This figure illustrates how reservoir storage and operations tend to result in lower winter flows and higher summer flows in the Upper Deschutes River when compared to calculated unregulated flows. Data are shown for mean flows (50 percent) and ranges of flows (20th to 80th percentile range).

The Crooked River basin is a more typical snowmelt-dominated hydrologic system with a pronounced seasonal pattern of high flow during spring runoff and low flows in late summer. Figure 6 shows summarized unregulated mean daily flow (blue) and modeled regulated mean daily flow (grey/black) in the Crooked River below Bowman Dam, representative of outflow from Prineville Reservoir. The shaded areas indicate the 20th to 80th percentile range of daily flow and the solid blue and black lines show the medians.

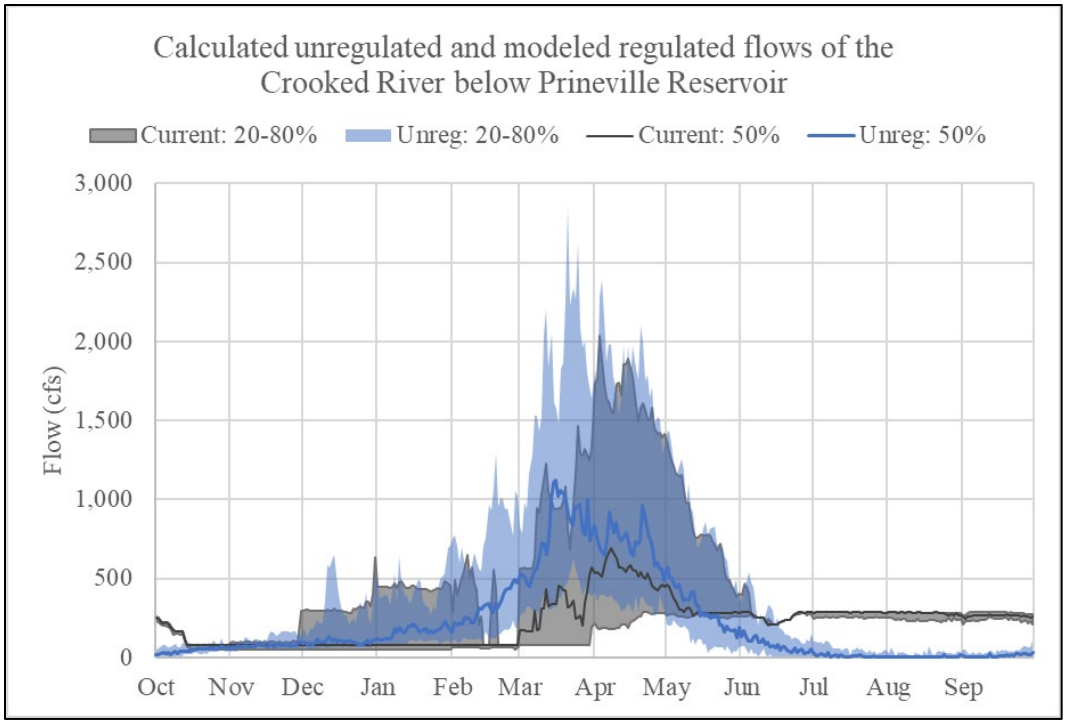

Figure 6. Crooked River flows (Reclamation 2018b).
This figure illustrates how flows in the Crooked River are typically higher during spring runoff and lower in late summer. Reservoir storage and operations tend to moderate flow variability when compared to expected unregulated flows. Data are shown for mean flows (50 percent) and ranges of flows (20th to 80th percentile range).

2.2 Assessment of Water Supply, Demand, and Distribution

The Basin Study evaluated hydrologic information and used water resources modeling to help quantify water supply shortages. As used in this report, the term *shortage* indicates a difference between a modeled water supply objective and the modeled water deliveries. Shortages were evaluated for instream and out-of-stream needs and varied with location, time of year, and modeled conditions.

Observed hydrologic data were used in hydrologic and water resources modeling to evaluate instream and agricultural water supply shortages for conditions representative of the current situation in the basin. Outcomes from this modeling are summarized in this section. Projected needs for municipal and quasi-municipal water suppliers were developed based on analyses of future demand and available supplies (Section 2.3). Ecological shortages relative to instream flows were also informed by flow-habitat and temperature assessments (Section 2.4). Large-scale climate change models were then used to help frame how future hydrology might affect shortages (Section 2.5). The modeling tools, approaches, assumptions, limitations, and results are described in detail in the associated technical memoranda (Reclamation 2018b and 2018c).

***WATER RESOURCES MODELING** USED RECORDED HYDROLOGIC DATA AND CURRENT RESERVOIR OPERATIONS, WATER RIGHTS, AND DIVERSIONS TO HELP QUANTIFY WATER SUPPLY SHORTAGES. MODELING ALSO PROVIDES A BASIS FOR TESTING DIFFERENT HYPOTHETICAL CONDITIONS AND EXPLORING POTENTIAL IMPACTS.*

For the Basin Study, model results were first used to evaluate and help quantify water supply and demand representative of current conditions. Shortages were evaluated for instream and out-of-stream needs and varied with location, time of year, and modeled conditions. The current-conditions modeling results for the Upper Deschutes River basin overall (Reclamation 2018b) indicate that:

- Total annual inflows to the basin (the Upper Deschutes drainage including the Tumalo, Whychus, and Crooked systems) vary from 860,000 acre-feet to 2.3 million acre-feet, depending on how much precipitation falls in a given year or sequence of years (estimates based on calculated unregulated flows in each sub-basin).
- Relative to an objective of meeting existing instream water rights established to support ecological objectives (including 300 cfs winter flows for the Upper Deschutes), instream demands experience median annual shortages of approximately 108,000 acre-feet. Those shortages may range up to 175,000 acre-feet in dry years.
- The average annual surface water diversion for irrigation districts totals approximately 720,000 acre-feet. Modeled irrigation district shortages total approximately 30,000 acre-feet in average or wet years and approximately 160,000 acre-feet in dry years.
- To meet higher flows that could contribute to broader ecological objectives in some reaches (including 600 cfs winter flows for the Upper Deschutes), total median shortages for instream and agricultural needs are modeled as approximately 200,000 acre-feet and could range up to 500,000 acre-feet in dry years.
- The current annual diversions for municipal and quasi-municipal purposes are derived primarily from groundwater and total approximately 40,000 acre-feet (GSI Water

Solutions, Inc. 2018e; see Section 2.3 below). It is anticipated that meeting all projected groundwater demands in the next 50 years will require approximately 21,000 acre-feet of permanent mitigation (water dedicated instream) to enable groundwater pumping. Of that amount, meeting projected 50-year demands specifically for cities and private water suppliers will require approximately 16,000 acre-feet of permanent mitigation (water dedicated instream). Because water for mitigation is dedicated instream, this water also contributes to addressing instream demands. Note that the Basin Study did not evaluate development and water use by rural domestic users on exempt wells.

2.3 Municipal and Quasi-Municipal Water Supplier Demands

The Basin Study included evaluations to better understand the current water use and future water needs of municipal and quasi-municipal water suppliers in the Basin; quasi-municipal water suppliers are entities other than a public corporation or a Federally recognized Indian tribe that supplies water for uses usual and ordinary to municipal water use. Since these types of future water supplies are anticipated to come from new uses of groundwater, the Basin Study evaluated the amount of mitigation credits the water providers would require under OWRD's Deschutes Basin Groundwater Mitigation Rules (Mitigation Rules) to allow their future uses of groundwater within the study area (GSI Water Solutions 2018e).

Future demand for mitigation credits was evaluated in terms of short-term (20-year) and long-term (50 year) projected demand for, and supply of, permanent mitigation credits (GSI Water Solutions, Inc. 2018e).

Projection of the short-term demand considered the following: existing permits that require mitigation but for which mitigation has not yet been provided; mitigation projected to be required for permits issued during the next 20 years; and mitigation requirements currently met with temporary credits, with the assumption that permanent credits would replace temporary credits (each permanent mitigation credit equates to 1 acre-foot of water legally protected instream).

*INCREASING **GROUNDWATER USES** IN THE BASIN – MUNICIPAL, INDUSTRIAL, COMMERCIAL, AND IRRIGATION – CAN REQUIRE MITIGATION, OFTEN BY DEDICATING WATER INSTREAM TO OFFSET GROUNDWATER PUMPING IMPACTS. WATER MANAGEMENT TOOLS EVALUATED IN THE BASIN STUDY CAN CONTRIBUTE TO MEETING GROUNDWATER MITIGATION NEEDS.*

The long-term demand for mitigation credits was estimated based on the mitigation projected to be required for permits issued from 2036 through 2065. This evaluation considered new municipal demand associated with use in the urban growth boundaries of the cities of Bend, Sisters, and La Pine, and new groundwater rights for other than municipal/quasi-municipal purposes (GSI Water Solutions, Inc. 2018e).

The evaluation concluded that there is an overall projected 50-year need for approximately 20,000 mitigation credits, the majority of which are for municipal and quasi-municipal water providers (GSI Water Solutions, Inc. 2018e). To put this in context, if all of this mitigation were generated by transferring existing surface water irrigation water rights instream, this would entail transferring water off of approximately 11,000 acres. This indicates that meeting the needs of municipal and quasi-municipal water providers will require the establishment of significant amounts of mitigation credits relative to the current supply.

2.4 Ecological Assessments and Instream Flow Demands

Existing state instream water rights, developed from Oregon Department of Fish and Wildlife (ODFW) applications, provided a starting point for understanding desired outcomes for restoring streamflows. To help refine desired outcomes for ecological benefits, the Basin Study included assessments of relationships between flows and habitat for the Upper Deschutes River for key species (River Design Group 2017) and relationships between flows, air temperature, and stream temperature for the Middle Deschutes River, Whychus Creek, and Tumalo Creek (Upper Deschutes Watershed Council 2016). In addition, modeling was completed to examine water temperature issues for Prineville Reservoir and the Crooked River downstream to Ochoco Creek (Portland State University 2017). The Basin Study habitat and water temperature assessments are described below. While instream water rights and the additional studies referenced in this report provide useful information for understanding flows needed to sustain key ecological functions, they do not represent a full accounting of instream needs or demands.

2.4.1 Habitat

An instream flow study was conducted as part of the Basin Study for two sites on the Upper Deschutes River below Wickiup Reservoir (i.e., Dead Slough and Bull Bend) to evaluate relationships between streamflow and instream/riparian wetland habitats. The methodology, supporting research, and results for this ecological assessment are presented in the corresponding technical memorandum (River Design Group 2017). The study considered weighted usable area (WUA) as a metric to evaluate the surface area having specific habitat suitability characteristics at various flow rates; WUA is a habitat suitability index that allows comparisons of localized habitat conditions in response to changes in river flows. Results provide information relevant to potential instream flow objectives for redband trout and the Oregon spotted frog in the Upper Deschutes River.

For redband trout, WUA curves developed for adult holding habitat at the Dead Slough and Bull Bend sites rise quickly as flows increase from low values up to 700 cfs; this type of relationship is illustrated in Figure 7. The results indicate that increases in streamflow in this range are associated with significant increase in usable habitat (River Design Group 2017). For flows above 700 cfs, the WUA curve for Bull Bend is much flatter while the WUA curve for Dead Slough declines, indicating minimal change in holding habitat with changing streamflows in this range (River Design Group 2017). In addition to suitable water depth and

velocity, the highest holding habitat values for redband trout require riparian vegetation, stream wood, or undercut banks. The habitat analysis did not include spawning or juvenile rearing habitat for redband trout. The Basin Study assessment looked at adult holding habitat for redband trout; similar, prior instream flow studies that helped inform ODFW recommendations relevant to instream water right applications addressed different trout species and habitat needs.

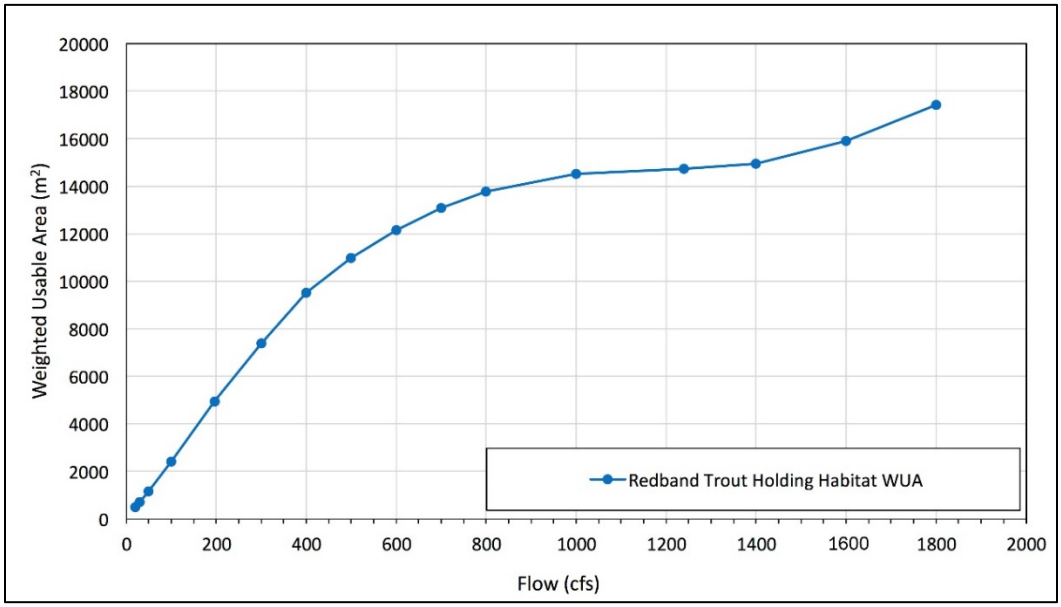

Figure 7. Redband trout holding habitat WUA for the Bull Bend site (River Design Group 2017).

For the Oregon spotted frog, modeling focused on two important life stages of the frog – overwintering and breeding (which occurs in the spring). Overwintering habitat is sensitive to substrate type, water depth, and water velocity. Under existing channel and wetland conditions, the total WUA for overwintering varies between sites, but in general increases with increasing water depth. As winter flows increase, more high-quality overwintering habitat is created along the margins of the river and in adjacent wetlands, while larger patches of low-quality habitat within the river channel become unsuitable (River Design Group 2017).

Desirable breeding habitat for the Oregon spotted frog is driven by water depth, water velocity, substrate composition, and proximity to vegetation. Under existing channel and wetland conditions, the WUA for breeding habitat varies between sites. In general, values remain relatively low with moderate increases up to flows of 800 cfs when water enters the sedge vegetation (grasslike plants that grow in wet conditions) for the studied locations. At this point, the rate of increasing suitable habitat for breeding is more variable, with changes in water depth and vegetation transitions driven by local topography (River Design Group 2017).

The riparian vegetation component of the study found that high summer streamflows were the limiting factor in the distribution of vegetation (specifically sedges) along channel margins and in wetlands at the two study locations (River Design Group 2017). This sedge

vegetation is an important component to all life stages of the Oregon spotted frog. With decreasing summer streamflow, sedge vegetation could expand into the river margins and wetlands. Analysis of breeding conditions for frogs under varying flows at the Dead Slough site (Table 2) suggests that increases in WUA are greater for flows in the 500-1,200 cfs range at that location (River Design Group 2017).

