DESCHUTES BASIN
HABITAT CONSERVATION PLAN

STUDY REPORT

Study 1 – Phase 1: Comparison of Natural and Current Stream Flows in the Deschutes River Basin

Prepared for:

Deschutes Basin Board of Control, and
City of Prineville, Oregon

Prepared by:

Newton Consultants, Inc.

August 2012

TABLE OF CONTENTS

1.0 Introduction 1
1.1 Background 1
1.2 Overview 1
2.0 Definitions 3
3.0 Methods 3
4.0 Results 6
4.1 Whychus Creek 6
4.1.1 Analysis Points and Reference Years 6
4.1.2 Effects of Water Diversion on Instream Flow 8
4.2 Crooked River 16
4.2.1 Ochoco Irrigation District 16
4.2.2 North Unit Irrigation District Crooked River Pumping Plant Diversion .. 53
4.3 Tumalo Creek 61
4.3.1 Analysis Points and Reference Years 61
4.3.2 Low-flow Year Analysis 61
4.3.3 Effects of Water Diversion on Instream Flow 63
4.4 Deschutes River 69
4.4.1 Analysis Points and Reference Years 69
4.4.2 Low-flow Year Analysis 70
4.4.3 Effects of Water Diversion on In-stream Flow 70
Literature Cited - References 111
APPENDIX A – Maps of the Diversions 112

LIST OF TABLES

Table 4.1-1. Total annual flow in Whychus Creek above the Three Sisters Irrigation District diversion for Water Years 1999 through 2010 (*OWRD website -2011*) 7

Table 4.1-2. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2001 9

Table 4.1-3. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2009 11

Table 4.1-4. Water Year 1970 through 2009 statistics of the monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion 13

Table 4.1-5. Water Year 2000 through 2009 statistics of the monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion 14

Table 4.1-6. Average monthly average daily flows for Whychus Creek above and below the Three Sisters Irrigation District diversion, and diversion flows for Water Years 2000 through-2009 15

Table 4.2-1. Total annual inflow to Prineville Reservoir for Water Years 2000 through 2010 17

Table 4.2-2. Estimated evaporation loss per month for Prineville Reservoir 20

Table 4.2-3. Mean daily flows for Crooked River Diversion Canal and Crooked River below the Canal Diversion for Water Year 2001 (cubic feet per second) 23

Table 4.2-4. Mean daily flows for Crooked River Diversion Canal and Crooked River below the Canal Diversion for Water Year 2001 (acre-feet/day) 24

Table 4.2-5. Mean daily flows in Crooked River Diversion Canal and Crooked River below the canal diversion for Water Year 2010 (cubic feet/second) 29

Table 4.2-6. Mean daily flows in Crooked River Diversion Canal and Crooked River below the canal diversion for Water Year 2010 (acre-feet/day) 30

Table 4.2-7. Water Year 1983 through2010 statistics of the monthly average mean daily flow for Crooked River below Crooked River Diversion Canal (cubic feet per second) 33

Table 4.2-8. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for Crooked River below Crooked River Diversion Canal (cubic feet per second) 34

Table 4.2-9. Water Year 2001 through 2010 monthly average flows for the Crooked River below Crooked River Diversion Canal, inflow to Prineville Reservoir, and Crooked River Diversion Canal Flow, (cubic feet per second) 35

Table 4.2-10. Total annual flow of Ochoco and Mill creek's combined 37

Table 4.2-11. Estimated evaporation loss for Prineville Reservoir (and applied to Ochoco Reservoir) 39

Table 4.2-12. Flow impact analysis on Ochoco Creek from Ochoco Main Canal Diversion for Water Year 2001 (cubic feet per second) 42

Table 4.2-13. Flow impact analysis on Ochoco Creek from Ochoco Feed Canal Diversion for Water Year 2001 (acre-feet/day) 42

Table 4.2-14. Flow impact analysis on Ochoco Creek from Ochoco Feed Canal Diversion for Water Year 2010 (cubic feet per second) 47

Table 4.2-15. Flow impact analysis on Ochoco Creek from Ochoco Feed Canal Diversion for Water Year 2010 (acre-feet/day) 47

Table 4.2-16. Water Year 1970 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir and the Ochoco Feed Canal Diversion (cubic feet per second) 50

Table 4.2-17. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir and the Ochoco Feed Canal Diversion (cubic feet per second) 51

Table 4.2-18. Water Year 2001 through 2010 monthly average flows for Ochoco Creek below Ochoco Reservoir, inflow to Ochoco Reservoir, and Ochoco Feed Canal Diversion flow, cubic feet per second) 52

Table 4.2-19. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2001 (cubic feet per second) 54

Table 4.2-20. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2001 (acre-feet per day) 55

Table 4.2-21. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2010 (cubic feet per second) 56

Table 4.2-22. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2010 (acre-feet/day) 57

Table 4.2-23. Water Year 1994 through 2010 statistics of the monthly average mean daily flow for the Crooked River below North Unit Irrigation District pumping plant 59

Table 4.2-24. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for the Crooked River below North Unit Irrigation District Pumping Plant 60

Table 4.3-1. Total annual Tumalo Creek flow for Water Years 2000 through 2010 62

Table 4.3-2. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2001 64

Table 4.3-3. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2005 65

Table 4.3-4. Statistics of the monthly average mean daily flow for Tumalo Creek below Tumalo Feed Canal for Water Years 2000 through 2005 67

Table 4.3-5. Average of the monthly average flows in Tumalo Creek above and below Tumalo Feed Canal and the Tumalo Feed Canal Flow for Water Years 2000 through 2005 68

Table 4.4-1. Total Deschutes River flow at Benham Falls and total diverted flow by irrigation districts, water years 2001 through 2010 70

Table 4.4-2. Irrigation diversion impacts on Deschutes River flow for April 2-30, 2001 72

Table 4.4-3. Irrigation diversion impacts on Deschutes River flow for May 1-14, 2001 74

Table 4.4-4. Irrigation diversion impacts on Deschutes River flow for May 15-31, 2001 76

Table 4.4-5. Irrigation diversion impacts on Deschutes River flow for June, 2001 78
Table 4.4-6. Irrigation diversion impacts on Deschutes River flow for July, 2001.... 80
Table 4.4-7. Irrigation diversion impacts on Deschutes River flow for August, 2001 82
Table 4.4-8. Irrigation diversion impacts on Deschutes River flow for September 1-14, 2001.... 84
Table 4.4-9. Irrigation diversion impacts on Deschutes River flow for September 15-30, 2001 86
Table 4.4-10. Irrigation diversion impacts on Deschutes River flow for April 10-30, 2010.... 89
Table 4.4-11. Irrigation diversion impacts on Deschutes River flow for May 1-14, 2010 91
Table 4.4-12. Irrigation diversion impacts on Deschutes River flow for May 15-31, 2010 93
Table 4.4-13. Irrigation diversion impacts on Deschutes River flow for June, 2010 95
Table 4.4-14. Irrigation diversion impacts on Deschutes River flow for July, 2010....97
Table 4.4-15. Irrigation diversion impacts on Deschutes River flow for August, 2010 99
Table 4.4-16. Irrigation diversion impacts on Deschutes River flow for September 1-14, 2010....101
Table 4.4-17. Irrigation diversion impacts on Deschutes River flow for September 15-30, 2010 103
Table 4.4-18. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 1971 through 2010 (cubic feet per second) 105
Table 4.4-19. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 2001 through 2010 (cubic feet per second)....106
Table 4.4-20. Monthly average mean daily flows for Deschutes River for Water Years 2001 through 2010 (cubic feet per second).... 107
Table 4.4-21. Monthly Statistics of Stock Runs for Arnold Irrigation District Canal, Water Years 2001-2010....110
Table 4.4-22. Monthly statistics of stock runs for COID central Oregon canal, water years 2001-2010....110
Table 4.4-23. Monthly statistics of stock runs for COID Pilot Butte canal, water years 2001-2010 110
Table 4.4-24. Monthly statistics of stock runs for Tumalo Irrigation District canal, water years 2001-2010 111
Table 4.4-25. Monthly statistics of stock runs for Swalley Irrigation District canal, water years 2001-2010 111

LIST OF FIGURES

Figure 1.2-1. Map of the Deschutes Basin Board of Control member Irrigation Districts 2

Figure 4.1-1. Total annual flow in Whychus Creek above the Three Sisters Irrigation District diversion for Water Years 1999 through 2010 (*OWRD website -2011*) 7

Figure 4.1-2. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2001 8

Figure 4.1-3. Effects of Three Sisters Irrigation District Diversion for Water Year 2001 10

Figure 4.1-4. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2009 10

Figure 4.1-5. Effects of Three Sisters Irrigation District Diversion for Water Year 2009 12

Figure 4.1-6. Water Year 1970 through 2009 monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion 13

Figure 4.1-7. Water Year 2000 through 2009 monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion 14

Figure 4.1-8. Average monthly average daily flows for Whychus Creek above and below the Three Sisters Irrigation District diversion, and diversion flows for Water Years 2000 through-2009 15

Figure 4.2-1. Total annual inflow to Prineville Reservoir for Water Years 2000 through 2010 18

Figure 4.2-2. Comparison of methods for calculating inflow to Prineville reservoir for Water Year 2001 19

Figure 4.2-3. Prineville Reservoir volume at midnight for Water Year 2001 21

Figure 4.2-4A. Crooked River monthly average, mean daily flow below Crooked River Diversion Canal for Water Year 2001 22

Figure 4.2-4B. Monthly average, mean daily flow for Crooked River Diversion Canal for Water Year 2001 22

Figure 4.2-5. Flow comparison between Crooked River Diversion Canal, Prineville Reservoir inflow, and Crooked River flow below Canal Diversion for Water Year 2001 26

Figure 4.2-6. Prineville Reservoir volume at midnight for Water Year 2010 27

Figure 4.2-7A: Crooked River monthly average daily flow below Crooked River Diversion Canal for Water Year 2010 28

Figure 4.2-7B. Monthly average mean daily flow for Crooked River Diversion Canal for Water Year 2010 28

Figure 4.2-8 Flow comparison between Crooked River Diversion Canal, Prineville Reservoir inflow, and Crooked River flow below diversion for Water Year 2010. 31

Figure 4.2-9. Prineville Reservoir inflow, outflow, and volume for Water Years 1990 -1993 32

Figure 4.2-10. Water Year 1983 through 2010 statistics of the monthly average for the Crooked River Below Crooked River Diversion Canal 33

Figure 4.2-11. Water Year 2001 through 2010 statistics of the monthly average for the Crooked River below the Crooked River Diversion Canal....34

Figure 4.2-12. Monthly average mean daily flows for inflow to Prineville Reservoir, Crooked River Diversion Canal Flow, and Crooked River flow below diversion for Water Years 2001 through 2010....35

Figure 4.2-13. Ochoco Reservoir midnight volume for Water Years 2000 through 2010....38

Figure 4.2-14. Ochoco Reservoir volume for Water Year 2001....40

Figure 4.2-15A. Ochoco Creek monthly average mean daily flow below Ochoco Reservoir for Water Year 2001....41

Figure 4.2-15B. Monthly average mean daily flow for Ochoco Main Canal for Water Year 2001....41

Figure 4.2-15C. Flow comparison between Ochoco Main Canal Diversion, Ochoco Reservoir inflow, and Ochoco Creek below reservoir for Water Year 2001....43

Figure 4.2-16A Daily live flow below Ochoco Reservoir for Water Year 2001....43

Figure 4.2-16B. Daily mean Ochoco Feed Canal Diversion flow for Water Year 2001....44

Figure 4.2-17. Ochoco Reservoir daily volume for Water Year 2010....45

Figure 4.2-18A. Ochoco Creek monthly average mean daily flow below Ochoco Reservoir for Water Year 2010....46

Figure 4.2-18B. Monthly average mean daily flow for Ochoco Main Canal for Water Year 2010....46

Figure 4.2-18C. Flow comparison between Ochoco Main Canal Diversion, Ochoco Reservoir Inflow, and Ochoco Creek below reservoir for Water Year 2010....48

Figure 4.2-19A. Daily live flow below Ochoco Reservoir for Water Year 2010....48

Figure 4.2-19B. Daily mean Ochoco Feed Canal Diversion flow for Water Year 2010....49

Figure 4.2-20. Water Year 1970 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir and the Ochoco Feed Canal diversion....50

Figure 4.2-21. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir and the Ochoco Feed Canal diversion....51

Figure 4.2-22. Water Year 2001 through 2010 monthly average flows for Ochoco Creek below Ochoco Reservoir, inflow to Ochoco Reservoir, and Ochoco Feed Canal diversion....52

Figure 4.2-23. Effects of NUID Pumping Plant on Crooked River flows for Water Year 2001....54

Figure 4.2-24. North Unit Irrigation District daily pumping effects on the Crooked River for Water Year 2001....55

Figure 4.2-25. Effects of NUID Pumping Plant on Crooked River flows for Water Year 2010....56

Figure 4.2-26 North Unit Irrigation District pumping effects on the Crooked River for Water Year 2010....57

Figure 4.2-27. Water Year 1994 through 2010 statistics of the monthly average mean daily flow for the Crooked River below NUID Pumping Plant....58

Figure 4.2-28. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for the Crooked River below NUID Pumping Plant 59
Figure 4.2-29. Average of the monthly average flows above and below NUID Pumping Plant and the pumping plant flow for Water Years 2001 through 2010 60
Figure 4.3-1. Flow data quality for Tumalo Feed Canal gage (Station #14073500) from 1971 through 2010 (*OWRD website- 2011*).... 61
Figure 4.3-2. Total accumulated precipitation, Upper Deschutes Basin for Water Years 2000 through 2010....62
Figure 4.3-3. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2001 63
Figure 4.3-4. Tumalo Feed Canal effects on Tumalo Creek for Water Year 2001 64
Figure 4.3-5. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2005....65
Figure 4.3-6. Tumalo Feed Canal effects on Tumalo Creek for Water Year 2005.... 66
Figure 4.3-7. Statistics of the monthly average mean daily flow for Tumalo Creek below Tumalo Feed Canal for Water Years 2000 through 2005....67
Figure 4.3-8. Average of the monthly average flows in Tumalo Creek above and below Tumalo Feed Canal and the Tumalo Feed Canal Flow for Water Years 2000 through 2005 68
Figure 4.4-1. Total accumulated precipitation in the upper Deschutes Basin for Water Years 2000 through 2010....70
Figure 4.4-2A. Deschutes River flows relative to district diversions for April 2-30, 2001 71
Figure 4.4-2B. Irrigation diversions for April 2-30, 2001 71
Figure 4.4-3A. Deschutes River flows relative to district diversions for May 1-14, 2001....73
Figure 4.4-3B. Irrigation diversions for May 1-14, 2001....73
Figure 4.4-4A. Deschutes River flows relative to district diversions for May 15-31, 2001 75
Figure 4.4-4B. Irrigation diversions for May 15-31, 2001 75
Figure 4.4-5A. Deschutes River flows relative to district diversions for June, 2001 77
Figure 4.4-5B. Irrigation diversions for June, 2001 77
Figure 4.4-6A. Deschutes River flows relative to district diversions for July, 2001....79
Figure 4.4-6B. Irrigation diversions for July, 2001....79
Figure 4.4-7A. Deschutes River flows relative to district diversions for August, 2001 81
Figure 4.4-7B. Irrigation diversions for August, 2001 81
Figure 4.4-8A. Deschutes River flows relative to district diversions for September 1-14, 2001....83
Figure 4.4-8B. Irrigation diversions for September 1-14, 2001....83
Figure 4.4-9A. Deschutes River flows relative to district diversions for September 15-30, 2001....85
Figure 4.4-9B. Irrigation diversions for September 15-30, 2001 85

Figure 4.4-10. Deschutes River daily mean flow as a result of irrigation diversions at and above Bend in 2001 87
Figure 4.4-11A. Irrigation diversion impacts on Deschutes River flows for April 10-30, 2010 88
Figure 4.4-11B. Irrigation diversions for April 10-30, 2010 88
Figure 4.4-12A. Irrigation diversion impacts on Deschutes River flows for May 1-14, 2010 90
Figure 4.4-12B. Irrigation diversions for May 1-14, 2010 90
Figure 4.4-13A. Irrigation diversion impacts on Deschutes River flows for May 15-31, 2010 92
Figure 4.4-13B. Irrigation diversions for May 15-31, 2010 92
Figure 4.4-14A. Irrigation diversion impacts on Deschutes River flows for June 2010 94
Figure 4.4-14B. Irrigation diversions for June 2010 94
Figure 4.4-15A. Irrigation diversion impacts on Deschutes River flows for July 2010 96
Figure 4.4-15B. Irrigation diversions for July 2010 96
Figure 4.4-16A. Irrigation diversion impacts on Deschutes River flows for August 2010 98
Figure 4.4-16B. Irrigation diversions for August 2010 98
Figure 4.4-17A. Irrigation diversion impacts on Deschutes River flow for September 1-14, 2010 100
Figure 4.4-17B. Irrigation diversion for September 1-14, 2010 100
Figure 4.4-18A. Irrigation diversion impacts on Deschutes River flows for September 15-30, 2010 102
Figure 4.4-18B. Irrigation diversions for September 15-30, 2010 102
Figure 4.4-19. Deschutes River daily mean flow as a result of irrigation diversions at and above Bend in 2010 104
Figure 4.4-20. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 1971 through 2010 105
Figure 4.4-21. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 2001 through 2010 106
Figure 4.4-22. Monthly average mean daily flows for Deschutes River for Water Years 2001 through 2010 107
Figure 4.4-23. Deschutes River below Bend, August minimum mean daily flow for water years 1971-2010 108
Figure 4.4-24. Total district diversions by districts in upper Deschutes and Crooked River sub-basins 108
Figure 4.4-25. Measured Deschutes River flow at Madras gage compared to in-stream water right March, 2008 – November, 2011 109

1.0 INTRODUCTION

1.1 BACKGROUND

Seven central Oregon irrigation districts (Arnold, Central Oregon, North Unit, Ochoco, Swalley, Three Sisters, and Tumalo) and the City of Prineville, Oregon (City) are seeking Federal Endangered Species Act (ESA) incidental take permits for the Middle Columbia River steelhead (*Oncorhynchus mykiss*), bull trout (*Salvelinus confluentus*), and up to 14 other listed and unlisted species inhabiting the Deschutes River basin. As required by Section 10 of the ESA, the City and the irrigation districts (collectively the Applicants) are preparing the Deschutes Basin Multi-species Habitat Conservation Plan (DBHCP) to minimize and mitigate the effects of the proposed incidental take on the covered species. The DBHCP is being prepared in cooperation with a multi-stakeholder Working Group representing the US Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), US Bureau of Reclamation (Reclamation), US Bureau of Land Management (BLM), Oregon Department of Fish and Wildlife (ODFW), Oregon Department of Environmental Quality (ODEQ), Oregon Water Resources Department (OWRD), the Confederated Tribes of the Warm Springs, Crook County, and several non-governmental entities.

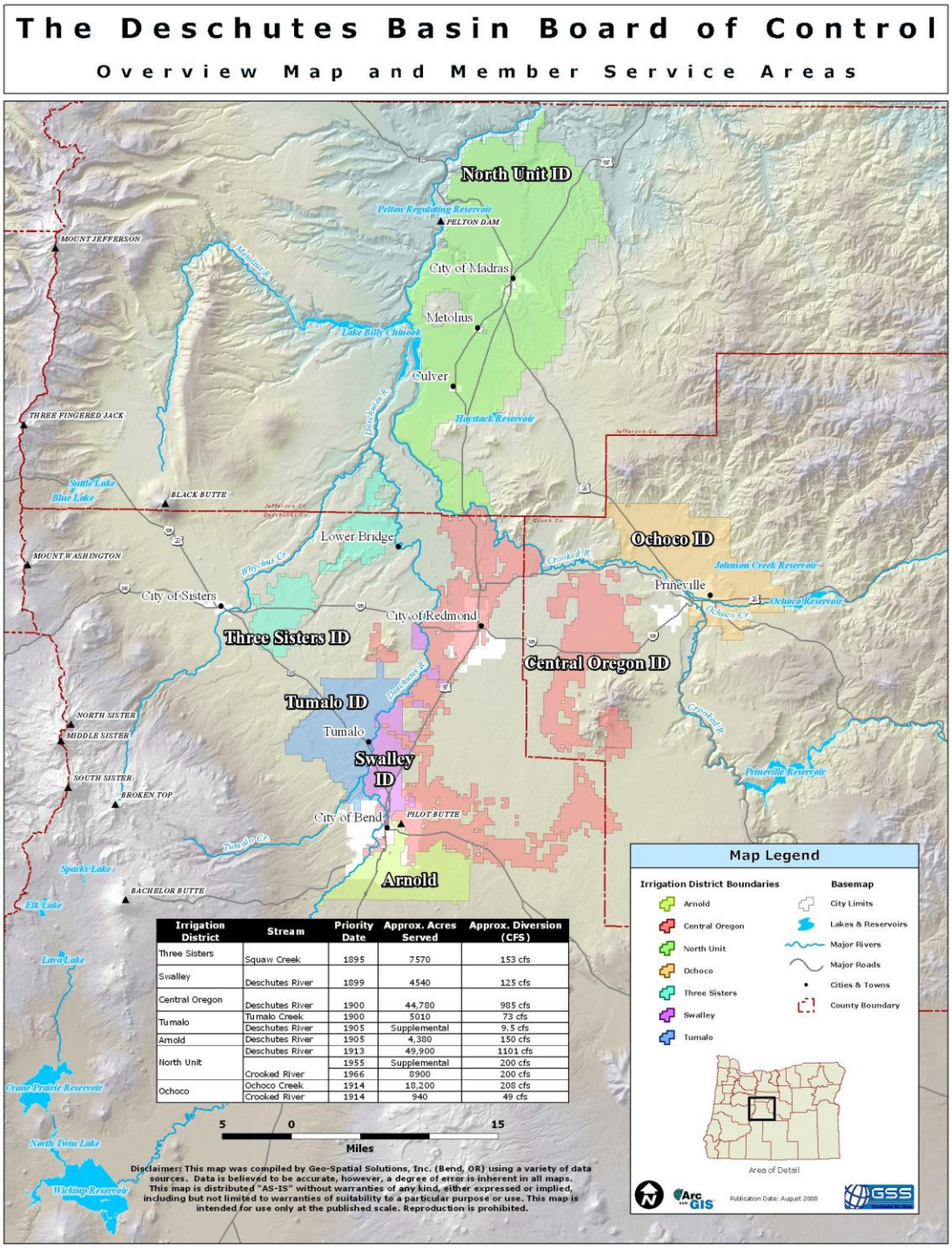
This study has been completed to support development of the DBHCP. The scope of work for the study was reviewed and approved by the Working Group prior to initiation. Drafts of this report are being provided to the Working Group for review and comment, and the final report will reflect their input.

1.2 OVERVIEW

The seven applicant irrigation districts rely on varying combinations of live flows and stored water to meet their irrigation needs. This first phase of Study 1 quantifies their diversions of both stored water and live flows to estimate the resulting effects on natural instream flows. The effects of storing and releasing water prior to diversion will be addressed separately in Phase 2.

The water diversions addressed in this study occur in a number of forms. Five of the applicant irrigation districts obtain water directly from the Deschutes River above Bend, Oregon (Figure 1.2-1). These are Arnold, Central Oregon (which has two points of diversion), Tumalo, Swalley, and North Unit. Lone Pine Irrigation District (formally known as Crook County Improvement District No. 1) obtains water through Central Oregon Irrigation District (COID) diversions. While Lone Pine is not participating in the DBHCP, the diversion of their water by COID is recognized in this report, but is not individually analyzed. Tumalo Irrigation District also obtains water from Tumalo Creek, which flows into the Deschutes River below Bend. In addition, some patrons of Swalley and COID obtain their water directly from the river and not from the districts' main diversion canals. North Unit also obtains some water from the Crooked River.

Swalley Irrigation District relies entirely on live flows. The four other districts diverting Deschutes River water rely on combinations of live flow and stored water from Crescent Lake, Wickiup Reservoir, and Crane Prairie Reservoir. The percentage of stored water utilized is different for each district and may vary by the time of year. Three Sisters Irrigation District obtains its water from Whychus Creek, which flows into the Deschutes River about 39 miles downstream from Bend. All of their diverted water is live flow.



Irrigation District	Stream	Priority Date	Approx. Acres Served	Approx. Diversion (CFS)
Three Sisters	Squaw Creek	1895	7570	153 cfs
Swalley	Deschutes River	1899	4540	125 cfs
Central Oregon	Deschutes River	1900	44,780	985 cfs
Tumalo	Tumalo Creek	1900	5010	73 cfs
	Deschutes River	1905	Supplemental	9.5 cfs
Arnold	Deschutes River	1905	4,380	150 cfs
North Unit	Deschutes River	1913	49,900	1101 cfs
		1955	Supplemental	200 cfs
	Crooked River	1966	8900	200 cfs
Ochoco	Ochoco Creek	1914	18,200	208 cfs
	Crooked River	1914	940	49 cfs

Figure 1.2-1. Map of the Deschutes Basin Board of Control Member Irrigation Districts.

Ochoco Irrigation District (OID) draws most of its water from Ochoco Creek (live flow and storage in Ochoco Reservoir) and the Crooked River. A substantial part of the water diverted from the Crooked River is stored water from Prineville Reservoir. Some patrons of OID obtain water directly from Ochoco Creek and the Crooked River downstream of the district's main diversions. OID also obtains water from four small tributaries (Johnson Creek, Dry Creek, McKay Creek and Lytle Creek) downstream of the major diversions.

For the Districts that divert water from the main stem of the Deschutes River, virtually all diversions into main district canals have gages from which daily mean flows can be downloaded. Gages on the river, however, are limited. For instance, there is no river gage between the Arnold diversion at river mile (RM) 175 above Bend and the North Canal Dam (RM 165) where NUID, Swalley, and COID divert. COID and Tumalo divert water between these two points. The relative impact of these separate diversions was therefore calculated, rather than directly measured, by estimating flows at and below the points of diversion. The methods for estimating are described for the individual districts in Section 4.0

2.0 DEFINITIONS

For the purposes of this study, the following definitions apply:

- **Natural flow** is an estimate of the flow in the stream prior to significant diversions for irrigation or other human uses. In actuality, the natural flow values used in this report are probably better defined as "unregulated" flow instead of "natural" flow. The true "natural" flow cannot be determined because there is no way to quantify or account for impacts due to watershed-scale landscape changes over the past 100 years (landscape changes that, in turn, are due to altered vegetation and beaver populations). The sources of these flow estimates are described below.

- **Stored flow** is water that has been stored and then released from a storage reservoir. It is calculated as the net release from the reservoir minus the net inflow. For the Crooked River reservoirs, inflow was determined from the change in reservoir volume; for the Deschutes River reservoirs, inflow was determined from flow gages above the reservoir.

- **Live flow** is water other than stored flow. It can originate from reservoir inflow, tributary flow below reservoirs, irrigation return flow, and groundwater discharge.

3.0 METHODS

After identifying all significant points of diversion for the seven irrigation districts, we obtained data to quantify the diversions by individual district. Diversion data were compiled by water year (October through September), which is the generally accepted timeframe over which water use is evaluated. By including winter months in the analysis, we were able to address effects of stock runs as well as irrigation diversions. For diversions where storage reservoirs are used to augment water supply, we determined the proportion of flow coming from stored water and the proportion from live flow.

Effects of diversion were analyzed for two representative years: a) the most recent entire water year for which flow data are available, and b) the driest year during the past 10 years.

Actual flow data were obtained from the OWRD website (http://apps2.wrd.state.or.us/apps/sw/hydro_near_real_time/Default.aspx), which provides access to current and historic stream flow gage data and storage reservoir data. Gage data quality is classified as follows (from OWRD website http://apps2.wrd.state.or.us/apps/sw/hydro_near_real_time/faq.aspx):

- **Raw** - Gage height data as downloaded from the data logger. Unchecked discharge measurements.

- **Preliminary** - Gage height data are uploaded to the WISKI database, discharge measurements entered into BIBER. Observations of gage height and recorder readings from inspections entered into appropriate time series. Necessary time and gage height corrections are applied. Gage height record is then recomputed and reviewed using standard WISKI layout. Necessary shifts are applied and the discharge is computed and reviewed by the Regional Hydrotech. No review by Salem Hydrographic staff has been done. This designation is reserved for monthly water-management reports that require rapid turnaround. All other data are generally required to meet the provisional standard.

- **Provisional** - All of the above steps are completed. Copies of measurement notes have been provided to Salem Hydrographics. On successful completion of a review by Salem Hydrographic staff, this partial water year record is releasable as provisional record for monthly management reports. This is the preferred process for all data released outside of the Department that has not been finalized. This step can normally be completed within two weeks of the request with properly entered and complete data.

- **Published** - At the end of the water year, record entries are completed by field staff and Salem staff is notified that the record for the year is ready for review. Original measurement and inspection notes, raw gage height modules and digital measurement files are submitted to Salem. Salem staff review the record. On successful completion of review, the record is posted to the Department's web site and is releasable for all purposes.

- **Missing** - No data are available for that date/time

Use of Natural Flow Data in the Study 1 – Phase 1 Report

To facilitate an analysis of the effects of covered irrigation diversion on covered aquatic species, it will be necessary to isolate or separate the effects of the covered diversions from the effects of other irrigation and municipal diversions not under consideration in this project. In other words, it will be necessary to determine the effects of the covered diversions as if they were the only diversions occurring in the basin. A precise separation or isolation of these effects is not possible given the myriad activities that have occurred and are occurring in the basin that influence flow. However, an approximation of the effects can be provided by comparing covered diversions to "natural" stream flows in the basin.

The OWRD Water Availability Report System (available on the OWRD website (www.wrd.state.or.us/OWRD/SW/index.shtml) is used in portions of this report to describe natural stream flows at the selected points. The term natural flow is used here because that is how it is described in the Water Availability System (Cooper, R.M., 2004). In actuality and, as stated above, the natural flow is probably better defined as "unregulated" flow instead of natural flow. The true natural flow cannot be determined because there is no way to quantify or account for impacts due to watershed-scale landscape changes over the past 100 years (including those related to altered vegetation and beaver populations).

These natural flow data are only available for 50% and 80% exceedances. A 50% exceedance flow means that 50% of the time the specified flow rate (in cubic feet per second, cfs) will be exceeded. These data are available only as monthly means in cubic feet per second derived from a 30-year period of record (water years 1958 through 1987).

While the OWRD natural stream flows provide a general reference for determining the effects of the covered irrigation diversions, they are imprecise estimates of stream flows that would exist in the basin in the absence of human activity. There are a number of reasons for imprecision, including:

1. Natural stream flows are determined by adding consumptive uses (e.g., irrigation and municipal diversions) to actual stream flows during the period of record. Ideally, both the consumptive uses and the stream flows would be derived from direct measurements, but this is not always possible. The OWRD process for determining natural flows cannot accommodate measured flows for streams affected by significant storage, such as the Deschutes and Crooked rivers. For streams with significant storage, flow is therefore estimated by a regional regression analysis in which measured flows from part of the basin, or from a similar basin, are extrapolated to the unmeasured portions of the basin. In a similar way, consumptive use is rarely measured, but is instead estimated as potential consumptive use based on current water rights that may or may not have been fully utilized during the period in question. These estimates of flows and consumptive use introduce a number of potential inaccuracies in the resulting calculations of natural flows.

2. Human activities that influence streamflow other than direct consumptive uses, such as changes in drainage patterns or land uses that alter water yield are not accounted for in natural flows.

3. Natural flows are based on a finite period of record that may or may not represent current conditions or future conditions during the term of the DBHCP, particularly in the event of global climate change.

For these reasons, the natural exceedance flows are provided in this report for reference only, and should not be considered precise measurements of the effects of covered irrigation activities. They are the best information available, and they are useful for indicating general trends and orders of magnitude in the effects of covered irrigation diversions, but they are not suitable for detailed accounting of those effects. Above all, it should be remembered that natural flows do not represent conditions that would exist in the streams covered by the DBHCP

if the covered irrigation activities ceased. All other human activities in the basin would continue to exert their influence on stream flows.

In this report, the effects of diversions have been compared to natural flows only in the Upper Deschutes subbasin, including Tumalo Creek and Whychus Creek. This is because very few ungaged diversions exist above the covered irrigation diversions and it is believed that the natural flow estimates are fairly reasonable. For the Crooked River subbasin, however, many of the diversions above Prineville and Ochoco Reservoirs are ungaged and the amount of diverted flow was determined from existing water rights, some of which were not being exercised. Because of this inaccuracy, the natural flow data in the Crooked River is believed to be much more uncertain. Because of this uncertainty, natural flow is not compared to the effects of any of the diversions in the Crooked River.

(See Reference of Open File Cooper Report, pg. 110 this report)

4.0 RESULTS

Study results are presented by irrigation district in the following subsections. For each district, we first identify the analysis points and reference years used for the analysis, and then present the results in tabular and graphic format.

4.1 WHYCHUS CREEK

4.1.1 ANALYSIS POINTS AND REFERENCE YEARS

Three Sisters Irrigation District (TSID) obtains its water from Whychus Creek upstream of the City of Sisters. One TSID patron withdraws a portion of the district's water right from the Plainview Ditch which diverts water from Whychus Creek above the TSID diversion season. This patron withdraws a maximum of 0.8 cfs. This diversion is not considered in this analysis. TSID briefly stores water after it has been diverted, but there are no in-channel storage facilities upstream from the diversion. All flow in the creek at the point of diversion is therefore considered to be live flow.

According to the rules and regulations of TSID (TSID 2010) the district has a water right for 158.55 cfs from Whychus Creek to irrigate 7,925 acres. Of this water right, 9.5 cfs are leased for instream use, so only 149.05 cfs may be diverted for irrigation.

This analysis is based on data from two gages. Whychus Creek is gaged upstream from the diversion at Station No. 14075000, and the district's canal diversion is gaged at Station No. 14076000. The gage on Whychus Creek has been operational since 1908, and most of the data for the past 40 years are classified by OWRD as "published," which is their highest quality rating. The gage on the district's diversion canal has been operational since 1924. OWRD ratings reflect a similar preponderance of published data for the canal gage. A map of Whychus Creek, the main canal diversion and the gages is in the Appendix as Figure A-1.

The analysis of most current year is based on Water Year 2009 because construction on the canal in early 2010 prevented the collection of flow data after February 4 of that year. Analysis of flow data since 1999 indicates that Water Year 2001 was the driest over the last 10 years. Table 4.1-1 shows the total annual flow in acre-feet for Whychus Creek at Gage No. 14075000 for Water Years 1999 through 2010. Figure 4.1-1 is a graphical presentation of the data in that table.

Table 4.1-1. Total annual flow in Whychus Creek above the Three Sisters Irrigation District diversion for Water Years 1999 through 2010 (*OWRD website -2011*).

Water Year	Total Annual Flow (acre-feet)
1999	97,321
2000	86,025
2001	**47,488**
2002	69,953
2003	64,671
2004	66,016
2005	52,762
2006	81,988
2007	73,224
2008	80,620
2009	69,792
2010	69,348

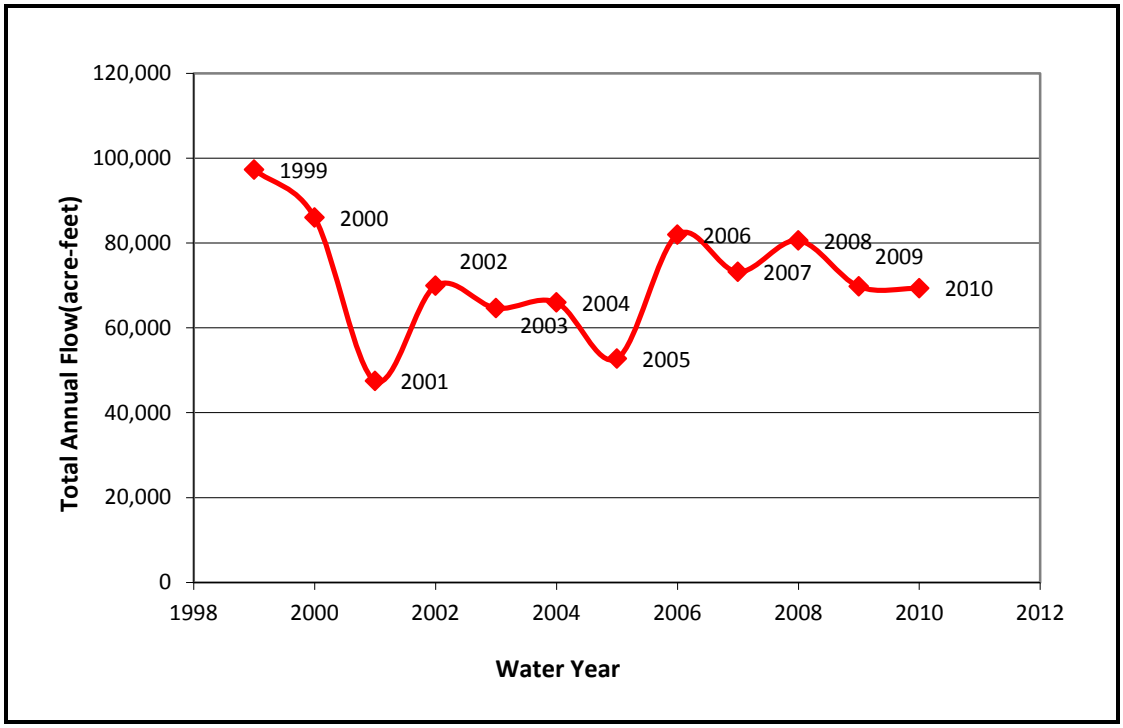


Figure 4.1-1. Total annual flow in Whychus Creek above the Three Sisters Irrigation District diversion for Water Years 1999 through 2010 (*OWRD website -2011*).

4.1.2 EFFECTS OF WATER DIVERSION ON INSTREAM FLOW

Figure 4.1-2 and Table 4.1-2 show the effects on Whychus Creek flow from diversion into the TSID Canal for Water Year 2001. Figure 4.1-3 the effects on a daily flow basis for Water Year 2001. Figure 4.1-4 and Table 4.1-3 show comparable data for Water Year 2009, which is the most current water year for which there are available data. Figure 4.1-5 shows the effects on a daily flow basis for Water Year 2009. Some months have been split into two segments in the tables and figures because active diversion began mid-month. The average flows represented during these periods are for the individual month segments.

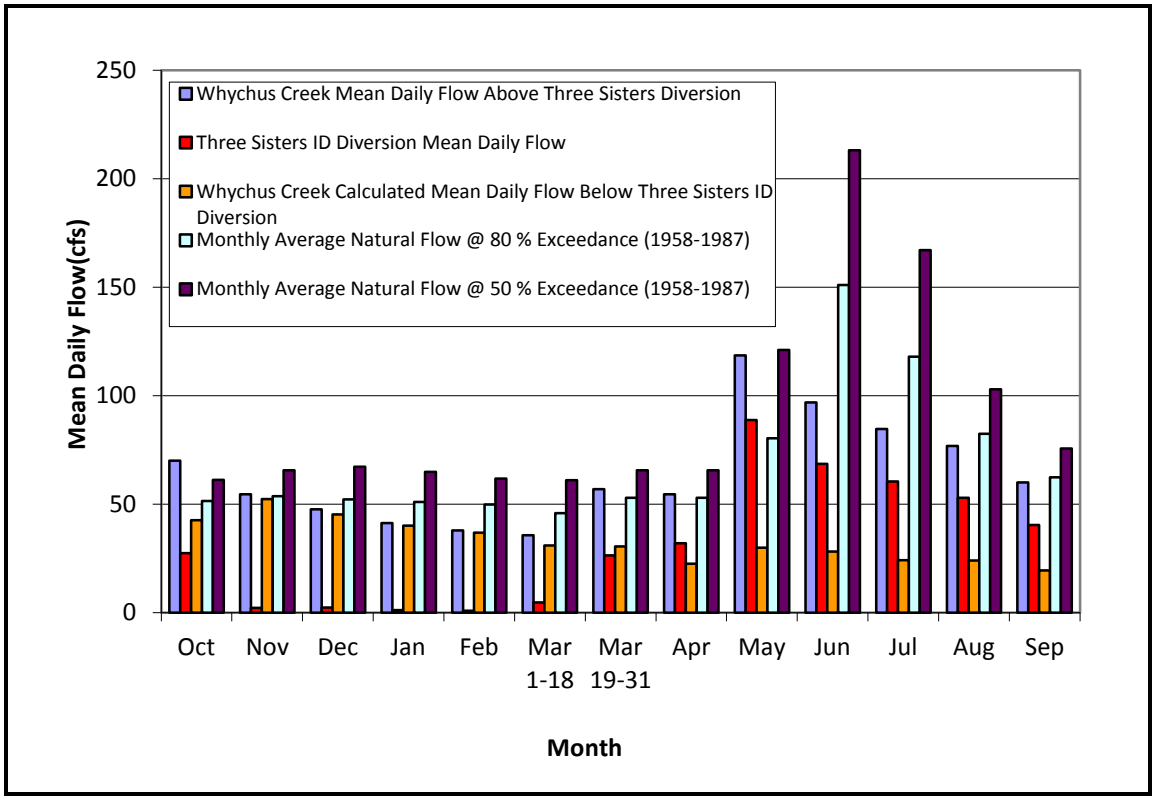


Figure 4.1-2. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2001.

Table 4.1-2. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2001.

Month	Whychus Creek Mean Daily Flow Above Three Sisters Diversion	Three Sisters ID Diversion Mean Daily Flow	Whychus Creek Calculated Mean Daily Flow Below Three Sisters ID Diversion	Monthly Average Natural Flow @ 80 % Exceedance (1958-1987)	Monthly Average Natural Flow @ 50 % Exceedance (1958-1987)
Oct	70.0	27.4	42.6	51.5	61.2
Nov	54.6	2.3	52.3	53.7	65.6
Dec	47.6	2.3	45.3	52.2	67.2
Jan	41.3	1.2	40.1	51.0	64.9
Feb	37.9	1.0	36.9	49.8	61.8
Mar 1-18	35.7	4.7	31.0	45.9	61.0
Mar 19-31	57.0	26.5	30.5	53.0	65.7
Apr	54.6	32.0	22.6	53.0	65.7
May	118.6	88.7	29.9	80.4	121.0
Jun	96.8	68.6	28.2	151.0	213.0
Jul	84.6	60.5	24.2	118.0	167.0
Aug	76.9	52.9	24.0	82.4	103.0
Sep	60.0	40.5	19.5	62.4	75.6

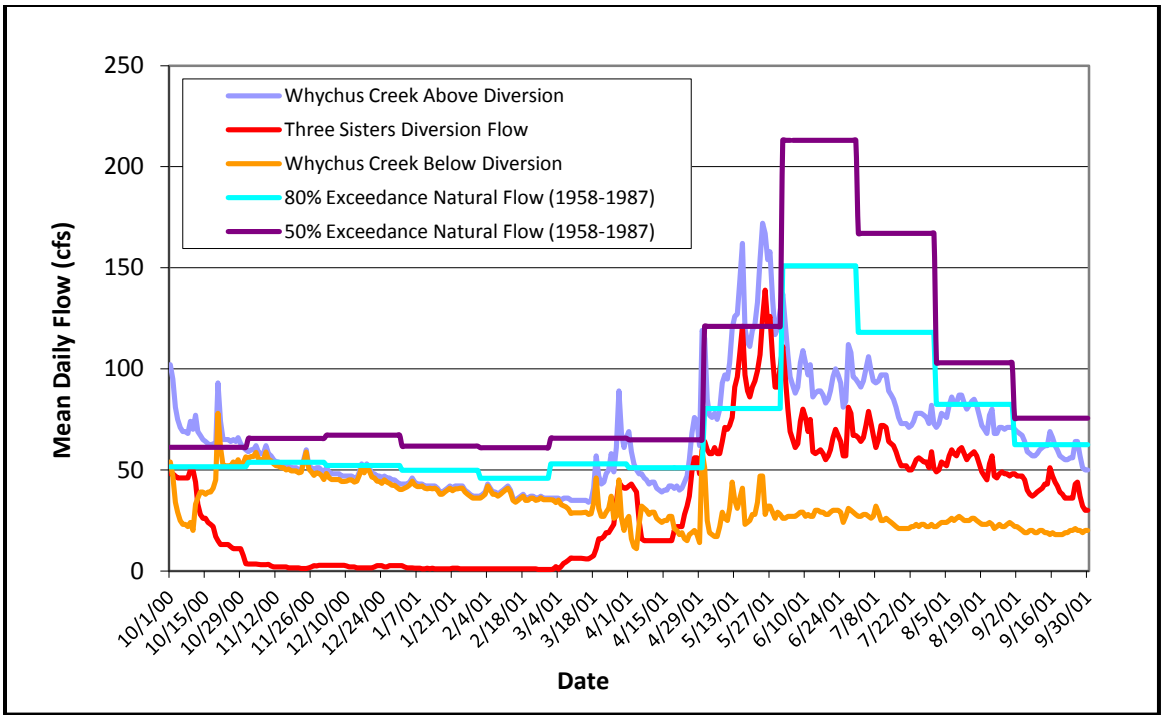


Figure 4.1-3. Effects of Three Sisters Irrigation District Diversion for Water Year 2001.

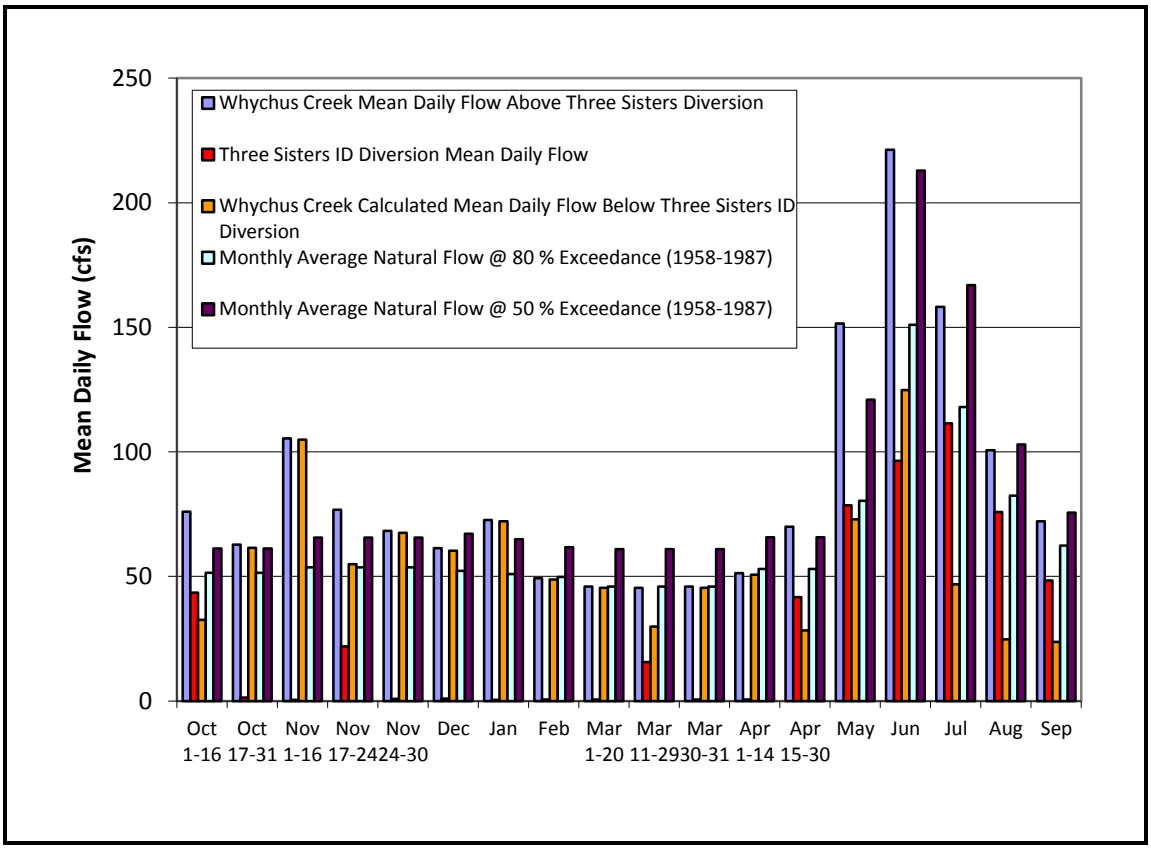


Figure 4.1-4. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2009.

Table 4.1-3. Effects of Three Sisters Irrigation District diversions on Whychus Creek flows in Water Year 2009.

Month	Whychus Creek Mean Daily Flow Above Three Sisters Diversion	Three Sisters ID Diversion Mean Daily Flow	Whychus Creek Calculated Mean Daily Flow Below Three Sisters ID Diversion	Monthly Average Natural Flow @ 80 % Exceedance (1958-1987)	Monthly Average Natural Flow @ 50 % Exceedance (1958-1987)
Oct 1-16	76.1	43.5	32.6	51.5	61.2
Oct 17-31	62.8	1.3	61.5	51.5	61.2
Nov 1-16	105.4	0.4	104.9	53.7	65.6
Nov 17-24	76.8	21.9	54.9	53.7	65.6
Nov 24-30	68.3	0.8	67.5	53.7	65.6
Dec	61.4	1.0	60.4	52.2	67.2
Jan	72.7	0.5	72.2	51.0	64.9
Feb	49.3	0.5	48.7	49.8	61.8
Mar 1-20	46.0	0.6	45.4	45.9	61.0
Mar 11-29	45.4	15.6	29.9	45.9	61.0
Mar 30-31	46.0	0.6	45.4	45.9	61.0
Apr 1-14	51.3	0.6	50.7	53.0	65.7
Apr 15-30	70.0	41.7	28.3	53.0	65.7
May	151.5	78.5	73.0	80.4	121.0
Jun	221.3	96.4	124.9	151.0	213.0
Jul	158.3	111.5	46.8	118.0	167.0
Aug	100.6	75.9	24.7	82.4	103.0
Sep	72.1	48.4	23.7	62.4	75.6

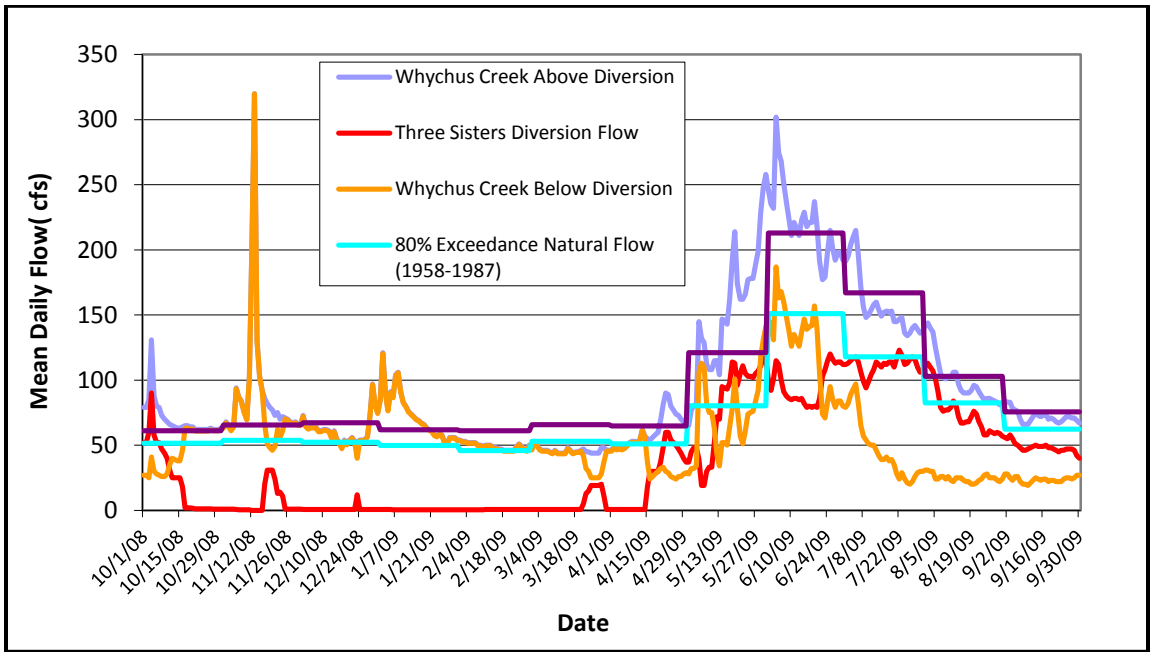


Figure 4.1-5. Effects of Three Sisters Irrigation District Diversion for Water Year 2009.

Figures 4.1-6 Table 4.1-4 present a statistical analysis of the monthly average flows in Whychus Creek below the TSID diversion for Water Years 1970 through 2009. Figures 4.1-7 and Table 4.1-5 present statistical analyses of the monthly average flows in Whychus Creek below the TSID diversion for Water Years 2000 through 2009.

These flow numbers were determined by subtracting the measured diversion flow in the diversion from the measured flow in Whychus Creek above the diversion. Figure 4.1-8 and Table 4.1-6 are graphical and tabular presentations, respectively, of the average monthly average flows for Water Years 2000 through 2009 for Whychus Creek both above and below the diversion and the average monthly average flow for the diversion.

