Reservoir Management

DWA Final Report

August 2006

Kate Fitzpatrick[1],

Kyle Gorman[2],

and Bruce Aylward, Ph.D.[1]

[1], Deschutes River Conservancy, 700 NW Hill Street, Bend, Oregon 97701, (541) 382-4077
[2] Oregon Water Resources Department, 1128 NW Harriman St, Bend, Oregon 97701, (541) 388-6669

The authors wish to thank the Bureau of Reclamation for sponsoring this report as part of the Deschutes Water Alliance Water 2025 Grant (see www.deschutesriver.org/Water_summit for more information).

Deschutes Water Alliance
<u>Reservoir Management</u> – August 2006

Prepared by:

Kate Fitzpatrick	Deschutes River Conservancy
Kyle Gorman	Oregon Water Resources Department
Bruce Aylward	Deschutes River Conservancy

Feedback and comments were received by:

David Newton	Newton Consultants, Inc.
Mathias Perle	Newton Consultants, Inc.
Patrick Griffiths	City of Bend
Tom Hickman	City of Bend
Pat Dorning	City of Redmond
Ray Johnson	City of Redmond
Tod Heisler	Deschutes River Conservancy
Brett Golden	Deschutes River Conservancy
Steve Johnson	Central Oregon Irrigation District & Deschutes Basin Board of Control
Jan Lee	Swalley Irrigation District
Kathy Kihara	Bureau of Reclamation
Bonnie Lamb	Oregon Department of Environmental Quality

Foreword

BACKGROUND

The upper Deschutes Basin comprises about 4,500 square miles of catchment between the highland areas to the east, south and west, and Lake Billy Chinook to the north. The Central Oregon area, located within the upper Basin, is experiencing rapid population growth and associated changes in lifestyles and land uses. Existing water resource issues have become more important to local communities as these changes have occurred, and a number of new water resource issues have developed

Irrigation has historically been the primary water user in the upper Deschutes Basin. As the population of the Basin has increased, streamflow restoration, protection of state Scenic Waterways, and water quality restoration have emerged as important issues. Other developing issues include the need for a clean and reliable water supply for future Basin needs, the urbanization of irrigated lands and associated impacts on agriculture, and the need to protect instream flows for multiple uses.

The significance of basin water issues has increased considerably over the last few years. The rapid growth and subsequent water needs that the region is experiencing presents an opportunity to study these issues in more detail given changing values and availability of funding. Consequently, water usage and availability are now a major topic in discussions among basin water suppliers and planners. Due to increased dialogue and awareness relative to water issues, regional urban water suppliers, irrigation districts and other private, government and individual water users now recognize their interdependency in the use, management and protection of Deschutes Basin water resources. This recognition and related dialogue enjoined the major water suppliers in a common vision that compels commitment of energy and resources in a unified way for responding to basin water issues.

Water supply, water quality, and irrigation district urbanization issues in the upper Deschutes Basin have driven the development of and created a framework for the Deschutes Water Alliance. Mutually beneficial opportunities exist for municipal and flow restoration interests to obtain additional water and for irrigation districts to resolve urbanization and conservation issues. Some of the key management considerations involved with these opportunities include:

- Full appropriation of surface waters
- Declaration of groundwater restrictions and related mitigation requirements
- Dependency of municipal water providers on groundwater for future needs
- Diversion of substantial river flows by irrigation districts
- TMDL water quality parameters for the Deschutes and Crooked Rivers
- Protection of scenic waterway flows in the lower reaches of the Deschutes and Crooked Rivers
- Potential Endangered Species Act issues

- Rapid growth, urbanization and land-use change in the basin

Organization

The Deschutes Water Alliance (DWA) was formed by four major Basin partners to develop and implement integrated water resources management programs in the upper Deschutes Basin. The partners include**:**

- Deschutes Basin Board of Control (DBBC): represents seven irrigation districts in the basin including BOR's Deschutes Project (North Unit Irrigation District) and Ochoco Projects formed under ORS 190.125.
- Central Oregon Cities' Organization (COCO): an organization comprised of cities in the basin, affiliated drinking water districts and private companies providing potable water supply.
- Deschutes River Conservancy (DRC): a non-profit organization focused on restoring streamflow and water quality in the Deschutes Basin.
- Confederated Tribes of Warm Springs (CTWS): comprised of the Warm Springs, Wasco, and Paiute Native American tribes.

Goals and objectives

The DWA is investing in management of the Deschutes Basin in a unified way to provide:

- Reliable and safe water supply for the region's future municipal and agriculture needs and sustained economic viability considering growth, urbanization and related effects on water resources;
- Financial stability for the Basin's irrigation districts and their patrons;
- Protection of the fishery, wildlife, existing water rights, recreational and aesthetic values of the Deschutes River along with stream flow and water quality improvements;
- Focus on maintaining the resource and land base in the Basin, consistent with acknowledged comprehensive land use plans; and
- An institutional framework that supports the orderly development of local water markets to protect participants and create an "even playing field" for water transactions.

These considerations are key elements to be incorporated into development of the integrated water resources management and restoration program.

Approach

Mutually beneficial opportunities exist to boost water supply for agriculture, municipal needs and stream flow for fish, wildlife and water quality improvements. Mutually beneficial opportunities also exist through integrated planning for irrigation districts to resolve urbanization issues. In order to develop a framework and program to achieve these objectives, the DWA is implementing five planning studies under a Water 2025 Program grant to generate facts and background information necessary for program formulation. The planning study results will be synthesized into a Water Supply, Demand and Water Reallocation document with project scenarios, five-year implementation bench marks and 20-year timeframe. The five planning studies are as follows:

- Irrigation District Water Conservation Cost Analysis and Prioritization-an evaluation and prioritization of opportunities to save water through piping and lining of canals, laterals and ditches, as well as through on-farm conservation technologies.
- Impacts of urbanization on Irrigable Lands-an inventory of amounts, patterns and rates of district water rights becoming surplus due to urbanization or other changes in land use patterns in Central Oregon and corresponding impact on district assessments.
- **Reservoir Operation and Management Study - a rapid assessment of potential gains from optimization of existing reservoirs and their potential impact on improving flow and quality, and preparation of terms of reference for more formal and rigorous assessment.**
- Municipal Water Demand-assessment of the water supply needs, quantity and timeline of the Basin's regional urban suppliers.
- In-stream Flow Needs for Fish, Wildlife and recreation along with Measurement, Monitoring and Evaluation Systems-assessment of the suitability and completeness of existing flow measurement sites and existing Water Quality and Monitoring Plan for the Upper Deschutes Basin and prepare funding and implementation action plan.

Table of Contents

1 EXECUTIVE SUMMARY

1.1 Background

The Deschutes Water Alliance (DWA) is investing in several water resources management studies in the upper Deschutes Basin. The objective is to build the foundation for a comprehensive plan to provide reliable and safe water supply for the region to meet its growing new population, to maintain the water supply available to agriculture, and to restore stream flows to identified targets. The purpose of this paper is to describe the reservoir system in the basin, identify the impacts it has had on stream flows, and introduce and briefly assess potential ways of managing the reservoirs to enhance stream flow while maintaining or improving water supply reliability for the irrigation districts that rely on them. This paper provides background on the five large storage reservoirs in the basin – Wickiup, Crane Prairie, Crescent Lake, Prineville, and Ochoco, including their current operations and their impacts on stream flow and water quality. It then focuses the assessment of opportunities for instream flow restoration on the upper Deschutes reservoirs, specifically using Crane Prairie and Wickiup Reservoirs as a case study.

The assessment identifies and describes a number of opportunities for improving reservoir operation, makes a preliminary effort to quantify their potential in terms of water that could be made available, and ranks the relative importance of each opportunity to meet instream and agricultural needs. Finally, this paper provides a basis for planning and implementing other projects in conjunction with efficiency improvements. A companion DWA Issues Paper on water use efficiency addresses how the efficiency improvements and reduced water demand described in this paper combined with optimizing reservoir management can help provide for future basin water needs. As part of this effort the irrigation districts holding the storage water rights in these reservoirs have been involved in discussions, along with Oregon Water Resources Department and the Deschutes River Conservancy in a pilot conservation lease of winter water from Crane Prairie.

1.2 Findings

1.2.1 Reservoir Impacts

All five reservoirs impact stream flow and water quality, but the majority of this paper focuses on the impacts of Wickiup and Crane Prairie reservoirs. The operations of Wickiup and Crane Prairie for winter storage and summer irrigation have significantly altered flows, and consequently water quality in the upper Deschutes River. Wickiup operations contribute more to flow alterations than Crane Prairie operations because the storage supply, allocation, and demand is significantly greater in Wickiup.

Under natural conditions, summer flows below Wickiup Reservoir averaged 730 cubic feet per second (cfs) and winter flows averaged 660 cfs. Currently, during the storage season from October through March, the minimum flow is set at 20 cfs, or 3% of natural low-flow levels. The dam impacts are moderated by downstream tributary inflows such as Fall River, Little Deschutes River, and Spring River, so that flows at Benham Falls are reduced to about 30% of what they were historically. During the irrigation season from April to October, storage releases from the reservoirs increase the flow of the Deschutes River up to 1500 cfs, or 200 % of what would have flowed naturally. These flow alterations have altered the channel bank stability, degraded water quality, reduced fish habitat, and created channel sedimentation problems downstream. The storage regime also impacts the middle Deschutes, as most of the stream flow in the summer is diverted above Bend for irrigation.

The DWA has targeted specific goals to restore flows to 300 cfs in the upper Deschutes River below Wickiup Reservoir in the winter and 250 cfs in the middle Deschutes reach below North Canal Dam in the summer. The alternatives presented in this paper focus on meeting the flow target in the upper Deschutes, because changes in storage use and operations are the only way to restore flows in this reach.

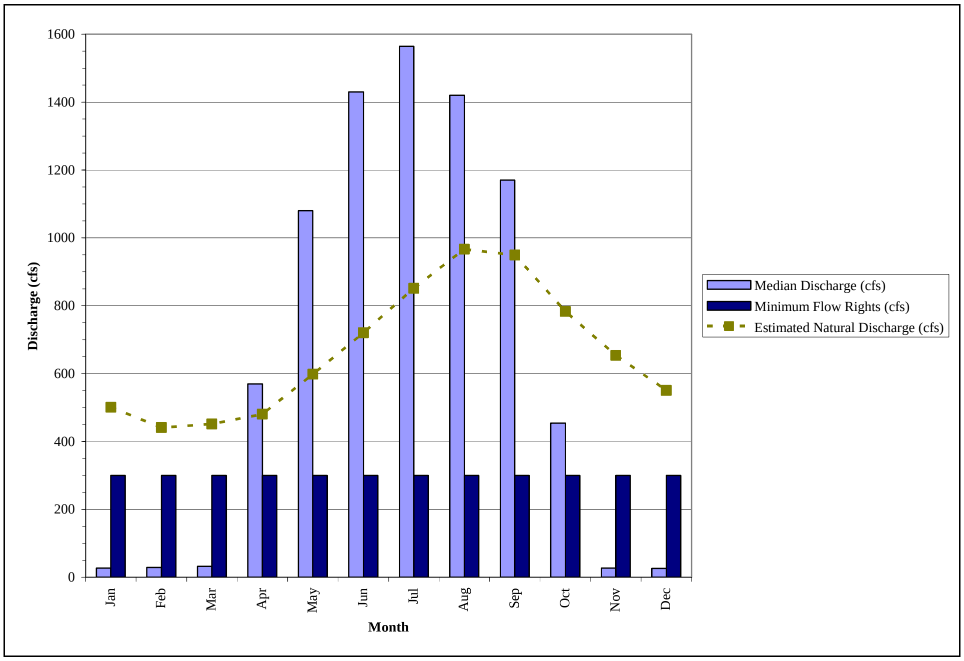
1.2.2 Current Reservoir Operations

Crane Prairie and Wickiup reservoirs are operated based on a demand system to meet the needs of irrigation districts at Bend. The reservoirs are used as a supplemental supply in times of shortages where natural flow of the Deschutes River is not sufficient to meet the demand. Lone Pine Irrigation District, Arnold Irrigation District, and Central Oregon Irrigation District together hold 50,000 acre-feet (AF) of water rights in Crane Prairie Reservoir, and North Unit Irrigation District holds a water right for 200,000 AF in Wickiup Reservoir. The allocation of the water in these two reservoirs is dictated by a 1938 inter-district agreement, which identifies their filling order and contains specific provisions for water allocation when the reservoirs do not fill completely. As district demands have changed over the years, this agreement does not necessarily align storage supply with current priority demands.

1.2.3 Instream Flow Needs

Current reservoir operations have significantly impacted the natural hydrograph in the upper Deschutes. Figure ES-1 illustrates current median discharge below the reservoirs as compared with the instream flow target set by ODFW (which has been certificated as an instream right) and estimated natural discharge.

Figure ES-1. Instream flows in the upper Deschutes River reach, 1968 – 1997



Flow as measured at the Wickiup Gage (WICO) #14056500

Average daily discharge reached or exceeded the instream flow target of 300 cfs on 26% of the days during the 1968-1997 storage seasons. The increase in discharge required to meet this target 100% of the time ranged from over 100,000 AF to under 1,000 AF over the period of record. Over the 30 year period of record, the annual average increase in discharge required to reach the target is approximately 62,000 AF.

Discharge in excess of the 300 cfs flow target ranged from 0 to almost 84,000 AF during the period of record. This water may be accessible through better forecasting to meet the target at times of need.

1.2.4 Potential Reservoir Management Opportunities

The opportunities introduced in this paper share the objective of meeting flow targets while maintaining or increasing water reliability for agriculture. They fall into several categories:

1. optimization under the current water rights and water use regime
2. trading or renegotiation of storage allocations
3. conserved water protected instream
4. instream transfer of storage rights
5. reductions in demand by irrigators
6. reduced reservoir losses

While further study is imperative, the brief and rapid assessment provides a sense of the alternative prospects and their potential to contribute to the identified average annual need of

62,000 acre feet per year. The alternatives and their potential contributions are described in the table below. These alternatives are conceptual at this point, and are meant to provide the terms of reference and a foundation for future discussions with all parties interested in stored water.

Table ES-1. Summary of Alternatives and their Contribution to Flow Restoration in the Upper Deschutes

Reservoir Management Approach/Method	Potential contribution (acre feet)	Likely Importance Rating
1. Reservoir optimization	480 to 1,200	4 to 5- minor to insignificant
2. Trading or altering allocations	10,000 to 15,000	2 to 3 - important to very important
3. Conserved Water	8,350	3-important
4. Instream Transfers/Leases	1,450	4-minor
5. Reductions in Demand		
a. Transfers – Storage	-	5-insignificant
b. Transfers – Transmission Loss	5,350-10,700	3-important
c. Water Management - Lease Agreements	10,000	3-important
d. Water Conservation - Lease Agreements	16,370	1- major
6. Avoided Seepage Losses	up to 10,000	3-important
Potential Total	62,000-73,070	

1.3 Issues

1.3.1 Federal Constraints

The Federal Government through the United States Bureau of Reclamation has strict authority in the use of water from Wickiup Reservoir and to a lesser extent in Crane Prairie. Modifications to the use of water in reservoirs with Reclamation authority will require Reclamation's permission and possible legislative changes.

1.3.2 Irrigation District Consensus

Any changes in reservoir management and operations can only occur within a framework of collaboration between all of the districts with contract storage interests. This is a practical matter, as all are parties to the agreement that governs the reservoirs, but also a desirable framework, as the objective is to meet target flows while improving the efficiency of reservoir allocation and ensuring districts' water supply.

1.3.3 Modeling Needs

The DWA will need a peer reviewed, calibrated model that can demonstrate existing conditions, and can model various scenarios, including changes in demands due to conservation, and changes in management, and optimization potentials.

1.4 Conclusion

Improvement of reservoir operation and management will play an important role in responding to changing basin needs. Reservoir operations have greatly impacted the natural hydrograph, particularly in the upper Deschutes River between Wickiup and Bend. This paper introduces a wide variety of opportunities to adjust reservoir management to restore stream flows while maintaining or improving the water supply for irrigators. The existing management of the reservoirs is dictated by the storage water rights and by the 1938 inter-district agreement. Options possible within the current allocation framework include optimization through better forecasting, conserved water allocations of stored water, instream transfer of storage rights, temporary lease agreements tied to conservation practices, and reduction in demand by irrigators resulting from transfers, leasing, and conservation. Because the 1938 agreement does not necessarily align supply and priority demands, there are also opportunities to work with the districts party to the agreement to consider alterations to the allocation framework. Alterations could be temporary or permanent, with some measure of flexibility ideally being retained.