Table 2. Weighted Usable Area (WUA) Comparisons, Oregon Spotted Frog (River Design Group 2017)

Flow (cfs)	Breeding Habitat WUA, Dead Slough Site (m^2), Existing Condition	Breeding Habitat WUA, Dead Slough Site (m^2), Modified Summer Flow Condition	Change from Existing Condition to Modified Summer Flow Condition, Dead Slough Site
100	1,467	1,468	0%
200	1,410	1,410	1%
300	1,422	1,478	4%
400	1,731	1,876	8%
500	1,815	3,154	74%
600	2,074	3,906	88%
700	2,419	4,621	91%
800	2,793	4,709	69%
1,000	3,005	4,087	36%
1,200	3,679	4,457	21%
1,400	9,939	10,455	5%

The technical memorandum for the ecological assessment (River Design Group 2017) presents detailed information on methods, assumptions, inputs, and results for the evaluations of habitat suitability and river flows. Overall, the results of the flow/habitat studies provide context for projecting potential ecological benefits associated with various water management options (Section 4). As seen in the study results, conditions vary from site to site; the BSWG recognized that broad conclusions for an entire river system cannot be drawn from a study of two individual sites.

2.4.2 Water Temperature

Water supply shortages also affect instream ecological conditions related to water temperature objectives (e.g., higher-than-desired temperatures in summer and early fall months).

For the Deschutes River system, stream temperature analyses were completed by selecting one site each from Whychus Creek, the Middle Deschutes River, and Tumalo Creek to develop relationships among stream temperature, stream flow, and air temperature[1] during the irrigation season (Upper Deschutes Watershed Council 2016).

Regression analyses indicated that flow rates and air temperatures correlated with stream temperature, with better correlations seen for the months from April through July (Upper Deschutes Watershed Council 2016). Analyses of data for each location generated relationships indicating how flow increases correlated with decreases in stream temperature, and how different changes in air temperature correlate with changes in stream temperature. The outcomes help inform assessments of water management strategies, as described in Section 4.

For the Crooked River basin, a temperature model of Prineville Reservoir and the Crooked River was developed to explore the effects of potential water management approaches on water temperatures (Portland State University 2017). The CE-QUAL-W2 modeling tool (Cole and Wells 2016) was used to simulate flow, water level, and water temperature for both the reservoir and the river downstream to its confluence with Ochoco Creek. Analyses of various scenarios indicated that increasing releases from Prineville Reservoir can reduce water temperatures in the river between Bowman Dam and the City of Prineville by increasing river depth and reducing travel time for water moving downstream. The projected benefits of increased releases diminish by late summer due to decreased volume and increased water temperature within the reservoir. Management strategies could address whether or how it may be possible to preserve cooler water at the bottom of the reservoir later through the summer (Portland State University 2017).

2.5 Evaluation of Future Climate Conditions

Climate change models were used to evaluate climate conditions in the future (i.e., approximately 10 to 50 years out). Combinations of climate change models that used a range of emission scenarios (Representative Concentration Pathway emission scenarios 4.5 and 8.5) were used to develop projections that describe the potential trend in future climate conditions comparing the 2060s (2050 to 2079) to the historical period (1980 to 2009). Ten models representing similar conditions were combined for each of five projections: Less Warming-Wet (LWW), Less Warming-Dry (LWD), Median, More Warming-Wet (MWW), and More Warming-Dry (MWD). Those models are described in the associated technical memorandum (Reclamation 2018c) and indicate that:

- Future annual precipitation is projected to increase by approximately 5 percent based on climate change models for median projections. The climate projections suggest a

[1] It should be noted that air temperature is only one factor affecting streamflow temperature, and other factors were not addressed in this analysis.

potential range from a 3 percent decrease in annual precipitation to an 11 percent increase, respectively.

- Future annual average temperatures may increase by 2.8° C (4.9° F) based on climate change models for median projections. The climate projections for both drier and wetter trends suggest potential future annual average temperature increases ranging from 1.4 to 3.4° C (2.5 to 6.1° F).
- The climate projections also indicate that the timing patterns for precipitation may change in the future. Though there is wide variation in modeled future changes in precipitation, there is general agreement that winter precipitation may increase while summer precipitation decreases. To illustrate potential changes in precipitation, Figure 8 shows precipitation data for the five bounding climate change projections. Each of the climate change projections indicates an increase in temperature. This information indicates that changes in timing of precipitation, combined with higher temperatures, could shift runoff to earlier in the year on average, with higher winter and spring volumes and lower summer volumes (Reclamation 2018c).

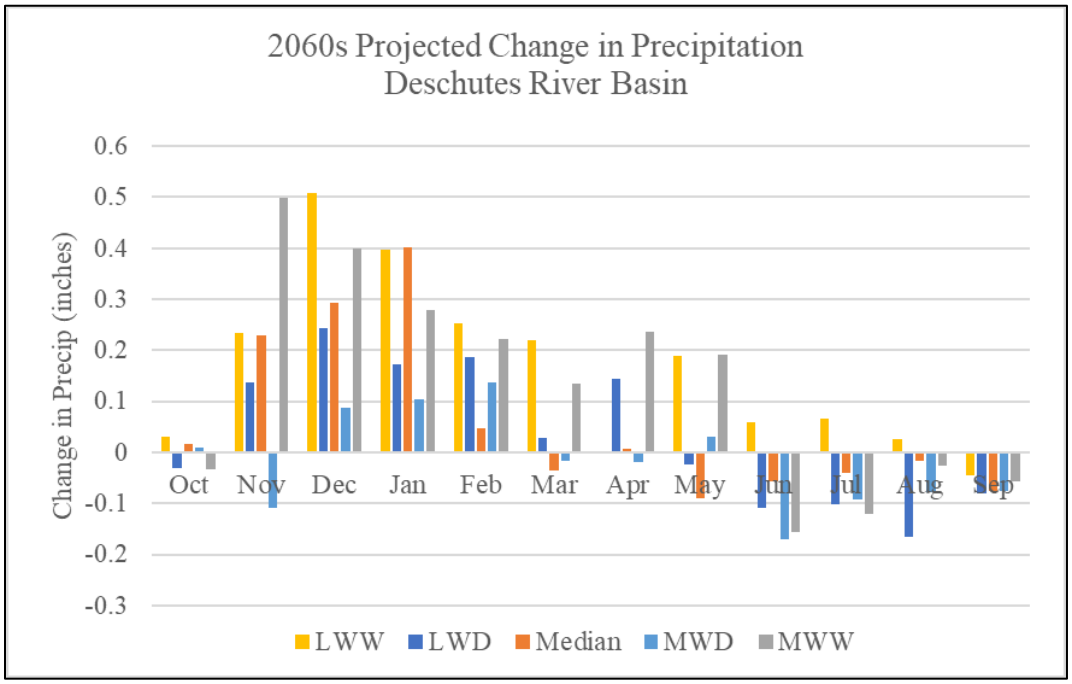

Figure 8. Potential future changes in precipitation (Reclamation 2018c).
To provide information for a range of potential future conditions, assessments of future climate conditions considered five bounding climate change projections; note that all of the projections indicate an increase in temperature. The projections are: Less Warming-Wet (LWW); Less Warming-Dry (LWD); Median; More Warming-Dry (MWD); and More Warming-Wet (MWW). The bars in this graph indicate the difference between historical average monthly precipitation and projected potential future precipitation for the thirty year period surrounding the 2060s (i.e., from the year 2050 to the year 2079).

In order to understand how potential climate changes may affect streamflow, hydrologic models are typically used to generate streamflows using temperature and precipitation as

input. After considerable effort devoted to calibration, running, and analyzing output from the available hydrologic models for the Upper Deschutes basin, it was decided that model performance was not sufficient to support meaningful quantitative conclusions about potential future changes in Deschutes hydrology. The performance issues are likely related to the complex groundwater-surface water interactions that are somewhat unique to the Upper Deschutes basin, compared to many other western basins (Section 2.1), and are described in detail in the technical memorandum for hydrologic analyses (Reclamation 2018b). However, the potential impacts on temperature, precipitation, and runoff timing can be used to qualitatively describe potential impacts on the current system:

- Increased winter and spring runoff volumes could increase the possibility of higher peak flows.
- Increased winter and spring runoff volumes could increase the likelihood that reservoirs would fill in the spring; however, demands on stored water could increase as noted below.
- Lower natural flows in the summer could increase reliance on stored water for those irrigation districts that use stored water.

Additional modeling could help to refine understandings of these impacts. The GSFLOW model developed by the U.S. Geological Survey (USGS 2017) is being updated, and forthcoming versions may provide a basis for use with the RiverWare water resources model developed for the Basin Study (Section 2.6) to provide more quantitative assessments of future hydrologic variability for the Upper Deschutes River. The GSFLOW hydrologic model has the most potential to develop representative flows for the Upper Deschutes basin because it simulates the groundwater-surface water interaction that other hydrologic models do not. Groundwater conditions in the Upper Deschutes basin have been investigated in other studies (USGS 2004; USGS 2013; Waibel et al. 2013) and this information is available to support more detailed assessments of groundwater issues.

Hydrologic model calibration using the PRMS model (USGS 2008; Reclamation 2018b) was sufficient to support assessment of potential impacts of future climate conditions on flows in the Crooked River basin and provides a tool that can help inform future water management activities. The PRMS model was considered to be appropriate for the Crooked River basin because this basin does not have the same complex groundwater interactions as the Upper Deschutes.

2.6 Study Approach

Based on identified water supply shortages, the Basin Study examined potential water management options that could help meet future needs in the basin. Desired outcomes for the Basin Study were to identify and evaluate options for addressing low and altered streamflows to benefit ecological conditions while maintaining or improving water supply

reliability and/or financial security for irrigated agriculture, and while planning to meet future groundwater mitigation needs for municipal, industrial, and commercial uses.

The BSWG conducted the Basin Study under the direction of a Steering Committee comprising approximately 40 representatives from the member organizations. Steering Committee meetings were held generally on a monthly basis and involved participation by other interested stakeholders. Public outreach efforts throughout the progress of the Basin Study included more than 30 presentations to stakeholder organizations and at public meetings, as well as media communications and a series of open-house presentations at different locations in the basin.

The BSWG established technical working groups to develop the Plan of Study (Reclamation 2015b) and to guide and monitor progress on study tasks. The BSWG hired a number of consultants to carry out specific study tasks, including hiring a technical director and a process coordinator who worked closely with the Reclamation study lead throughout the process. The BSWG Steering Committee established a smaller Planning Team, with representation from the three legs of the stool, to help guide decisions as study tasks progressed. Technical memoranda were developed for each of the study tasks to describe and document the detailed methods, inputs, and results. As summarized in Table 1, the technical memoranda helped clarify water management objectives, provided inputs for modeling and other analyses, and described opportunities and barriers associated with water management strategies.

Basin Study assessments of surface water supply and demand in the Upper Deschutes River basin were developed using the RiverWare modeling program (Zagona et al. 2001; Reclamation 2018b). This program allows representation of water management based on precipitation, streamflow, groundwater-surface water interactions, reservoir operations, diversions for water uses, and water rights. It provides a basis for determining how the many different water right priorities can affect flows and water availability/distribution. Developing the RiverWare model for the Upper Deschutes River basin was a significant effort involving staff from OWRD, the U.S. Fish and Wildlife Service, irrigation districts, Reclamation, and other BSWG member entities. The resulting model as developed for the Basin Study provides an updated foundation available to support future water management in the basin. Detailed information on the RiverWare modeling methodology, assumptions, inputs, and results are presented in the corresponding technical memorandum (Reclamation 2018b).

In addition to the RiverWare modeling and as described previously, other models developed or used for the Basin Study included hydrologic models, flow-habitat modeling of ecological conditions for two sites in the Upper Deschutes, simplified regression analyses of stream temperature issues, reservoir-stream temperature modeling of Prineville Reservoir and the Crooked River, and existing global climate change models of potential future climate conditions.

Using model results to improve and refine understandings of water supply and demand, the Basin Study evaluated water management options/tools in terms of their potential to help address water supply needs. In this report, the term *options* is used to indicate broad categories of water management approaches, while the term *tool* is used to indicate specific water management tools within the options. Water management options and related tools considered in the Basin Study involved:

- **Water Conservation** (Irrigation) – The water conservation option considered specific tools related to agricultural demands, including piping district canals, piping privately owned laterals, and on-farm infrastructure upgrades (e.g., flood-to-sprinkler shifts in irrigation). Water conservation can decrease irrigation demand in particular areas, making water available to meet other water needs in the basin and possibly increasing water security for other users.
- **Market-Based Approaches** – The market-based option considered the use of price incentives to promote efficient water use and reallocation of supply. Tools relevant to agricultural uses include temporary lease of water rights (fallowing acres on an annual basis), voluntary duty reduction (incentives to reduce water use per acre), and permanent sale of water rights (moving irrigation water rights permanently off acres). Market-based approaches can also decrease irrigation demand in one area, making water available to meet other needs in the basin and possibly increasing water security for other users. For example, market transactions can be used to move water from one irrigator to another irrigator or instream.
- **Enhanced/New Storage** – Enhanced and new storage facilities could potentially support improved streamflows by relocating existing storage (for the mainstem Deschutes River system) and/or restoring water storage capacity to a current reservoir (in the Crooked River system) to provide additional flexibility in water operations.
- **Other Options** – The Basin Study also evaluated tools involving adding snow telemetry stations to improve runoff forecasts, expanding gaging of diversions, and improving hydrologic forecasting methods.

These water management options are described in Section 3 of this report. Section 4 describes water resources modeling used to evaluate potential water management scenarios. The BSWG developed four hypothetical water management scenarios to examine the potential effectiveness of a range of approaches, from nearer-term and less-costly scenarios to longer-term and more-costly scenarios. The BSWG intended the scenarios to evaluate factors including how combinations of tools may work together, how concepts of moving senior water rights to junior water rights holders could help Upper Deschutes flows, and how flexible tools could effectively be scaled for use in dry years. Information about water management tools, derived from both the technical memoranda and from modeling of the four hypothetical scenarios, can support future decisions about water management to address identified shortages.

The BSWG acknowledged and agreed that the water management scenarios were examined on a hypothetical basis for informational purposes. Significant challenges may be associated with implementation, and some of the evaluated approaches may not be feasible under existing conditions, system configurations, or legal/policy constraints. As a result, Basin Study results should not be viewed as recommendations or endorsements of any particular approach or predictions of future conditions that are actually achievable, but rather as information to help inform future basin-wide efforts.

3. Water Management Options

The BSWG referenced prior planning efforts in the Upper Deschutes River basin (Deschutes Water Alliance 2006; Deschutes Water Planning Initiative 2013) to identify broad categories of water management options that could contribute to meeting water supply shortages. The Basin Study considered those options to identify and analyze specific tools that could be included in future water resource planning efforts. The following sections describe water conservation options, market-based incentives, options involving new or enhanced water storage, and other more focused approaches.

3.1 Water Conservation

Water conservation options for agricultural uses include actions that increase the efficiency of water delivery and use. Improving the infrastructure of irrigation water conservation has successfully restored flows in the Upper Deschutes River basin, with projects completed between 2004 and 2017 resulting in total flow restoration of more than 130 cfs (Deschutes River Conservancy 2018).