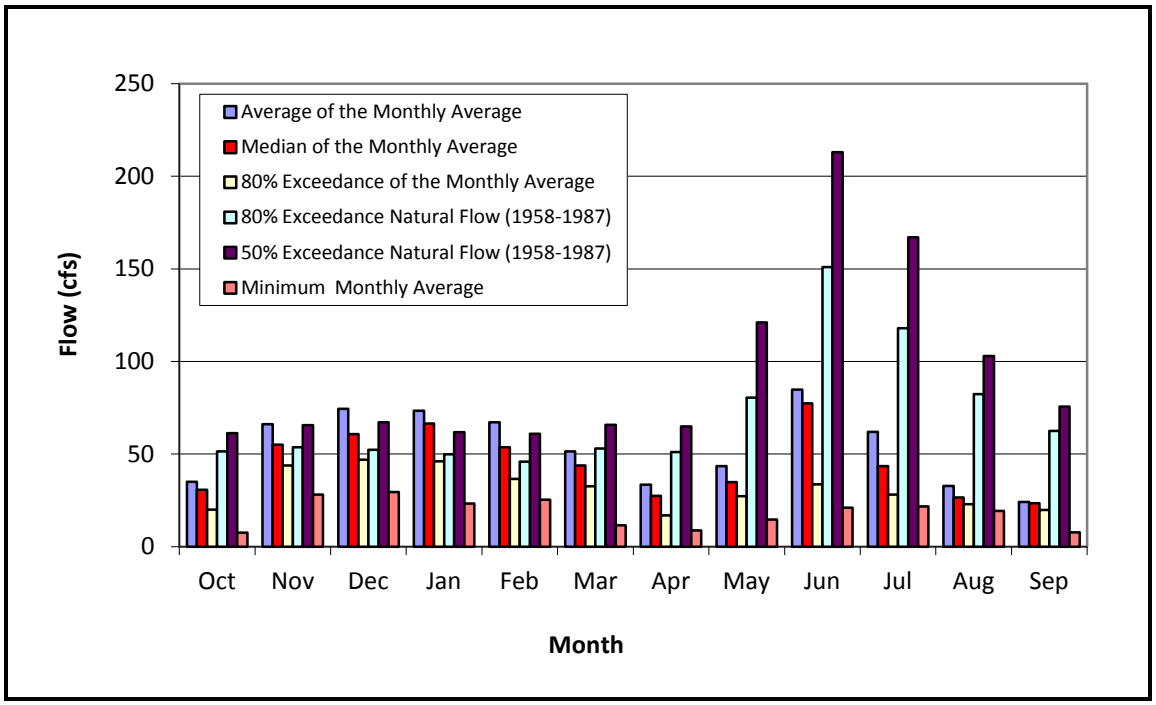


Figure 4.1-6. Water Year 1970 through 2009 monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion.

Table 4.1-4. Water Year 1970 through 2009 statistics of the monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion.

Month	Average of the Monthly Average	Median of the Monthly Average	80% Exceedance of the Monthly Average	Minimum Monthly Average	80% Exceedance Natural Flow (1958-1987)	50% Exceedance Natural Flow (1958-1987)
Oct	35.1	30.8	19.9	7.5	51.5	61.2
Nov	66.0	55.0	43.9	28.1	53.7	65.6
Dec	74.3	60.7	47.0	29.5	52.2	67.2
Jan	73.5	66.4	46.1	23.2	49.8	61.8
Feb	67.1	53.6	36.5	25.3	45.9	61
Mar	51.3	43.8	32.6	11.5	53	65.7
Apr	33.5	27.3	16.9	8.8	51	64.9
May	43.5	34.8	27.2	14.6	80.4	121
Jun	84.8	77.4	33.7	20.9	151	213
Jul	61.9	43.5	28.1	21.6	118	167
Aug	32.8	26.5	23.0	19.3	82.4	103
Sep	24.2	23.4	19.9	7.7	62.4	75.6

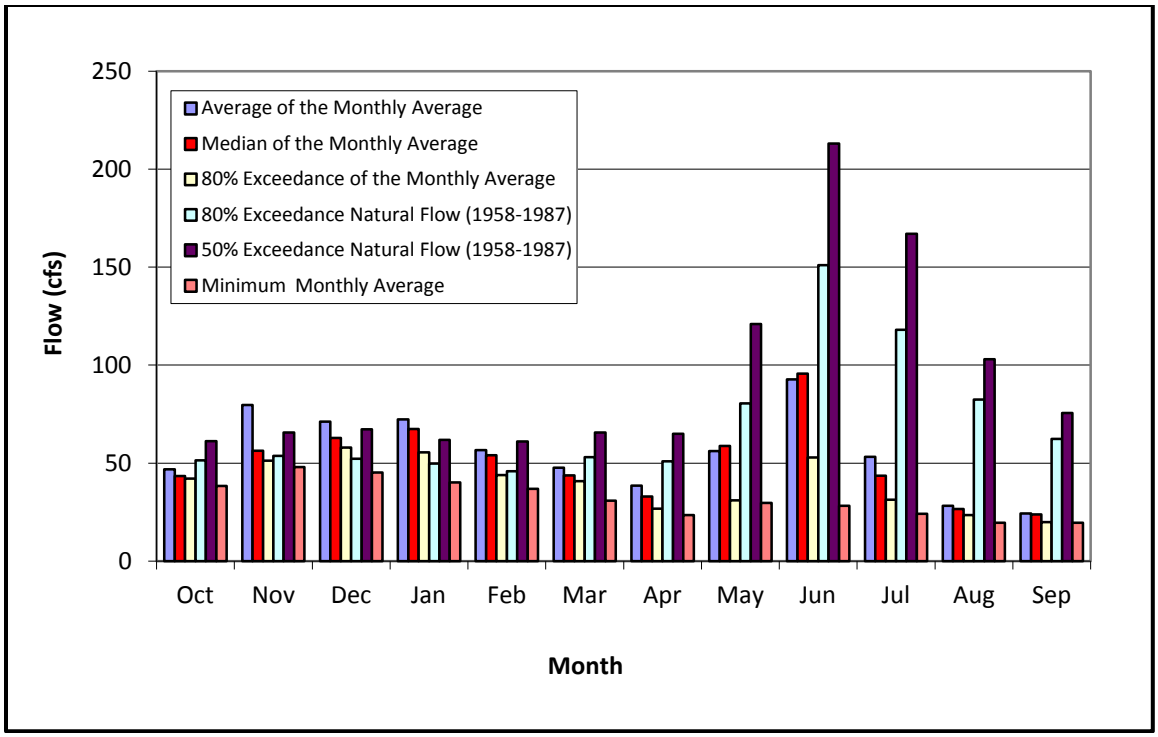


Figure 4.1-7. Water Year 2000 through 2009 monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion.

Table 4.1-5. Water Year 2000 through 2009 statistics of the monthly average flows for Whychus Creek below the Three Sisters Irrigation District diversion.

Month	Average of the Monthly Average	Median of the Monthly Average	80% Exceedance of the Monthly Average	Minimum Monthly Average	80% Exceedance Natural Flow (1958-1987)	50% Exceedance Natural Flow (1958-1987)
Oct	46.9	43.5	42.1	38.3	51.5	61.2
Nov	79.7	56.3	51.3	48.1	53.7	65.6
Dec	71.2	62.8	57.9	45.3	52.2	67.2
Jan	72.2	67.5	55.5	40.1	49.8	61.8
Feb	56.6	54.1	44.0	36.9	45.9	61
Mar	47.6	43.8	40.9	30.8	53	65.7
Apr	38.5	33.0	26.8	23.5	51	64.9
May	56.2	58.7	31.1	29.8	80.4	121
Jun	92.7	95.7	52.8	28.2	151	213
Jul	53.2	43.5	31.3	24.2	118	167
Aug	28.2	26.6	23.5	19.5	82.4	103
Sep	24.3	23.9	19.9	19.5	62.4	75.6

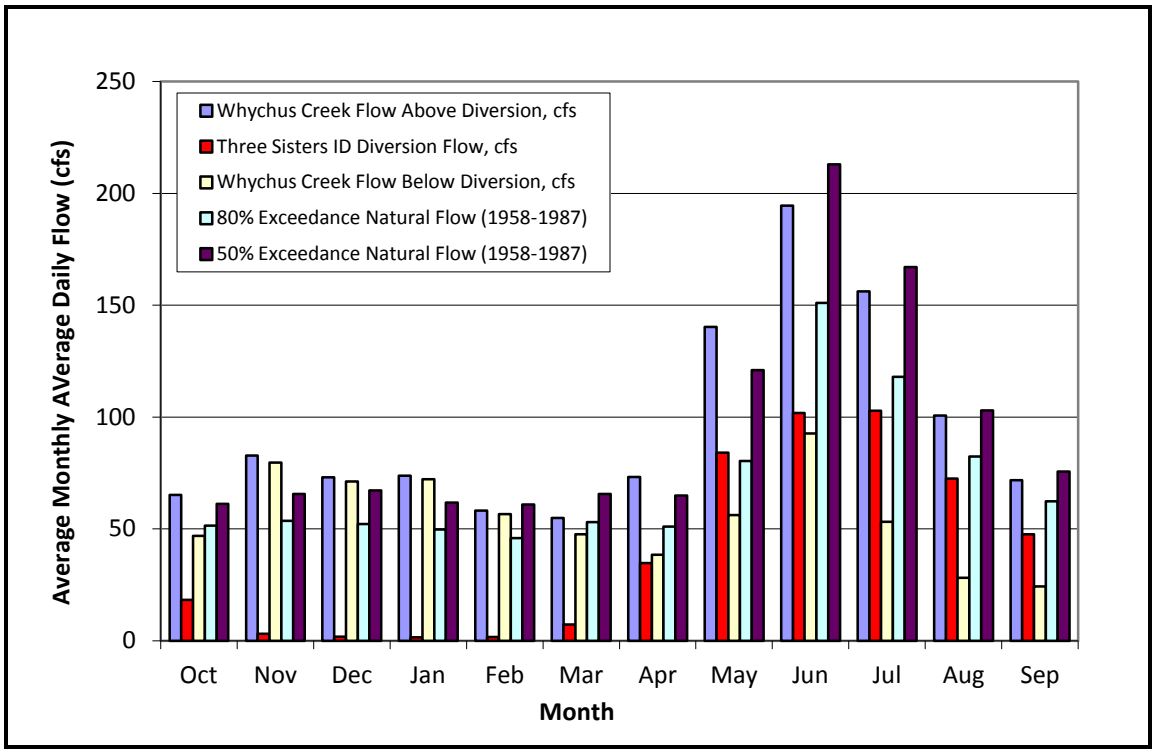


Figure 4.1-8. **Average monthly average daily flows for Whychus Creek above and below the Three Sisters Irrigation District diversion, and diversion flows for Water Years 2000 through-2009.**

Table 4.1-6. **Average monthly average daily flows for Whychus Creek above and below the Three Sisters Irrigation District diversion, and diversion flows for Water Years 2000 through-2009.**

Month	Whychus Creek Flow Above Diversion, cfs	Three Sisters ID Diversion Flow, cfs	Whychus Creek Flow Below Diversion, cfs	80% Exceedance Natural Flow (1958-1987)	50% Exceedance Natural Flow (1958-1987)
October	65.2	18.4	46.9	51.5	61.2
November	82.8	3.1	79.7	53.7	65.6
December	73.1	1.9	71.2	52.2	67.2
January	73.9	1.6	72.2	49.8	61.8
February	58.3	1.7	56.6	45.9	61
March	55.0	7.4	47.6	53	65.7
April	73.3	34.8	38.5	51	64.9
May	140.4	84.2	56.2	80.4	121
June	194.5	101.8	92.7	151	213
July	156.1	102.9	53.2	118	167
August	100.7	72.5	28.2	82.4	103
September	71.8	47.6	24.3	62.4	75.6

4.2 CROOKED RIVER

4.2.1 OCHOCO IRRIGATION DISTRICT

Ochoco Irrigation District (OID) obtains water from multiple sources. This report, however, only analyzes the two main sources: Crooked River below Prineville Reservoir and Ochoco Reservoir, which impounds Ochoco Creek a few miles above the City of Prineville. The diversion on the Crooked River is called the Crooked River Diversion Canal and the flow effects analysis is presented in subsection 4.2.1.1. The diversion from Ochoco Reservoir is called the Ochoco Main Canal and is analyzed in subsection 4.2.1.2. The other sources of water do not have continuous gages from which to obtain data for analysis.

4.2.1.1 Ochoco Irrigation District Crooked River Diversion Canal

4.2.1.1.1 Analysis and Reference Points

This section of the report analyzes the effect on the Crooked River by the diversion of water from the river into the Crooked River Diversion Canal, which transports and distributes water to a portion of the Ochoco Irrigation District.

The Crooked River Diversion Canal diverts water from the Crooked River at RM 55.8. The point of diversion is approximately 14 miles downstream from Bowman Dam, which impounds the Crooked River to form Prineville Reservoir. The diversion flow is gaged (Gage No. 14080590). OWRD maintains a gage on the Crooked River above the reservoir at RM 86.2 (Gage No. 14079800) and one below the reservoir (Gage No. 14080500) at RM 63.3, but about 7-8 miles above the Crooked River Diversion Canal. There are no other stream gages that measure flow into the river or reservoir in the vicinity. In addition to flow gages on the river and diversion canal, there is a gage for measuring and recording Prineville Reservoir water elevation. This gage is used to calculate the volume of storage in the reservoir. The storage volume data are available on the OWRD website (Gage No. 14080400). A map is provided in the Appendix (Figure A-2) to indicate the locations of the two river gages plus the locations of the gage for the Crooked River Diversion Canal.

The gage on the Crooked River above Prineville Reservoir has been operational since October 1, 1960, although there are no data available on the OWRD website between sometime in the late 1960s and about 1994. The data from 1994 through Water Year 2010 appears to be published data. The gage on the Crooked River below Prineville Reservoir has been operational since well before 1970, and the data appear to be published through 2010. The Crooked River Diversion Canal gage has been operational since about 1981. The data between about 1989 and 2006 are considered raw data and are not published. The data after 2006 are published data. Reservoir volume data from the internet are available from about 2001 forward. According to Bob Main, Ochoco Irrigation District, additional data are also available for previous years, but cannot be obtained directly from the internet. The data from 2001 forward are considered preliminary for the most part.

Based upon the information above relative to data quality, the flow data available for the Crooked River above and below the reservoir for both 2001 and 2010 are very good for the two river gages. The reservoir volume data are considered preliminary, which indicates they have had a preliminary review. The data for 2001 for the Crooked River Diversion Canal itself,

however, are classified "raw" and may not be accurate. Nevertheless, because 2001 is the low flow water year for the past 10 years, it is analyzed in this report. The 2010 data are published.

4.2.1.1.1. Low Flow Year Analysis

Analysis of flow and reservoir storage data since Water Year 2000 indicates that Water Year 2001 was the driest over the last 10 years. Table 4.2-1 shows the total annual flow in acre-feet of the Crooked River above the reservoir. Fig. 4.2-1 is a graphical representation of Table 4.2-1.

Table 4.2-1. Total annual inflow to Prineville Reservoir for Water Years 2000 through 2010.

Year	Total Annual Flow (acre-feet)
2000	194,542
2001	**67,370**
2002	128,074
2003	120,092
2004	244,397
2005	151,581
2006	458,757
2007	165,025
2008	180,704
2009	141,779
2010	212,842
Average	**187,742**

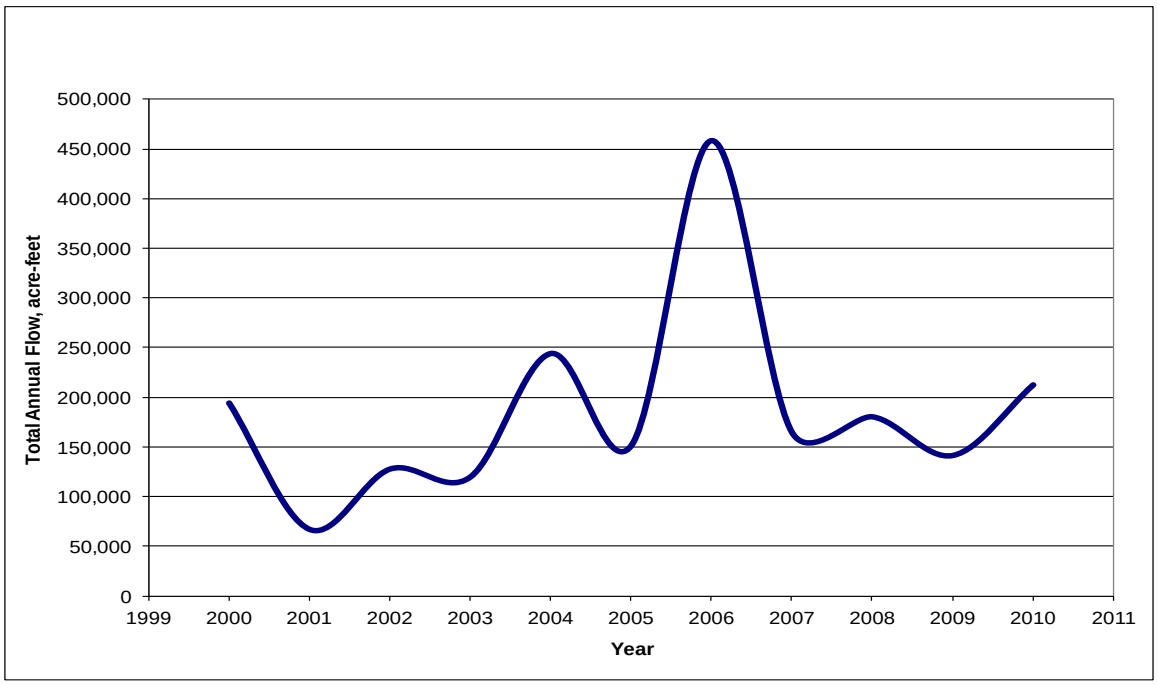


Figure 4.2-1. Total annual inflow to Prineville Reservoir for Water Years 2000 through 2010.

4.2.1.1.2. Effects of Water Diversion on In-Stream Flow

Determination of reservoir inflow is important because it is needed to calculate the amount of live flow leaving the reservoir. As a general rule, all flow leaving the reservoir during the time of year when irrigation water is being actively stored in the reservoir is considered live flow. Exceptions to this are voluntary releases of stored water in the fall after the irrigation season to increase flow in the Crooked River, which would not otherwise occur in some dry years. In addition, there are releases of storage to accommodate the U.S. Army Corps of Engineers' flood control requirements that may apply during periods of high precipitation and/or rapid snowmelt. Once the release of stored irrigation water begins in the spring, and the reservoir level begins to drop, the portion of flow leaving the reservoir that is considered live flow is equal to the inflow. If more flow is leaving the reservoir than inflow, the flow in excess of inflow is considered stored flow. These individual periods (storage vs. release) will be indicated in the analyses below.

There are two means for determining inflow into Prineville Reservoir:

- Using the Crooked River flow gage above the reservoir at Post, and
- Using the change in reservoir volume.

The problem with using the Post gage above the reservoir is that it does not capture any flow that may be entering the reservoir below the gage, such as Bear Creek. This can be significant in the winter and spring periods. If one uses the change in reservoir volume to capture the ungaged flow, losses in the reservoir due to evaporation, which can be significant during the summer, must be factored in. Figure 4.2-2 shows the reservoir inflow for Water Year 2001 calculated two different ways: (1) based on the Post gage above Prineville Reservoir, and (2) based on changes in reservoir volume.

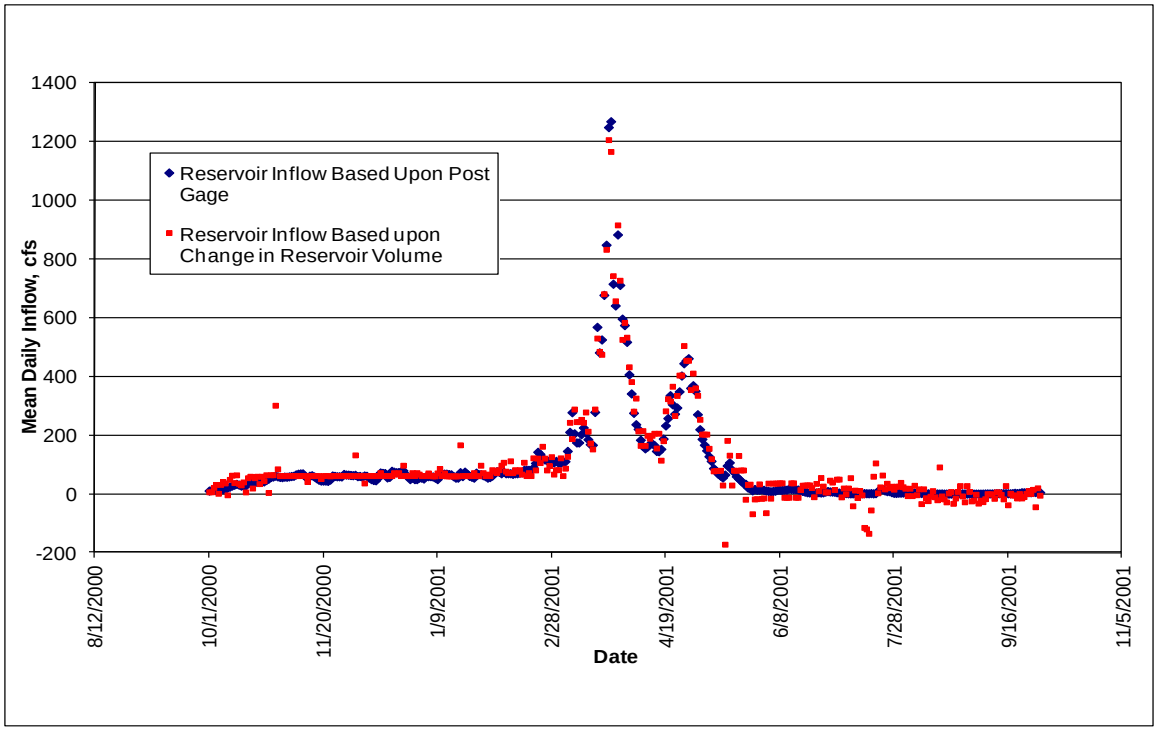


Figure 4.2-2. Comparison of methods for calculating inflow to Prineville Reservoir for Water Year 2001.

Inspection of Figure 4.2-2 shows that inflow based on change in volume is more erratic than inflow based on the Post gage, which is just above the reservoir. This appears to be particularly true during the low flow periods. The erratic nature is believed to be caused, in part, because reservoir volume calculations are based on single instantaneous readings at midnight, while the gage readings at Post are daily means. Further, the change in volume calculation requires assumptions about evaporation because there are no evaporation data at or near this location for the period under consideration. As a result, the analysis using change in volume will produce slightly different results from an analysis using the inflow measured at Post. However, because the differences are small and the change in volume approach will better reflect inflow due to ungaged inflow, all analyses for that year are based on change in reservoir volume as well.

As stated above, this analysis uses the change in reservoir volume to determine inflow. To account for evaporation, estimated evaporation loss is based upon predicted evaporation loss used by Reclamation when it designed Bowman Dam (source: Crooked River Project, February, 1953, page 45). Table 4.2-2 provides the estimated evaporation loss in feet per month.

Table 4.2-2. Estimated evaporation loss per month for Prineville Reservoir.

Month	Evaporation Loss (feet/month)
Oct	0.07
Nov	0
Dec	0
Jan	0
Feb	0
Mar	0
Apr	0.16
May	0.28
Jun	0.32
Jul	0.53
Aug	0.41
Sep	0.25

The actual evaporation depends on the surface area of the reservoir. Based upon discussions with Bob Main, Ochoco Irrigation District, an average surface are of 2,500 acres was used in calculating reservoir evaporation loss.

Figure 4.2-3 shows the volume in Prineville Reservoir over Water Year 2001. Inspection of the curve indicates the reservoir was releasing stored water early in the water year (after the end of the 2000 irrigation season), stayed steady until about the middle of January 2001, and then began filling around January 20, 2001. The reservoir filled until about May 8, 2001, and then began releasing stored water throughout the rest of the water year. For the purpose of calculating live flow, the storage period is assumed to start on January 20, 2001. The storage period is assumed to have ended on May 7, 2001. During the storage period, all flow released from the reservoir is considered live flow.

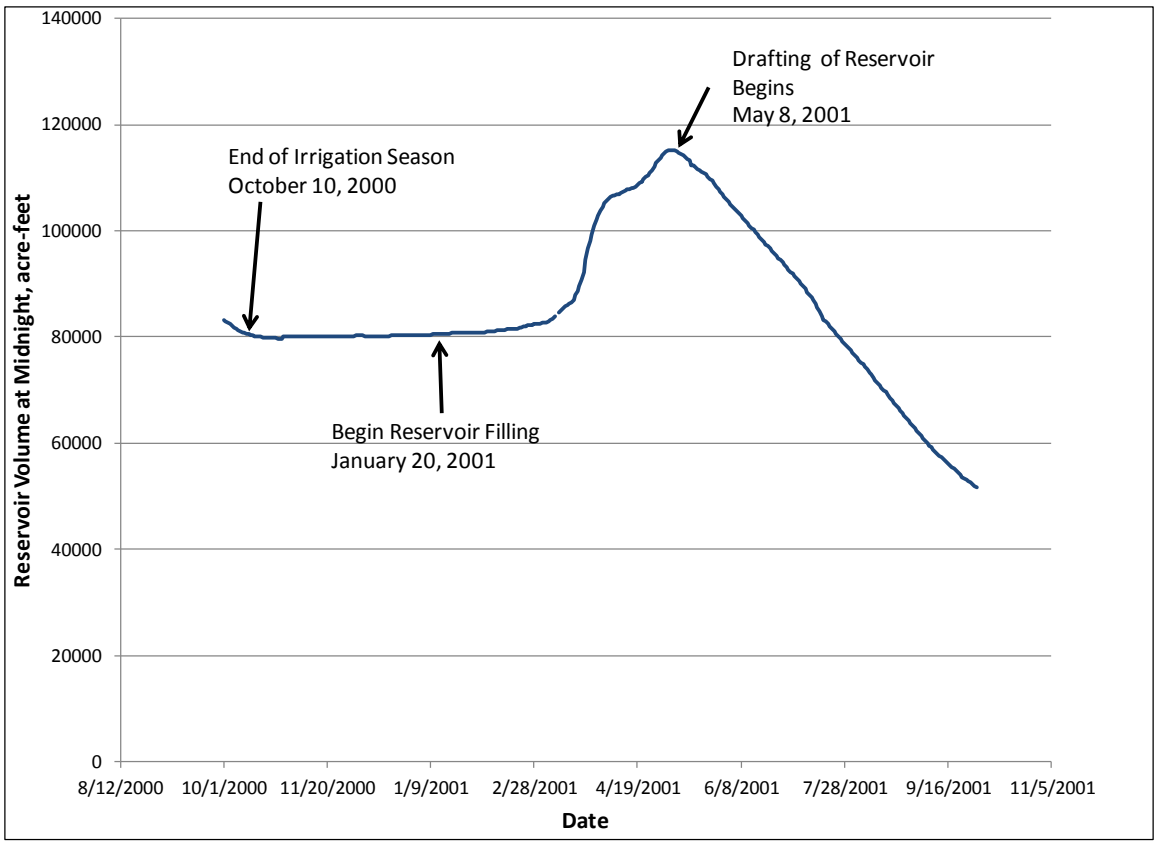


Figure 4.2-3. Prineville Reservoir volume at midnight for Water Year 2001.

Figures 4.2-4A and 4.2-4B provide a graphical analysis of the flow effect during Water Year 2001 in cfs and acre-feet per day, respectively. Figure 4.2-4A displays the total, live, and stored flows for 2001 in the Crooked River below the Crooked River Diversion; Figure 4.2-4B displays the total, live and stored flows for 2001 in the Diversion Canal for each month. Tables 4.2-3 and 4.2-4 are tabular representation of Figures 4.2-4A and 4.2-4B. As noted above, the live, stored, and total flows described and displayed in these graphs and tables are based on change in volume calculations from single, instantaneous stage readings for each day. The Crooked River flow into the reservoir is a mean daily flow calculated from Post gage readings. This accounts for the variance in the two numbers in the graphs and tables.

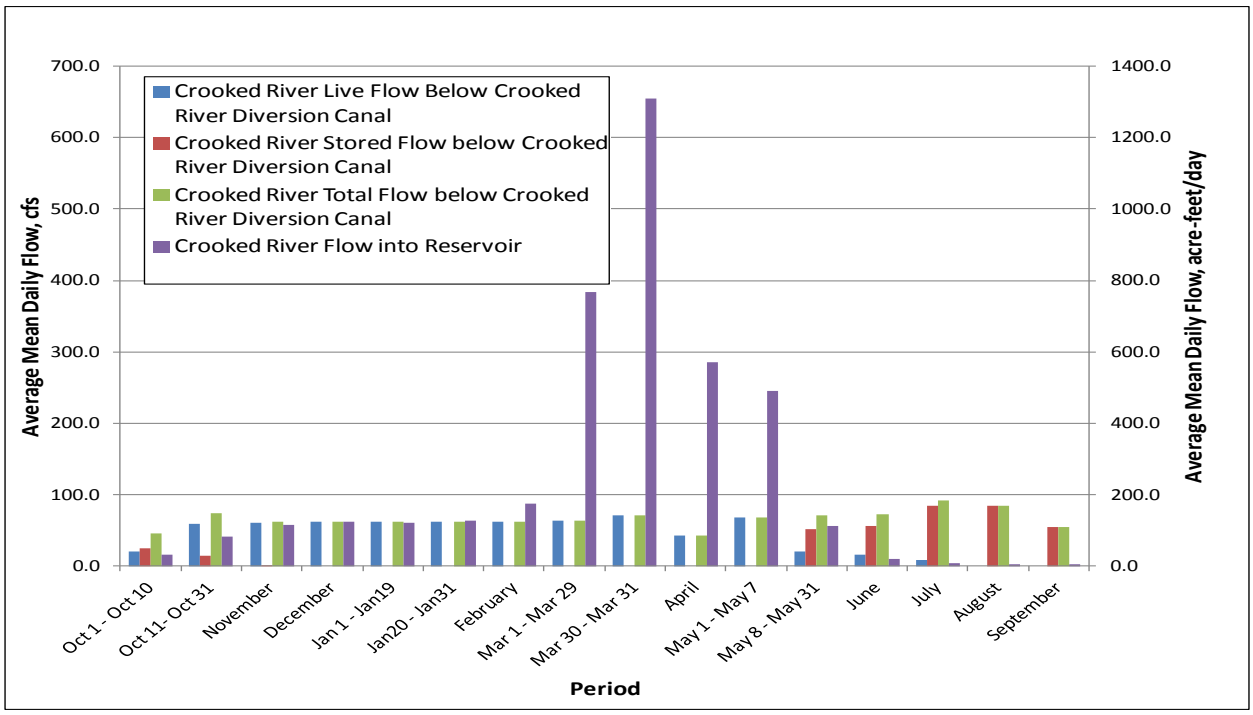


Figure 4.2-4A. Crooked River monthly average, mean daily flow below Crooked River Diversion Canal and Crooked River Flow above Reservoir for Water Year 2001.

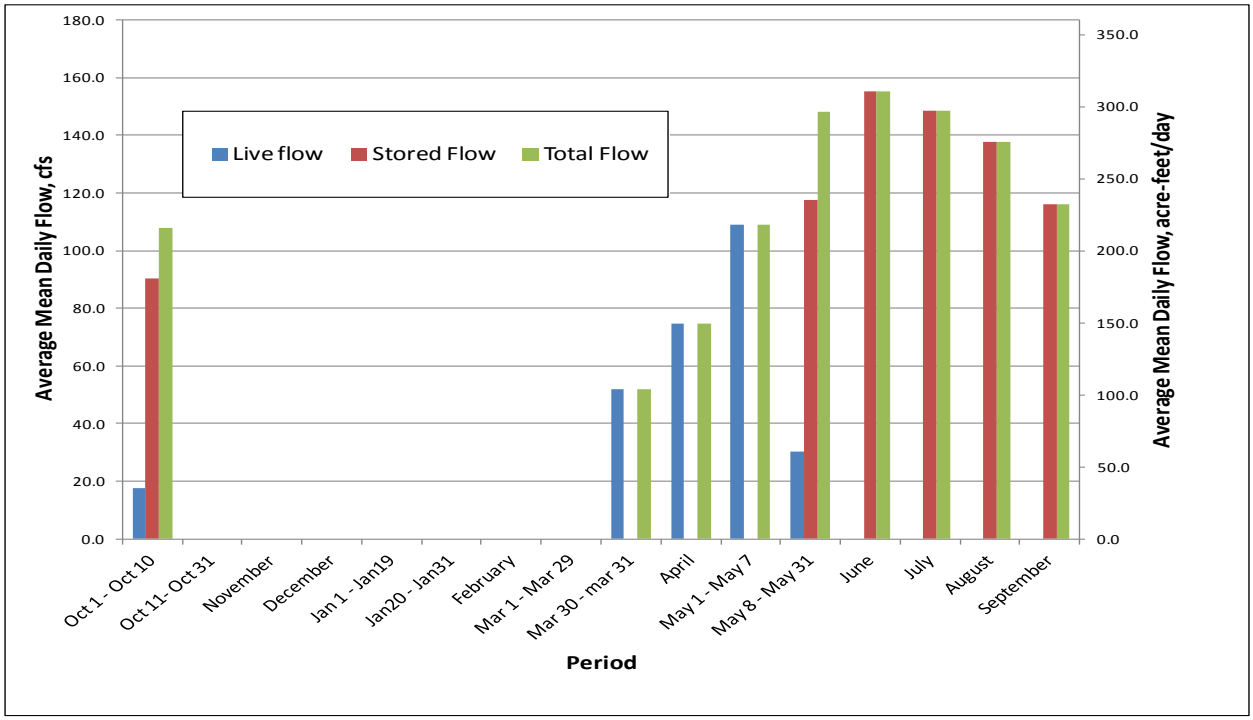


Figure 4.2-4B. Monthly average, mean daily flow for Crooked River Diversion Canal for Water Year 2001.

Table 4.2-3. Mean daily flows for Crooked River Diversion Canal, Crooked River below the Canal Diversion, and the gaged Crooked River Flow into the Reservoir at Post for Water Year 2001 (cubic feet per second).

	Crooked River below Crooked River Diversion Canal			Crooked River Diversion Canal			Gaged Crooked River Flow into Reservoir (@ Post)
	Live Flow	Stored Flow	Total Flow	Live Flow	Stored Flow	Total Flow	
Oct 1 - Oct 10	20.0	25.4	45.4	2.4	105.4	107.8	15.7
Oct 11- Oct 31*	59.6	14.7	74.3	0.0	0.0	0.0	40.9
November	61.0	1.0	62.0	0.0	0.0	0.0	58.1
December	62.0	0.0	62.0	0.0	0.0	0.0	62.1
Jan 1 - Jan 19	61.3	0.0	61.3	0.0	0.0	0.0	60.4
Jan 20 - Jan 31	62.0	0.0	62.0	0.0	0.0	0.0	63.5
February	61.7	0.0	61.7	0.0	0.0	0.0	86.7
Mar 1 - Mar 29	63.6	0.0	63.6	0.0	0.0	0.0	384.3
Mar 30 - Mar 31	71.0	0.0	71.0	52.0	0.0	52.0	654.5
April	43.2	0.0	43.2	74.6	0.0	74.6	285.1
May 1 - May 7	67.7	0.0	67.7	109.0	0.0	109.0	244.9
May 8 - May 31	20.0	51.5	71.5	66.4	81.6	148.0	56.4
June	15.7	56.5	72.2	0.0	155.1	155.1	10.0
July	7.7	84.0	91.7	0.0	148.5	148.5	4.6
August	0.0	84.5	84.5	0.0	137.8	137.8	2.1
September	0.0	54.7	54.7	0.0	116.2	116.2	2.7

* This line in the table is noted because it demonstrates the difference in calculated stored flow between using change in volume and using river gage data. If gage data had been used, the portion of flow below the Crooked River Diversion Canal from storage would be 33.4 cfs instead of 14.7 cfs.

Table 4.2-4. Mean daily flows for Crooked River Diversion Canal and Crooked River below the Canal Diversion for Water Year 2001 (acre-feet/day).

	Crooked River below Crooked River Diversion Canal			Crooked River Diversion Canal			Gaged Crooked River Flow into Reservoir (@ Post)
	Live Flow	Stored Flow	Total Flow	Live Flow	Stored Flow	Total Flow	
Oct 1 - Oct 10	39.6	50.3	89.9	4.8	208.6	213.4	31.0
Oct 11- Oct 31	118.0	29.1	147.1	0.0	0.0	0.0	81.1
November	120.7	2.0	122.7	0.0	0.0	0.0	115.1
December	122.8	0.0	122.8	0.0	0.0	0.0	123.0
Jan 1 - Jan19	121.4	0.0	121.4	0.0	0.0	0.0	119.7
Jan 20 - Jan 31	122.8	0.0	122.8	0.0	0.0	0.0	125.6
February	122.2	0.0	122.2	0.0	0.0	0.0	171.7
Mar 1 - Mar 29	126.0	0.0	126.0	0.0	0.0	0.0	761.0
Mar 30 - Mar 31	140.6	0.0	140.6	103.0	0.0	103.0	1295.9
April	85.5	0.0	85.5	147.8	0.0	147.8	564.5
May 1 - May 7	134.1	0.0	134.1	215.8	0.0	215.8	484.8
May 8 - May 31	39.6	102.0	141.6	131.5	161.7	293.1	111.6
June	31.1	112.0	143.0	0.0	307.2	307.2	19.8
July	15.3	166.3	181.5	0.0	294.1	294.1	9.1
August	0.0	167.4	167.4	0.0	272.9	272.9	4.1
September	0.0	108.4	108.4	0.0	230.0	230.0	5.3

***** This line in the table is noted because it demonstrates the difference in calculated stored flow between using change in volume and using river gage data. If gage data had been used, the portion of flow below the Crooked River Diversion Canal from storage would be 66 acre-feet instead of 29.1 acre-feet.

Generally, Figures 4.2-4A and 4.2-4B show the monthly average mean daily flow for each month for the flow in the Crooked River below the Crooked River Diversion Canal and the flow in Crooked River Diversion Canal, respectively. For October and March, however, these months are split because, for a period of time during these months, there was no flow at all being diverted in to the Crooked River Diversion Canal. An average calculated over the entire month would have been misleading. In addition, the months of January and May 2001 has been split because during these months storage began and ended, respectively.

There were several assumptions used in generating these graphs and the accompanying tables in Appendix A:

- Inflow is based on the change in reservoir volume, plus the estimated loss to evaporation (during the period April through October), plus gaged outflow.
- All inflow to the reservoir is considered "live" flow.
- During the storage period, all flow out of the reservoir is considered live flow unless water is released from storage for flood control.
- Flow leaving the reservoir during the release period is considered "live" flow up to the point where it equals flow entering the reservoir; outflow in excess of flow entering the reservoir is considered "stored" flow.
- The first 20 cfs of live flow leaving the reservoir is assumed to go to water right holders senior to OID. Available live flow in the Diversion Canal, therefore, is reduced by 20 cfs in this analysis.
- OID and its patrons withdraw up to 8.7 cfs directly from the Crooked River at 34 surface pumps between RM 38.4 and RM 49.7 (downstream of the Crooked River Diversion). These pumps effectively reduce flows below RM 38.4 during the irrigation season by up to 8.7 cfs. For this analysis, this 8.7 cfs is not considered in the calculations as an effect on the river flow at the point of diversion for the Diversion Canal.
- Live flow is credited first to the 20 cfs reserved for senior water rights and then to the Diversion Canal. If there is insufficient live flow available to meet diverted flow, the rest of the diverted flow is considered stored flow.
- There are other diversions from Crooked River between the outlet of Prineville Reservoir and the Diversion Canal. Because these diversions are ungaged and not covered by the DBHCP, they are not considered in this quantitative analysis.

Inspection of Figures 4.2-4A and 4.2-4B shows that, after the winter snowmelt runoff is over, almost the entire flow below the Crooked River Diversion Canal and in the canal itself is stored water. After the irrigation season is over, the reservoir outflow can have both live and stored water components until the inflow is augmented by the fall/winter rains. Typically, the minimum reservoir outflow is set at 60-75 cfs, and is augmented with stored water if inflow is less than 75 cfs. In the very driest of years the outflow can be set as low as 30 cfs.

Figure 4.2-5 compares the 2001 Crooked River Diversion Canal Flow with Prineville Reservoir inflow based upon change in volume calculations, the Crooked River flow into the reservoir, and the flow in the Crooked River below the point of diversion. There are noticeable differences, particularly in the March 30-31 period between inflow (based upon change in volume) and the gaged Crooked River flow measured at Post. This is caused likely by the fact that the gaged river flow is a daily mean and the reservoir inflow which is based upon change in reservoir volume. As noted above, inflow measured by change in reservoir volume (elevation) is typically greater than inflow based on the Post gage because the former also accounts for local inflow below the gage. The single exception to this in Figure 4.2-5 is for the brief period of March 30-31, and is likely due to a malfunction of the reservoir elevation gage.

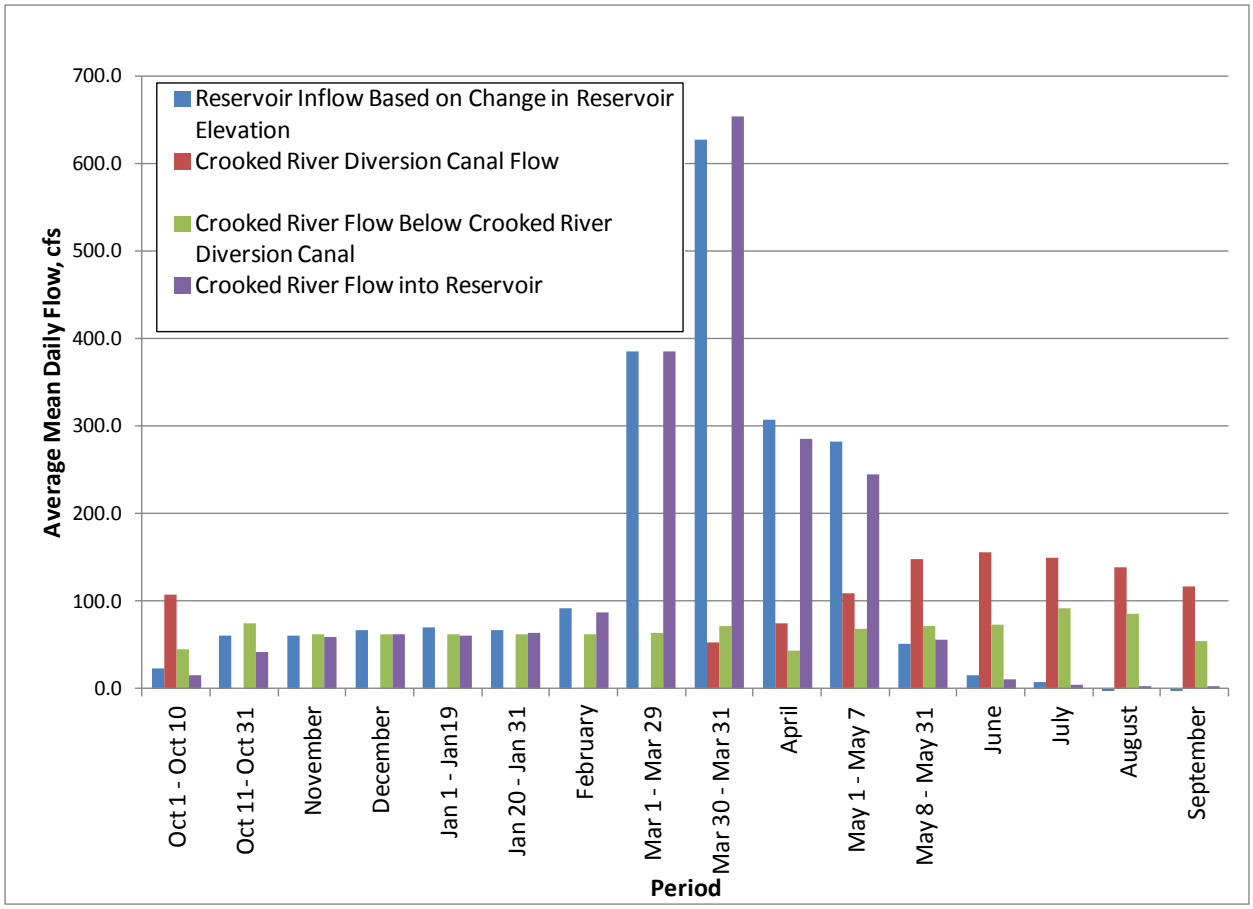


Figure 4.2-5 Flow comparison between Crooked River Diversion Canal, Prineville Reservoir inflow, and Crooked River flow below Canal Diversion for Water Year 2001.

The analysis of water year 2010 was done identically as the analysis of water year 2001. Live and stored flows were calculated based upon change in volume of the reservoir with evaporation estimated as in the 2001 analysis.

Figure 4.2-6 shows the volume in Prineville Reservoir over Water Year 2010. Inspection of the curve indicates the reservoir was releasing stored water early in the water year, stayed steady until about January 1, 2010 when it began filling. The reservoir filled until about April 23, 2010 when, for 7 days, stored water was released to make room for high runoff flows. No significant release of stored water after May 1, 2010 until June 6, 2010 when the reservoir began releasing stored water throughout the rest of the water year. For the purpose of calculating live flow, the storage period is deemed to start on January 1, 2010. The storage period is deemed to have ended for a short, 7 day period on April 23, 2010, then resumed until June 6, 2010. During the storage period all flow released from the reservoir is considered live flow.

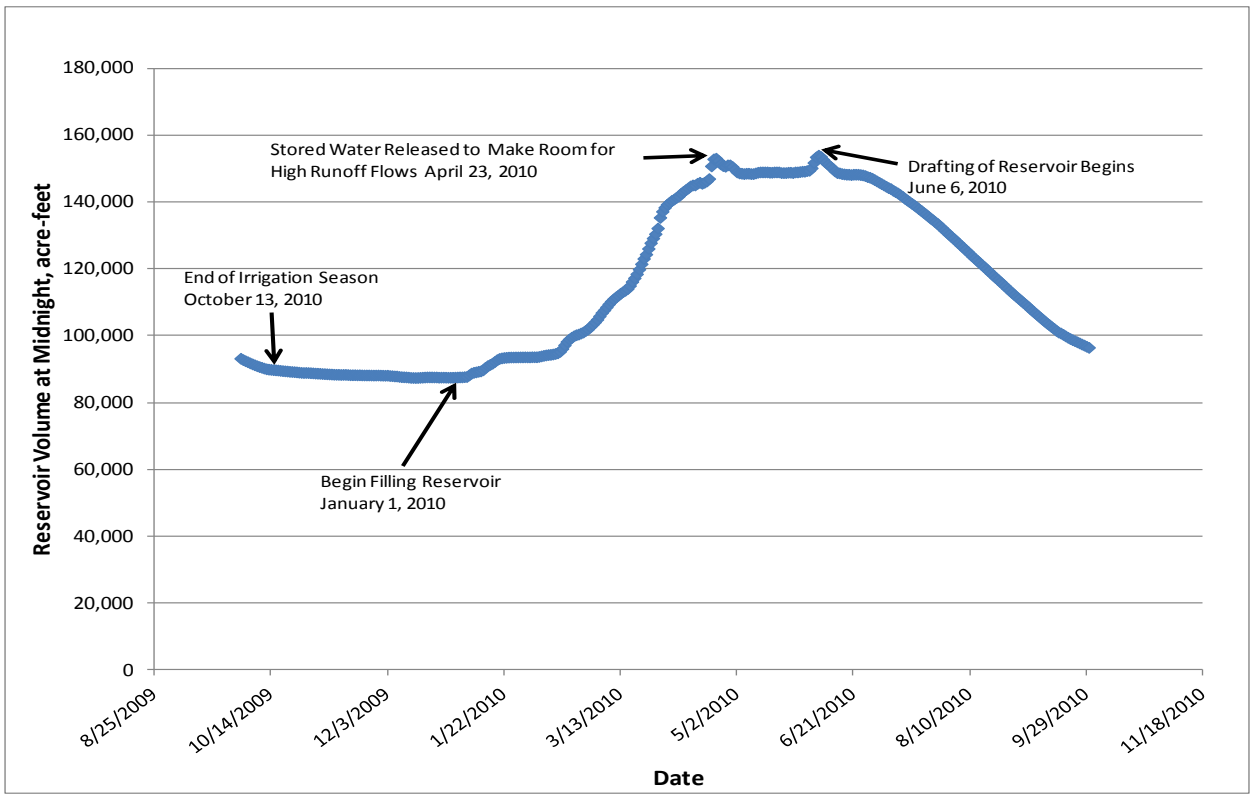


Figure 4.2-6. Prineville Reservoir volume at midnight for Water Year 2010.

Figures 4.2-7A and 4.2-7B provide graphical analyses of the flow effects during Water Year 2010 in cfs and acre-feet per day, respectively. Figure 4.2-7A displays the total, live, and stored flows for 2010 in the Crooked River below the Crooked River Diversion; Figure 4.2-7B displays the total, live and stored flows for 2010 in the Crooked River Diversion Canal for each month. Except for the natural flows, the data are averages of the mean daily flow. The same assumptions used for the Water Year 2001 analysis were used for the 2010 analysis. As noted for Water Year 2001, some months are split in calculating averages. In Water Year 2010, October 2009 and April 2010 are split because these are months when the feed canal began diverting. In addition, the month of June has been split because, beginning June 6, 2010, is the day that reservoir releases began. Tables 4.2-5 and 4.2-6 are tabular representation of Figures 4.2-7A and 4.2-7B.

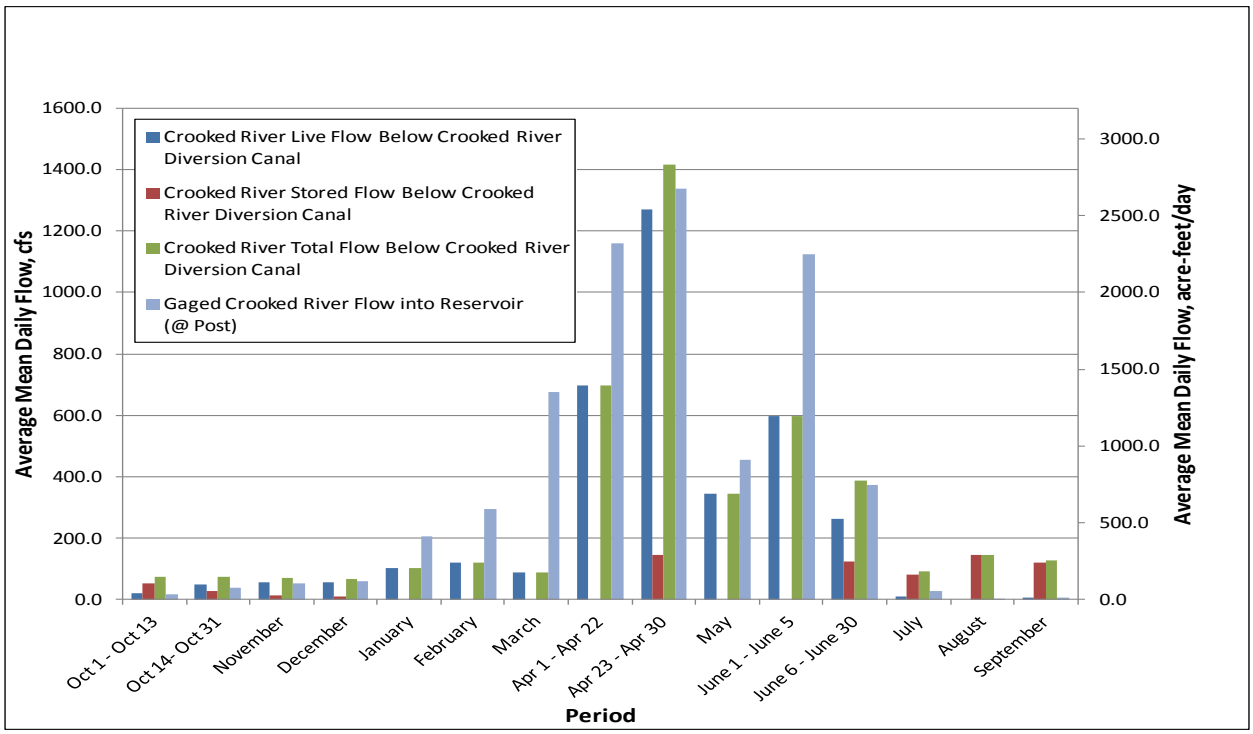


Figure 4.2-7A: Crooked River monthly average, mean daily flow below Crooked River Diversion Canal and Crooked River Flow above Reservoir for Water Year 2010.

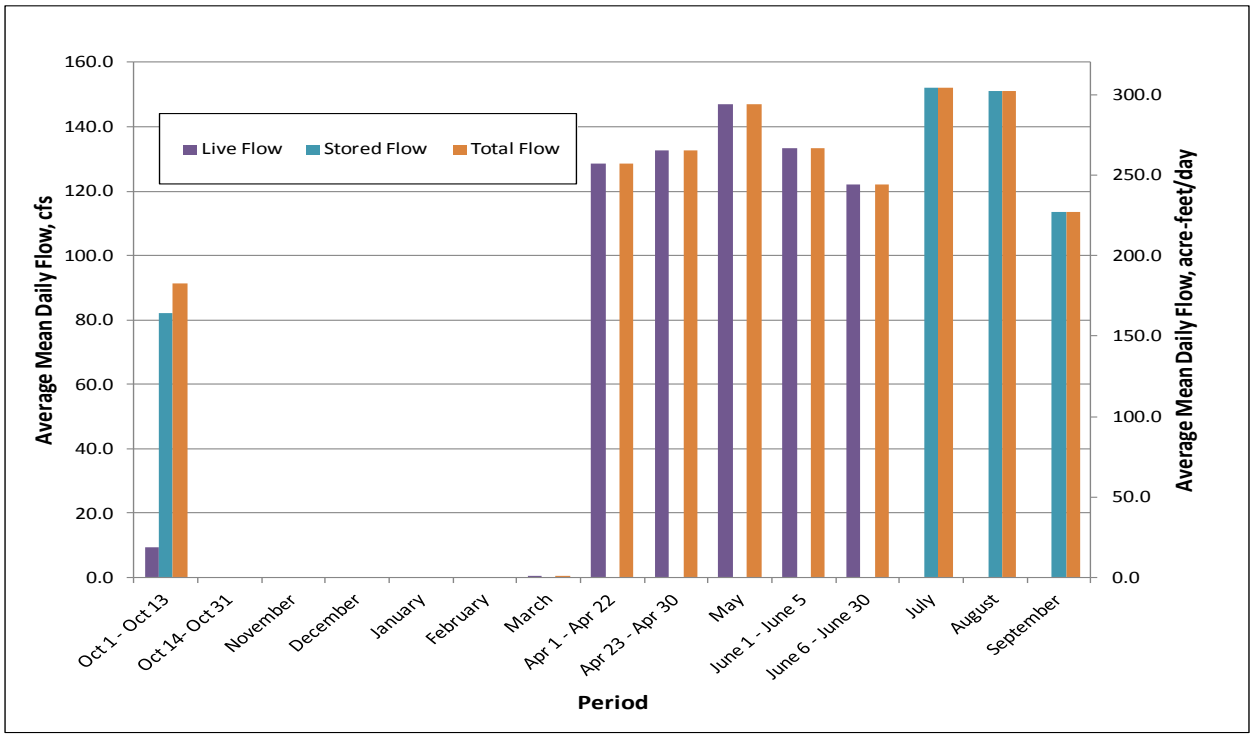


Figure 4.2-7B. Monthly average mean daily flow for Crooked River Diversion Canal for Water Year 2010.