Reservoirs represent a critically important measure of safety and reliability for water users, while simultaneously, a resource to help restore stream flows in critically-low reaches. Multiple benefits can be achieved with close collaboration by all interested parties.

This paper has focused largely on operations and opportunities in Crane Prairie and Wickiup Reservoirs. Many of these same tools are likely applicable in the other basin reservoirs, and should be explored in the future in the particular contexts of those reservoirs. In addition, future analysis could examine how the Crooked River and upper Deschutes reservoirs could be re-operated to meet water resource management objectives for both sub-basins, as well as regional-scale impacts of changes in reservoir storage and instream flow on groundwater recharge and discharge in the lower Deschutes.

2 ACKNOWLEDGMENTS

The Deschutes River Conservancy, the Oregon Department of Water Resources and Newton Consultants, Inc. prepared the draft of this report with substantial feedback and input from Central Oregon Cities Organization entities, the Oregon Department of Water Resources, the Deschutes River Conservancy, the Deschutes Basin Board of Control, Deschutes Soil and Water Conservation District, Bureau of Reclamation, the U.S Geological Surveys, Oregon Department of Environmental Quality, Oregon State Parks, Oregon Department of Fish and Wildlife and the Upper Deschutes Watershed Council.

3 INTRODUCTION

3.1 Purpose

This paper presents a preliminary assessment of reservoir operations and management in the Deschutes Basin, and presents opportunities to use the reservoirs to maintain or improve water reliability for irrigation while restoring stream flows. It provides a brief overview of the storage facilities, their patterns of use, and their potential to enhance stream flows in the upper Deschutes Basin through the efforts of the Deschutes Water Alliance (DWA). Although background information is presented on the five major reservoirs in the Deschutes Basin- Wickiup, Crane Prairie and Crescent Lake reservoirs in the upper basin, and Prineville and Ochoco reservoirs in the Crooked River drainage, the paper focuses on analyzing operations and exploring opportunities in Crane Prairie and Wickiup Reservoirs.

The study identifies specific reservoir management opportunities that will provide water to meet growing basin needs, evaluates their costs, and identifies their potential benefits. The study identifies opportunities to meet growing water supply needs with existing water rights while restoring streamflows and maintaining limited increases in consumptive use.

Management opportunities seek to meet the following objectives:

- Explore opportunities to change irrigation demand at Bend so that more water becomes available for instream flow enhancement through conservation, instream transfers, and;
- Modify existing reservoir management, without harm to existing water rights, to reallocate stored water for flow augmentation and water quality enhancement; and
- Maintain and improve water availability for existing irrigation.

4 STORAGE INFRASTRUCTURE & IMPACTS ON STREAMFLOW & WATER QUALITY

Five major Basin reservoirs store water for irrigation in the winter and release water for irrigation in the summer: Crane Prairie, Wickiup and Crescent Lake in the upper Basin and Prineville and Ochoco in the Crooked River drainage. The operation of these reservoirs has altered flow patterns and water quality conditions in the Deschutes River and its tributaries. The following sections provide background information on each storage facility and their impacts on streamflow and water quality. More specific information on the impacts of low flows on ecosystem health can be found in the DWA Issues Paper *Instream Flows in the Deschutes Basin.*

The five major reservoirs in the Deschutes Basin are summarized in Table 1. Figure 1 identifies their approximate spatial location.

Table 1. Major Storage Reservoirs in Central Oregon

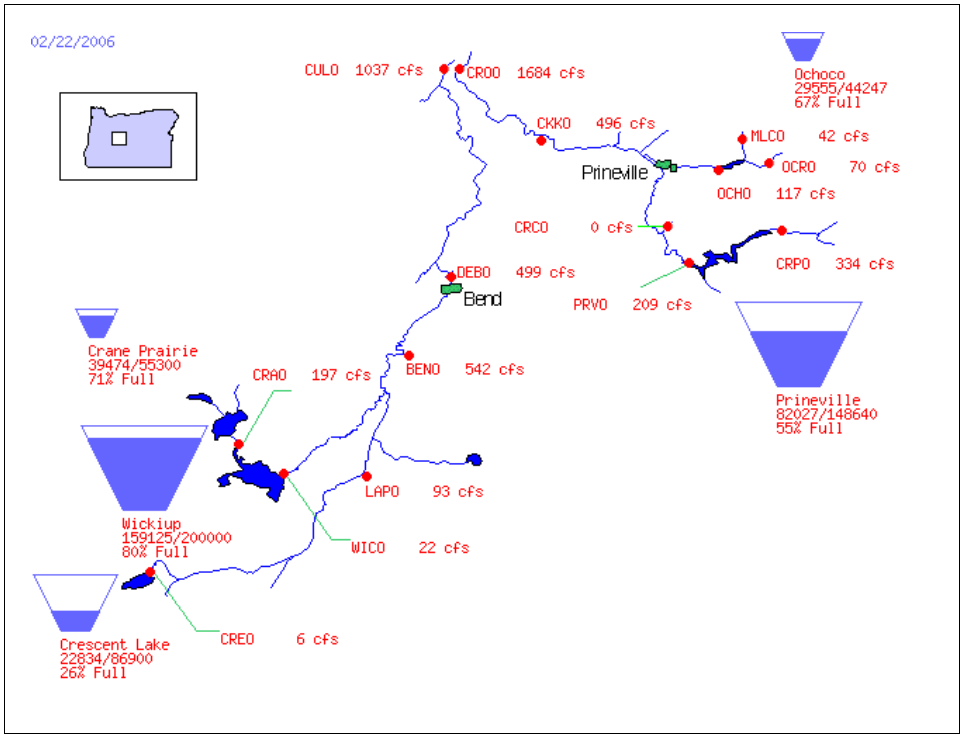
Storage Facility (from upstream to downstream)	**Year Constructed or Rehabilitated**	**Owner**	**Entity Responsible for O&M**	**Notes**
Upper Deschutes River				
Crane Prairie Dam and Reservoir	1940	United States	COID[1]	55,300 AF of active storage
Wickiup Dam and Reservoir	1949	United States	North Unit ID[1]	200,000 AF of active storage
Crescent Creek				
Crescent Lake	1922; 1954	Tumalo ID	Tumalo ID	86,900 AF of active storage
Crooked River				
Arthur R. Bowman Dam and Prineville Reservoir	1961	United States	Ochoco ID[2]	148,640 AF of active storage
Ochoco Creek				
Ochoco Dam and Reservoir	1918-1920; 1950; 1995	OID	OID	39,000 AF of active storage; 5,266 AF of dead storage via pump

Source: Bureau of Reclamation (2005)

[1]These are “Transferred Works”- facilities in which daily responsibility for O&M activities are transferred to and financed by the irrigation district.

[2]These are “Reserved Works” - facilities in which the O&M is the responsibility of the United States. Daily O&M responsibility may be contracted to another entity, but the United States maintains the financial responsibility.

Figure 1. Location of Major Reservoirs in the Basin



4.1.1 Upper Deschutes Basin Reservoirs

Crane Prairie (CP) Reservoir is situated a few river miles downstream from the headwaters of the Deschutes River. Local irrigation districts built the reservoir originally, and Reclamation rehabilitated it in 1940. Crane Prairie is a relatively shallow lake that holds 55,300 acre-feet (AF) at a maximum and has water rights for the storage of 50,000 AF. The earthen rock dam is controlled by two manually operated slide gates. The Reservoir has a height gauge with near-realtime telemetry that provides hourly readings on the internet and which allows water managers to make decisions based on current reservoir heights.

Crook County Improvement District #1 (Lone Pine), Central Oregon Irrigation District (COID) and Arnold Irrigation District (Arnold) hold water rights in CP. Although Reclamation holds the title to the reservoir, the reservoir has been paid off and COID is the operator, and the primary name on the water right certificate. The reservoir was authorized for multiple purposes by the State of Oregon in 2000, including instream flows for fish and wildlife.

Wickiup Reservoir is located two miles downstream of Crane Prairie and is the primary supplemental storage facility for North Unit Irrigation District (NUID). Wickiup holds 200,000 AF at full capacity, all of which is permitted for NUID to use for irrigation. Wickiup receives numerous inputs from springs in and around the reservoir, with spring incharge being measured at close to 500 cfs. Reclamation holds the title to Wickiup, and NUID is the operator. In contrast to Crane Prairie, Wickiup is only authorized for irrigation water uses.

Crescent Lake Reservoir is a moderate sized reservoir located on Crescent Lake, headwaters of Crescent Creek and tributary of the Little Deschutes River. Unlike Wickiup and Crane Prairie, Crescent Lake is a storage facility built on an existing natural lake. The reservoir has been estimated to hold 500,000 AF. Crescent Lake Dam was built in 1911 and has had several modifications and upgrades since its original construction. The reservoir provides a supplemental source of irrigation water for the Tumalo Irrigation District (TID), and is privately owned and operated by TID.

Impacts on the upper Deschutes River

The operations of Wickiup and Crane Prairie reservoirs for winter storage and summer irrigation have significantly altered flows, and consequently water quality in the upper Deschutes River. In practice, Crane Prairie and Wickiup operations are interconnected. Wickiup operations contribute more to flow alterations than Crane Prairie operations because the storage supply, allocation, and demand is significantly greater in Wickiup.

Under natural conditions, summer flows below Wickiup Reservoir averaged 730 cfs and winter flows averaged 660 cfs. Currently, during the storage season from October through March, the minimum flow is set at 20 cfs, or 3% of natural low-flow levels. During the irrigation season, storage releases from the reservoirs, most prominently Wickiup Reservoir, increase the flow of the Deschutes River to approximately 200 % of what would have flowed naturally. Between the 1940s and 1970s, flows below Wickiup reached 2,000 cfs. More recently, the flow from Wickiup Reservoir peaks at 1,500 cfs in the middle of July through the middle of August.

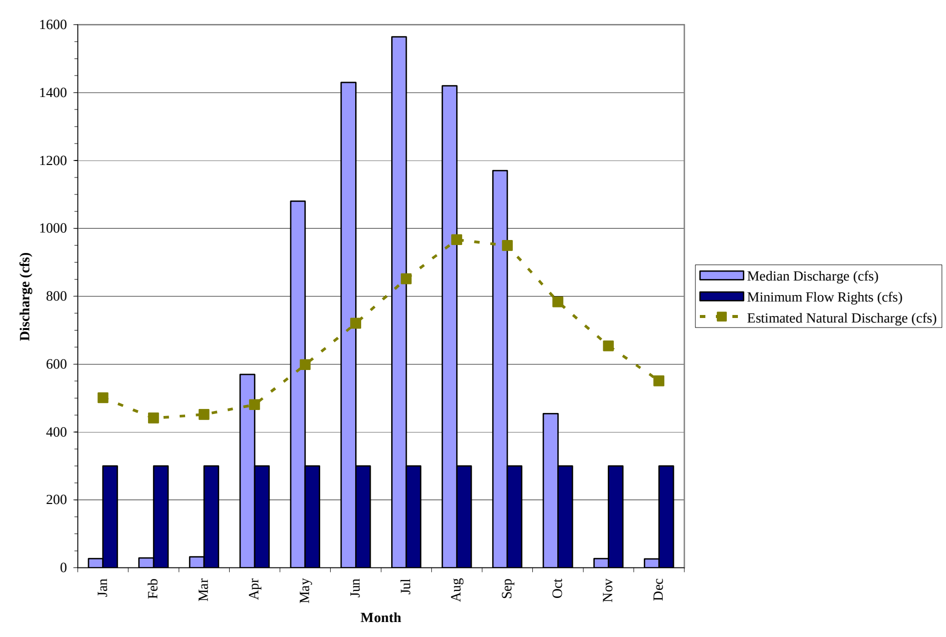
Certificated instream flow rights exist on most reaches in the upper Deschutes Basin (Table 2). These instream rights serve as preliminary restoration targets. While DWA partners do not necessarily expect these targets to fully restore aquatic, riparian and floodplain processes, they serve as initial restoration targets that can be altered through a collaborative process involving input from local, state, and federal stakeholders. See the DWA companion paper, *Instream Flows*, for a more in-depth discussion of flow targets in the Deschutes Basin.

Table 2. Selected instream water rights in the upper Deschutes Basin

Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Deschutes R. - Wickiup Dam to L. Deschutes	300	300	300	300	300	300	300	300	300	300	300	300
Deschutes R.- L. Deschutes to Spring River	400	400	400	400	400	400	400	400	400	400	400	400
Deschutes R. -Spring River to N. Canal Dam	660	660	660	660	660	660	660	660	660	660	660	660
Deschutes R. below Bend	500	500	500	250	250	250	250	250	250	500	500	500
Little Deschutes River	200	200	236	240	240	200	126	74.5	92.2	116	164	196

Figure 2 shows the median discharge under current reservoir operations in relation to the flow targets and the estimated natural discharge.

Figure 2. Instream flows in the upper Deschutes River reach, 1968 – 1997



Storage operations influence stream flows most critically between River Mile 226, just below Wickiup, and River Mile 195, near the mouth of the Little Deschutes River. Tributary inflows from the Little Deschutes, Fall River and Spring River buffer the effects of the dam operations further downstream.

The change in the flow regime has altered the channel bank stability, degraded water quality, reduced fish habitat, and created channel sedimentation problems downstream in Bend. Flow alterations are a major contributor to water quality problems in the upper Deschutes, resulting in sections of the river being listed as water quality impaired under the Clean Water Act (Table 3). In addition, increased water temperatures in Crane Prairie due to its shallow pool affects water quality in the river.

Table 3. 303(d) listed sections of the upper Deschutes River reach

River	River Mile	Parameter	Season	Year Listed
Deschutes River	162.6 to 168.2	pH	Summer	1998
Deschutes River	162.6 to 168.2	Temperature	Summer	2002
Deschutes River	162.6 to 168.2	Temperature	September 1 - June 30	2002
Deschutes River	168.2 to 189.4	Chlorophyll a	June 1 - September 30	2002
Deschutes River	168.2 to 189.4	Dissolved Oxygen	July 1 - August 31	2002
Deschutes River	168.2 to 189.4	Dissolved Oxygen	September 1 - June 30	1998
Deschutes River	168.2 to 189.4	Sedimentation	none stated	1998
Deschutes River	168.2 to 189.4	Temperature	September 1 - June 30	2002
Deschutes River	168.2 to 189.4	Turbidity	Spring/Summer	1998
Deschutes River	189.4 to 222.2	Turbidity	Spring/Summer	1998
Deschutes River	189.4 to 222.2	Dissolved Oxygen	September 1 - June 30	1998
Deschutes River	189.4 to 222.2	Sedimentation	none stated	1998

Source: DEQ 2006

The operation of Crescent Lake Reservoir on Crescent Creek, a tributary to the Little Deschutes River, has created a similar pattern of flow alteration, but at a smaller scale. The flow fluctuations, however, do contribute to accelerated stream bank erosion throughout the reach. Crescent Lake operations also contribute to extreme fluctuations on Crescent Creek from the dam to the creek's confluence with major tributaries such as Big Marsh Creek and Cold Springs Creek. Because the scale of impact from Crane Prairie and Wickiup Reservoirs is significantly greater, the rest of this paper will focus largely on operations and opportunities in these two reservoirs. Impacts and opportunities associated with Crescent Lake should be further explored in the future.

Impacts on the Middle Deschutes River

Figure 3. North Canal Dam at approximately 30 cfs

The majority of the effects in the middle Deschutes River reach from reservoir management occur during the summer irrigation season. The middle Deschutes River reach is defined as the reach from North Canal Dam in Bend (Figure 3) to the confluence with the high water mark of Lake Billy Chinook. Reservoir operations alter the flow of the middle Deschutes River by up to 50% of its historic natural flow on a long-term average basis. The effect of alterations is minimized downstream of the confluence of Whychus Creek due to both surface and groundwater inflows near the mouth of the creek.