Irrigation water conservation tools that were evaluated in the Basin Study include[2]:

- Piping Canals – Opportunities for piping district-owned canals vary widely between and within irrigation districts. The estimated total opportunity for water conservation with this tool is approximately 200,000 acre-feet annually, with representative average

***WATER CONSERVATION OPTIONS** – PIPING DISTRICT CANALS, PIPING PRIVATELY-OWNED LATERALS, AND UPGRADING ON-FARM INFRASTRUCTURE – ARE PROVEN AS TOOLS FOR RESTORING FLOWS IN THE DESCHUTES. SIGNIFICANT ADDITIONAL OPPORTUNITIES EXIST, BUT PROJECT COSTS AND COORDINATION NEEDS WILL AFFECT WHAT CAN ACTUALLY GET DONE.*

[2] Studies funded by the Energy Trust of Oregon provided relevant information to support Basin Study assessments (Farmers Conservation Alliance 2017).

potential costs estimated to be on the order of $12,000 per acre-foot. The potential piping projects that the BSWG viewed as relatively more cost-effective have an estimated total opportunity of 120,000 acre-feet, with representative average potential costs of about $6,000 per acre-foot.

- Piping Private Laterals – Opportunities for piping private laterals, which typically convey water from district-owned canals to privately owned properties, were estimated for Central Oregon Irrigation District (COID) at a total opportunity of approximately 35,000 acre-feet, with average potential estimated costs on the order of $1,000 per acre-foot. The Basin Study used recently developed information for piping private laterals in COID (Farmers Conservation Alliance 2017); other districts also have private laterals, and piping approaches would be expected to involve similar costs.
- On-farm Infrastructure – On-farm infrastructure upgrades include approaches such as converting from flood irrigation to sprinklers. The Basin Study used recently developed data developed for COID and NUID (Farmers Conservation Alliance 2017). The estimated total opportunity for water conservation for COID and NUID with this tool is up to approximately 64,000 acre-feet annually, with average costs estimated to be on the order of $9,700 per acre-foot. Focusing on the approaches viewed as more cost-effective by the BSWG resulted in an estimated total opportunity of 30,000 acre-feet with representative average potential costs of about $4,000 per acre-foot.

Potential volumes and costs for water conservation tools, as evaluated and selected by the BSWG, are shown in Figure 9. The estimated total volumes are 120,000 acre-feet for piping of district-owned canals, 35,000 acre-feet for piping COID private laterals, and 30,000 acre-feet for COID and NUID on-farm infrastructure. Amounts for individual irrigation districts are summarized in Table 3. These values are high-level summaries based on assumptions and simplifications, as noted in the associated analyses (Farmers Conservation Alliance 2017; Watershed Professionals Network 2017), but are representative of potential infrastructure-related water conservation approaches in the Basin Study area.

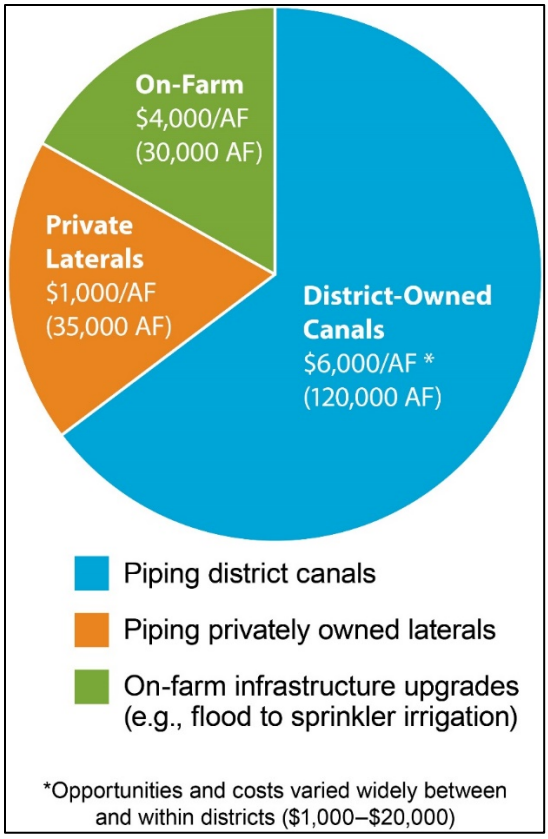

Figure 9. Estimated potential irrigation water conservation opportunities (Watershed Professionals Network 2017).

Table 3. Summary of irrigation water conservation potential and estimated costs (Watershed Professionals Network 2017).

Irrigation District	District-owned Canals			Private Laterals			On-farm Infrastructure Upgrades		
	Acre-Feet	Cost	Cost/ Acre-Foot	Acre-Feet	Cost	Cost/ Acre-Foot	Acre-Feet	Cost	Cost/ Acre-Foot
Arnold	11,000	$49M	$4,100	*	*	*	*	*	*
Central Oregon	89,000	$640M	$7,200	35,000	$36M	$1,000	48,000	$300M	$6,300
Lone Pine	1,900	$6.8M	$3,700	*	*	*	*	*	*
Ochoco	15,000	$260M	$17,000	*	*	*	*	*	*
North Unit	62,000	$1.4M	$22,000	*	*	*	17,000	$330M	$19,000

Irrigation District	District-owned Canals			Private Laterals			On-farm Infrastructure Upgrades		
	Acre-Feet	Cost	Cost/ Acre-Foot	Acre-Feet	Cost	Cost/ Acre-Foot	Acre-Feet	Cost	Cost/ Acre-Foot
Swalley	6,400	$16M	$2,400	*	*	*	*	*	*
Tumalo	18,000	$42M	$2,400	*	*	*	*	*	*
Three Sisters	500	$5.2M	$10,000	*	*	*	*	*	*
Total	200,000	$2.4B	$12,000	(Totals not provided as not all districts were evaluated)					

*Not evaluated in detail in this study; opportunities exist beyond those quantified in the table and will vary with each irrigation district.

Benefits associated with water conservation infrastructure approaches include the following:

- Irrigation conservation is a proven tool in the Upper Deschutes basin for increasing water supply.
- Upgrades to infrastructure improve management and operations.
- Infrastructure improvements do not affect the number or locations of irrigated acres.
- Piping canals and laterals increases opportunities for other tools such as water marketing.

Challenges or barriers associated with water conservation infrastructure approaches include the following:

- Piping district-owned canals is expensive.
- Some canal-piping projects have faced opposition to changing the nature of open, flowing canals that have been present for years.
- Some canals face land use policy barriers and historic designation barriers.
- Work on private laterals and implementation of on-farm upgrades requires action and/or agreement by multiple (often numerous) private parties.

Based on cumulative estimates for the three water conservation tools described above, the total opportunity for the more favorable water conservation infrastructure approaches is estimated to be about 185,000 acre-feet annually at an estimated average cost of $5,000 per acre-foot (Watershed Professionals Network 2017). An overall total volume of up to about 300,000 acre-feet may be available annually at higher costs (Watershed Professionals

Network 2017). It is recognized that canal piping involves potential landowner and legal challenges and additional cost factors that would be expected to affect implementation.

3.2 Market-based Incentives

Market-based water management options involve the use of price incentives to change water use behavior through actions such as leasing and water right transfers. The effectiveness of this type of approach for restoring flows in the Middle Deschutes River below Bend has been demonstrated by transfers that have resulted in 50 cfs permanently instream; some of this flow restoration has also been associated with establishing groundwater mitigation. Up to 75 cfs has been leased on an annual basis between 2004 and 2017 (Deschutes River Conservancy 2018). Market-based tools have also contributed to flow restoration in Whychus Creek, Tumalo Creek, Ochoco Creek, McKay Creek, and other stream reaches in the Deschutes basin.

***MARKET-BASED APPROACHES** USING PRICE INCENTIVES CAN PROVIDE WATER SUPPLY AT RELATIVELY LOW COST. LARGER VOLUMES OF WATER WOULD INVOLVE INCREASING COSTS. SOME APPROACHES MAY FACE POLICY, OPERATIONAL, AND OTHER CHALLENGES.*

Market-based tools evaluated in the Basin Study involved incentives based on the following approaches (Summit Conservation Strategies 2017):

- Temporary Leasing or Temporary Transfer of Water Rights – This approach involves fallowing acres on an annual basis to free up water for instream or out-of-stream uses.
- Voluntary Duty Reduction – Voluntary duty reduction would generate water through incentives to reduce the amount of water used per acre, although legal impediments to duty reduction in Oregon may limit the utility of this approach.
- Permanent Water Transfers – This approach involves the sale of water rights to permanently move irrigation water off of acreage to other acres or instream.

Water generated from market-based incentives could be moved from farm to farm or from farm to river. Additional work would be needed to explore and develop specific mechanisms and the institutional infrastructure needed to operationalize a large-scale market-based option.

The assessment of market-based approaches considered past leasing experience from DRC's water leasing program, results from an irrigation district patron survey, data from permanent water right transactions to date, and a literature review of tiered and other volumetric approaches to pricing water (Summit Conservation Strategies 2017).

Figure 10 illustrates the estimated aggregate water supply available by price for market-based tools, and Table 4 summarizes results from the assessment (Summit Conservation Strategies 2017). The outcomes indicate that while water supply may be available at relatively low cost, higher volumes of water would come at correspondingly higher prices – but still at a relatively low cost compared to other approaches. Benefits associated with market-based incentive approaches include:

- Temporary leasing and permanent transfers of water rights are tested approaches that have proven to be effective. Temporary leases can be used to generate temporary mitigation credits, and permanent transfers can be used to establish permanent mitigation credits for current and future groundwater use while also restoring streamflow.
- Water could be available in the near-term at relatively low costs.
- Temporary market-based tools are flexible and can be scaled in response to dry-year conditions.

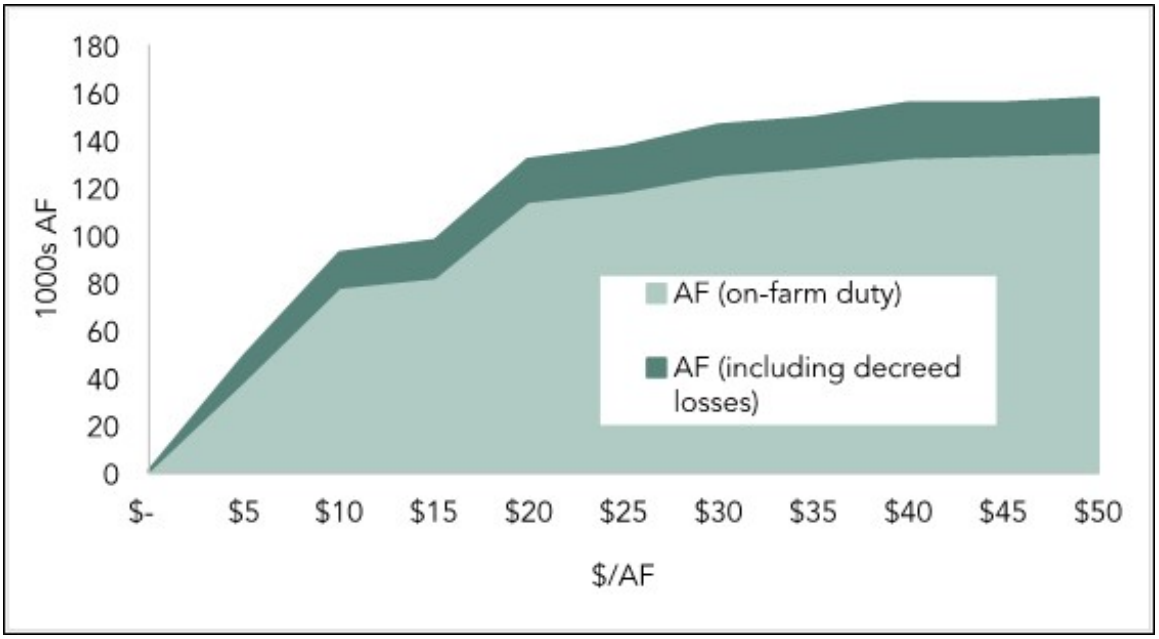

Figure 10. Estimated potential water supply available by price for market-based tools (Summit Conservation Strategies 2017).
Decreed losses reflect water lost to delivery system inefficiencies and represent the difference between a decreed diversion amount and the on-farm duty.

Table 4. Estimated water supply, market-based tools[1] (Summit Conservation Strategies 2017)

Price at or Below ($)			Estimated Potential Supply (acre-feet)	
Per Annual Acre-foot	Per Permanent Acre-foot	Cubic Feet Per Second	On-farm Duty	Including Decreed Losses
No cost (donation)	--	--	860	1,100
5	91	33,000	39,000	49,000
10	180	65,000	78,000	93,000
20	370	130,000	115,000	132,000
30	550	196,000	126,000	150,000
50	910	326,000	135,000	160,000

[1] Analysis assumed a discount rate of 5 percent.

Challenges or barriers associated with market-based approaches include:

- Irrigation district operational issues ("carry water") associated with leasing/transferring larger quantities of water may limit this tool's viability in some locations.
- Leasing and transfers have a state legal framework, but in most cases, irrigation districts would need to revise or develop new policies and programs to optimize these options. For example, current policy for irrigation districts in the basin is to not reduce their water right certificates by permanently transferring water instream; many districts also have constraints on instream leasing.
- In some cases, legal changes may be required to realize the full potential of market-based approaches.
- Costs may increase during implementation due to the need to coordinate with multiple private parties.

In summary, the total opportunity for market-based incentives is estimated to be up to 160,000 acre-feet annually at an estimated average potential cost on the order of $400 per acre-foot (Summit Conservation Strategies 2017). These approaches involve challenges and additional cost factors that would be expected to affect potential implementation (Section 4.5), but they could be used in a portfolio of water management tools and help with adaptively managing water to respond to variable water supply.

3.3 Storage

The Basin Study evaluated potential approaches for managing water storage for existing reservoirs in the Upper Deschutes basin, and the possibility of developing new, expanded, or enhanced storage facilities to help address water supply shortages. The objective for considering these water management tools was to explore the potential for additional

operational flexibility that could benefit instream flow conditions. These evaluations are described below.

3.3.1 Managing Existing Storage (Water Movement)

The Basin Study included evaluation of potential water right opportunities to manage Upper Deschutes basin reservoirs to increase streamflow outside of the irrigation season (GSI Water Solutions, Inc. 2018d).

Reservoirs in the Upper Deschutes basin (Wickiup, Crane Prairie, and Cresent Lake Reservoirs) are generally filled during the period outside of the irrigation season. To facilitate filling the reservoirs, flow released below the dams is limited during this period and can significantly reduce flows that benefit downstream ecological functions. During the irrigation season, water is released from the reservoirs to meet the needs of water users holding water rights for the use of the stored water. The Upper Deschutes River is used to convey the water to where it is diverted and used. This release of water can result in streamflows that are higher below the dams during the irrigation season than flows would have been prior to dam construction. Water rights mechanisms, such as the movement of conserved water and/or water rights to NUID (as a junior water rights district with lands located downstream in the basin) in exchange for storage releases, could potentially provide opportunities for managing storage differently to help address instream flow and other Basin Study objectives (GSI Water Solutions, Inc. 2018d).

