Environmental Flow Restoration through Environmental Water Transactions: Case Study of Whychus Creek, Oregon

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All errors and omissions remain the property of the authors.

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1. Introduction

This case study details a formative success story of restoring environmental flows using environmental water transactions. Whychus Creek is tributary to the Deschutes River in the Columbia River Basin and historically provided important salmonid habitat. Diversions for irrigation dating to the 1880s dewatered the creek for much of the last century. Unrelated hydropower development in the Deschutes in the 1950s extirpated salmon above mid-basin dams and in Whychus Creek. Hydropower relicensing in the late 1990s provided the opportunity to restore salmon runs above the dams, however this relied on a complementary program of investment in acquiring irrigation rights through changes in irrigation and water use efficiency. This case study reports on 20 years of transactions that involved the expenditure of some USD 17 million to acquire 1 m3/s (~35 cfs) of water rights dedicated to environmental flows. The study is in part a result of a multi-organizational effort funded by the National Center for Ecological Analysis and Synthesis at the University of California Santa Barbara to generate indicators for water transactions program.

Structure of paper

- What issues/topics does the paper address (and where/when)?
- Why are we writing the paper; ie. for what purpose and for who?
- Brief overview of approach and methods in the paper
- How is the paper organized (list main sections and content)?

> ***Water markets are embedded within a particular basin geography and an evolved jurisdiction-specific governance framework.***

or not and how well or efficiently they work, but whether markets are healthy. In other words do water markets contribute not just to private gains between buyers and sellers, but do markets support and reinforce environmental and social outcomes of water governance. The framework puts forward a set of conditions and criteria on which water markets may be examined drawing on neoclassical economics, political economy and institutional economics.

2. Context Before Transactions: Whychus Creek, Oregon

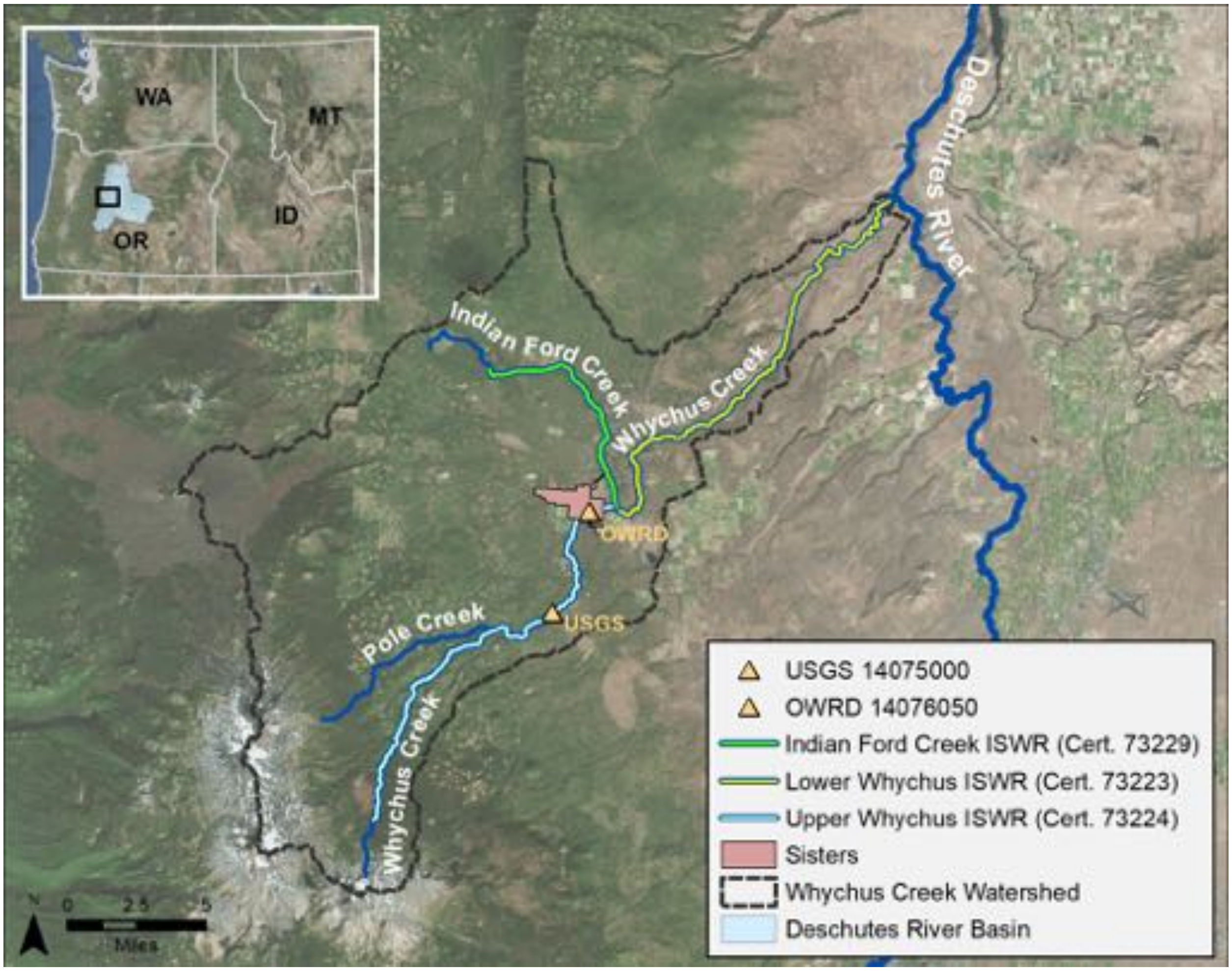
In order to understand the genesis, approach, mechanics and outcomes of a water transactions program it is vital to understand the context in which the work occurs, which consists of both the basin setting in all its dimensions and the policy and legal setting (Aylward, Pilz, Dyson, et al. 2016). This section presents the Whychus Creek setting within which water resources are managed, including the geography, population, land use and the economy. The discussion is framed initially within the larger setting of Deschutes Basin and Deschutes County, with watershed specifics as available. The water resources of the watershed, including the hydrograph and water supply, are then summarized, followed by an overview of water management including the water rights and their reliability, the water resource infrastructure, and the water uses. This presentation is used to characterize the situation in the watershed up until the mid- to late 1990s, i.e., the period prior to the onset of environmental water transactions. An effort is also made to briefly describe related events (natural and human initiated) during the period 1998-2016, during which the environmental water transaction program described here in detail took place

2.1 Geography

Whychus Creek is a tributary of the Deschutes River, which flows north to the Oregon/Washington border, entering the Columbia River just to the east of Mount Hood and the Cascade Range (Figure 1). From glacial headwaters in the Cascades, on the flanks of Broken Top and the Three Sisters, Whychus Creek flows 35 miles, first through forest and then sagebrush steppe, before joining the Deschutes just three miles above Lake Billy Chinook in mid-basin. Whychus Creek streamflow is fed primarily by runoff from snow, glaciers and rain, though springs do supplement flows below the town of Sisters and towards the confluence with the Deschutes. Before the construction of the Pelton and Round Butte dams downstream on the Deschutes blocked passage in 1964, Whychus Creek was one of the primary spawning area for steelhead and spring chinook salmon in the upper Deschutes River Basin.

As the creek emerges from the Deschutes National Forest water is diverted to privately-owned ranches and farms above and below the City of Sisters. The creek itself winds through the small town and, for many years, provided water to the city and its settlers. Principal tributaries to Whychus Creek are Pole Creek and Indian Ford Creek. Pole Creek, with a significantly lesser drainage area than Whychus Creek, parallels Whychus Creek in the upper watershed, before dropping into Whychus Creek between River Mile 29 and 30. Below Sisters, at about river mile 19.5 is the confluence of Whychus Creek with Indian Ford Creek. Indian Ford Creek is the only major non-headwater tributary to Whychus Creek and is spring-fed on lands that now form part of Black Butte Resort, an upscale destination resort located off the highway from Sisters over the Cascades. In the summer, Indian Ford Creek runs dry due to irrigation diversions and channel loss upstream of its confluence with Whychus Creek. These losses (as well as irrigation return flows) contribute to springs that discharge to Whychus Creek near the confluence of the two creeks above Camp Polk Meadow. Historically representing prime spawning habitat, Camp Polk Meadow was home to the first settlement in the area and was later channelized by the Corps of Engineers. From Camp Polk, Whychus Creek winds through a few ranches and a deepening canyon before entering Bureau of Land Management lands. At Alder Springs (river mile 1.5) over 100 cfs of flow are discharged from the canyon walls, providing an important cold-water refuge for fish just off the Deschutes River, including Bull Trout, listed as threatened under the ESA. The confluence area with the Deschutes River sis a spectacular natural area and popular hiking area.

Figure 1: Whychus Creek and Watershed, along with ODFW Instream Water Rights (ISWRs)



2.2 Socio-Economics

2.2.1 Population and Demographics

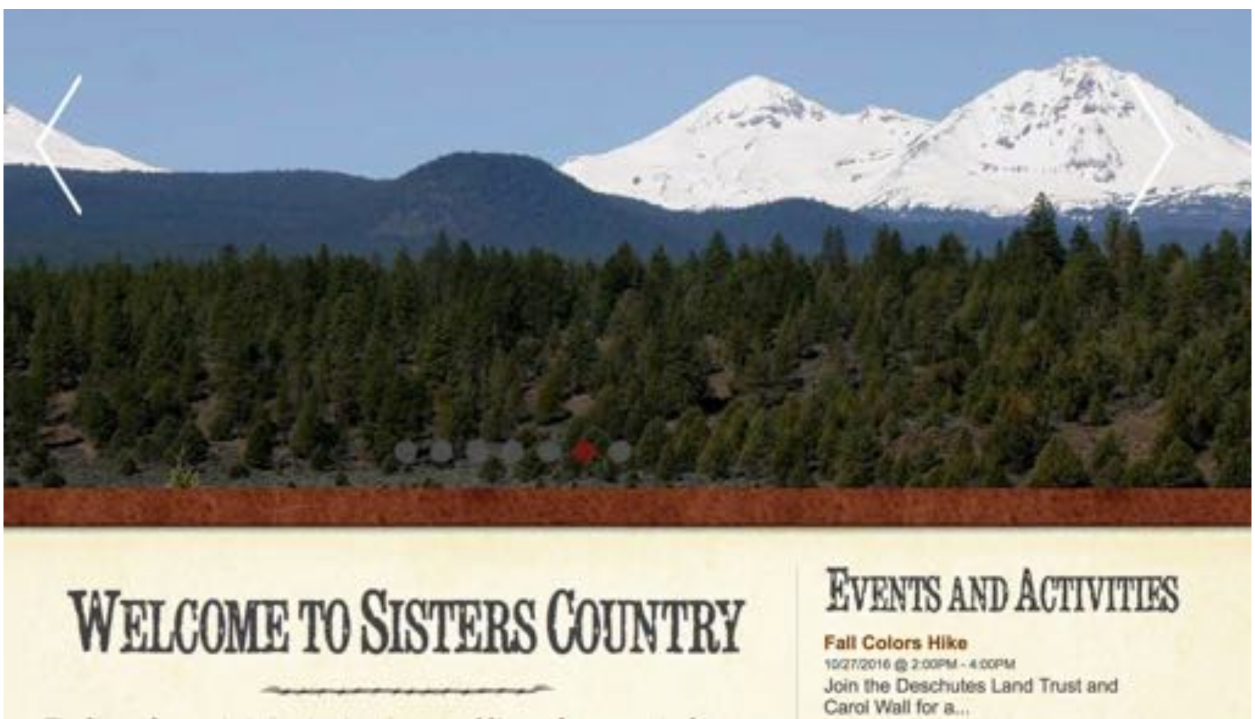
The Whychus Watershed lies largely within Deschutes County, with just a small portion of the watershed near the confluence with the Deschutes located in Jefferson County. Deschutes County had a population 115,000 and 158,000 in the 2000 and 2010 census, respectively. The Census Bureau estimates that the county grew by 11% to 175,000 people in the five years following the census (i.e., to 2015) as compared to 4% growth nationally. The City of Sisters reports a population of just over 2,000, however there are a number of rural subdivisions in the watershed that are home to a large number of residents. There is no available estimate of the population within the Whychus Watershed, but a rough guess suggests that maybe 5,000 people live in the watershed or derive benefit from its water resources (in the economic catchment as described below). However, as a tourist destination, the transient population during peak visitation periods probably doubles this number at the numerous resorts in the area.

Demographic data from the Census Bureau suggest that the main differences between national patterns and Deschutes County is a slightly higher proportion of senior citizens (19% to 15%) and a population lacking in racial and ethnic diversity (95% to 77% white, 5% to 13% foreign born and 7% to 21%

language other than English spoken at home). During the 2012-2014 period half of the growth in population came from the 65 and over cohort.

County median household income is $49,000 per year, just below the national average. Income distribution resembles that of the nation as a whole, however, income data are not reflective of the likely gap in wealth found in the county, given its status as a high-end destination for wealthy young couples with children and retirees from Seattle, Portland and San Francisco. The town of Sisters is home to relatively older and modest homes, however the rural subdivisions and resorts (Black Butte and Aspen Lakes), and many of the irrigated farms are decidedly upmarket. A socio-economic divide therefore exists between the less well-off residents employed in the service sector and the wealthy that may be living off unearned income. This applies to the agricultural sector where a 10 or 20-acre farm may be immaculate maintained and owned by a retired executive as a lifestyle choice and another will be less well attended and serving as a low-cost residence for a family deriving much of its income from off-farm service sector employment. In Deschutes County as a whole there are only a few large, commercial farms, a number of which are located at the tail end of the Three Sisters Irrigation District which withdraws water from Whychus Creek.

FIGURE 2: SISTERS OREGON (CITY WEBSITE PHOTO)



2.2.2 The Economy

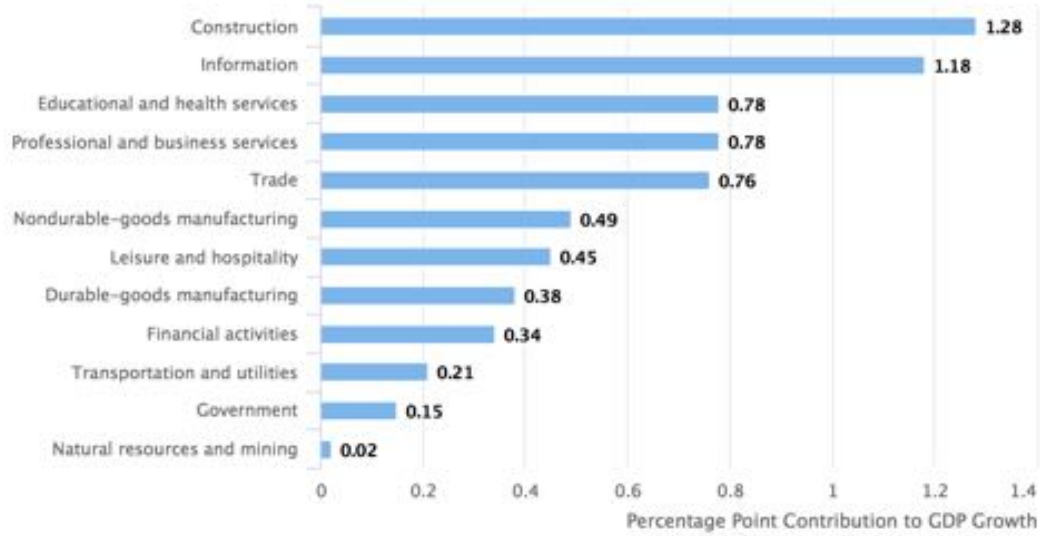
Over its history the Deschutes County area (formerly part of Crook County) has cycled from lumber to agriculture to tourism and recreation as its main industries. The economy and growth have cycled through hot and cold spells. Since 1980s two major recessions led to unemployment rates to peak near 15% (1982 and 2009) with the rate rising and falling between 5 and 8%. During the recent recession, the fall was rapid and severe and the recovery in employment trailed that of the nation as a whole.