Irrigation districts divert up to 97% of the water at the head of the middle Deschutes River reach, which includes both natural flow and stored water components. A "gentlemen's agreement" between irrigation districts allows approximately 30 cfs to be released by the Watermaster below Bend to enhance instream flows. The flow below Bend exceeds 30 cfs in the summer only in wet years. In the relatively wet years of the late 1990s, the flow below Bend averaged between 150 to 400 cfs during the summer months. Tributary streams to the middle Deschutes River reach, which also suffer from extremely low flows due to irrigation withdrawals, provide only about 5-10 cfs each during much of the summer. A variety of tools exist to restore summer flows in the middle Deschutes, many of which are discussed in the DWA companion papers on urbanization and conservation. Flows in the upper Deschutes between Wickiup and Bend, however, can only be addressed through reservoir management. For that reason, the rest of this paper will focus on opportunities specific to flow restoration in the upper Deschutes River.

4.1.2 Crooked River Basin Reservoirs

Prineville Reservoir

Prineville Reservoir is located southeast of Prineville at River Mile 70 on the Crooked River. The reservoir was built by Reclamation in 1960, is authorized solely for flood control and irrigation, and it has an active conservation pool of 148,633 AF. The reservoir serves as a supplemental water supply for the Ochoco Irrigation District (OID) around Prineville, and provides primary and supplemental water for other private storage accounts.

The required minimum release out of Prineville Reservoir is 10 cfs measured at the gaging station 0.4 miles downstream from the reservoir. For the past 11 years, Reclamation, OID, ODFW and OWRD have agreed to release 75 cfs in the winter when water is available to enhance flows and support the trout fishery below the dam.

Approximately 80,360 acre-feet of uncontracted space remain in Prineville reservoir. This space could be allocated for a variety of demands, including new uses such as instream flow enhancement, and current uses such as irrigation. Reclamation has launched at least three studies on reallocating the remaining space in the reservoir, but it has never completed the reallocation process. The most recent study ran from 1997-2001. Any future analysis to restore streamflow in the Crooked River should seriously incorporate opportunities for reallocation of this water.

Ochoco Reservoir

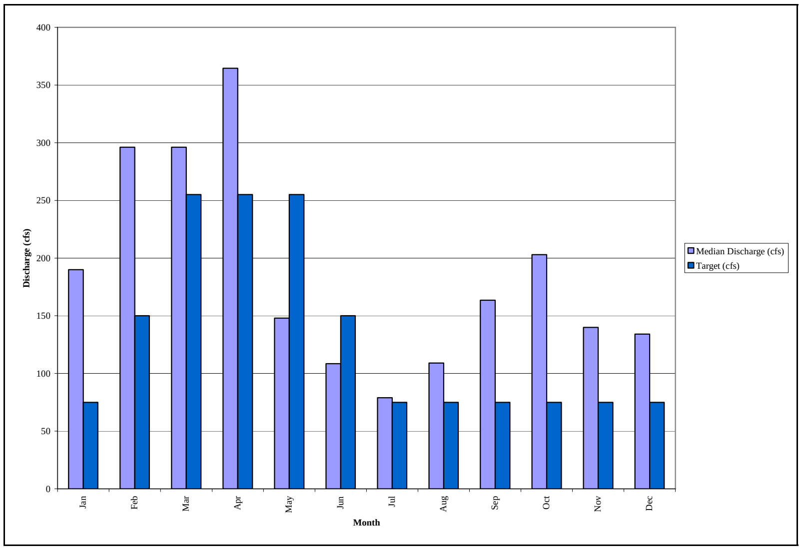
Ochoco Reservoir is located approximately five miles due east of the town of Prineville on Ochoco Creek. This facility was built by private interests for irrigation in 1922. Reclamation completed major modifications to the reservoir's dam in the 1940s, 1950s, and 1990s. During the last set of modifications, Reclamation breached the dam, placed new upstream face material, and installed draining and lining systems to prevent seepage. The reservoir holds approximately 44,000 acre-feet of water when full and is fully allocated to irrigation for the Ochoco Irrigation District. This reservoir is also used as a flood control reservoir for Ochoco Creek which runs directly through the middle of the town of Prineville.

Impacts on the lower Crooked River and its tributaries

The Crooked River and Ochoco Creek have different hydrograph patterns than streams and rivers on the western side of the Deschutes Basin, including the upper and middle Deschutes River reaches. The geology of the drainage area is comprised of much older, finer-grained rocks and clays. The natural geology, combined with human impacts in the floodplain, reduce infiltration and make these systems prone to dramatic run-off events. Consequently, late season flows into the reservoirs are very low and net inflow is less than zero when evaporation exceeds inflow. Precipitation in these drainages is lower than precipitation on the western side of the basin, resulting in lower annual runoff. The Crooked River at Bowman Dam (Prineville Reservoir), for example, yields approximately 273,000 AF from a 2,700 square mile drainage area, while the Deschutes River at Benham Falls yields 1,100,000 AF from a 1,759 square mile drainage area.

Ochoco and Prineville Reservoirs have altered the natural hydrographs of Ochoco Creek and the Crooked River, reducing flows below the reservoirs during the storage season, and increasing historic flows during the irrigation season, up to the points of diversion whereafter flows drop significantly due to irrigation diversions. Figure 4 shows the median discharge in relation to the instream flow targets set by the Oregon Department of Fish and Wildlife. Because these two reservoirs are operated in a much different hydrologic environment and have different authorities, requirements, and operation criteria than the Deschutes River reservoirs, they should be explored more in depth in a different paper. However, reallocation of the uncontracted space in Prineville Reservoir represents the major opportunity to enhance streamflows and meet other water demands in the basin. This option will become increasingly important with the pending reintroduction of anadramous fish above the Pelton Round Butte Dam complex.

Figure 4. Discharge in the lower Crooked River, 1968-2004



5 HISTORIC OPERATION OF RESERVOIRS

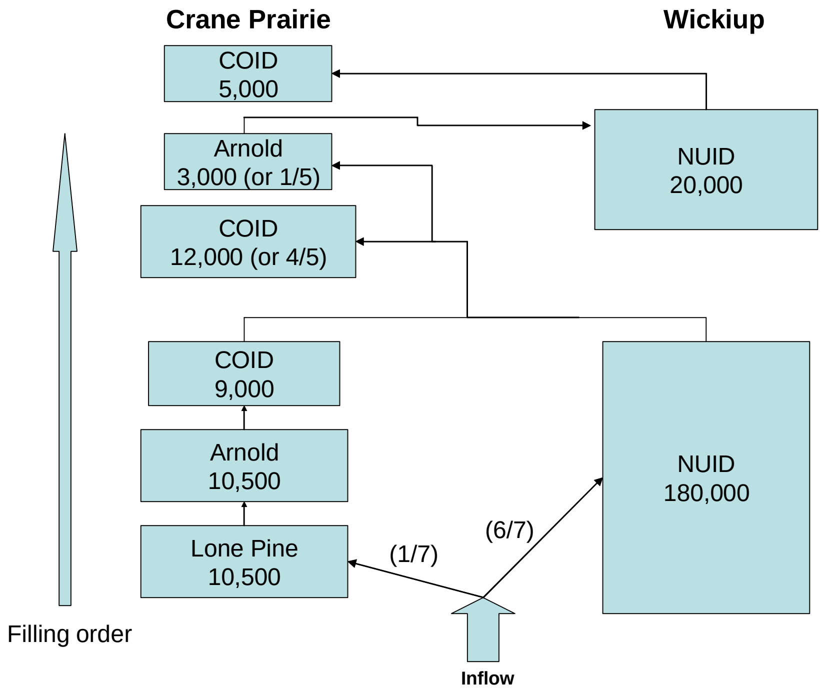
5.1 Irrigation Storage and Storage Period

This section focuses on characterizing storage patterns in Crane Prairie and Wickiup Reservoirs, and to a lesser extent Crescent Lake. The information here provides the foundation for the reservoir management opportunities that will be discussed.

Crane Prairie Reservoir is the supplemental storage supply for Crook County Improvement District #1 (Lone Pine), Arnold Irrigation District and Central Oregon irrigation District, who together share 50,000 AF of water stored in Crane Prairie. Wickiup Reservoir is the supplemental storage supply for North Unit Irrigation District who holds rights to 200,000 AF. Storage and allocation of this water is governed by a 1938 inter-district agreement ("agreement").

The agreement describes in detail the accounting methods to be used to fill the reservoirs during the storage season, which generally occurs between mid-October and early April (Figure 4). The terms of the agreement account for years of shortage such that, at capacity, Wickiup receives 80 percent of the inflow and in dry years Wickiup receives 85.7 percent of the inflow.

Figure 4. Filling sequence described in the 1938 Inter-District Agreement (AF)



Note: Filling order proceeds from the bottom of the chart to the top of the chart, following the arrows.

Wickiup operations currently require a minimum outflow of 20 cfs, which is set at the end of the irrigation season. The OWRD tries to comply with target ramping rates set by the Upper Deschutes Wild and Scenic River Management Plan, adopted by the USDA Forest Service in 1996 (Table 5).

Table 5. Upper Deschutes Wild and Scenic River flow targets & ramping rates

	Current Practice	Intermediate Flow Targets			Long Term Flow Target
Minimum	20 cfs	50 cfs	100 cfs for 90% of time[2]	200 cfs for 90% of time[2]	300 cfs for 90% of time[2]
Maximum	No limitation	1650 cfs	1600 cfs	1500 cfs	1400 cfs
Ramping Rate Rising	0.5 ft/day	0.1 ft/4 hr			
RR falling	0.5 ft/day[3]	0.2 ft/12 hr			

Source: Adapted from Table 9 in the Upper Deschutes River Wild and Scenic River adaptive management plan (1996).

1. Flow as measured at the Wickiup Gage #14056500
2. 90% of the time means that on the average 9 out of 10 years the minimum flow would be maintained in the river in winter.
3. Existing standards for flow management allow a ramping rate of 1.0 ft/hour. In practice, the watermaster attempts to limit changes to 0.5 ft/day.

In most years, natural inflow into the reservoirs is steady and the Watermaster tries to keep a constant outflow below Wickiup throughout the storage season. In above average to wet years when the reservoirs are expected to fill, the Watermaster estimates the additional water that can be released throughout the storage season and sets the outflow from Wickiup accordingly. The Watermaster attempts to keep outflow from Wickiup as uniform as possible, but when forecasting has been less accurate, the outflow has fluctuated from the minimum of 20 cfs to nearly 500 cfs by the end of March.

5.2 Storage Use by District

The five irrigation districts that use stored water from the Deschutes River reservoirs have very different storage needs. District storage use ranges from occasional to constant, with some districts needing storage water during most of the season during a normal year and some districts needing storage water only during dry years.

The figures in this section reflect preliminary research into average and annual district storage use. The data is from storage records kept by the Oregon Water Resources Department, and reflects the time period 1986-2005, with several years excluded due to data gaps, most of which were wet years where storage records were not generated. Thus, the average numbers are likely higher than actual averages, as they do not reflect years of non-use. It is important to keep in mind that averages do not reflect dry-year conditions. District use in dry-year conditions is best represented by their use in 1994, a very dry year.

District storage accounts get charged each year for both the storage that gets delivered to them, as well as some portion of the losses that occur in the reservoirs through evapotranspiration and seepage. The bar graphs represent water charged to the district's account (total 'used') compared to the district's total storage available each year. The pie charts denote averages, and break out actual use (water delivered from the reservoirs), reservoir loss that was charged to the district's account, and the amount of unused water remaining at the end of the season.

5.2.1 North Unit Irrigation District (NUID)

North Unit has the right to store 200,000 AF and depends on the supply from Wickiup every year to meet irrigation demends. NUID, being the most junior water right holder in Deschutes River system, fail to meet their demand from natural flow in every year. In some years, such as 2005, they depended completely on supply from Wickiup between May 15th and September 15th. The NUID restricts patron water use during dry years in order to decrease demand. In Figure 6, note the low percentage of reservoir loss relative to use.

Figure 5. NUID storage availability & use, 1986-2005

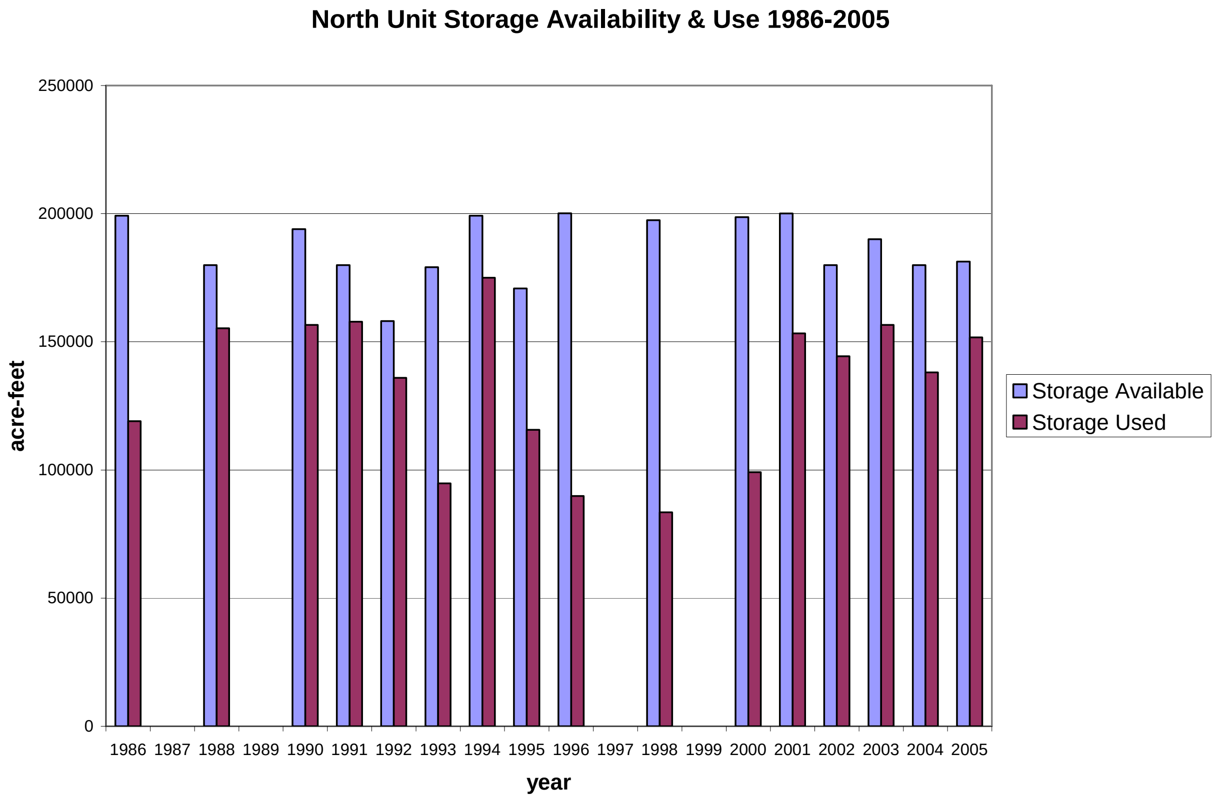
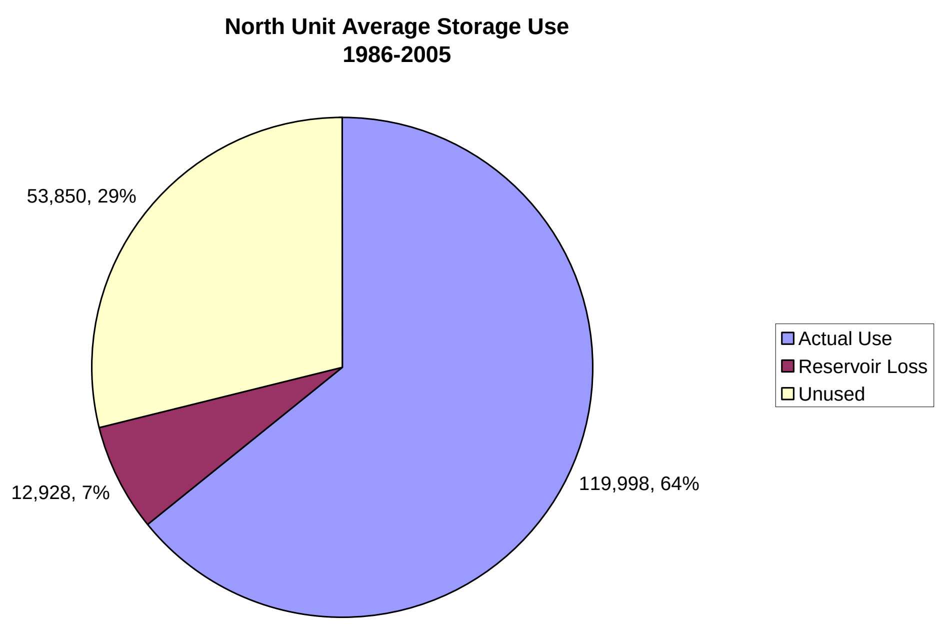


Figure 6. Average NUID storage use, 1986-2005



5.2.2 Crook County Improvement District #1 (Lone Pine)

Lone Pine is able to store a total of 10,500 AF, and because it has the first fill rights to Crane Prairie, it also receives 10,500 AF. Lone Pine relies on some storage usage every year. In normal years, the district relies on storage from Crane Prairie to supplement their natural flow right when irrigation demands are at their peak. In the driest years, which occur 2 to 3 times per century, Lone Pine may rely totally on stored water. Notice in Figure 8 the high percentage of loss relative to use, which is the case for each District that uses Crane Prairie Reservoir.