Storage and use of water in the Upper Deschutes basin is in accordance with Oregon water rights, as well as Federal authorizations and requirements relative to the Federal Deschutes Project and Crooked River Project authorizations. Changed operations involving storage and use of water in Wickiup and Crane Prairie Reservoirs for purposes such as instream, or fish and wildlife, uses may require legislative changes to relevant Federal authorizations and may involve associated Endangered Species Act considerations, as well as consideration of Oregon State law and policy.

The BSWG Steering Committee considered potential short-term mechanisms associated with water rights to use stored water that may be able to facilitate water movement without requiring Federal legislation. These mechanisms include: surplus storage (sale of surplus water for non-irrigation purposes that may be possible under specific conditions); forbearance of stored water, per agreement by the storage rights holder; and retaining stored water to maintain minimum pools in reservoirs, per agreement by the storage rights holder (GSI Water Solutions, Inc. 2018d).

The current authorization for Wickiup Dam and Reservoir limits the use of the reservoir for instream purposes to the amount required for NUID to participate in water conservation programs under Oregon State Law. It may be possible to execute additional leases or transfers if legislation were to authorize the use of the dam and reservoir for instream purposes generally. Potential long-term mechanisms that could facilitate water movement associated with water rights to store water could also involve: supplementing

flows by leasing (5-year increments) or transferring (permanent or time-limited) storage water rights to be used instream, subject to resolution of Federal authority issues; and transferring storage water rights instream (permanent or time-limited), subject to resolution of Federal authority issues, as well as statutes and rules at the state level.

In addition to increasing streamflow outside of the irrigation season, leasing or transferring a storage right instream could potentially provide a basis for establishing mitigation credits under OWRD's Deschutes Basin Ground Water Mitigation Program. If approved, a permanent transfer of a storage water right could be used to establish permanent mitigation credits. If the transfer were time-limited, this type of project would establish temporary credits.

Legal (both state and Federal authorities), policy, and other obstacles limit the current feasibility of some of the potential water movement tools described above. However, the BSWG Steering Committee determined that it is beneficial to consider hypothetical approaches to help inform future water management planning. Such hypothetical approaches were evaluated on an informational basis in scenarios developed for modeling analyses (Section 4.1).

3.3.2 Enhanced/New Storage Facilities

The BSWG identified an opportunity to potentially improve streamflows by moving locations of existing water storage and/or restoring water storage capacity to enhance flexibility in water operations (Reclamation 2018d). For the Upper Deschutes River, the Basin Study explored concepts to move a portion of the existing storage in Wickiup Reservoir to potential off-channel storage sites closer to NUID agricultural lands. These concepts focused on NUID as a junior water rights district with lands located downstream in the basin.

> ***NEW OR ENHANCED WATER STORAGE*** *FACILITIES COULD HELP IMPROVE STREAMFLOWS BY RELOCATING EXISTING STORAGE AND/OR ADDING CAPACITY TO PROVIDE FLEXIBILITY IN WATER OPERATIONS. STORAGE PROJECTS WOULD BE VERY EXPENSIVE AND YEARS OF STUDY WOULD BE REQUIRED.*

Several off-channel storage concepts were examined in the Upper Deschutes River system to evaluate the potential range of storage capacities and how water operations might be improved. The assessments were completed at an early planning level intended to inform stakeholder consideration of storage as a possible long-term component for future water management (Reclamation 2018d). All information was pre-decisional, and no project or plan is recommended or proposed; years of investigation would be needed before any particular project could be advanced, and numerous local, state, and Federal permits and approvals would be required before any project could be implemented.

The Basin Study identified several locations where off-channel storage facilities could potentially provide storage volumes ranging from less than 5,000 to approximately 70,000

acre-feet (Figure 11). Storing some water in the winter at one or more off-channel facilities located farther downstream, rather than storing that particular volume of water at Wickiup Reservoir, could increase winter flows in the Upper Deschutes by an average of roughly 15 to 200 cfs. Storing water at one or more new facilities would involve using the NUID Main Canal to convey water and then pumping to raise water up to the new storage site(s). Stored water would then be released from the new facility for use by NUID during the irrigation season (Reclamation 2018d).

Based on prior studies of other storage concepts (Reclamation 2018d), potential construction costs could range from $30 million for a smaller facility (less than 5,000 acre-feet) to more than $300 million for the scale of the larger facilities considered (Table 5). Ongoing costs after construction would include power costs for pumping water into, and in some cases from, new storage facilities. Power costs would be dependent on many concept-specific factors but may be $1 million or more annually. Significant additional costs would be incurred for other elements of any new storage project, such as: land acquisition; environmental impacts and mitigation; engineering design to address site-specific conditions; existing utilities, road, and other infrastructure; historic properties; cultural resources; permitting; and other issues (Reclamation 2018d).

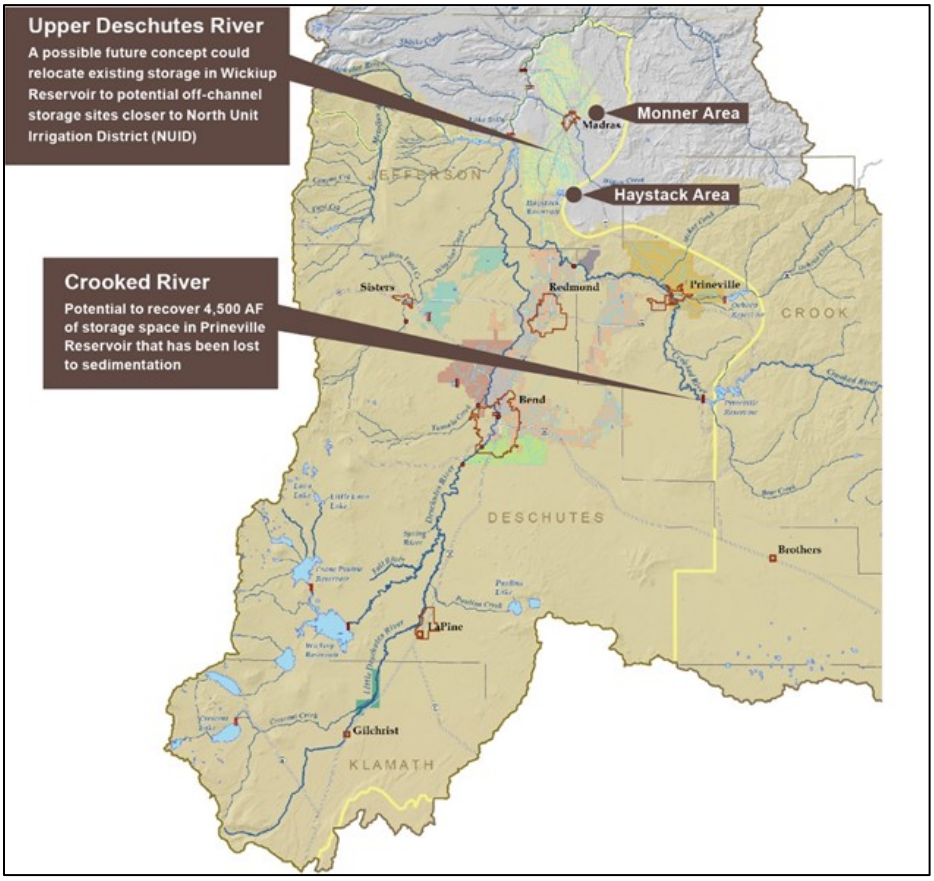

Figure 11. Potential enhanced/new storage locations (Reclamation 2018d).

For the Crooked River basin, the Basin Study looked at the potential for restoring approximately 4,500 acre-feet of storage space in Prineville Reservoir that has been lost to sedimentation (Reclamation 1999). The concept involves installing a spillway gate at A. R. Bowman Dam to allow controlled storage at elevations of up to 1.5 feet higher than is possible with the current facilities (Figure 12). The ability to recover this storage space could allow more flexibility in water operations to the benefit of instream ecological conditions downstream of Prineville Reservoir. Based on similar projects, construction costs could be $1 million or more. The viability of this approach may depend on the project being considered as restoration of existing storage capacity and thus not meeting the definition of increased storage, such that ODFW fish passage requirements would not apply; other waiver/exemption approaches could also be explored. Additional permitting issues, dam safety considerations, and potential impacts would also need to be addressed (Reclamation 2018d).

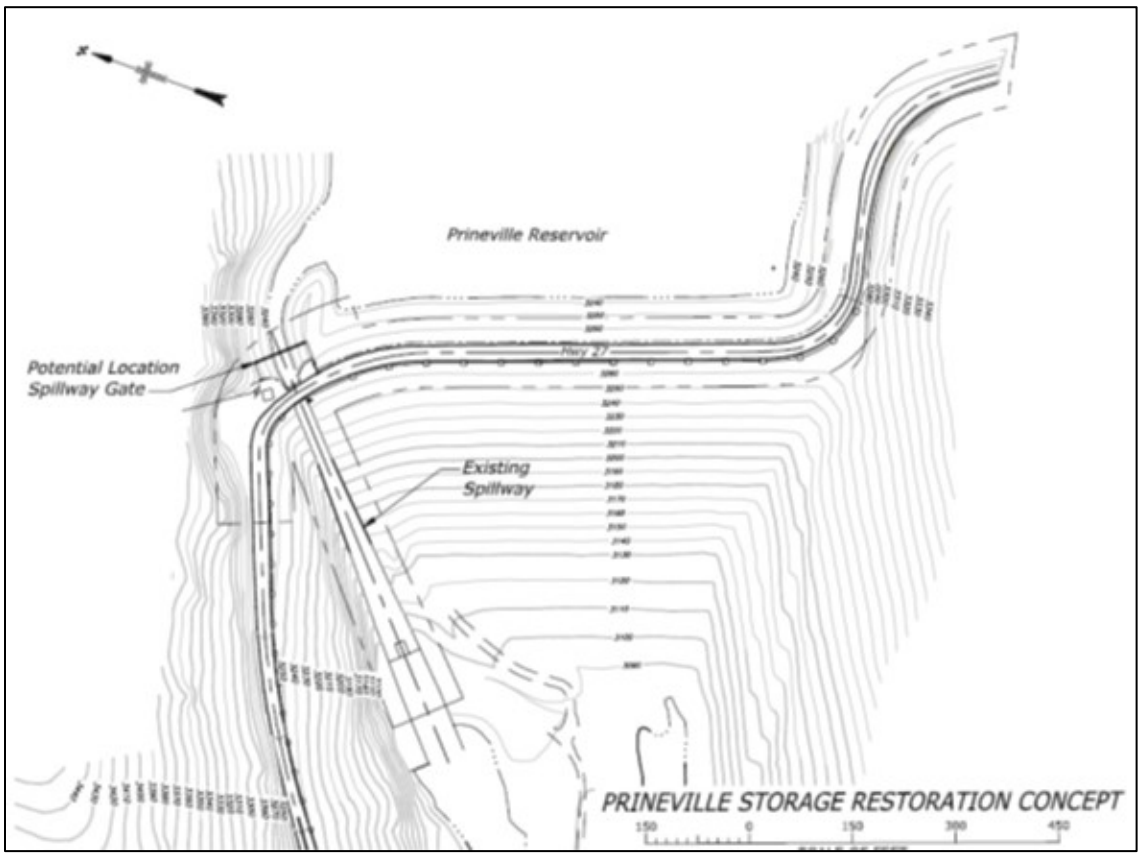

Figure 12. Prineville storage restoration concept (Reclamation 2018d).

Table 5. Potential concepts for enhanced/new storage (Reclamation 2018d).

Concept	Description	Potential Additional Storage Volume	Cost Factors	Other Factors
Prineville Storage Restoration	Regain storage capacity lost to sedimentation in Prineville Reservoir; spillway gates would be constructed to allow storage at higher elevations; could provide additional operational flexibility relative to Crooked River legislation objectives.	Approx. 4,500 acre-feet for gates that would allow water storage approx. 1.5 feet above current reservoir elevations.	Construction options likely to be relatively straightforward, with potential construction costs around $1 million; permitting, water rights, dam safety, and security issues would add to costs.	The viability of this concept may be largely dependent on whether storage is viewed as restoration of existing capacity, or as new storage (potentially triggering fish passage requirements); lands and recreation facilities would be affected.
Monner Area – Potential New Off-Channel Storage	New off-channel dam located east of Madras that could serve NUID lands; storage would be in lieu of storing particular volumes at Wickiup to help address winter flow objectives in the Upper Deschutes River.	Potential storage volumes could range from approx. 20,000 to 70,000 acre-feet; water would flow in the Upper Deschutes, outside of irrigation season, to a diversion in Bend; the NUID Main Canal would convey water, with pumping up to reservoir.	Concept would likely involve an earthfill dam with associated dikes; significant pumping would be required to get water from the NUID Main Canal to the facility; large-scale transmission lines and pipelines are present; estimates for similar-scale projects suggest construction costs could be $100 million to more than $300 million; power costs would be dependent on many concept-specific factors but may be $1 million or more annually.	Canal operations outside of irrigation season would be limited during freezing weather; pumping costs would be significant; land acquisition, environmental impacts, permitting, existing utilities, etc., would need to be investigated and would add significantly to potential costs.

Concept	Description	Potential Additional Storage Volume	Cost Factors	Other Factors
Haystack Area – Potential New or Expanded Storage	A new off-channel dam located just up-valley of the existing Haystack Dam and/or expansion of the existing Haystack Dam; could serve NUID lands via storage in lieu of storage at Wickiup to help address winter flow objectives in the Upper Deschutes River.	Potential storage volumes could range from less than 5,000 acre-feet to 40,000 acre-feet; additional water would flow in the Upper Deschutes, outside of irrigation season, to a diversion in Bend; the NUID Main Canal would convey water, with pumping up to reservoir.	Concept would likely involve a new earthfill dam and/or an earthfill raise to the existing dam; significant pumping would be required to get water from the NUID Main Canal; private/historic properties, transmission lines are present; estimates for similar scale projects suggest construction costs could be $100 million to more than $300 million; power costs would be dependent on many concept-specific factors but may be $1 million or more annually.	Canal operations outside of irrigation season would be limited during freezing weather; pumping costs would be significant; land acquisition, environmental impacts, permitting, existing utilities, etc., would need to be investigated and would add significantly to potential costs.
Other Areas for Potential New Storage	Other locations may also be topographically suitable for new off-channel storage; stored water could serve NUID lands in lieu of storage at Wickiup.	Other potential opportunities are likely to be at the lower end of the 5,000- to 70,000-acre-foot range (the BSWG Storage Assessment Working Group did not identify other promising large-scale potential opportunities).	Construction costs would vary with facility size and location specifics; recent data suggest that smaller-scale projects (less than 5,000 acre-feet) could involve construction costs of $30 million.	Water conveyance to a new reservoir would likely involve limited canal operations outside of irrigation season as noted above; pumping costs would likely be incurred for any off-channel concept; land acquisition, environmental impacts, permitting, existing utilities, etc., would need to be investigated and would add significantly to potential costs.

3.4 Hydrologic Forecasting and Measurement

The Basin Study included assessments of specific opportunities for improving hydrologic forecasts and diversion measurement as identified by the BSWG. These approaches could

improve water management efficiencies and contribute to reducing water supply shortages consistent with study objectives.