According to the American Community Survey, agriculture, fishing and forestry in Deschutes County employs approximately 2,000 people or 3% of the active workforce. In comparison about 15% of the county workforce is engaged in arts, entertainment and recreation. The National Agricultural Statistics Survey (NASS) of 2012 reports that there were just less than 1,300 principal operators for farms and ranches in the county. Of these only 44% reported that farming was their major occupation. Five-sixths of these operators were male, their average age was almost 60 years and they were overwhelmingly white and non-Hispanic.

The NASS also reports agricultural sales for 2012 in Deschutes County of $20 million per year with 54% from crops and 46% from livestock. Hay and cattle/calf operations form the primary sources of revenue. Farm production expenses in 2012 are close to $40 million. Net farm income in Deschutes County is therefore negative. While land in farms includes 130,000 acres, the NASS reports that there were 34,000 acres actively irrigated in 2012. Using this figure to reflect actively farmed acres net farm income in Deschutes County is approximately negative $500/acre. More disaggregated data shows that the 31 farms (2%) with revenues over $100,000 per year make up over 40% of the total revenue. Meanwhile 80% of farms have revenues of less than $10,000 per year. Unfortunately cost data is not provided on a similar basis. However, the data reflects that Deschutes County divides into two camps. A large number of small acreage farms some of which are used to supplement income or produce food for own consumption and some of which are amenity farms with little intent to make a profit. The latter farms, including those raising horses or largely farming a view of the mountains, will have expenditures but no revenue. The remaining 20% of farms are generating revenues, with a much smaller percentage – i.e. the top 2% – likely producing hay, cattle or specialty crops and operating at a reasonable profit.

In 2015, the Bureau of Economic Analysis reports Deschutes County gross domestic product of $7.3 billion. At $20 million, agricultural revenues make up just 0.3% of county income. The lack of influence of agriculture in the local economy is shown in Figure 3, where the natural resources and mining sector, which presumably includes agriculture, is a lagging sector contributing a negligible 0.02 percentage points towards total economic growth in 2015 ($1.5 million). Leisure and hospitality, in comparison, which reflect the tourism and recreation-based economy contributed 20 times this amount to growth in 2015 (or $30 million). It is therefore clear that the economy of Deschutes County is not reliant on agriculture, nor are many families' livelihoods dependent on agriculture as a source of income. Note that with median family income of approximately $50,000 annually, agricultural revenues of $20 million are equivalent to the income of 400 families. However, family income would consist of farm revenue less farm costs. It is therefore likely that the 31 family farms generating revenues of over $100,000 per year represent roughly the number of families that actually rely on agriculture to meet their livelihood needs. Some of the larger farms within the Three Sisters Irrigation District that depend on water from Whychus Creek likely meet this profile.

Figure 3: Contribution to Deschutes County Economic Growth (2015)

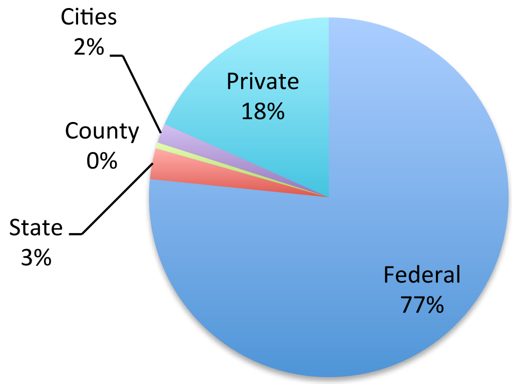


Source: Runberg (2016)

2.3 Land: Zoning, Ownership and Use

Deschutes County is about 3,000 square miles or about 1.9 million acres. The watershed by contrast is somewhat less than 200,000 acres and so constitutes about one-tenth of the county. Three-quarters of land in the county is owned by the federal government. The Forest Service manages large areas of forest in the higher elevation areas of the Cascades. In the Whychus Watershed the Three Sisters Wilderness includes the headwater portions of the Deschutes National Forest. The Bureau of Land Management manages large areas of juniper dominated sagebrush systems in the center of the county, including lands in the lower Whychus. Sandwiched between these public lands are the private lands which include the major cities of Bend, Redmond and Sisters, as well as surrounding rural sub-divisions and destination resorts. Ranches and farmland make up the bulk of private landholdings. Some 38% of county land is zoned for agriculture, but two-thirds of this is BLM and county lands that are held for recreation and/or grazing. Just 44,000 acres are in farm deferral and irrigated in the county. In other words, only about 2% of land in the county is irrigated. Of this total, approximately 8,000 acres of irrigated land either lies within the Whychus drainage or is irrigated from Whychus Creek in the adjoining McKenzie Canyon drainage.

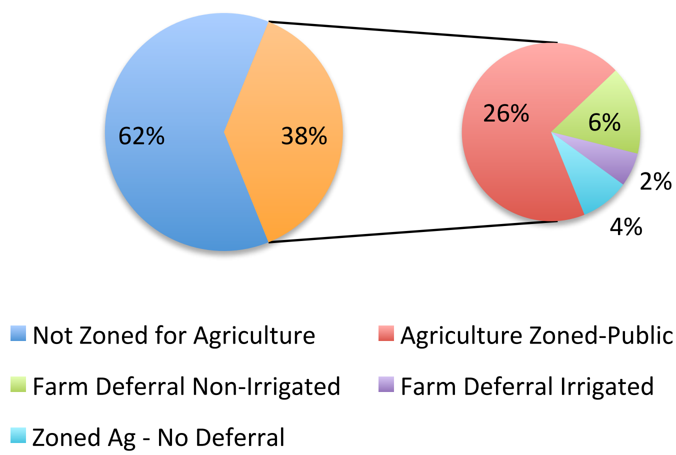
FIGURE 4: LAND OWNERSHIP IN DESCHUTES COUNTY



Ownership	Acres
Federal	1,466,067
State	53,051
County	10,434
Cities	33,298
Private	350,632
Total Land Area	1,913,482

Source: Deschutes County

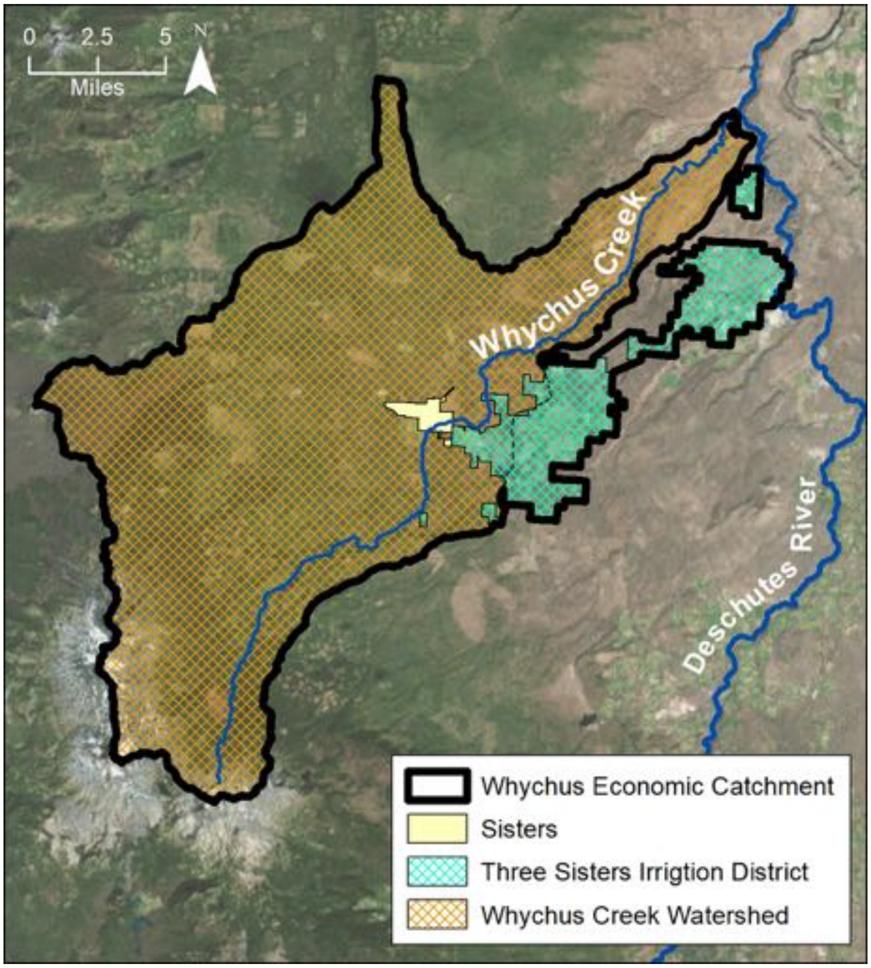
FIGURE 5: LAND USE ZONING IN DESCHUTES COUNTY



Zoned Land Use	Acres
Not Zoned for Agriculture	1,190,901
Zoned for Agriculture	722,581
of which	
Agriculture Zoned-Public lands	498,581
Farm Deferral Non-Irrigated	115,857
Farm Deferral Irrigated	44,221
Zoned Ag - No Deferral	63,922

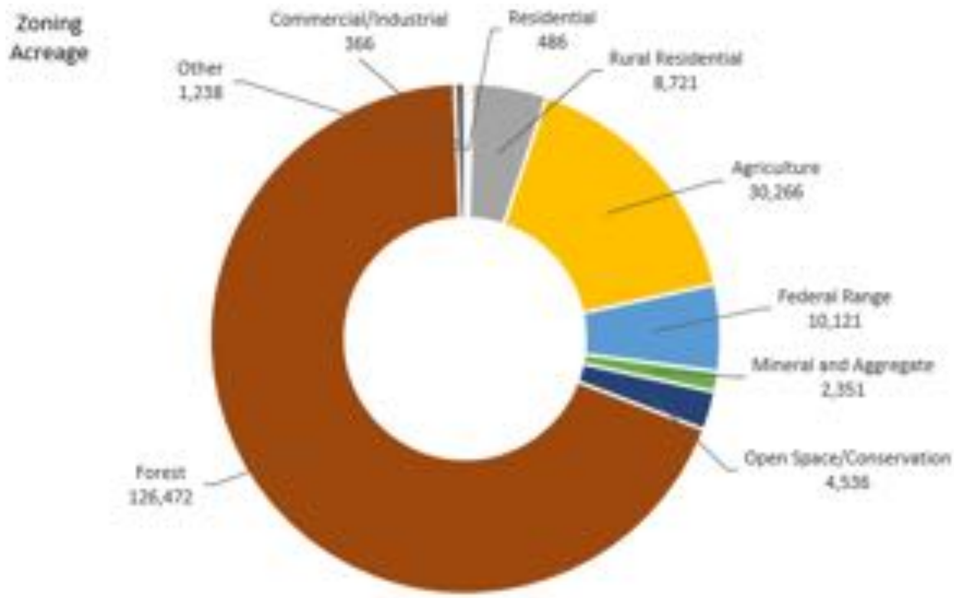
Water use does not always adhere to the drainage delineations of the source water. In these instances, it is important to also evaluate the water use and socio-economic characteristics of the area to which water is applied outside of the watershed boundary. This area of analysis – which can be called the "Economic Catchment" combines the natural watershed with the area outside of the watershed where water use occurs. For Whychus, the economic catchment includes the Whychus Creek Watershed and Three Sisters Irrigation District (TSID), an area of around 290 sq. miles or 185,000 acres (Figure 6). Although a portion of TSID lies outside of the Whychus Creek Watershed in the nearby McKenzie Canyon drainage, the point of diversion for the District is along Whychus Creek. Combining TSID with the watershed allows for a more accurate analysis of the impact of land use and water use changes related to water transactions in Whychus Creek water rights. Note water that is diverted from Whychus Creek and applied to lands in McKenzie Canyon do not return to Whychus Creek, but remain in the canyon and drain to the Deschutes River.

Figure 6. Whychus Creek Economic Catchment



Zoning. The Whychus Economic Catchment is zoned primarily for forest (126,000 acres) followed by agriculture (30,000 acres) (Figure 7). Of the area zoned for agriculture, over half is within TSID and is zoned for farms greater than 80 acres. The commercial, industrial, and residential zones make up approximately 0.5% of the land area.