Table 4.2-5. Mean daily flows for Crooked River Diversion Canal, Crooked River below the Canal Diversion, and the gaged Crooked River Flow into the Reservoir at Post for Water Year 2010 (cubic feet per second).

Period	Crooked River below Crooked River Diversion Canal			Crooked River Diversion Canal			Gaged Crooked River Flow into Reservoir (@ Post)
	Live Flow	Stored Flow	Total Flow	Live Flow	Stored Flow	Total Flow	
Oct 1 - Oct 13	20.0	54.0	74.0	9.2	82.0	91.2	17.2
Oct 14- Oct 31	47.7	26.8	74.6	0.0	0.0	0.0	38.8
November	58.1	12.3	70.3	0.0	0.0	0.0	54.6
December	56.1	10.4	66.5	0.0	0.0	0.0	61.7
January	103.4	0.0	103.4	0.0	0.0	0.0	204.2
February	122.3	0.0	122.3	0.0	0.0	0.0	294.5
March	90.1	0.0	90.1	0.0	0.0	0.0	674.3
Apr 1 - Apr 22	697.5	0.0	697.5	128.5	0.0	128.5	1160.9
Apr 23 - Apr 30	1271.2	144.9	1416.1	132.6	0.0	132.6	1337.9
May	345.6	0.0	345.6	147.1	0.0	147.1	456.1
June 1 - June 5	596.6	0.0	596.6	133.4	0.0	133.4	1122.0
June 6 - June 30	262.6	124.1	386.7	122.2	0.0	122.2	373.1
July	9.9	81.6	91.5	0.0	152.2	152.2	27.1
August	0.0	145.3	145.3	0.0	151.2	151.2	3.1
September	6.2	121.4	127.6	0.0	113.4	113.4	7.1

Table 4.2-6. Mean daily flows for Crooked River Diversion Canal, Crooked River below the Canal Diversion, and the gaged Crooked River Flow into the Reservoir at Post for Water Year 2010 (acre-feet/day).

Period	Crooked River below Crooked River Diversion Canal			Crooked River Diversion Canal			Gaged Crooked River Flow into Reservoir (@ Post)
	Live Flow	Stored Flow	Total Flow	Live Flow	Stored Flow	Total Flow	
Oct 1 - Oct 13	39.6	106.9	146.5	18.3	162.3	180.6	34.1
Oct 14- Oct 31	94.5	53.2	147.6	0.0	0.0	0.0	76.9
November	115.0	24.3	139.3	0.0	0.0	0.0	108.0
December	111.2	20.6	131.8	0.0	0.0	0.0	122.1
January	204.8	0.0	204.8	0.0	0.0	0.0	404.3
February	242.2	0.0	242.2	0.0	0.0	0.0	583.2
March	178.4	0.0	178.4	0.1	0.0	0.1	1335.2
Apr 1 - Apr 22	1381.0	0.0	1381.0	254.5	0.0	254.5	2298.6
Apr 23 - Apr 30	2516.9	287.0	2803.9	262.6	0.0	262.6	2649.0
May	684.2	0.0	684.2	291.3	0.0	291.3	903.0
June 1 - June 5	1181.3	0.0	1181.3	264.1	0.0	264.1	2221.6
June 6 - June 30	519.9	245.8	765.6	242.0	0.0	242.0	738.8
July	19.6	161.5	181.1	0.0	301.4	301.4	53.7
August	0.0	287.7	287.7	0.0	299.4	299.4	6.0
September	12.2	240.4	252.6	0.0	224.6	224.6	14.1

Figure 4.2-8 compares the total 2010 Crooked River Diversion Canal Flow with total gaged inflow to Prineville Reservoir and the Crooked River flow below the point of diversion.

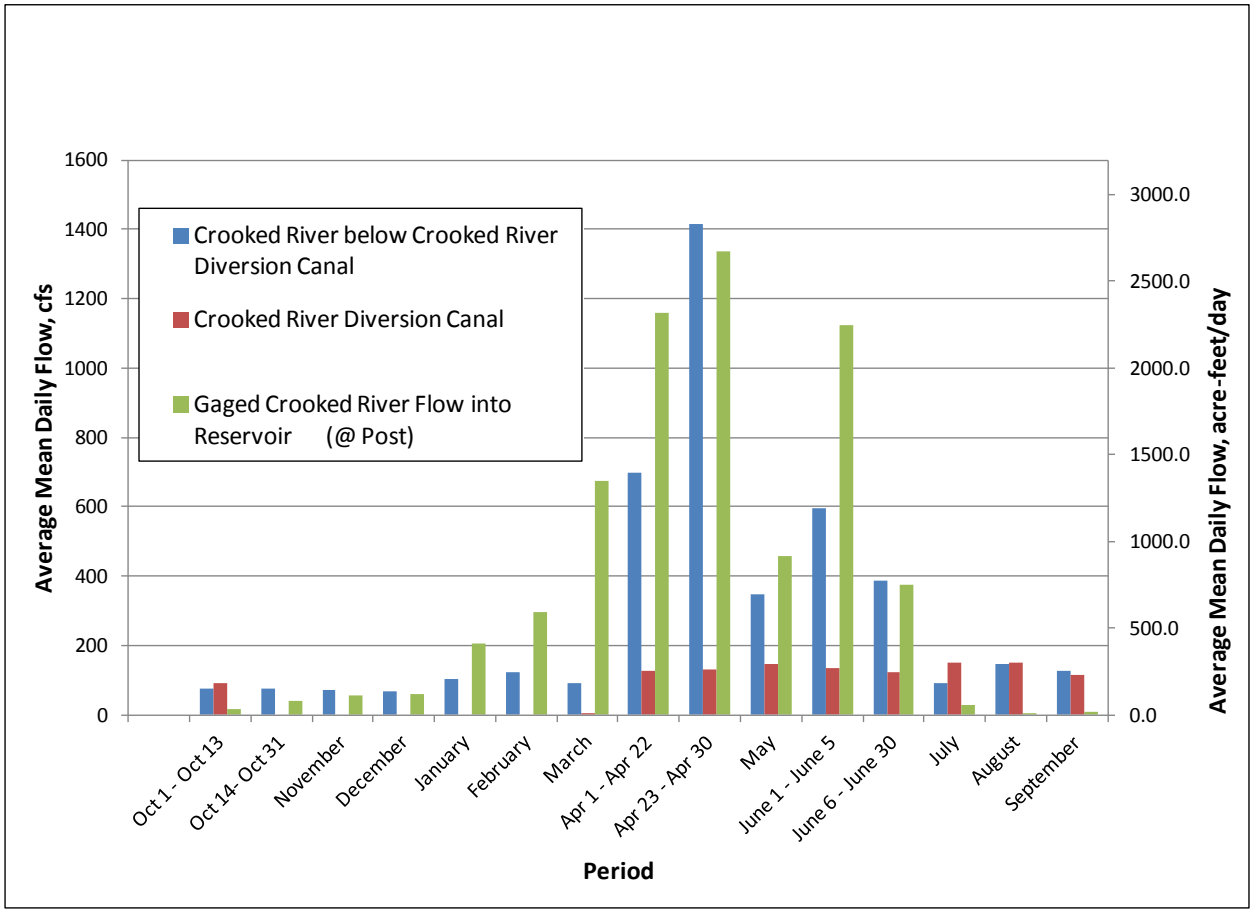


Figure 4.2-8. Flow comparison between Crooked River Diversion Canal, Prineville Reservoir inflow, and Crooked River flow below diversion for Water Year 2010.

Neither Water Years 2001 nor 2010 show the effect of several years in a row of low runoff, which can be significant. Figure 4.2-9 shows a graph of several dry water years (Water Years 1989 through 1994) in which three (1990, 1991 and 1992) were quite dry. Notice how the reservoir storage volume decreases during the dry water years. Also note that the y-axis is logarithmic. This was done to better illustrate reservoir inflow and outflow. Flows of 0.01 cfs actually indicate a zero flow which is not possible logarithmically.

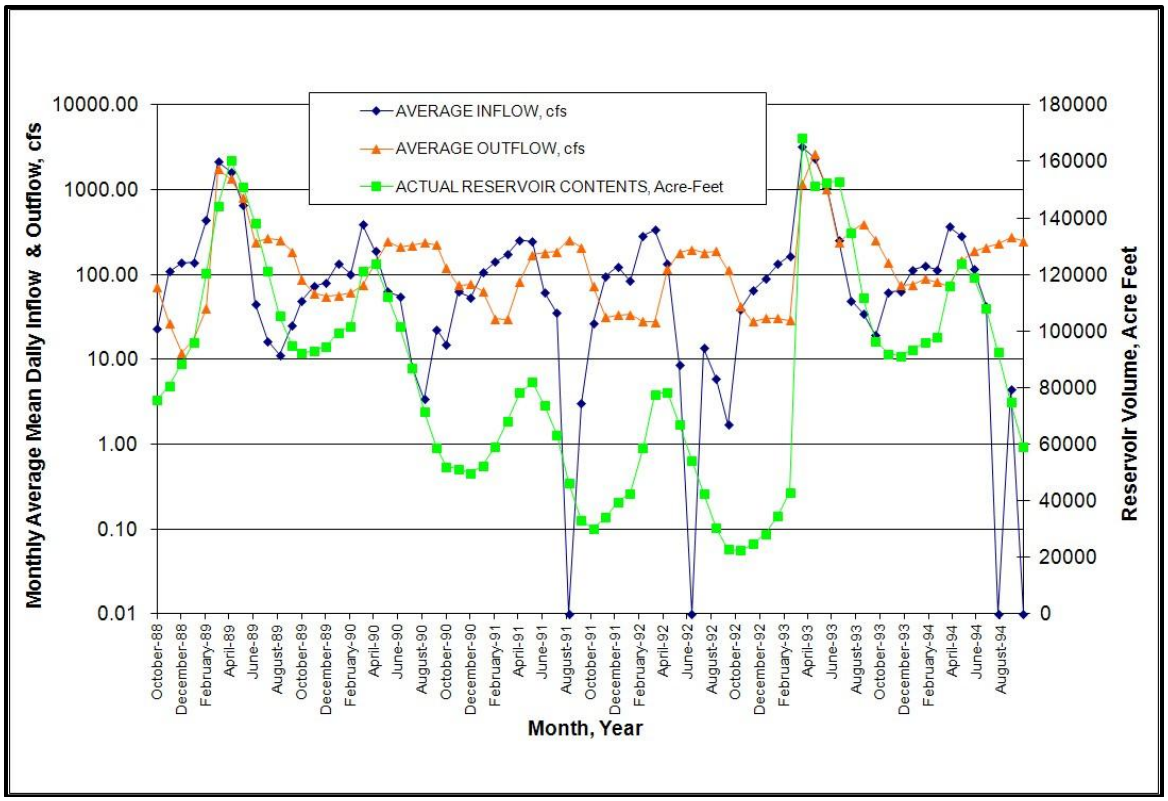


Figure 4.2-9. Prineville Reservoir inflow, outflow, and volume for Water Years 1989 through 1994.

Figure 4.2-10 shows a statistical summary of the monthly averages for the Crooked River below the Crooked River Diversion Canal for Water Years 1983 through 2010. The monthly statistics begin with Water Year 1983 because there are no flow data for the Crooked River Diversion Canal before that water year. Tables 4.2-7 is a tabular representations of Figures 4.2-10.

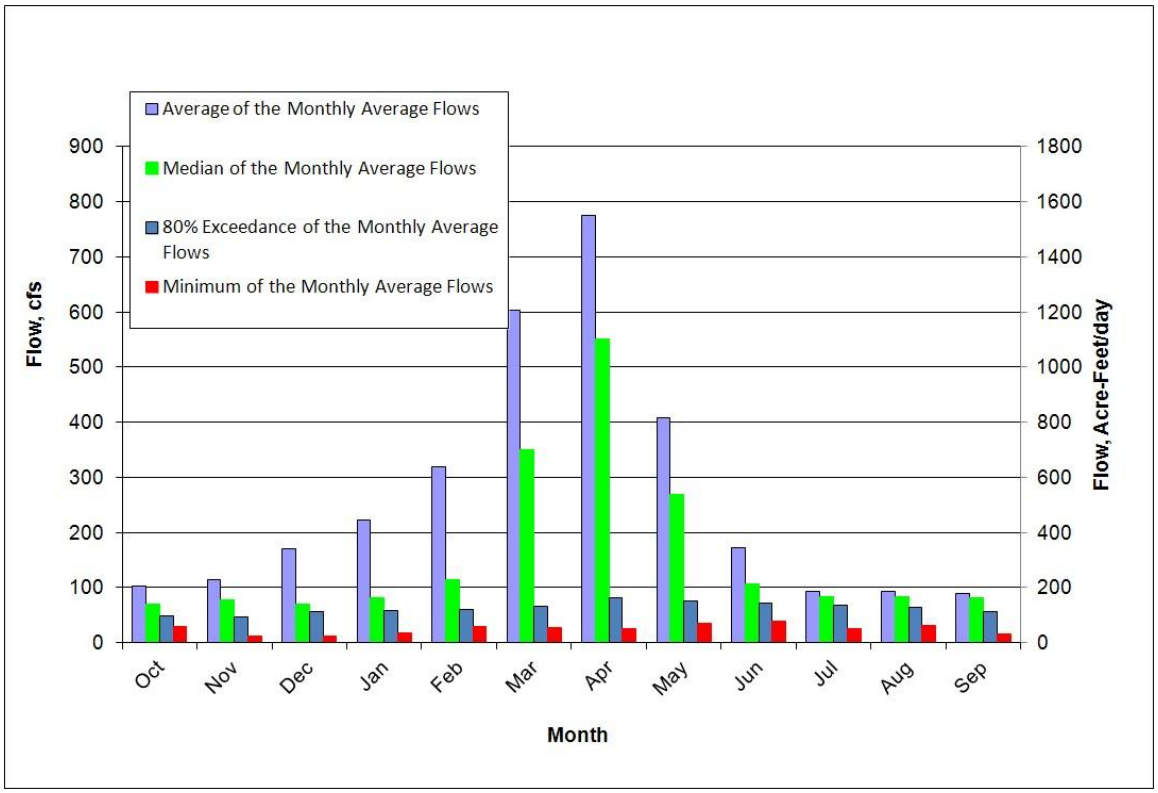


Figure 4.2-10. Water Year 1983 through 2010 statistics of the monthly average for the Crooked River Below Crooked River Diversion Canal

Table 4.2-7. Water Year 1983 through2010 statistics of the monthly average mean daily flow for Crooked River below Crooked River Diversion Canal (cubic feet per second).

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance of the Monthly Average Flows	Minimum of the Monthly Average Flows	80% Exceedance of the Natural Flows	50% Exceedance of the Natural Flows
Oct	102.2	70.1	47.8	29.4	47.6	67.2
Nov	114.4	77.4	45.9	12.6	61.0	81.5
Dec	170.2	69.9	56.0	11.9	77.1	136.4
Jan	222.0	81.5	57.8	17.0	79.7	196.1
Feb	319.6	113.5	60.0	30.1	176.9	400.9
Mar	602.3	349.6	65.3	27.6	341.3	761.5
Apr	775.9	551.2	81.3	26.1	603.9	980.0
May	408.3	269.0	76.1	34.4	408.3	633.8
Jun	173.0	107.4	72.2	38.1	264.4	327.3
Jul	92.3	82.6	67.7	26.0	81.2	95.2
Aug	93.2	82.5	64.7	30.6	39.2	48.7
Sep	89.1	81.0	56.5	16.1	45.7	56.6

Figure 4.2-11 is similar to Figure 4.2.1-10, but it is only for Water Years 2001 through 2010. Table 4.2-8 is a tabular representations of Figure 4.2-11.

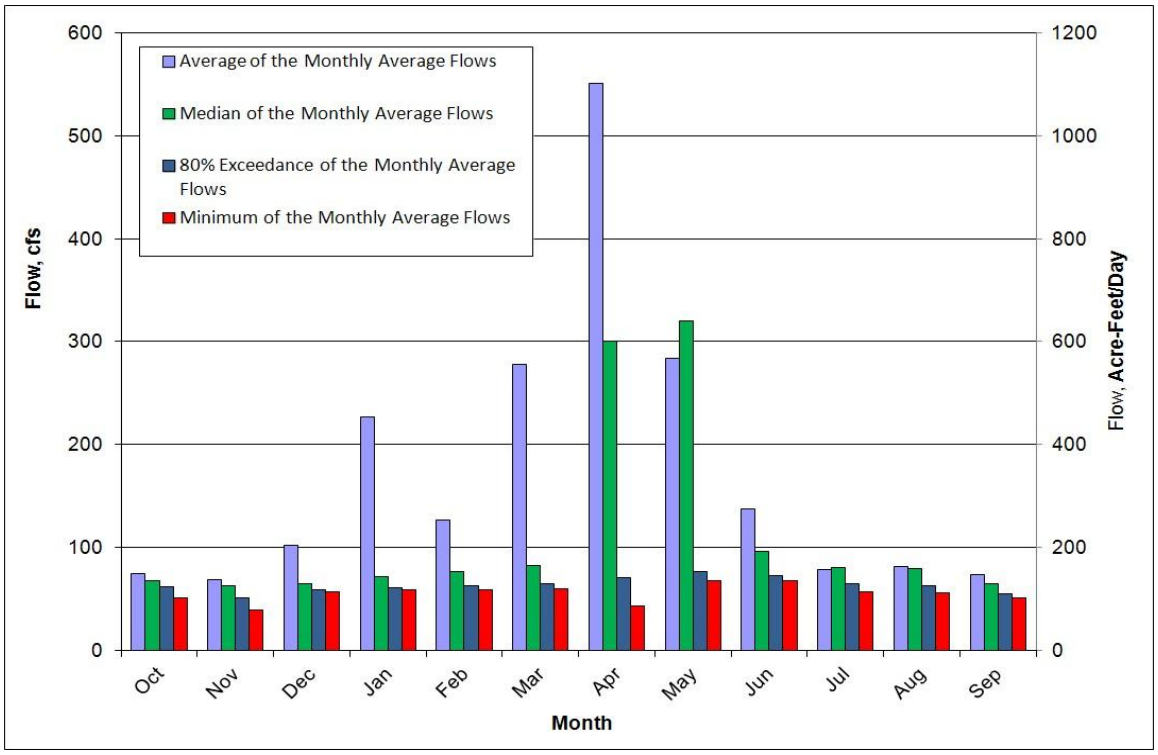


Figure 4.2-11. Water Year 2001 through 2010 statistics of the monthly average for the Crooked River below the Crooked River Diversion Canal.

Table 4.2-8. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for Crooked River below Crooked River Diversion Canal (cubic feet per second).

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance of the Monthly Average Flows	Minimum of the Monthly Average Flows	80% Exceedance of the Natural Flows	50% Exceedance of the Natural Flows
Oct	74.56	67.81	61.90	50.90	47.6	67.2
Nov	68.77	63.25	51.30	39.07	61.0	81.5
Dec	102.37	64.27	58.78	57.10	77.1	136.4
Jan	226.55	71.31	60.81	58.71	79.7	196.1
Feb	126.46	76.72	62.34	58.89	176.9	400.9
Mar	277.76	82.06	64.85	60.26	341.3	761.5
Apr	550.99	300.62	70.31	43.17	603.9	980.0
May	283.52	319.68	76.97	67.74	408.3	633.8
Jun	137.27	96.22	72.19	67.53	264.4	327.3
Jul	78.09	80.44	64.82	56.81	81.2	95.2
Aug	81.54	79.76	62.80	55.90	39.2	48.7
Sep	73.82	65.20	54.49	50.77	45.7	56.6

Figure 4.2-12 is a graph that shows the monthly average flows for each month for Water Years 2001 through 2010 for the inflow to Prineville Reservoir and below the Crooked River Diversion Canal and the monthly average flow for each month in the Diversion Canal. Note that if the inflow calculations indicated that inflow was negative, the value was set to zero (0). Table 4.2-9 is a tabular representation of Figure 4.2-12.

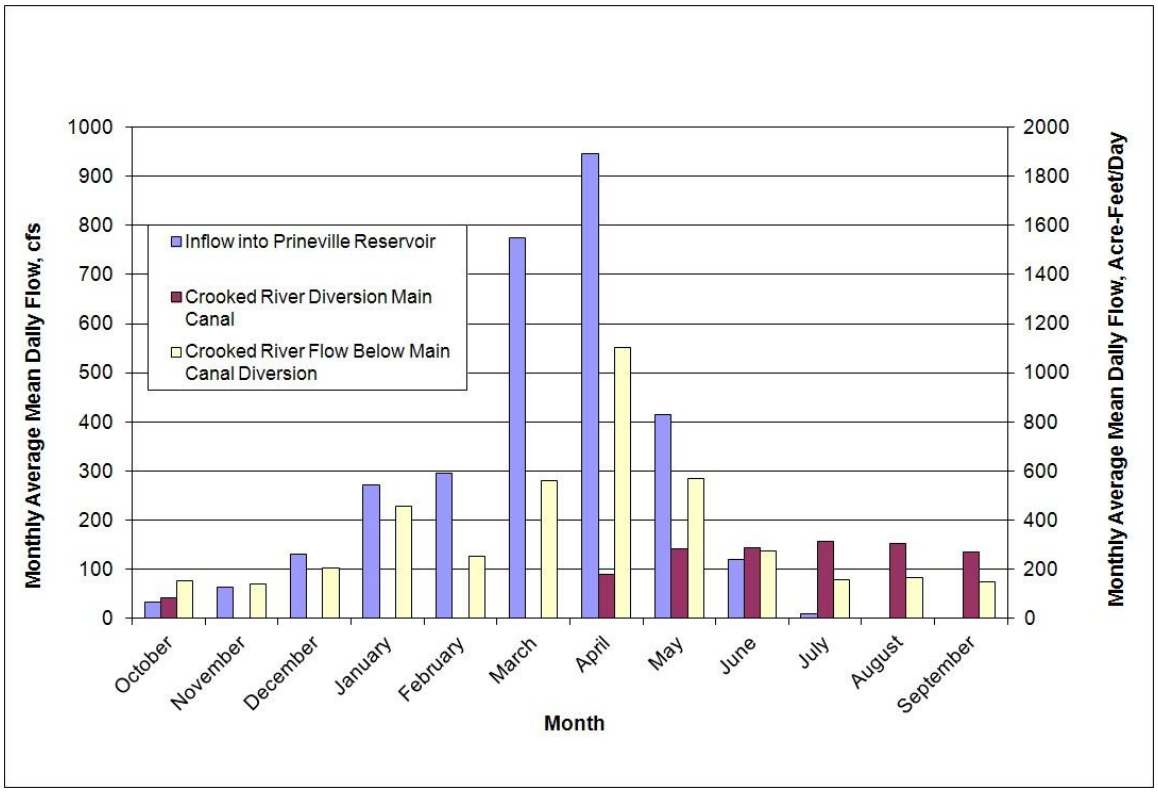


Figure 4.2-12. Monthly average mean daily flows for inflow to Prineville Reservoir, Crooked River Diversion Canal Flow, and Crooked River flow below diversion for Water Years 2001 through 2010.

Table 4.2-9. Water Year 2001 through 2010 monthly average flows for the Crooked River below Crooked River Diversion Canal, inflow to Prineville Reservoir, and Crooked River Diversion Canal Flow, (cubic feet per second).

Month	Inflow into Prineville Reservoir	Crooked River Diversion Main Canal	Crooked River Flow Below Main Canal Diversion
October	32	40	75
November	63	0	69
December	131	0	102
January	272	0	227
February	296	0	126
March	775	0	279
April	946	88	551
May	415	141	284
June	118	142	137
July	7	156	78
August	0	153	82
September	0	134	74

4.2.1.2 Ochoco Main Canal

4.2.1.1.1. Analysis and Reference Points

This section of the report analyzes the impact on Ochoco Creek from the diversion of live flow and stored water at the Ochoco Main Canal. Water is stored in Ochoco Reservoir, and the Ochoco Main Canal diverts water directly from the reservoir. In addition to the Ochoco Main Canal, the district operates four additional diversions on Ochoco Creek below the reservoir: the Red Granary Diversion (RM 10.4), Breese Diversion (RM 7.7), North and South Infiltration Galleries (RM 5.7), and Ryegrass Diversion (RM 4.7). Up to 53 cfs of flow released into Ochoco Creek below Ochoco Dam is withdrawn from the Creek by OID and its patrons before it reaches the Crooked River. In addition, OID patrons operate another 33 surface pumps that pump water directly from Ochoco Creek. Water for these diversions and pumps on Ochoco Creek is provided in part by water from the Crooked River Diversion Canal as well as some springs in the creek and return flows.

Ochoco Reservoir impounds water from Ochoco Creek and from Mill Creek. Both creeks have gages. The gage on Ochoco Creek (Gage No. 14082550) is several miles upstream from Ochoco Reservoir and is below the confluence of Marks Creek. This gage has been operational since November 1999; the gage data are published except for 2009 when they are considered only provisional. There are private water diversions from Ochoco Creek between the gage and the reservoir. The gage on Mill Creek (Gage No. 14083400) is located about 7 miles upstream from the reservoir and there are also private diversions between the gage and the reservoir. This gage has been operational since September 1999; the gage data are published except for 2009 when they are considered only provisional. These are the only gages from which data for flow entering the reservoir are available.

In addition to flow gages on Ochoco Creek and Mill Creek above the reservoir, there is a gage for measuring and recording Ochoco Reservoir water elevation. This gage is used to calculate the volume of storage in the reservoir. The storage volume data are also available on the OWRD website (Gage No. 14085100). The data for this gage are considered raw. The date when the gage began operating is apparently unknown, but data are available for Water Year 2001 to the present.

The gage on Ochoco Creek (Gage No. 14085300) below the reservoir has been operational since February 10, 1920. The data are published for the periods analyzed in this report.

Finally, the gage for Ochoco Main Canal (Gage No. 14085200, referenced on the OWRD website as Ochoco Feed Canal) has been operational since April 1, 1955. The data available during the periods of diversion are published except for Water Year 2010; during the non-diversion period, the data are missing and are assumed to indicate that there is no diversion occurring. A map of the locations of the gages is provided in Figure A-3 in the Appendix.

4.2.1.2.2 Effects of Water Diversion on In-Stream Flow Analysis

For analysis purposes, it is assumed that OID removes all of its Ochoco Creek Water at the Ochoco Main Canal Headworks. In reality, as stated above, a portion of the district's water right is returned to the creek at the headworks and subsequently withdrawn at multiple diversions or pumps described in the HCP before reaching the Crooked River. This analysis therefore overstates the effects of irrigation diversions on Ochoco Creek. Detailed evaluations of the actual flow effects at the multiple diversions and pumps is beyond the scope of this study, but can be evaluated later if necessary.

Analysis of flow data (Table 4.2-10) and reservoir storage data (Figure 4.2-13) since Water Year 1999 indicates that Water Year 2001 was the driest over the last 10 years.

Table 4.2-10. Total annual flow of Ochoco and Mill creek's combined.

Water Year	Total Annual Flow (acre-feet)		
	Ochoco Creek	Mill Creek	Combined Flow
2000	21,637	12,817	34,454
2001	**6,656**	**5,478**	**12,134**
2002	15,050	13,029	28,079
2003	14,381	12,299	26,680
2004	26,160	20,237	46,397
2005	10,344	11,642	21,986
2006	51,264	29,607	80,870
2007	21,542	14,042	35,583
2008	24,554	19,520	44,075
2009	11,952	10,273	22,225
2010	20,787	16,373	37,160

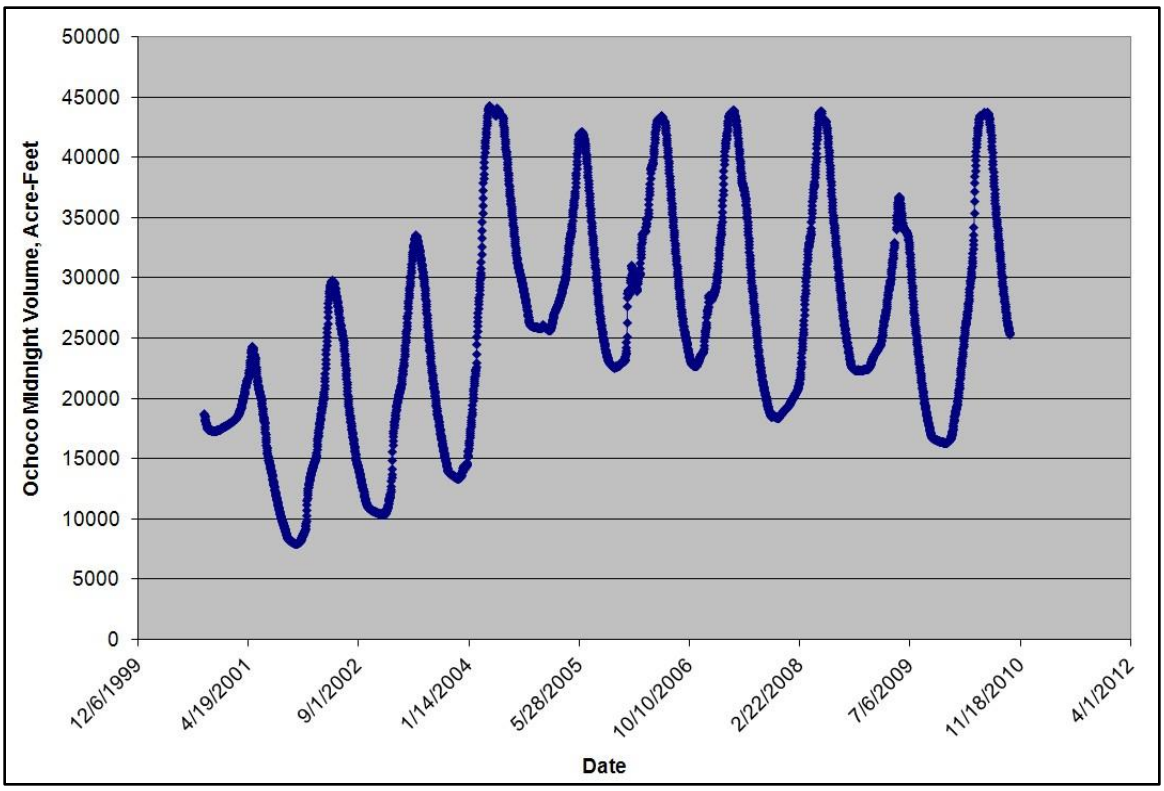


Figure 4.2-13. Ochoco Reservoir midnight volume for Water Years 2000 through 2010.

As stated in Section 4.2.1.1.2, determination of reservoir inflow is important because it is needed to determine the amount of live flow leaving the reservoir. If outflow is less than inflow, all the outflow is considered live flow. As a general rule, all flow leaving the reservoir during the time of year when irrigation water is being actively stored in the reservoir is considered live flow. Exceptions to this are voluntary releases of stored water in the fall after the irrigation season to increase flow in Ochoco Creek, which would not otherwise occur in some dry years. In addition, there are releases of storage to accommodate the U.S. Army Corps of Engineers' flood control requirements that may apply during periods of high precipitation and/or rapid snowmelt. Once the release of stored irrigation water begins in the spring, and the reservoir level begins to drop, the portion of flow leaving the reservoir that is considered live flow is equal to the inflow. If more flow is leaving the reservoir than inflow, the flow in excess of inflow is considered stored flow. These individual periods (storage vs. release) will be indicated in the analyses below.

There are two means for determining inflow into Ochoco Reservoir:

- Using the Mill Creek and Ochoco Creek flow gage above the reservoir, and
- Using the change in reservoir volume.

The problem with using the gages above the reservoir is that they do not capture any ungaged flow that may be entering the reservoir. This flow can come from tributaries to Ochoco and Mill Creeks between the gages and the reservoir or from tributaries to the reservoir itself. These flows can be significant in the winter and spring periods. In addition, the two upstream gages are considerable distance upstream from the reservoir and do not reflect diversions between the gages and the reservoir. Using the change in reservoir volume to estimated inflow captures

the ungaged flow, but it does not, in itself, consider losses in the reservoir due to evaporation which can be significant in the summer. Therefore, evaporation must be estimated.

Based upon the discussion in Section 4.2.1.1.2, this analysis uses the change in reservoir volume to determine inflow, but, to account for evaporation, estimates evaporation loss based on predicted evaporation loss used by Reclamation when it designed Bowman Dam (source: Crooked River Project, February, 1953, page 45). Table 4.2-11 provides the estimated evaporation loss in feet per month.

Table 4.2-11. Estimated evaporation loss for Prineville Reservoir (and applied to Ochoco Reservoir).

Month	Evaporation (feet/month)	Month	Evaporation (feet/month)
OCT	0.07	APR	0.16
NOV	0	MAY	0.28
DEC	0	JUN	0.32
JAN	0	JUL	0.53
FEB	0	AUG	0.41
MAR	0	SEP	0.25

The amount of water lost to evaporation is dependent upon the surface area of the reservoir as well as the depth of evaporation loss. For the Ochoco Reservoir analysis, daily surface areas were calculated for the specific period being analyzed using the relationship between reservoir volume and its corresponding surface area. This relationship is defined on page 16 in the 1990 Sedimentation Survey for Ochoco Reservoir by Reclamation. Using these data, the mean evaporation in cfs) was calculated for each day. It must be pointed out as it was in Section 4.2.1.1.2 that the determination of reservoir volume is based upon instantaneous reservoir elevation readings at midnight of each day. It is not a daily mean value as are the stream gage data. As a result, inflow calculations based upon change in volume may have some error. Nevertheless, the results are believed superior to using the two upstream stream gages which are too far upstream, do not account for stream diversions between the gages and the reservoir, and don't reflect other sources of reservoir inflow.

Reservoir inflow (also in cfs) is calculated using estimated evaporation, the change in volume (converted to a mean daily flow), and the gaged outflow (Ochoco Main Canal and Ochoco Creek below the reservoir) using the following equation:

$$Q_{Inflow} = Q_{change\ in\ volume} + Q_{Evap} + Q_{Ochoco\ Diversion} + Q_{Ochoco\ Creek}$$

Where

Q_{Inflow} ..... = Reservoir Inflow, cfs

Q_{Evap} ..... = Flow Lost to Evaporation, cfs

$Q_{Ochoco\ Diversion}$ ..... = Ochoco Main Canal Diversion Flow, cfs

$Q_{Ochoco\ Creek}$ ..... = Ochoco Creek Below Reservoir

Figure 4.2-14 shows the volume in Ochoco Reservoir over Water Year 2001. Inspection of the curve indicates the reservoir was releasing stored water early in the water year, then began filling around November 20, 2000. The reservoir filled until about May 8, 2001 and then began releasing stored water throughout the rest of the water year.

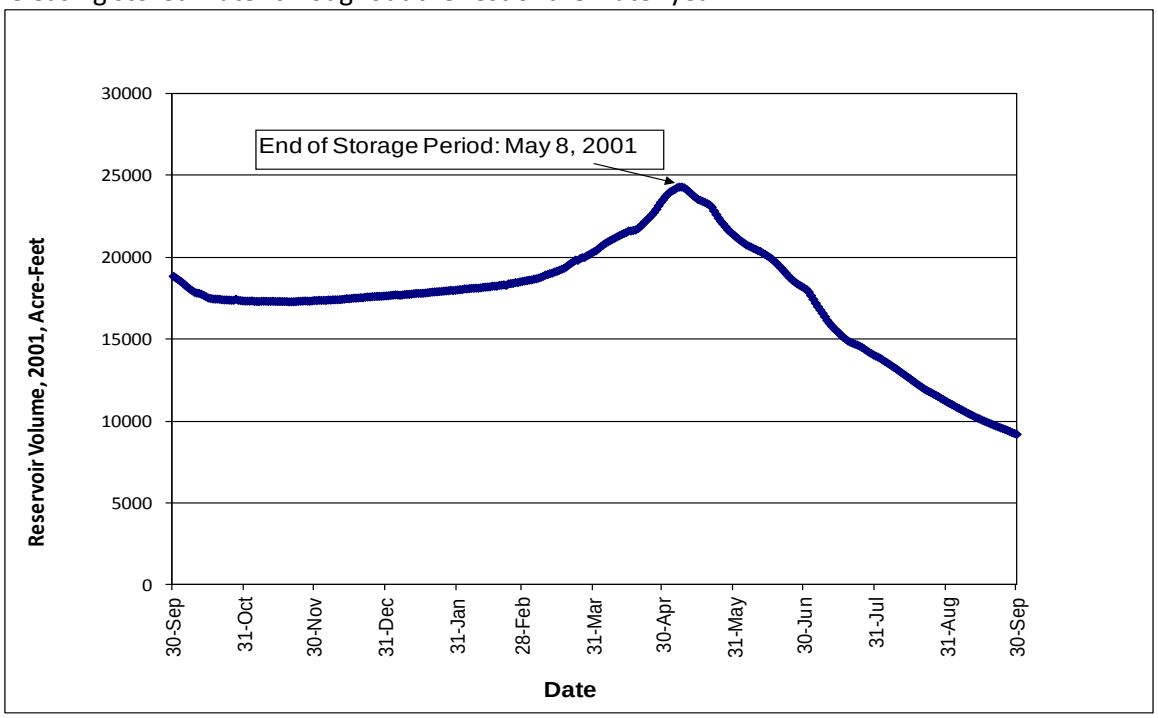


Figure 4.2-14. Ochoco Reservoir volume for Water Year 2001.

Figures 4.2-15A and 4.2-15B provide a graphical analysis of the monthly average flow effect during Water Year 2001 in cubic feet per second and acre-feet per day, respectively. Figure 4.2-15A displays the total, live, and stored flows for 2001 in Ochoco Creek below the Ochoco; Figure 4.2-15B displays the total, live and stored flows for 2001 in the Ochoco Main Canal for each month. Finally, Figure 4.2-15C shows the inflow and outflow of Ochoco Reservoir and the diversion flow of Ochoco Feed Canal for Water Year 2001. Except for the natural flows, the data are averages of the mean daily flow. The months of October, March and April are split because for a period of time during these months there was no flow at all being diverted into the Ochoco Main Canal. Averages calculated over the entire months would have been misleading. In addition, the month of May is also split into two at the point the reservoir changes from storing water to releasing water.

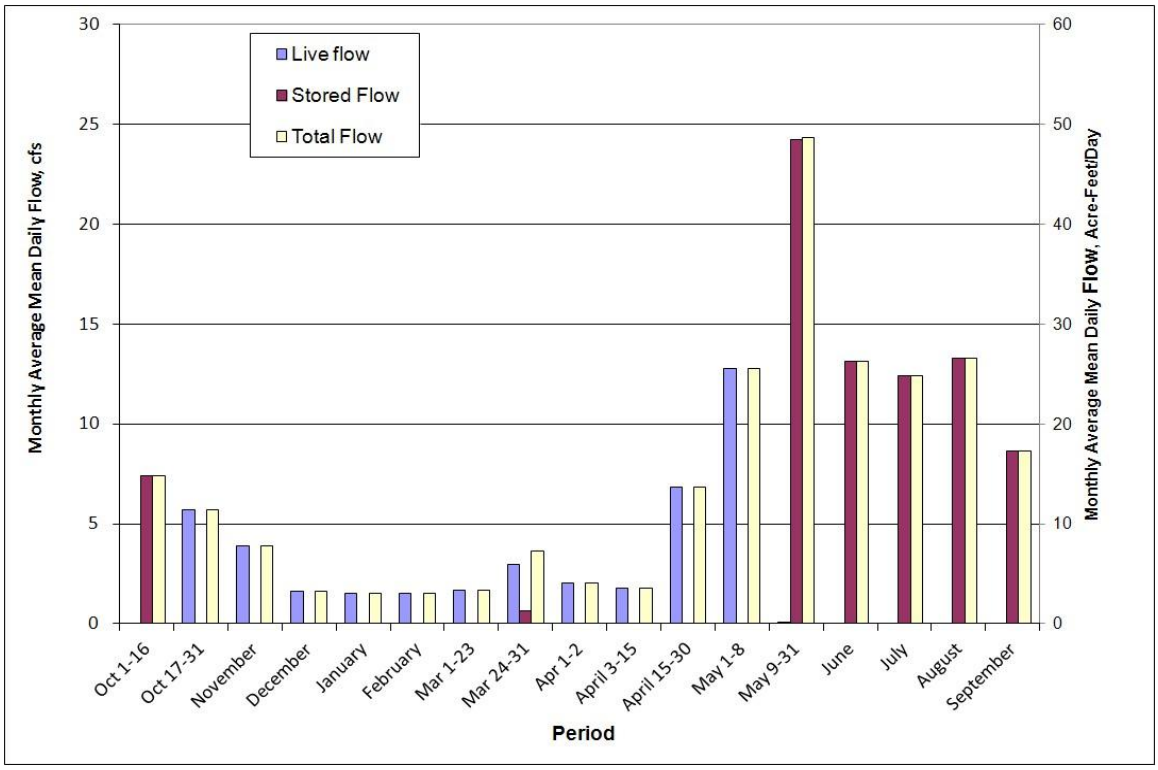


Figure 4.2-15A. Ochoco Creek monthly average mean daily flow below Ochoco Reservoir for Water Year 2001.

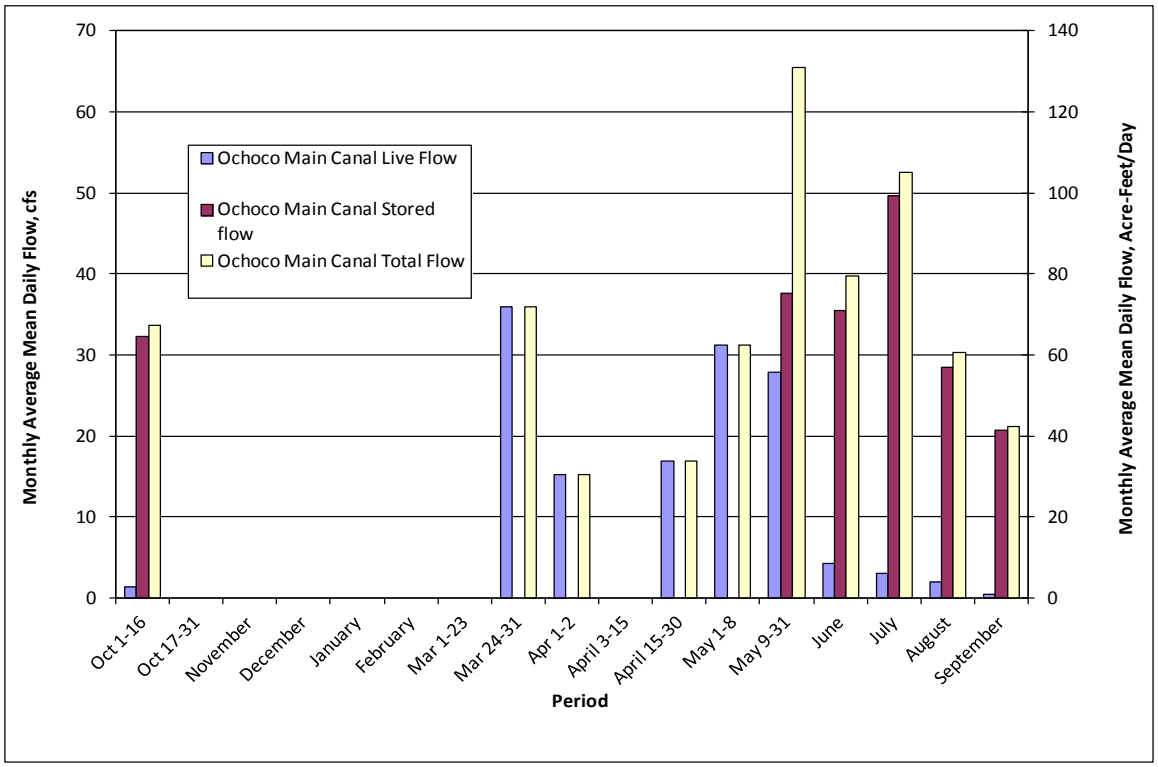


Figure 4.2-15B. Monthly average mean daily flow for Ochoco Main Canal for Water Year 2001.

Table 4.2-12. Flow impact analysis on Ochoco Creek from Ochoco Main Canal Diversion for Water Year 2001 (cubic feet per second).

Date	Ochoco Creek Flow Below Ochoco Reservoir			Ochoco Feed Canal Flow		
	Live	Stored	Total	Live	Stored	Total
Oct 1-16	0	7	7	1	32	34
Oct 17-31	6	0	6	0	0	0
November	4	0	4	0	0	0
December	2	0	2	0	0	0
January	2	0	2	0	0	0
February	2	0	2	0	0	0
Mar 1-23	2	0	2	0	0	0
Mar 24-31	3	1	4	36	0	36
Apr 1-2	2	0	2	15	0	15
April 3-15	2	0	2	0	0	0
April 15-30	7	0	7	17	0	17
May 1-8	13	0	13	31	0	31
May 9-31	0	24	24	28	38	65
June	0	13	13	4	36	40
July	0	12	12	3	50	53
August	0	13	13	2	28	30
September	0	9	9	0	21	21

Table 4.2-13. Flow impact analysis on Ochoco Creek from Ochoco Feed Canal Diversion for Water Year 2001 (acre-feet/day).

Date	Ochoco Creek Flow Below Ochoco Reservoir			Ochoco Feed Canal Flow		
	Live	Stored	Total	Live	Stored	Total
Oct 1-16	0	15	15	3	64	67
Oct 17-31	11	0	11	0	0	0
November	8	0	8	0	0	0
December	3	0	3	0	0	0
January	3	0	3	0	0	0
February	3	0	3	0	0	0
Mar 1-23	3	0	3	0	0	0
Mar 24-31	6	1	7	71	0	71
Apr 1-2	4	0	4	30	0	30
April 3-15	3	0	3	0	0	0
April 15-30	14	0	14	33	0	33
May 1-8	25	0	25	62	0	62
May 9-31	0	48	48	55	75	130
June	0	26	26	9	70	79
July	0	25	25	6	98	104
August	0	26	26	4	56	60
September	0	17	17	1	41	42

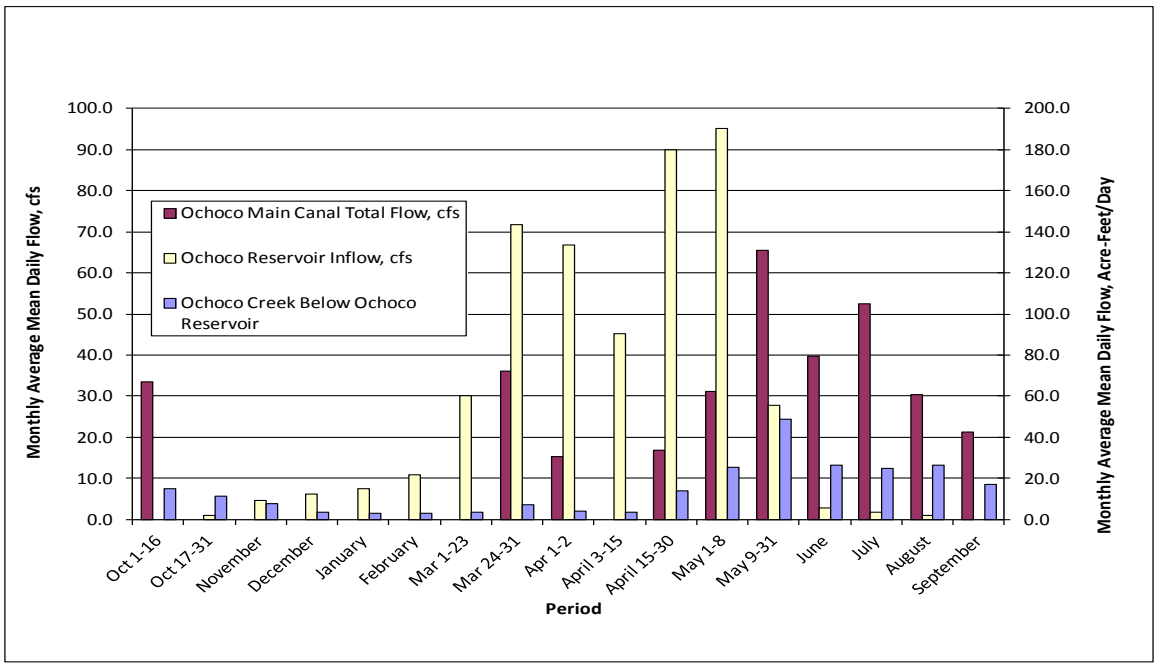


Figure 4.2-15C. Flow comparison between Ochoco Main Canal Diversion, Ochoco Reservoir inflow, and Ochoco Creek below reservoir for Water Year 2001.

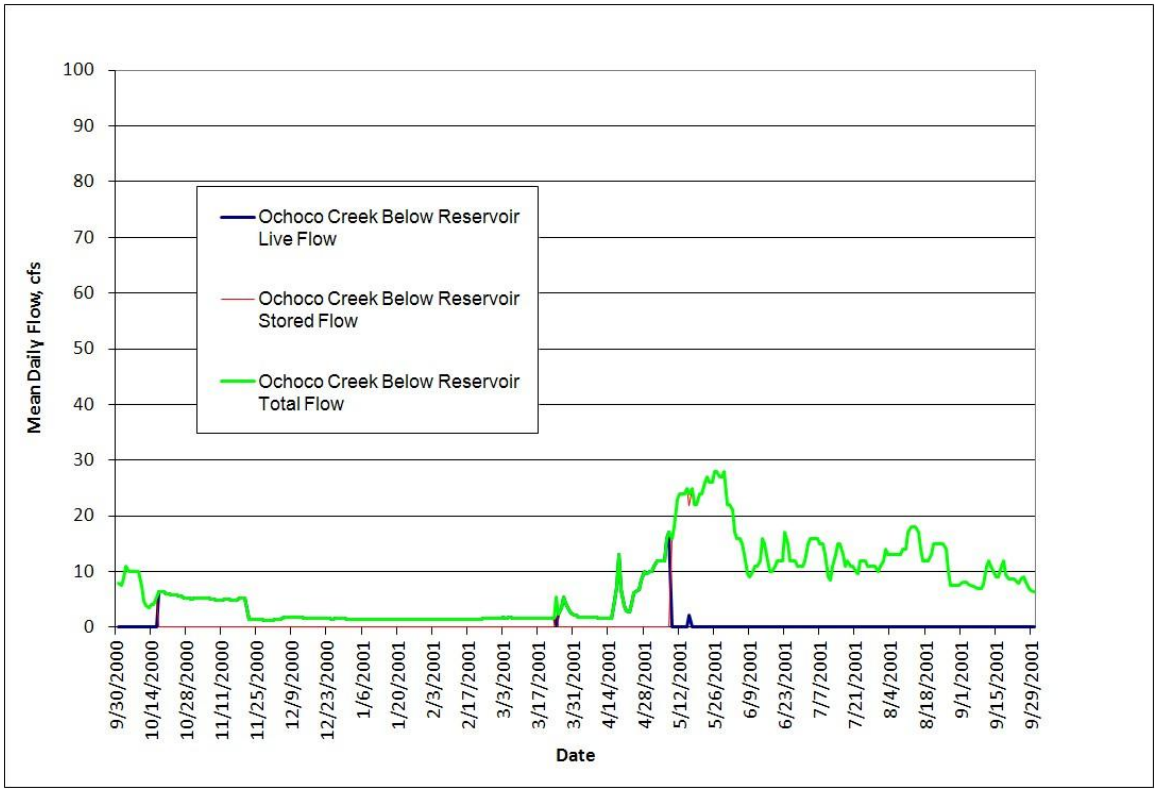


Figure 4.2-16A Daily live flow below Ochoco Reservoir for Water Year 2001.