An assessment of hydrologic forecasting (Watershed Professionals Network 2016) indicates that under historical operations (e.g., minimum winter releases from Wickiup Reservoir of 20 cfs), managing more to an inflow forecast could significantly increase November-through-February streamflow in most years. However, under operations involving mandated higher winter releases, the utility of forecasting in facilitating higher winter flows would be decreased. The hydrologic forecasts themselves could potentially be improved by approaches such as implementing aerial snow observations and other measures to collect additional snowpack data, evaluating the accuracy of current forecasting methods, and incorporating hydrologic modeling in developing runoff forecasts (Watershed Professionals Network 2016).

*ENHANCEMENTS TO **HYDROLOGIC DATA COLLECTION AND ANALYSIS** COULD HELP WATER MANAGERS IMPROVE OPERATIONAL EFFICIENCIES TO LEAVE MORE WATER IN STREAMS.*

The Basin Study specifically examined potential opportunities for improving hydrologic forecasting through adding snow telemetry (SNOTEL) stations in the Upper Crooked River basin (Reclamation 2016). Six potential sites were identified based on locations and elevation ranges that currently lack snowpack condition data. Data from additional SNOTEL stations could help improve runoff volume forecasts for Prineville and Ochoco Reservoirs, supporting more efficient water resource management (Reclamation 2018e).

Also in the Crooked River basin, water management efficiencies could be gained by installing additional gaging on Crooked River diversions below Prineville Reservoir (Reclamation 2018f). This approach could provide water managers with additional real-time data about diversions to help reduce operational losses and support improved decision-making about releases from Prineville Reservoir and state management of existing water rights. The potential for improving gaging information was identified for five existing diversion locations (Reclamation 2018f).

Potential costs for hydrologic forecasting and measurement tools are addressed in the corresponding technical memoranda, as referenced above. These approaches were not amenable to analysis using water resources modeling completed for the Basin Study but provide relatively lower-cost tools that can be considered for future water management in the basin.

3.5 Surface Water/Groundwater Exchanges

Seasonal low streamflow is often a limiting factor for water quality and fisheries in Whychus Creek. Although recent water conservation and other projects have restored streamflows in the reach below the Three Sisters Irrigation District (TSID) diversion, Whychus Creek is still

flow-limited during late summer months and experiences water quality challenges in the summer season. The use of groundwater instead of surface water during certain years or certain times of the year may offer opportunities for further streamflow restoration in the Whychus Creek basin. Any actions in the Whychus Creek basin regarding more flexible management practices to restore streamflows and alleviate temperature impairments through groundwater use would require additional hydrogeologic evaluations and coordination with OWRD and basin stakeholders (GSI Water Solutions, 2018f).

3.6 Summary of Water Management Options

The water management options described in Sections 3.1 through 3.3 are summarized in Table 6 in terms of potential water supply opportunities and estimates of associated potential costs.

Table 6. Summary of water management options.

Water Supply Option	Estimated Potential Opportunity (acre-feet)	Estimated Cost	Estimated Average Cost per Acre-foot
Water Conservation Infrastructure (Irrigation)	185,000	$990 million[1]	$5,000[1]
Market-based Incentives	160,000[2]	$65 million[2]	$400[2]
Enhanced/New Storage	40,000[3]	$200 million[3]	$5,000[3]

[1] Total estimated opportunity/cost representative for the relatively more cost-effective water conservation infrastructure tools; note that these totals include piping private laterals for COID only and on-farm infrastructure improvement values for COID and NUID only. Potential barriers such as land use regulations, historic designation, and local opposition would result in higher costs for canal piping.

[2] Evaluation of market-based incentives is at a planning level; opportunities may be limited by factors such as district operational issues (carry water) associated with leasing/transferring larger quantities of water and policy/program challenges. Costs may increase due to the need to coordinate with multiple private parties.

[3] Total estimated opportunity/cost representative for a generalized mid-range volume storage concept for the Upper Deschutes basin; assumed potential cost is representative for construction costs only.

4. Assessment of Water Management Options

Based on the water management options and specific tools described in Section 3, the BSWG developed hypothetical water management scenarios for use in modeling to evaluate how various water management tools might work together to meet water management objectives. The scenarios were designed to provide a range of information to help assess a variety of potential approaches and, as such, were specifically not intended to be perceived as implementation plans or prescriptive in nature. The scenario modeling approach and results

are described in Section 4.1. Sections 4.2 and 4.3 describe multi-criteria evaluations of a range of water management options.

The scenario modeling was intended to provide additional information to help inform BSWG evaluations. The BSWG acknowledged that the scenarios themselves may not necessarily be implementable, realistic, advisable, or desired, and that existing legal, technological, and/or financial impediments to various aspects of the scenarios may exist. The BSWG also acknowledged that some of the modeled water management objectives, such as instream flow targets, are approximate and/or hypothetical and may be subject to refinement based on future studies.

4.1 Modeling Approach and Results

Water resources modeling using the RiverWare program (Reclamation 2018b) provided quantified estimates of shortages under current operational approaches and hydrologic conditions ranging from dry to wet years (Section 2.2). These results were used as a basis for comparison to evaluate the potential effectiveness of four water management scenarios in meeting water management objectives. The objectives and water management tools considered for each scenario are summarized in Figure 13.

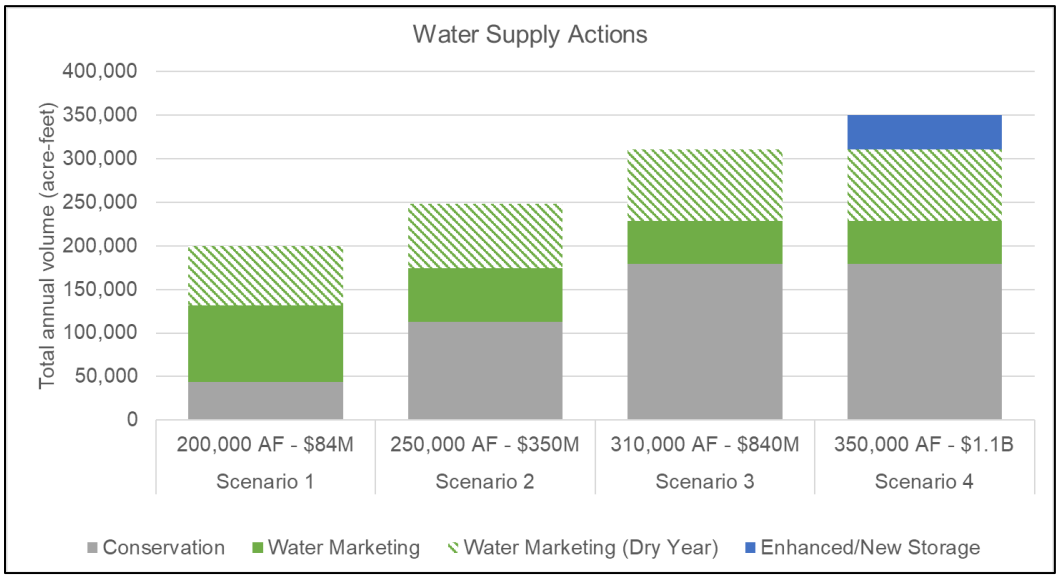

Figure 13. Hypothetical water management scenarios; the bar chart shows total annual volumes of assumed irrigation demand reductions using varying combinations of water management tools.

The model objectives in the four hypothetical scenarios included the objectives of attempting to meet irrigation demands and attempting to meet increased instream flow objectives (Reclamation 2018b). The specified irrigation demands were reduced in each scenario by assuming the successful use of a combination of water management tools. Some of the water management tools assumed for the scenarios could potentially be used for generating groundwater mitigation for municipal and quasi-municipal water providers; however, the

amount of potential mitigation was not quantified due to current uncertainties about tools that can be used to establish mitigation. The water management objectives guiding the scenario analysis involved the following factors:

- The BSWG agreed to evaluate different specified model flow objectives, involving meeting instream flows of 300 cfs and 600 cfs winter flows for the Upper Deschutes River; 33 cfs summer flows for Tumalo Creek; 33 cfs and 45 cfs summer flows for Whychus Creek; and 80 and 140 cfs summer flows for the Crooked River. Although the scenarios prioritized flows for the Upper Deschutes River, consideration was also given to contributing toward 250 cfs for the Middle Deschutes River by designating 10 percent of additional flows for the Middle Deschutes.
- Improving NUID water supply reliability relative to its status as a junior water rights district. Current annual shortages for NUID are 30,000 acre-feet on average and 100,000 acre-feet during dry years.
- Although the modeled scenarios do not specifically quantify the amount of water made available to meet the projected groundwater mitigation needs of municipal and quasi-municipal water suppliers (21,000 acre-feet), qualitative analyses in the Basin Study describe potential options for establishing mitigation.

The combinations of assumed water management tools, estimated costs, and modeled flow objectives for each scenario are summarized below.

Water Management Scenario 1 was designed to attempt to meet instream water rights for ecological objectives (i.e., an assumed Upper Deschutes model flow objective of 300 cfs). The suite of water supply options assumed for Water Management Scenario 1 involved water rights leasing, duty transfers, and water rights transfers, as well as piping private laterals. For the Crooked River basin, this scenario assumed reduced irrigation demand through instream leasing and an 80 cfs model flow objective. Representative costs for the water management options included in Scenario 1 were estimated to be on the order of $84 million, and the overall reduction in irrigation demand, based on the assumed suite of water supply options illustrated in Figure 13, was about 200,000 acre-feet.

Water Management Scenario 2 involved the same assumed Upper Deschutes model flow objective of 300 cfs but with more extensive and more costly water conservation infrastruture approaches. Representative costs for the water management options included in Scenario 2 are therefore higher than for Water Management Scenario 1 (i.e., approximately $350 million). The assumed suite of water supply options illustrated in Figure 13 resulted in an assumed overall reduction in irrigation demand of about 250,000 acre-feet.

Water Management Scenario 3 was designed to attempt to meet higher instream flow objectives that could contribute to ecological benefits for certain reaches (i.e., an assumed Upper Deschutes model flow objective of 600 cfs). This scenario included a 140 cfs model flow objective for the Crooked River. The water supply options assumed for Scenario 3 involved maximizing potential water conservation and water marketing options.

Representative costs for the suite of options included in Scenario 3 were estimated to be $840 million, and the assumed suite of options reduced overall irrigation demand by about 310,000 acre-feet.

Water Management Scenario 4 involved the same assumptions as Scenario 3, but with the additional consideration of a new Upper Deschutes storage concept having a representative capacity of 40,000 acre-feet, and the 4,500 acre-foot storage restoration concept in the Crooked River system. Representative costs for the water management options included in Scenario 4 were estimated to be $1.1 billion for a reduction in overall irrigation demand of about 350,000 acre-feet.

As noted previously, all scenarios assumed that a portion of Upper Deschutes flow resulting from the assumed reduction in irrigation demand would be left instream to support Middle Deschutes River flow objectives.

EVALUATIONS OF HYPOTHETICAL WATER MANAGEMENT SCENARIOS ASSUMED DIFFERENT ***COMBINATIONS OF WATER MANAGEMENT TOOLS*** *THAT COULD REDUCE IRRIGATION DEMANDS AND HELP CONTRIBUTE TO INSTREAM FLOW OBJECTIVES. MODELING OUTCOMES INDICATE THAT THE FULL SUITE OF POTENTIAL TOOLS WILL NEED TO BE CONSIDERED TO ADDRESS SHORTAGES FOR BOTH INSTREAM AND OUT-OF-STREAM NEEDS.*

Modeling results for the four water management scenarios are summarized in Figures 14 through 22 relative to model river flow objectives and to the ability to meet reduced irrigation demands at different locations in the Upper Deschutes basin. The results presented here are highly summarized; more detail on the timing, volume, and frequency of shortages in specific reaches is available in the technical memorandum on hydrologic and water resources modeling (Reclamation 2018b).

The bar heights in the figures indicate calculated model flows and assumed flow objectives for critical time periods. Hollow boxes indicate where flows did not reach the model objective during the critical time period (i.e., where a projected shortage would occur). Outlined boxes indicate situations in which modeled flows in the river reach exceeded model flow objectives.

For the Upper Deschutes, the results in Figure 14 indicate that the model flow objective of 300 cfs would be met if all the demand reductions incorporated in Scenarios 1 and 2 could be achieved (Reclamation 2018b). If the additional assumed demand reductions for Scenarios 3 and 4 could be achieved, the higher model flow objective of 600 cfs could be met much of the time (i.e., it could not be achieved in some dry years). For the Middle Deschutes, Figure 15 shows that the four scenarios, if successful, could result in progressively improved outcomes toward achieving 250 cfs in that reach.

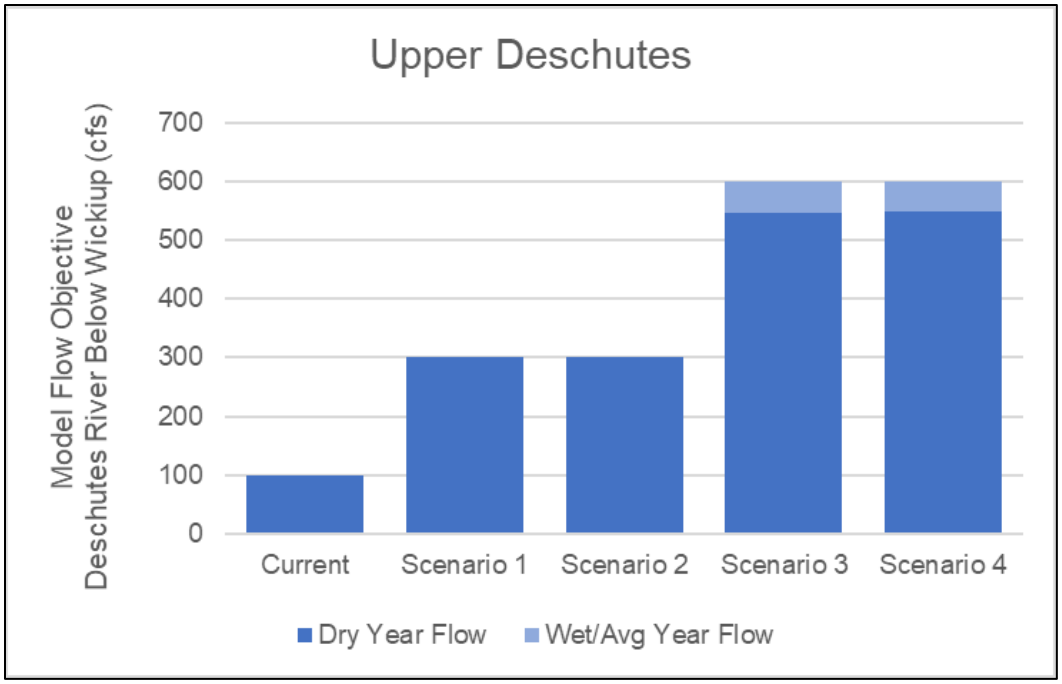

Figure 14. Model flow outcomes, Upper Deschutes River (winter streamflow; Reclamation 2018b).