FIGURE 7. ZONING OF THE WHYCHUS ECONOMIC CATCHMENT

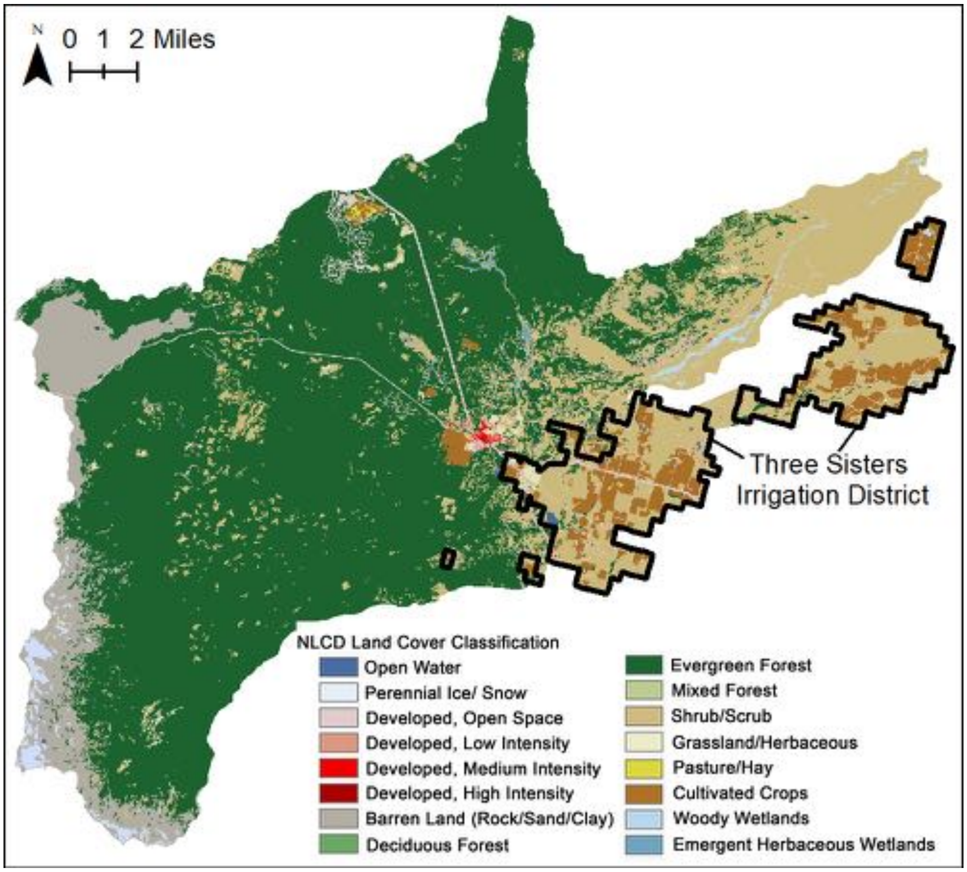


Land Use. The Multi-Resolution Land Characteristics Consortium is a group of federal agencies that creates and distributes the National Land Cover Database (NLCD), a geospatial dataset of land classifications in the U.S. This dataset categorizes land use into 20 classes (Homer et al. 2015). The land use map of the Whychus Economic Catchment (Figure 8) shows the general progression of land cover from the headwaters of the Whychus on North Sister, South Sister, and Broken Top Mountains, transitioning to evergreen forest, and then to shrub/scrub. The map shows that the majority of cultivated cropland lies within TSID.

Agriculture. Water right data provide a historic look back at agricultural land use (covered later in this section). As of the mid to late 1990s a majority of the water rights on Whychus Creek were re-mapped and consolidated within the Squaw Creek Irrigation District. The District was later renamed as Three Sisters Irrigation District (after the former Squaw Creek was renamed to Whychus Creek). Recent estimates by the District are that 175 farmers in TSID irrigate approximately 8,000 acres of cropland (TSID 2012). Roughly 53% of cropland is alfalfa or grass hay, 25% is pasture, and 22% is specialty crops including carrot seed, grass seed, radish seed, and grains (TSID 2012).

These acreage figures were checked against CropScape, a geospatial crop mix mapping tool developed by NASS, as well as the NLCD. NLCD reported around 6,000 acres of cultivated crops and 500 acres of grassland/herbaceous, which may be pasture. When compared with aerial imagery, the land use land cover data correlated with irrigated areas. CropScape data, on the other hand, suggests 3,000 acres of cropland for the years 2011 and 2016, and these areas did not closely correspond with aerial imagery of agricultural fields. However, 2014 CropScape data showed more consistent coverage of irrigated land, measuring 4,800 acres of crop. Due to the inaccuracies and inconsistencies of CropScape, this data was not used to develop a more detailed evaluation of crop type within the District.

FIGURE 8. LAND USE LAND COVER IN WHYCHUS ECONOMIC CATCHMENT, 2001



Source: Homer et al. (2007)

2.4 Water Resources

This section describes the water resources of Whychus Creek, primarily the surface water resources. More generalized information about surface and ground water in the Deschutes Basin can be found in the relevant literature, including several USGS reports (O'Connor and Grant 2003; Marshall W. Gannett and Lite 2004; Marshall W. Gannett et al. 2001; M. W. Gannett et al. 2017).

2.4.1 Streamflow Measurement

There are two continuous stream gages on Whychus creek (Figure 1):

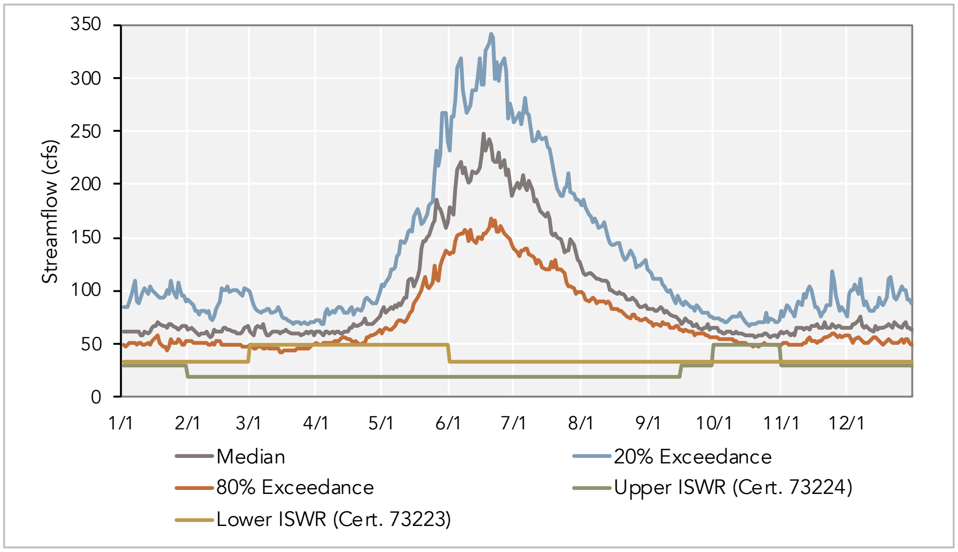
1. A USGS gage located above all diversions, Gage #14075000, Whychus Cr nr Sisters, with data since 1906.
2. An OWRD gage located in Sisters and below diversions on the upper portion of the creek, Gage #14076050, Whychus Cr at Sisters, with data since May 2000.

The USGS Gage provides a long-term dataset for inflow to the system. The OWRD gage was installed once the transaction program was underway. The OWRD gage is located towards the bottom end of the dewatered upper section of Whychus Creek and is useful for assessing trends over time and the success of the program.

2.4.2 Hydrograph and Water Supply

A representative hydrograph for the purposes of deriving statistical measure of the hydrograph and estimating water supply is the 1958-1987 period, which was the reference period used by the Oregon Water Resources Department at the time the transactions program was initiated. The hydrograph is shown in Figure 14.

FIGURE 9: WHYCHUS CREEK HYDROGRAPH, 1958-1987, AND 1990 INSTREAM WATER RIGHTS (ISWRS)



During this 30-year reference period the average annual water supply is 76,000 AF or a mean daily flow of 105 cfs. As there is no on channel storage, the inflow for April through October represents the water supply during the irrigation season. This amounts to roughly 52,000 AF or 69% of the total annual supply. Due to snow melt and the release of water stored in the snowpack average during the May to July period, natural flows during the irrigation season are substantially higher than those during the winter months.

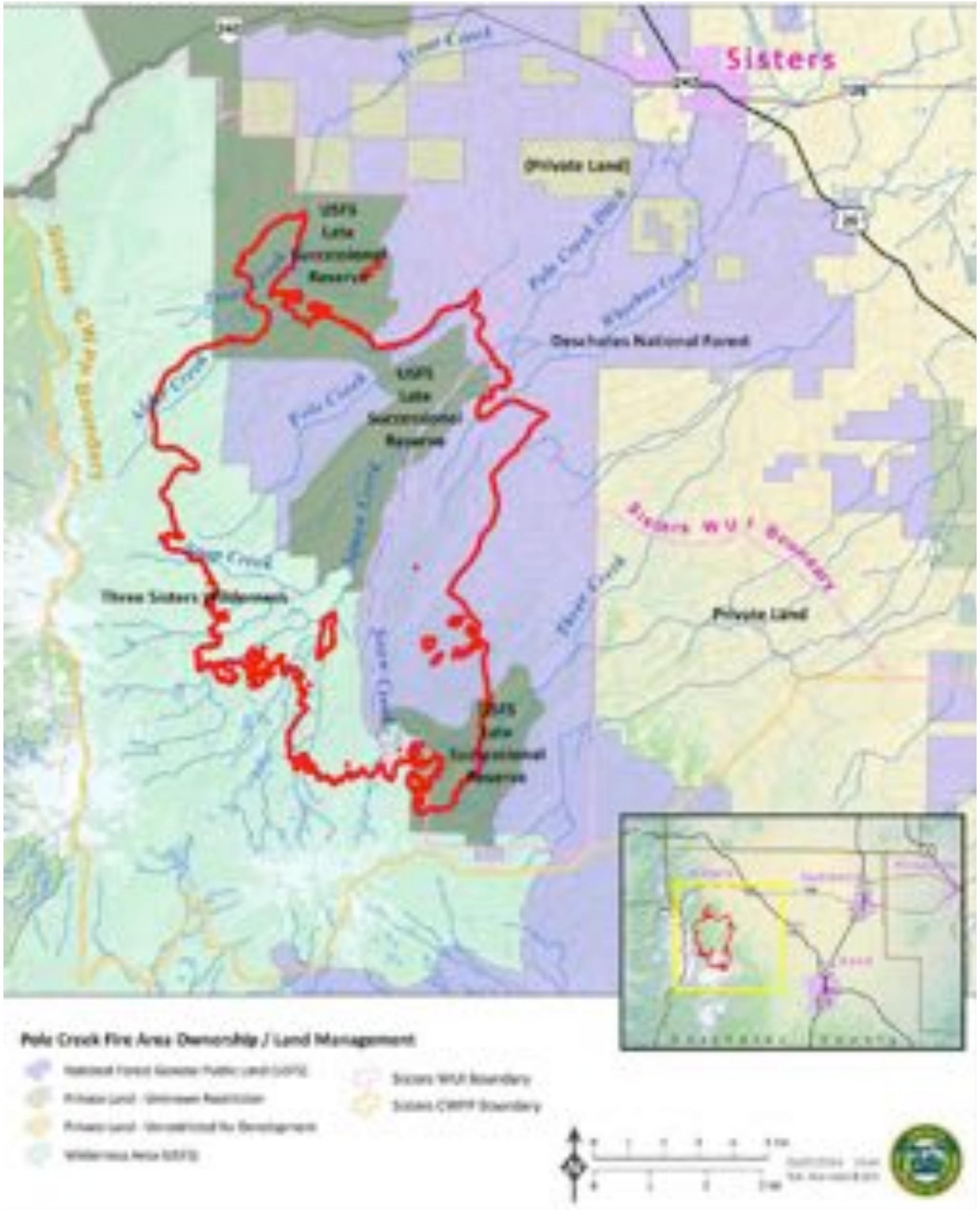
The lack of historic stream gage data below diversions means that there is no baseline record of the extent of dewatering of the Creek as it reaches and passes through Sisters. In the analysis of environmental flow attainment presented later in this paper, the data for water years 2001 through 2016 from the OWRD gage at Sisters is used however to portray the improvements in flow as the transactions program is implemented. To address the question of whether or not these sixteen years are representative of the historic record the water supply statistics at the USGS gage for the reference period and for the 2001 to 2016 period are compared in Table 1. This is done to understand if conditions were generally more or less favorable for streamflow during the transaction period. The results in the table suggest minor differences (<5%) in mean and median streamflow between these period, with fewer high and low water years during the 2001 to 2016 period resulting in a lower overall standard deviation for this period compared to the reference period.

Table 1: Streamflow Comparison: Reference Period and Flow Restoration Period

Statistic (yearly AF)	1958-87 Water Year	1958-87 Irrigation Season	2001-2016 Water Year	2001-2016 Irrigation Season	Percent Difference Water Year	Percent Difference Irrigation Season
Max	104,889	82,744	98,326	76,918	-6%	-7%
80% Percentile	88,362	68,138	82,861	61,959	-6%	-9%
Mean	75,767	56,423	74,163	54,652	-2%	-3%
Median	72,332	55,009	76,267	54,534	5%	-1%
20% Percentile	62,717	45,457	65,926	48,909	5%	8%
Min	43,885	30,187	47,489	35,913	8%	19%
Stdev	15,491	12,995	12,784	10,283	-17%	-21%

A larger question is that of the direction of hydrologic change generally in the watershed, and how this may affect the water supply and hence the reliability of water rights. This is difficult to diagnose as climate change, fire and changes in land use present short- and long-term drivers of change. Since 1900 wildfire has affected some 85,000 acres in the watershed, and since 1998 some 20,000 acres in the watershed have been subject to stand replacing fires (USFS 2013). Most recently in 2012 the Pole Creek Fire burned over 26,000 acres right across the forested portion of the Pole Creek and Whychus Creek drainages as shown in Figure 10. This led to flashier conditions in the watershed during the period of interest. In the years following the fire higher than normal ratios of non-irrigation to irrigation season runoff are observed and may have exacerbated low flows during drought periods. Over the full historic record, the winter flow volume (November through March) is 43% of the flow volume recorded during the irrigation season. In 2015, winter flow volume was 121% of irrigation season flow, which is some 20% higher than the prior historic maximum value observed for a single year. The 2015 water year was one of the driest years on record in the region and, as shown later in this paper, resulted in a downward spike in the trend toward environmental flow recovery in the creek. It may be that the fire served to exacerbate the impacts of an already abnormally dry year on streamflow.

FIGURE 10: POLE CREEK FIRE MAP



Source: OHA & ODF (2014)

2.5 Water Rights

2.5.1 Surface Water Right Adjudications and Permits

Surface water rights on Whychus Creek and its tributaries were adjudicated through a series of Crook County decrees for Squaw Creek issued between 1910 and 1916. Decreed rights range from an 1869 right through to 1911 rights, in terms of priority dates. A substantial number and volume of permits for additional rights were granted after 1911 with a portion of these ultimately being certificated as water rights. Although, the Deschutes Basin was closed to further appropriation by a federal reservation in 1913, OWRD continued issuing natural flow surface water rights on Whychus Creek through to 1937. Rights issued in these later years were generally rights issued for domestic water supply in the City of Sisters.

Decreed water rights consisted primarily of irrigation rights as well as domestic and stock rights. Permitted rights include irrigation rights and later rights for municipal water supply for the City of Sisters. These water rights typically included the type of use, diversion rate, acres irrigated, delivery ditch and place of use. The irrigation season is not specified in the decree but was subsequently determined by the Oregon Water Resources Department (OWRD) to be from April 1 to October 31st. The point of diversion for these water rights is not specified in the decree or in the certificates. Although period maps assist in locating some of the ditches and therefore inferring points of diversion this is not a complete record due to the plethora of ditch names, some of which overlap and, in some cases, may have proved short-lived in usage. It is therefore not always possible to determine where these rights were to be diverted, though the location of the place of use is largely determinative in terms of which rights were diverted from which source stream.