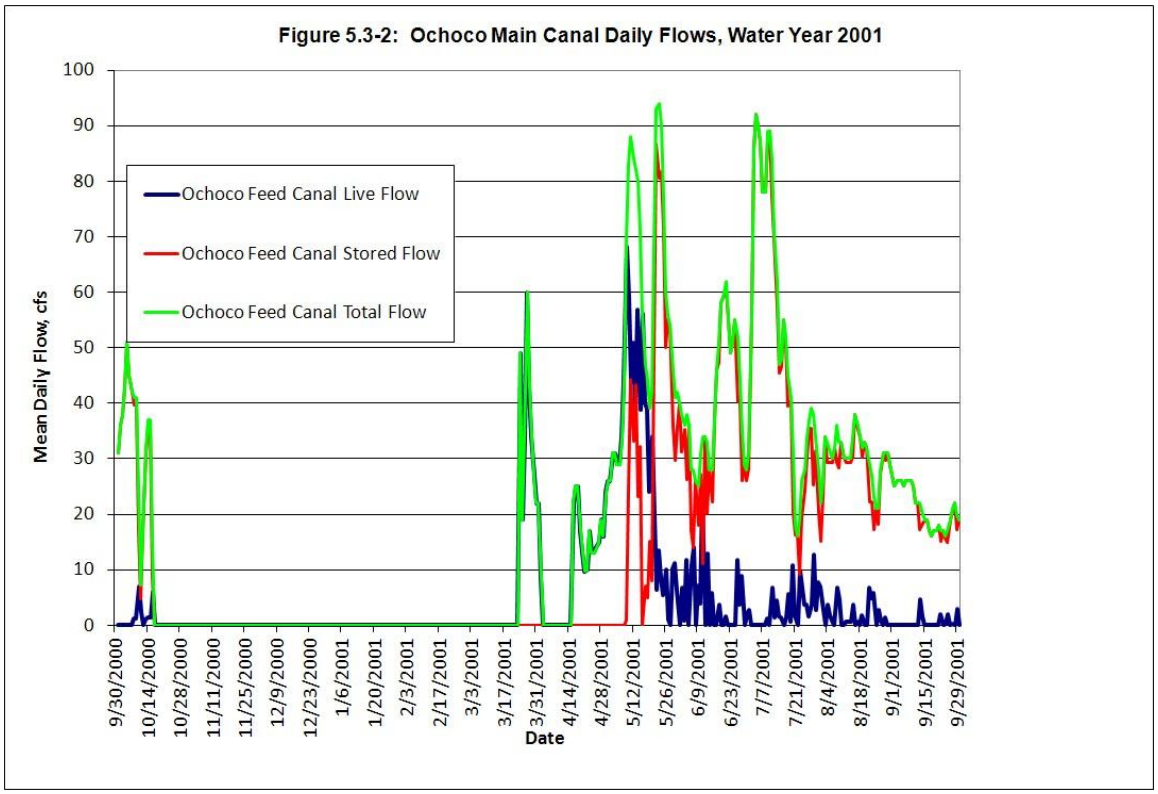


Figure 4.2-16B. Daily mean Ochoco Feed Canal Diversion flow for Water Year 2001.

Tables 4.2-12 and 4.2-13 provide the same data that are in Figures 4.2-15A, B, C, but are in tabular form. Figures 4.2-16A and 4.2-16B show the daily mean flow for Ochoco Creek below Ochoco Reservoir and the Ochoco Main Canal, respectively. Each of these latter two figures also shows the monthly average natural flow for Ochoco Creek at its confluence with the Crooked River.

There were several assumptions used in generating these graphs and the accompanying tables:

- All inflow to Ochoco Reservoir is considered "live" flow.
- All flow exiting Ochoco Reservoir is considered "live" flow until reservoir elevation begins to drop and release of stored water begins.
- After the reservoir begins to release water, flow exiting Ochoco Reservoir, either in Ochoco Main Canal or Ochoco Creek, is live flow up to the amount of inflow to the reservoir. Outflow in excess of inflow is considered stored flow.
- Available live flow is first credited to the Ochoco Main Canal; any live flow exiting the reservoir over that which is in the Ochoco Main canal is credited to Ochoco Creek below the reservoir.
- Outflow in excess of available live flow is considered stored flow.
- In applying these assumptions, if calculations indicated a negative live flow, live flow was set at zero and all released flow was considered stored flow.

Figure 4.2-17 shows the volume in Ochoco Reservoir over Water Year 2010. Inspection of the curve indicates the reservoir filled until about June 20, 2010 and then began releasing stored water throughout the rest of the water year. All outflow up until this date will be considered live flow.

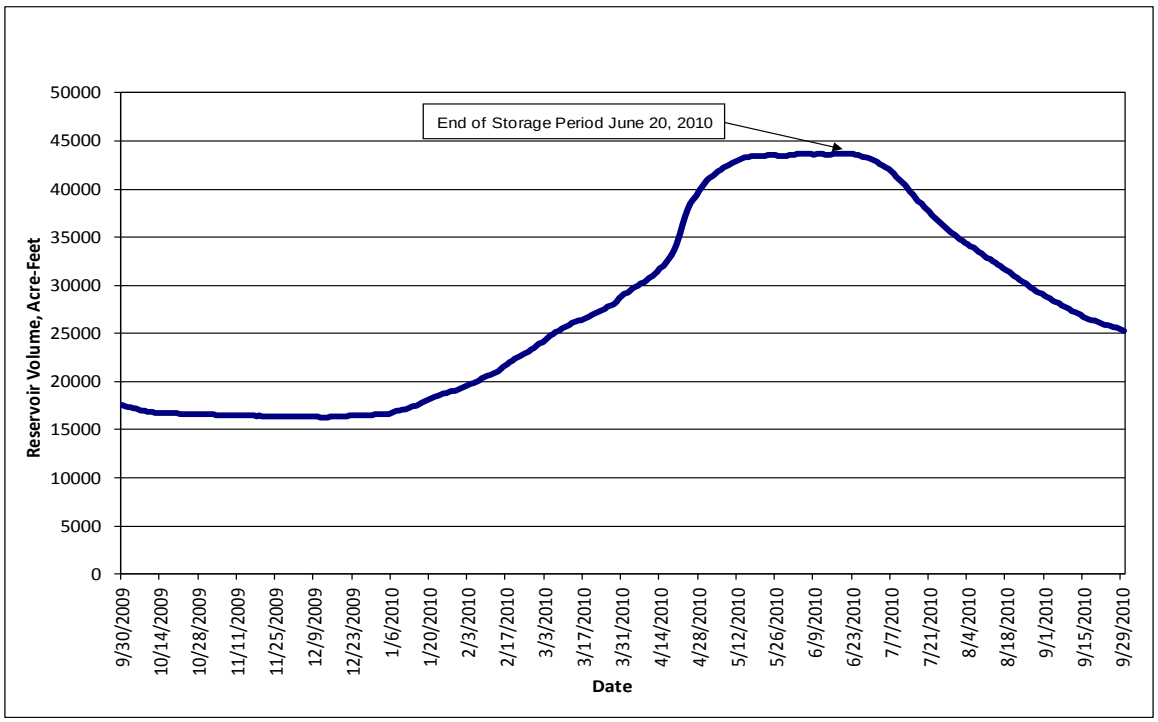


Figure 4.2-17. Ochoco Reservoir daily volume for Water Year 2010.

Figure 4.2-18A shows the impact on flow of Ochoco Creek in Water Year 2010 as a result of both diversion from and storage in Ochoco Reservoir. Figure 4.2-18B shows the diversion flow of Ochoco Main Canal for Water Year 2010. Finally, Figure 4.2-18C shows the both the inflow and outflow of Ochoco Reservoir and the flow of Ochoco Main Canal for Water Year 2010. Again, as in the analysis for Water Year 2001, the months when diversion either started or stopped, are split. In addition, the month of June is split because during this month Ochoco Reservoir began to release stored water.

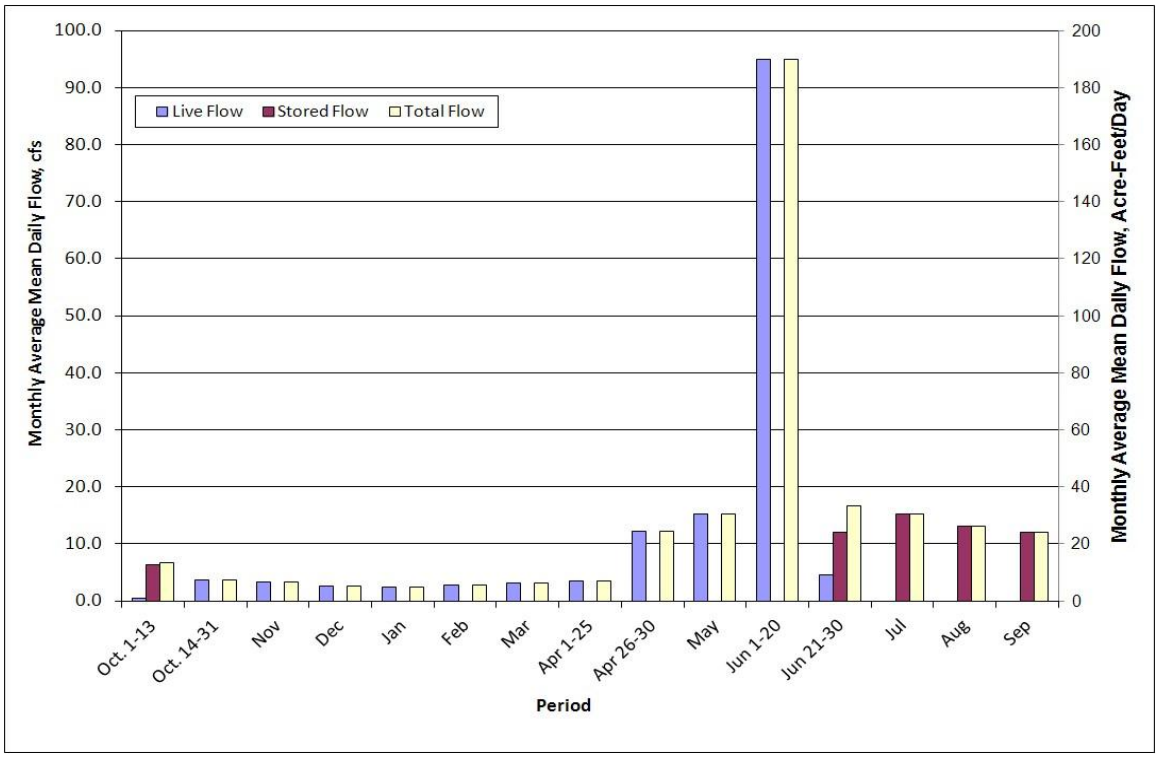


Figure 4.2-18A. Ochoco Creek monthly average mean daily flow below Ochoco Reservoir for Water Year 2010

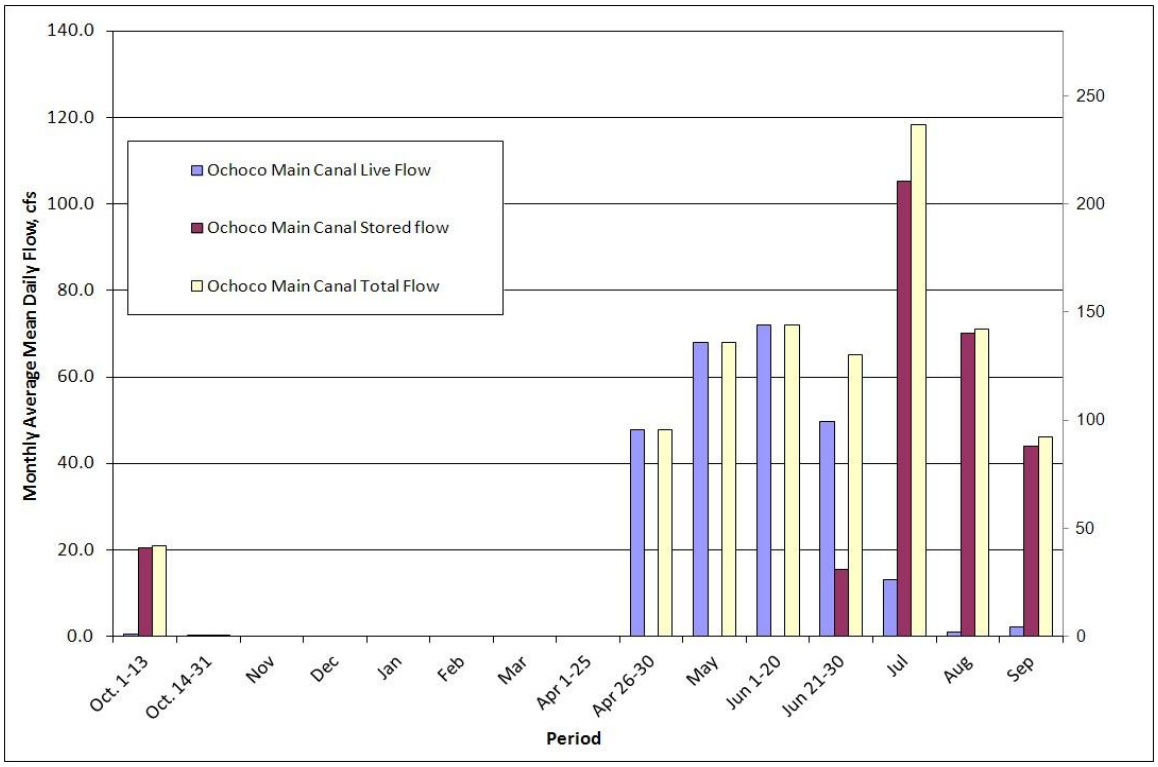


Figure 4.2-18B. Monthly average mean daily flow for Ochoco Main Canal for Water Year 2010.

Table 4.2-14. Flow impact analysis on Ochoco Creek from Ochoco Feed Canal Diversion for Water Year 2010 (cubic feet per second).

Date	Ochoco Creek Flow Below Ochoco Reservoir			Ochoco Main Canal Flow		
	Live	Stored	Total	Live	Stored	Total
Oct. 1-13	0.4	6.3	6.7	0.4	20.5	20.9
Oct. 14-31	3.7	0.0	3.7	0.0	0.0	0.0
Nov	3.3	0.0	3.3	0.0	0.0	0.0
Dec	2.5	0.0	2.5	0.0	0.0	0.0
Jan	2.4	0.0	2.4	0.0	0.0	0.0
Feb	2.7	0.0	2.7	0.0	0.0	0.0
Mar	3.1	0.0	3.1	0.0	0.0	0.0
Apr 1-25	3.4	0.0	3.4	0.0	0.0	0.0
Apr 26-30	12.2	0.0	12.2	47.8	0.0	47.8
May	15.2	0.0	15.2	68.0	0.0	68.0
Jun 1-20	95.0	0.0	95.0	72.0	0.0	72.0
Jun 21-30	4.6	12.0	16.6	49.6	15.5	65.1
Jul	0.0	15.2	15.2	13.0	105.4	118.4
Aug	0.0	13.0	13.0	0.9	70.1	71.0
Sep	0.0	12.1	12.1	2.2	44.0	46.1

Table 4.2-15. Flow impact analysis on Ochoco Creek from Ochoco Feed Canal Diversion for Water Year 2010 (acre-feet/day).

Date	Ochoco Creek Flow Below Ochoco Reservoir			Ochoco Main Canal Flow		
	Live	Stored	Total	Live	Stored	Total
Oct. 1-13	1	13	13	1	41	42
Oct. 14-31	7	0	7	0	0	0
Nov	6	0	6	0	0	0
Dec	5	0	5	0	0	0
Jan	5	0	5	0	0	0
Feb	5	0	5	0	0	0
Mar	6	0	6	0	0	0
Apr 1-25	7	0	7	0	0	0
Apr 26-30	24	0	24	95	0	95
May	30	0	30	135	0	135
Jun 1-20	188	0	188	143	0	143
Jun 21-30	9	24	33	98	31	129
Jul	0	30	30	26	209	235
Aug	0	26	26	2	139	141
Sep	0	24	24	4	87	92

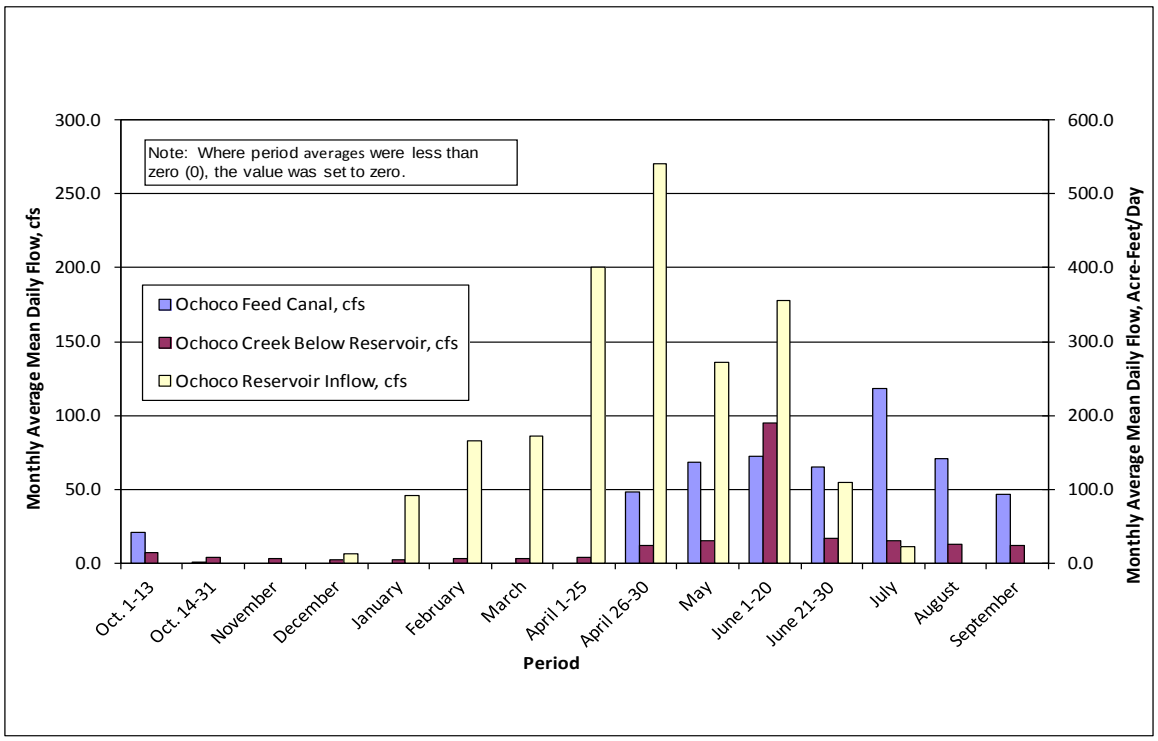


Figure 4.2-18C. Flow comparison between Ochoco Main Canal Diversion, Ochoco Reservoir Inflow, and Ochoco Creek below reservoir for Water Year 2010.

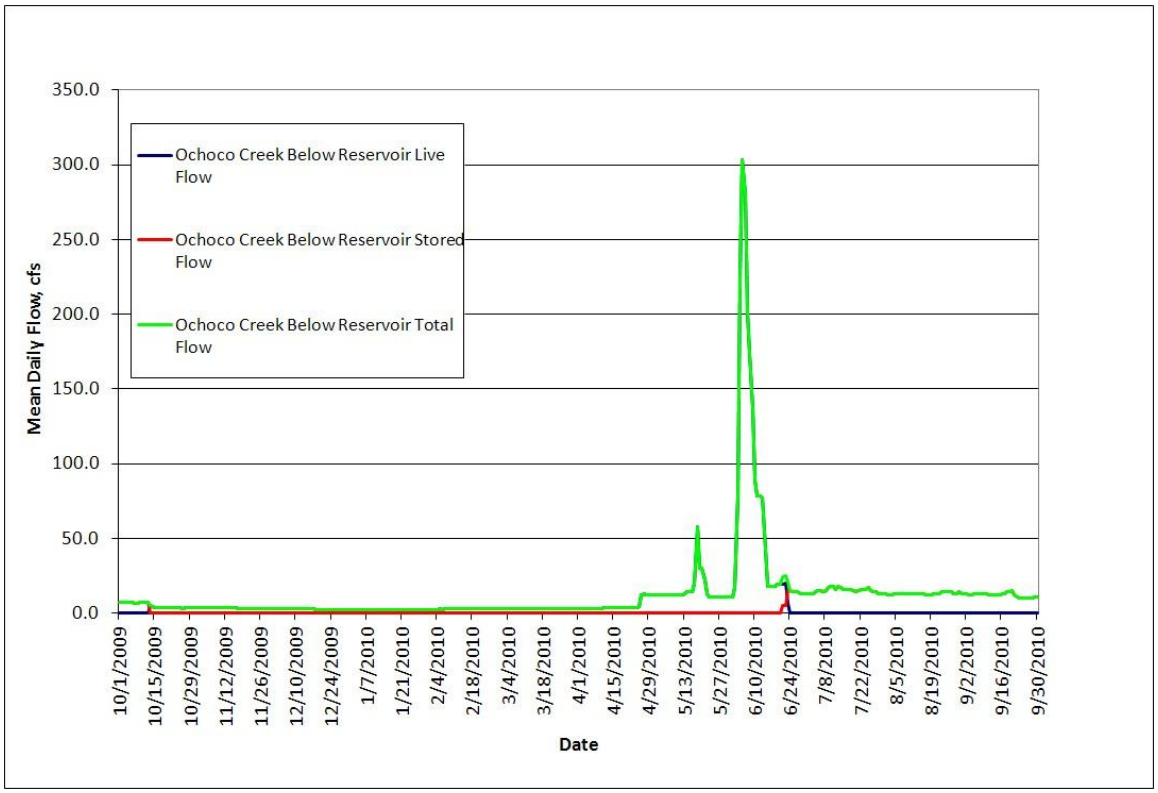


Figure 4.2-19A. Daily live flow below Ochoco Reservoir for Water Year 2010.

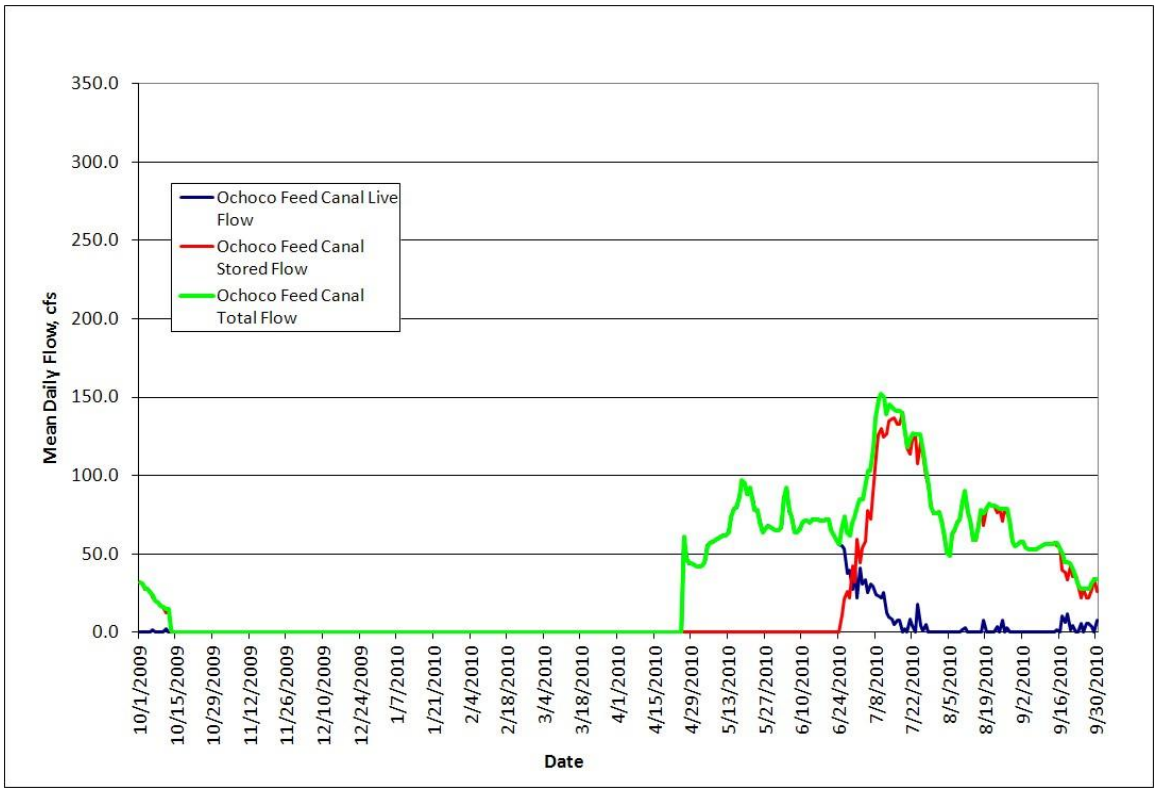


Figure 4.2-19B. Daily mean Ochoco Feed Canal Diversion flow for Water Year 2010.

Tables 4.2-14 and 4.2-15 provide the same data that are in Figures 4.2-18A, B, and C, but are in tabular form. Figures 4.2-19A and 4.2-19B show the daily mean flow for Ochoco Creek below Ochoco Reservoir and the Ochoco Main Canal, respectively for Water Year 2010.

Figure 4.2-20 shows a statistical summary of the monthly averages for the Ochoco Creek below Ochoco Reservoir and the Ochoco Main Canal for Water Years 1970 through 2010. Figure 4.2-21 is similar to Figure 4.2-20, but is only for Water Years 2001 through 2010. Tables 4.2-16 and 4.2-17 are tabular representations of Figures 4.2-20 and 4.2-21.

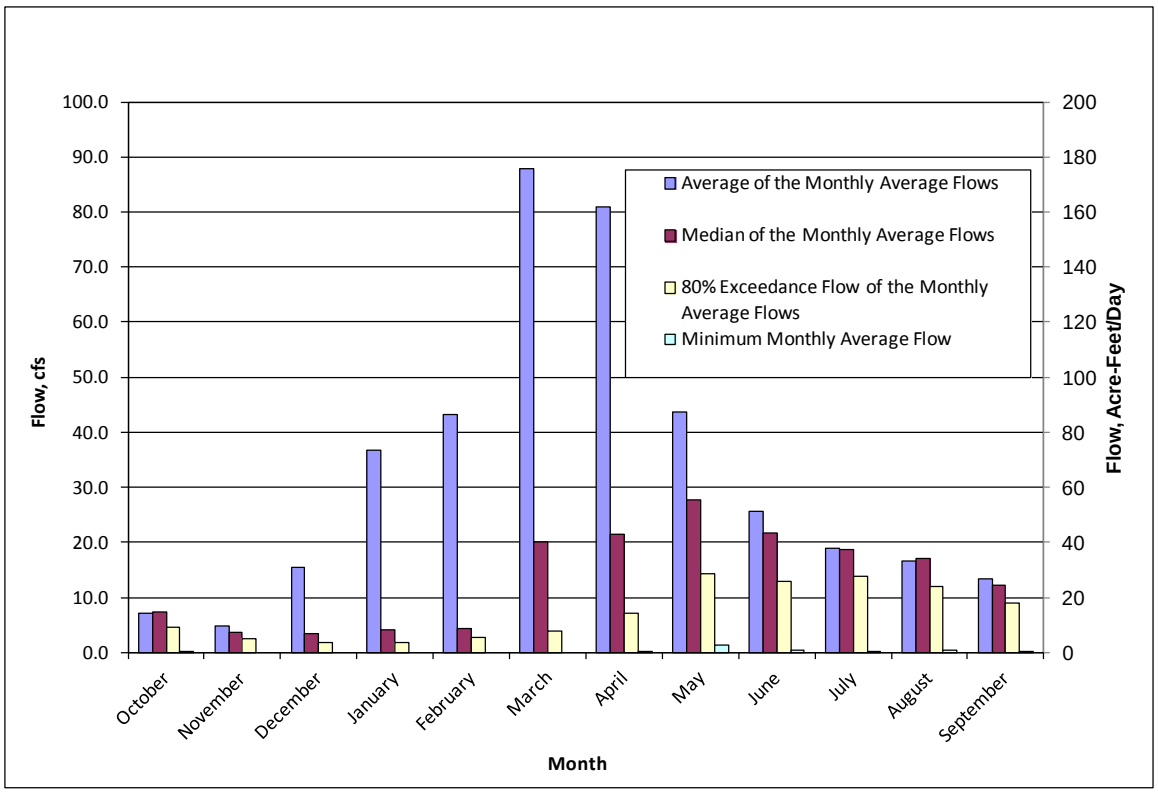


Figure 4.2-20. Water Year 1970 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir.

Table 4.2-16. Water Year 1970 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir (cubic feet per second).

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance Flow of the Monthly Average Flows	Minimum Monthly Average Flow
October	7.2	7.4	4.6	0.2
November	4.8	3.7	2.5	0.0
December	15.4	3.5	1.8	0.0
January	36.8	4.2	1.8	0.0
February	43.3	4.3	2.7	0.0
March	87.9	20.1	4.0	0.0
April	80.9	21.5	7.1	0.1
May	43.6	27.8	14.4	1.3
June	25.6	21.8	12.9	0.4
July	19.0	18.6	13.8	0.3
August	16.6	17.1	12.1	0.4
September	13.3	12.3	9.1	0.0

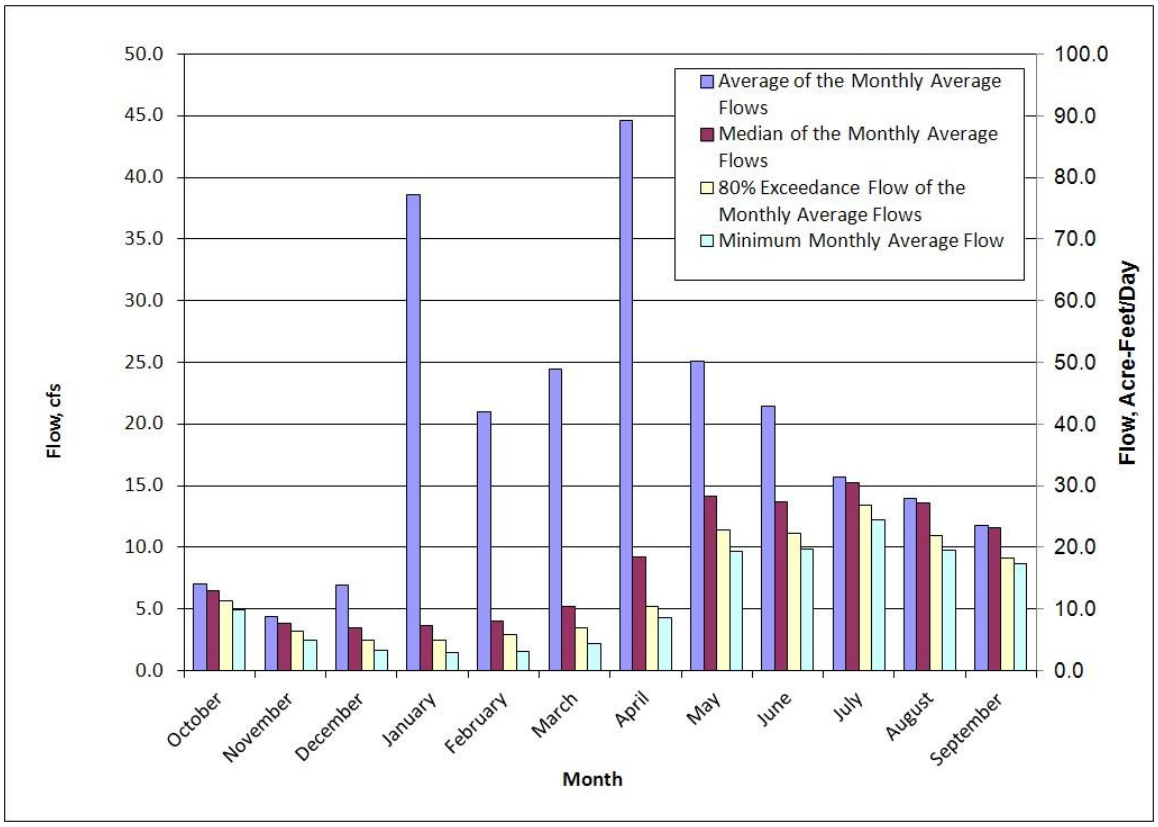


Figure 4.2-21.: Water Year 2001 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir.

Table 4.2-17. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for Ochoco Creek below Ochoco Reservoir (cubic feet per second).

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance Flow of the Monthly Average Flows	Minimum Monthly Average Flow
October	7.0	6.5	5.7	5.0
November	4.3	3.8	3.2	2.5
December	6.9	3.5	2.5	1.6
January	38.6	3.6	2.5	1.5
February	21.0	4.0	2.9	1.5
March	24.5	5.2	3.4	2.2
April	44.6	9.2	5.2	4.3
May	25.1	14.1	11.4	9.7
June	21.4	13.7	11.1	9.8
July	15.7	15.2	13.4	12.3
August	14.0	13.6	10.9	9.8
September	11.8	11.6	9.1	8.6

Figure 4.2-22 is a graph that shows the monthly average flows for each month for Water Years 2001 - 2010 for the inflow to Ochoco Reservoir, the flow in Ochoco Creek below the reservoir, and the flow in Ochoco Main Canal. Table 4.2-18 is a tabular representation of Figure 4.2-22.

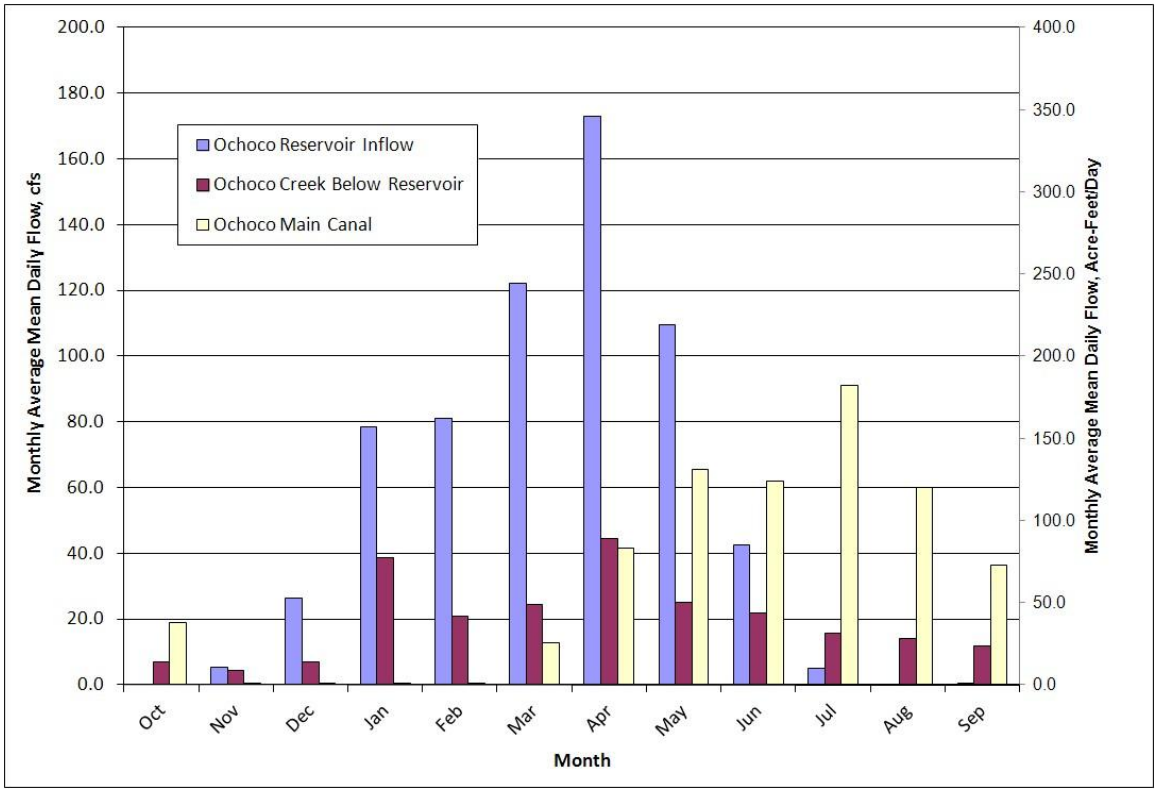


Figure 4.2-22. Water Year 2001 through 2010 monthly average flows for Ochoco Creek below Ochoco Reservoir, inflow to Ochoco Reservoir, and Ochoco Feed Canal diversion.

Table 4.2-18. Water Year 2001 through 2010 monthly average flows for Ochoco Creek below Ochoco Reservoir, inflow to Ochoco Reservoir, and Ochoco Feed Canal Diversion flow, cubic feet per second).

Month	Ochoco Reservoir Inflow, cfs	Ochoco Creek Below Reservoir, cfs	Ochoco Feed Canal, cfs
Oct	0.0	7.0	18.8
Nov	5.5	4.3	0.0
Dec	26.4	6.9	0.1
Jan	78.3	38.6	0.5
Feb	80.9	20.9	0.3
Mar	122.1	24.5	12.9
Apr	173.1	44.6	41.5
May	109.5	25.2	65.5
Jun	42.4	21.7	62.0
Jul	4.9	15.8	91.2
Aug	0.0	14.1	60.1
Sep	0.3	11.8	36.4

4.2.2 NORTH UNIT IRRIGATION DISTRICT CROOKED RIVER PUMPING PLANT DIVERSION

4.2.2.1. Analysis Points and Reference Years

North Unit Irrigation District (NUID) obtains a portion of its water from the Crooked River at RM 27.3. The water is lifted by a series of pumps up from the river and into the North Unit Main Canal, which transports water from the District's Deschutes River diversion near Bend to the point of use.

This flow effect analysis is based on data from a gage operated by OWRD near Terrebonne on the Crooked River at RM 25; 2.3 miles below the NUID pump station. Data for Water Years 1994 through 2006 at this gage are published, and data after 2006 are provisional. Figure A-4 in the Appendix is a map of this segment of the Crooked River showing the locations of the Terrebonne gage (No. 14087300), the pumping plant, and the gage on the Crooked River at Osborne Canyon. This location of this latter gage is included because this is the closest location on the Crooked River downstream of both the pumping plant and the Terrebonne gage where natural flow data may be obtained from the OWRD Water Availability Report System. While the gage record indicates that data are available since 1967, the gage was not operational between 1973 and 1992.

There is no OWRD gage that measures and records flow data at the pumping plant. A totalizing flow meter is read daily during the periods when the pump station is operating. These data have been provided to Newton for use in this analysis. The daily mean flow below the pumping plant is based upon the data at the Terrebonne gage; the daily mean flow above the pumping plant is derived by determining the daily mean flow rate from the total acre-feet pumped in a given day and adding it to the Terrebonne gage mean daily flow.

4.2.2.1 Low-flow Year Analysis

As noted in Section 4.2.1.1.1, analysis of flow and reservoir storage data since Water Year 2000 indicates that Water Year 2001 was the driest over the last 10 years (see Figure 4.2-1 and Table 4.2-1).

4.2.2.2 Effects of Water Diversion on Instream Flow

NUID has no stored water rights upon which to draw water from the Crooked River. All of the water pumped from the river by NUID is considered to be live flow because it has not rights for stored water.

Figure 4.2-23 displays the monthly average daily mean flow effects on the Crooked River caused by the NUID pumping plant for Water Year 2001. Some months have been split in the figure because active diversion began or ended during the month. The flows are represented as both cfs and acre-feet per day. The graph also shows the amount of water pumped and the calculated Crooked River flow above the pumping plant as monthly average daily mean flows.
Tables 4.2-19 and 4.2-20 are tabular representations of the data in Figure 4.2-23 and 4.2-24. Figure 4.2-24 is a graph showing the daily mean flows for Water Year 2001 for the Crooked River flow above and below the NUID pumping plant and the daily mean flow pumped from the river.

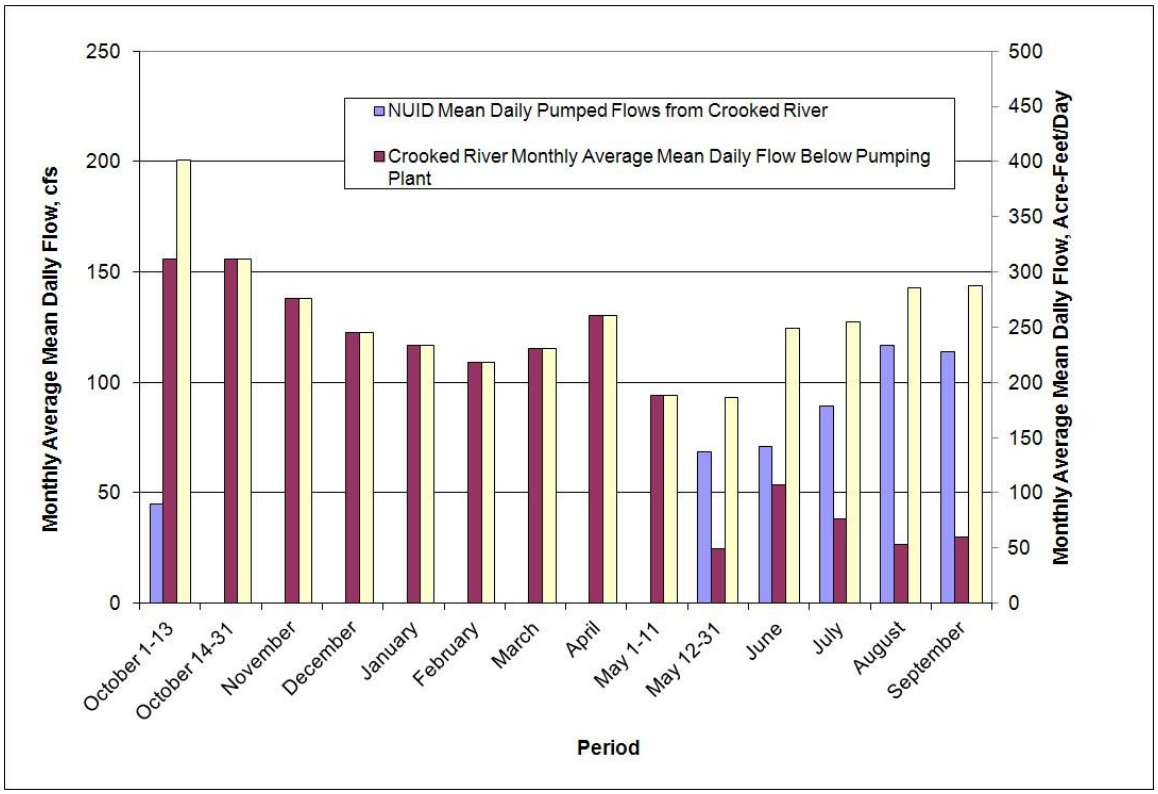


Figure 4.2-23. Effects of NUID Pumping Plant on Crooked River flows for Water Year 2001.

Table 4.2-19. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2001 (cubic feet per second).

Month	NUID Mean Daily Pumped Flows from Crooked River	Crooked River Monthly Average Mean Daily Flow Below Pumping Plant	Calculated Crooked River Flow Above Pumping Plant
October 1-13	45	156	201
October 14-31	0	156	156
November	0	138	138
December	0	123	123
January	0	117	117
February	0	109	109
March	0	115	115
April	0	130	130
May 1-11	0	94	94
May 12-31	68	25	93
June	71	54	124
July	89	38	127
August	117	26	143
September	114	30	144

Table 4.2-20. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2001 (acre-feet per day).

Month	NUID Mean Daily Pumped Flows from Crooked River	Crooked River Monthly Average Mean Daily Flow Below Pumping Plant	Calculated Crooked River Flow Above Pumping Plant
October 1-13	89	309	398
October 14-31	0	310	310
November	0	274	274
December	0	243	243
January	0	231	231
February	0	216	216
March	0	228	228
April	0	258	258
May 1-11	0	186	186
May 12-31	136	49	185
June	141	106	247
July	177	76	253
August	231	52	283
September	226	60	285

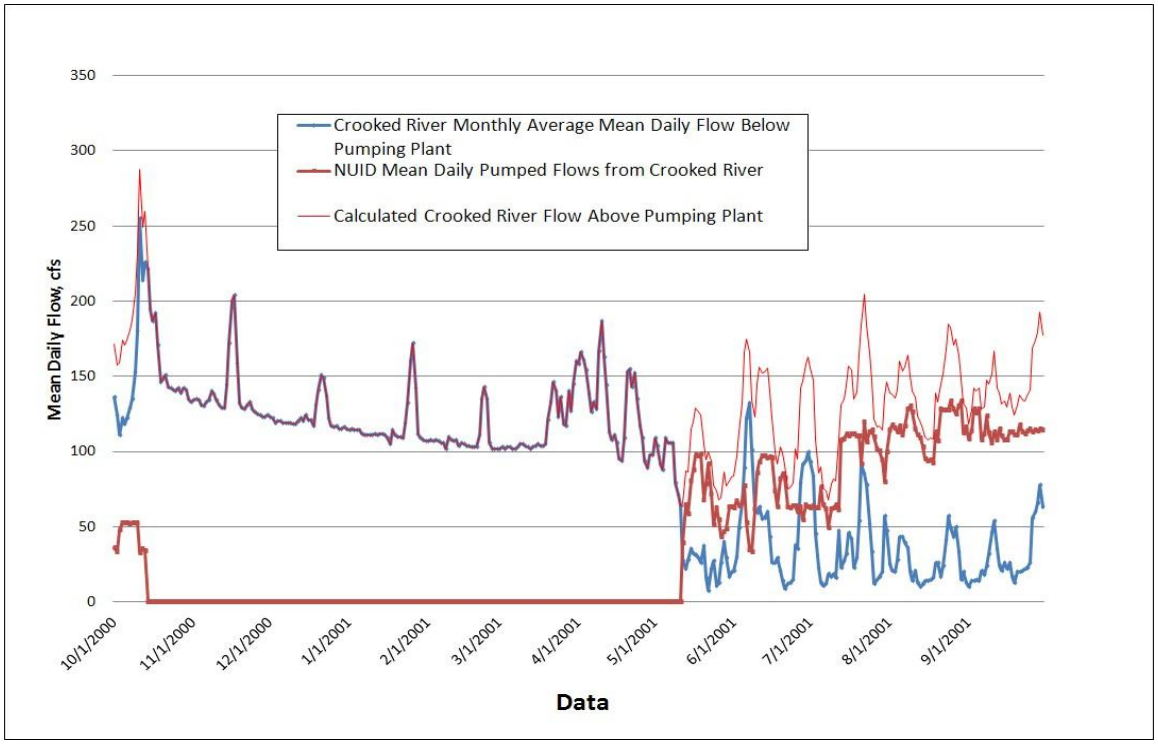


Figure 4.2-24.North Unit Irrigation District daily pumping effects on the Crooked River for Water Year 2001.

Figure 4.2-25 displays the monthly average daily mean flow effects on the Crooked River caused by the NUID pumping plant for Water Year 2010. Tables 4.2-21 and 4.2-22 are tabular representations of the data in Figure 4.2-25. Figure 4.2-26 is a graph showing the daily mean flows for Water Year 2010 for the Crooked River flow above and below the NUID pumping plant and the daily mean flow pumped from the river.

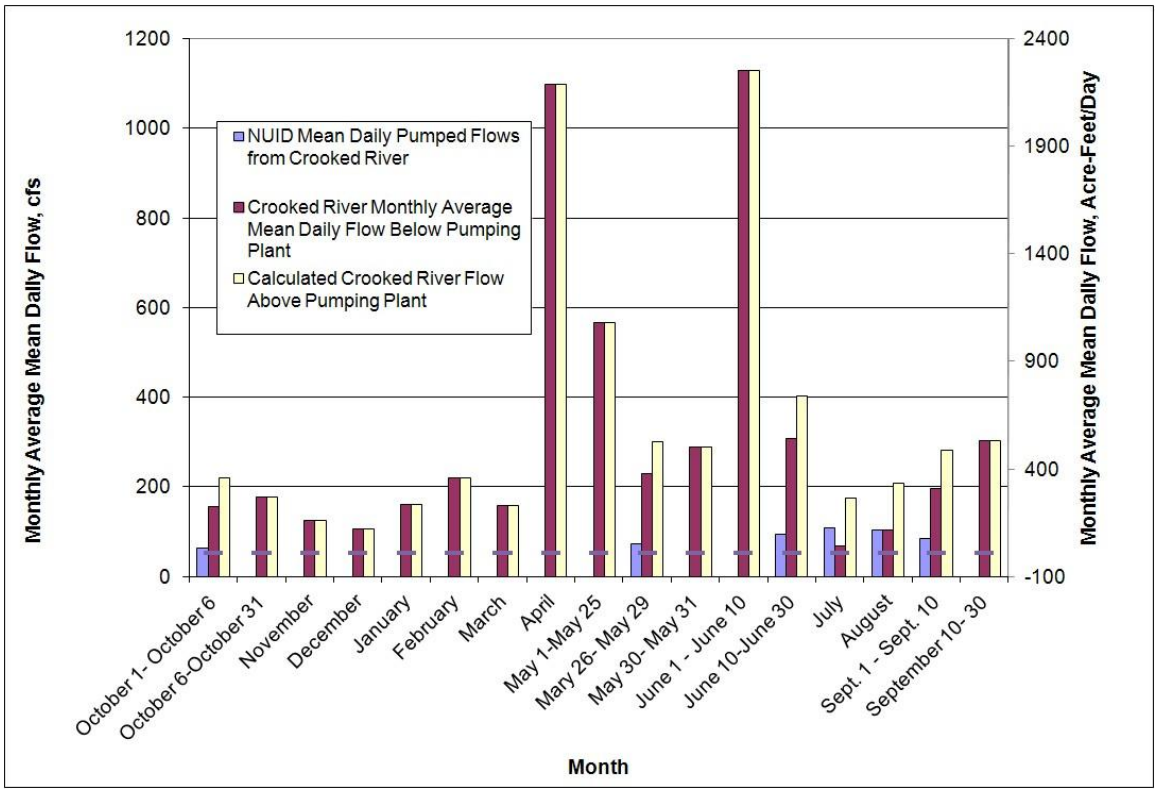


Figure 4.2-25. Effects of NUID Pumping Plant on Crooked River flows for Water Year 2010.

Table 4.2-21. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2010 (cubic feet per second).

Month	NUID Mean Daily Pumped Flows from Crooked River	Crooked River Monthly Average Mean Daily Flow Below Pumping Plant	Calculated Crooked River Flow Above Pumping Plant
October 1- October 6	64	155	219
October 6-October 31	0	176	176
November	0	125	125
December	0	106	106
January	0	161	161
February	0	219	219
March	0	157	157
April	0	1098	1098
May 1-May 25	0	566	566
Mary 26- May 29	72	229	301
May 30- May 31	0	289	289
June 1 - June 10	0	1129	1129
June 10-June 30	94	309	403
July	108	68	176
August	104	103	208
Sept. 1 - Sept. 10	84	197	281
September 10- 30	0	303	303

Table 4.2-22. Flow impact analysis from North Unit Irrigation District Pumping Plant on Crooked River for Water Year 2010 (acre-feet/day).

Month	NUID Mean Daily Pumped Flows from Crooked River	Crooked River Monthly Average Mean Daily Flow Below Pumping Plant	Calculated Crooked River Flow Above Pumping Plant
October 1- October 6	127	308	435
October 6-October 31	0	350	350
November	0	248	248
December	0	210	210
January	0	319	319
February	0	434	434
March	0	312	312
April	0	2177	2177
May 1-May 25	0	1123	1123
Mary 26- May 29	143	454	597
May 30- May 31	0	572	572
June 1 - June 10	0	2239	2239
June 10-June 30	186	612	798
July	214	135	349
August	207	205	412
Sept. 1 - Sept. 10	167	390	557
September 10- 30	0	600	600

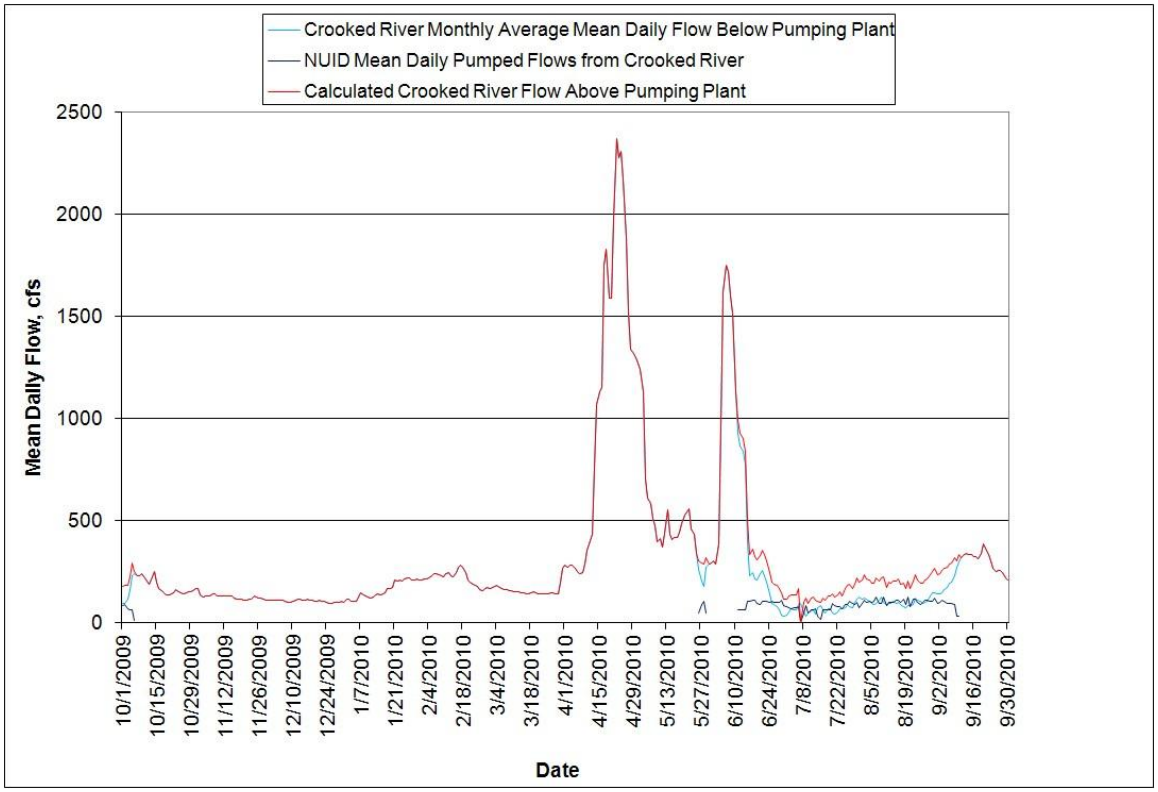


Figure 4.2-26 North Unit Irrigation District pumping effects on the Crooked River for Water Year 2010.