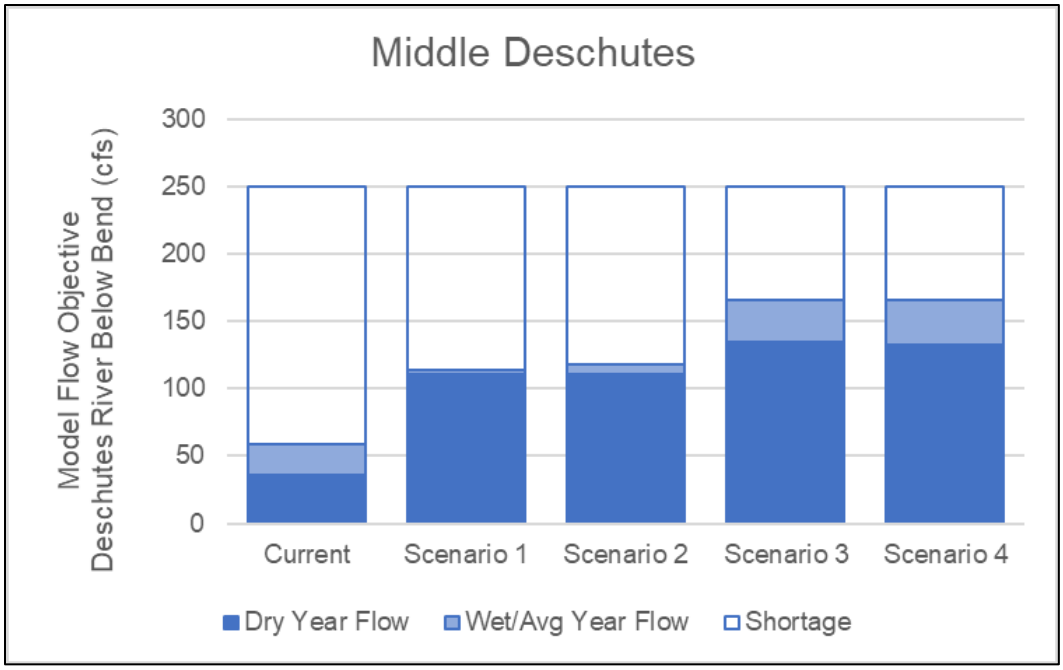

Figure 15. Model flow outcomes, Middle Deschutes River (summer streamflow; Reclamation 2018b).

Model results for irrigation demands in the Upper Deschutes are shown in Figure 16 (Reclamation 2018b). The total heights of the bars in the chart decrease progressively as additional demand reductions are assumed for Scenarios 1 through 4. The model results show that irrigation shortages could generally be avoided if all of the hypothetical reductions

in irrigation demand could be achieved except for some dry year shortages shown for Scenario 1.

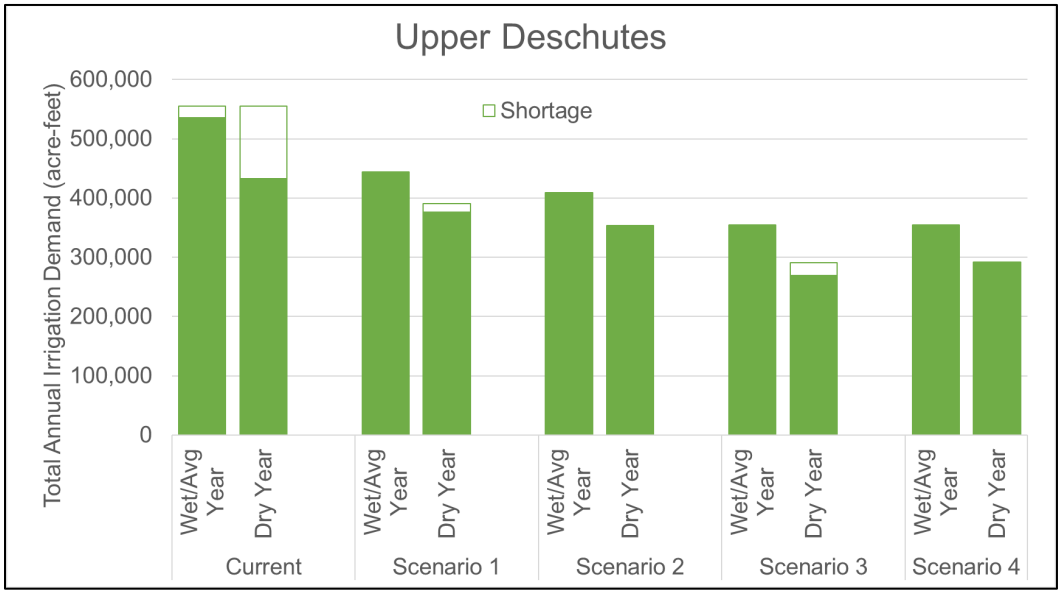

Figure 16. Model irrigation demand outcomes, Upper Deschutes River (Reclamation 2018b). Chart includes data for Arnold Irrigation District, COID, NUID, Swalley Irrigation District, and Lone Pine Irrigation District.

For Tumalo Creek, the flow results in Figure 17 indicate that the demand reductions assumed for Scenario 1 could contribute toward meeting the 33 cfs model flow objective, but that shortages would still occur in dry years (Reclamation 2018b). The further demand reductions assumed for Scenarios 2, 3, and 4 could result in meeting or exceeding the model flow objective. Figure 18 shows results for Tumalo Creek in terms of irrigation demand; if hypothetical reductions in demand were achieved, shortages could generally be avoided for all scenarios except in some dry years.

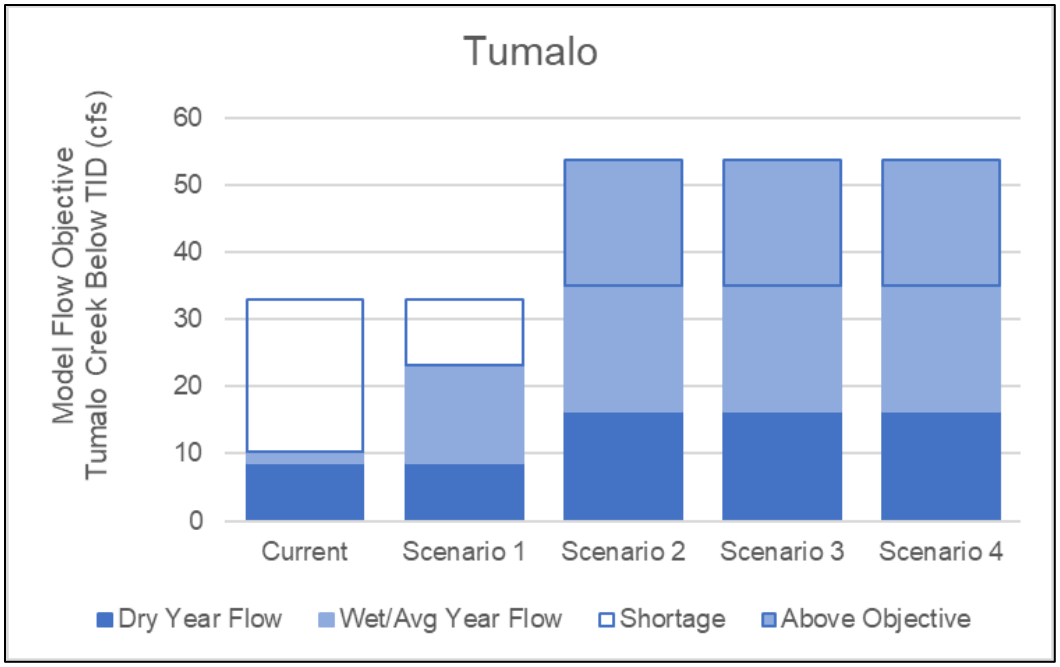

Figure 17. Model flow outcomes, Tumalo Creek (summer streamflow; Reclamation 2018b).

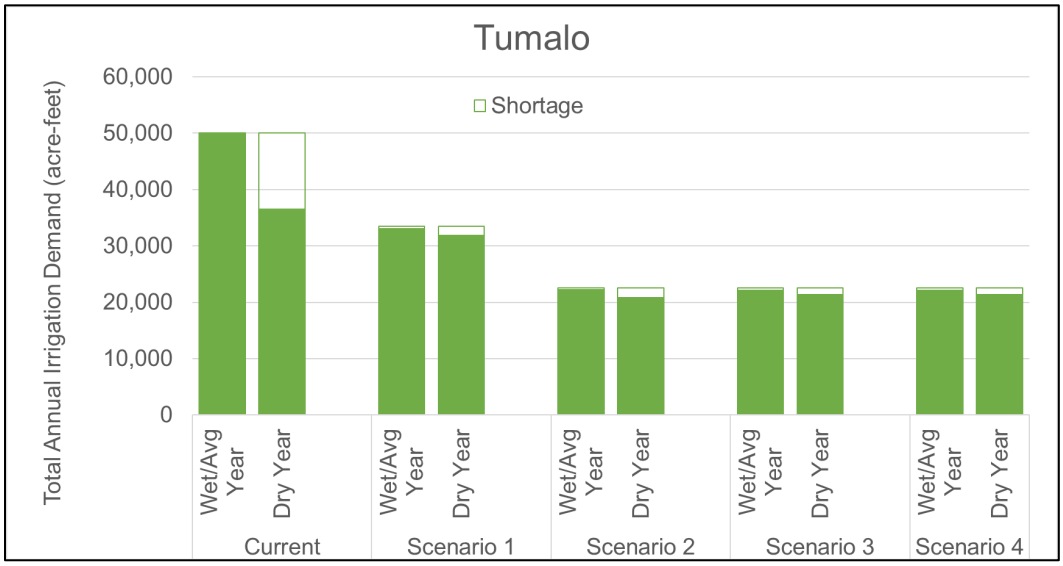

Figure 18. Model irrigation demand outcomes, Tumalo Creek (Reclamation 2018b).

Figure 19 and Figure 20 show results for Whychus Creek in terms of flow objectives and ability to meet irrigation demands, respectively (Reclamation 2018b). In Figure 19, the model instream flow objectives (33 cfs for Scenarios 1 and 2; 45 cfs for Scenarios 3 and 4) could be met or exceeded in wet and average years if all the assumed reductions in irrigation demand occurred; dry-year flows were below the model instream flow objectives. Irrigation shortages (Figure 20) would still occur in some dry years under Scenarios 1 and 2 (Reclamation 2018b).

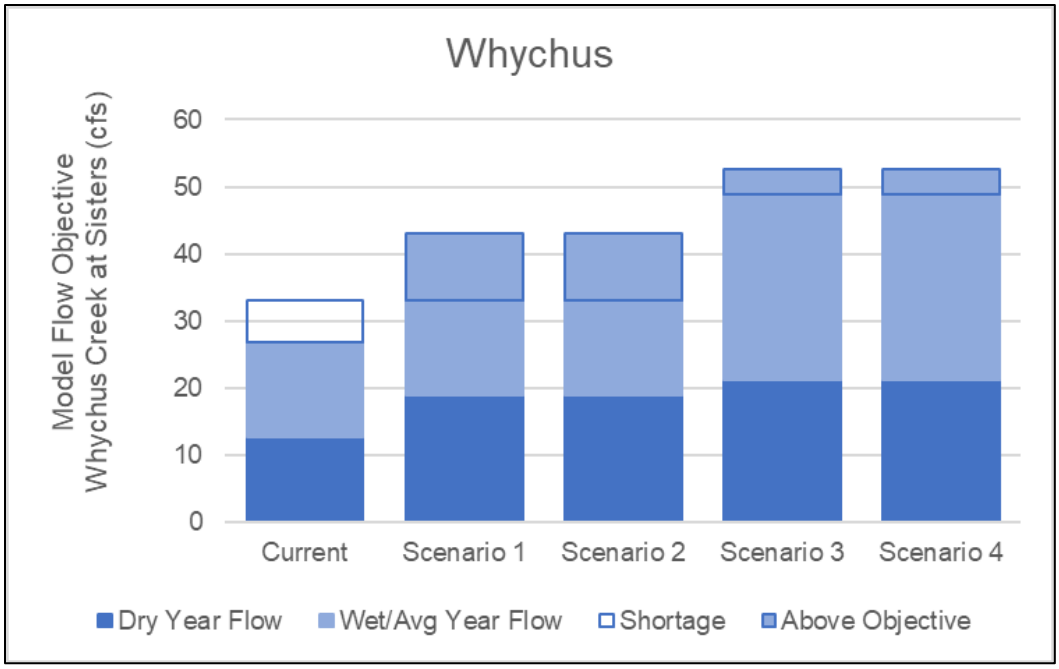

Figure 19. Model flow outcomes, Whychus Creek (summer streamflow; Reclamation 2018b).

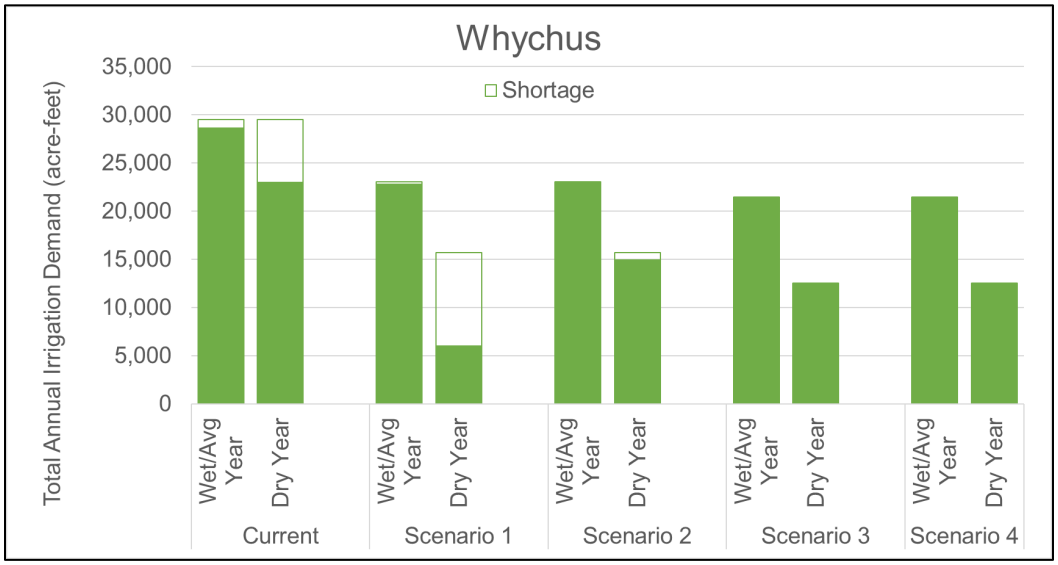

Figure 20. Model irrigation demand outcomes, Whychus Creek (Reclamation 2018b).

For the Crooked River, model flow objectives were 80 cfs for Scenarios 1 and 2 and 140 cfs for Scenarios 3 and 4. Results in Figure 21 indicate an improved ability to meet 80 cfs in dry years for Scenarios 1 and 2 if all hypothetical demand reductions occurred (Reclamation 2018b). With the higher model flow objective of 140 cfs for Scenarios 3 and 4, the ability to achieve increased flows in dry years is reduced, even with all the hypothetical reductions in demand, due to increased demands on storage in Prineville Reservoir (Figure 22). The results for irrigation demands in Figure 22 (Reclamation 2018b) indicate that needs would largely be met under the assumed scenario conditions.