2.5.2 The Water Rights Abstracts

The Squaw Creek decrees covered the watershed as a whole including rights off of Pole Creek, Squaw Creek above and below Sisters, Indian Ford Creek and a few ancillary headwater streams that peter out on the young basalts that make up the landscape below the Cascades. For this paper, a partial water rights abstract was prepared. The abstract documents the decreed and permitted surface water rights diverted on Squaw Creek above Sisters, i.e., from the upper portion of the creek. A few rights that served lands in the floodplain downstream from Sisters were also included either due to uncertainty as to their original point of diversion or later changes in points of diversion as part of a known water rights transaction. The water rights serving the handful of ranches on the lower portion of the creek are not included in the analysis.

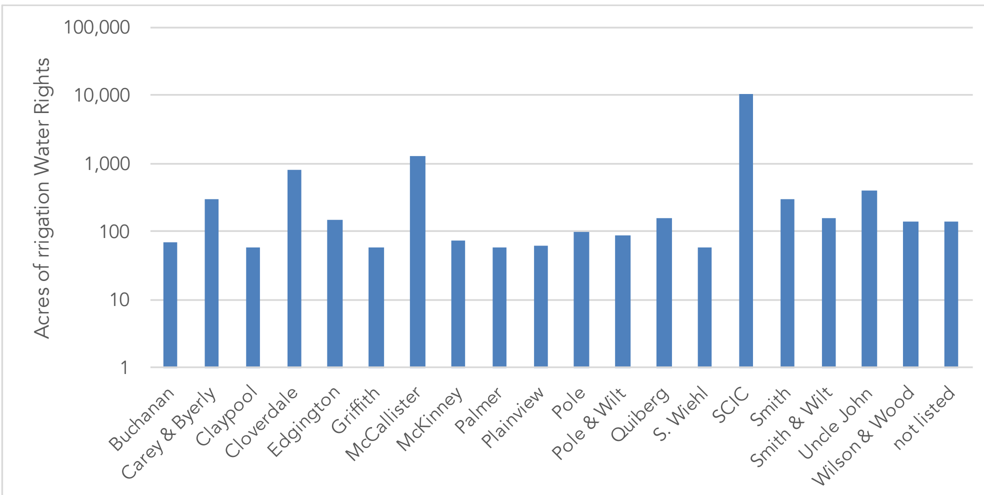
The water rights abstract was compiled for three points in time. First, the decrees and permits were used to compile diversion rates and irrigated acres by ditch for the natural flow surface water rights as decreed or permitted through 1937. The abstract was then updated twice, once at the end of 1997 and then again for the end of 2016. The 1997 abstract is the "before transactions" water right data set and the 2016 abstract is the "with transactions" data set. The abstract is partial in that while name, rate, acres, use, source and ditch were compiled, no effort was made to systematically record the place of use for all rights. Instead, place of use was examined only as useful in understanding water right transfers from one ditch to another. The year 1997 was chosen as a fulcrum for the analysis for a number of reasons. First, at the close of 1996 the Oregon Department of Fish and Wildlife (ODFW) had certificated junior instream rights on the creek for the first time. More importantly, at the close of 1997 OWRD issued both the new Squaw Creek Irrigation District (SCID) water right certificates and the first senior instream water right certificate resulting from an EWT. So, the 1997 abstract includes the new SCID certificate but stops short of including that first senior instream certificate.

The 1997 and 2016 abstracts were developed through extensive water rights research using the online OWRD Water Right Information System (or WRIS). Lists of water right lists from the Deschutes River Conservancy and the OWRD watermaster were also consulted during this process. These latter two abstracts track the fate of each water right included in the 1937 abstract as of 1997 and 2016. In two cases, irrigation water rights were transferred to incidental fish pond and municipal use. However, as reported below and later in the paper (for 2016) the primary changes were rights that were cancelled or transferred to instream use. In addition, based on available evidence, including corroborating evidence from water rights research, historical analysis of land use with Google Earth™, and a 2015 water right list from the OWRD watermaster, a number of water rights are categorized by the authors as "abandoned," although they remain in a "non-cancelled" status according to OWRD (and on the WRIS).

2.5.3 Surface Water Rights as Issued (through 1937)

All told 296.39 cfs of surface water diversion rights were issued, including for 14,813 acres of irrigation. Of this total allocation, just 4.2 cfs was for municipal use and 0.20 for power and steam. By far the largest agglomeration of users were those serviced by the Squaw Creek Irrigation Company (SCIC), at just over 10,348 acres of irrigation and decreed diversion total of 201 cfs. Other large ditches included the McAllister ditch and Cloverdale Irrigation Company at 1,268 acres and 797 acres, respectively. Most of the other ditches come in in and around 100 acres of irrigation each. As the decreed rate for irrigation is 50 acres per cfs of diversion this means there were a large number of small ditches with diversion rights of about 2 cfs (see Figure 11).

FIGURE 11: LANDS IRRIGATED FROM (UPPER)WHYCHUS CREEK BY DITCH, AT ISSUE (THROUGH 1937)

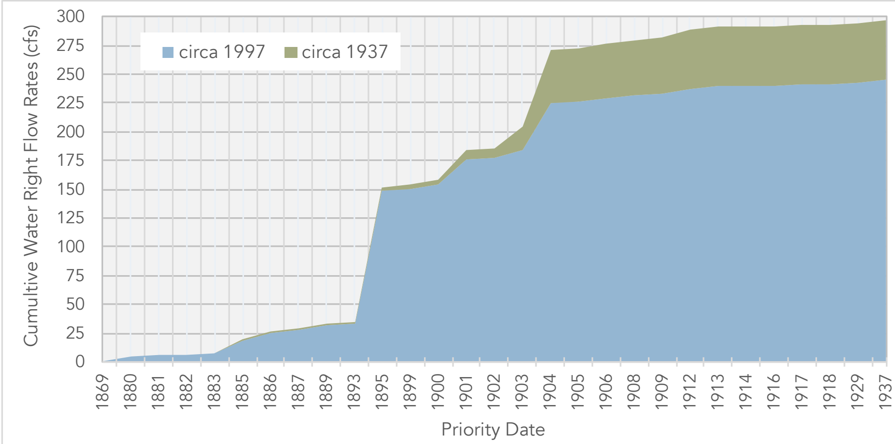


2.5.4 Water Rights in 1997

Between 1937 and 1997 a number of ad hoc transfers and cancellations of water rights occurred on and between water right holders on the creek. By far the most important development, however, was the 1997 finalization of a legislatively authorized (HB 3111) re-mapping of water rights appurtenant to land serviced by SCID, the successor to the SCIC. The new certificates consolidated rights from a number of smaller ditches (and from a number of historic transfers) on to the SCID Ditch The consolidation also led to the cancellation of some 52 cfs and 2,600 acres of largely junior irrigation water rights, presumably due to their abandonment over the course of the 20th Century.

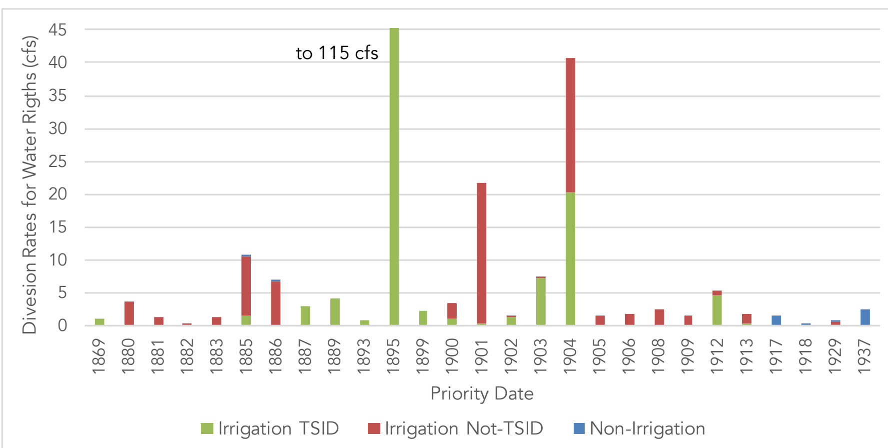
Total and Irrigation Rights. As of 1997, there were a total of 245 cfs of non-cancelled rights on the creek of which 240 cfs were for irrigation. Irrigation rights totaled 14,802 acres. Figure 12 compares active rights as of 1937 with those in 1997 by priority date. The figure shows that most of the rights cancelled during this interim period were of 1901 priority date or junior.

Figure 12: Non-Cancelled Irrigation Water Rights on (upper) Whychus Creek



As of 1997. irrigation rights can be grouped as those that are diverted and delivered by the Three Sisters Irrigation District (or TSID, successor to SCID) and those diverted by individual water right holders (denoted as "non-TSID"). Figure 13 reports water rights by priority for these two categories, as well as for the small quantity of non-irrigation rights. Two-thirds of irrigation rights were on the TSID delivery system which served rights totaling 160 cfs and served 8,185 acres. Including all rights there were some 33 cfs of water rights senior to 1895 and 115 cfs of priority 1895. Another 36 cfs have priorities junior between 1899 and 1903. There are 41 cfs of water rights with 1904 priority and a batch of 15 cfs junior to 1904.

Figure 13. Upper Whychus Water Rights in and out of TSID,1997



Municipal Rights. The City of Sisters is the sole municipality in the Whychus Watershed. A number of water users in the area that ultimately became the City of Sisters obtained irrigation and domestic rights under the original adjudication. Later, Sisters itself applied for and was granted rights for 4.2 cfs with priority dates of 1913, 1915 and 1937 on Squaw and Pole Creek. The Pole Creek water was diverted into the Pole Creek Ditch high in the watershed, along with some water that would have drained to Squaw Creek but was delivered to the Pole Creek Ditch via a pick-up ditch. The Squaw Creek water was delivered through the Branton Ditch located close to town (and alongside the Buchanan Ditch). As noted later in this paper these rights were all junior and likely not available for much of the summer (and at other times of the year). Eventually, the City obtained a permit (1.45 cfs) and developed a storage facility (6.3 AF) with 1967 priority on the Pole Creek Ditch. In 1977 the City completed the purchase and transfer of 0.2 cfs of senior 1885 water rights on Pole Creek to bolster its portfolio. Despite these efforts to meet needs from surface water, the city began developing groundwater as an additional source in the 1980s when it developed the first of two groundwater permits (totaling 3.31 mgd or 5.12 cfs of priority 1983 and 1991) (HGE 2005). By 2000 the added burden of water treatment requirements for its unreliable surface water supply led the city to abandon their surface water source and go to a groundwater only source. As municipal rights in Oregon are not subject to forfeiture the City's surface water rights were later eligible for instream leases and transfer, as well as for use in mitigating new groundwater rights.

Instream Rights. In the 1990s, following on the 1987 Instream Water Rights Act, ODFW applied for some 500 instream water rights across the state based on earlier studies of flows and fish habitat. These rights were subject to public review and, ultimately, most of these were approval by OWRD. In 1996, OWRD issued three instream water right certificates with a priority date of 1990 for the Whychus Watershed. Certificate 73224 is for the upper portion of Whychus Creek and covers some 15.5 river miles above the confluence with Indian Ford Creek. This is the reach that is the subject of this analysis. Additional rights were issued for the lower portion of Whychus Creek, from the confluence down to the mouth (Certificate 73223) and for Indian Ford Creek (Certificate 73229). The reaches for these certificates are shown in Figure 1. The applications were made by the Oregon Department of Fish and Wildlife (ODFW) and were approved for a purpose of migration, spawning, egg incubation, fry emergence, and juvenile rearing. Flow rates on these certificates are specified by month or for the first and second half of each month. The rates on the upper Whychus Creek reach are 20 cfs from February through mid-September, rising to 50 cfs for October and otherwise set at 30 cfs. On the lower Whychus Creek reach instream flow rights are set at 33 cfs from June to February with 50 cfs from March through May. These flow rates are shown against the natural flow in Whychus Creek in Figure 9, revealing that these rates were largely set at levels approximating the 80% exceedance inflows on the creek (flows met 8 out of 10 years). The higher rate for instream flow rights on the lower portion of the creek from February until September and then the higher rate in October for the upper portion may reflect fisheries needs in each section or may reflect the perceived potential availability of water. Due to the large diversions upstream of Sisters and the groundwater discharge to the creek below Sisters, streamflow is typically more abundant below Sisters than above town.

Irrigation and Domestic Groundwater. In addition to these rights there are supplemental irrigation groundwater rights and numerous domestic groundwater uses in the watershed. For household and small-scale irrigation uses that are less than one-half acre groundwater uses are exempt from permitting under state law. Given the dispersed, small acreage nature of landholdings in and around Sisters there are numerous such exempt wells. No formal count of these wells or monitoring of their water use is undertaken by the state. In addition, as amenity or "hobby" farming took hold in the Sisters area many landowners addressed the reliability problem of junior surface water rights by developing new groundwater rights or turning supplemental groundwater irrigation rights into primary rights. Prior to and after 1997 this trend is evident in the numerous partial cancellation of junior surface water irrigation rights by new landowners seeking to move to a reliable groundwater supply. As cancelling a surface water right is irreversible it can be inferred that these junior rights were neither marketable nor of any real value as a dependable source of irrigation water.