Figure 4.2-27 shows a statistical summary of the monthly averages for the Crooked River below the NUID pumping plant for Water Years 1994 through 2010. This analysis was limited to 1994 and after because that is the limit of the gage record. Figure 4.2-28 is similar to Figure 4.2-27, but is only for Water Years 2001 through 2010. Tables 4.2-23 and 4.2-24 are tabular representations of Figures 4.2-27 and 4.2-28. Figure 4.2-29 is a graph that shows the monthly average flows for each month for Water Year 2001 through 2010 for the flow in the Crooked River below and above the NUID pumping plant and the pumping plant flow for Water Years 2001 through 2010.

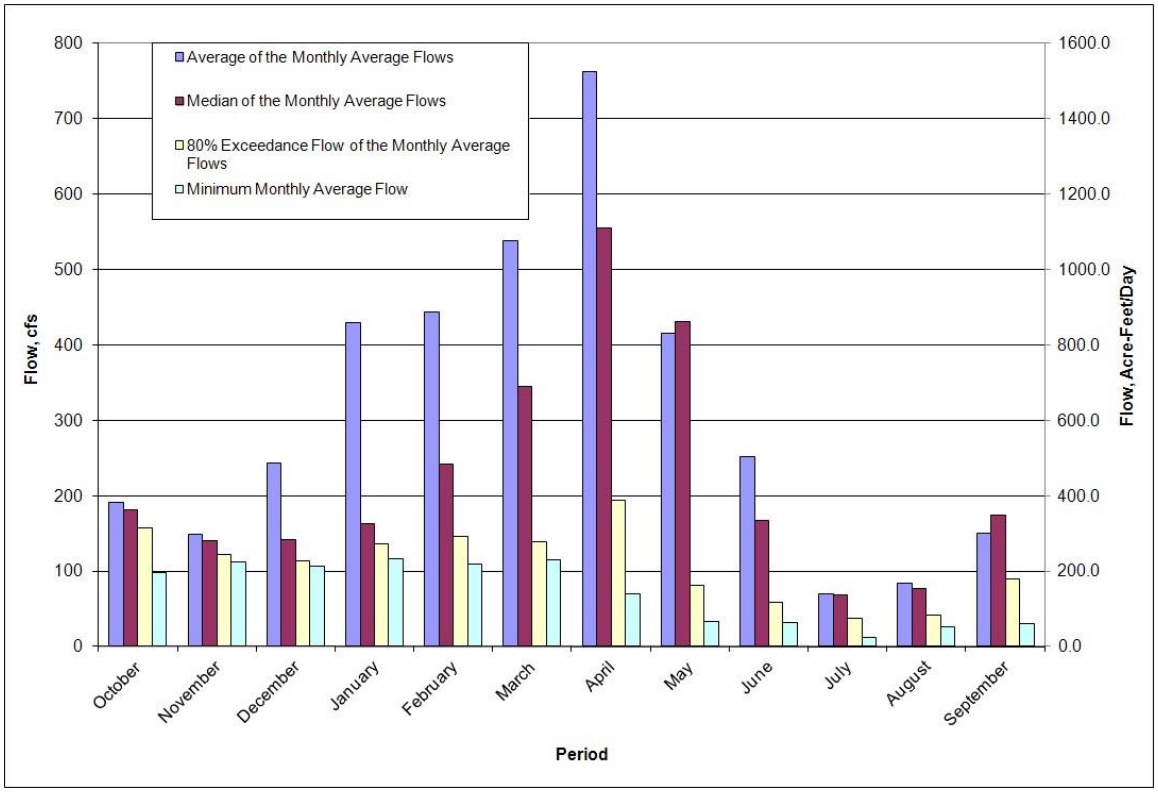


Figure 4.2-27. Water Year 1994 through 2010 statistics of the monthly average mean daily flow for the Crooked River below NUID Pumping Plant.

Table 4.2-23. Water Year 1994 through 2010 statistics of the monthly average mean daily flow for the Crooked River below North Unit Irrigation District pumping plant.

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance Flow of the Monthly Average Flows	Minimum Monthly Average Flow
October	191	181	157	99
November	149	141	122	112
December	243	141	114	106
January	429	163	137	116
February	443	241	146	109
March	538	345	139	115
April	762	555	193	70
May	415	431	81	33
June	252	167	58	32
July	70	68	38	12
August	84	76	42	26
September	150	175	90	30

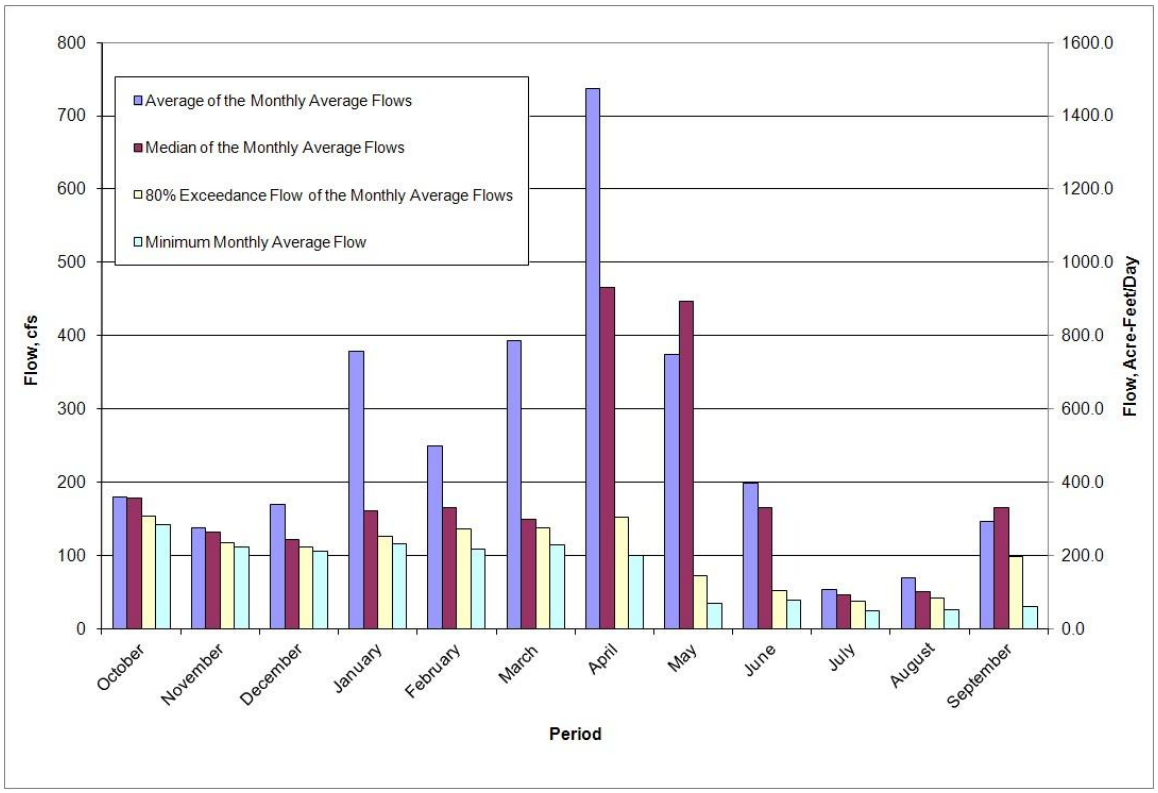


Figure 4.2-28. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for the Crooked River below NUID Pumping Plant.

Table 4.2-24. Water Year 2001 through 2010 statistics of the monthly average mean daily flow for the Crooked River below North Unit Irrigation District Pumping Plant.

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance Flow of the Monthly Average Flows	Minimum Monthly Average Flow
October	180	178	154	142
November	138	132	118	112
December	169	122	112	106
January	379	161	127	116
February	249	165	137	109
March	394	149	138	115
April	737	465	152	100
May	374	446	72	35
June	199	166	53	39
July	54	47	37	24
August	69	50	42	26
September	146	166	98	30

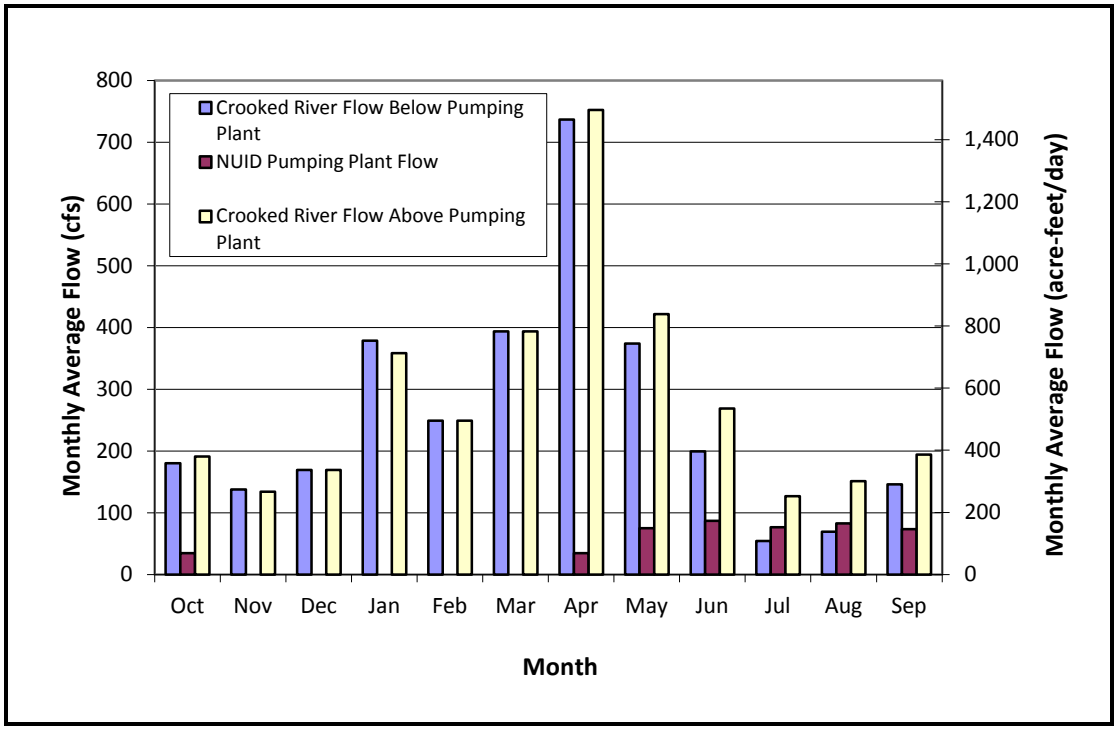


Figure 4.2-29. Average of the monthly average flows above and below NUID Pumping Plant and the pumping plant flow for Water Years 2001 through 2010.

4.3 TUMALO CREEK

4.3.1 ANALYSIS POINTS AND REFERENCE YEARS

Tumalo Irrigation District obtains a portion of its water from Tumalo Creek. Water from this diversion is added to the water being diverted from the Deschutes River via the Bend Feed Canal. This flow effect analysis is based on data from a gage operated by OWRD at the diversion and from a gage located on the creek below the diversion.

Figure A-5 in the Appendix is a map of Tumalo Creek showing the locations of the Tumalo Creek gage (No. 14073520) and the diversion and its gage (No. 14073500). Figure 4.3-1 displays the flow data quality graph provided by OWRD for the Tumalo Feed Canal diversion for Water Years 2001 through 2010. As can be seen in this figure, flow data are very limited after the end of the 2005 irrigation season. This is, in part, due to piping construction.

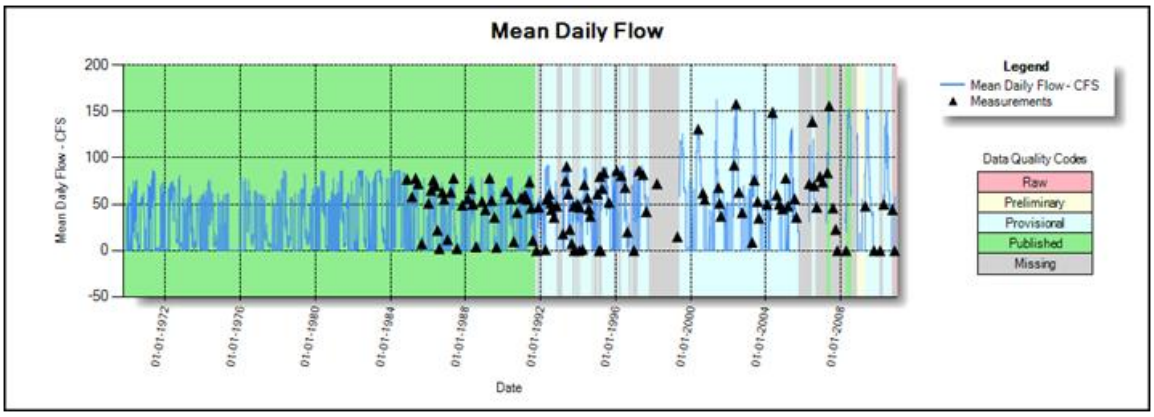


Figure 4.3-1. Flow data quality for Tumalo Feed Canal gage (Station #14073500) from 1971 through 2010 (*OWRD website- 2011*).

In 2006, ODFW installed a fish passage facility on the diversion structure. This structure also bypassed the flow gage on Tumalo Creek below the diversion. As a result, flow data from the Tumalo Creek gage after 2005 do not accurately represent the flow in the creek below the diversion. For this reason, this analysis of flow effects by the Tumalo diversion on Tumalo Creek is limited to Water Years 2000 through 2005.

4.3.2 LOW-FLOW YEAR ANALYSIS

Figure 4.3-2 shows accumulated precipitation in the Upper Deschutes River subbasin for Water Years 2001 through 2010. These data are from the SNOTEL website operated by the U.S. Natural Resource Conservation Service, U.S. Department of Agriculture. The data represented by this graph indicate Water Years 2001 and 2005 were the driest of the last 10 years. Table 4.3-1 shows the total annual flow in Tumalo Creek (diverted flow plus Tumalo Creek gage flow) for Water Years 2000 through 2010. This table shows that 2001 had the lowest total flow of the past 10 years. Therefore, 2001 creek flow data will be used to determine effects of the Tumalo Creek diversion on Tumalo Creek flow for a low flow year.

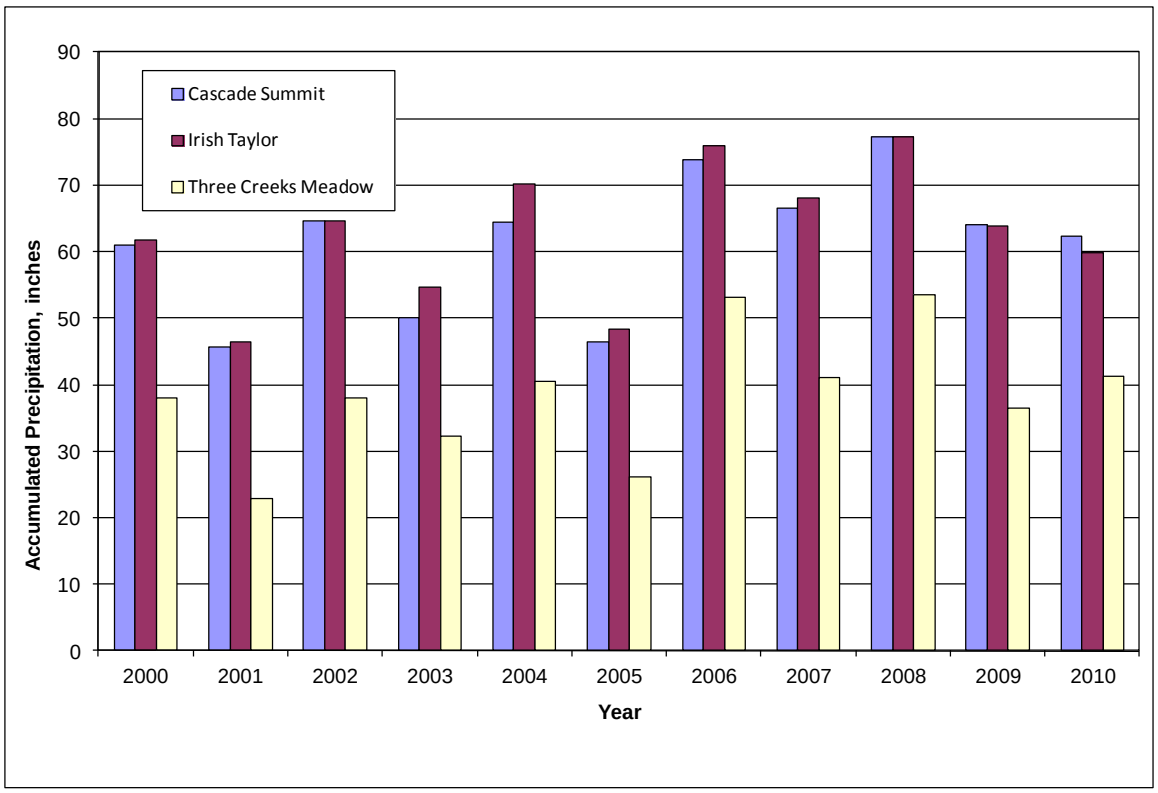


Figure 4.3-2. Total accumulated precipitation, Upper Deschutes Basin for Water Years 2000 through 2010.

Table 4.3-1. Total annual Tumalo Creek flow for Water Years 2000 through 2010.

Water Year	Water Volume (acre-feet/year)	Water Year	Water Volume (acre-feet/year)
2000	75007	2006	53127
2001	**47965**	2007	53370
2002	65866	2008	70958
2003	59112	2009	70603
2004	63251	2010	59518
2005	50884		

The OWRD's Water Availability Report System has determined the 80% and 50% exceedance natural flows for Tumalo Creek at the mouth. These natural flow figures are monthly averages based upon flow data from 1958-1987 and are believed to reasonably represent the natural flows that would occur in the segment of the river affected by the Tumalo Feed Canal diversion. This assumes there are no diversions or return flows between the diversion and the mouth of Tumalo Creek.

4.3.3 EFFECTS OF WATER DIVERSION ON INSTREAM FLOW

Because Tumalo Irrigation District has no storage reservoirs on Tumalo Creek, all analyses will be in terms of cfs. Data will not be presented as acre-feet per day. Also, because of this, all flows are considered live flows.

Figure 4.3-3 shows the flow effects (monthly average mean daily flow) of Tumalo Feed Canal diversion on Tumalo Creek for Water Year 2001. The 80% and 50% exceedance natural flows are also displayed on this figure. Table 4.3-2 is a tabular representation of Figure 4.3-3. Figure 4.3-3 and Table 4.3-2 also show the number of days of diversion for each month. The monthly average flows for Tumalo Feed Canal diversion are for the days of diversion only. Averaging flows over the entire month when, perhaps, there would only 5 days of diversion, did not seem appropriate as it would misrepresent the data. Figure 4.3-4 is a graph showing the mean daily flow of both flow above and below the diversion and the diversion flow for Water Year 2001.

Figure 4.3-5, Table 4.3-3, and Figure 4.3-6 are similar to Figure 4.3-3, Table 4.3-2, and Figure 4.3-2, respectively, except these figures and table are for Water Year 2005. Water Year 2005 is used because, as previously stated Tumalo Creek flow gage data for water years after 2005 are believed to be inaccurate because a fish passage facility by-passes flow around the gage.

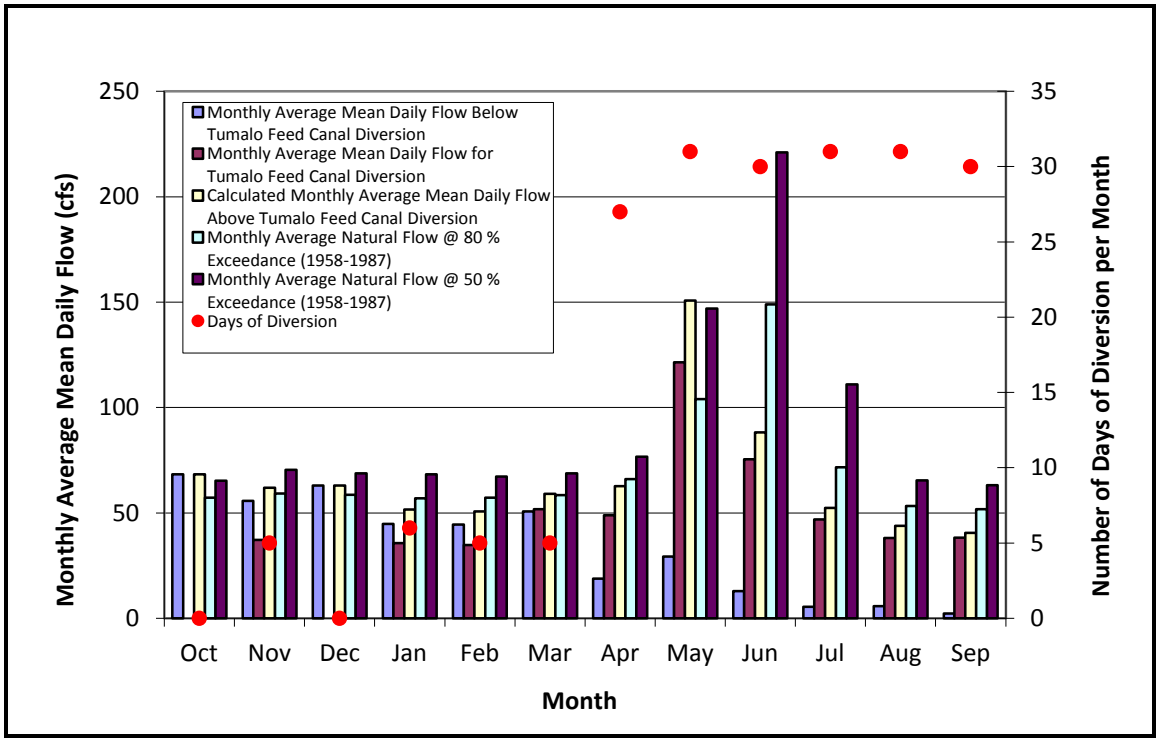


Figure 4.3-3. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2001.

Table 4.3-2. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2001.

Month	Monthly Average Mean Daily Flow Below Tumalo Feed Canal Diversion	Monthly Average Mean Daily Flow for Tumalo Feed Canal Diversion	Calculated Monthly Average Mean Daily Flow Above Tumalo Feed Canal Diversion	Number of Days of Diversion	Monthly Average Natural Flow @ 80 % Exceedance (1958-1987)	Monthly Average Natural Flow @ 50 % Exceedance (1958-1987)
October	68	0	68	0	57	65
November	56	37	62	5	59	70
December	63	0	63	0	59	69
January	45	36	52	6	57	68
February	44	35	51	5	57	67
March	51	52	59	5	59	69
April	19	49	63	27	66	77
May	29	121	151	31	104	147
June	13	75	88	30	149	221
July	5	47	52	31	72	111
August	6	38	44	31	53	65
September	2	38	41	30	52	63

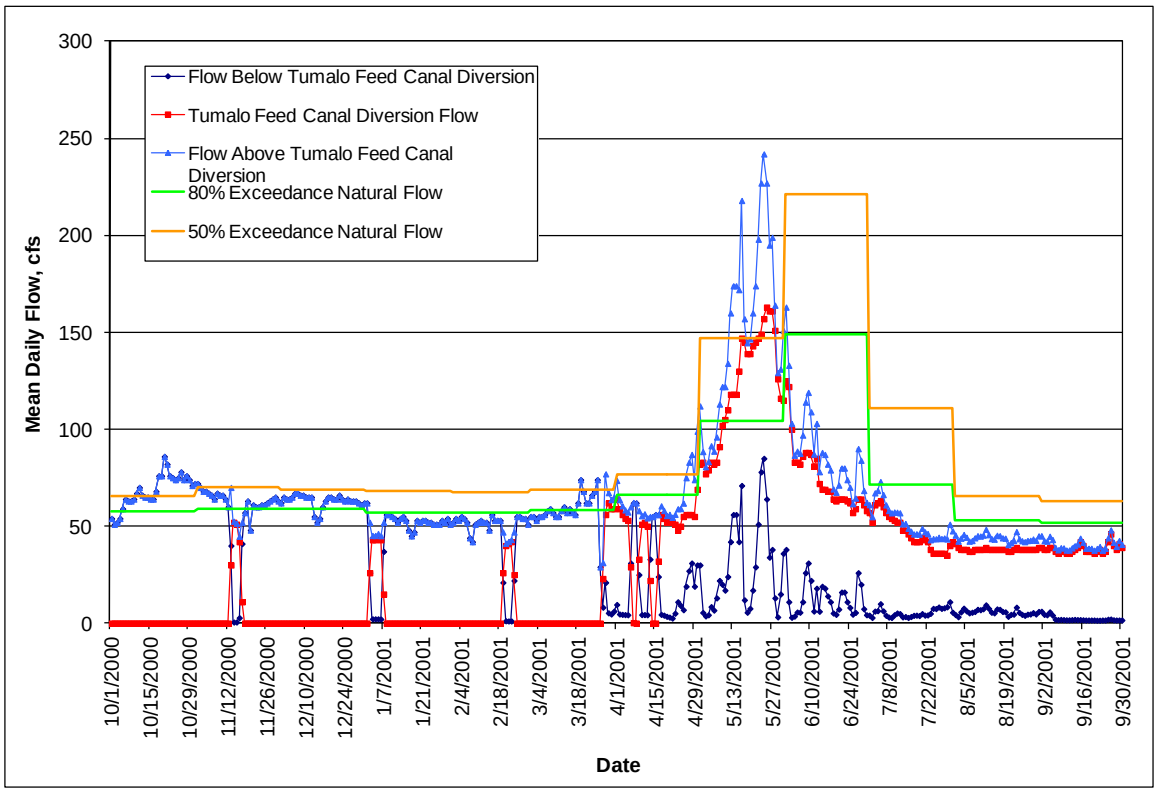


Figure 4.3-4. Tumalo Feed Canal effects on Tumalo Creek for Water Year 2001.

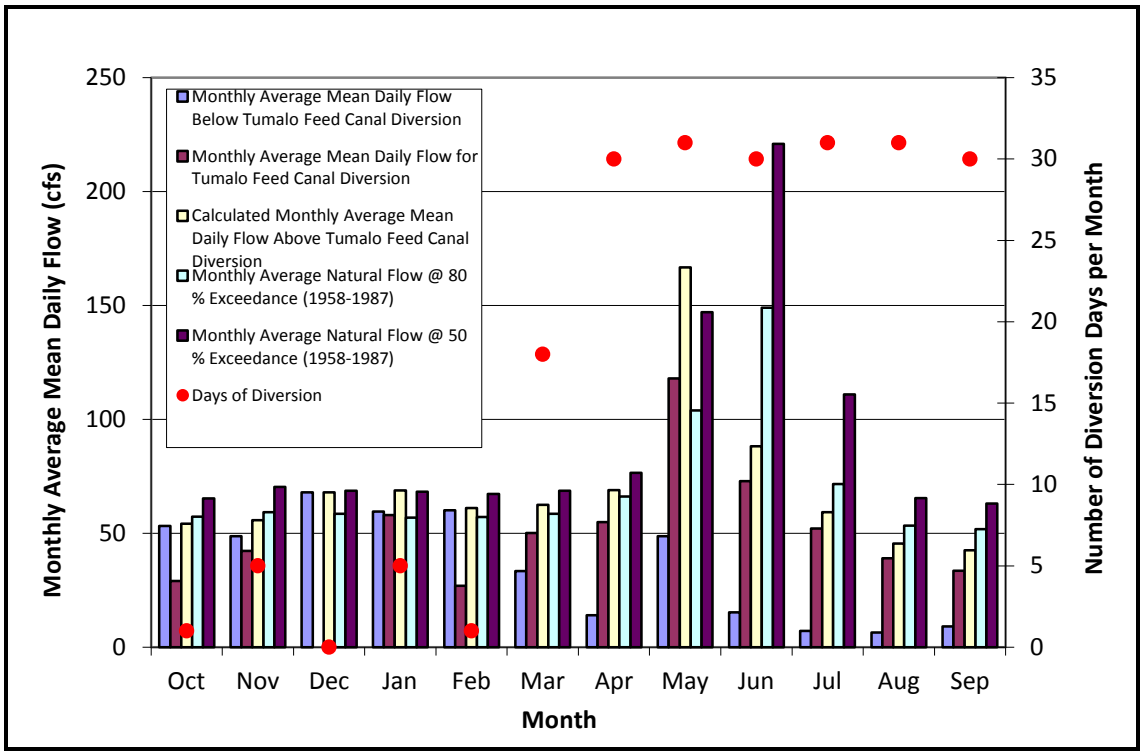


Figure 4.3-5. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2005.

Table 4.3-3. Monthly average flow effects of Tumalo Feed Canal on Tumalo Creek for Water Year 2005.

Month	Monthly Average Mean Daily Flow Below Tumalo Feed Canal Diversion	Monthly Average Mean Daily Flow for Tumalo Feed Canal Diversion	Calculated Monthly Average Mean Daily Flow Above Tumalo Feed Canal Diversion	Number of Days of Diversion	Monthly Average Natural Flow @ 80 % Exceedance (1958-1987)	Monthly Average Natural Flow @ 50 % Exceedance (1958-1987)
October	53	29	54	1	57	65
November	49	42	56	5	59	70
December	68	0	68	0	59	69
January	60	58	69	5	57	68
February	60	27	61	1	57	67
March	33	50	63	18	59	69
April	14	55	69	30	66	77
May	49	118	167	31	104	147
June	15	73	88	30	149	221
July	7	52	59	31	72	111
August	6	39	45	31	53	65
September	9	34	43	30	52	63

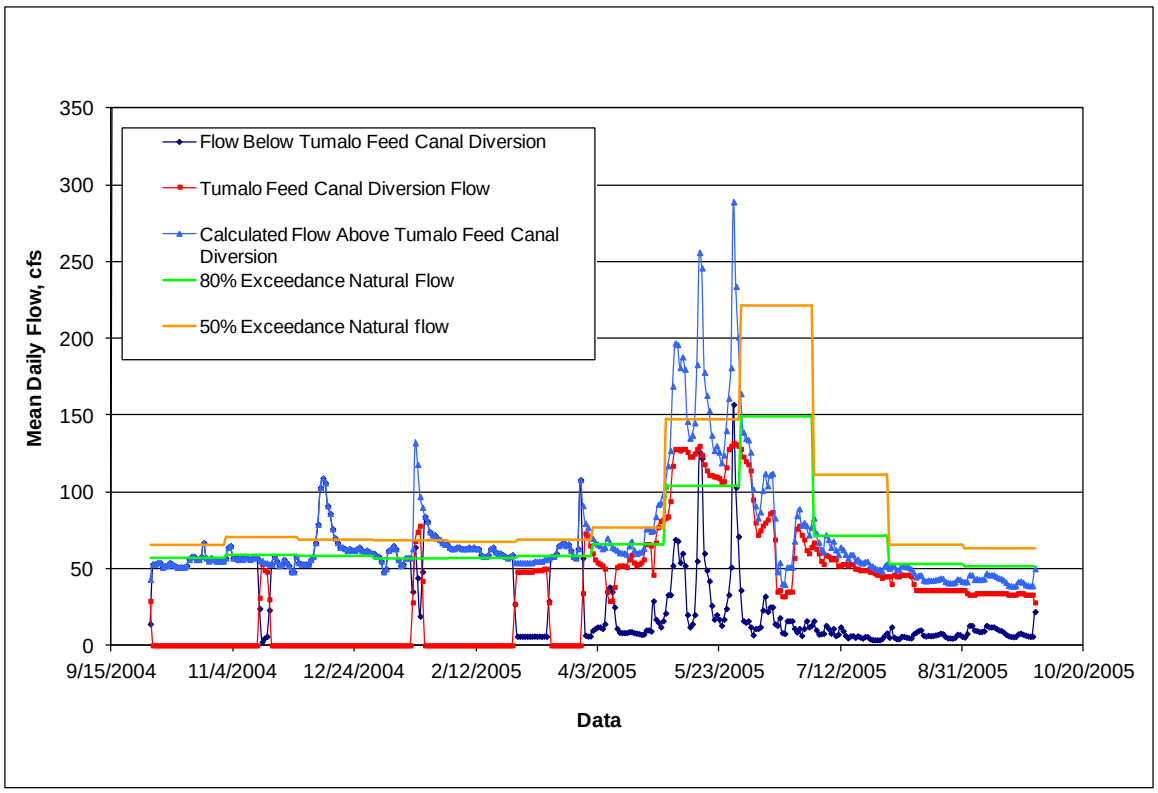


Figure 4.3-6. Tumalo Feed Canal effects on Tumalo Creek for Water Year 2005.

Figure 4.3-7 shows the statistics for the monthly average flows for the period 2000-2005 for Tumalo Creek below the Tumalo Feed Canal diversion. Table 4.3-4 is a tabular representative of the same data. Figure 4.3-8 shows the monthly average mean daily flows for the Tumalo Feed Canal Diversion and Tumalo Creek flow both above and below the feed canal diversion for Water Years 2000 to 2005. Table 4.3-5 is a tabular representation of Figure 4.3-8 that also shows the average and maximum days of diversion for Water Years 2000-2005.

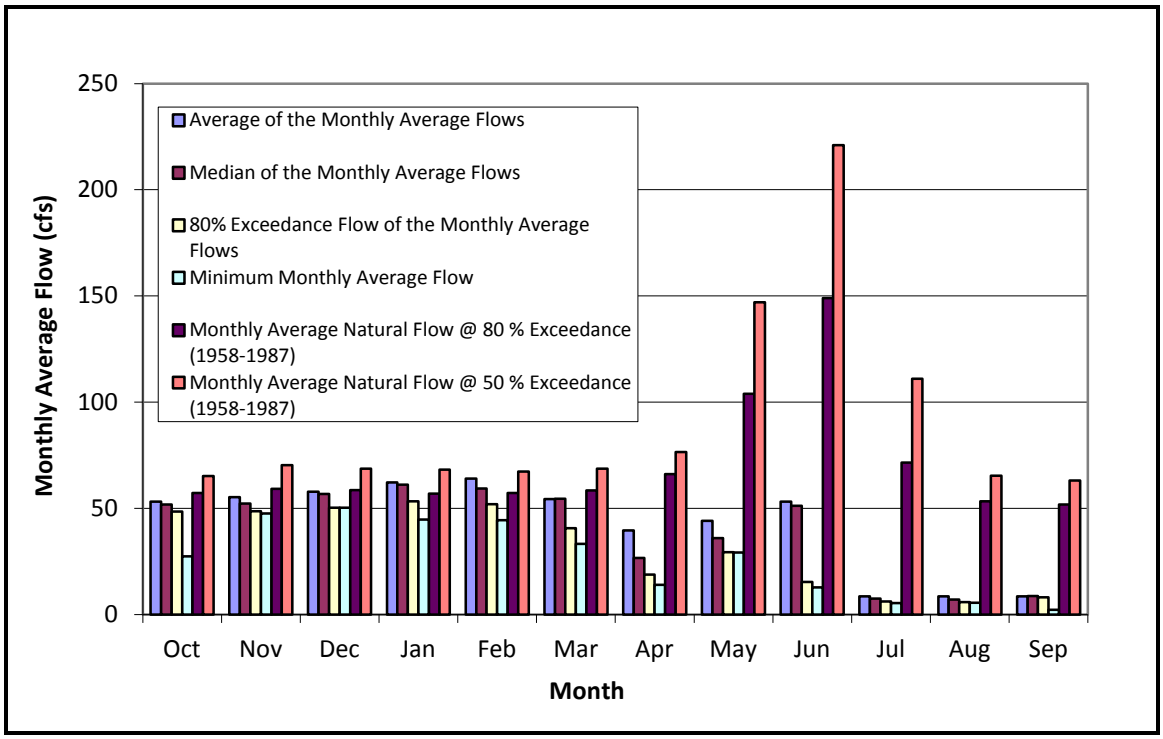


Figure 4.3-7. Statistics of the monthly average mean daily flow for Tumalo Creek below Tumalo Feed Canal for Water Years 2000 through 2005.

Table 4.3-4. Statistics of the monthly average mean daily flow for Tumalo Creek below Tumalo Feed Canal for Water Years 2000 through 2005.

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance Flow of the Monthly Average Flows	Minimum Monthly Average Flow	Monthly Average Natural Flow @ 80 % Exceedance (1958-1987)	Monthly Average Natural Flow @ 50 % Exceedance (1958-1987)
October	53	52	48	27	57	65
November	55	52	49	48	59	70
December	58	57	50	50	59	69
January	62	61	53	45	57	68
February	64	59	52	44	57	67
March	54	55	41	33	59	69
April	40	27	19	14	66	77
May	44	36	29	29	104	147
June	53	51	15	13	149	221
July	9	8	6	5	72	111
August	9	7	6	6	53	65
September	9	9	8	2	52	63

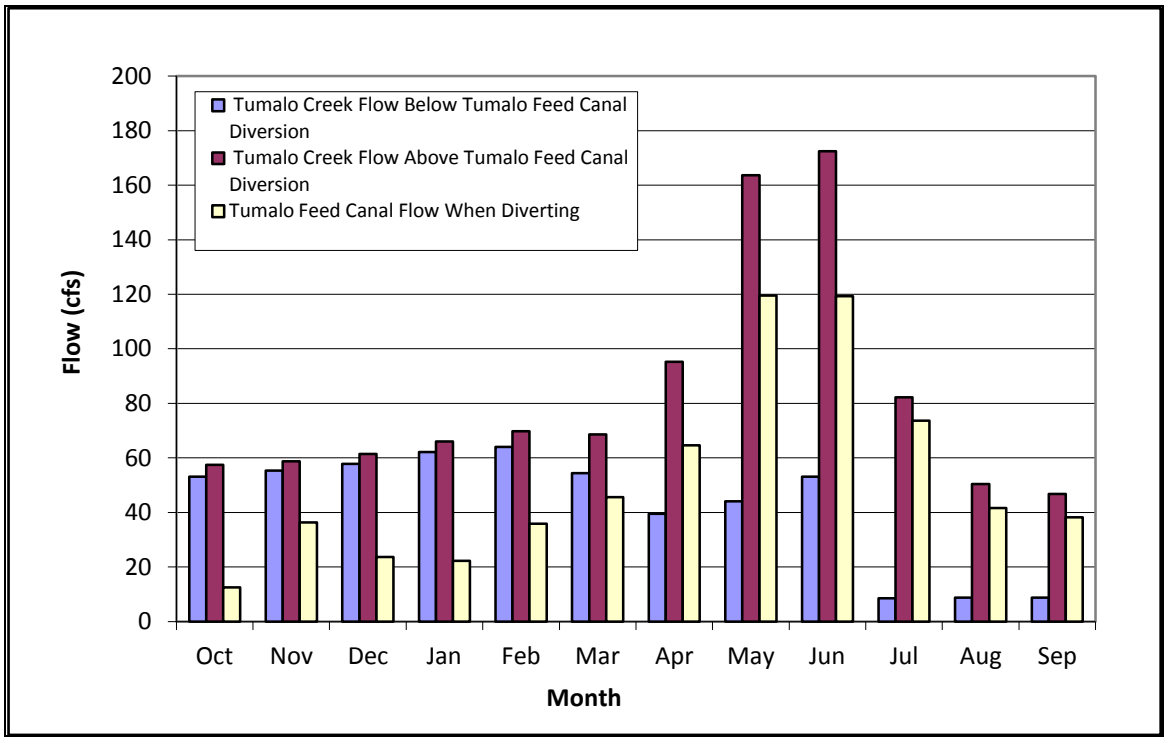


Figure 4.3-8. Average of the monthly average flows in Tumalo Creek above and below Tumalo Feed Canal and the Tumalo Feed Canal Flow for Water Years 2000 through 2005.

Table 4.3-5. Average of the monthly average flows in Tumalo Creek above and below Tumalo Feed Canal and the Tumalo Feed Canal Flow for Water Years 2000 through 2005.

Month	Tumalo Creek Flow Below Tumalo Feed Canal Diversion	Tumalo Creek Flow Above Tumalo Feed Canal Diversion	Tumalo Feed Canal Flow When Diverting	Average Days of Diversion	Maximum Days of Diversion
October	53	57	13	3	18
November	55	59	36	4	5
December	58	61	24	2	5
January	62	66	22	3	6
February	64	70	36	4	5
March	54	69	46	8	18
April	40	95	65	27	30
May	44	164	120	31	31
June	53	172	119	30	30
July	9	82	74	31	31
August	9	50	42	31	31
September	9	47	38	30	30

4.4 DESCHUTES RIVER

4.4.1 ANALYSIS POINTS AND REFERENCE YEARS

This component analyzes the flow impacts on the Deschutes River from five irrigation districts (6 points of diversions) that withdraw water from the Deschutes River at or a short distance above Bend. Figure A-6 in the Appendix is a map showing the points of diversion. The irrigation districts are Arnold, COID (which has two diversions), Tumalo, NUID, and Swalley. In addition to the primary points of diversion analyzed here, Arnold, Tumalo and Swalley District have a total of 31 surface pumps where district patrons withdraw water directly from the Deschutes River during the irrigation season. These pumps are located between the Arnold headworks south of Bend and Cline Falls State Park west of Redmond. The total capacity of these pumps is about 4.45 cfs.

The OWRD operates a gage on the Deschutes River below Bend (and the 6 diversions) and one above the diversions at Benham Falls. There is a significant flow loss just below the Benham Falls gage, however, so it is not a reliable source of flow data above the Deschutes River diversions. Flows above the diversions are calculated based upon the gage data from the canal diversions. All but a very small portion of these data are published.

The COID Central Oregon Canal also feeds a small hydro-electric unit that returns water to the Deschutes River several miles below its river diversion. There are no readily available flow data for the amount of water that returns to the river. The canal gage (No. 14066500) reports flow rates after a portion of the flow is diverted into the hydro unit. A spreadsheet model was developed to determine the amount of return flow based upon the following assumptions of how the hydro unit is operated:

a. COID maximizes the amount of flow through the hydro unit, but within the constraints of its operating license. (Note: the water right certificate allows up to 640 cfs of water for the unit.)
b. The diversion canal cannot divert more than 830 cfs.
c. The hydro unit maximum flow capacity is 550 cfs.
d. The hydro unit minimum operating flow is 90 cfs.
e. COID maintains at least 400 cfs in the river between its diversion and the return flow from the hydro unit as required by its operating license.

The calculated return flow is used to analyze the effects of the COID Central Oregon Canal diversion.

The OWRD generates a monthly spreadsheet entitled “storage reports” that determines the amount of upriver storage utilized by each district during the irrigation season from April through September. OWRD routinely does not generate a storage report for October if there appears to be ample storage remaining in the reservoirs for those drawing on them pursuant to their respective storage water rights. These storage reports also determine the amount of live flow diverted by each of the districts. These reports were used in this analysis to determine the amount of live and stored flow diverted by each of the districts.

The OWRD’s Water Availability Report System has determined the 80% and 50% exceedance natural flows for the Deschutes River above the confluence of Tumalo Creek, which is about 2 miles downstream from the gaging station located below Bend. These natural flow figures are monthly averages and are believed to reasonably represent the natural flows that would occur in the segment of the river affected by the six irrigation diversions being analyzed here.

4.4.2 LOW-FLOW YEAR ANALYSIS

Figure 4.4-1 shows the accumulative precipitation in the Upper Deschutes River sub-basin for Water Years 2001 through 2010. These data are from the SNOTEL website operated by the U.S. Natural Resource Conservation Service, U.S. Department of Agriculture. The data represented by this graph indicate that Water Year 2001 was the driest of the last 10 years. Therefore, 2001 river flow data will be used to represent the low-flow year.

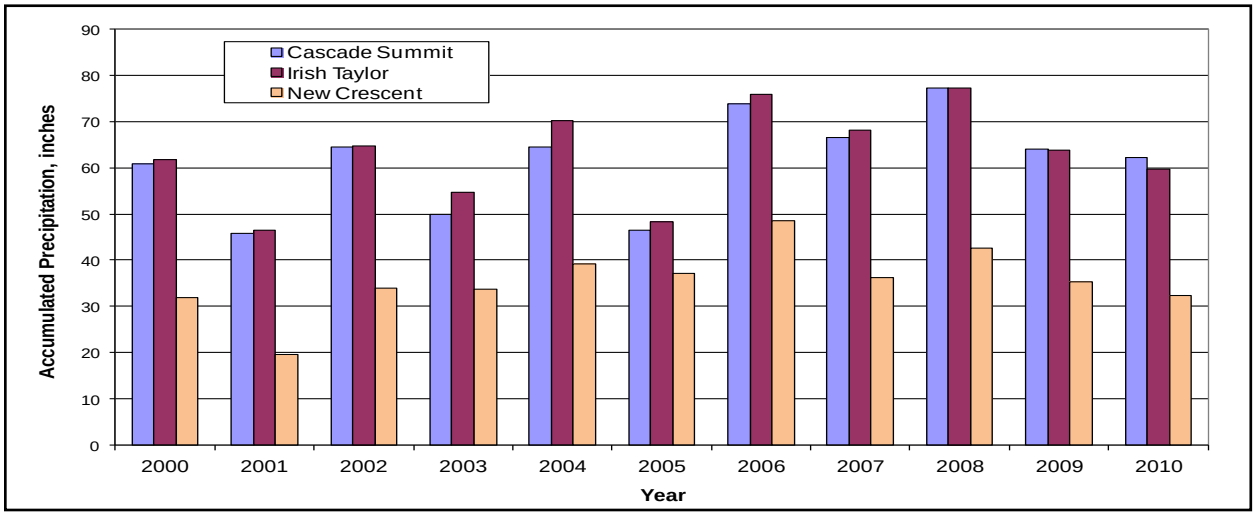


Figure 4.4-1. Total accumulated precipitation in the upper Deschutes Basin for Water Yrs 2000 - 2010.

Table 4.4-1 shows the annual, total amount of Deschutes River flow in acre-feet at Benham Falls compared to the annual, total amount of flow diverted by the districts for water years 2001 through 2010.

Table 4.4-1. Total Deschutes River flow at Benham Falls and total diverted flow by irrigation districts, water years 2001 through 2010.

Water Year	Water Annual Volume @ Benham Falls, Acre Feet	Total Annual District Diversions, Acre Feet	Water Year	Water Annual Volume @ Benham Falls, Acre Feet	Total Annual District Diversions, Acre Feet
2001	920,089	595,484	2006	804,889	529,893
2002	817,912	588,087	2007	937,888	608,934
2003	793,462	549,183	2008	833,205	586,272
2004	787,501	565,315	2009	903,293	579,922
2005	750,970	528,611	2010	864,399	550,780

4.4.3 EFFECTS OF WATER DIVERSION ON IN-STREAM FLOW

Figures 4.4-2A through 4.4-9A show the live, stored and total flow effects (monthly average mean daily flow) of the Deschutes River diversions for April through September of 2001. Both May and September are divided in half because the first half and second half have different water rights that apply to certain diversions. The 80% and 50% exceedance natural flows are also displayed on the first figure for each month (or portion of month). The Figures 4.4-2B through 4.4-9B the monthly average mean daily flow for each diversion in cfs and acre-feet/day for April through September 2001. Please note that for both COID Central Oregon Canal and the Pilot Butte Canal, as noted in the tables, but not on the graphs, some flow is diverted in to North Unit and into Lone Pine, respectively.

Tables 4.4-2 through 4.4-9 are tabular representations of Figures 4.4-2A&B through 4.4-9A&B. Figure 4.4-10 is a graph that represents the daily effects on Deschutes River flow as a result of irrigation diversions at and above Bend in 2001. The "Below Bend" location is a short distance below the north dam which is approximately at river mile 164

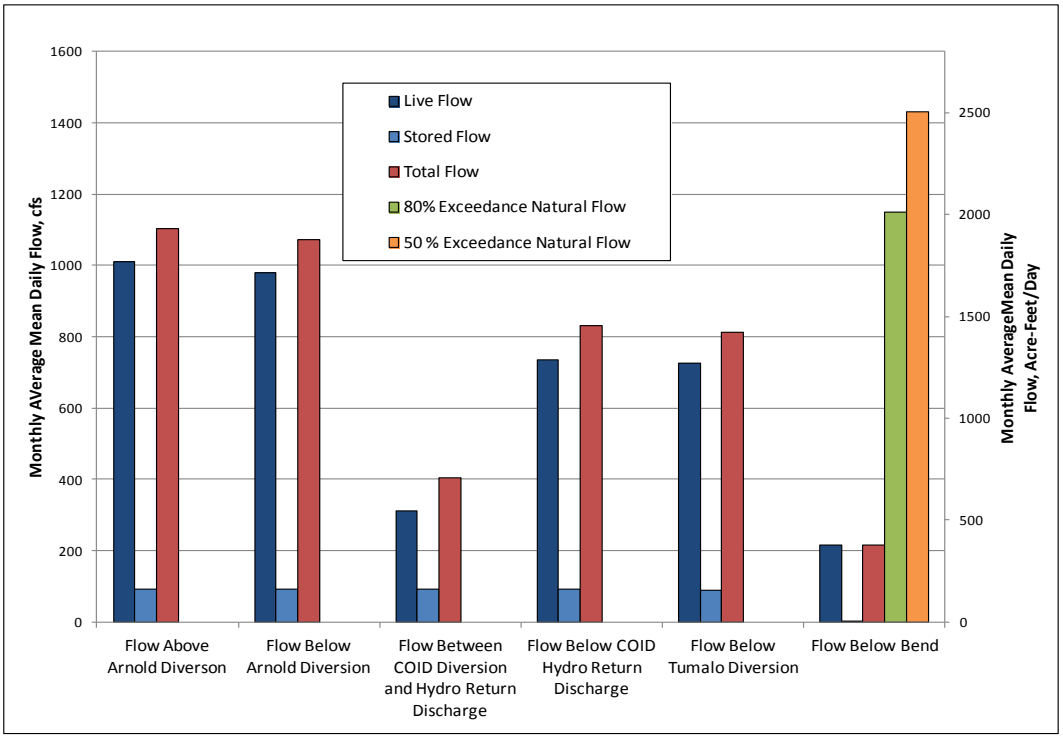


Figure 4.4-2A. Deschutes River flows relative to district diversions for April 2-30, 2001.

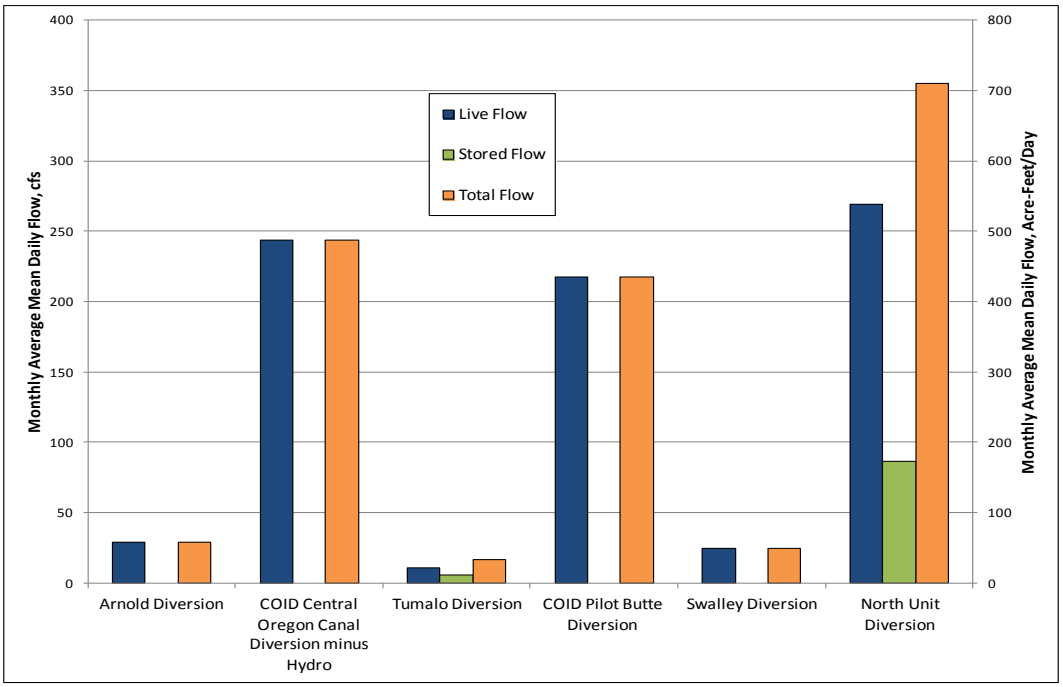


Figure 4.4-2B. Irrigation diversions for April 2-30, 2001.

Table 4.4-2. Irrigation diversion impacts on Deschutes River flow for April 2-30, 2001.