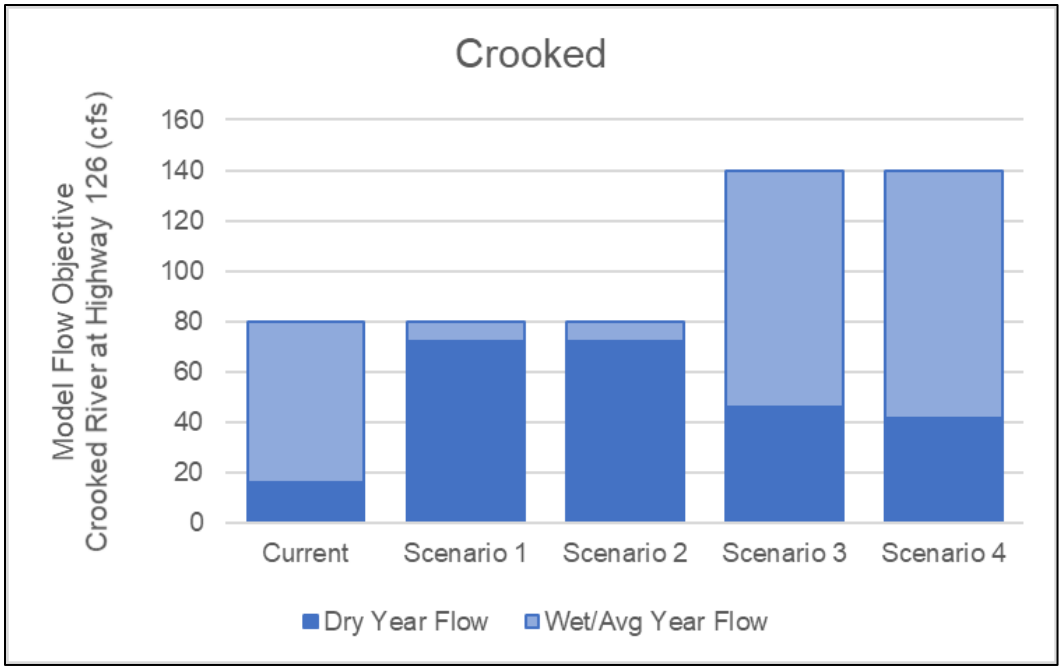

Figure 21. Model flow outcomes, Crooked River (year-round streamflow; Reclamation 2018b).

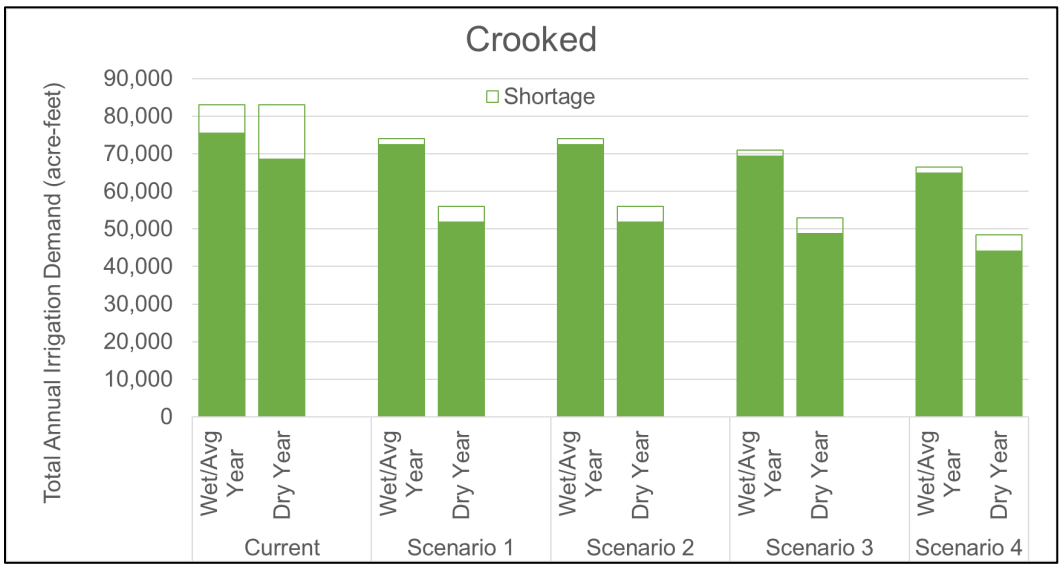

Figure 22. Model irrigation demand outcomes, Crooked River (Reclamation 2018b).

The simulations of hypothetical water management scenarios suggest that, on a hydrologic basis, the assumed suites of potential water management tools could effectively support objectives of improving instream flows for ecological benefits. The scenarios involve different levels of assumed reductions in irrigation demand, and the modeling results confirm that greater reductions in irrigation demand result in additional projected ability to meet instream flow objectives. However, it is important to note that higher levels of assumed demand reduction involve correspondingly higher costs and other practical challenges for potential implementation (Sections 4.3 and 4.5).

In addition to considering model flow objectives for instream demands and ability to meet irrigation demands, evaluations of scenario results included consideration of potential changes in stream temperature for the Middle Deschutes, Tumalo Creek, and Whychus Creek as analyzed using regression equations (Upper Deschutes Watershed Council 2016; see Section 2.4.2). These equations used recorded data to relate stream temperature to both air temperature and stream flow. While the regression analysis was a simplified approach, the results generally indicate that increases in stream flow correlated with stream temperature decreases given the same air temperature. Since the modeling outcomes for all four water management scenarios show generally increased flows at all three locations, the scenario conditions may contribute to improved (lower) stream temperatures. Modeled July river temperatures for Tumalo and Whychus Creeks (Reclamation 2018b) are shown in Figure 23.

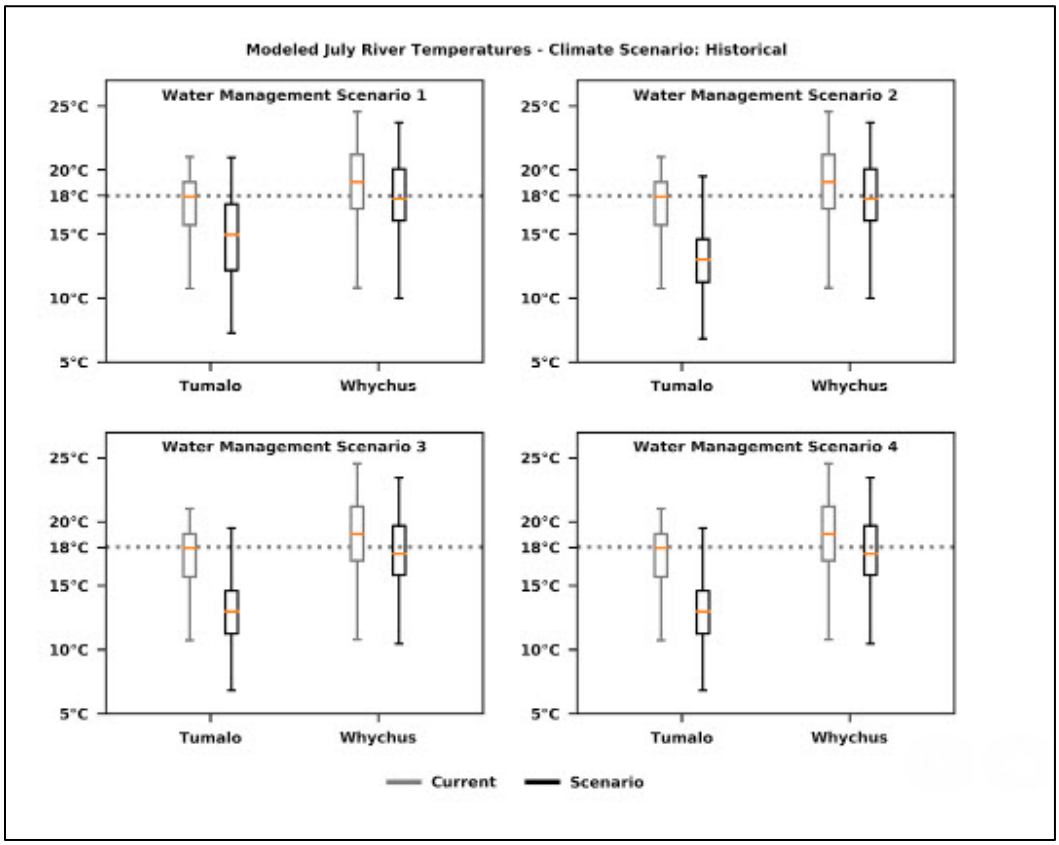

Figure 23. Calculated July stream temperatures for water management scenarios (Reclamation 2018b).
Lines in these charts indicate minimum and maximum calculated temperatures, while the open boxes indicate the range between the 25th and 75th percentile values. Median values are shown by orange lines within the open boxes.

Scenario outcomes were also considered relative to potential changes to redband trout habitat based on weighted usable area (WUA) curves (River Design Group 2017; see Section 2.4.1). These curves indicate the amount of suitable habitat for a species at incremental flow rates, showing that the amount of suitable habitat generally increases with increasing flows. Using the modeled outflow from Wickiup Reservoir, two sites were evaluated using the WUA

curves (Reclamation 2018b). At both locations, model results for winter flows showed increases for each scenario. Therefore, the WUA curves indicate the potential for corresponding increases in suitable habitat.

The assumed water management scenarios included tools designed to restore instream flow. Per potential limitations associated with these water management tools (Section 4.5), tools that meet OWRD requirements of the Deschutes Basin Groundwater Mitigation Program could potentially support generation of groundwater mitigation credits for municipal and quasi-municipal water providers.

4.2 Criteria for Evaluating Options

In addition to assessing the ability to meet assumed instream flow objectives and increase water security, the BSWG also identified criteria to assess factors not incorporated in the RiverWare model that could affect implementation of water management tools (Summit Conservation Strategies 2018). The BSWG used these criteria to evaluate both individual water management tools and the four water management scenarios to develop a multi-criteria analysis of potential effectiveness (see Section 4.3). The criteria established for the multi-criteria evaluations are presented in Table 7.

Table 7. Criteria for evaluation of water management tools (Summit Conservation Strategies 2018).

Criterion	Definition	Example(s) or Description
A. Reliability	The degree of certainty that the water management tool meets the desired outcomes.	Reliability may be greater for options involving infrastructure improvements compared to options involving voluntary participation.
B. Flexibility/ Adaptability	The ability of the water management tool to change in response to different conditions, changing circumstances, evolving objectives, etc.	A leasing effort can be scaled and redirected annually as needed, whereas the scope (and cost) of a pipe cannot be changed once constructed.
C. Duration/Durability	The length of time that the water management tool addresses the desired outcomes; is it temporary or permanent?	Water leases are temporary, while the sale of water rights to move irrigation water to other acres or instream may be permanent.
D. Legal/ Administrative Feasibility	Is the potential water management tool legal and feasible?	Certain alternatives may have legal and administrative barriers that impact feasibility.
E. Timeliness	How quickly can the water management tool be implemented?	Are there permitting, compliance, and regulatory timelines, or can the solution be deployed immediately? Optimization of reservoir operations could potentially be enacted quickly, while reservoir construction would be a longer-term proposition.

Criterion	Definition	Example(s) or Description
F. Externalities	The extent to which the potential water management tool avoids unreasonable new adverse impacts to other sectors/users.	Certain tools may adversely impact groundwater tables.
G. Viability as Mitigation	The extent to which the potential water management tool can provide a viable source of groundwater mitigation credits.	Water right transfers are a proven source of mitigation, while conserved water is allowed by the mitigation program but unproven.
H. Transaction Cost	Cost efficiency of the potential water management tool and administrative effort required used to enact it.	This criterion addresses all costs besides water costs.
I. Financial Risk	The risk of cost/price changes or overruns.	Lease costs could change over time. Hydropower revenues could change over time. A permanent purchase agreement has secure terms that are locked in. Construction cost overruns can occur in large infrastructure projects.

4.3 Multi-Criteria Analysis

The BSWG Steering Committee completed a multi-criteria analysis to evaluate how identified water management options and specific tools may help achieve desired outcomes for instream flows, agricultural uses, and municipal and quasi-municipal needs for groundwater mitigation (Summit Conservation Strategies 2018). The analysis involved the criteria identified in Section 4.2 to provide information about how different water management tools could impact the multiple identified objectives given a finite water supply.

The trade-off evaluation used a scoring system to evaluate each water management tool on all of the identified criteria. The evaluations summarized in Table 8 describe the characteristics of evaluated water management tools. In addition, a multi-criteria evaluation of the four water management scenarios was used to summarize, at a high level, some of the other important elements of the scenarios so that potential benefits and challenges can be understood in context. Because many of the criteria are qualitative and hard to measure, the evaluation documented in the relevant technical memorandum (Summit Conservation Strategies 2018) used a simple 1-to-3 scale to score water supply tools in order to avoid false precision. More detailed descriptions of the methodology and results are available in the associated Technical Memorandum (Summit Conservation Strategies 2018).

Table 8. Multi-criteria analysis of potential water management tools (Summit Conservation Strategies 2018).

Water Supply Tool	Estimated Potential Quantity (acre-feet)	Representative Estimated Cost (per acre-foot)	Summary of Tools Relative to Criteria
Water Conservation (Irrigation)			
Private Lateral Piping	35,000	$1,000	Private lateral piping is a cost-effective piping approach, offering reliable, long-term water supply at lower cost than other hard-infrastructure investments. Private ownership entails coordination and authority challenges that must be addressed in implementation.
District-owned Piping	120,000	$6,000	District-owned piping is a proven approach to securing reliable, long-term water supply. It is significantly more costly than private lateral piping in all cases, though there is also variation in cost across district-owned piping alternatives. District ownership simplifies implementation. Opposition from owners of adjacent property is possible.
On-farm Infrastructure Upgrades	30,000	$4,000	On-farm upgrades to irrigation methods are another source of conserved water. Though in some (but not all) cases, costlier than canal and lateral piping projects, on-farm upgrades may offer greater flexibility, often with less opposition. Savings from these upgrades require reinvestment to provide water in the long term.
Market-Based Approaches			
Water Leasing	70,000	$130 - $680	Significant supply of water may potentially be generated cost-effectively through leasing water rights. A base level of water leasing would be both reliable and low-cost relative to other tools. As the quantity of leasing increases, costs are higher, and the approach is less proven, although it is still expected to be lower cost than other approaches. Leasing is flexible and can be implemented at different scales as needs change. Costs could change over the long-term, and there may be constraints on leasing volume as a function of irrigation district delivery infrastructure. Leases are a proven source of mitigation, but municipalities strongly prefer permanent mitigation due to large investments in water supply infrastructure. Leases do not typically spur opposition.

Water Supply Tool	Estimated Potential Quantity (acre-feet)	Representative Estimated Cost (per acre-foot)	Summary of Tools Relative to Criteria
Water Rights Transfers	15,000	$300	Water transfers are an effective, reliable, and proven approach to reallocation of existing water supplies. Costs are estimated to be lower than water conservation, though they can vary significantly with quantities acquired and per irrigation district policies. Transfers to instream use are permanent, limiting the flexibility of this approach. Transfers are also a proven source of mitigation. Currently, irrigation districts are generally not in favor of permanently reducing their water rights by permanently transferring water instream.
Duty Reduction	50,000	$260 - $530	Voluntary duty reduction may offer a significant source of lower-cost water. Depending on the specific design of duty reduction initiatives, it can vary significantly in terms of reliability, permanence, and cost. Voluntary duty reduction programs generally do not raise opposition. Duty reduction techniques are largely untested in central Oregon, though they have been successfully implemented elsewhere.
Storage-Related Approaches			
Enhanced/New Storage	5,000 - 70,000	Likely greater than $5,000 (based on potential construction cost only)	Development of additional reservoir storage may allow operational changes to support water for instream objectives. Implementation of this approach would be a challenge due to high costs, required planning processes, and siting issues.