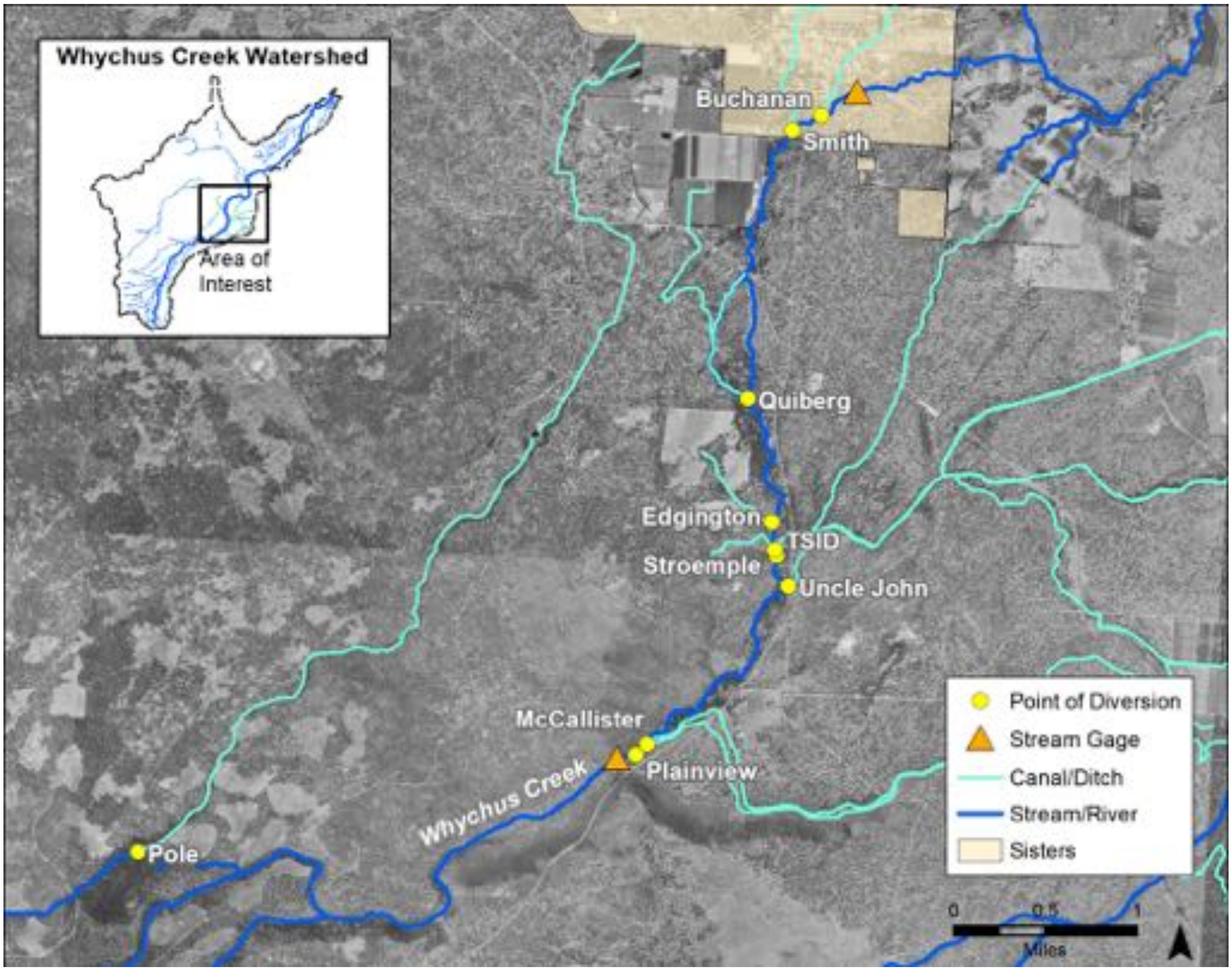
2.5.5 Water Infrastructure

Water resource development in the watershed is limited. There are no significant storage facilities on Whychus Creek or its tributaries. The major water resource infrastructure consists of the diversions, canals and laterals that serve to deliver irrigation water. The major irrigation diversions as of 1997 are summarized in Table 2 and shown on the map in Figure 14. Eight of the nine historic major diversions off the upper creek in or above Sisters are individual or shared ditches irrigating relatively small acreages. By far the largest diversion and the only extensive canal and lateral system is one that serves patrons of the Three Sisters Irrigation District (shown earlier in Figure 6). The district diverts water relatively high up in the basin and routes water down and through Sisters and through the Watson Reservoir, which serves as a re-regulating reservoir. Irrigation water is delivered across the area to the north east of Sisters, as well as down the McKenzie canyon. The lands irrigated in the canyon and on the plateau above the Deschutes and Metolius Rivers is outside of the Whychus Watershed but included in this analysis as the lands are watered with Whychus Creek water rights.

Table 2. Irrigation Water Rights by Diversion, 1997

	Total Rate (cfs)	Total Acres	Other Names
TSID	160.9	8,185	SCID, SCIC
non-TSID			
Buchanan	1.1	56	Leithauser, Tehan
Edgington	2.6	149	Old Cox, Hartley, Frisbee
McCallister	21.4	1,068	Maxwell
Plainview	25.2	1,317	
Pole	3.3	165	
Quiberg	8.7	361	Claypool, Sokol
Smith	6.2	301	Smith-Barclay
Stroemple	0.3	14	
Uncle John	9.5	454	Reed
Other	1.0	77	
Total	240.0	12,145	

FIGURE 14: UPPER WHYCHUS CREEK IRRIGATION DIVERSIONS AND DITCHES



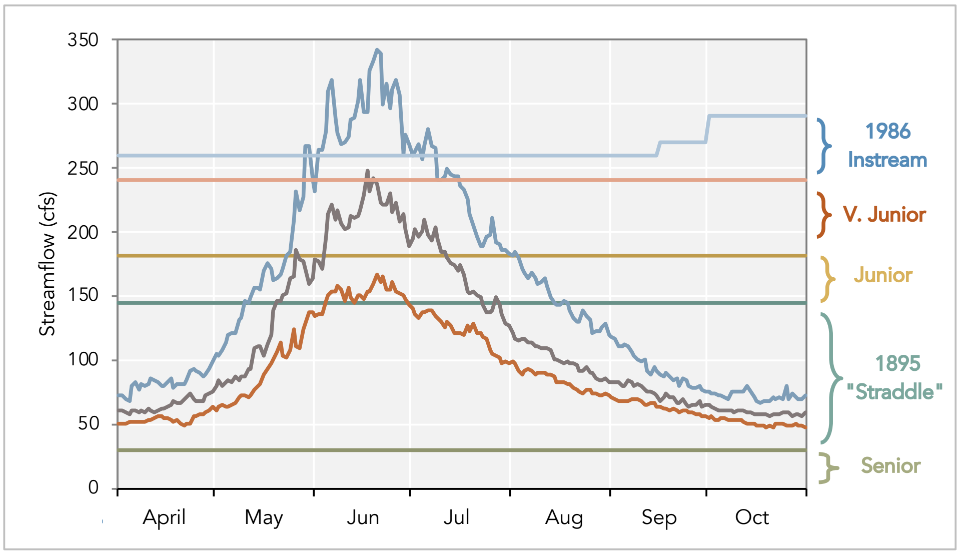
2.5.6 Water Right Reliability

Water right priority dates determine the reliability of surface water rights in Whychus Creek. In order to gage the utility of water rights for in- and out-of-stream use for transactional purposes it is essential to understand the priority date system on the creek. This can be done by quantifying these demands on the creek by order of priority and comparing them to streamflow throughout the year (the supply), in graphical and frequency distribution form below. With more than 25 different priority dates it is first useful to group rights into priority date classes. The classes used are as follows:

1. High Security – senior rights or those with pre-1895 priority date.
2. Medium Security – the "straddle" rights of 1895 priority date.
3. Low Security – junior rights with priority between 1895 and 1903 inclusive.
4. Very Low Security – very junior rights with priority of 1904 to 1967.
5. Junior Instream Security – the 1990 instream right in the upper creek (Cert. 73224)

Figure 15 superimposes a compilation and classification of Whychus water rights against the statistical measures of water availability at the gage on upper Whychus Creek, as previously explained. Pole Creek diversions are not included as the confluence of Pole Creek and Whychus Creek is upstream of the flow gage. The graphic indicates that under normal flow conditions (median flows), only the water rights senior to 1895 are available for the full irrigation season. The TSID 1895 rights straddle the difference between being senior and junior rights as they are fully met for about 2 and a half months and then only partially filled for the rest of the season. The junior and very junior rights only receive water in normal and wet years and only during the May to July period when the snowpack is melting. The instream rights would likely be "in priority" only for a brief period of a month or so during the wettest of years.

FIGURE 15: WHYCHUS CREEK STREAMFLOW (1958-1987) AND WATER RIGHTS BY PRIORITY



Note: The hydrograph shown is the same as that in Figure 9, with 80% exceedance, median and 20% exceedance flows shown in ascending order.

For the purpose of estimating the cost-effectiveness of water transactions it is necessary to have a quantitative estimate of the "wet" volume of water associated with these water rights. This volume of water is called "reliable" in this paper and is denoted by "R-AF" in tables and figures. A simple flow and water rights allocation model is used to estimate the reliability of these water right classes. Daily gage data for the 30-year reference period (as explained above) is used as the inflow to the system and the demands of each class are then filled in order of priority until the flow is exhausted. In other words, the model assumes no losses or return flows on the reach between the City of Sisters and the highest diversions in the system. This is not an unreasonable assumption. As pointed out earlier the first significant interaction with the groundwater system is downstream of the City of Sisters near the confluence with Indian Ford Creek. Another assumption is that demand is constant and that the ditches will divert their water right amount if available. This assumption may over-estimates diversions by senior or 1895 rights in the shoulder seasons of April and October. However, as shown in the hydrograph, supply is scarce at these times so that, for example, even if TSID diverts only a portion of its demand the flow would be fully diverted at the 1895 priority date. And if diversions are low due to weather and its impact on irrigation demand, such periods are not that relevant to the purpose of determining water right reliability.

The reliability model is intended to be forward looking. It attempts to estimate the expected reliability of water rights that might be purchased as part of the water transaction program. For this purpose, the 1997 water right data set was used. Indeed, the DRC used a similar allocation model in its strategic analysis of water transaction opportunities in the early 2000s. The results are shown for the five classes and for the full irrigation season and the two-month period of August and September in Table 3. While there is no historic record of flows at the City of Sisters these two months were likely to be the most critical for the creek in terms of the extent of irrigation demand and low levels of natural flow.

Table 3. Irrigation Season Water Right Reliability, as % of Total Right

Security Class	Full Season	Aug-Sept
High	100%	100%
Medium	62%	55%
Low	24%	6%
Very Low	13%	2%
Instream	7%	0%

As expected from the graphic overlay senior, high security rights can be met at all times. The straddle rights are of medium security realizing 55-62% of the right during the critical period and for the season as a whole. The drop off in reliability from that point is considerable. Perhaps as important as the low reliability of the junior and very junior rights is that they provide practically no water during the August and September period. In other words, these rights are not suitable for full season irrigation but may rather be viewed as "flood" rights that are available only in very wet years or at the peak of snowmelt. The figures for the instream rights confirm that they protect very little water for instream use, being essentially junior to all the out-of-stream water rights on the system.

2.6 Water Use

In this section, a brief review of data on actual water usage in the period prior to the onset of EWTs is offered.

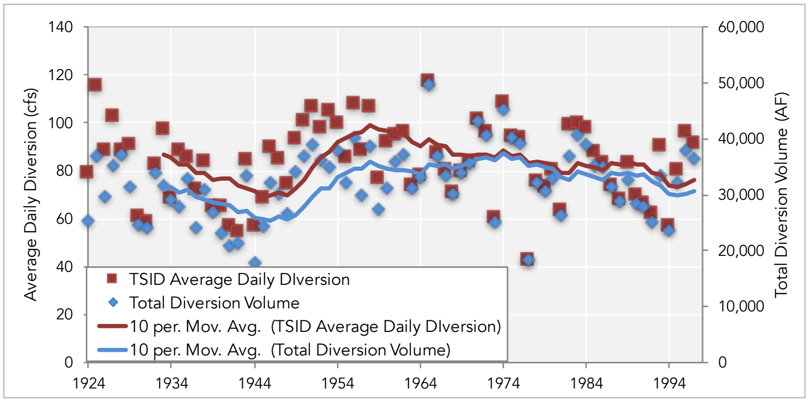
2.6.1 Irrigation Water Use

Water use by irrigators can be measured at points from where the water is diverted through to the consumptive use by the plant. In Whychus Creek, as with many areas in the western US there are few records of historic water use besides that for the withdrawal of water from the source, i.e. diversions. Intermittent diversion records for some of the smaller diversion do exist but are of limited reliability. These were not collected by OWRD but by employees of the City of Sisters for a number of years in the early 2000s. Review of these records and field observations suggest that for senior ditches, like the Uncle John Ditch, the behavior was similar to many streams in the western US. At the beginning of the season irrigators would reconstruct a push up dam in the stream and divert water through a headgate, which was often set to divert the water right amount and left that way until the end of the season. Junior diverters would instead need to be more responsive turning their diversions on and off as instructed by the watermaster. In the case of the largest diverter on the stream, TSID (and SCIC/SCID before that), a concrete dam across the stream was used to more closely regulate the amount of water taken and left to senior diverters downstream on the Edgington, Quiberg, Smith and Buchanan ditches.

Records for the TSID diversion were kept by OWRD for the TSID diversion (OWRD gage #14076000), back to 1924. After a dip during the Depression and Second World War diversions peaked in the 1950s. Figure 16. According to TSID the conversion from flood irrigation to sprinkler irrigation in the 1960s lowered diversions from 50,000 AF to 35,000 AF, and during drought years diversions may be as low as 20,000 AF (TSID 2012). Figure 16 confirms a downward trend in water use in TSID as of about 1960. The ten-year (trailing) moving average for the daily average diversion rate has dropped from 100 cfs to around 80 cfs and the diversion volume to 35,000 or lower by 1997. The difference between these two is affected by the tendency for data to be missing in October (presumably to winter shut down) up to about

1960. For this reason, the data before 1960 is difficult to interpret. However, looking at the moving averages in year 1970 (which refer back to data from 1960 on) the two moving averages crossover at about 85 cfs and 37,000 AF. In the years since the diversion volume has dropped more rapidly than the diversion rate.

FIGURE 16: THREE SISTERS IRRIGATION DISTRICT DIVERSIONS, 1924-1997



Source: OWRD Gage #14076000

It is also worth noting that historic TSID daily diversions exceeded 160 cfs quite frequently. As noted earlier the 1997 TSID water rights totaled just over 160 cfs so these figures are in rough agreement. However, it would appear that even when streamflow was high during wet periods the potential for TSID to pull more than the water right may have impacted stream flow. For example, in June of 1965 the median diversion was 203 cfs. The assumption that in wet periods ample flow would have remained in the creek historically may be incorrect.

2.6.2 Municipal and Domestic Water Use

As noted above, the City of Sisters has only a small population. In 2000 the census recorded 973 inhabitants. In that year Sisters produced about 170 million gallons or 520 AF of water (HGE 2005). This would be over 450 gallons per capita per day (gpcd), a very, very large number. It is therefore helpful to understand the context further. City production far exceeded the 2000 figures in 1987 at 262 million gallons. Work to reduce system losses dropped usage by 25% by 1994. In 1995 water use was metered leading to a further 32% drop in consumption. Population growth continued rapidly to 2000 and continued at a rate of 11% after 2000. Although a small town, Sisters is a summer tourist destination and may see daytime populations of 10,000. On top of irrigation demands this leads to a vast difference between summer and winter production, at a ratio of up to 7 to 1, and explains the overall high per capita water consumption. By the 2000s due to the leak reduction work, annual water consumption was only slightly less than water consumption. Winter consumption was in the 100 to 150 gpcd range during the 2002 to 2004 period. This provides a better indicator of non-irrigation indoor residential and commercial use and is not unreasonable given the number of commercial establishments, particularly restaurants, that line the highway through downtown.

As noted earlier, a rough estimate may be that within the watershed as many people live outside of Sisters as within Sisters. Overall, municipal and domestic water withdrawals are probably no more than 1,000 AF/year (or withdrawals of 178 gpcd for a population of 5,000). Municipal and domestic water use is thus minor in the overall context of water use in the watershed.

2.6.3 Environmental Flows and Instream Uses

Following development of senior irrigation rights as well as the 1895 rights on the (then) Squaw Creek Irrigation Company's canal the creek was regularly dewatered during the irrigation season by the time it passed through Sisters, with Buchanan Ditch diversion, the last diversion occurring just upstream from the site of the OWRD gage, located near the juncture of the creek and state route 20 on the outskirts of Sisters. According to available streamflow records the stream "ran dry" two out of every three years from 1960 to 1999 (UDWC 2013). The comparison of water rights and the creek's hydrograph presented earlier suggests that dewatering of the stream was a likely occurrence in all but extremely high flow periods.