April, 2001 (Note: Record for only April 2 thru April 30)									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		63285			1031				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		63285	57932	5353	1009	93	1102		
Arnold Diversion		1666	1666	0	29	0	29		
Flow Below Arnold Diversion		61619	56266	5353	980	93	1073		
COID Central Oregon Canal Diversion including Hydro	Note: 666 ac-ft later diverted into North Unit Main Canal	38415	38415	0	669	0	669		
Flow Between COID Diversion and Hydro Return Discharge		23204	17851	5353	311	93	404		
COID Central Oregon Canal Diversion minus Hydro		13974	13974	0	243	0	243		
Flow Below COID Hydro Return Discharge		47645	42292	5353	737	93	830		
Tumalo Diversion		927	618	309	11	5	16		
Flow Below Tumalo Diversion		46718	41674	5044	726	88	814		
COID Pilot Butte Diversion	Note: 1280 ac-ft later diverted into Lone Pine Canal	12486	12486	0	217	0	217		
Swalley Diversion		1390	1390	0	24	0	24		
North Unit Diversion		20400	15454	4946	269	86	355		
Flow Below Bend		12442	12344	98	215	2	217	1150	1430

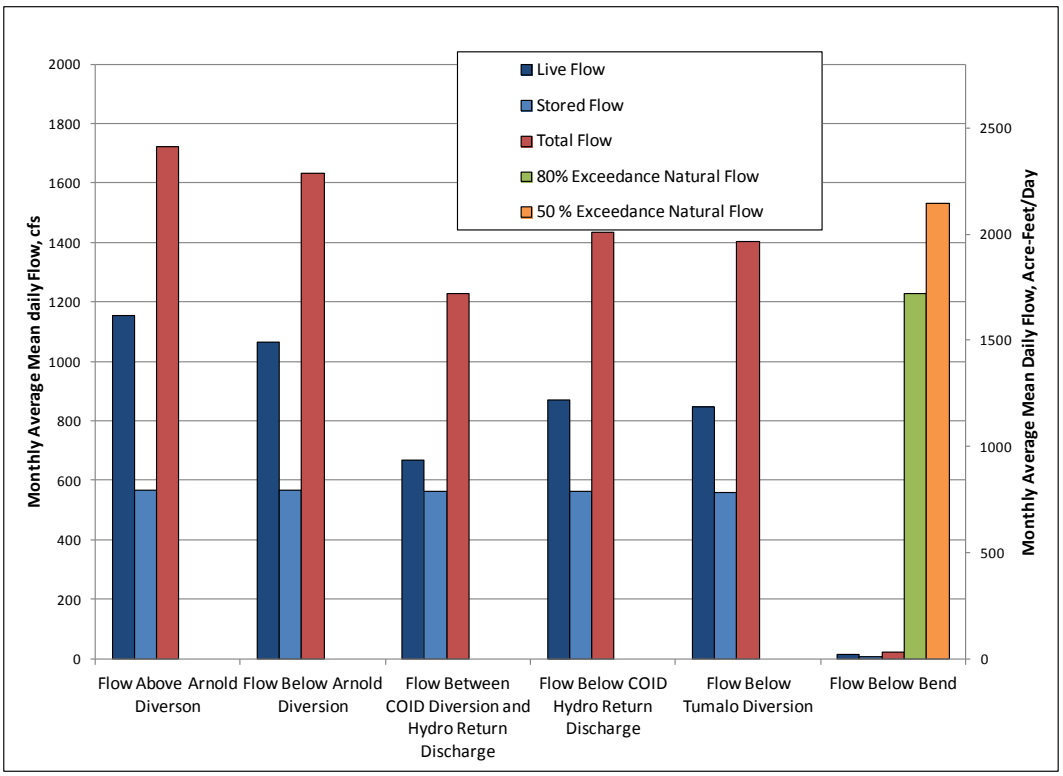


Figure 4.4-3A. Deschutes River flows relative to district diversions for May 1-14, 2001.

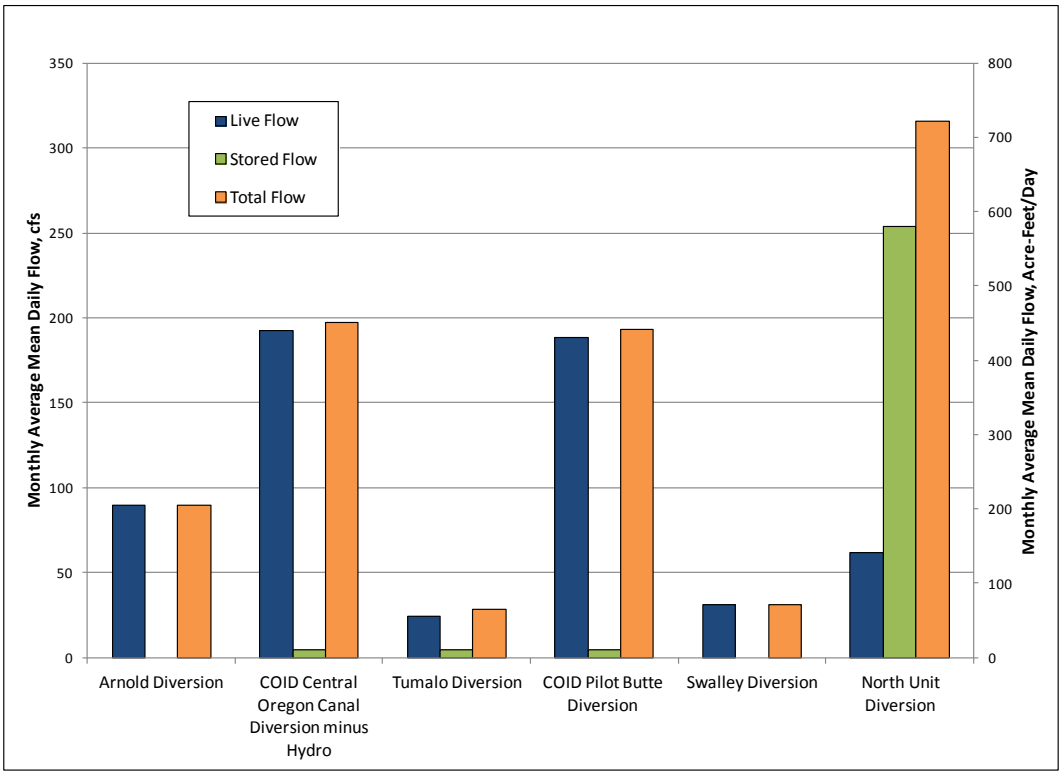


Figure 4.4-3B. Irrigation diversions for May 1-14, 2001.

Table 4.4-3. Irrigation diversion impacts on Deschutes River flow for May 1-14, 2001.

May 1-14. 2001									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft 47700			Monthly Mean Daily Flow, cfs 1721			Natural Flow	
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		47700	31982	15718	1154	567	1721		
Arnold Diversion		2491	2491	0	90	0	90		
Flow Below Arnold Diversion		45209	29491	15718	1064	567	1631		
COID Central Oregon Canal Diversion including Hydro	Note: 97 ac-ft later diverted into North Unit Main Canal	23042	22780	262	397	5	401		
Flow Between COID Diversion and Hydro Return Discharge		22167	6711	15456	667	562	1230		
COID Central Oregon Canal Diversion minus Hydro		11322	11060	262	193	5	197		
Flow Below COID Hydro Return Discharge		33887	18431	15456	871	562	1434		
Tumalo Diversion		1644	1397	247	24	4	29		
Flow Below Tumalo Diversion		32243	17034	15209	847	558	1405		
COID Pilot Butte Diversion	Note: 1124 ac-ft later diverted into Lone Pine Canal	11080	10819	261	188	5	193		
Swalley Diversion		1777	1777	0	31	0	31		
North Unit Diversion		18117	3533	14584	62	254	316		
Flow Below Bend		1269	905	364	16	6	22	1230	1530

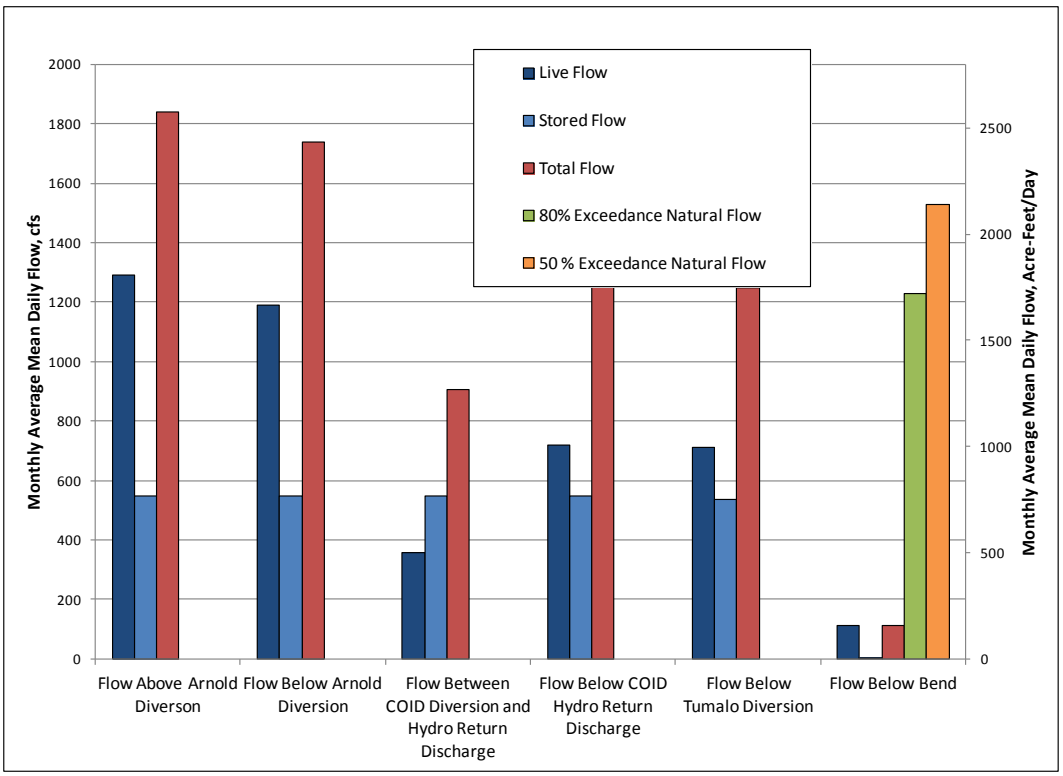


Figure 4.4-4A. Deschutes River flows relative to district diversions for May 15-31, 2001.

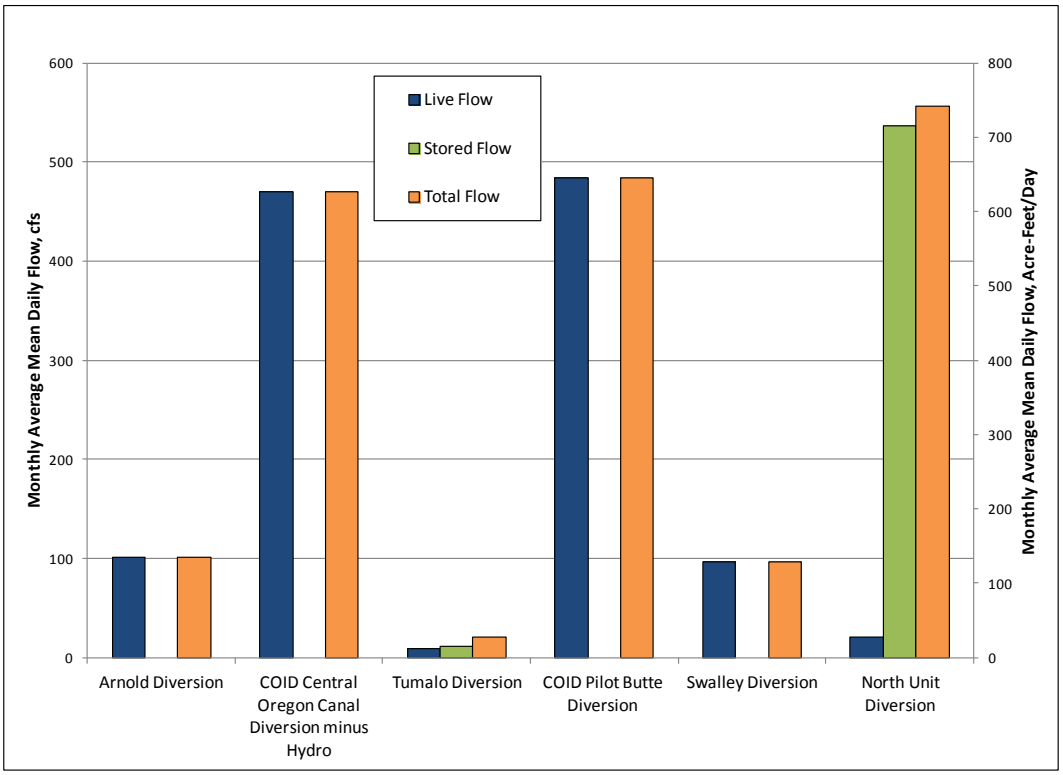


Figure 4.4-4B. Irrigation diversions for May 15-31, 2001.

Table 4.4-4. Irrigation diversion impacts on Deschutes River flow for May 15-31, 2001.

May 15-31. 2001									
Deschutes River Flow or Diversion as Indicated	Total Monthly Flow, acre-ft 61902				Monthly Mean Daily Flow, cfs 1839			Natural Flow	
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		61902	43456	18446	1291	548	1839		
Arnold Diversion		3386	3386	0	101	0	101		
Flow Below Arnold Diversion		58516	40070	18446	1190	548	1738		
COID Central Oregon Canal Diversion including Hydro	Note: 666 ac-ft later diverted into North Unit Main Canal	28014	28014	0	832	0	832		
Flow Between COID Diversion and Hydro Return Discharge		30502	12056	18446	358	548	906		
COID Central Oregon Canal Diversion minus Hydro		15832	15832	0	470	0	470		
Flow Below COID Hydro Return Discharge		42684	24238	18446	720	548	1268		
Tumalo Diversion		690	2236	-1546	9	12	20		
Flow Below Tumalo Diversion		41994	22002	19992	711	536	1248		
COID Pilot Butte Diversion	Note: 1629 ac-ft later diverted into Lone Pine Canal	16282	16282	0	484	0	484		
Swalley Diversion		3253	3253	0	97	0	97		
North Unit Diversion		20071	706	19365	21	536	557		
Flow Below Bend		2388	1761	627	110	0	110	1230	1530

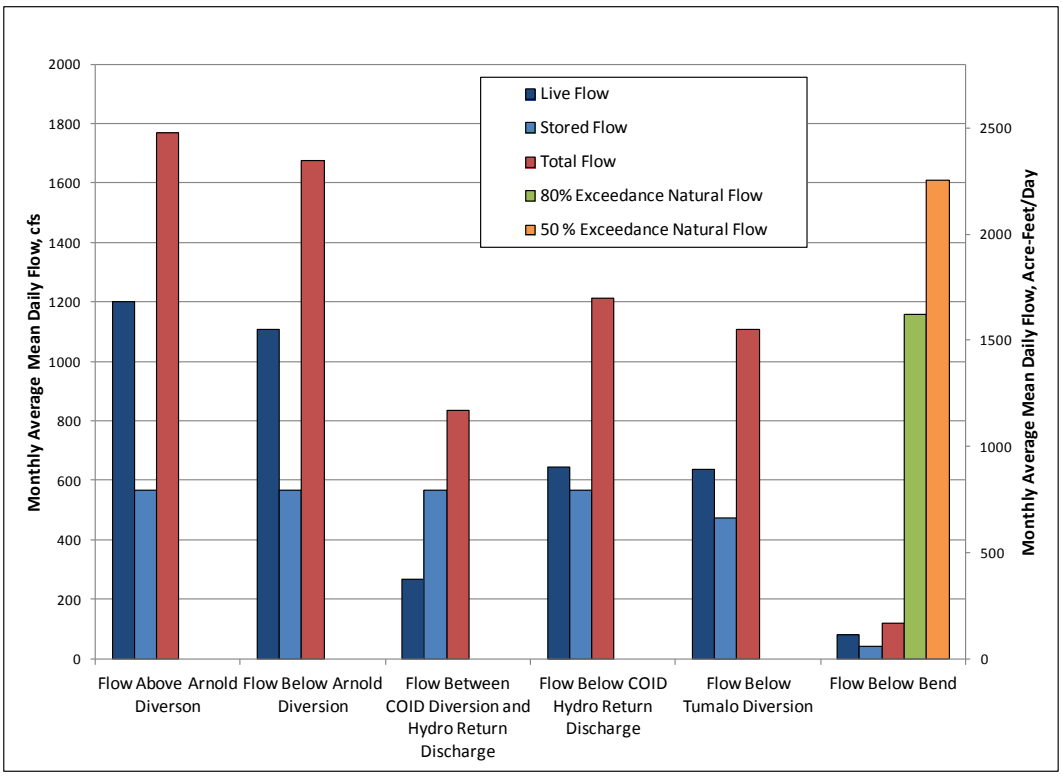


Figure 4.4-5A. Deschutes River flows relative to district diversions for June, 2001.

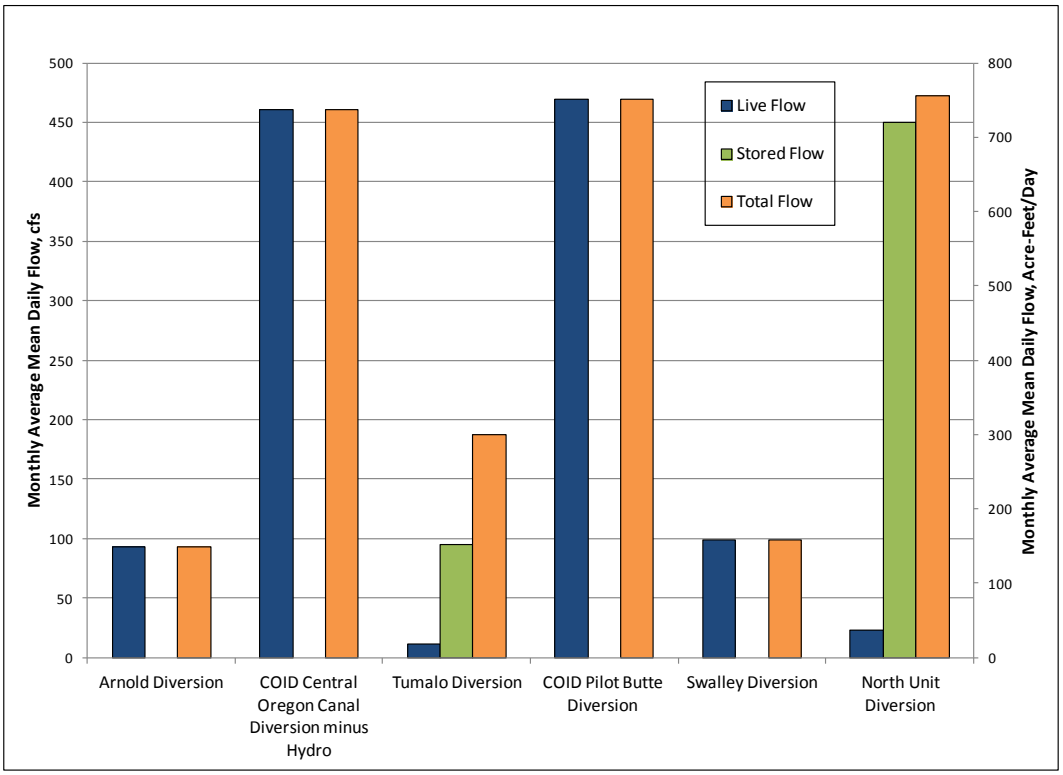


Figure 4.4-5B. Irrigation diversions for June, 2001.

Table 4.4-5. Irrigation diversion impacts on Deschutes River flow for June, 2001

June 2001									
Deschutes River Flow or Diversion as Indicated	Total Monthly Flow, acre-ft 105059				Monthly Mean Daily Flow, cfs 1769			Natural Flow	
		Total Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		105059	71299	33760	1200	568	1769		
Arnold Diversion		5532	5532	0	93	0	93		
Flow Below Arnold Diversion		99527	65767	33760	1107	568	1676		
COID Central Oregon Canal Diversion including Hydro	Note: 624 ac-ft later diverted into North Unit Main Canal	50006	50006	0	842	0	842		
Flow Between COID Diversion and Hydro Return Discharge		49521	15761	33760	265	568	834		
COID Central Oregon Canal Diversion minus Hydro		27388	27388	0	461	0	461		
Flow Below COID Hydro Return Discharge		72139	38379	33760	646	568	1214		
Tumalo Diversion		6301	659	5642	11	95	187		
Flow Below Tumalo Diversion		65838	37720	28118	635	473	1108		
COID Pilot Butte Diversion	Note: 2790 ac-ft later diverted into Lone Pine Canal	27870	27870	0	469	0	469		
Swalley Diversion		5847	5847	0	98	0	98		
North Unit Diversion		28068	1341	26727	23	450	473		
Flow Below Bend		4053	2662	1391	79	41	120	1160	1610

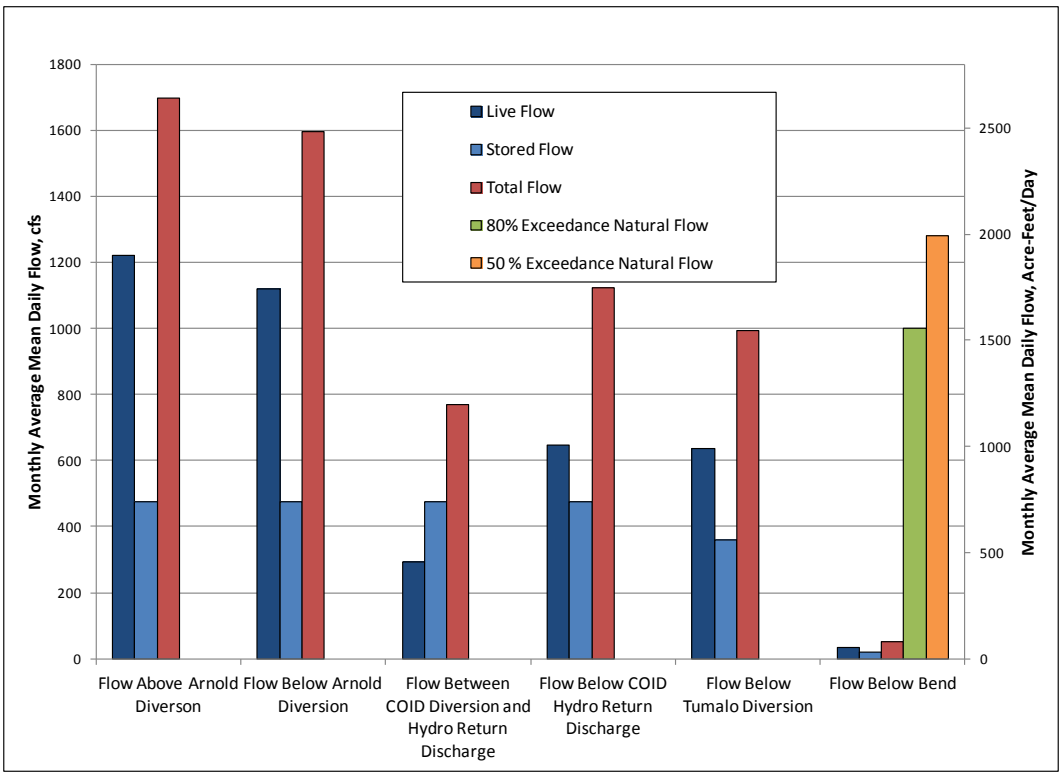


Figure 4.4-6A. Deschutes River flows relative to district diversions for July, 2001.

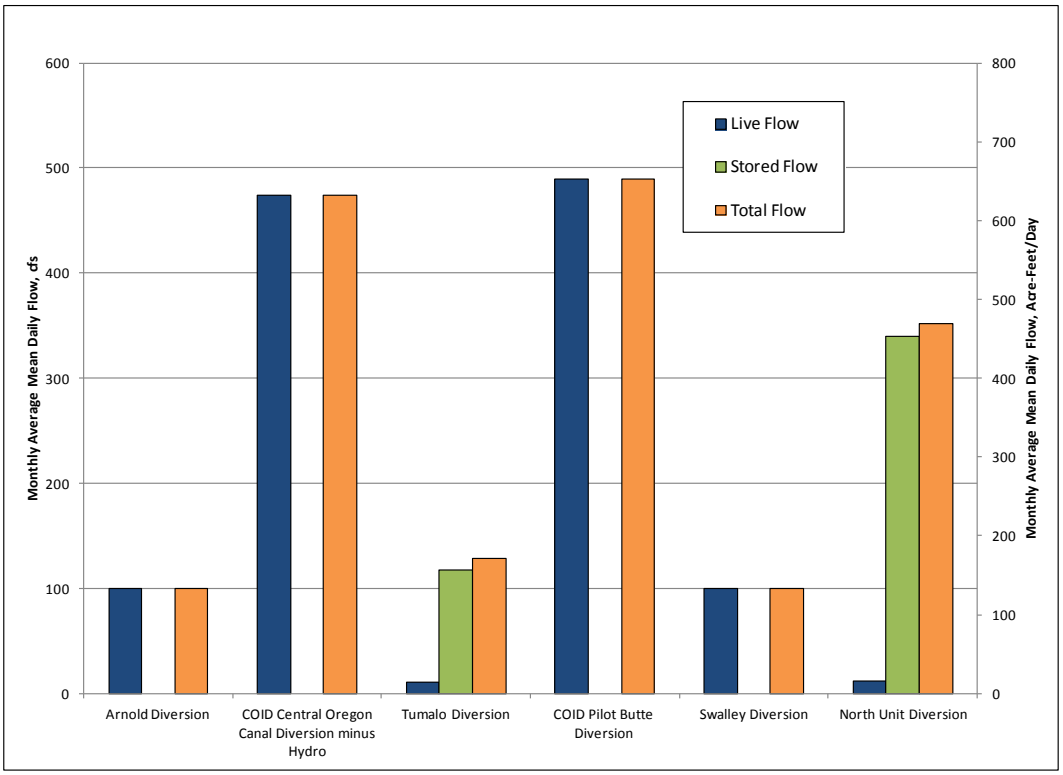


Figure 4.4-6B. Irrigation diversions for July, 2001.

Table 4.4-6. Irrigation diversion impacts on Deschutes River flow for July, 2001.

July 2001									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		104075			1696				
		Total Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		104075	74901	29174	1220	475	1696		
Arnold Diversion		6093	6093	0	99	0	99		
Flow Below Arnold Diversion		97982	68808	29174	1121	475	1596		
COID Central Oregon Canal Diversion including Hydro	Note: 536 ac-ft later diverted into North Unit Main Canal	50840	50840	0	828	0	828		
Flow Between COID Diversion and Hydro Return Discharge		47142	17968	29174	293	475	768		
COID Central Oregon Canal Diversion minus Hydro		29117	29117	0	474	0	474		
Flow Below COID Hydro Return Discharge		68865	39691	29174	647	475	1122		
Tumalo Diversion		7860	681	7179	11	117	128		
Flow Below Tumalo Diversion		61005	39010	21995	636	358	994		
COID Pilot Butte Diversion	Note: 2679 ac-ft later diverted into Lone Pine Canal	30065	30065	0	490	0	490		
Swalley Diversion		6143	6143	0	100	0	100		
North Unit Diversion		21592	721	20871	12	340	352		
Flow Below Bend		3205	2081	1124	34	18	52	1000	1280

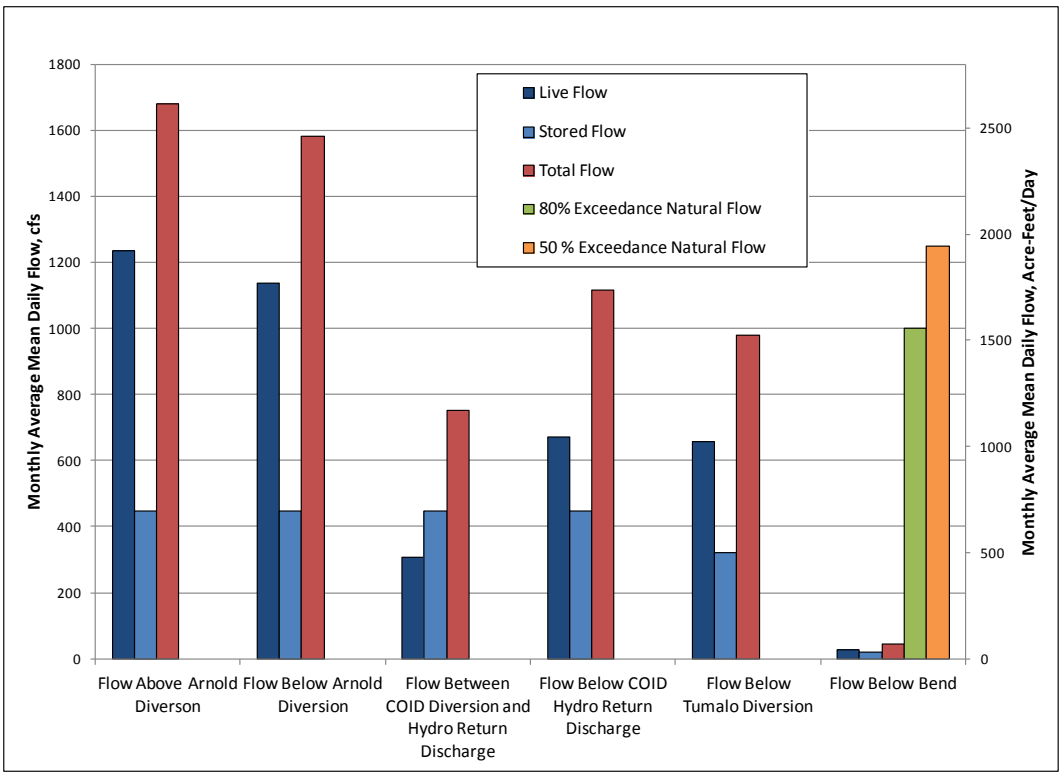


Figure 4.4-7A. Deschutes River flows relative to district diversions for August, 2001.

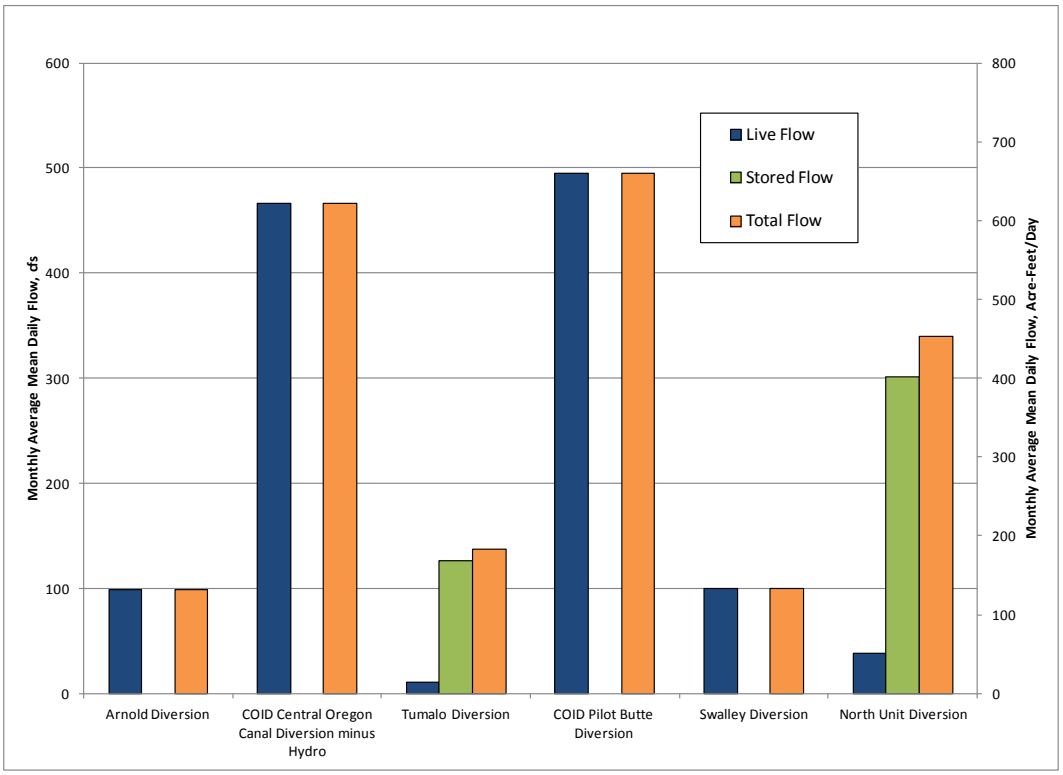


Figure 4.4-7B. Irrigation diversions for August, 2001.

Table 4.4-7. Irrigation diversion impacts on Deschutes River flow for August, 2001.

August 2001									
Deschutes River Flow or Diversion as Indicated	Total Monthly Flow, acre-ft 103182				Monthly Mean Daily Flow, cfs 1681			Natural Flow	
		Total Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		103182	75782	27400	1235	446	1681		
Arnold Diversion		6032	6032	0	98	0	98		
Flow Below Arnold Diversion		97150	69750	27400	1136	446	1583		
COID Central Oregon Canal Diversion including Hydro	Note: 408 ac-ft later diverted into North Unit Main Canal	50969	50969	0	830	0	830		
Flow Between COID Diversion and Hydro Return Discharge		46181	18781	27400	306	446	752		
COID Central Oregon Canal Diversion minus Hydro		28657	28657	0	467	0	467		
Flow Below COID Hydro Return Discharge		68493	41093	27400	669	446	1116		
Tumalo Diversion		8422	681	7741	11	126	137		
Flow Below Tumalo Diversion		60071	40412	19659	658	320	979		
COID Pilot Butte Diversion	Note: 2854 ac-ft later diverted into Lone Pine Canal	30361	30361	0	495	0	495		
Swalley Diversion		6145	6145	0	100	0	100		
North Unit Diversion		20840	2351	18489	38	301	340		
Flow Below Bend		2725	1555	1170	25	19	44	1000	1250

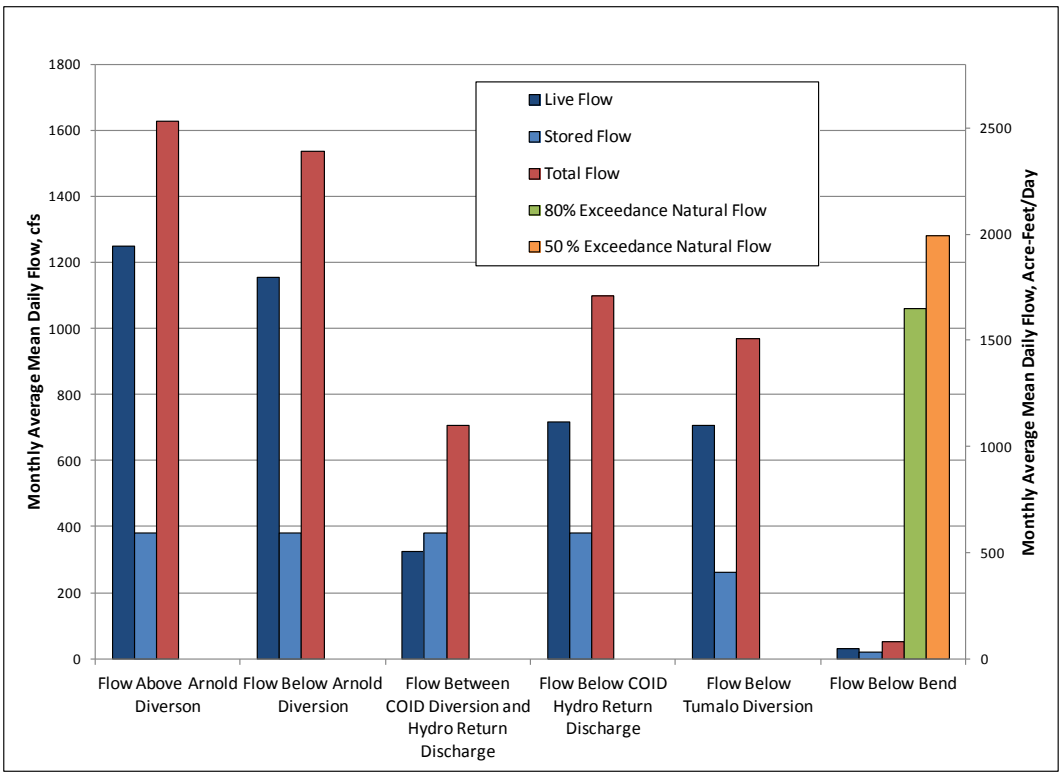


Figure 4.4-8A. Deschutes River flows relative to district diversions for September 1-14, 2001.

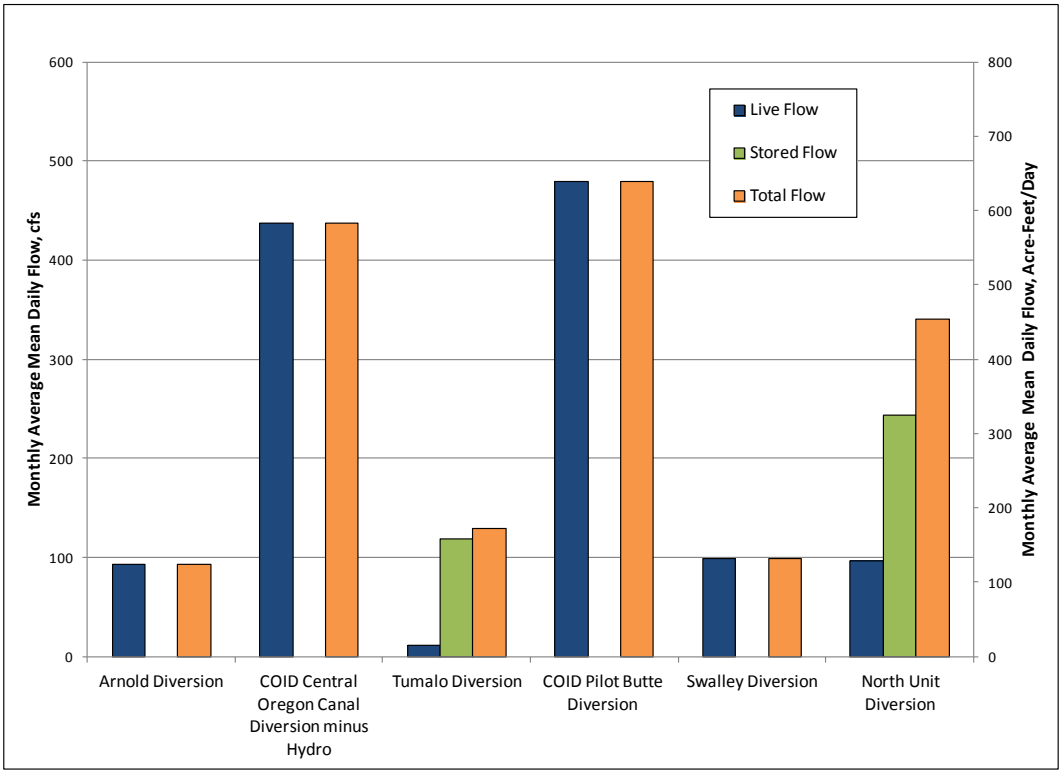


Figure 4.4-8B. Irrigation diversions for September 1-14, 2001.

Table 4.4-8. Irrigation diversion impacts on Deschutes River flow for September 1-14, 2001.

Sept 1-14, 2001									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft 45152			Monthly Mean Daily Flow, cfs 1629			Natural Flow	
		Total Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		45152	34591	10561	1248	381	1629		
Arnold Diversion		2579	2579	0	93	0	93		
Flow Below Arnold Diversion		42573	32012	10561	1155	381	1536		
COID Central Oregon Canal Diversion including Hydro	Note: 216 ac-ft later diverted into North Unit Main Canal	22977	22977	0	829	0	829		
Flow Between COID Diversion and Hydro Return Discharge		19596	9035	10561	326	381	707		
COID Central Oregon Canal Diversion minus Hydro		12131	12131	0	438	0	438		
Flow Below COID Hydro Return Discharge		30442	19881	10561	717	381	1098		
Tumalo Diversion		3584	308	3276	11	118	129		
Flow Below Tumalo Diversion		26858	19573	7285	706	263	969		
COID Pilot Butte Diversion	Note: 1275 ac-ft later diverted into Lone Pine Canal	13279	13279	0	479	0	479		
Swalley Diversion		2743	2743	0	99	0	99		
North Unit Diversion		9421	2684	6737	97	243	340		
Flow Below Bend		1415	867	548	31	20	51	1060	1280

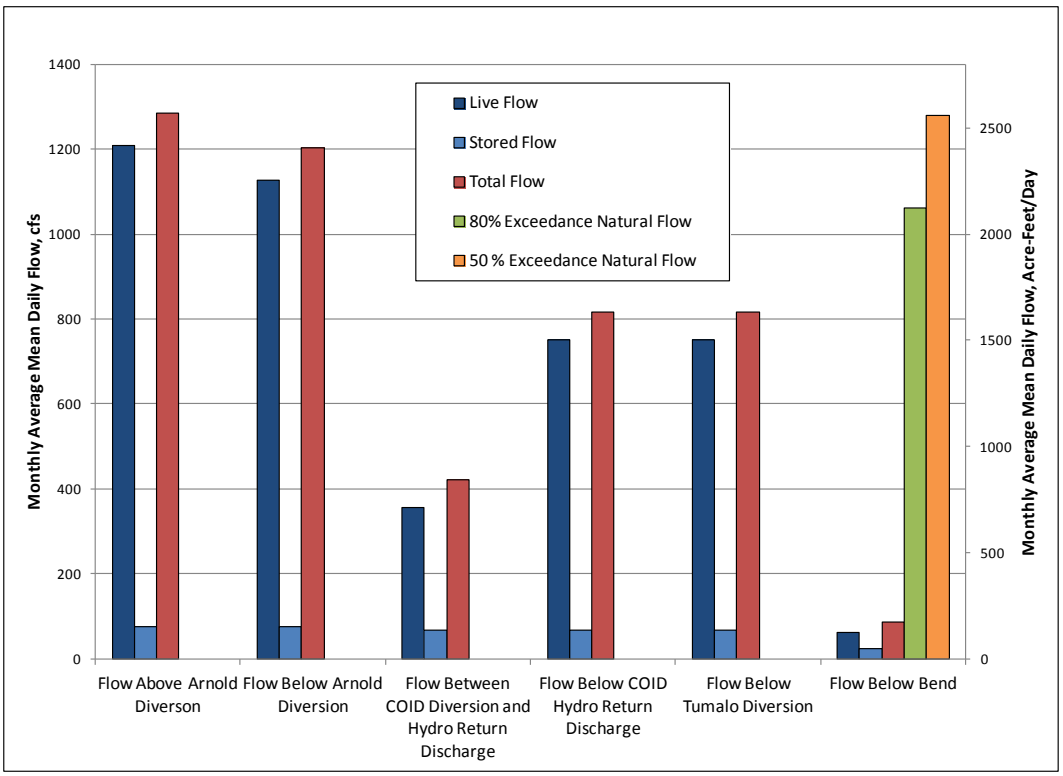


Figure 4.4-9A. Deschutes River flows relative to district diversions for September 15-30, 2001.

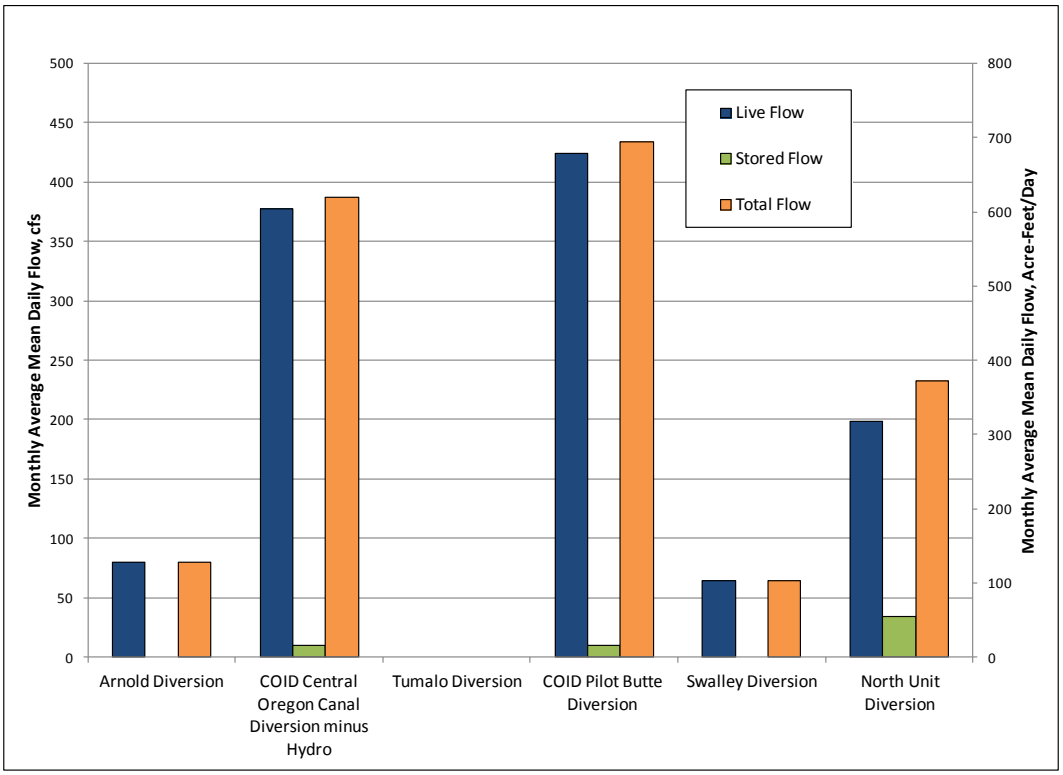


Figure 4.4-9B. Irrigation diversions for September 15-30, 2001.

Table 4.4-9. Irrigation diversion impacts on Deschutes River flow for September 15-30, 2001.

Sept 15-30, 2001									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft 40685			Monthly Mean Daily Flow, cfs 1284			Natural Flow	
		Total Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diverson		40685	38267	2418	1208	76	1284		
Arnold Diversion		2541	2541	0	80	0	80		
Flow Below Arnold Diversion		38144	35726	2418	1128	76	1204		
COID Central Oregon Canal Diversion including Hydro	Note: 325 ac-ft later diverted into North Unit Main Canal	24796	24489	307	773	10	783		
Flow Between COID Diversion and Hydro Return Discharge		13348	11237	2111	355	67	421		
COID Central Oregon Canal Diversion minus Hydro		12280	11973	307	378	10	388		
Flow Below COID Hydro Return Discharge		25864	23753	2111	750	67	816		
Tumalo Diversion		0	0	0	0	0	0		
Flow Below Tumalo Diversion		25864	23753	2111	750	67	816		
COID Pilot Butte Diversion	Note: 1190 ac-ft later diverted into Lone Pine Canal	13442	13442	307	424	10	434		
Swalley Diversion		2041	2041	0	64	0	64		
North Unit Diversion		7365	6291	1074	199	34	232		
Flow Below Bend		3016	1979	730	62	23	86	1060	1280

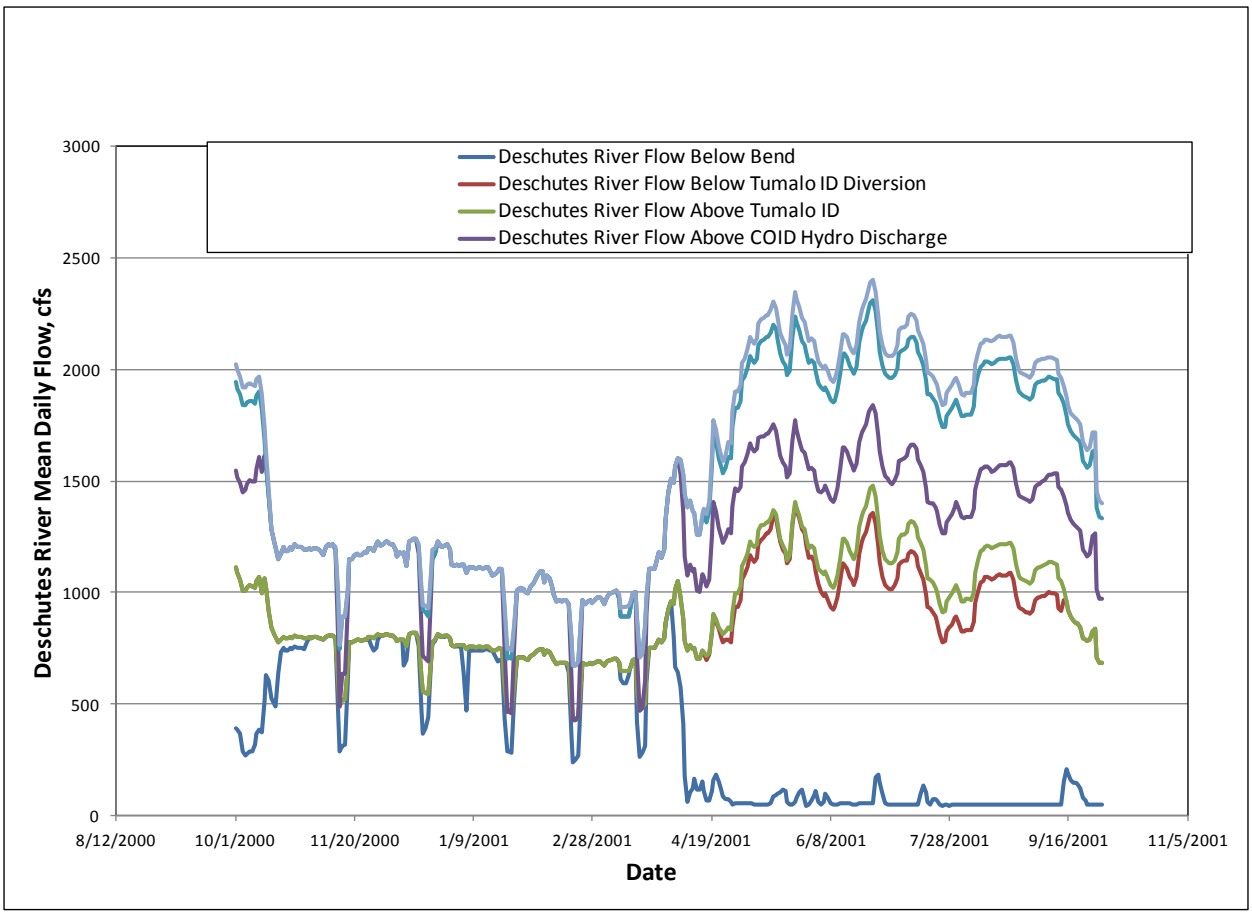


Figure 4.4-10. Deschutes River daily mean flow as a result of irrigation diversions at and above Bend in 2001.

Readers will notice that, in Table 4.4-3 for the period of May 15 to May 31, there is a negative number for Tumalo Irrigation for acre-feet stored. According to Kyle Gorman, regional manager of the Bend office of the Oregon Water Resources Department, "There was 1862 AF of natural flow available to TID at Crescent Lake. They stored about 1/2 in Crescent and the other half in Wickiup. The reason they got credit in Wickiup was because they let out more than what was needed to meet demand at Bend so North Unit essentially 'borrowed from Tumalo.' That might sound confusing but it happens a lot when the reservoir are operated in real-time throughout the summer and then we balance the books at the end of each month."

Figures 4.4-11A through 4.4-18A are similar to Figures 4.4-2A through 4.4-9A except that they are for Water Year 2010, which is the most current for which complete data were available at the time this analysis was started. The Figures 4.4-11B through 4.4-18B are the monthly average mean daily flow for each diversion in cfs and acre-feet/day for April through September 2010. Please note that for both COID Central Oregon Canal and the Pilot Butte Canal, as noted in the tables, but not on the graphs, some flow is diverted in to North Unit and into Lone Pine, respectively.

Tables 4.4-10 through 4.4-17 are tabular representations of Figures 4.4-11A&B through 4.4-18A&B. Figure 4.4-19 is a graph that represents the daily effects on Deschutes River flow as a result of irrigation diversions at and above Bend.

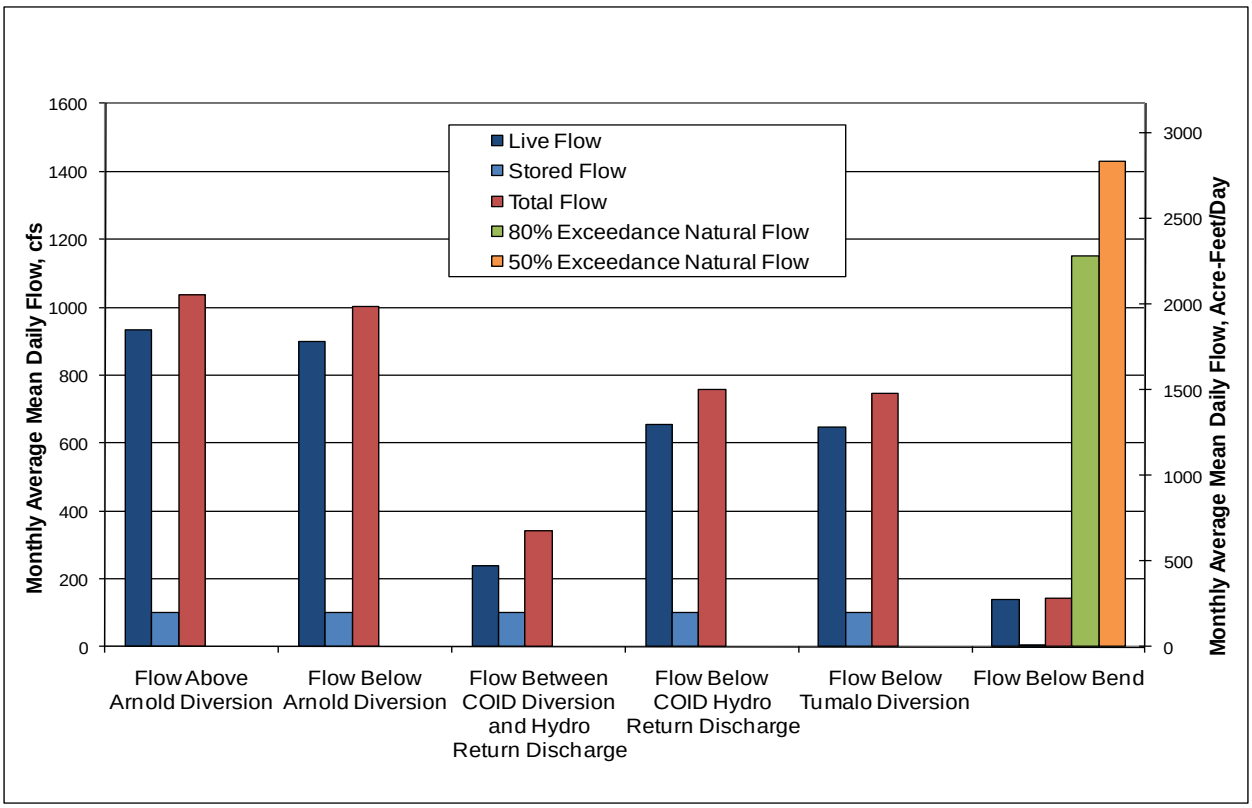


Figure 4.4-11A. Irrigation diversion impacts on Deschutes River flows for April 10-30, 2010.