Outcomes from the multi-criteria analyses (Summit Conservation Strategies 2018) are summarized below for each of the hypothetical water management scenarios described in Section 4.1.

Water Management Scenario 1 maximizes potential cost-effectiveness through reliance primarily on assumed leasing, transfers, and duty reduction to reduce demand by approximately 200,000 acre-feet. The scenario's assumed total cost is roughly one-quarter of Scenario 2; unit costs are accordingly lower. Modest shortages equivalent to about 3 percent of agricultural demand are projected to occur in dry years under this scenario. Implementation of this scenario could be constrained by operational factors where there are carry-water delivery issues. Scenario 1 is highly dependent on voluntary participation by irrigators and, in some cases, untested approaches such as duty reduction. Scenario 1

illustrates a potential approach for relatively lower-cost approaches that could still contribute significantly to water supply needs.

Water Management Scenario 2 incorporates assumed leasing, duty reduction, and transfers but relies heavily on district-owned piping to reduce demand by approximately 250,000 acre-feet. Through this hypothetical approach, the scenario is projected to largely avoid shortages. While the assumed water management tools are viewed as reliable and durable, the piping elements of Scenario 2 have a longer timeline to implementation and much higher cost at roughly four times that of Scenario 1. Through comparison with Scenario 1, outcomes for Scenario 2 can inform planning around potential investments in developing a water system that could further avoid shortages in dry years.

Water Management Scenario 3 maximizes assumed piping to result in a reduced demand of approximately 310,000 acre-feet. Modest shortages equivalent to about 7 percent of agricultural demand are projected to occur in dry years under this scenario. Both total and unit costs are much higher than in Scenarios 1 and 2 due to the need to include higher-cost water management tools to address the more ambitious flow objectives; this scenario is 10 times the cost of Scenario 1. The assumed extensive infrastructure investment would result in reliable and durable supply increases using relatively proven approaches.

Water Management Scenario 4 assumes significant investments in piping and in the development of reservoir storage to generate a large and more reliable supply of water via an overall demand reduction of approximately 350,000 acre-feet. This more robust water supply would come at a very high estimated cost of more than $1.1 billion, more than 13 times the cost of Scenario 1. Modeling results for Scenario 4 suggest that tools exist that could develop relatively large amounts of additional water supply, although cost and feasibility barriers are much greater than for other scenarios.

The scenario evaluations do not provide complete detail on each scenario or the associated water management tools, nor can they be relied upon as a single source of information on which to base water management decisions. Full details on the scenarios, the assumed assemblages of water management tools, and the multi-criteria evaluations are provided in the water resources modeling technical memorandum (Reclamation 2018b) and the multi-criteria analysis technical memordandum (Summit Conservation Strategies 2018). This background would be relevant to any related water management efforts in terms of understanding assumptions and limitations.

4.4 Municipal and Quasi-Municipal Water Needs

As discussed in Section 2.3, the Basin Study identified a 50-year projected demand of up to 21,000 acre-feet of water for mitigation (21,000 mitigation credits), which would be secured through the Deschutes Groundwater Mitigation Program, to satisfy future groundwater demand in the basin. This projected demand includes up to 16,000 mitigation credits for municipal and quasi-municipal use (GSI Water Solutions, Inc. 2018e).

Under the Deschutes Groundwater Mitigation Program, temporary mitigation credits can be created by leasing live-flow water rights (typically irrigation rights) instream and permanent mitigation credits are created by permanently transferring water rights instream (GSI Water Solutions, Inc. 2018e). Municipalities and many quasi-municipal (private) water suppliers must seek permanent mitigation credits due to the large investments they are making in infrastructure. In some cases, the use of temporary credits can serve as a bridge until permanent credits are available.

The hypothetical water management scenarios described in Section 4.1 included 2,750 acres of permanent instream transfers with the potential to generate approximately 5,000 mitigation credits. However, current policy for irrigation districts in the basin is to not reduce their water right certificates by permanently transferring water instream.

An additional opportunity to establish mitigation credits could be associated with managing reservoirs differently to address future instream and out-of-stream water demands (GSI 2018b). Temporary credits could be established by leasing storage rights instream, or permanent credits could be established by permanently transferring a storage right instream. Such projects would need to be approved by OWRD under the Deschutes Groundwater Mitigation Program. OWRD recognizes that it currently has the ability to lease storage rights instream. In addition, OWRD recognizes that it has the authority to permanently transfer a storage right instream but needs additional guidance through administrative rule-making before this approach could be considered for implementation.

An additional potential approach could involve using stored water to establish mitigation credits (GSI Water Solutions, Inc. 2018e). Consistent with relevant Mitigation Rules (Oregon Administrative Rules 690-505), obtaining a new secondary water right that authorizes the use of stored water for an instream purpose, such as flow augmentation, may be considered a mitigation project. Consequently, mitigation credits could potentially be established as a result of the secondary water right. There is one example of this approach having been used in the basin at Prineville Reservoir. Any future use of this method would have to be evaluated on an individual basis.

It is important to recognize that policy and/or legal barriers may exist to limit implementation of some of the identified opportunities for establishing mitigation credits. For example, as mentioned above, irrigation district policies may prioritize securing water supplies for agricultural lands that have less-reliable sources of water as compared to transferring water rights for instream purposes. Pending resolution of policy and/or legal barriers, there may be future opportunities to pair a district-to-district transfer with an instream transfer of a storage right to generate mitigation, thus meeting multiple goals of agricultural water reliability, flow restoration and the generation of mitigation credits (GSI Water Solutions, Inc. 2018e).

Additional challenges are addressed in Section 4.5 and more-detailed discussions are provided in the relevant technical memorandum (GSI Water Solutions, Inc. 2018e). The technical memorandum suggests that while some of the potential concepts may be relatively straightforward to implement, others would involve issues that would first need to be

resolved with OWRD and other basin stakeholders. Accordingly, further continued coordination among municipal and quasi-municipal water providers, OWRD, and other stakeholders could contribute toward development of effective new mechanisms for securing mitigation credits (GSI Water Solutions, Inc. 2018e).

4.5 Summary of Barriers and Challenges

Over the past two decades, stakeholders involved in water management in the Upper Deschutes River basin have implemented various actions to help better address water resource objectives for instream, agricultural, and municipal and quasi-municipal needs. Making further progress to meet water resource objectives as defined for the Basin Study will involve additional challenges and barriers to be addressed. The BSWG determined that it was beneficial to examine potential water management options and tools even though significant challenges and barriers may currently exist, acknowledging that consideration of a potential tool does not imply any recommendation, endorsement, or proposal.

Potential policy, legal, and financial challenges associated with various water management tools considered in the Basin Study include:

- Finances and Funding Sources – Implementation of water management tools considered in the Basin Study would involve a range of potential costs. It is clear that significant investment will be required for implementation of projects to achieve longer-term objectives as identified by the BSWG, and that a key challenge will be to identify and secure associated funding sources.
- Challenges for Water Conservation Infrastructure – Work on private laterals and implementation of on-farm upgrades requires action and/or agreement by multiple private parties. In addition, some district canal piping projects have faced opposition to changing the nature of open, flowing canals that have been present for years. Prior district canal piping projects have faced landowner opposition, with resulting land use and historic designation factors acting as obstacles to implementation. These barriers could result in delays and increased costs for similar future efforts.
- Challenges for Market-Based Approaches – Some of the market-based water supply tools are well proven; for others, irrigation districts may need to develop new policies and programs to optimize effectiveness, and legal changes may be required to realize the full potential of market-based approaches. The need to coordinate with multiple private parties could increase costs for implementation.
- Limitations on New/Expanded Storage – New and expanded storage options were considered as ways to increase operational flexibility to improve instream flows. Significant impacts would be associated with construction of new storage facilities, and relocating storage from Wickiup Reservoir would raise water right and availability issues that would need to be addressed. Restoring storage capacity at

Prineville Reservoir could be affected by fish passage requirements and/or flood rule curve operational requirements.

- Federally Authorized Projects – Wickiup and Crane Prairie Reservoirs are Federally authorized for irrigation purposes. Leasing or transferring water rights for instream purposes may require changes to authorization.
- Mechanisms for the Flexible Movement and Protection of Water Instream – State water administration involves limitations on changing points of diversion using current transfer and conserved water right processes. Water conserved or transferred in the Middle Deschutes does not currently have a clear path to allow the concurrent protection of stored water in the Upper Deschutes.
- Exclusive Farm Use Tax Deferral – There is a potential disincentive for leasing water for instream purposes if exclusive farm use tax deferral is a perceived or actual risk.
- Split-Duty or Split-Rate Leasing – There is not an existing legal mechanism to transfer or lease part of a water right's stated duty. This could affect volumes of water that may be available through voluntary or incentivized duty reduction.
- Expedited Inter-District Temporary Transfers – Irrigation districts currently can expedite intra-district temporary transfers with the State, but not between districts. This may limit temporary movements of water that could contribute to water management objectives.
- District Caps on Instream Leasing – Some irrigation districts limit annual leasing volumes, affecting volumes of water that could be associated with this approach.
- Restrictions on Water Leaving Irrigation Districts – Most districts do not currently have policies that allow for water to exit irrigation districts. This has implications for permanently transferring water to farms in other districts or to the river for restoration or groundwater mitigation purposes.

The BSWG's approach to the Basin Study was to identify and acknowledge challenges and potential barriers to help inform future implementation of water management tools.

5. Outcomes and Future Considerations

The Basin Study evaluated water supplies and shortages in the Upper Deschutes River basin. Through the collaborative efforts of the BSWG, basin stakeholders developed potential water management options that could address identified water supply shortages. Specific water management tools were examined for each option and water resources modeling was used to help illustrate the features of different water supply strategies and to provide information about how various tools might interact if applied in combination.

5.1 Key Outcomes

The Basin Study developed quantified assessments of water supply shortages to evaluate achievable and sustainable actions that could secure and maintain:

- Increased streamflows and improved water quality for the benefit of fish, wildlife, and people.
- A reliable and affordable water supply to sustain agriculture.
- A safe, affordable, and high-quality water supply for urban communities.

Evaluation of water management options indicates that a variety of tools can effectively help address current and future water supply needs. Market-based approaches are proven and can provide relatively less-expensive water supply, but have limitations that will affect implementation. Water conservation infrastructure improvements for irrigation uses are also well-established in the basin and could provide significant volumes of water to help address shortages; however, these projects can be costly and some approaches may be limited by factors such as the need for coordination with multiple parties. Development of new or expanded storage facilities offers the potential for further reducing shortages in the longer-term; however, new storage projects typically involve high cost and significant uncertainties.

Water resources modeling included evaluation of specific water management tools combined in four hypothetical water management scenarios. These scenarios were designed to help illustrate the features of different water supply strategies and provide information about how various tools might interact if applied in combination. Results for the different scenarios and different geographical areas in the basin, along with multi-criteria evaluation of water supply tools and water management scenarios, show that the identified water supply tools can be effectively applied in combination to address key basin objectives.

EACH WATER SUPPLY TOOL HAS UNIQUE OPPORTUNITIES AND CHALLENGES/BARRIERS; COMBINING AVAILABLE TOOLS SHOULD LEAD TO THE MOST EFFICIENT OUTCOMES.

Some of the water management tools evaluated in the Basin Study would face financial, legal, policy, and other barriers for implementation. Accordingly, and because no single approach can meet all identified water shortages, the BSWG recognizes that pursuing a combination of water management tools will be necessary to best achieve goals for instream, agricultural, and municipal needs in the basin. Basin Study assessments of different water management scenarios indicate that the identified water management tools can work together effectively.

5.2 Potential Future Paths

BSWG's pursuit and completion of the Basin Study incorporated a collaborative approach. Future water management decisions affecting multiple interests may similarly be most effective if they are completed in an open and collaborative venue. Options for future collaborative work in the Upper Deschutes River basin can build off other existing water-related partnerships and organizations in the basin and can complement and leverage efforts that are already underway.

While the Basin Study does not propose or recommend any particular approach or plan, the collaborative process among basin stakeholders during the Basin Study has identified the following key considerations that may help basin stakeholders relative to future water management strategies:

Considerations for Implementation of Water Supply Options

- Integrating water conservation and water marketing activities may reduce costs and implementation timelines.
- Seeking matching funding for large-scale piping projects could leverage funding from other sources (e.g., the Watershed Protection and Flood Prevention Program managed by the U.S. Department of Agriculture Natural Resources Conservation Service, Reclamation's WaterSMART Program Water and Energy Efficiency Grants, Water Marketing Strategy Grants, drought resiliency projects under Reclamation's Drought Response Program, and Reclamation's Water Management Options Pilots).
- Piping projects could be complemented by on-farm efficiency, private lateral improvement, and water marketing programs.
- Developing market-based strategies could help increase water leasing and facilitate voluntary reductions in water use.
- Water management tools can be selected for implementation based on specific water-year conditions and associated shortages. Permanent projects would be complemented by flexible programs optimized in dry years, such as dry-year leasing.
- Stakeholders may consider how and if potential transfers from senior districts to NUID could support instream transfers in the Upper Deschutes River, and how such transfers could benefit mitigation under the Deschutes Basin Groundwater Mitigation Program.

Information Needs/Areas of Potential Further Study

- Future climate conditions and related effects on water supply and instream flows can be more effectively evaluated when refinements to basin-specific hydrologic modeling become available. Work is currently underway at the USGS to advance the GSFLOW model for the Deschutes River basin.

- Based on refined hydrologic models, it would be helpful to assess the collective impacts of water management strategies on groundwater and any associated impacts on springs and/or water temperature.
- Identifying and prioritizing irrigation district carry-water issues could help increase near-term water marketing opportunities in areas where it is feasible from a delivery standpoint, and/or to inform prioritization of piping activities.
- In the Upper Deschutes, further evaluation of how increased flows interact with floodplain connectivity and wetlands could help identify and prioritize habitat restoration efforts to optimize flow restoration.
- Further stakeholder involvement and engagement would be needed if there is interest in evaluating concepts for new off-channel storage facilities in the Upper Deschutes and/or the storage restoration concept at Prineville Reservoir in the Crooked River basin. Funding would need to be secured to support studies of technical viability, environmental impacts, and cost/benefit considerations.

Policy Considerations

- It would be helpful for OWRD and stakeholders to clarify approaches for how water could be moved most efficiently between districts, and how best to address associated policy/legal obstacles.
- OWRD and stakeholders could further clarify appropriate mechanisms for protecting instream flows in the Upper Deschutes River and how such restored flows could contribute to establishing groundwater mitigation. Strategies for addressing related policy/legal obstacles would also need to be evaluated.

Future Planning & Collaboration

- Future water management actions should be planned to work within the present context of water management planning. For example, the ongoing development of the Deschutes River Basin Habitat Conservation Plan (HCP) will inform permitting under the Endangered Species Act and may provide opportunities for complementary water management initiatives.
- Stakeholders may consider building on the HCP to develop a basin-wide integrated water management plan, if or as appropriate.
- The collaborative framework developed through the Basin Study process could continue via new forums for collaboration around water management planning and implementation.

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