Figure 7. Lone Pine storage use and availability, 1986-2005

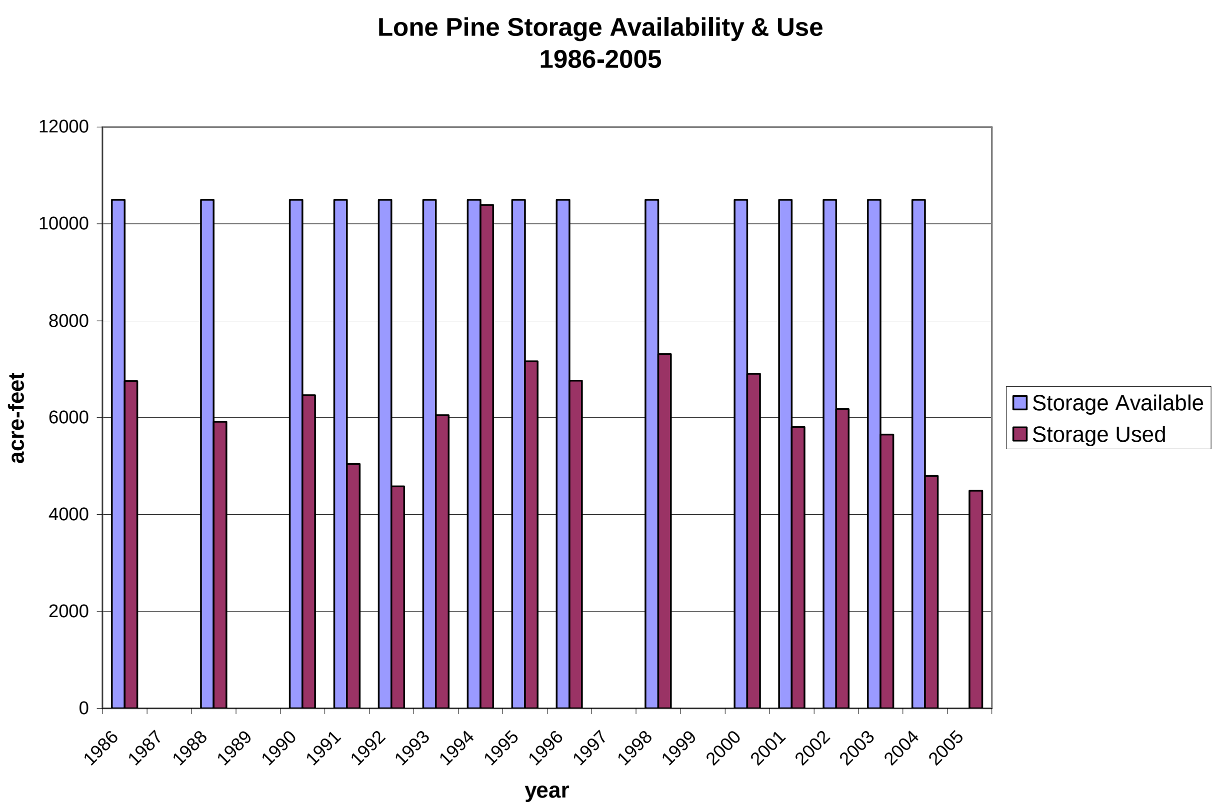
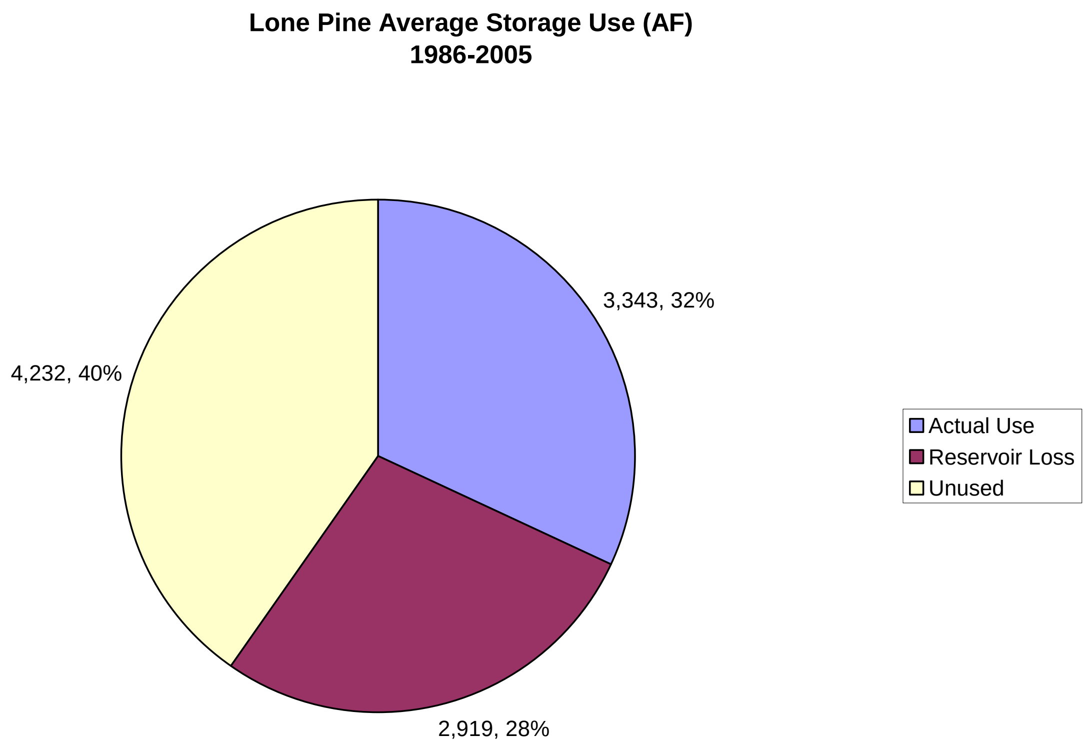


Figure 8. Average Lone Pine storage use, 1986-2005



5.2.3 Arnold Irrigation District (AID)

Arnold uses storage on a limited basis. The district has the right to store up to 13,500 AF in Crane Prarie, and uses all of this storage only in the driest of years. The district's needs are met almost exclusively through Deschutes River flows during normal years. In a dry year, such as 2005, the AID relies almost totally on storage during the latter part of the summer. In two occasions over the past 50 years, AID demand has exceeded both storage availability and Deschutes River flows. The district ran out of water and had to shut down operations in 1941 and 1994.

Figure 9. AID storage use and availability, 1986-2005

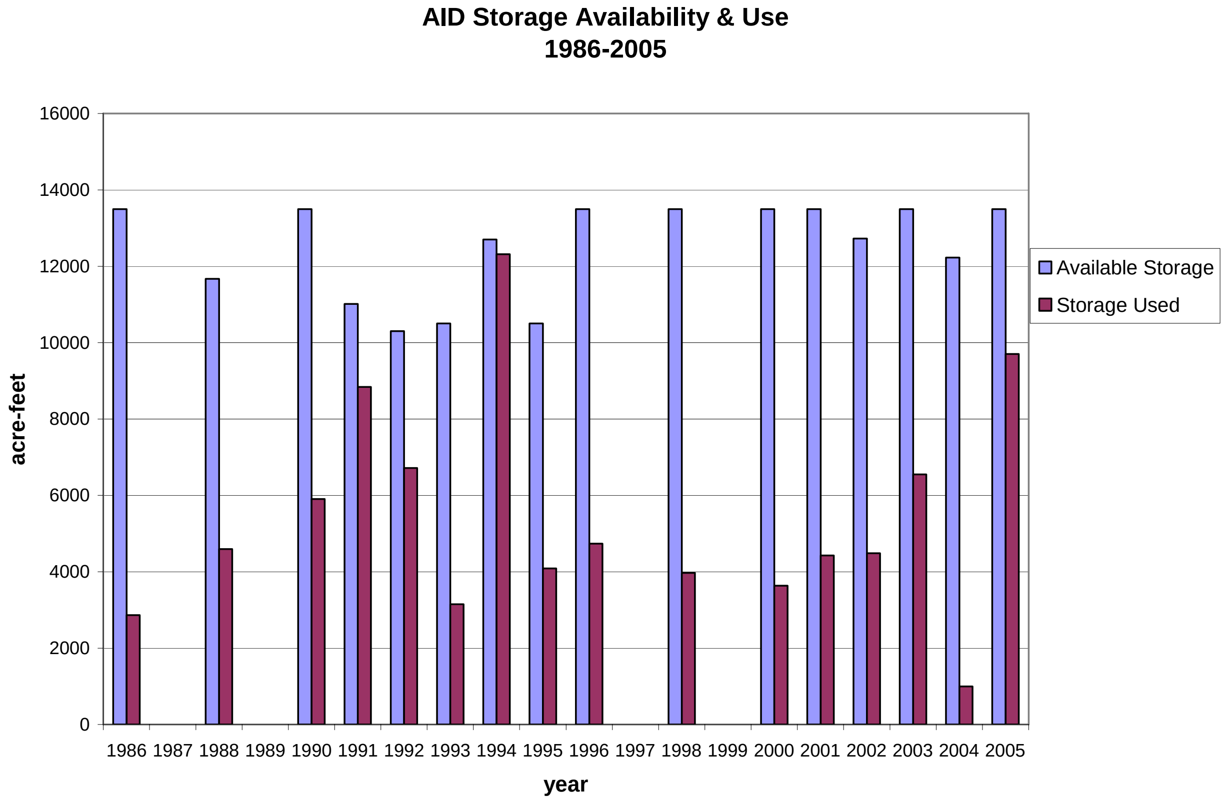
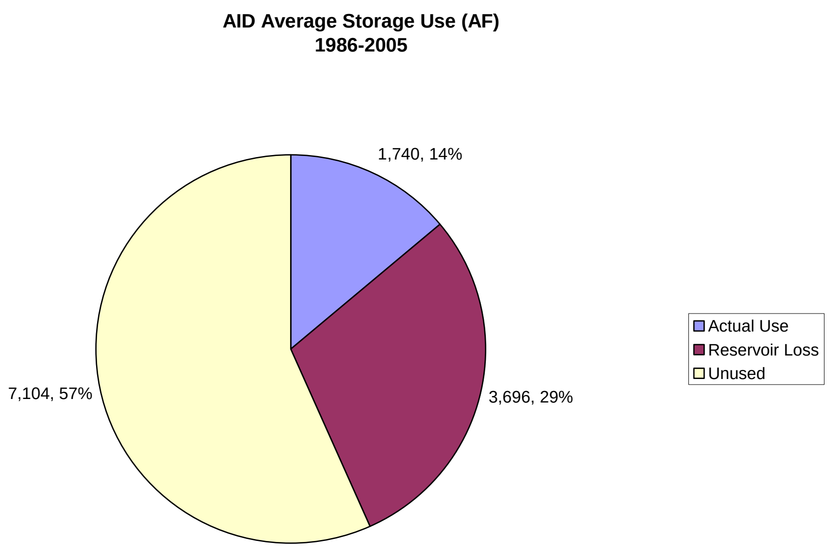


Figure 10. Average AID storage use, 1986-2005



5.2.4 Central Oregon Irrigation District (COID)

COID has the largest storage right in Crane Prairie at 26,000 AF. COID also has a senior priority date for Deschutes River flows and does not rely heavily on stored water to meet their needs in dry years. The district uses roughly 2-3 percent of their total diversion from storage, and use occurs in the early and late part of the season, when the rate on its natural flow right is not sufficient to meet its irrigation demand.

Figure 11. COID storage use and availability, 1986-2005

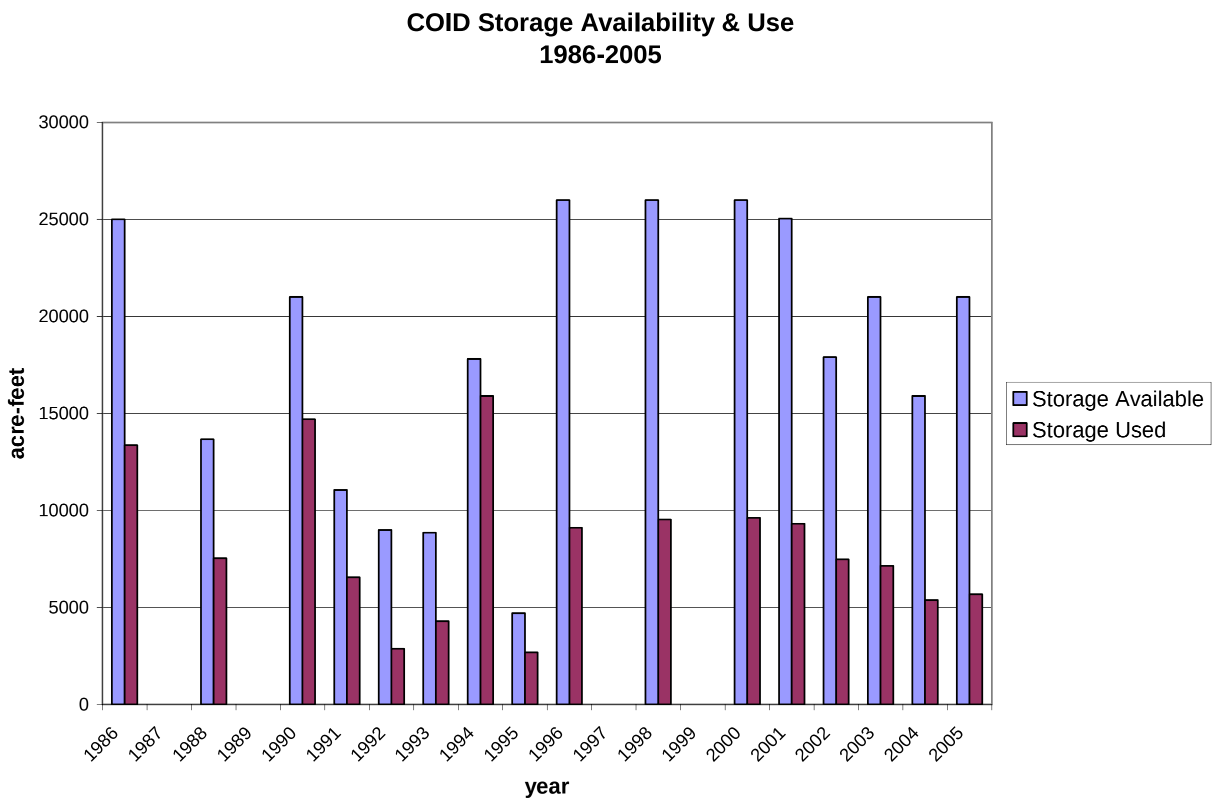
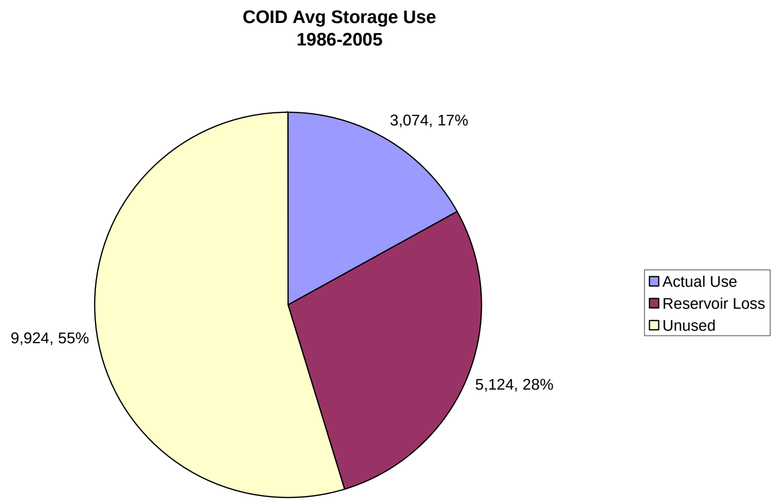


Figure 12. Average COID storage use, 1986-2005



5.2.5 Tumalo Irrigation District (TID)

Tumalo uses Crescent Lake water as a supplemental supply each year. The district has two priority dates for storage within the reservoir. Their 1911 priority date restricts filling more than 35,000 AF in any one year and their 1961 priority date allows TID to fill the reservoir to its 86,050 AF capacity water right. This junior right adds an additional 51,050 AF of storage to TID's account. TID relies on this stored water every year as their supplemental source, as Tumalo Creek diminishes late in the season. TID normally uses approximately 15,000 to 20,000 AF per year from Crescent Lake when it is available.