3. Environmental Water Transactions in Whychus Creek

3.1 Environmental Water Transactions

Transactional approaches to restoring streamflow in the western United States emerged in Nevada and then in Colorado, Oregon and Washington in the 1990s (Neuman & Chapman, 1999; Willey 1992). Since that time environmental water transactions (EWTs) have spread to most of the western states. As the approach moved southwards into more arid regions transactions were also deployed to acquire water for the restoration of riparian and floodplain restoration. EWTs are agreements by which a water user commits to a change in their water use and/or water right leading to legal or de facto dedication of water to environmental purposes (Aylward 2013).

There a number of features that define EWTs and that can served to categorize "like" transactions (Aylward 2013):

- how the water is freed up for environmental use or "saved" in the original water use;
- whether or not the transaction involves the buyer taking ownership (fee title interest) in the water right;
- how the water that is saved is committed to environmental use, i.e. is it protected instream through a change in the water right so that it can be called to the prior point of division and on past diverters junior in priority or does the irrigator simply abstain from diverting the water;
- the duration of the commitment, i.e., the term of the agreements from a single year to a transfer in perpetuity; and
- the source of water involved in the transaction, i.e., natural flow, stored surface water and/or groundwater.

A one year, full season agreement for an irrigator to fallow a field will be effectively the same type of transaction according to four of these features, but differ substantially in practice if the transaction is just a contract between a conservation group and the irrigator (i.e., a forbearance agreement) or is such a contract plus an instream lease of the irrigator's water right approved by the relevant state authority. And, of course, a lease in one location may be different than a lease in another due to the terms and conditions imposed by the relevant legislative authorities, applicable agency rules and the interpretations of such by agency personnel.
Despite these distinctions the primary feature used to "type" or categorize EWTs is the manner in which the water is saved. In part, this is because what the irrigator needs to do in order to make the water available for instream use is going to determine the implications of the transaction for the irrigator and hence drive the incentives to participate. These implications are not just monetary, as in what the irrigator gives up in revenue or what the irrigator must spend to become more efficient in their water use, but may also include cultural, environmental and other consequences. From the perspective of the conservation group the implications for the seller will be the primary determinants of what it will cost to buy the water. These costs will include the water cost, i.e., the monies paid to the irrigator obtain the water, and the transaction costs, i.e., the effort and associated costs of developing, negotiating and implementing the transaction. A list of the major transaction types is included in Table 4.

TABLE 4. LIST OF WATER TRANSACTION TYPES

Water Savings Approach
A. Water Management Savings
1. Upstream

	Timing of Storage Release	Changing the timing of release of stored water to create additional environmental flow.
	Source Switch	Change from one source to another frees up water for environmental flow.
	Point of Diversion Change	Downstream point of diversion creates environmental flow throug leaving water instream longer or saving on losses.
2.	Conveyance Systems	
	Diversion Efficiency	Improving a diversions structure reduces the amount of water that must be diverted to meet water user needs.
	Delivery Efficiency	Improving water management within a ditch system, e.g. through ditch controls, ordering or automation, reduces water losses and diversions needs.
	Transmission Efficiency	Improving the efficiency with which water is conveyed through the system, such as with lining or piping of ditches and canals.
3.	At Point of Use (e.g. at the farm)	
	On-Farm Efficiency	Improving the application efficiency for water on the farm, e.g. going from sprinkler to drip.
	Shallow Aquifer Recharge	Spreading water on the ground surface, either in a passive or managed fashion (e.g. with technology to increase infiltration) to generate environmental flow at a later period in time.
	Aquifer Storage and Recovery	Storing water during the off-season in order to then pump it out for later use when needed.
B.	Consumptive Use Savings	
	Crop Switch	Changing from a high consumptive use crop to a low consumptive use crop, or deficit irrigating.
	Deficit Irrigation	Purposefully irrigation a crop at a rate that constrains the crop's growth rate or productivity.
	Take Land out of Agricultural Production	Fallowing or permanently removing water from land area.

3.2 State Legal/Regulatory Setting: History of Water Management in Oregon

Over the last 100 years water use and management in Oregon can be loosely seen as moving through a series of phases or eras as described below.

3.2.1 The Open Access Era: Settlement pre-Water Code

From the 1840s on settlers moved to the region, displacing indigenous communities and engaging in primary production, largely harvesting of wildlife, mining, timber extraction and agricultural production. During this era there was no explicit water code and in many places "first in time, first in right" was the accepted customary practice for acquiring claims on water use. Waterways were highways for steamships and transporting logs to mills and markets. Gradually settlers constructed diversions and dug canals and ditches to convey water to their properties. Such gravity irrigation diversions were particularly prevalent where the stream course could easily be diverted out of the stream and transported down-gradient to arable lands. The area in and around Sisters on Whychus Creek was one such area with efforts to irrigate lands occurring as early as 1869 (the priority date of the most senior right on Whychus Creek).

3.2.2 The Prior Appropriation Era: Development of a Water Rights System

In 1909 the Oregon legislature established the first state water code. Waters of the "state" were defined and a permit system established to allocate water to beneficial uses, which at the time largely meant the diversion of surface waters for agriculture and other economic activities, as well as for communities and towns. Early settlers established pre-1909 claims for water were recognized by the Code. The claims were often for the typical yield of a stream (if not more) and thus in the years up to World War II the state adjudicated their claims in a number of basins through the state. Through the adjudications these earlier claims were confirmed as vested rights and incorporated into the priority date system alongside post-1909 rights established under the code. During this period the federal government, through the Bureau of Reclamation, entered the picture as it helped to develop medium- and large-sized irrigation projects in sites with large amounts of irrigated acreage. In some basins, this also meant the construction of storage reservoirs once the supply of natural summer flows was fully tapped. As noted earlier the waters of Whychus were adjudicated by decree from 1911 to 1916. While storage facilities were developed on the main stem Deschutes, including the Deschutes Project build by Reclamation, the Whychus Watershed offered little opportunity for the damming and storage of water and remains unregulated by dams to this day.

3.2.3 The Era of New Supply: Hydropower, Flood Control, Large Dams and Rural Electrification

Up to World War II, low population levels in Oregon meant that the primary use of water in the state was for agriculture. In some places, irrigated agriculture expanded quickly enough to dewater streams and degrade ecosystems and associated fish and wildlife resources. For example, the Deschutes River went dry at Bend during the summer of 1932. However, starting in the 1930s a new era of water resource development began, one that ultimately led to the current day conflicts of water management. On the Columbia River, the development of a federal power system led to the damming and storage of waters throughout the Northwest, with eventual catastrophic effects for the regional salmon fishery. During this period federal, state and local entities also constructed significant storage dams not just for hydropower but also for irrigation and flood control purposes on rivers across Oregon. These facilities allowed the further expansion of irrigation agriculture as well as providing power sources that, starting in the 1950s, expanded the power grid to rural areas. As access to power spread, farmers, communities and, ultimately, homeowners were able to expand their water use via wells in areas without direct access to surface water systems. While the impact of this new draft on groundwater resources was not felt until later, the increase in storage facilities and accompanying investments in channelization of downstream waterways for flood control, greatly modified the downstream hydrograph and freshwater aquatic habitat, causing widespread ecosystem decline, perhaps best exemplified by the local extirpation of wild salmon stocks across the state. These trends were felt in Whychus Creek which not only lost its salmon runs once the Pelton Round Butte Hydropower Complex was installed downstream on the Deschutes River, but often went dry in and around Sisters due to the overallocation of water rights.

3.2.4 The Environmental Era: Instream Use and Water Conservation

As part of a national trend towards addressing the growing imbalance between development and the environment, the State of Oregon began addressing the decline in its aquatic ecosystems in the 1950s. Minimum stream flows and a new multiple use integrated policy reflecting the federal National Water Commission Report were passed by the legislature in 1955 as part of a set of broad environmental reforms that continued into the 1970s. These reforms included the creation of the Department of Environmental Quality, the Fill and Removal Program of the Department of State Lands, and represented a centralized response to water quantity and quality issues.

With the passage of the Oregon Instream Water Rights Act in 1987 the legislature provided an additional set of tools for addressing stream flow concerns. The act recognized instream, and therefore ecosystem uses, as beneficial uses and thus incorporated them into the prior appropriation system. The transfer of existing prior rights to instream use was authorized and provisions made for the legal reallocation of water saved through conservation measures. Such reallocations of water were allowed through purchase, lease, or gift, in effect enabling transactions in instream water rights. The conversion of minimum stream flow into instream water rights only served to further over-allocate such basins and effectively close them to further appropriation of surface water rights. These instream rights with priority dates after 1955 were of junior priority in the system and were met only once prior natural flow and storage water rights were filled. Still the act represented a major change in vision as it directed the Oregon Water Resource Department to serve all beneficial uses, including both out-of-stream uses and public, instream uses. In the mid-1990s, public funding sources and a number of non-profit water trusts and conservancies were established and paired up to invest in water rights acquisitions and funding large conservation projects as a means of obtaining senior rights for instream flow.

Meanwhile, demand for new groundwater pumping continued to increase across the state, in some places as much for the purpose of acquiring water to satisfy residential and commercial demands associated with growing population as for supplemental use in irrigation. Responding to the inevitable concern that new groundwater pumping would ultimately take surface water away from both long-established irrigation uses and the newly developed instream water rights, the state began experimenting with regulatory and market-based approaches to limiting groundwater extraction. During this period, the interest in dam building and major water development projects also subsided based largely due to the realization that the best sites had been taken, the onset of increased environmental restrictions and concerns over the use of public investment to cover the escalating costs of such projects.

3.2.5 Whychus as Experimental Case Study

The end of the era of new supply and an increasing realization that basins were going to need to live within the finite constraints of their water supply has led to a reshaping of policy, law and regulation at the state level. It fell then to stakeholders in specific places to figure out how to implement these reforms. This led to a mix of experimentation, pilots and innovation in an effort to meet ecosystem and new human needs through a variety of technological and market-based approaches. All of these trends come together in the case of Whychus Creek, long a poster child for the environmental effects of overallocating streamflow through appropriation of out-of-stream water rights.

The junior instream rights on Whychus Creek are insufficient for ecological recovery of systems that have been dewatered for almost a century. They serve to protect remaining flow in streams but do not augment flow in and of themselves. The effect of these junior rights was to insert a protected class of instream rights in front of any further out-of-stream appropriations. In another policy advancement, OWRD takes a regulatory approach to the granting of additional water rights that involves a determination as to whether water is available for further appropriation (Cooper 2002). During the period of time investigated here, efforts by potential appropriators to acquire new surface water rights for irrigation from Whychus Creek were processed and denied by OWRD due to the lack of water available for appropriation. This determination relies on the expected consumptive use of already granted rights, as well as the extent of ODFW junior instream rights. Thus, Whychus Creek is closed to further appropriations, at least during the irrigation season.

The Oregon Department of Fish and Wildlife (ODFW), which applied for these instream rights, had no intention however of deploying the authorities established under the Instream Water Rights Act to carry out transactions to meet these instream flows, i.e. to "fill" these junior instream rights with senior water rights. As described below, this market-based reallocation of water rights relied on the development of another set of actors. These actors and the transactions they carried out avail themselves of the policy, legal and regulatory reforms that have followed on the 1987 Instream Water Rights Act. Almost all the transactions reported on involved the use of the following administrative rules (OARs) for the creation of instream water rights (even if only temporarily), consistent with the Act:

- Division 690-077 Instream Water Rights (transfers and leasing);
- Division 690-018 Allocation of Conserved Water;

Assessment of the Act and the broader policy environment surrounding environmental water transactions in Oregon can be found elsewhere (Neuman and Chapman 1999; Neuman 2004; Aylward 2008; Garrick et al. 2009; Neuman, Squier, and Achterman 2006; Pilz 2006) The focus of this paper is on the transactions, their cost and their performance in improving environmental flows. The impact of these transactions more broadly on the watershed are also considered.

Another important policy development in the Deschutes Basin was the closing of the basin to further groundwater appropriation, absent the appropriate mitigation. Separate regulations govern this groundwater mitigation program:

- Division 690-505 Deschutes Basin Program (groundwater mitigation);
- Division 690-521 Mitigation Bank Credit Rules: and
- Division 690-522 Deschutes Basin Water Management

Originally, passed by the Water Resources Commission as regulations, these were challenged in the courts and found to be lacking the necessary legislative authority. Subsequently, the Oregon legislature instated these regulation into statute (HB 3623). The objectives of the mitigation program are (OWRD n.d.):

- to maintain flows for Scenic Waterways and senior water rights, including instream water rights;
- to facilitate restoration of flows in the middle reach of the Deschutes River and related tributaries; and
- sustain existing water uses and accommodate growth through new ground water development.

The groundwater mitigation program and relevant transactions are included here as despite serving a "mitigation" many of these transactions confer a net streamflow benefit. The program anticipates that groundwater withdrawals will adversely affect flows in streams where the groundwater resource is linked to the surface water resource. In the upper Deschutes Basin the young and permeable Deschutes Formation is underlain by the older more impermeable John Day Formation. At certain points in the basin this intersection forces groundwater up and out onto the surface as springs, springs that feed streams and rivers in the basin. For example, in the Whychus Watershed there are small springs in the vicinity of the confluence of Whychus Creek and Indian Ford Creek and very large springs (over 100 cfs) at Alder Springs just above the confluence of Whychus Creek with the Deschutes River.

Water right leases and transfers (under 690-077 and 690-018) are used to create mitigation credits under the Deschutes Program. These instream rights are protectable at the old point of diversion and on downstream. Typically, impacts from pumping on streamflow generally occur downgradient from where the groundwater is pumped. In Whychus Creek, depending on the depth of the well, these impacts occur at the confluence with Indian Ford Creek or far downstream at Alder Springs. The instream water rights, however, are protected at points of diversion up higher on the creek, above Sisters. As a result, the mitigation program is creating a restoration benefit from the old point of diversion through to the point of impact. For this reason, the environmental flows created by mitigation transactions are included in the analysis of performance in this paper, though they are not directly a result of environmental flow restoration activity per se.

This logic of net environmental benefit underpinned the DRC's application for a water bank charter under the groundwater mitigation program rules. This bank allows the DRC to use water leased instream to generate temporary mitigation credits that can be sold on an interim basin to new groundwater users pending their acquisition of permanent mitigation credits. It is worth noting that temporary credits created from leases are effectively sold at a 1:2 trading ratio, that is for each credit the bank allocates to a customer it must keep an extra credit in reserve. Leasing for mitigation thus carries an additional net environmental benefit as each groundwater user is returning double their expected impact to the stream.