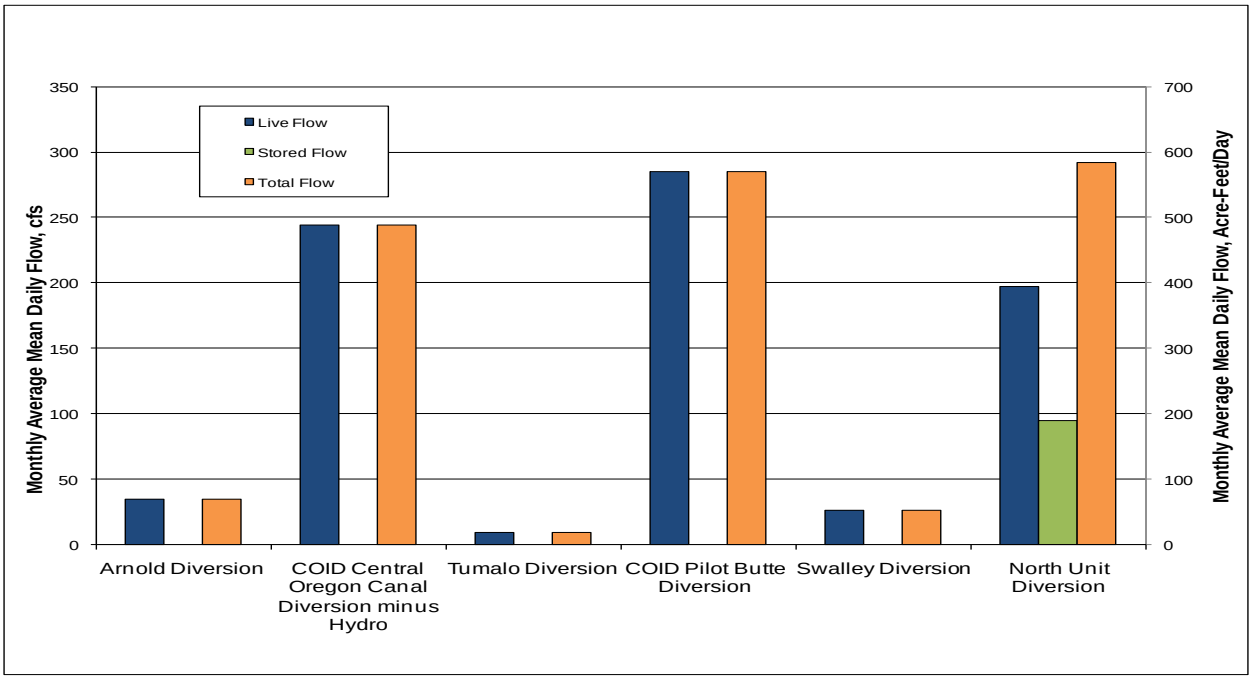


Figure 4.4-11B. Irrigation diversions for April 10-30, 2010.

Table 4.4-10. Irrigation diversion impacts on Deschutes River flow for April 10-30, 2010.

April, 2010 (Note: Record for only April 10 thru April 30)									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		43124			1035				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		43124	38879	4245	933	102	1035		
Arnold Diversion		1433	1433	0	34	0	34		
Flow Below Arnold Diversion		41691	37446	4245	899	102	1001		
COID Central Oregon Canal Diversion including Hydro	Note: 583 ac-ft later diverted into North Unit Main Canal	27438	27438	0	659	0	659		
Flow Between COID Diversion and Hydro Return Discharge		14253	10008	4245	240	102	342		
COID Central Oregon Canal Diversion minus Hydro		10174	10174	0	244	0	244		
Flow Below COID Hydro Return Discharge		31517	27272	4245	655	102	757		
Tumalo Diversion		364	364	0	9	0	9		
Flow Below Tumalo Diversion		31153	26908	4245	646	102	748		
COID Pilot Butte Diversion	Note: 124 ac-ft later diverted into Lone Pine Canal	11861	11861	0	285	0	285		
Swalley Diversion		1091	1091	0	26	0	26		
North Unit Diversion		12173	8224	3949	197	95	292		
Flow Below Bend		6028	5732	296	138	7	145	1150	1430

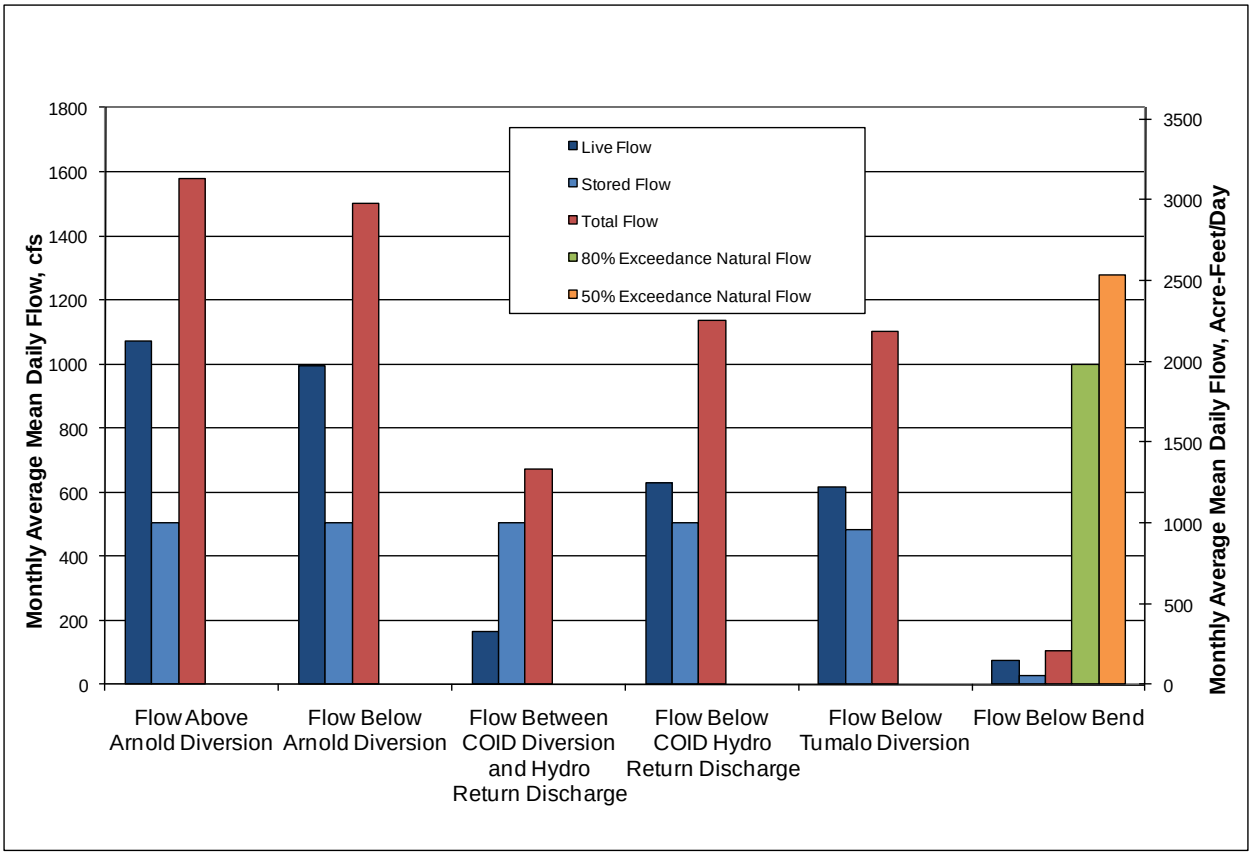


Figure 4.4-12A. Irrigation diversion impacts on Deschutes River flows for May 1-14, 2010.

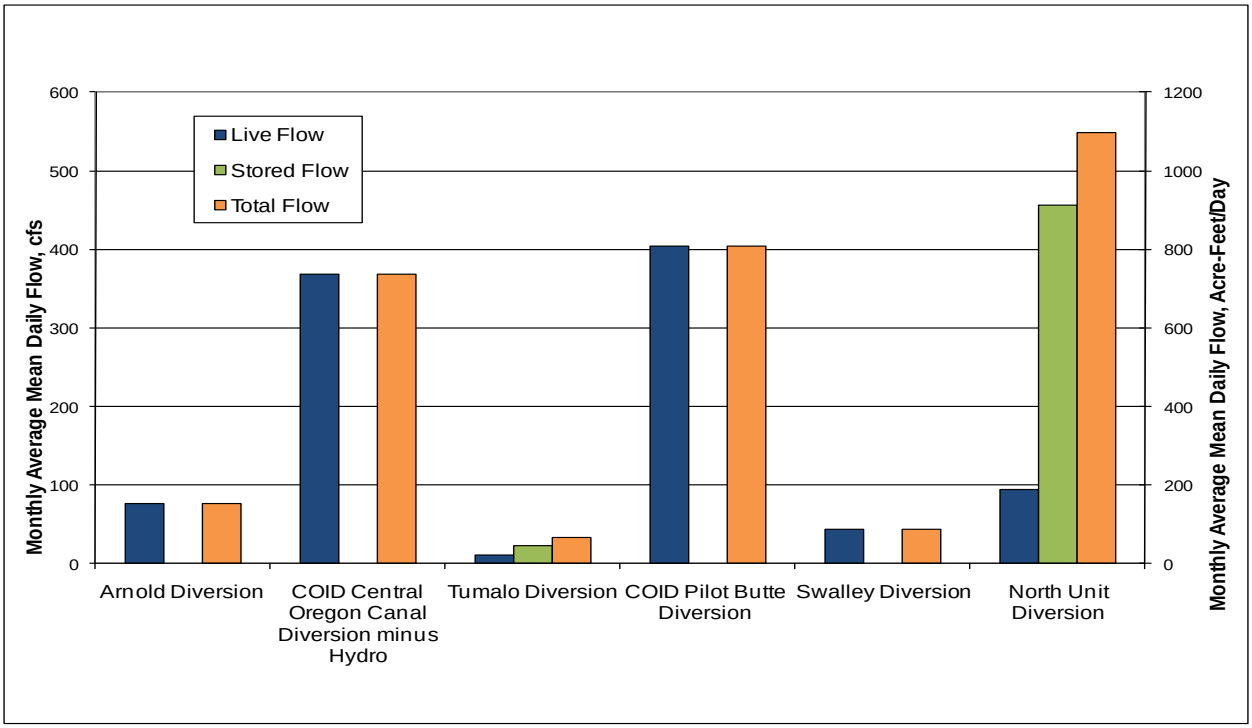


Figure 4.4-12B. Irrigation diversions for May 1-14, 2010.

Table 4.4-11. Irrigation diversion impacts on Deschutes River flow for May 1-14, 2010.

May 1-14, 2010									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		43818			1578				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		43818	29750	14069	1071	507	1578		
Arnold Diversion		2092	2092	0	75	0	75		
Flow Below Arnold Diversion		41727	27658	14069	996	507	1503		
COID Central Oregon Canal Diversion including Hydro	Note: 347 ac-ft later diverted into North Unit Main Canal	23048	23048	0	831	0	831		
Flow Between COID Diversion and Hydro Return Discharge		18679	4610	14069	166	507	673		
COID Central Oregon Canal Diversion minus Hydro		10221	10221	0	369	0	369		
Flow Below COID Hydro Return Discharge		31506	17437	14069	628	507	1135		
Tumalo Diversion		912	300	612	11	22	33		
Flow Below Tumalo Diversion		30594	17137	13457	617	485	1102		
COID Pilot Butte Diversion	Note: 838 ac-ft later diverted into Lone Pine Canal	11213	11213	0	404	0	404		
Swalley Diversion		1199	1199	0	43	0	43		
North Unit Diversion		15249	2583	12666	93	456	549		
Flow Below Bend		2934	2143	791	77	28	106	1000	1280

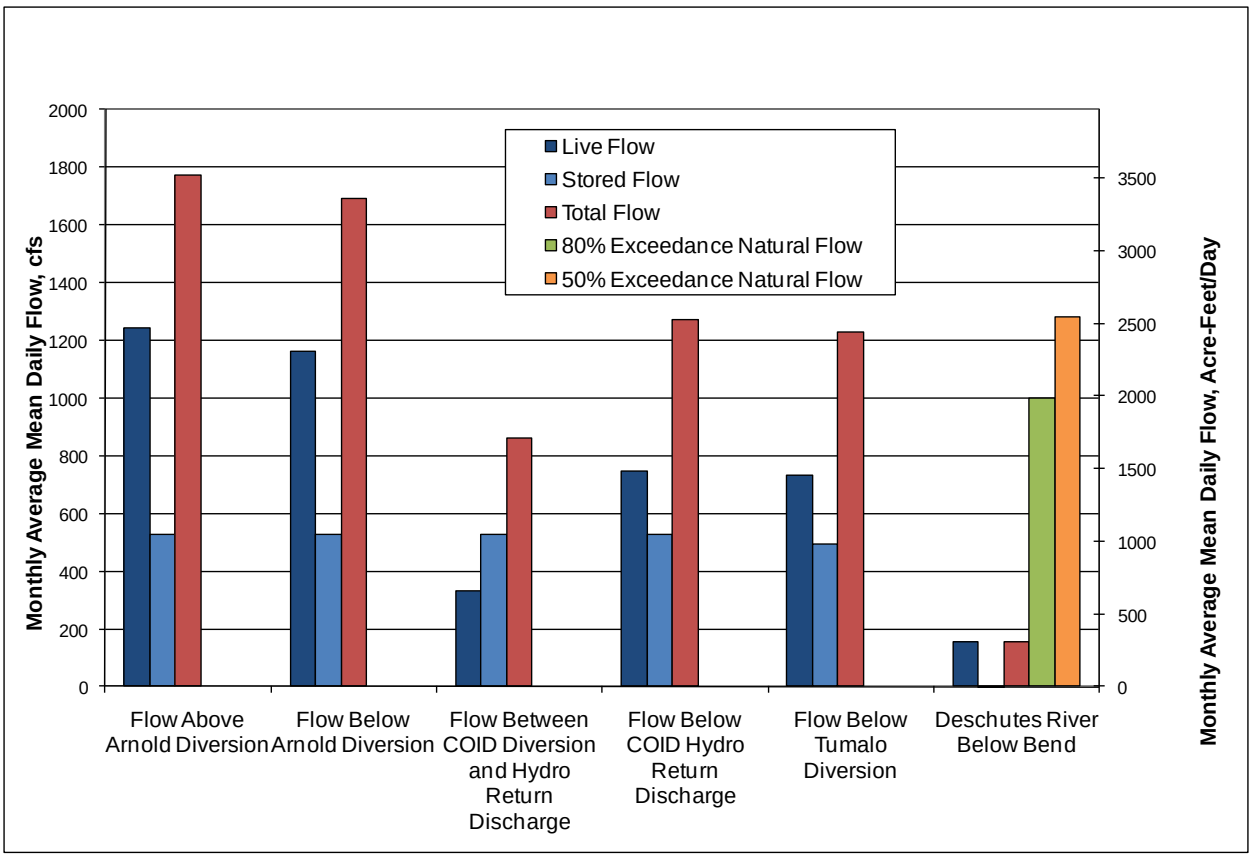


Figure 4.4-13A. Irrigation diversion impacts on Deschutes River flows for May 15-31, 2010.

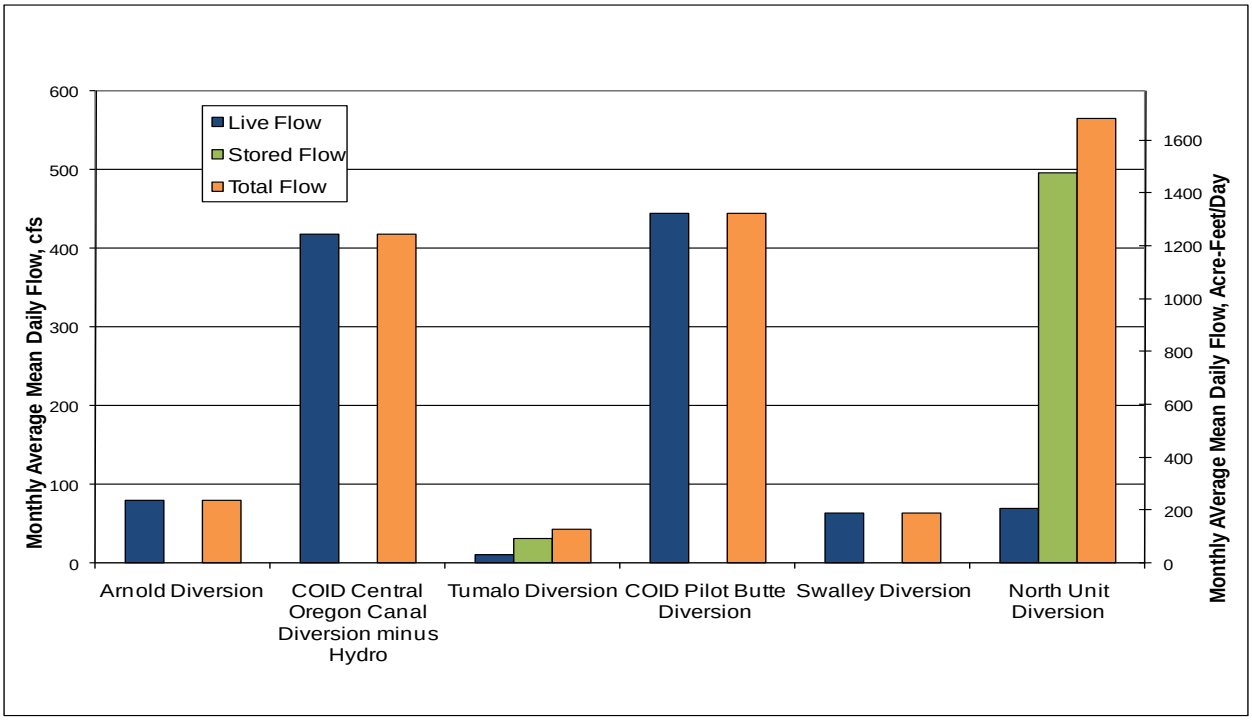


Figure 4.4-13B. Irrigation diversions for May 15-31, 2010.

Table 4.4-12. Irrigation diversion impacts on Deschutes River flow for May 15-31, 2010.

May 15-31, 2010									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		59719			1771				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		59719	41920	17800	1243	528	1771		
Arnold Diversion		2684	2684	0	80	0	80		
Flow Below Arnold Diversion		57035	39236	17800	1164	528	1691		
COID Central Oregon Canal Diversion including Hydro	Note: 463 ac-ft later diverted into North Unit Main Canal	27987	27987	0	830	0	830		
Flow Between COID Diversion and Hydro Return Discharge		29049	11249	17800	334	528	861		
COID Central Oregon Canal Diversion minus Hydro		14110	14110	0	418	0	418		
Flow Below COID Hydro Return Discharge		42925	25125	17800	745	528	1273		
Tumalo Diversion		1443	374	1070	11	32	43		
Flow Below Tumalo Diversion		41482	24752	16730	734	496	1230		
COID Pilot Butte Diversion	Note: 1419 ac-ft later diverted into Lone Pine Canal	14979	14979	0	444	0	444		
Swalley Diversion		2157	2157	0	64	0	64		
North Unit Diversion		19067	2337	16730	69	496	565		
Deschutes River Below Bend		5278	5278	0	157	0	157	1000	1280

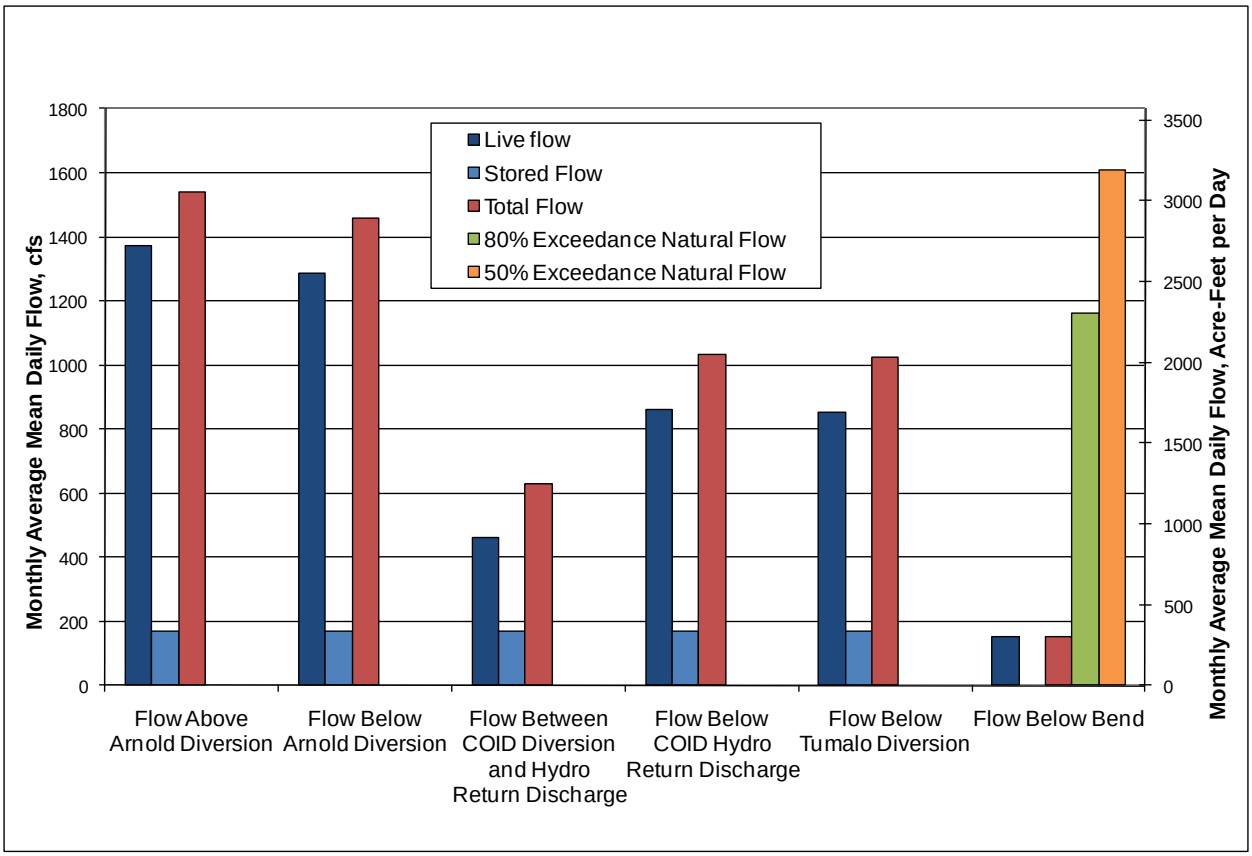


Figure 4.4-14A. Irrigation diversion impacts on Deschutes River flows for June 2010.

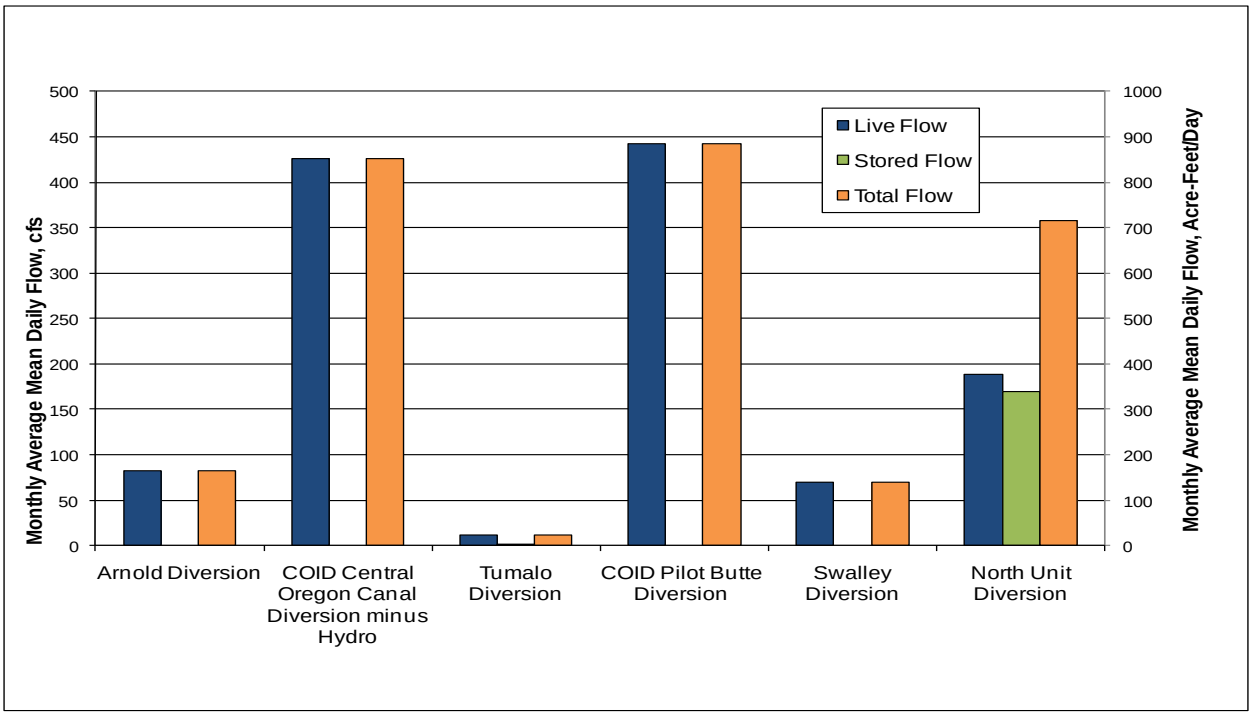


Figure 4.4-14B. Irrigation diversions for June 2010.

Table 4.4-13. Irrigation diversion impacts on Deschutes River flow for June, 2010.

June, 2010									
Deschutes River Flow or Diversion as Indicated	Notes	Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		91691			1541				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		91691	81549	10142	1370	170	1541		
Arnold Diversion		4870	4870	0	82	0	82		
Flow Below Arnold Diversion		86821	76680	10142	1289	170	1459		
COID Central Oregon Canal Diversion including Hydro	Note: 689 ac-ft later diverted into North Unit Main Canal	49291	49291	0	828	0	828		
Flow Between COID Diversion and Hydro Return Discharge		37530	27388	10142	460	170	631		
COID Central Oregon Canal Diversion minus Hydro		25363	25363	0	426	0	426		
Flow Below COID Hydro Return Discharge		61459	51317	10142	862	170	1033		
Tumalo Diversion		701	659	42	11	1	12		
Flow Below Tumalo Diversion		60758	50658	10100	853	170	1023		
COID Pilot Butte Diversion	Note: 2297 ac-ft later diverted into Lone Pine Canal	26297	26297	0	442	0	442		
Swalley Diversion		4147	4147	0	70	0	70		
North Unit Diversion		21291	11191	10100	188	170	358		
Flow Below Bend		9023	9023	0	153	0	153	1160	1610

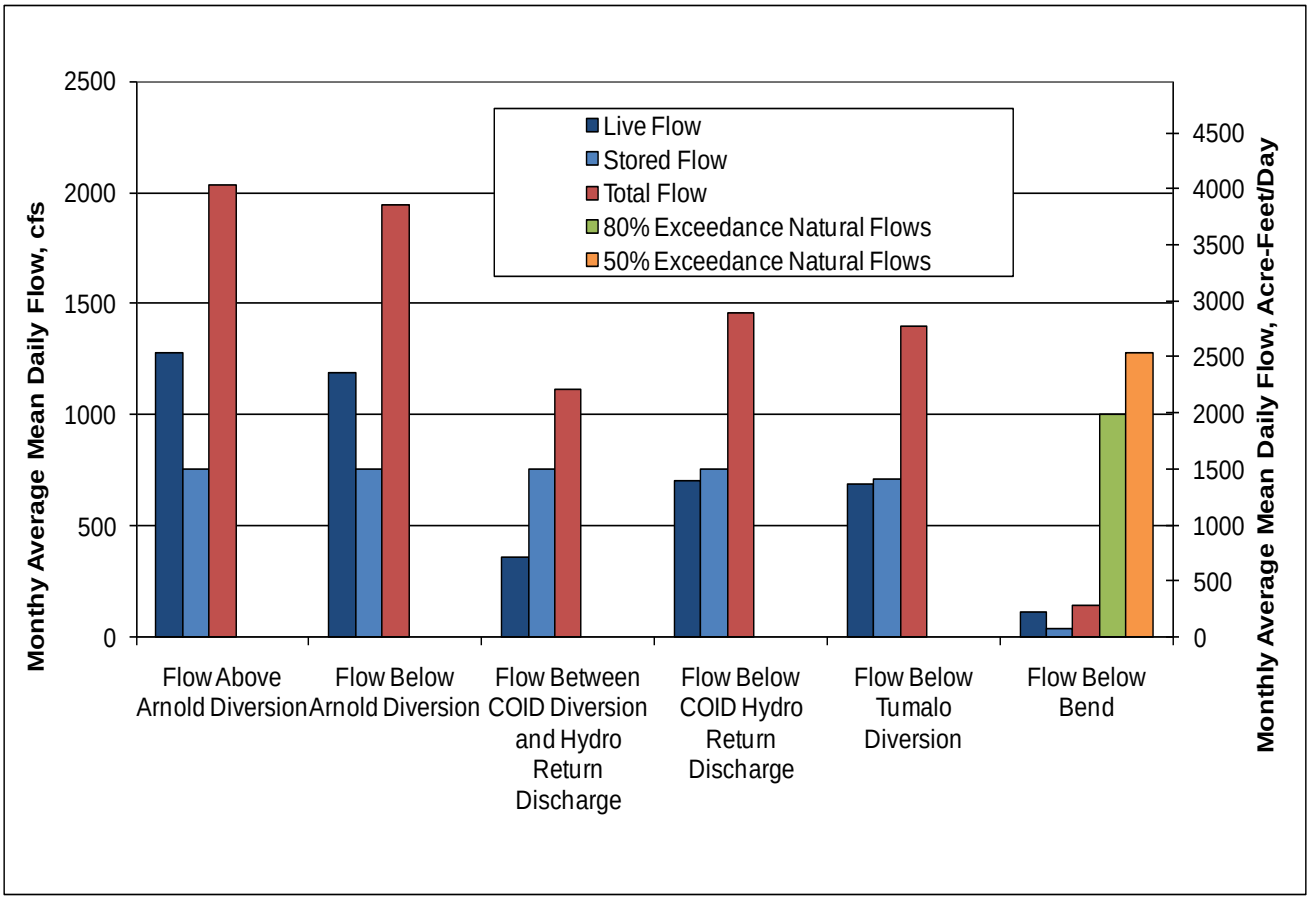


Figure 4.4-15A. Irrigation diversion impacts on Deschutes River flows for July 2010.

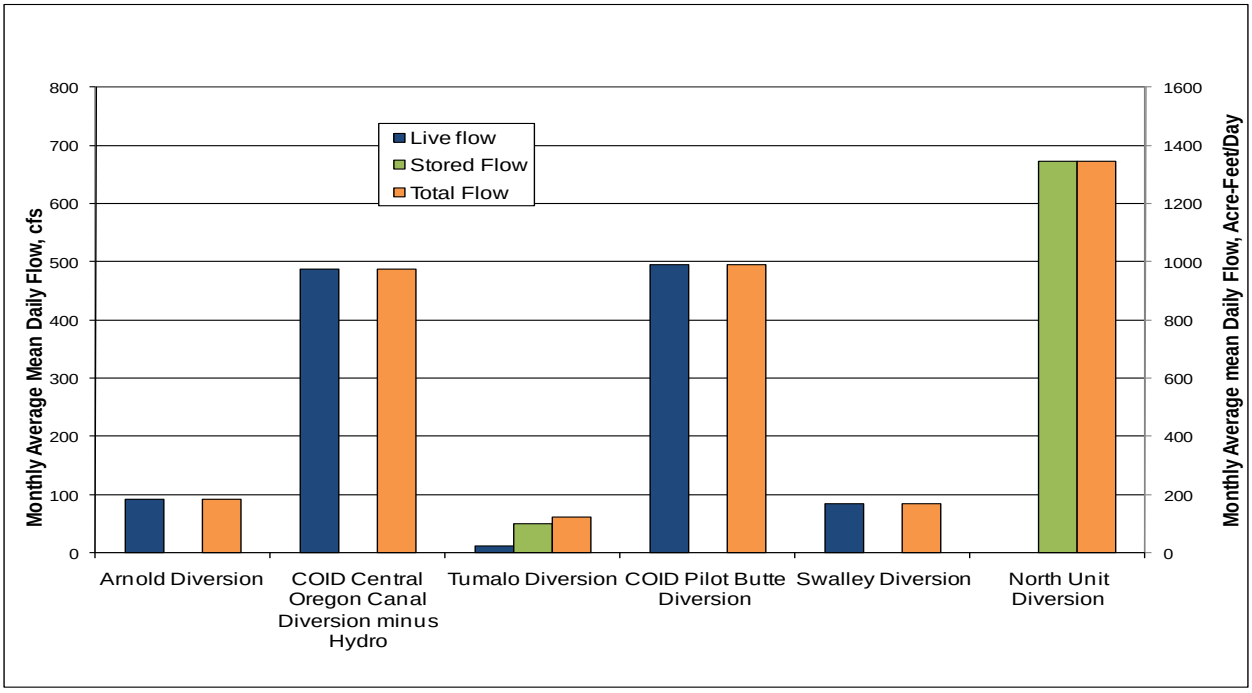


Figure 4.4-15B. Irrigation diversions for July 2010.

Table 4.4-14. Irrigation diversion impacts on Deschutes River flow for July, 2010.

July, 2010									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		125270			2037				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		125270	78690	46580	1280	758	2037		
Arnold Diversion		5591	5591	0	91	0	91		
Flow Below Arnold Diversion		119679	73099	46580	1189	758	1946		
COID Central Oregon Canal Diversion including Hydro	Note: 186 ac-ft later diverted into North Unit Main Canal	51035	51035	0	830	0	830		
Flow Between COID Diversion and Hydro Return Discharge		68644	22064	46580	359	758	1116		
COID Central Oregon Canal Diversion minus Hydro		29976	29976	0	488	0	488		
Flow Below COID Hydro Return Discharge		89703	43123	46580	701	758	1459		
Tumalo Diversion		3759	681	3078	11	50	61		
Flow Below Tumalo Diversion		85943	42442	43502	690	707	1398		
COID Pilot Butte Diversion	Note: 3422 ac-ft later diverted into Lone Pine Canal	30476	30476	0	496	0	496		
Swalley Diversion		5151	5151	0	84	0	84		
North Unit Diversion		41401	0	41401	0	673	673		
Flow Below Bend		8916	6815	2101	111	34	145	1000	1280

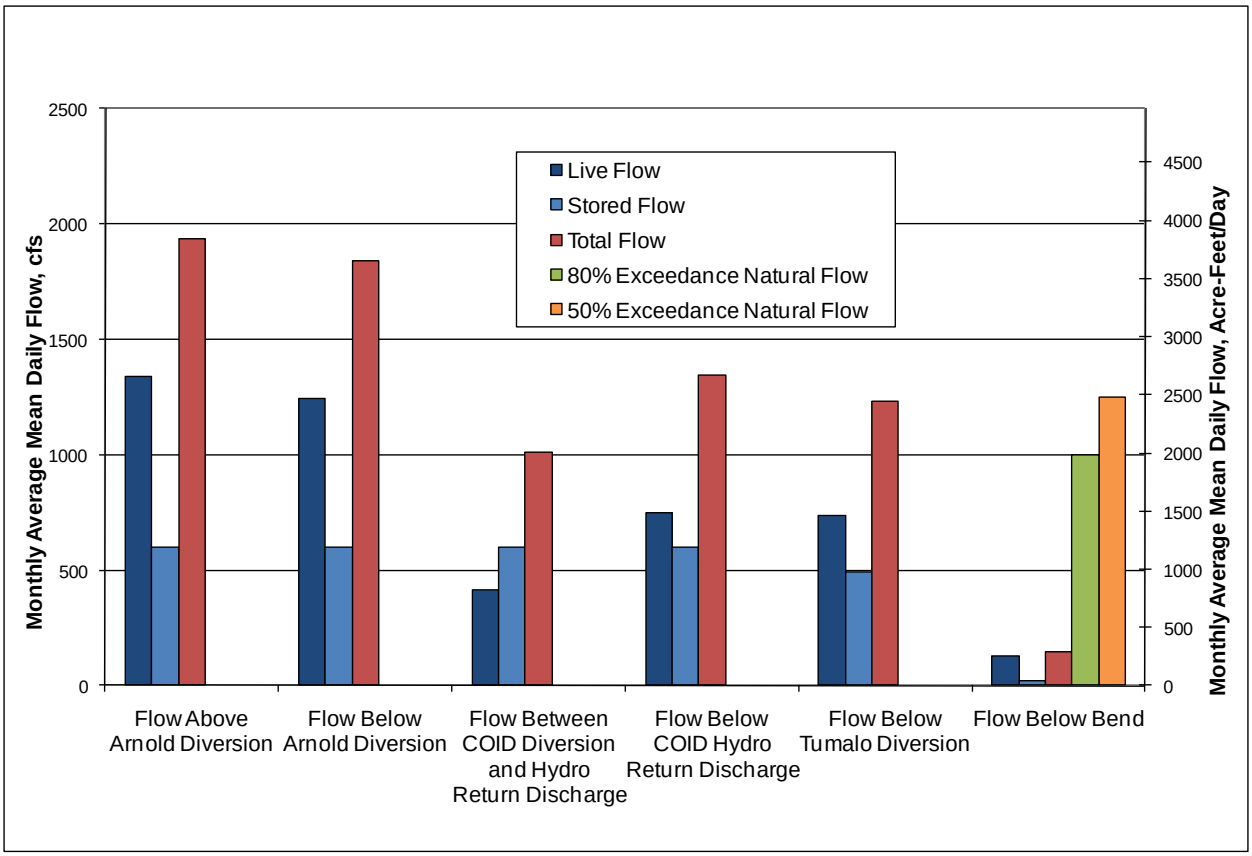


Figure 4.4-16A. Irrigation diversion impacts on Deschutes River flows for August 2010.

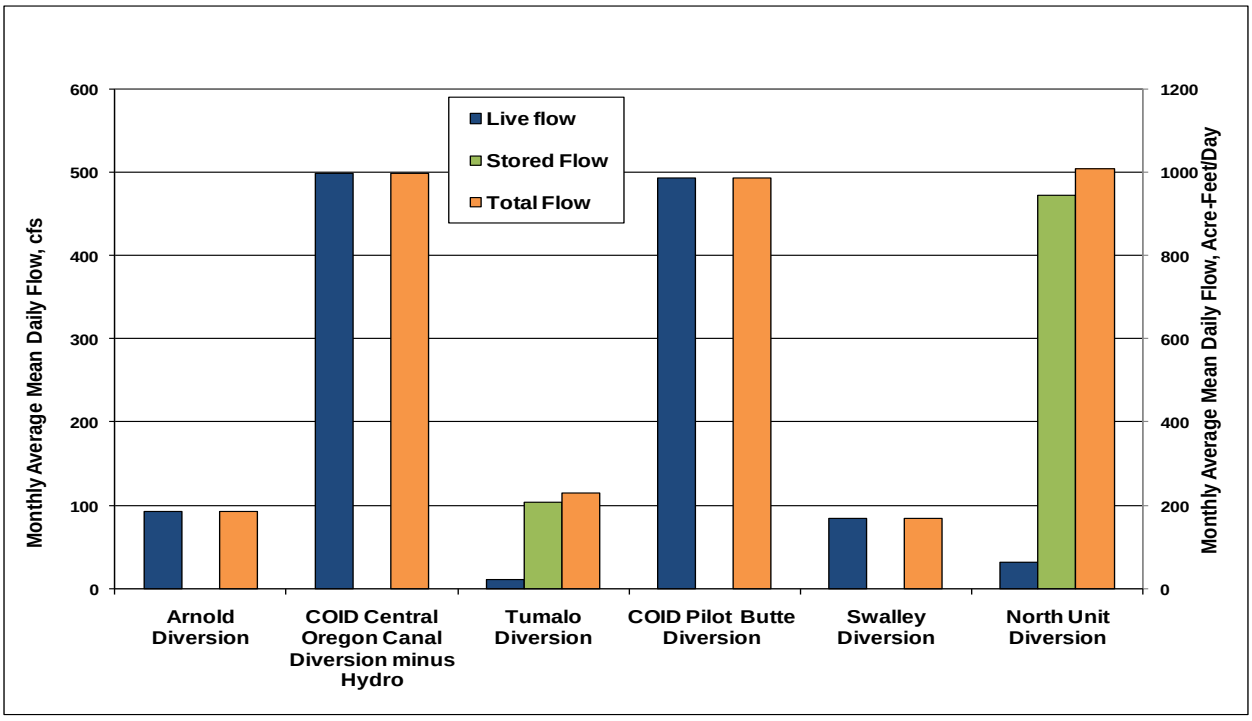


Figure 4.4-16B. Irrigation diversions for August 2010.

Table 4.4-15. Irrigation diversion impacts on Deschutes River flow for August, 2010.

August, 2010									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		118971			1935				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		118971	82189	36782	1337	598	1935		
Arnold Diversion		5671	5671	0	92	0	92		
Flow Below Arnold Diversion		113300	76518	36782	1244	598	1843		
COID Central Oregon Canal Diversion including Hydro	Note: 471 ac-ft later diverted into North Unit Main Canal	51035	51035	0	830	0	830		
Flow Between COID Diversion and Hydro Return Discharge		62265	25483	36782	414	598	1013		
COID Central Oregon Canal Diversion minus Hydro		30619	30619	0	498	0	498		
Flow Below COID Hydro Return Discharge		82681	45899	36782	746	598	1345		
Tumalo Diversion		7085	681	6404	11	104	115		
Flow Below Tumalo Diversion		75596	45218	30378	737	494	1229		
COID Pilot Butte Diversion	Note: 3162 ac-ft later diverted into Lone Pine Canal	30351	30351	0	494	0	494		
Swalley Diversion		5165	5165	0	84	0	84		
North Unit Diversion		31027	1951	29076	32	473	505		
Flow Below Bend		9053	7752	1301	126	21	147	1000	1250

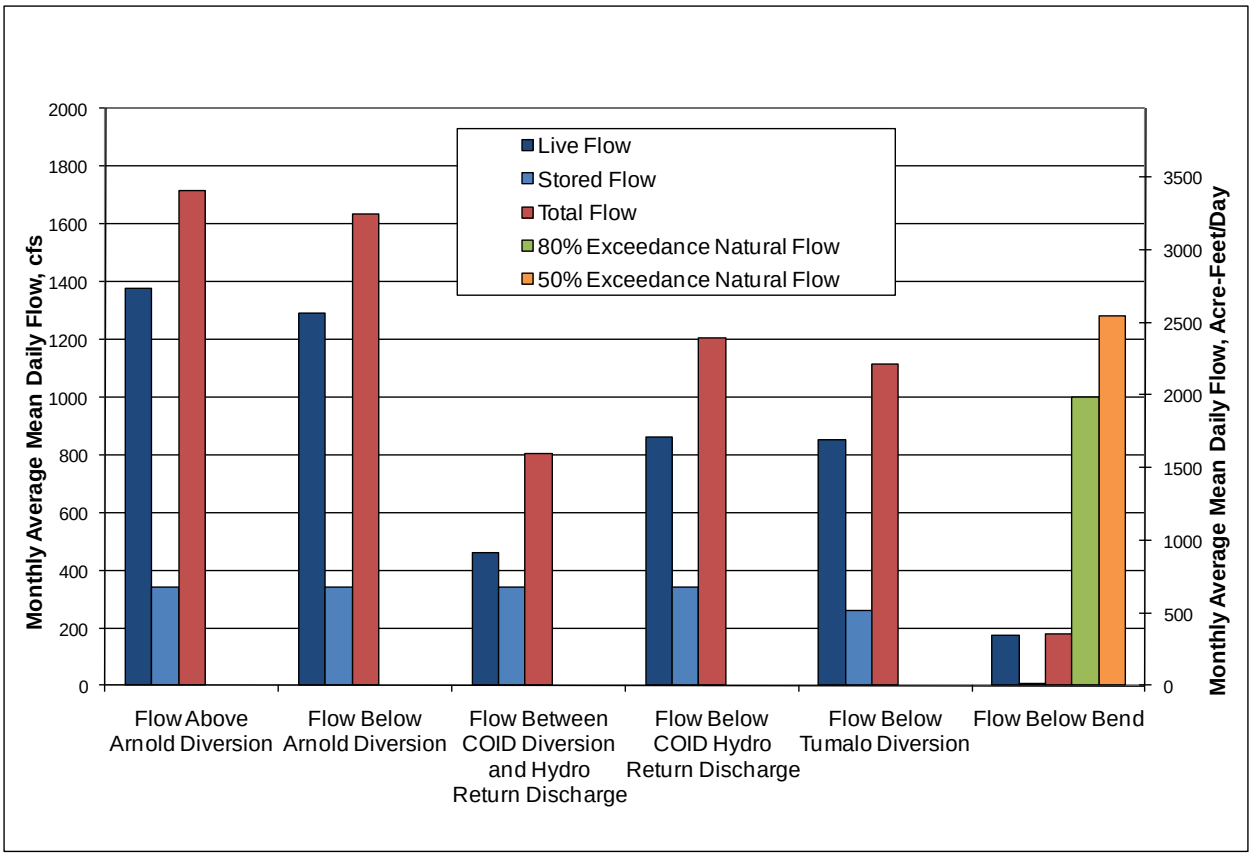


Figure 4.4-17A. Irrigation diversion impacts on Deschutes River flow for September 1-14, 2010.

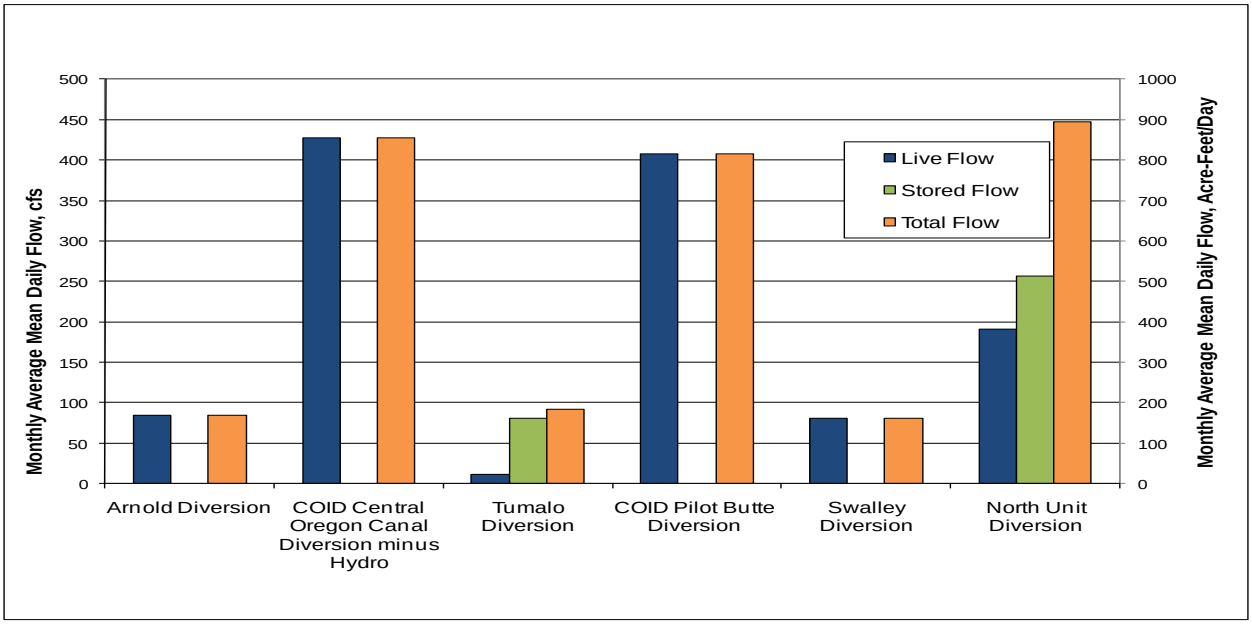


Figure 4.4-17B. Irrigation diversion for September 1-14, 2010

Table 4.4-16. Irrigation diversion impacts on Deschutes River flow for September 1-14, 2010.

September 1-14, 2010									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		47713			1718				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		47713	38212	9501	1376	342	1718		
Arnold Diversion		2362	2362	0	85	0	85		
Flow Below Arnold Diversion		45351	35850	9501	1291	342	1633		
COID Central Oregon Canal Diversion including Hydro	Note: 303 ac-ft later diverted into North Unit Main Canal	23048	23048	0	830	0	830		
Flow Between COID Diversion and Hydro Return Discharge		22304	12802	9501	461	342	803		
COID Central Oregon Canal Diversion minus Hydro		11881	11881	0	428	0	428		
Flow Below COID Hydro Return Discharge		33470	23969	9501	863	342	1205		
Tumalo Diversion		2535	308	2227	11	80	91		
Flow Below Tumalo Diversion		30935	23662	7274	852	262	1114		
COID Pilot Butte Diversion	Note: 960 ac-ft later diverted into Lone Pine Canal	11314	11314	0	407	0	407		
Swalley Diversion		2256	2256	0	81	0	81		
North Unit Diversion		12405	5292	7112	191	257	447		
Flow Below Bend		4961	4799	161	173	6	179	1000	1280

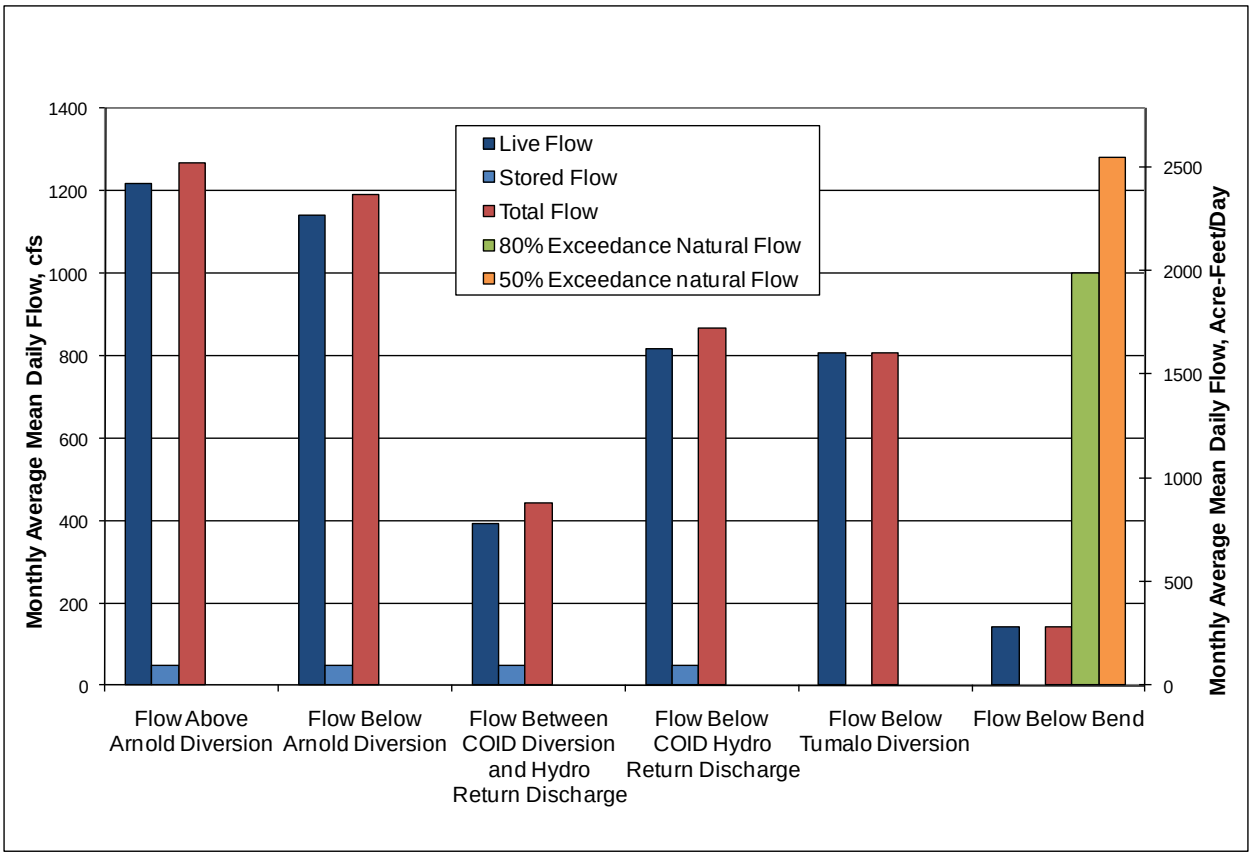


Figure 4.4-18A. Irrigation diversion impacts on Deschutes River flows for September 15-30, 2010.