5.3 District Summary

Table 6 summarizes the average amount of water available and used by districts in Crane Prairie and Wickiup. Average total use identifies the average volume charged to each district's account, which includes actual use and reservoir loss. Table 7 identifies the maximum amount of storage used annually by district (dry-year scenario) during the period of record.

Table 6. Average storage availability and use by district, 1986-2005

District	Max Right (AF)	Average Available (AF)	Average Total Use (AF)	Average Actual Use (AF)	Average Reservoir Loss (AF)	Avg End-Year Contents (AF)
Lone Pine	10,500	10,500	6,267	3,343	2,924	4,232
Arnold	13,500	12,540	5,436	1,740	3,696	7,104
COID	26,000	18,122	8,197	3,074	5,124	9,924
North Unit	200,000	186,777	132,927	119,998	12,928	53,850
Total	250,000	227,939	152,827	128,155	24,672	75,111

Table 7. Maximum annual storage use by district during period of record

District	Max Right (AF)	Max Total Use (AF)	Max Actual Use (AF)	Max Loss (AF)
Lone Pine	10,500	10,390	6,404	3,986
Arnold	13,500	12,316	7,735	4,581
COID	26,000	15,899	10,217	5,682
North Unit	200,000	175,017	161,036	13,981
Total	250,000	213,622	185,392	28,230

Figure 13 shows the average storage use during the period of record in Crane Praire and Wickiup Reservoirs combined, while Figure 14 shows the combined storage use in Crane Prairie and Wickiup in 1994, a dry year.

Figure 13. Average Combined Storage Use in Crane Prairie & Wickiup

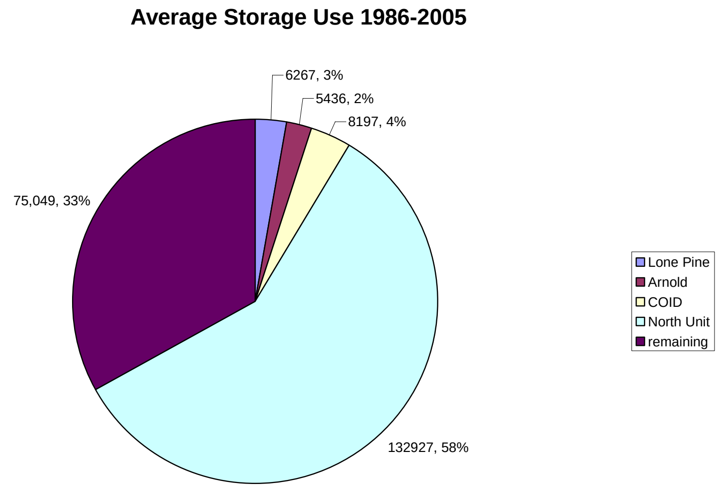
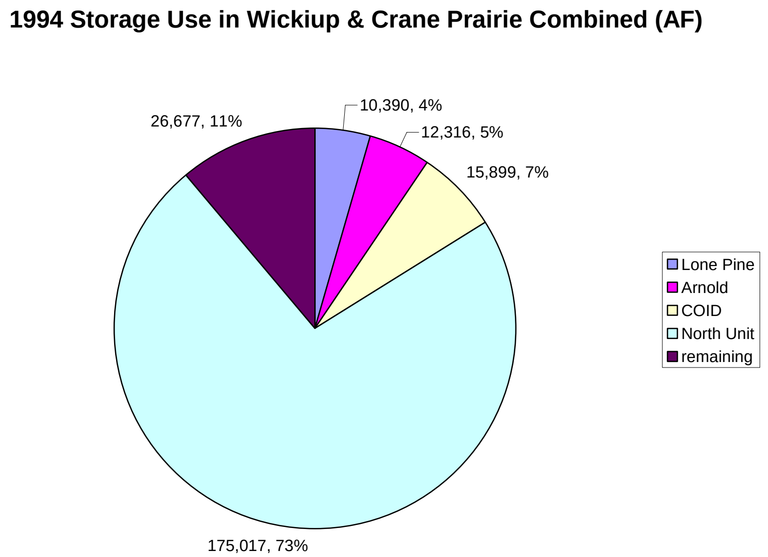


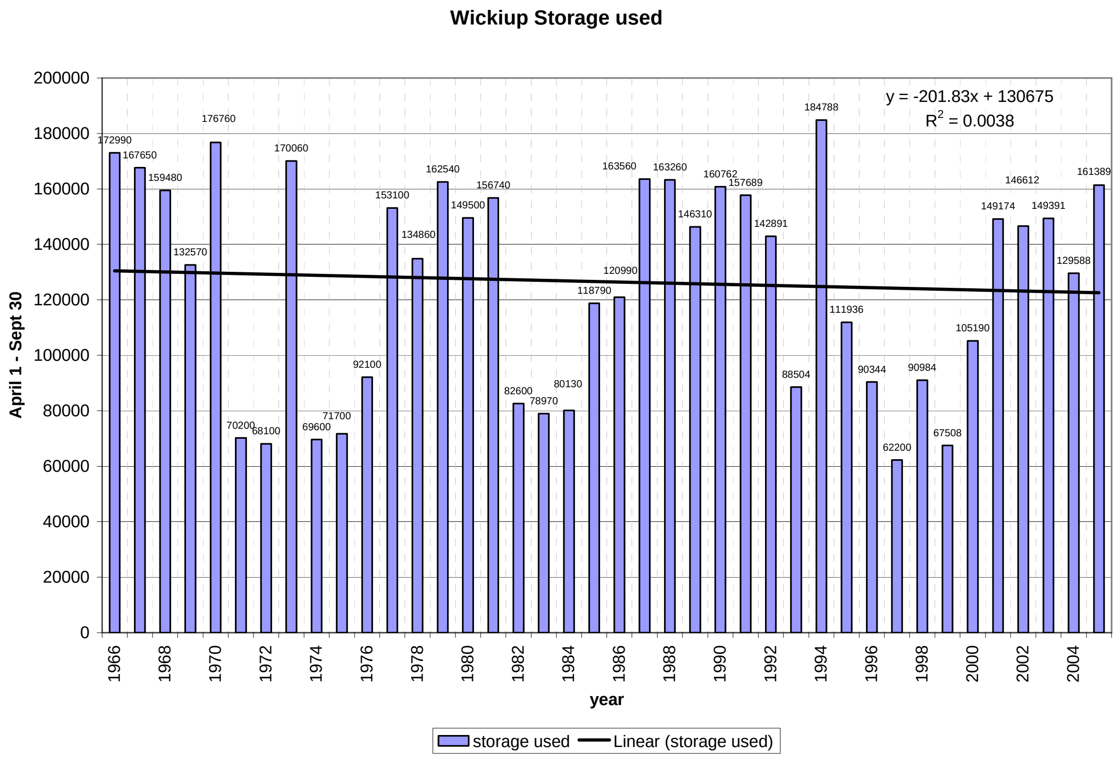
Figure 14. 1994 Combined Storage Use in Crane Prairie & Wickiup



5.4 Storage Operations: Wet and Dry Cycles

Storage operations change annually with water availability, and all five irrigation districts decrease their storage use during wet years. Wickiup storage use reflects the variation between wet and dry year storage use (Figure 15). 1997 provides an example of a wet year, while 1994 provides an example of a dry year. Wickiup storage use during the period of record ranged from a low of 62,200 AF in 1997 to a high of 184,788 AF in 1994. The amount of storage used directly relates to how much water is available as natural flow during the year. Figure 15 shows a declining trend in storage use over the period of record.

Figure 15. Storage used in Wickiup Reservoir between April 1 and September 30, 1966-2004



Figures 16 and 17 show the spring contents for Crane Prairie and Wickiup and again are dominated by the wet and dry weather cycles. Note the short period of time between wet and dry years, averaging about six years between wet and dry cycles.

Figure 16. Spring contents in Crane Prairie Reservoir, 1966-2005

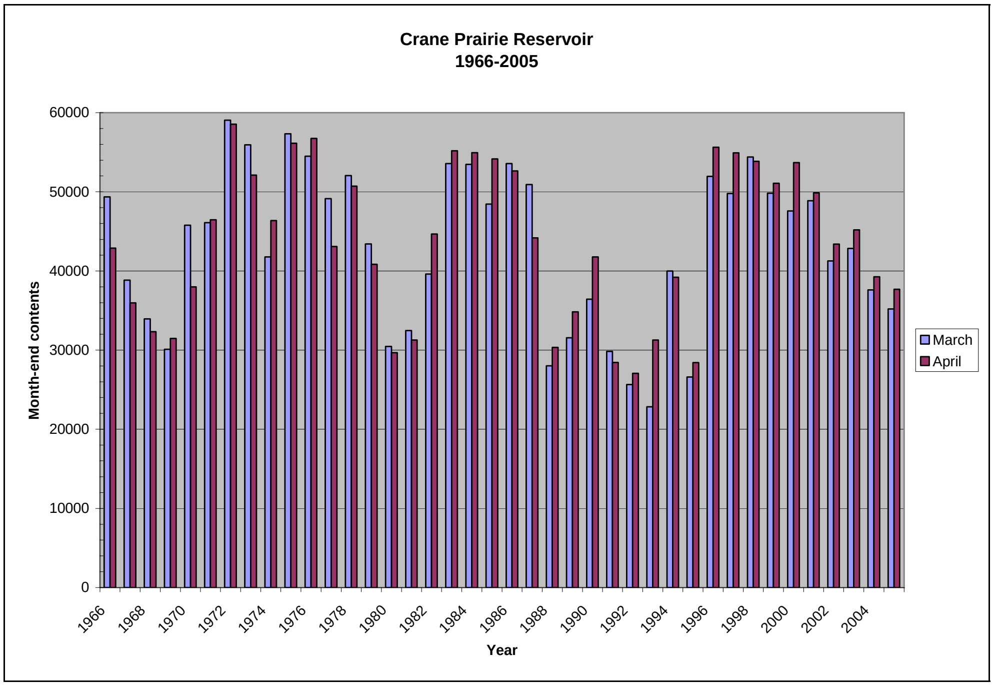
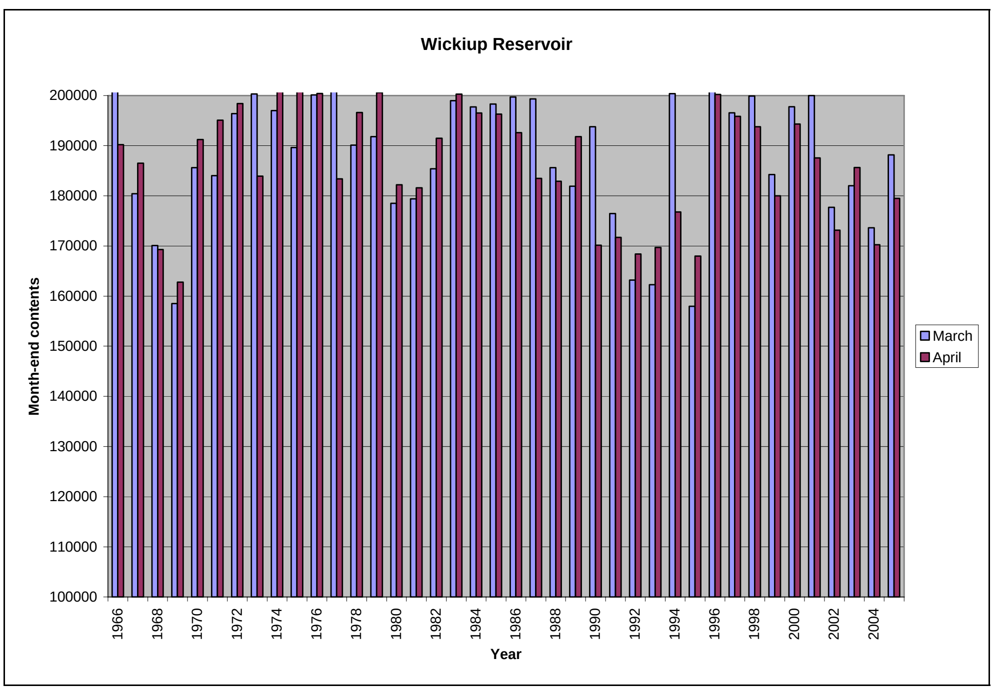


Figure 17. Spring contents in Wickiup Reservoir, 1966-2005



Existing agreements require minimum discharges from the three Deschutes River reservoirs. Minimum discharge requirements are totaled in Table 8.

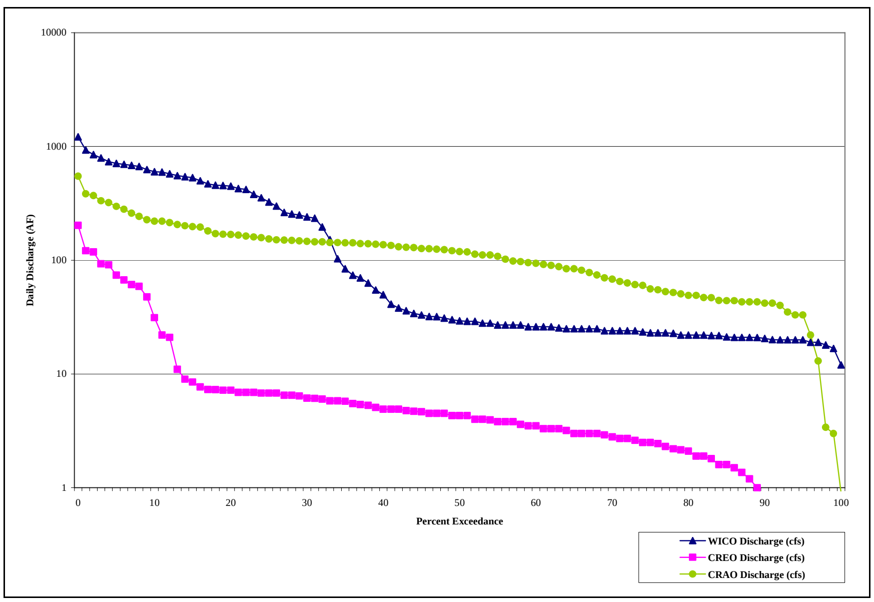
Table 8. Discharge requirements and storage season discharge calculations.

Location	Discharge(cfs)	Discharge (AF/day)	Location of change in slope of exceedance curve (AF)
Blw Crane Prairie	30	1782	2000
Blw Wickiup	20	1188	1500
Blw Crescent Lake	10	594	650

*The target is set by the Oregon Water Resources Department for Crane Prairie and Crescent Lake outflows as there are no required minimums.