3.3 Actors and Partnerships

The Oregon Water Trust (OWT) was founded in 1993 with the aim of restoring streamflow across Oregon. In its early years Whychus Creek (or as it was known then Squaw Creek) was a focal priority for OWT efforts to deploy water leasing and transfers made feasible by the 1987 Instream Water Act. Much of the interest in the creek stemmed from it representing a large portion of the spawning habitat for anadromous fish in the upper Deschutes Basin (UDWC 2013). These fish were extirpated from the upper basin by the construction of the Pelton-Round Butte Hydropower Complex in the early 1950s.

The Deschutes Basin Resources Conservancy (later renamed the Deschutes River Conservancy or DRC) was founded in 1996 through an act of Congress. The DRC is a non-profit organization with a mission of improving the water quantity and quality of the Deschutes River and its tributaries. The board of the DRC is made up of sectoral and administrative interest in the basin. In its early years the DRC was authorized to receive Congressional appropriations. These funds were used to launch a challenge grant program for projects that addressed the DRC's mission. These included all types of land and water projects related to the organization's mission. Two of the projects funded in the late 1990s involved the piping of two canals in the Three Sisters Irrigation District and the dedication of a portion of the saved water to instream use under the State of Oregon's Allocation of Conserved Water Program. Over time, environmental water transactions came to be the DRC primary activity, using funds from a number of sources including Bonneville Power Administration, the Oregon Watershed Enhancement Board, the Bureau of Reclamation (DRC appropriation and challenge grants), the Pelton Water Fund and a number of other public and private funding sources.

The Pelton Water Fund was initiated following successful relicensing of the hydropower complex in 2005. The relicensing included over $100 million in funding for the reintroduction of anadromous fish including a fish collection facility in Lake Billy Chinook and a fund for habitat restoration, to include streamflow restoration. The first release of juveniles occurred in 2010, with first returns above the dams occurring the next year. DRC efforts in Whychus Creek dating to the late 1990s reflect the active participation of Portland General Electric and the Confederated Tribes of the Warm Springs Reservation on the DRC board and the need to frontload flow restoration efforts to provide habitat for the anticipated return of salmonids to the watershed.

The Upper Deschutes Watershed Council and the Deschutes Land Trust were also active participants and partners in early efforts to restore streamflow. Over time a partnership evolved between DRC, UDWC and the DLT in which each entity focused on a particular restoration activity as part of an overarching plan to restore anadromous fish to Whychus Creek. The UDWC took on the removal of entrainments, stream channel restoration, riparian and floodplain habitat restoration, including lead on design and implementation of the restoration of Camp Polk Meadow. The DLT engaged with landowners up and down the creek to develop easements and land restoration/protection actions and partnered on the restoration of Camp Polk Meadow, a land trust property.

The streamflow restoration work that began in the late 1990s was only possible due to the active participation of senior water right holders on the creek and TSID. In particular the visionary and practical leadership of the TSID manager was instrumental in first experimenting with and then upscaling all phases of piping district laterals and canals, from the design and construction through to collaboration on financing and water rights changes for the projects.

3.4 Streamflow Targets

The State of Oregon instream water rights summarized earlier provide the State's determination of beneficial use of flow in Whychus Creek for fish and wildlife purposes. These are water rights not streamflow targets. The Oregon Department of Fish and Wildlife (ODFW), which applied for these rights, had no intention of carrying out transactions to meet these instream flows.

In formulating its work program the DRC adopted streamflow targets in its priority reaches for flow restoration. In the case of Whychus Creek, the DRC established a target for streamflow through Sisters, i.e., in the same reach as Certificate 73224 for the upper reach of the creek. The initial target selected by DRC was a target of 20 cfs. In this the DRC was guided by Certificate 73224 and ODFW's application for this amount as an instream right. The target was approved early on in the organization's history and was affirmed in the 2003 DRC Strategic Plan. More recently, the DRC board approved a Strategic Plan that included a higher flow target for Whychus Creek, setting the target at "DRC's target is 33 cfs from April through October, or whenever else TSID is operating" (Golden, pers. com 2015). The adoption of this higher target reflected two developments. First, as shown later in this paper, by the early 2010s the DRC had succeeded in largely meeting the 20 cfs target during the irrigation season. However, research carried out by UDWC staff suggested that this streamflow level would not result in temperatures low enough to support "robust fish populations in some locations and at some times of year." The DRC set this 33 cfs target based on the June to February amounts in Certificate 73223 for the lower reach of Whychus Creek. The target was set as an achievable target for a ten-year period and the DRC Board reserved the option to increase the target as necessary to meet goals in the creek.

In the analysis that follow the 20 cfs DRC target is used as most reflective of the objective that applied during the period when most of the transactions reported on here were developed. The results for the later (and current) 33 cfs DRC target are also included as reflective of the current restoration situation.

3.5 Whychus Creek Water Transactions

As part of the larger cooperative effort to restore functional habitat on Whychus Creek a large number of water transactions have been undertaken in Whychus Creek since the late 1990s. These include the following transactions:

- purchase and instream transfer of individual senior rights;
- instream leases of individual senior rights and Three Sisters Irrigation District (TSID) rights;
- surface to groundwater switch with TSID;
- piping of canals and laterals (largely within TSID) for allocations of conserved water;
- downstream point of diversion switch and conserved water with individual and TSID water right holders;
- instream lease and transfer of municipal surface water rights for groundwater mitigation
- municipal purchase of land and water rights for water security and potential future use in groundwater mitigation.

In the last of these transactions the City of Sisters has purchased portions of a ranch (the Lazy Z) with senior and junior water rights that borders the City. The City sited its wastewater ponds on the corner of the property and may use its wastewater on the property. This might free up the surface water rights for instream use and/or use as mitigation credits. As this transaction has not yet led to environmental water transactions it is not included in the analysis. However, the numerous leases and occasional transfers for groundwater mitigation are included in the analysis of environmental flows. In some cases, these mitigation credits are purchased and can be assigned a cost. In others, the entity that owns the surface water right and that desires a new groundwater right is one and the same. In this case there is no directly observable cost. In the cost-effectiveness analysis, transactions that have no cost are left out of the analysis. Transactions where water right holders were paid for leases and transfers, even if they were subsequently remarketed as mitigation credits by the DRC are included in the cost-effectiveness analysis.

Aylward et al. (2016) provide a robust discussion of the usefulness of cost-effectiveness analysis for various participants in environmental water transaction programs, be they practitioners, nonprofit leaders and board members, funders or the public. The Whychus program includes transactions with a variety of durations (annual to permanent) that have occurred across a span of twenty years. It is impossible to compare and group the effectiveness of these transactions on a cost basis without a systematic approach to effectiveness and cost. In this paper, the cost-effectiveness of each transaction and transaction type is calculated as the inflation adjusted financial cost of acquiring the water rights divided by the discounted reliable water volume. Computing the constant 2016 dollar cost per reliable discounted acre-foot puts all the transactions on an equal footing for comparison. These results are present below in the tables for each type of transaction. The Appendix to the paper contains a more detailed explanation of the procedure used for computing the cost-effectiveness of transactions.

Data for this effort comes from a number of sources but primarily from OWRD and the DRC. The environmental flows expected from leases, transfers and conserved water are established by referencing the water right applications, final orders and resulting certificates on the OWRD WRIS (as explained in Section 2.5.2). The actual instream flows over this period are sourced from the online gage data for the USGS and OWRD gages above diversions and at Sisters, respectively. Information about each transaction, and in particular the amount paid to water right holders, was provided by the DRC and the Oregon Water Trust. The data was gathered and processed in a spreadsheet format linked to a dashboard providing transaction, effectiveness and cost-effectiveness metrics, as developed for The Nature Conservancy – California Chapter.

The data which forms the basis for the analysis below excludes transactions that exclusively relate to flows in Indian Ford Creek and the lower portion of Whychus Creek, but include all transactions related to flows in the upper portion of Whychus Creek, including those on Pole Creek.

Generally, the data can be considered to consist of environmental flow information, consisting of individual records of water rights obtained for instream use. A given water rights transaction may have several of these records as a single transaction may involve one or more rights and a given right may itself have two or more priorities (or seasons or reaches) each with their own rate or duty of water. A single transaction is defined largely as the payment associated with a given commitment to environmental flows (as evidenced by a single lease, transfer or conserved water application or finalization). As such it should be noted that a single transaction may impact a number of landowners. Piping projects and leases which pool a number of water right holders on a single lease are examples where a single transaction will affect the water rights and water use of multiple landowners.

Some transactions that involved specific sums of money and that result in specific instream water right certificates are clearly part of larger projects. Due to their size, a number of the major TSID canal piping projects were carried out as separate transactions, effectively resulting in an annual financing construction task for TSID and the DRC. Similarly, each year multiple instream leases were carried out between TSID, the DRC and participating landowners. When viewed at the twenty-year scale of the current other suites of transactions also logically fall into place as a project. For example, a series of leases and then a transfer of water rights by individuals is effectively a "lease and transfer project."

In the data set assembled there are 186 environmental flow records, 83 transactions and 30 projects. Each of these datsets is linked in a one to many fashion with its corresponding parent records.

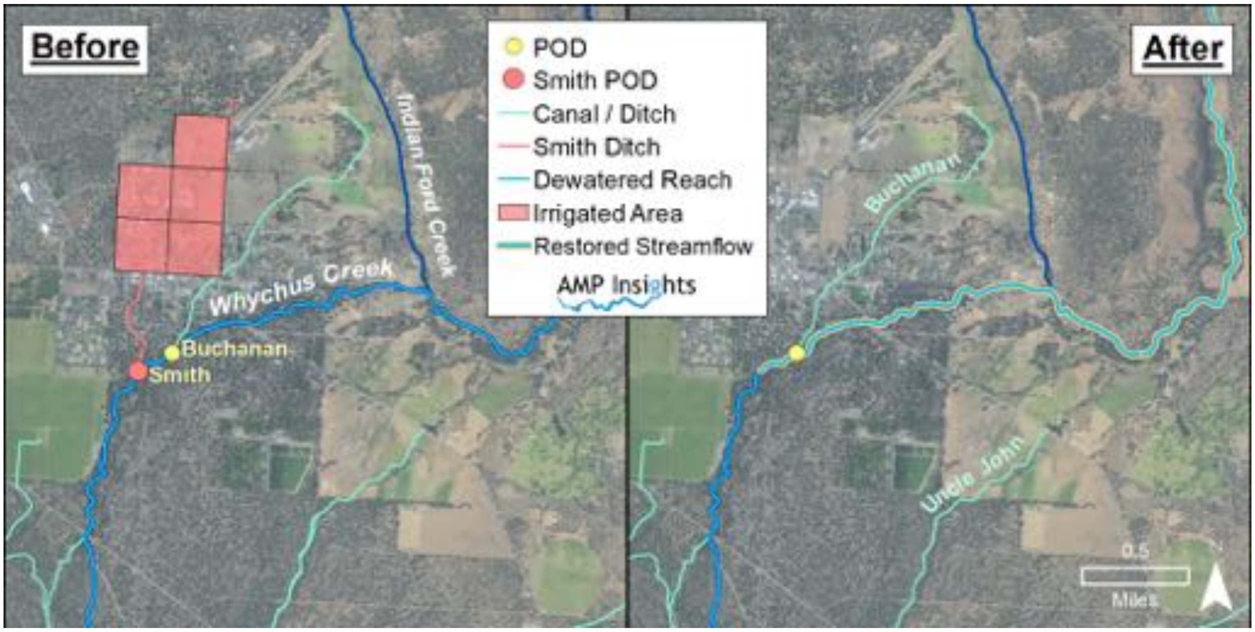
In the following sub-sections an explanation of each type of transaction is provided along with the description of one or more examples and a full reporting on the costs and water acquired, including the cost-effectiveness results.

3.5.1 Water Right Purchase and Instream Transfer

As reported earlier the Oregon Water Trust began operations in 1993. In 1994 the Trust completed its first (and Oregon's first) paid instream lease with Rocky Webb on Buck Hollow Creek a tributary to the Deschutes River below the hydropower complex. In 1996 the Trust completed its first transfer, an $8,000 transfer of 8.2 acres of water rights for 0.16 cfs in the Rogue Basin. As the Trust began work in Squaw Creek the first opportunity that emerged was to carry out a transfer with a small number of landowners that still had active senior water rights on the Smith Ditch. The point of diversion for the ditch was on the outskirts of the City of Sisters and the ditch itself crossed the downtown area to irrigate lands within the city, which was increasingly being developed. The Smith-Barclay project consists of payments of just over $109,000 to three landowners in respect of two instream transfer applications. As with the prior transfer completed buy OWT, the payments amounted to about $1,000 per acre of water rights. The transfers were for a total of 1.81 cfs and were completed at the end of 1997 and the other in September of the following year. In the process of the transfer about 10 of the 100 acres being transferred had to be cancelled due to non-use.

Not only was this a seminal transfer for the Trust, but it represented the first permanent dedication of senior instream rights in the upper portion of Whychus Creek. While instream leases began contributing to flows in the creek in the early 2000s, it was not until 2006 that another transaction permanently dedicating a senior water right to instream use was completed. Notably, as the first instream transfer in Whychus, and the second completed in Oregon, the final orders on the two transfers did not exceed three pages in length, and the full rate of the transfer was protected to the mouth of Whychus Creek. A before and after view of the transaction is provided in Figure 17 showing the location of the acres that were transferred and the reach of restored streamflow. This transfer effectively shut down irrigation on the Smith Ditch, stranding a number of other irrigation water rights on the ditch. As summarized in Table 2 in 1997 the Smith Ditch was home to 6.2 cfs and 301 acres of water rights. While the remaining rights are technically still on the books, they are considered as abandoned in the water rights reckoning as of 2016, presented later in this paper.