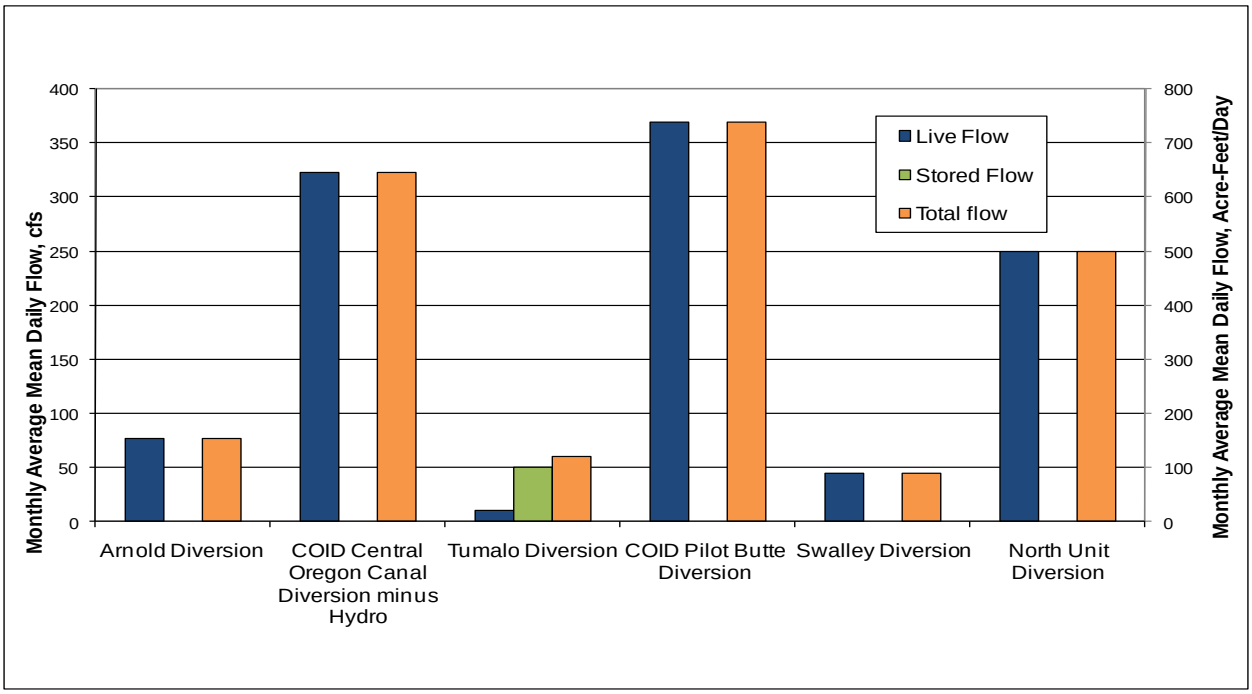


Figure 4.4-18B. Irrigation diversions for September 15-30, 2010.

Table 4.4-17. Irrigation diversion impacts on Deschutes River flow for September 15-30, 2010.

September 15-30, 2010									
Deschutes River Flow or Diversion as Indicated		Total Monthly Flow, acre-ft			Monthly Mean Daily Flow, cfs			Natural Flow	
		40208			1267				
		Diverted Flow	Live Flow	Stored Flow	Live Flow	Stored Flow	Total Flow	80% Exceedance	50% Exceedance
Flow Above Arnold Diversion		40208	38626	1582	1217	50	1267		
Arnold Diversion		2428	2428	0	77	0	77		
Flow Below Arnold Diversion		37780	36198	1582	1141	50	1190		
COID Central Oregon Canal Diversion including Hydro	Note: 329 ac-ft later diverted into North Unit Main Canal	23744	23744	0	748	0	748		
Flow Between COID Diversion and Hydro Return Discharge		14036	12454	1582	392	50	442		
COID Central Oregon Canal Diversion minus Hydro		10251	10251	0	323	0	323		
Flow Below COID Hydro Return Discharge		27530	25948	1582	818	50	867		
Tumalo Diversion		1926	344	1582	11	50	61		
Flow Below Tumalo Diversion		25604	25604	0	807	0	807		
COID Pilot Butte Diversion	Note: 646 ac-ft later diverted into Lone Pine Canal	11728	11728	0	370	0	370		
Swalley Diversion		1431	1431	0	45	0	45		
North Unit Diversion		7934	7934	0	250	0	250		
Flow Below Bend		4510	4510	0	142	0	142	1000	1280

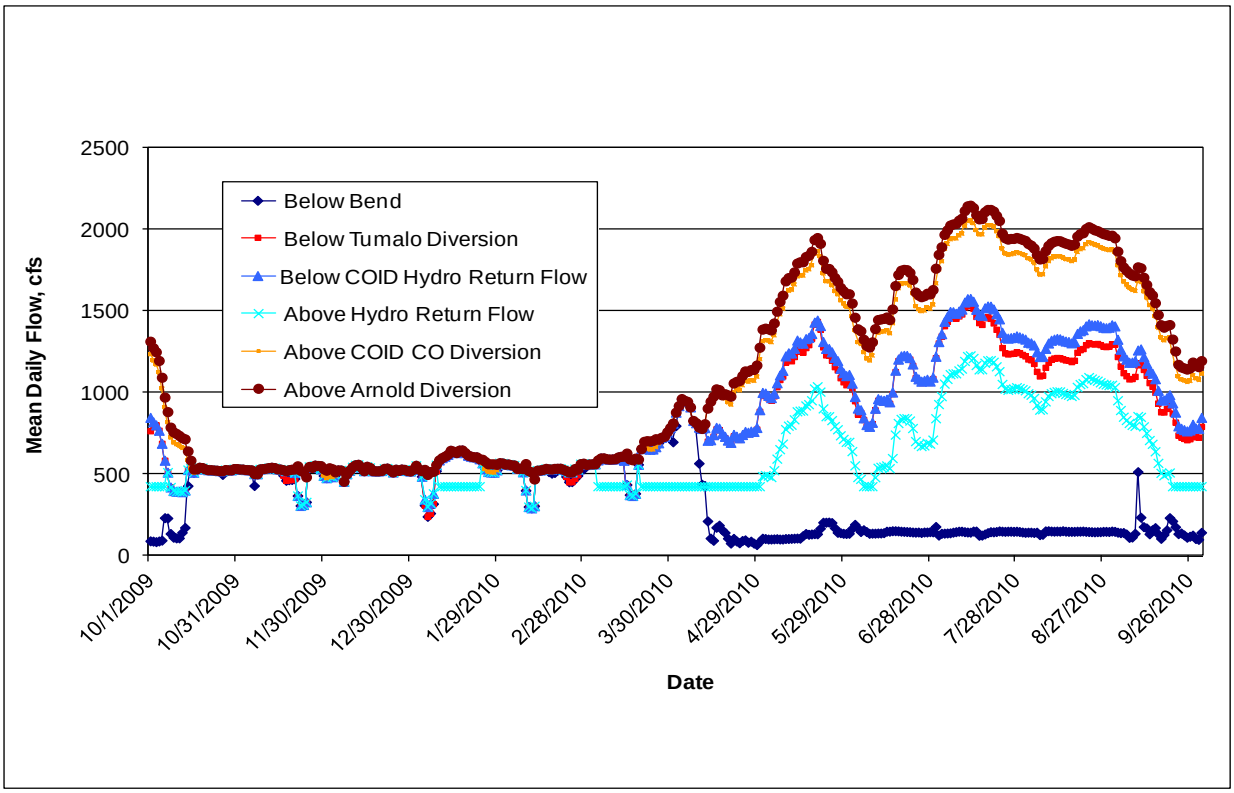


Figure 4.4-19. Deschutes River daily mean flow as a result of irrigation diversions at and above Bend in 2010.

Figure 4.4-20 and Table 4.4-18 show the statistics for the monthly average flows for the periods for the Deschutes River flow below Bend for 1971 through 2010 and Figure 4.4-21 and Table 4.4-19 show similar statistics for 2001 through2010. Figure 4.4-22 shows the monthly average mean daily flows for the Deschutes River Irrigation Diversions and the Deschutes River flow both above and below the diversions for Water Years 2001 to 2010. Table 4.4-20 is a tabular representation of Figure 4.4-22.

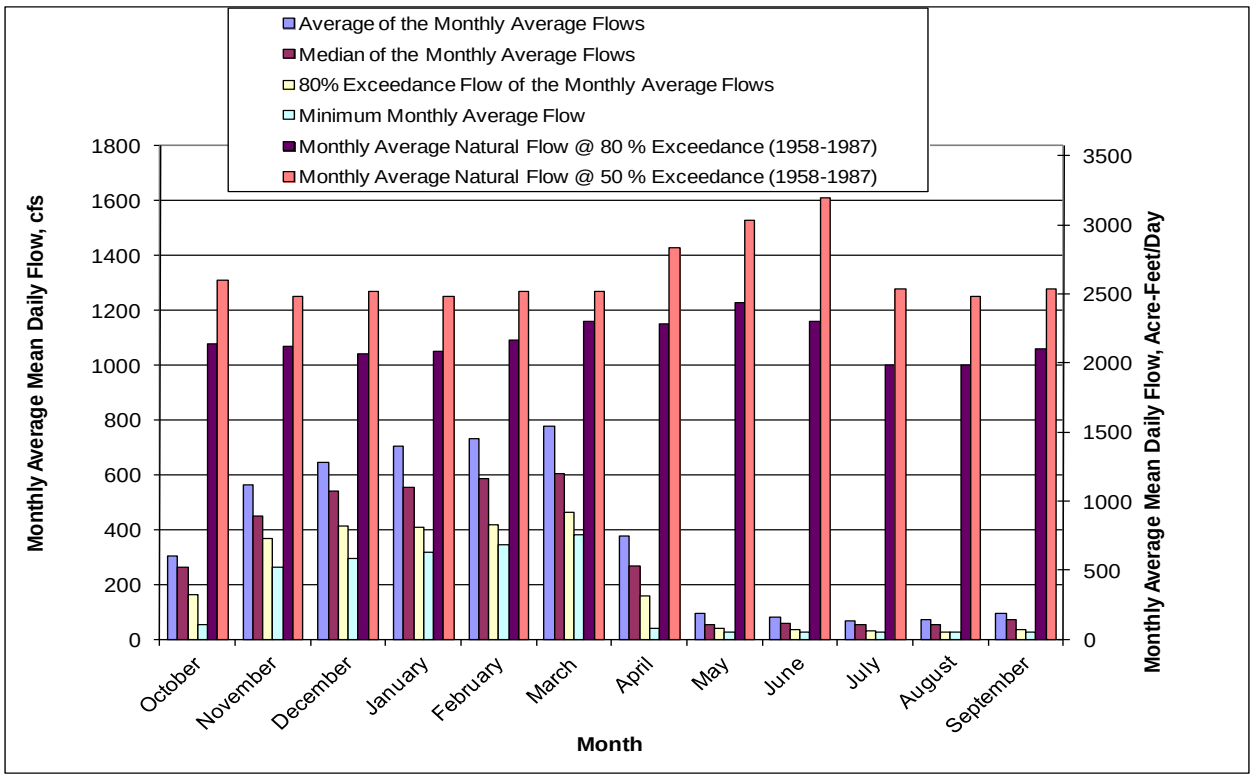


Figure 4.4-20. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 1971 through 2010.

Table 4.4-18. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 1971 through 2010 (cubic feet per second).

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance Flow of the Monthly Average Flows	Minimum Monthly Average Flow	Monthly Average Natural Flow @ 80 % Exceedance (1958-1987)	Monthly Average Natural Flow @ 50 % Exceedance (1958-1987)
October	304	265	162	54	1080	1310
November	564	450	368	265	1070	1250
December	647	540	412	293	1040	1270
January	703	554	410	318	1050	1250
February	734	588	419	346	1090	1270
March	777	603	466	382	1160	1270
April	376	269	158	41	1150	1430
May	93	55	42	27	1230	1530
June	81	58	34	26	1160	1610
July	68	55	31	27	1000	1280
August	72	54	29	25	1000	1250
September	96	74	34	25	1060	1280

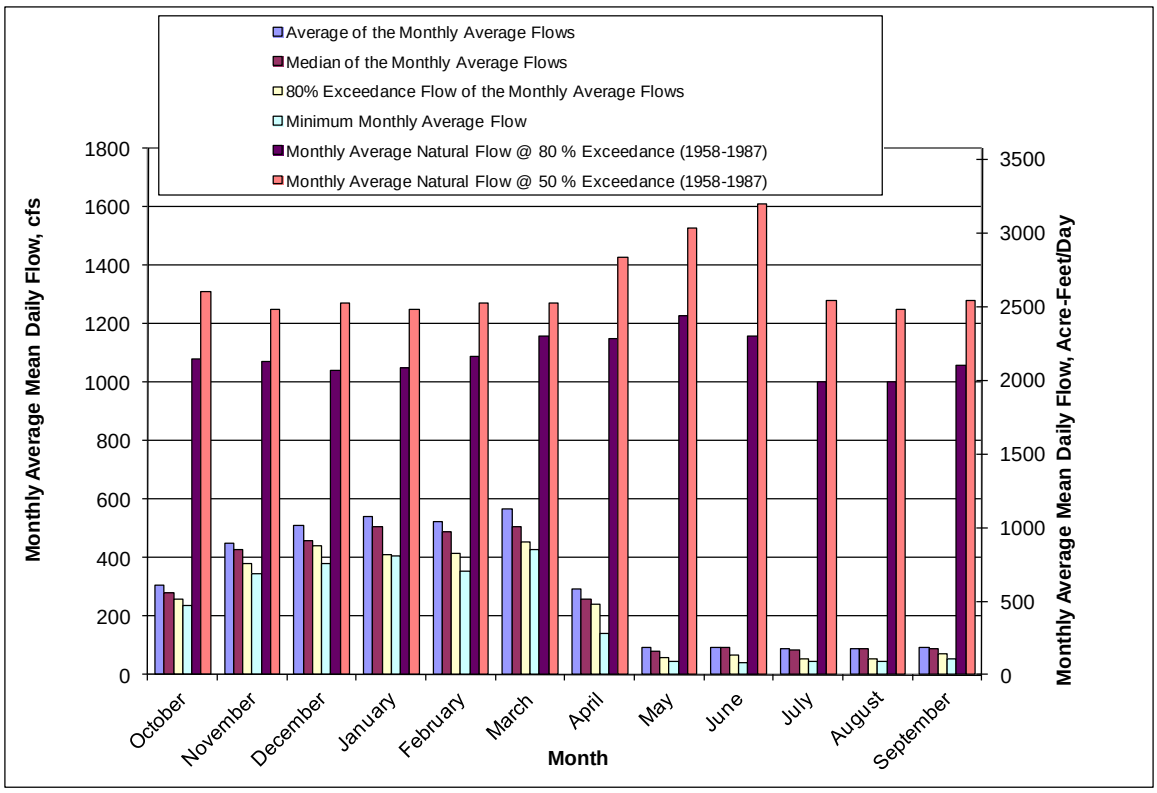


Figure 4.4-21. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 2001 through 2010.

Table 4.4-19. Statistics of the monthly average mean daily flow for the Deschutes River below Bend for Water Years 2001 through 2010 (cubic feet per second).

Month	Average of the Monthly Average Flows	Median of the Monthly Average Flows	80% Exceedance Flow of the Monthly Average Flows	Minimum Monthly Average Flow	Monthly Average Natural Flow @ 80 % Exceedance (1958-1987)	Monthly Average Natural Flow @ 50 % Exceedance (1958-1987)
October	305	279	260	236	1080	1310
November	448	428	382	345	1070	1250
December	510	458	439	380	1040	1270
January	540	508	410	406	1050	1250
February	523	488	416	354	1090	1270
March	567	505	452	430	1160	1270
April	293	261	241	141	1150	1430
May	93	81	59	45	1230	1530
June	94	95	68	42	1160	1610
July	90	86	56	47	1000	1280
August	90	89	54	47	1000	1250
September	92	88	70	53	1060	1280

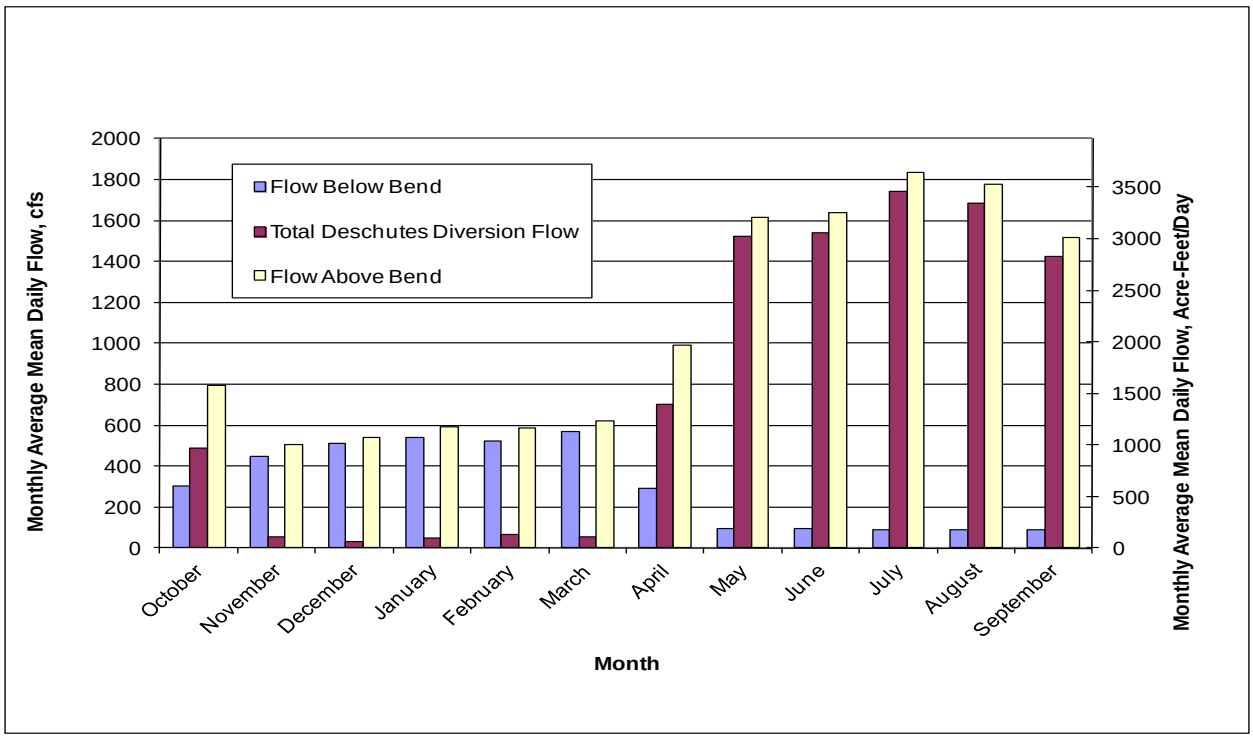


Figure 4.4-22. Monthly average mean daily flows for Deschutes River for Water Years 2001 through 2010.

Table 4.4-20. Monthly average mean daily flows for Deschutes River for Water Years 2001 through 2010 (cubic feet per second).

Month	Flow Below Bend	Total Deschutes Diversion Flow	Flow Above Bend
October	305	489	794
November	448	57	505
December	510	31	541
January	540	51	591
February	523	64	587
March	567	56	623
April	293	700	993
May	93	1522	1615
June	94	1543	1637
July	90	1743	1833
August	90	1687	1777
September	92	1425	1517

The preceding graphs and tables likely do not indicate the progress achieved by the Districts in conserving water and increasing flow in the Deschutes River. The following three figures are intended to better demonstrate this progress. Figure 4.4-23 shows the minimum August flow in the Deschutes River below Bend for Water Years 1971 through 2010.

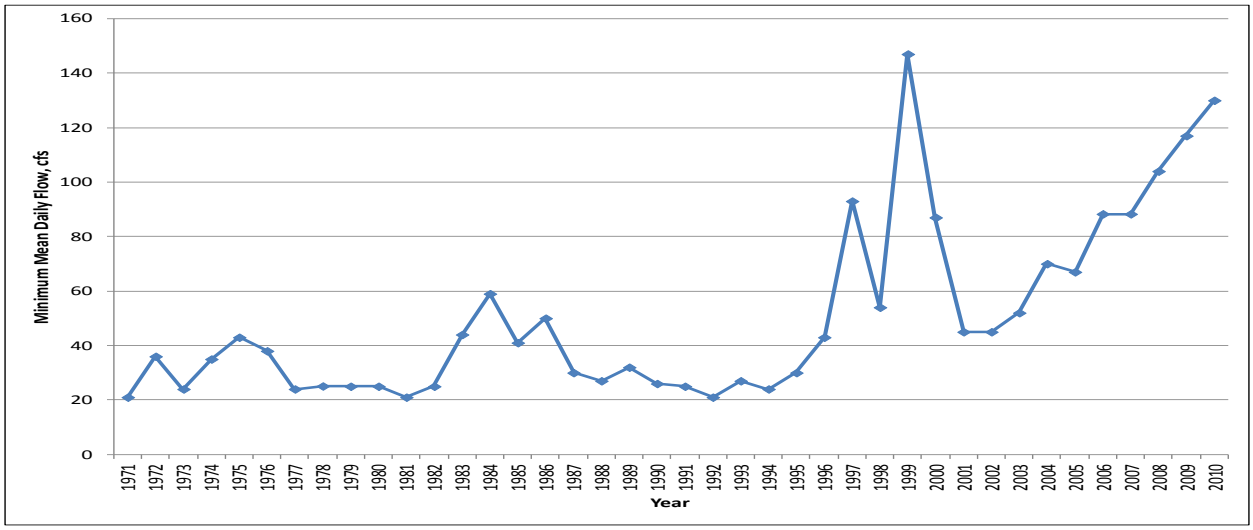


Figure 4.4-23. Deschutes River below Bend, August minimum mean daily flow for water years 1971-2010

Figure 4.4-24 shows the reduction in diverted flow by the Districts since 1966. This graph shows the districts diverting water from the Crooked River as well.

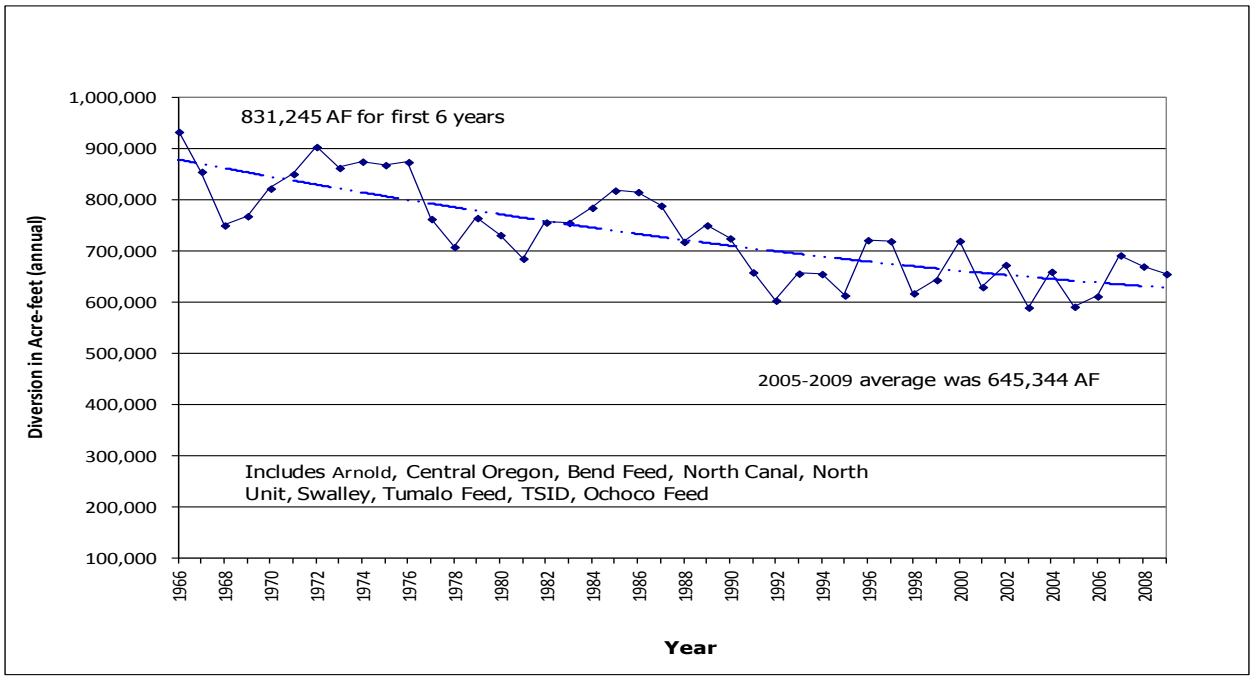


Figure 4.4-24. Total district diversions by districts in upper Deschutes and Crooked River sub-basins.

Figure 4.4-25 shows the gaged flow of the Deschutes River at Madras compared to the in-stream water right at that location for March 13, 2008 through November 7, 2011.

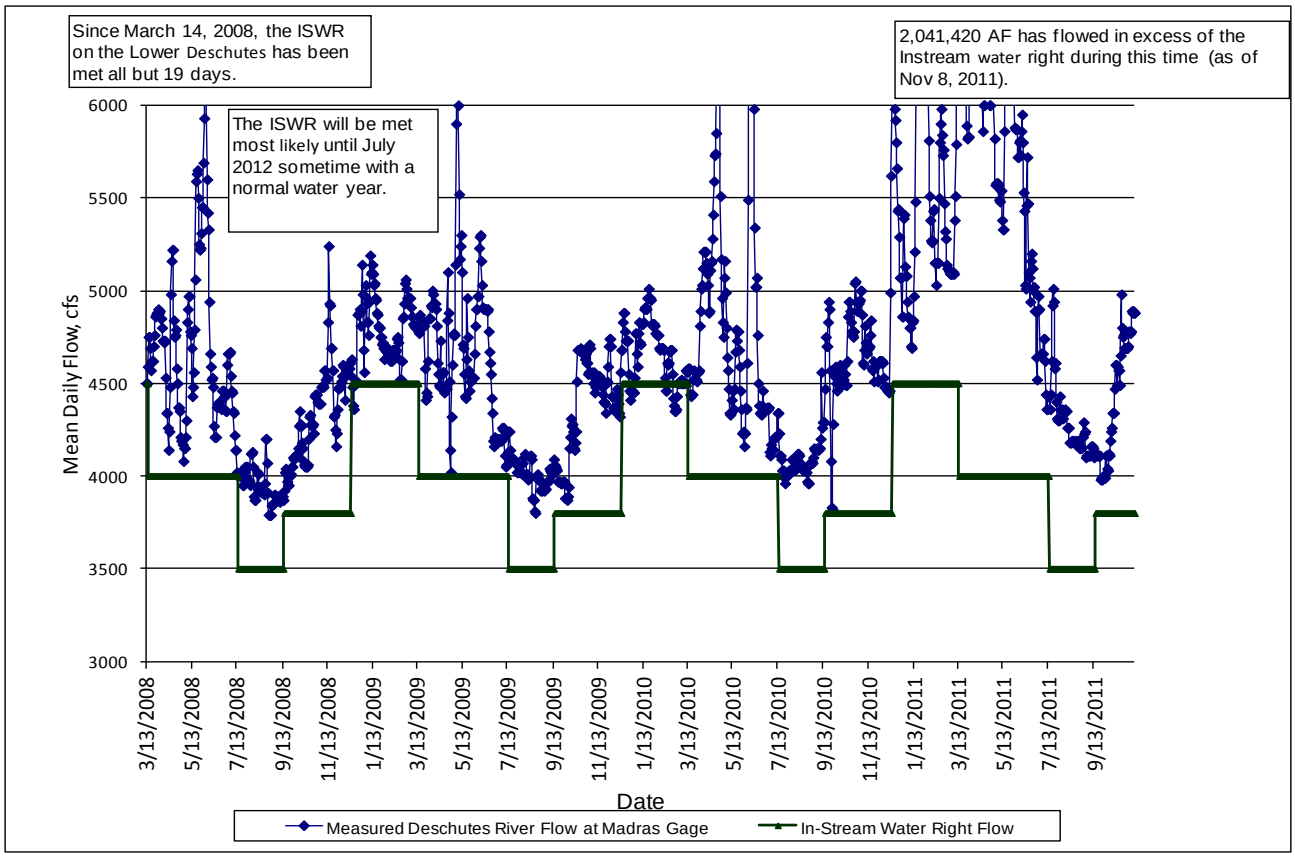


Figure 4.4-25. Measured Deschutes River flow at Madras gage compared to in-stream water right March, 2008 – November, 2011.

The following districts have periodic stock runs during the non-irrigation period from November through March: COID (both canals), Swalley, Arnold, and Tumalo. North Unit does not have stock runs. The stock runs are river diversions generally lasting for 4 to 5 days that provide water for district patrons to refill stock ponds. Tables 4.4-21 thorough 4.4-25 are statistical summaries of the non-irrigation season stock runs for the districts that conduct them for Water Years 2001 through 2010.

Table 4.4-21. Monthly Statistics of Stock Runs for Arnold Irrigation District Canal, Water Years 2001-2010

Month	Monthly Average Mean Daily Flow During Stock Run, cfs	Maximum Daily Mean Flow During Stock Run, cfs	Average Number of Days of Stock Runs Per Month	Maximum Number of Days of Stock Runs Per Month	# of Times since 2001 Water Year that a Stock Run Occurred in this Month
Novembe	32	53	4.8	6	10
Decembe	36	50	5.5	8	6
January	30	51	6.3	10	7
February	29	47	5.1	6	7
March	37	55	6.1	7	8

Table 4.4-22. Monthly statistics of stock runs for COID central Oregon canal, water years 2001-2010.

Month	Monthly Average Mean Daily Flow During Stock Run, cfs	Maximum Daily Mean Flow During Stock Run, cfs	Average Number of Days of Stock Runs Per Month	Maximum Number of Days of Stock Runs Per Month	# of Times since 2001 Water Year that a Stock Run Occurred in this Month
November	183	271	4.4	5	10
December	171	249	5.25	6	4*
January	166	251	4	5	9
February	165	257	5	8	10
March	182	264	5	6	9
*Note: COID has not had a stock run in December for this diversion since 2005.					

Table 4.4-23. Monthly statistics of stock runs for COID Pilot Butte canal, water years 2001-2010.

Month	Monthly Average Mean Daily Flow During Stock Run, cfs	Maximum Daily Mean Flow During Stock Run, cfs	Average Number of Days of Stock Run Per Month	Maximum Number of Days of Stock Run Per Month	# of Times since 2001 Water Year that a Stock Run Occurred in this Month
November	166	207	5	7	8
December	151	205	5	7	5*
January	155	204	5	6	8
February	157	218	5	6	9
March	164	224	4	5	9
*Note: COID has not had a stock run in December for this diversion since 2005.					

Table 4.4-24. Monthly statistics of stock runs for Tumalo Irrigation District canal, water years 2001-2010

Month	Monthly Average Mean Daily Flow During Stock Run, cfs	Maximum Daily Mean Flow During Stock Run, cfs	Average Number of Days of Stock Run Per Month	Maximum Number of Days of Stock Run Per Month	# of Times since 2001 Water Year that a Stock Run Occurred in this Month
November	50.6	63.0	5.0	5.0	1.0
December	0.0	0.0	0.0	0.0	0.0
January	43.4	63.0	5.5	6.0	2.0
February	35.7	60.0	7.5	9.0	2.0
March	0.0	0.0	0.0	0.0	0.0

Table 4.4-25. Monthly statistics of stock runs for Swalley Irrigation District canal, water years 2001-2010

Month	Monthly Average Mean Daily Flow During Stock Run, cfs	Maximum Daily Mean Flow During Stock Run, cfs	Average Number of Days of Stock Runs Per Month	Maximum Number of Days of Stock Runs Per Month	# of Times since 2001 Water Year that a Stock Run Occurred in this Month
November	27	53	4	4	3
December	40	84	3	4	7
January	36	54	3	4	5
February	33	53	5	7	3
March	34	54	4	5	8

Literature Cited

Reference

Cooper, R. M. 2004. Determining surface water availability in Oregon. Open File Report SW 02-002. State of Oregon Water Resources Department, Salem, OR. 158 pp.
Available at www.wrd.state.or.us/OWRD/SW/index.shtml

APPENDIX A – MAPS OF THE DIVERSIONS

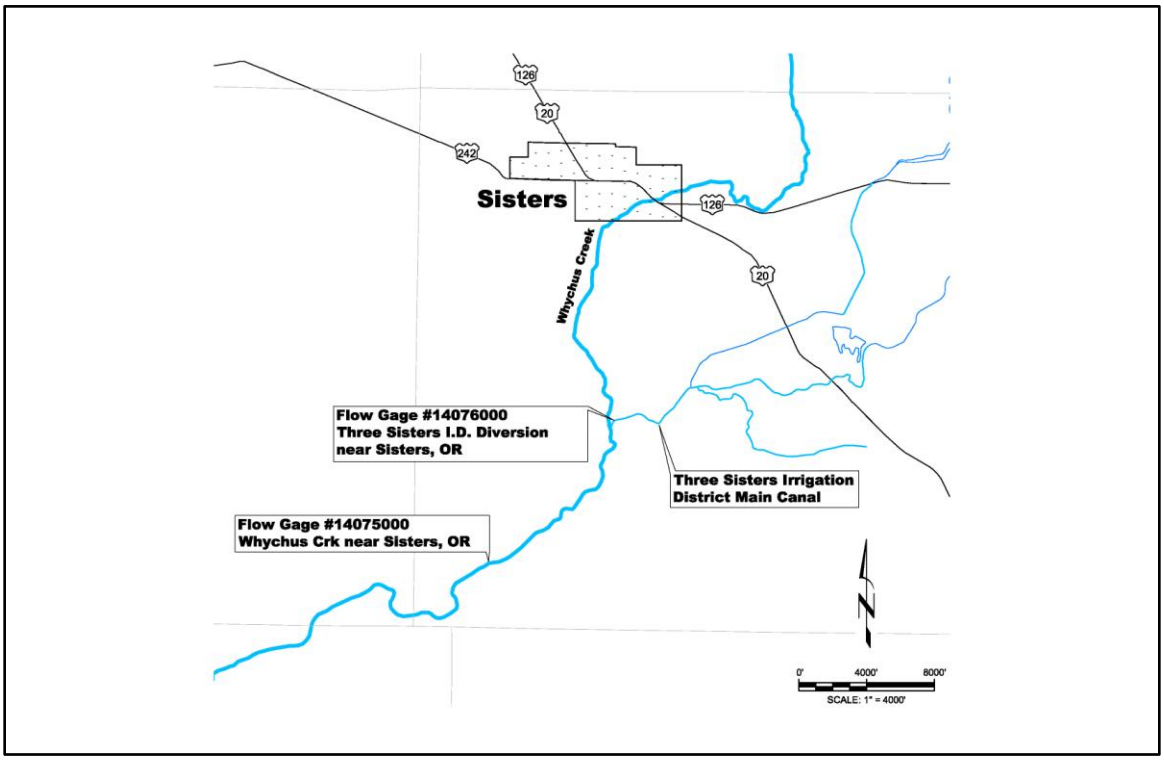


Figure A-1. Map of Whychus Creek gage station No. 14075000 and Three Sisters Diversion Canal gage station No. 14076000.

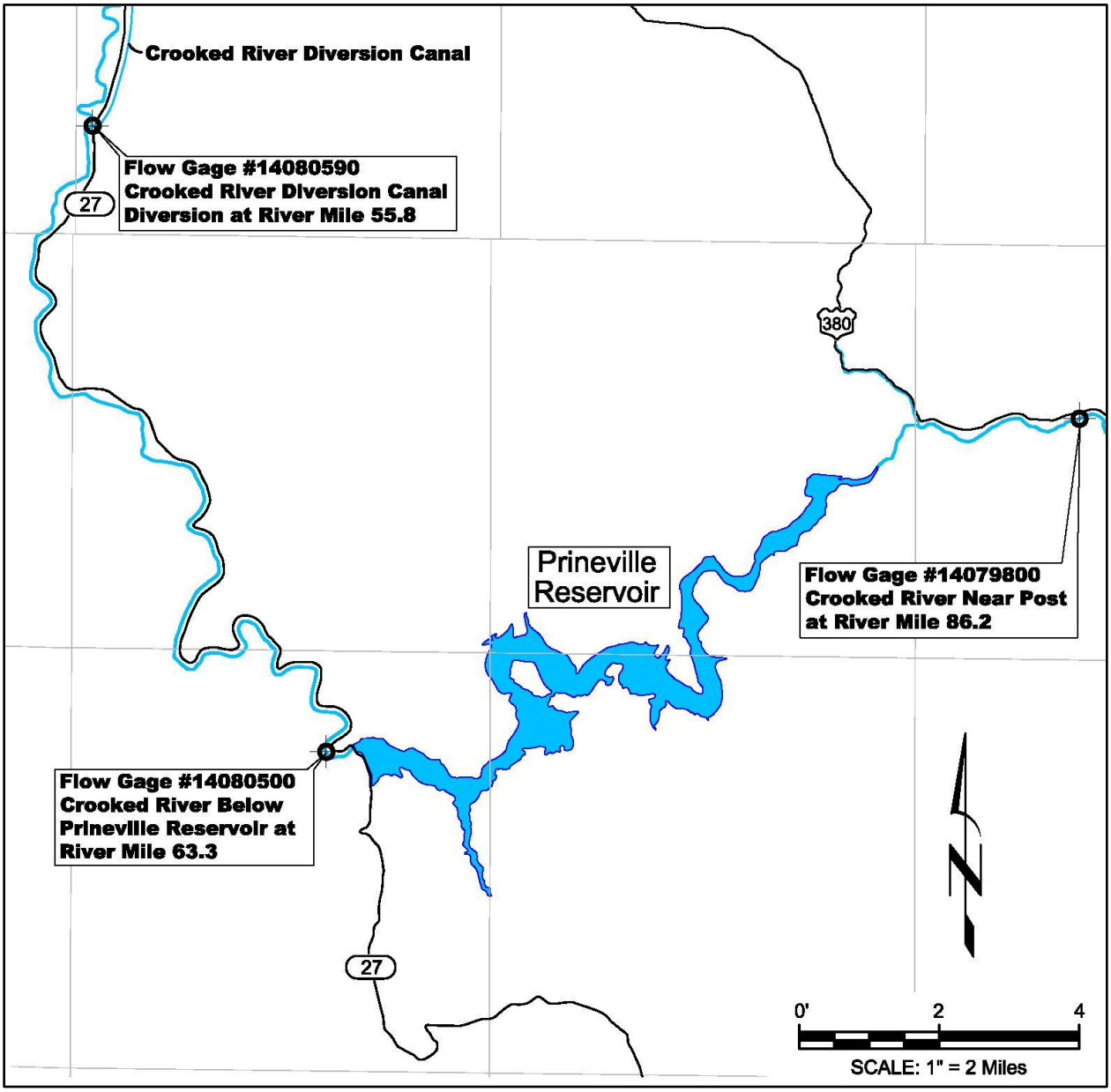


Figure A-2. **Map of river and diversion canal gages for Crooked River Diversion Canal flow effect analysis.**

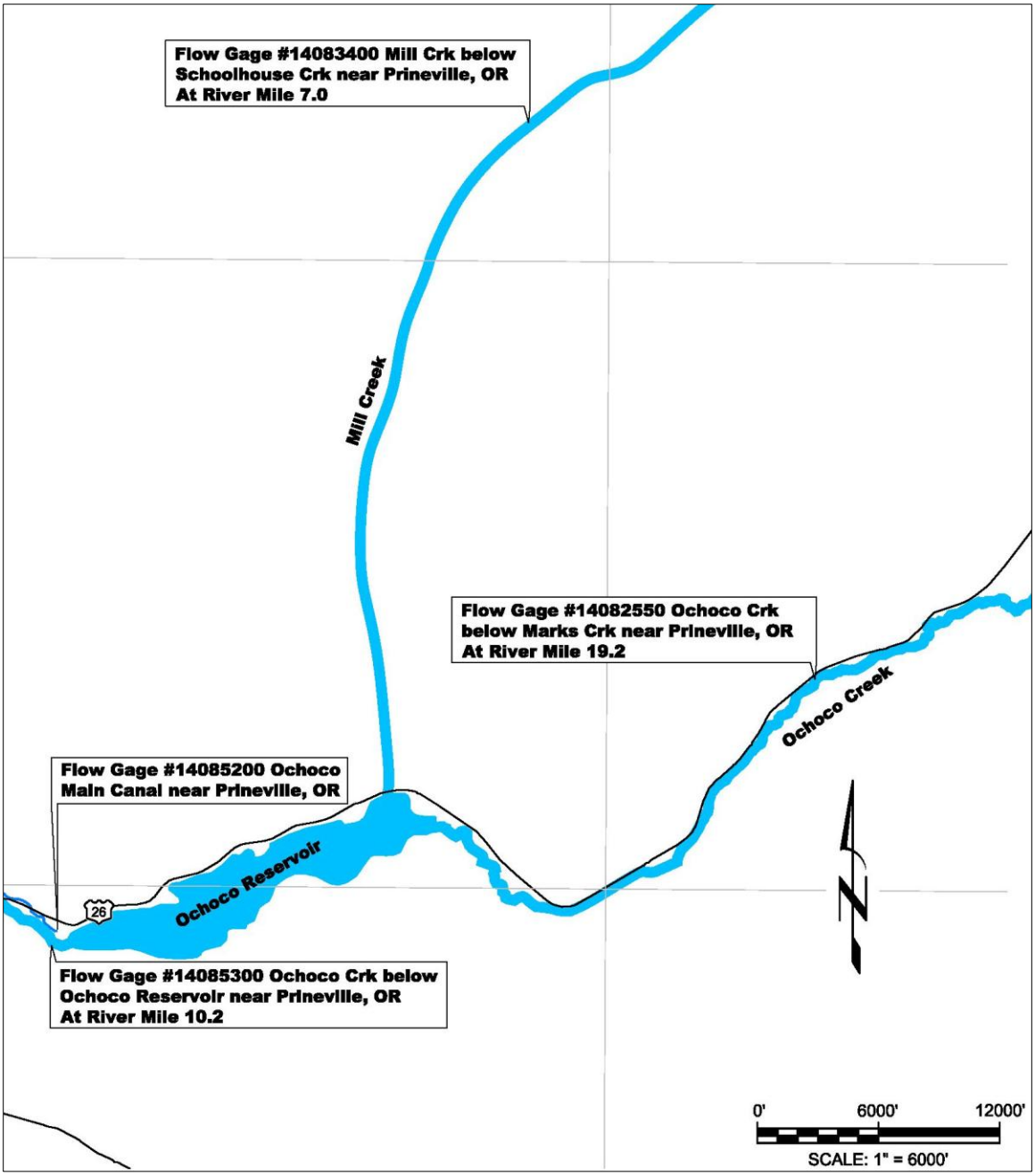


Figure A-3. Map of Ochoco Creek above Ochoco Dam showing gage locations.

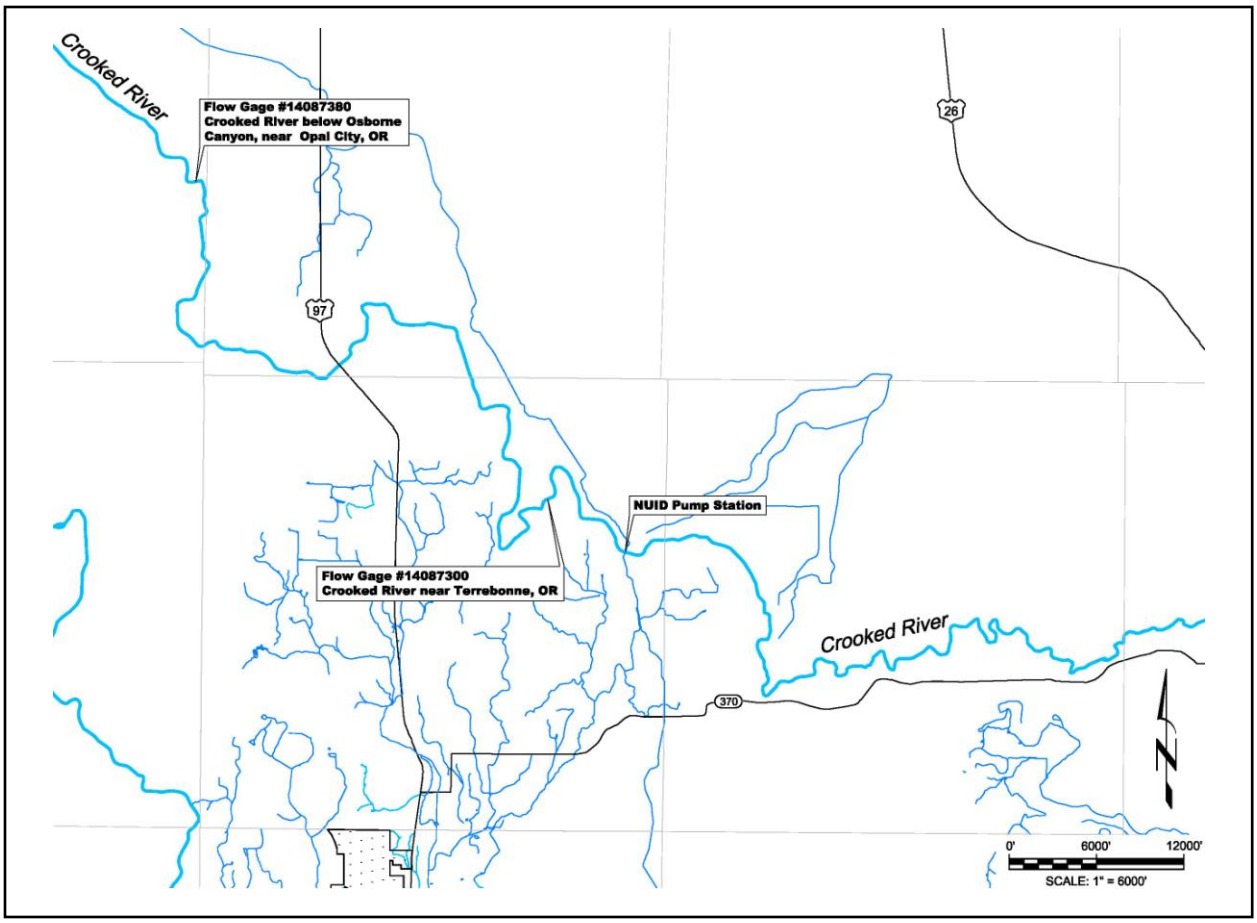


Figure A-4. Map of North Unit's Crooked River Pump Station on Crooked River showing gage locations.

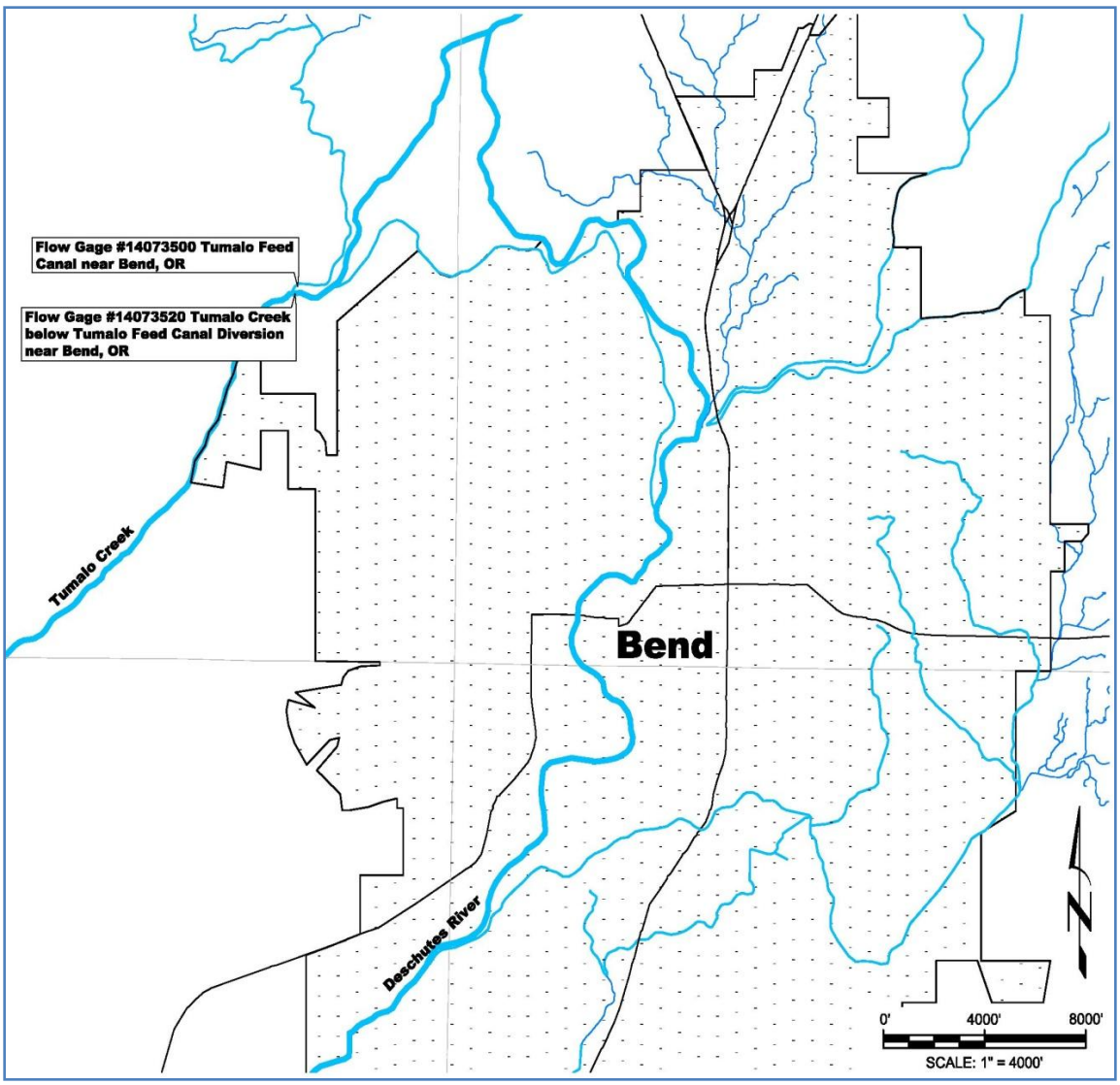


Figure A-5. Map of Tumalo Creek showing the locations of flow gages.

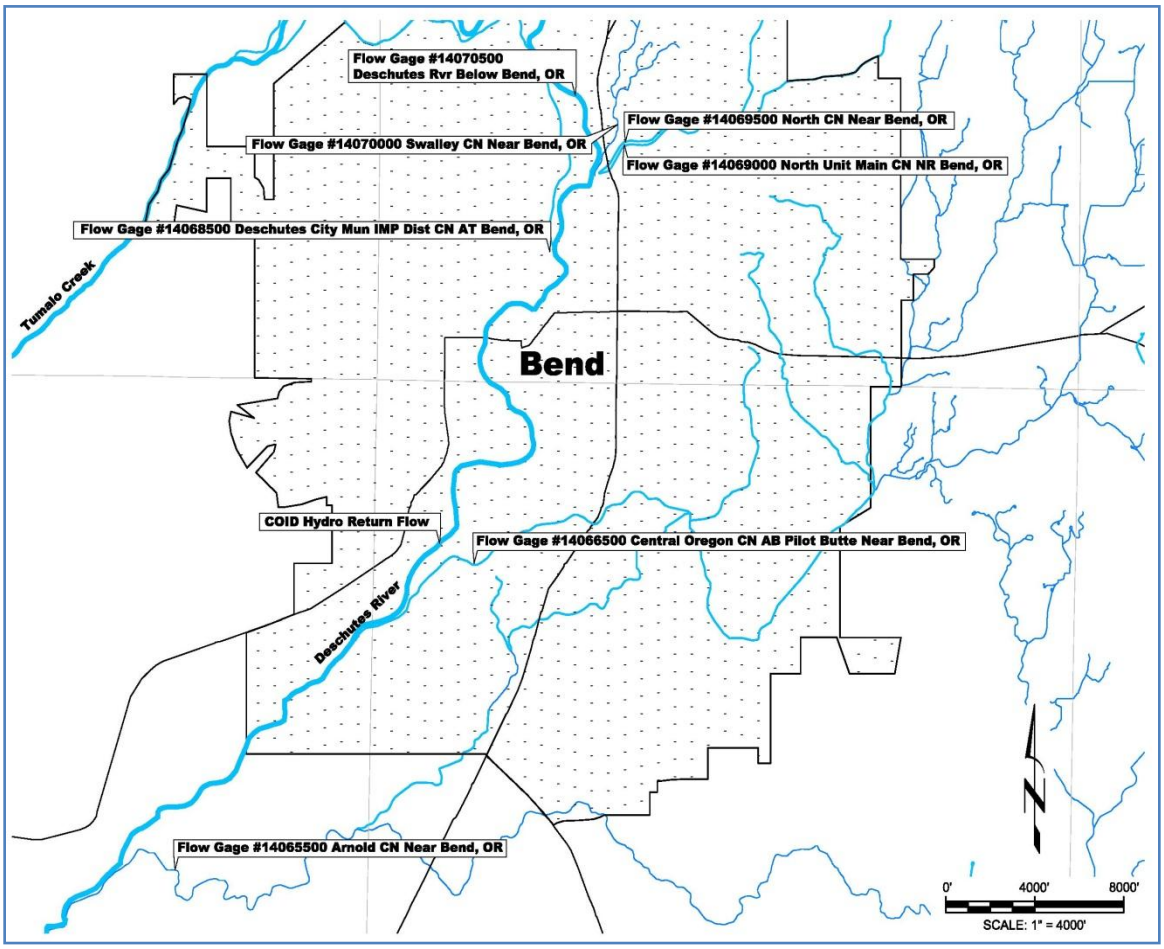


Figure A-6. Map of the Deschutes River showing gage locations within the reaches influenced by covered irrigation district activities.