Exceedance analyses for the three Deschutes River reservoirs help to demonstrate annual differences in storage operations. While the reservoirs show different discharge patterns, higher discharges are less common than lower discharges for each reservoir (Figure 19).

Figure 18. Exceedance curves for storage season discharge from three Deschutes River reservoirs, 1968-1997



WICO=gage below Wickiup
CREO=gage below Crescent Lake
CRAO=gage below Crane Prairie

No distinguishable steps appear in Crane Prairie's discharge exceedance curve. The lack of a clear step in Crane Prairie's exceedance curve likely comes for two reasons. First, Crane Prairie's storage allowance is largely dictated by the Wickiup outflow. Second, the Deschutes River at Crane Prairie has a much smaller range of flows than the Deschutes River at Wickiup. A break does appear around 33 cfs; discharge from Crane Prairie exceeded 33 cfs during 95% of the storage season.

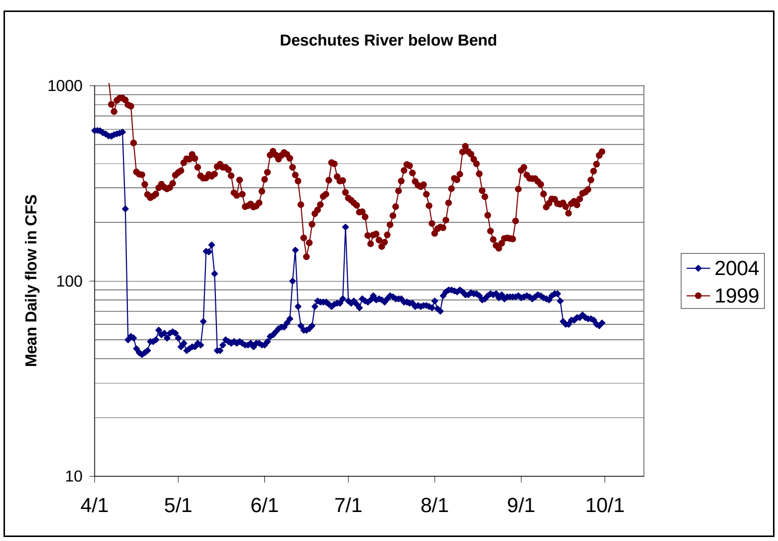
A clear step does appear in Wickiup's discharge exceedance curve. An increase in slope appears appears around 34 cfs. Daily discharge exceeded the required 20 cfs target during 93% of the period of record, and exceeded 34 cfs during 44% of the period of record

Storage use varies during wet and dry years. Correspondingly, Deschutes River discharge below Bend varies during wet and dry years. Two examples illustrate the difference in discharge between wet and dry years. The 1999 water year illustrates wet year discharge use, while the 2004 water year illustrates dry year storage use. During dry years, districts will divert all of the water available from natural flows and call for storage releases from Crane Prairie and Wickiup Reservoirs. When diversions and releases are managed efficiently during a dry year, the discharge in the Deschutes River below Bend should not exceed 30 cfs plus any additional water leased or permanently protected instream. Discharges in excess of this amount will only occur during wet years due to natural flows.

The 1997-1999 water years were relatively wet years. During the 1999 water year, very little water was leased or permanently protected in the Deschutes River. Discharge below Bend in excess of 30 cfs was mostly due to natural flows. Discharge in the Deschutes River below Bend averaged 299 cfs during the 1999 irrigation season, an increase of 265-270 cfs above the historic average summer flow. Discharge in the Deschutes River below Bend peaked above 400 cfs on several days.

In contrast, in the dry year 2004 the discharge remained between 40 and 60 cfs (Figure 20). This discharge includes water legally protected instream by the Deschutes River Conservancy's leases and 30 cfs of water protected by the Gentleman's Agreement.

Figure 19. Dry year and wet year discharge in the Deschutes River below Bend



5.5 Carry Over & Minimum End of Year Content Targets

Some irrigation districts rely on storage every year. The Watermaster needs to maximize carry – over storage each season in order to maximize next year's storage in case of drought. In dry years, this step is critical, but in wetter years this step is not as important. During wet years, the Watermaster only needs to restrict the outflow from Wickiup Reservoir so as to minimize changes in flow, as requested by ODFW.

End of season reservoir carry-over amounts can be summarized by taking the month-end reservoir contents for September, as this is essentially the end of the more intensive part of the irrigation season. Irrigation diversions do occur in October, but they are much less than peak diversions and usually end by mid to late October. Carry-over reservoir storage amounts follow a cyclical pattern (Figure 21). These storage amounts relate to water availability during the preceding water year. In wet years, the reservoirs maintain a substantial carry-over and in dry years the reservoirs are drawn down. Carry-over water is not kept in specific district storage accounts, but is automatically attributed to the filling sequence described in the agreement.

Figure 20. September month-end contents in three Deschutes River reservoirs, 1966-2004

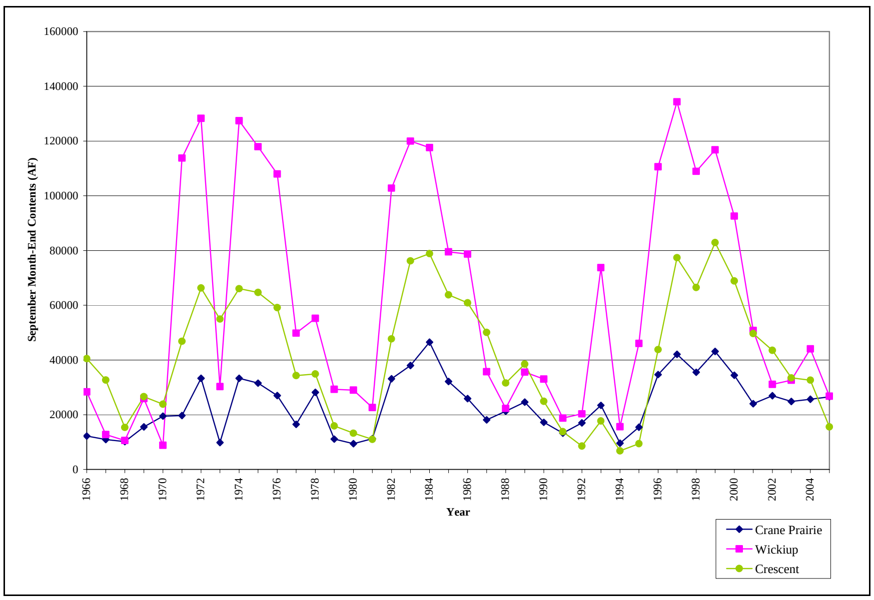
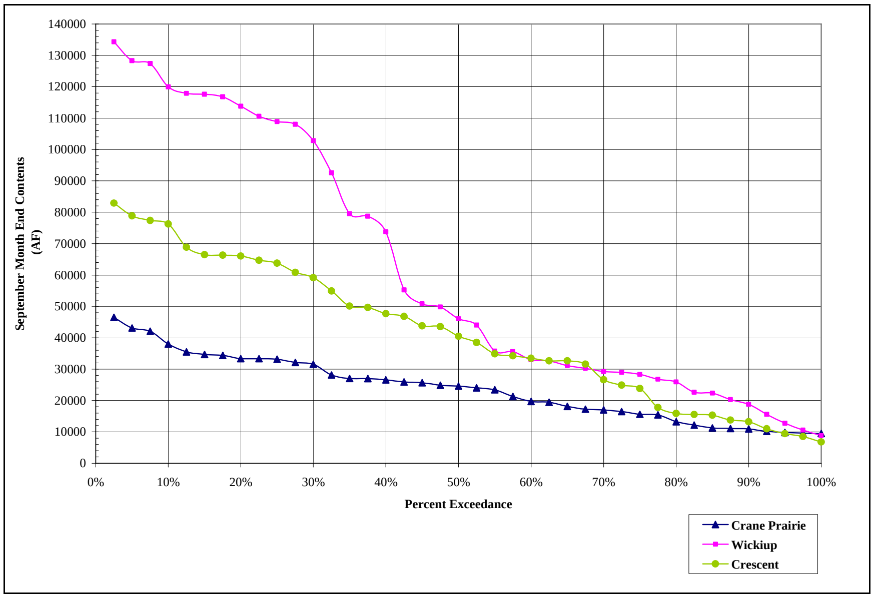


Figure 21. Exceedance curve for September month-end contents in three Deschutes River reservoirs, 1966-2004



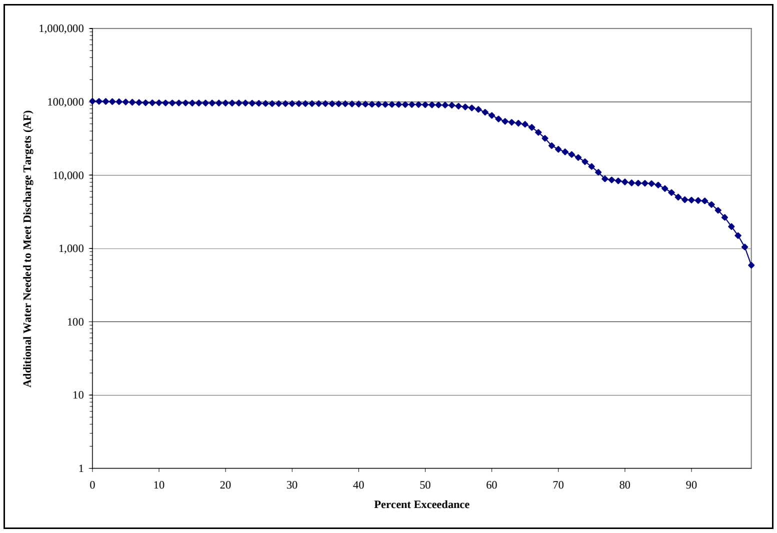
Considerations other than irrigation needs do factor into the management of the reservoirs. ODFW requests that changes in Crane Prairie outflow are minimized during fish spawning periods in the fall, and they request that reservoir drawdown be minimized. The fisheries in the reservoirs are negatively impacted when Wickiup storage decreases below 40,000 AF and when Crane Prairie decreases below 15,000 AF (ODFW, personal communication). These levels should be considered when looking at reservoir management. Figure 21 shows that Wickiup droped below the 410,000 AF target approximately 46% of the years, and Crane Prairie dropped below the 15,000 AF target approximately 22% of the years.

6 FLOW NEEDS TO MEET INSTREAM TARGETS

6.1 Upper Deschutes River

Certificated instream rights serve as preliminary targets for flow enhancement in the Deschutes River below Wickiup Reservoir. Currently, the instream flow target is 300 cfs. ODFW applied for and had this right certificated based on extensive fish studies. The right, however, is junior to the district storage rights, and so it is not protectable through regulation by OWRD under the current water rights regime. Average daily discharge reached or exceeded this target on 26% of the days during the 1968-1997 storage seasons. Assuming a constant minimum discharge of 20 cfs, meeting the target of 300 cfs 100% of the time would require an additional 100,000 AF discharged instream during the storage season.

Figure 22. Exceedance curve for additional water needed to reach targets below Wickiup Reservoir 100% of the days during the storage season, 1968-1997 water years.



In reality, the need is not always 100,000 AF. This increase ranged from over 100,000 AF to under 1,000 AF over the period of record. Over the 30 year period of record, the annual average increase in discharge required to reach targets is approximately 60,000 AF (see Table 9).

Changes in discharge timing could help to meet targets without increasing total annual storage season discharge. Discharge in excess of the 300 cfs flow target occurs in some years. Daily average flows exceeded 300 cfs during approximately 26% of the time during the storage season (October through March) between the 1968 and 1997 water years. This ‘excess discharge’, or ‘spill’ does not occur in every year; it depends on hydrologic conditions. Excess storage season discharge ranged from 0 to almost 84,000 AF during the period of record, averaging 24,000 AF/year (Table 9). It should be noted that this ‘spill’ water likely does have ecological benefit, so should not necessarily be considered as ‘excess.’

Table 9. 'Excess' storage season (Oct-Mar) discharge ('spill') and instream flow needs, 1968-1997

Water Year	Storage Season Discharge in Excess of Target (AF)	Additional Water Needed to Reach Target 100% of Days (AF)
1968	0	97,014
1969	0	93,992
1970	0	92,027
1971	0	92,374
1972	59,599	4,640
1973	68,449	1,884
1974	0	90,036
1975	80,904	4,424
1976	65,869	8,894
1977	14,385	23,754
1978	0	100,247
1979	0	94,389
1980	0	96,080
1981	0	96,120
1982	0	96,235
1983	63,678	17,288
1984	67,172	135
1985	83,718	7,845
1986	23,852	48,734
1987	7,510	54,755
1988	0	91,420
1989	0	101,734
1990	0	94,407
1991	0	94,296
1992	Not Available	Not Available
1993	0	96,596
1994	0	81,029
1995	Not Available	Not Available
1996	Not Available	Not Available
1997	119,926	7,623
Median		91,420
Average		62,517

6.2 Middle Deschutes River

Pending instream rights serve as flow restoration targets in the middle Deschutes River. These rights are generally not met during the summer when water is required for irrigation, and storage re-allocation may not affect how often they are met. Annual water needed to meet instream flow targets below Bend range from approximately 25,000 AF to almost 100,000 AF. Solutions other than storage allocation will form the majority of the water acquired for restoring the middle Deschutes River, so storage discharge will not be discussed further. The remainder of the paper will discuss reservoir management opportunities to meet instream targets in the upper Deschutes, while meeting irrigation needs.

7 RESERVOIR MANAGEMENT TO MEET AGRICULTURAL AND INSTREAM NEEDS

Given the magnitude of the water required, meeting the instream flow needs in the Upper Deschutes below Wickiup is a significant challenge. The objective in this paper is to explore scenarios that meet flow needs while also maintaining or increasing water reliability for agriculture. For example, a regulatory approach to reallocating water would be one method of moving towards the flow needs. However, given current operating practice – including current forecasting ability, the inter-district contract governing allocations and current irrigation demand – it is unlikely that significant water could be made available through regulation by the Oregon Water Resource Department without imposing a shortage on junior storage users at the end of dry periods. The regulatory option is therefore not explored further here. Rather, only collaborative and voluntary approaches are pursued.

There are a number of potential collaborative opportunities to meet instream flow targets in the upper Deschutes without negatively affecting the reliability of existing irrigation water rights. They fall into six categories:

1. optimization under the current water rights and water use regime
2. trading or renegotiation of storage allocations
3. conserved water protected instream
4. instream transfer of storage rights
5. reductions in demand by irrigators
6. resultant gains from reduced reservoir losses

Each opportunity is covered below, providing a description of the mechanism and a brief assessment of the potential contribution to the instream flow need. The objective is to provide a preliminary assessment that can be used. Information needs and further steps required to move beyond this initial brief assessment are also provided where relevant. This paper does not consider the potential impacts of global climate change on reservoir inflows. Future analysis should incorporate the best scientific information possible concerning climate change.

7.1 Reservoir Optimization

Optimal operation of reservoirs involves management of storage space available in anticipation of future inflows of water and current and future needs for stored water (Howard et al. 2000). Optimization can be used to increase efficiency and manage tradeoffs in reservoir management. There is a significant academic literature regarding methods for optimizing reservoir operation. There is also considerable practical experience with the development and application of decision support systems.

Much of the water resources engineering literature concerns the optimal operation of hydrothermal electric power systems and hydroelectric reservoirs. Early efforts tended to consider the application of deterministic release rules given stochastic flows. Subsequently authors attempted to determine optimal release (or operation) rules under different scenarios: Cypser (1953) using deterministic inflows in a two-reservoir system, Little (1954) employing stochastic and statistically dependent inflows at the Grand Coulee Dam, Gessford and Karlin (1958) using statistically independent inflows and infinite reservoir capacity, and Ahmed (1967) using stochastic and statistically independent flows in the single and multiple reservoir case for the Columbia River system.

Initially, methods to examine the dynamic nature of the optimization problem were limited to applications of the calculus of variations. In the late 1950s the development of dynamic programming led to an increase of activity in this field as efforts to develop modeling approaches yielding numerical algorithms and solutions became popular. Given the complexity of the problem, subsequent efforts have followed methodological developments in the field of dynamic optimization with attention in the 1980s and 1990s continuing to focus on linear and dynamic programming approaches (given the increased ability to runs such models on computers). Further developments include the application of optimal control methods, expert systems and fuzzy programming to the problem.

In practical terms the question addressed by optimization is whether improved information and modeling tools (decision support) would allow the operation of Crane Prairie and Wickiup to better meet agricultural and instream needs than has been the case historically. Implicitly, this means managing the reservoirs for multiple purposes rather than a single purpose. While it is likely that maintenance of stream flow below Wickiup has been a consideration in reservoir management, it is equally likely that instream flow has been a second priority after ensuring supplies for agriculture. Reservoir optimization in this case then begs the question of the relative priority of the purposes of storing and releasing water. As indicated above the emphasis of this paper is on ensuring that irrigation interests are served the same as, if not better than, under historic conditions.

This assumption simplifies the problem by assigning a much higher loss (or opportunity cost) to any change in the reliability of stored water for irrigation than for instream flow. The optimization question then is whether improved operational decision support produce additional water of value to either irrigation or instream purposes. As discussed in detail above, during wet periods, not all inflow to Crane Prairie and Wickiup is stored. These releases serve to support flows above the legal minimum (20 cfs) and up to the 300 cfs target. In very wet periods, these flows may also exceed the 300 cfs target (See Table 9). In an optimization framework in which the objective is to first meet irrigation needs and then meet instream needs it is this water (above 300 cfs) that is lost to desired uses – in a sense it is the water that is 'spilled'. Based on the 30-year time period used above (1968 – 1997) an average of 24,000 acre feet per year was 'spilled,' as discussed in section 6.1. The question then is whether improved decision support could have led to that water being available for irrigation needs or to meet the 300 cfs target.

A full study on precisely this topic would be required to assess the actual potential for re-operating the reservoir. These would vary from deterministic forecasts to long-range probability-based forecasts (Howard, 2000). Probably even more beneficial than examining these two reservoirs alone would be to examine how the Crooked River system reservoirs and the Deschutes reservoirs (including Crescent) could be re-operated to meet water resource management objectives for both sub-basins. Optimal operations would require development of software for forecasting reservoir inflows.

It is quite likely that a large portion of the 'spilled' water cannot be captured for irrigation or to meet the instream water right. In addition, it is a gross simplification to assume that such water has no value. Ecologists are increasingly focused on the need to at least occasional (or even artificial) flood flows to maintain long-term ecosystem health. Yet, from optimization work for hydropower projects, gains in productivity of 10% or more have been observed (Howard 2000). The improvements that could be made in operating Crane Prairie and Wickiup are unknown at this time. However, given existing data on the water that is theoretically available to be redistributed to higher value uses (the 24,000 acre feet) it is useful to consider what amount of improvement would be needed to provide a measurable contribution to the instream needs. For example, a 2% improvement would yield 480 acre feet and a 5% improvement would yield 1,200.

Although there are many questions that remain, on the basis of this review it appears likely that reservoir optimization will have only a limited contribution towards meeting instream needs in the upper Deschutes.

7.2 Trading/Altering Allocations

Because contract holders have varying demands for storage, there may be opportunities to trade allocations on a temporary or permanent basis in order to better serve agricultural and instream demands. For example, during dry periods, North Unit Irrigation District, and to some extent Arnold Irrigation District, rely heavily on storage due to their junior natural flow priority dates. There may be opportunities for leasing or trading water from Lone Pine or COID to these districts during these years, while contributing a portion to flow targets. Wet-year agreements could also be implemented, whereas if the reservoirs filled to a certain level, a certain amount of water could be traded and/or leased instream. Impacts on year-end contents and carry-over issues, however, would need to be closely analyzed to ensure that such trades provide joint benefits to junior districts and the river over the long-term.

Trading or leasing arrangements would depend on analysis of how much water is available in some districts and how much water is needed in others. Preliminary research into historical storage use by districts was presented in Section 3. Closer analysis of these numbers can provide the foundation for discussions and negotiations concerning what needs are unmet, and what water is available for trading. Referring to Table 6 from Section 3, this preliminary analysis shows that on average, 75,112 AF remained unused in Crane Prairie and Wickiup combined during the last twenty years. It is interesting to note that in Crane Prairie, loss is particularly high proportionate to use. Using the averages presented in Table 6, of the 19,900 AF charged to district accounts, 8,157 (41%) is actually used and 11,744 (59%) is reservoir loss. If trading arrangements reduced the overall water stored in Crane Prairie, reservoir losses could be recaptured for beneficial use, as will be discussed in the section below on reservoir losses.

Storage allocation is governed by the 1938 Inter-District Agreement. Demands within and between districts have shifted since the original allocation. It may therefore be time for all parties to mutually re-examine the agreement and brainstorm potential alternative allocation regimes that may yield win-win solutions and more closely align allocation with priority demands. This would involve amending the Inter-District Agreement and changing current practice regarding how the reservoirs fill and which districts have which fill rights. Figures 24 and 25 illustrate the difference in average water availability by district and average water use by district, proportionately, revealing that North Unit Irrigation District relies most heavily on the reservoirs. Again, it is important to note that averages do not capture dry-year conditions when, for example, Arnold may use proportionately more of its allocation due to its junior surface water right.

Figure 23. Average available water in Crane Prairie & Wickiup by District, 1986-2005

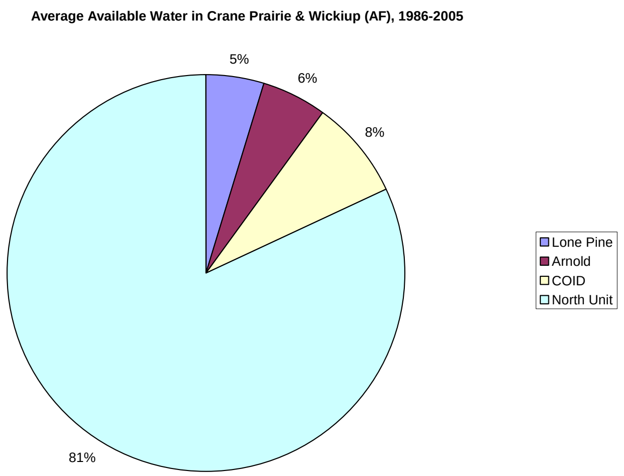
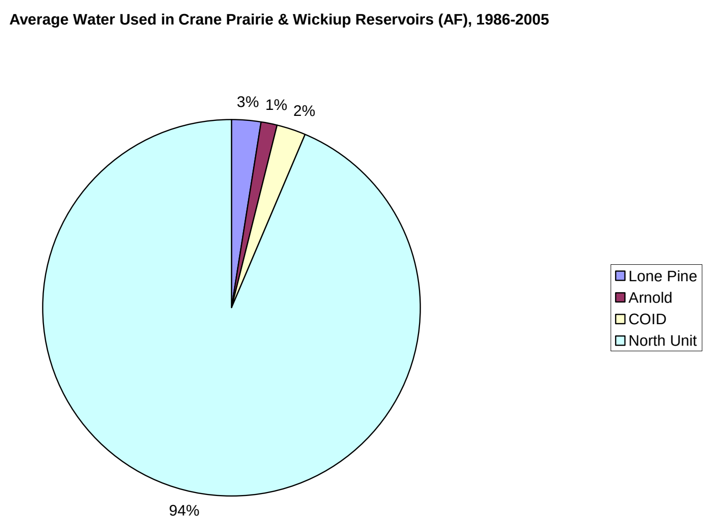


Figure 24. Proportion of Average Water Used by District in Crane Prairie & Wickiup, 1986-2005



Concepts on making allocations more flexible are in preliminary phases, but discussions amongst several irrigation districts, the DRC, and OWRD has generated several creative scenarios that may be explored further. For example, the districts could agree to move Arnold's second fill right before COID's, eliminating Arnold's concern that its needs will be unmet in dry years if any water is traded. COID could then lease a portion of its storage allocation to North Unit and to instream flow, gaining benefits from increased hydropower simultaneously. Under this arrangement, Wickiup would receive the same amount of water it would have otherwise received, and Arnold would be less concerned about carry-over effects on its second fill right the next year, because it was bumped up in the filling order (See Figure 4 in Section 3).

Part of this renegotiation could involve preparation of a Drought Management Plan. Such a plan would define the conditions that constitute drought and therefore trigger implementation of the plan. The plan would lay out the steps required in managing available water during drought to best serve agricultural and instream needs. Drought year options might be triggered that alter storage allocations to pre-programmed levels or that initiate demand assessments and market measures to allocate existing water. Drought management planning would recognize that in the midst of a drought, attempting to manage already over-allocated water supplies according to the status quo will mean shortfalls. It would be better to have agreement in advance on how best to allocate such shortfalls and what steps need to be taken to maximize the productivity of the water that is actually available. In a sense this is part of reservoir optimization and could be examined as part of such a study, as discussed above.

An additional way to amend the agreement is to look at combining the total storage of Crane Prairie, Wickiup and Crescent Lake and drawing on those reservoirs on an as-needed basis disregarding the inter-district agreement and water rights. This would require major overhauls in the agreements and water transfers, but may be a more efficient way to optimize reservoir management.

Benefits of trading or altering the allocation system in the reservoirs include a more effective way of meeting real water demands, while having the flexibility to reallocate some allocations to instream flow. These options have the potential to provide more certainty for AID and NUID, while providing COID and Lone Pine with more flexibility to use storage as an asset. COID also gains increased hydropower opportunities in the winter. This could be accomplished through temporary or permanent amendments to the agreement and/or trading schemes between districts.

Potential carry-over effects in the driest of years would benefit from modeling and a closer analysis, akin to the optimization forecasting discussion. Gauging by the cyclical nature of water years, however, and the amount of time that water is discharged in excess of the flow targets, carry-over in the reservoirs may not be unduly affected by trading/altering allocations at the scale necessary to reach target flows. Better information will dictate how much water could be available for trades and/or leasing in different water years.

Challenges to altering the agreement include concerns from irrigation districts who use storage as a critical safeguard. These concerns, however, should be minimized because any changes would only occur within a framework that maintained or improved current storage supply needed by districts. It would be advisable to begin with one-year agreements provide a measure of safety to the districts involved and the opportunity to learn through adaptive management. Amending the agreement would also require amending the storage certificates, which would require the approval of OWRD and potentially Reclamation.

Another option that districts may voluntarily explore is establishing a “gentlemen’s agreement” similar to the one in place below Bend from the middle Deschutes. Under this scenario, the districts would cooperatively agree to leave a minimum flow below Wickiup, splitting the responsibility equally among districts or providing some flexibility in which district's account the water comes from. Because the gentlemen's agreement is an informal arrangement, however, it should not be depended on to permanently restore stream flows.

7.3 Conserved Water

The water savings from water conservation projects undertaken by irrigation districts or irrigation water users can be transferred to instream use under administrative rules for the Allocation of Conserved Water (ORS 537.455 to 537.500, OAR Chapter 690, Division 18). In this paper the 'saved water' associated with an agricultural water conservation project is used to refer to the physical amount of water previously 'lost' to the agricultural system from transmission loss, on-farm seepage, evaporation or tailwater. 'Conserved' water refers to the amount of water applied for by project partners through an Allocation of Conserved Water submitted to the Oregon Water Resources Department.

Further elaboration and definition of conservation projects and the mechanisms by which such projects are financed and dedicated to instream use through Allocations of Conserved Water appears in the companion DWA Issues Paper *District Water Efficiency Cost Analysis and Proritization* (Newton et al. 2006). The important point is that when conserved water is applied for in irrigation districts with storage rights the conserved water may be awarded in terms of storage rights rather than natural flow rights. In other words, in the upper Deschutes Basin, water conservation projects undertaken with Central Oregon Irrigation District, Arnold Irrigation District, Crook County Improvement District #1 (Lone Pine) and North Unit Irrigation District may all be used to develop permanent instream flows from conserved water. The potential of this source is therefore considerable

As the leakage rate from the permeable Deschutes Formation geology in Central Oregon is quite high, there are is a very large total conservation potential in the relevant irrigation districts. According to Newton et al. (2006) there are already-identified projects of reasonable cost in these districts that have the potential to save 98,373 acre-feet, from piping and lining canals and laterals in these districts (Table 10). It is probable that at least a portion of the conserved water from these projects would be dedicated to instream use below Wickiup.

Table 10. Conservation Potential in Districts with Storage Rights in Wickiup and Crane Prairie Reservoirs

	Conserved Water Potential (AF)	Storage Rights Held (AF)	Percent Storage	Conserved Water from Storage (AF)
North Unit	20,000	200,000	18.75%	3,750
COID	in excess of storage rights	26,000	0%	-
Lone Pine	3,600	10,500	50%	1,800
Arnold	2,250	13,500		-
Totals				8,350

Notes: These numbers are in draft status.

The amount of water that would go to this purpose will vary between districts. For example in the case of a completed piping project in North Unit (the 51-94 piping project), approximately 75% of the conserved water came from storage with the remaining water in the form of natural or live flow. If the minimum allocation of 25% to the Deschutes River is taken for North Unit projects (where the other 75% are exchanged for primary Crooked River rights that go instream) this implies that 18.75% of conserved water from North Unit would be available for protection below Wickiup.

For the other districts there is no precedent set in this regard. Only COID has completed an Allocation of Conserved Water and it was based on 100% natural flow right. Still, as long as the conserved water projects in these districts do actually produce saved water there is the opportunity to make the allocation from storage. For example in Lone Pine, piping the main canals may well save 10 cfs or 3,600 acre feet. The district could well apply for up to 50% of this water to be from storage, particularly as the district's typical use of storage in a year is 6,267 acre feet.

In the case of Arnold identified projects estimated potential savings of 2,250 AF. Given the district's junior natural flow right, it may be more likely that any Arnold project would protect natural flow instream. COID only rarely uses their storage and, thus, protecting stored rights as conserved water might be problematic for the junior users (Arnold and North Unit). COID's contribution to storage management is more likely to emerge from demand reductions and storage trading.

In sum, preliminary analysis suggests that 8,350 acre feet could potentially be acquired to support flows below Wickiup in the winter months. This water would be acquired permanently and thus would form part of the base of instream water rights in the reach.

7.4 Instream Transfers of Storage Rights

A number of districts that hold storage rights in Crane Prairie and Wickiup Reservoir are currently subject to changes in land use and development, particularly urbanization. As discussed in detail in the companion DWA Issues Paper on *Development, Land Use Change, and Irrigation in Central Oregon,* irrigation districts currently have a total of 9,100 acres of irrigation located within Urban Growth Boundaries (UGB's) or Urban Reserve Areas (URA's) in Central Oregon. The result has been rapid growth in instream leasing over the last few years and increasingly the purchase of water rights for the ultimate purpose of transferring them out of districts to an instream use – either to generate groundwater mitigation credits to underpin new groundwater pemits or purely for river restoration.

So far the transfers have been out of COID. Due to the seniority of COID's rights there has been no need to transfer the secondary right to release storage to instream use along with the primary right. However, to the extent that junior districts that make significant use of storage (Arnold and North Unit) enter into transfers the value of the transfer will depend to a much larger degree on the disposition of the secondary release rights. Similarly, the value of transfers from Lone Pine which has a senior right but a limited duty on its primary natural flow right (4.2 acre feet per acre duty) and therefore relies on its large storage right (4 acre feet per acre) would be highly dependent on the disposition of the storage.

In these cases, if the secondary rights are not cancelled but instead follow the primary to an instream use then these rights could contribute to summer flows in the Middle Deschutes. However, an alternative would be to use the acquisition of the water right to release water in the winter. This might involve some administrative complexity but ultimately is an opportunity if the underlying right to store is assigned to the buyer then the ability to release water in the winter, as currently enjoyed by the district, may also be allowable by the buyer.

The same considerations for these districts apply in the case of leasing, however, currently the storage release rights from these districts are not part of the instream process. Potentially, incentives could be offered in the way of increased leasing payments for protecting instream the storage portion of the leased water rights.

In the table below the available information on current leasing activity and projected future urbanization trends is used to generate estimates of the potential increment in water available for lease or transfer through to 2025. The numbers employed only represent water coming from urbanizing land as currently identified in UGBs and UARs and thus may be an underestimate given the rapid growth in Central Oregon and leasing/transfer activity in rural areas due to Measure 37 developments and other land use and demographic change. Given the discussion above it is unlikely that the stored water associated with COID rights is used regularly or would be protected instream in a transfer. The potential water available for meeting needs for reservoir re-operation to meet instream or irrigation needs would therefore be around 1,450 acre feet. This water would be available on a permanent basis.

Table 11. Potential Storage Water from Leasing and Transfers

District	2005 Leased Water (AF)	Projected 2025 urbanized acres	Potential additional lease/transfer acres	Associated Stored Water (AF)
North Unit	39	536	~500	~1,000
Arnold	156	598	~450	~450
Lone Pine	51	-	-	-

Swalley	473	902	~600	-
COID	2,093	5,380	~4,000	~2,000
Total	2,812	7,316	~5,550	~3,450

Notes: Potential additional lease/transfer acres based on estimates of the amount of 2005 leases that are included in the total of projected acres urbanized by 2025 less the total of urbanized acres.

7.5 Irrigation Demand Reductions

Reductions in demand by irrigation districts that divert water at Bend will lead to the availability of natural flow during the irrigation season to fill junior rights – with water that otherwise would not have been available. As a result of shifting natural flow to the next most junior user, there will be a corresponding reduction in the draw by junior districts with storage rights on their storage during the season. This implies that the following winter less of the total inflow that will be available is needed to store the amount of water that would have been stored absent the demand reduction. In other words, a portion of that winter's inflow can be made available to instream or irrigation purposes without affecting existing storage right holders access to water.

Water made available in this manner accrues to existing storage right holders according to the allocation rules. However, this water is available for lease or transfer without harming other parties to the reservoir. Given that there may be year to year variance in the actual reduction in demand, leasing and options to lease may be the most effective transactional arrangement for securing this water.

Three types of reductions in demand are featured below, although there may well be other opportunities

7.5.1 Transfers

New instream leases and transfers may have either or both an effect on demand through reducing demand directly on storage or through reducing demand for water that is part of the transmission loss incurred by districts. As discussed above future leasing and transfers have the potential to result in stored water dedicated permanently to a new use. Here the focus is on water that would not be permanently reassigned but that would effectively not be conveyed to the buyer in the lease or transfer of a right.

For districts at Bend that have storage in Crane Prairie or Wickiup a lease or transfer may be implemented in one of two ways. In the first case the primary right is put to instream use and the secondary storage release right is either not leased or cancelled (in the case of a transfer). In the case of COID, three instream transfers have been final ordered (two for groundwater mitigation credits and one for river restoration). In all three cases the storage right was cancelled. Cancellation of the secondary right to release water from the reservoir does not affect the permit to store water. In other words, after these transfers COID has the same access to stored water but needs to serve fewer acres with this water. Therefore COID's demand on storage is less than it was prior to the transfers.

Given COID's infrequent use of storage the potential savings are probably quite small and are not calculated here. The other district that is seeing considerable urbanization and leasing, with potential for future transfers is Swalley. Swalley does not have storage so will have no impact on storage. Similar analyses may be carried out for the other districts as shown in the table below.

Table 12. Handling of Storage on Leases and Transfers by District

District	Storage/use	Reduction in Demand due to lease	Transfer treatment of Storage Right	Reduction in Demand due to transfer
Swalley	none	no	na	na
COID	Infrequent use	yes	cancelled	insignificant
Arnold	frequent	yes	*	minor
Lone Pine	frequent	yes, significant	*	minor
North Unit	frequent and large	yes, significant	*	significant

Notes: * No precedent is available, however, given that these districts have rights that are filled to a significant degree by stored water the choice in the treatment of the stored water on a transfer may well have an important impact on the monetary value of the transfer.

The table shows that COID is a case unto itself and as other districts that have a significant portion of their rights filled by storage enter into transfer agreements the storage may well need to be transferred as well if the value of the water right is to be captured by the seller (as described above). If this is the case then the reassignment of the storage right would happen formally and there would be none of the ‘free’ increase in availability of surface water (as described above) to junior users. In other words this category is unlikely to significantly reduce demand and, therefore, will not result in water available for leasing by districts holding storage rights. As discussed further below, this does not mean that these transfers will not lead to increased availability of water for instream or agricultural needs.

The second reduction in demand that occurs as a result of leases and transfers comes about due to an oddity in the interpretation of water law by the Oregon Water Resources Department. Water rights diverted in Bend by irrigation districts are subject to the decree of 1933 which sets forth the transmission losses that are allowed as part of the district water rights. These loss rates vary from 35% to 65%. On leases and transfers the Department limits water right holders to protecting instream the amount of water on their certificate net of the transmission loss. For example, in COID the duty on the certificate is 9.91 ac-ft/acre but on a lease 5.5 ac-ft/acre is protectable instream.

In order to calculate the reduction in demand that might result from additional transfers and leases through to 2025 (as estimated in Table 11) it is important not to refer to the maximum duty on the certificate but instead to refer to baseline for actual use by the districts. The table below provides these calculations for each of the districts pulling water at Bend. The results suggest approximately 10,700 acre feet could be generated in this fashion. It is important to note that this should be regarded as a maximum amount. Given that most districts are not diverting the full extent of their legal right it is possible for districts to transfer water instream but not reduce their actual demand at the point of diversion. However, over a long time frame and with significant amounts of transfers and leases it can be expected that diversions will decline.

Table 13. Potential Reduction in Transmission Loss from Transfers and Leases to 2025

	Legal 'Paper' Irrigation Duties at POD (ac-ft/acre)	Duties for Instream Leases and Transfers (ac-ft/acre)	Decreed Loss	Actual Demand at POD (ac-ft/acre)	Freed up Trans. Loss on Transfer (ac-ft/acre)	Potential Water (ac-ft)
Swalley	9.58	5.46 decreed	43%	8.5	3	1,800
COID	9.91	5.53 decreed	45%	7.5	2	8,000
Lone Pine	6.46	4.20 decreed	35%	6.0	1.8	-
Arnold	15.42	5.40 decreed	65%	7.5	2	900
North Unit	5.25	2.0 allocation		4.0	-	-
Totals	7.17					10,700

7.5.2 Saved Water from Water Conservation Projects and Water Management

Whereas conserved water projects yield permanent water, there are opportunities to lease storage water on a temporary basis, if an irrigation district can demonstrate real savings through conservation or improved management practices. Benefits of this approach include a low-risk flexible approach that provides an irrigation district an incentive to be more efficient, without necessarily making a permanent allocation of conserved water. Also, medium-term efforts that are not permanent conservation projects may be supported and yield water that can be protected instream.

Baseline data exists to enable monitoring of conservation efforts and the resulting reductions in demands, and must be used to document real conservation. However, diversions of a given district in a given year are likely to reflect the aggregation of a number of different initiatives – thus monitoring will need to focus on long-term trends.

A pilot conservation storage lease is under development in Lone Pine, where a reduction in storage demand achieved through implementing better water management practices during the 2006 irrigation season will be leased instream below Wickiup from its storage right during the 2006-7 storage season. The project provides an incentive for the district to tighten up management, and results in improved winter flows in the upper Deschutes without affecting other districts in the reservoirs. In short, Lone Pine foregoes up to 2,000 acre feet of storage that would not have otherwise been available had it not achieved real conservation.

If successful, this idea could be expanded beyond Lone Pine to include other districts, or potentially Crane Prairie as an entity, within which Lone Pine, AID and COID could negotiate where the water savings would occur and who would get compensated for them. Given that Lone Pine is optimistic about saving 2,000 acre feet in 2006 it does not seem farfetched to expect that up to 10,000 acre feet could be saved through better management guided by financial incentives in this fashion. No management savings are anticipated from North Unit because the district already manages a tight system, and the district would apply any further management savings to shore up its water supply.

A major source of water for meeting instream flow needs below Wickiup or shoring up of junior irrigation rights will be saved water from district piping and lining projects. Portions of water saved from these projects that is not funded by public money, for example portions funded by districts themselves may be held back from an allocation of conserved water. This reduces the district's demand at the point of diversion. As indicated above, this will increase the availability of storage. As the operative concept is a reduction in demand with no corresponding permanent conserved water this approach will apply in all districts regardless of whether they hold storage rights. A project in Swalley that does not file for conserved water on all the water saved will make surface water available to the next junior user, ultimately conserving storage.

As the companion DWA companion paper on conservation identifies over 250 cfs of conservation projects, a large portion of which comes from the districts pulling water at Bend this option has the potential to supply very large amounts of water. In all likelihood it can be considered the residual source of supply to meet the identified instream need.

7.6 Avoided Losses from Reservoir Seepage

As the reservoirs, particularly Crane Prairie fill, they are subject to increasing losses from seepage. These losses are charged to districts based on storage they occupy. As the reservoirs make larger and larger contributions to winter instream needs below Wickiup, the water levels maintained in the reservoirs will fall. This in turn should lower the water that is currently lost to seepage, in effect conserving the inflow that does augment storage during the winter.

Information on losses is maintained by OWRD as part of their accounting system for live flow and storage on the Deschutes. During the period 1986 to 2005[3], losses charged to districts using Crane Prairie varied from 8,182 AF to 14,249 AF with an average figure of 11,743 AF. Similar numbers for Wickiup are losses varying from 11,150 AF to 13,981 AF with an average figure of 12,928 AF. According to OWRD losses in Crane Prairie rise rapidly once 30,000 acre feet is stored in the reservoir. A seepage report done by the USDA Forest Service in 1981 identified that at an elevation of 4,437 feet, or 22,500 AF, the reservoir leaks an average of 18 cfs. At an elevation of 4,442 feet, or 41,232 AF, the reservoir leaks roughly 100 cfs. Finally, at an elevation of 4,446 feet, the reservoir leaks 215 cfs. Theoretically, as demand is reduced in the reservoir and the reservoir level remains lower, reduced losses will yield more water. The water that is lost seeps into lateral pumice ponds and into the basin groundwater aquifer. Potential gains from reduced losses will take more analysis. Considerations of minimum pool levels for fishing and recreation will have to be considered as well.

7.7 Conclusions on Flow Restoration below Wickiup.

This section of the paper identifies a large number of alternatives for meeting flows below Wickiup while providing improved reliability to irrigation districts from stored water. While further study is imperative, the brief and rapid assessment above provides a sense of each alternative's prospects and its potential to contribute to the identified average annual need of 62,000 acre feet per year. The alternatives and their potential contributions are described in the

[3] Wet years, 1997 and 1999, were excluded from this data set. Loss was likely higher in wet years.

table below. It is imperative to keep in mind that these alternatives are very much conceptual at this point, and are meant to provide the terms of reference and a foundation for future discussions with all parties interested in stored water.

Table 14. Summary of Alternatives and their Contribution to Flow Restoration in the Upper Deschutes

Reservoir Management Approach/Method	Potential contribution (acre feet)	Likely Importance Rating
1. Reservoir optimization	480 to 1,200	4 to 5- minor to insignificant
2. Trading or altering allocations	10,000 to 15,000	2 to 3 - important to very important
3. Conserved Water	8,350	3-important
4. Instream Transfers/Leases	1,450	4-minor
5. Reductions in Demand		
a. Transfers – Storage	-	5-insignificant
b. Transfers – Transmission Loss	5,350-10,700	3-important
c. Water Management - Lease Agreements	10,000	3-important
d. Water Conservation - Lease Agreements	16,370	1- major
6. Avoided Seepage Losses	up to 10,000	3 to 4-important to minor
Potential Total	62,000-73,070	

7.8 Institutional Constraints

7.8.1 Bureau of Reclamation Contracts

Federal restrictions on use of the reservoirs vary by reservoir. No restrictions exist on Crescent Lake. Crane Prairie has a multipurpose storage right authorized by the State, but Reclamation continues to hold the title to the reservoir. Issues of how much authority the districts have versus Reclamation are not yet completely resolved. Severe restrictions by Reclamation exist in Wickiup. Federal re-authorization may be necessary to allow the usage of water from Wickiup for any other purpose than irrigation.

An opportunity exists to use federal legislation known at the 1920 Act[4] to use water from Reclamation projects for purposes other than irrigation if the reservoir meets the following four conditions:

1. Approval is obtained from the water users' association(s)
2. There is no other practicable source of water for the desired purpose
3. The use is not detrimental to the irrigation project or the rights of any prior appropriator
4. Moneys derived from the contract shall be put into the reclamation fund, in the credit of the storage project

[4] United States Code, Title 43, Chapter 12, Subchapter XIII, 521.

Staff at Reclamation have outlined a process to use the 1920 Act to allow other uses besides irrigation in specific projects. The process would require a contract between Reclamation, the operator of the reservoir, and the water right holder involved in the project.

7.8.2 Irrigation District Consensus

Any significant change in the allocation of stored water from the reservoirs must be supported by the irrigation districts with contract interest in the storage facilities. Sound information, scientific modeling, and close collaboration will be the tools for successful change.

8 CONCLUSION

Improvement of reservoir operation and management will play an important role in responding to changing basin needs. Reservoir operations have greatly impacted the natural hydrograph, particularly in the upper Deschutes River between Wickiup and Bend. This paper has introduced a wide variety of opportunities to adjust reservoir management to restore stream flows while maintaining or improving the water supply for irrigators. The existing management of the reservoirs is dictated by the storage water rights and by the 1938 inter-district agreement. Options possible within the current allocation framework include optimization through better forecasting, conserved water allocations of stored water, instream transfer of storage rights, temporary lease agreements tied to conservation practices, and reduction in demand by irrigators resulting from transfers, leasing, and conservation. Because the 1938 agreement does not necessarily align supply and priority demands, there are also opportunities to work with the districts party to the agreement to consider alterations to the allocation framework. Alterations could be temporary or permanent, with some measure of flexibility ideally being retained.

More in-depth analysis and modeling would provide better information to ensure that new arrangements benefited water users and the river in the long-term. Scenarios through modeling can be made with the help of Reclamation's MODSIM flow model. Examples of potential modeling questions include:

- How much optimization is possible with better forecasting
- What are the medium and long-term carry-over effects of management changes?
- What effect would it have on Wickiup if the demand at Bend was reduced by 100 cfs for Swalley and Central Oregon District?
- What would occur with storage accounts if the three upper Deschutes Basin reservoirs were reallocated to be one storage account which all districts could draw upon?

In addition, the United States Geological Survey's MODSIM model could be used to examine regional-scale impacts of changes in reservoir storage and instream flow on groundwater recharge and discharge in the lower Deschutes.

Reservoirs represent a critically important measure of safety and reliability for water users, and should be respected as such. At the same time, reservoirs can simultaneously help restore stream flows in critically-low reaches. Multiple benefits can be achieved with close collaboration by all interested parties.

This paper has focused largely on operations and opportunities in Crane Prairie and Wickiup Reservoirs. Many of these same tools are likely applicable in the other basin reservoirs, and should be explored in the future in the particular contexts of those reservoirs.

9 REFERENCES

Christensen, G.S. and S.A. Soliman. *Optimal Long-Term Operation of Electric Power Systems*. New York: Plenum Press, 1988.

Cypser, Rudolph John. "The Optimum Use of Water Storage in Hydrothermal Electric Systems." Ph.D. diss., Massachusetts Institute of Technology, 1953.

Dyson, M., Bergkamp, G., Scanlon, J. (eds). Flow: The Essentials, Gland, Switzerland and Cambridge, UK.

Gessford, J. and S. Karlin. "Optimal Policy for Hydroelectric Operations." In *Studies in the Mathematical Theory of Inventory and Production*, ed. K.J. Arrow and et al. Stanford: Stanford University Press, 1958.

Howard, C.D.D., 2000. Operation, Monitoring and Decommissioning of Dams, Thematic Review IV.5 prepared as an input to the World Commission on Dams, Cape Town, www.dams.org.

LaMarche, Jonathan. 2001. Upper and Middle Deschutes Basin Surface Water Distribution Model. Surface Water Open File Report #SW02-001. Oregon Water Resources Department.

Little, John. "Use of Storage Water in a Hydroelectric System." Ph.D. diss., Massachusetts Institute of Technology, 1954.

Warnick, C.C. *Hydropower Engineering*. Englewood Cliffs, NJ: Prentice-Hall, 1984.

Yeh, W. W-G. "Reservoir Management and Operation Models: a State-of-the-Art Review." *Water Resources Research* 21, no. 12 (1985): 1797-818.