FIGURE 17. SMITH-BARCLAY INSTREAM TRANSFERS

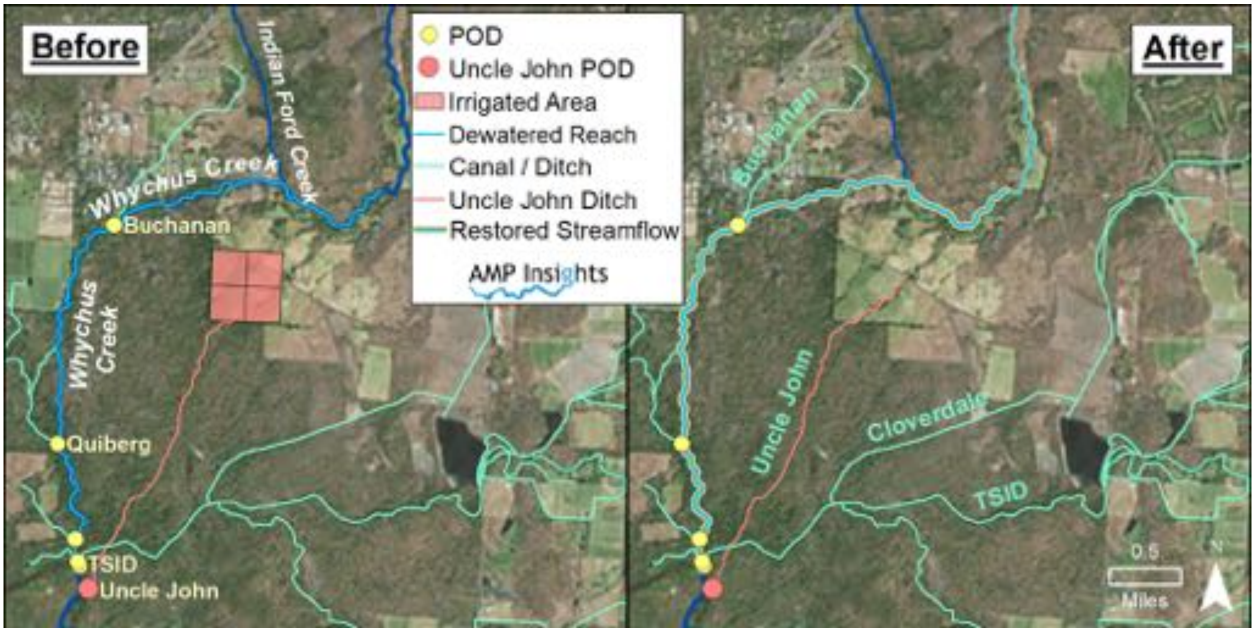


The next instream transfer in Whychus Creek did not happen until 2011. For many years efforts were made by OWT, DRC, DBLT and the UDWC to court the five or so senior water right holders on the creek with rights outside of TSID. This was necessary as TSID (to this day) maintains a stated policy of not allowing the transfer of water rights out of the district and to instream use. In many cases, the landowners were simply not interested in talking with representatives of these conservation organizations or if conversations were had they led nowhere. The exception was the Lazy Z Ranch, the iconic spread on the outside of Sisters on the way to the City of Bend. Owned by a businessman with diverse interests the DRC secured a tentative offer to purchase the entire 6 cfs of senior rights on the Uncle John Ditch at a price of $5,000 per acre. The DRC Board, leery of the price and total cost of this water looked to the OWT Board to partner on the transaction. However, the OWT Board was reluctant to do so given their experience with transactions around the state and the much lower price of the Smith-Barclay transaction. An effort by the DRC to support the price through an appraisal ran into difficulty when the local firm selected to do the work failed to produce a formal appraisal on a timely basis. While this avenue was still being pursued, the owner of the rights switched tack and approached the DBLT suggesting that they could buy the entire property at $15,000 acre, including the water rights. This negotiation was just as successful as that for the water rights alone. In the end, the owner decided on a plan to parcel out the property to the maximum extent and market the land and water as 25 different parcels. As part of this process a variety of landowners purchased land and water with the City of Sisters acquiring the larger parcels with senior rights.

All was not however lost as one of the landowners that acquired land and water from the Lazy Z moved to develop the property (on the edge of Sisters as shown in Figure 18) leading eventually to a DRC purchase and transfer of 63 acres of these senior rights. The cost of the water was $428,000. At over $6,000 per acre the price exceeded that of the offer made five or so years earlier by the owner of the Lazy Z. The transfer application for this transaction was submitted in September of 2009 and the final order was issued by OWRD in February of 2011. The final order ran 10 pages and notably included parsing out the environmental flows into different seasons and reaches, each of the latter with their own rate and duty of instream flow. The determination of the department was that up to May 15th of each year 1.61 cfs was protectable was protectable down to the point of return flow at the springs near the confluence with Indian Ford Creek. From May 15th onwards each year the rate is reduced to 1.26 cfs. From Indian Ford

Creek on downstream an amount consistent with the consumptive use (just 0.31 cfs) is protectable to the mouth of Whychus Creek.

FIGURE 18. LAZY Z-WILLETS INSTREAM TRANSFER



The Smith-Barclay and Lazy Z-Willets transactions provide an example of how the parties to these transactions can learn and evolve in their practice over time. After another hiatus of some five years two additional landowners with senior rights, this time on the Buchanan Ditch, also concluded purchase and transfers with the DRC and the City of Sisters. These transfers, completed in 2016, effectively terminated diversions on the Buchanan Ditch, again stranding a series of additional rights, much as the Smith-Barclay transfers did in the later 1990s. In addition to these transfers there have been three separate transfers of water rights, two by the City of Sisters and one by a water right holder. While a number of senior water right holders remain on Whychus Creek the passing of twenty years of action have seen a total of $854,000 (in 2016 dollars) invested in instream transfers (Table 5). All told the transfers have yielded 4.6 cfs of senior rights in the creek.

TABLE 5. WATER RIGHT TRANSFERS

Transaction Name	Transfer #	Payment Year	Effective Year	Payment Amount (current $)	CPI Adjusted Cost (2016 $)	Purchased Acres	Face Value Eflows		Reliable Discounted Volume (RD-AF)	Cost-Effectiveness (in 2016 $)			
							Volume (FV-AFY)	Rate (FV-cfs)		per Acre	Volume (FV-AFY)	Rate (FV-cfs)	Volume (RD-AF)
1. Smith-Barclay 1	7839	1997	1998	$ 42,900	$ 64,151	43	418	0.9	8,710	$ 1,495	$ 154	$ 74,595	$ 7
2. Smith-Barclay 2	7958	1997	1998	$ 52,647	$ 78,727	45	335	0.7	6,714	$ 1,749	$ 235	$ 114,097	$ 12
3. Smith-Barclay 3	7958	1997	1998	$ 13,860	$ 20,726	13	126	0.3	2,590	$ 1,607	$ 164	$ 79,715	$ 8
4. Lazy Z - Willets	10952	2009	2011	$ 428,400	$ 479,260	63	481	1.3	10,032	$ 7,607	$ 806	$ 380,365	$ 48
74. Sisters-PC-SR-Transfer	11300		2012	mitigation transfer		municipal	145	0.2	2,975				
85. Sisters-T2016	11321		2017	mitigation transfer		4	21	0.1	427				
86. Leithauser-T2016	11320	2016	2017	$ 211,251	$ 211,251	33	182	1.0	3,770	$ 6,338	$ 1,159	$ 203,126	$ 56
87. Tehan-T2016	11358		2016	mitigation transfer		11	61	0.1	1,240			$ -	
Totals				$ 749,058	$ 854,115	212	1,769	4.6	36,458				
Totals for Paid Transactions				$ 749,058	$ 854,115	197	1,543	4.1	31,816	$ 4,333	$ 553	$ 207,814	$ 27

Note: Face Value is abbreviated as FV, AF refers to an acre-foot and AFY refers to an acre-foot in perpetuity. See Section 4.4 for an explanation of CPI Adjusted Cost and Reliable Discounted Volume.

3.5.2 Water Rights Instream Lease (and Diversion Reduction Agreement)

TSID and the DRC have partnered on an annual water leasing program every year since 2002. Although TSID does not allow instream transfers it is supportive of leasing as a way of meeting landowner needs and augmenting instream flows each year. The district typically leases a batch of rights during the early irrigation season, usually up to July 1, and a second batch for the second portion of the season, from July 1 through October. The leases are typically one-year leases with new landowners and leases filed each year. While there are many landowners who have leased more than once, annually about ten landowners participate in the program on average. Each year from 2006 to 2010 the district filed a single split season lease under the special rules governing this type of lease. In 2011 this practice was ended and from the data collected, and the batched, seasonal manner in which regular leases are filed, it is not clear how these split season leases varied from the regular instream leases.

From 2002, the DRC paid a fixed $7/AF based on the face value of the water right. In the late 2000s the DRC moved to a payment system on Whychus Creek based on the effective "wet" water instream based on the priority date of the leased water.

All told, during the 15 years of leasing TSID has filed 39 lease applications, both split-season and regular Table 6). Lease payments of $173,000 (2016 dollars) have generated over 8,200 AF of reliable environmental flows at a cost of about $21 per AF of reliable water. Approximately 150 cfs of water rights have been leased meaning some 10 cfs per year is leased in two batches, or on average about 5 cfs of water rights throughout the irrigation season. In addition, to these formal leases through the state leasing program there have been a few cases where water rights in the transfer process were subject to a diversion reduction agreement, involving the landowner and TSID.

In addition, the DRC and a number of individual water rightholders have carried out instream leases of irrigation and municipal rights. The DRC has a policy of not paying public entities for water leases and thus the municipal leases result in environmental flows but are not compensated. In some cases, other leases were not compensated due to the rights being in a transfer process. A total of 11 of such leases since 2005 resulting in a total of 17 cfs (over the time period). As many of these leases were not compensated, were for mitigation or were effectively part of lease and transfer transactions the cost-effectiveness of this activity in total at $1 per AF of reliable water is quite good, but not a particularly useful figure.

TABLE 6. WATER RIGHT LEASES AND DIVERSION REDUCTION AGREEMENTS

Transaction Type	Number of Transactions	Payment Amount (current $)	CPI Adjusted Cost (2016 $)	Leased Acres	Face Value Rate (FV-cfs)	Reliable Discounted Volume (RD-AF)	Cost-Effectiveness	
							per Acre	Volume (2016 $/ RD-AF)
TSID Leases	39	$ 153,601	$ 173,410	7,844	149.8	8,219	$ 22	$ 21
TSID DRAs	3	$ 4,241	$ 4,728	330	7.2	749	$ 14	$ 6
Individual Leases	11	$ 3,029	$ 3,454	180	16.6	5,927	$ 19	$ 1
Totals	53	$ 160,871	$ 181,592	8,354	173.6	14,895	$ 22	$ 12
Totals for Paid Transactions	45	$ 160,871	$ 181,592	8,167	156.7	10,779	$ 22	$ 17

Note: Face Value is abbreviated as FV, AF refers to an acre-foot. See Section 4.4 for an explanation of CPI Adjusted Cost and Reliable Discounted Volume.

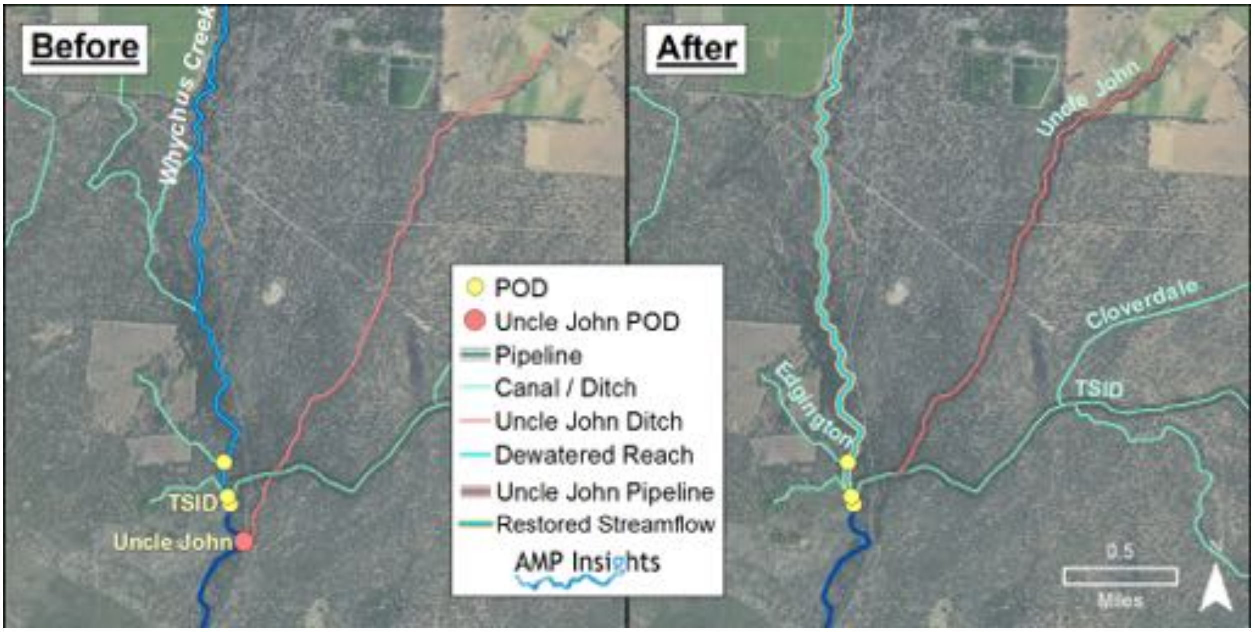
3.5.3 Piping and Conserved Water

Due to the young basalt geology in Central Oregon, open irrigation canals and laterals crudely carved out of this basalt are extremely leaky. In the Supplemental Deschutes Decree of 1933 the loss of water during conveyance to farms is explicitly recognized at rates of up to 65% of diverted water or more. The much earlier Whychus decrees do not have these same provisions but the decree is rate-based meaning that it specifies a flow rate diversion (acres/cfs) not a duty (acre-feet/acre). At the generous rate of 40 acres to the cfs some 10 AF/acre could theoretically be diverted during the irrigation season. This amount is sufficient to meet significant transmission losses on the way to farms and ranches. Given the limited reliability of many of the water rights appropriated on the creek (as discussed in Section 2.5.6), efforts to reduce these transmission losses have been a focal point of efforts to shore up irrigation water reliability and generate instream flow.

TSID has led these efforts on two fronts. On its own initiative and working with Farm Bill appropriations the district has worked to pipe many of its smaller laterals. Meanwhile, on district canals a partnership with the DRC developed into a series of projects and transactions using Bureau of Reclamation and other funds to pipe the district's main canals. On the lateral projects the water savings went solely to improve deliveries, on the canal projects the water savings were split between the district and instream water rights, using the State's Allocation of Conserved Water rules. In both cases the district was an early adopter of the use of high density polyethylene pipe for piping irrigation conveyances. The flexibility and durability of this pipe makes it ideal for piping such conveyances. The pipe simply needs to be joined and then pushed into existing canals and lateral right of ways and buried. This eliminate transmission loss. In addition, depending on the elevation drop involved, these piped systems create water pressure that can be used by farmers to run sprinkler systems or to generate hydropower. While the length of life of the material is unknown it is expected to last for a very, very long time. This has emboldened TSID – and other districts in the Deschutes and elsewhere in Oregon – to reduce their water right and transfer the saved water to an instream right through the conserved water process.

A somewhat complex example of such projects began in 2012 when TSID worked with landowners on the Uncle John Ditch to finance and pipe their ditch. Historically, the ditch and its water rights served the Lazy Z Ranch and adjacent lands on the outskirts of Sisters and was not part of the irrigation district. However, as part of a larger project that involved piping the TSID main canal and then installing a new creek-friendly diversion structure, the landowners on the Uncle John Ditch incorporated into TSID, changed their point of diversion to take water from the new TSID diversion structure and piped their ditch from where it had previously crossed the TSID main canal (see Figure 19). About 2.5 cfs of water savings was put through the conserved water right process, creating an instream right that is protected from the old point of diversion on downstream through Sisters.

Figure 19. Uncle John Ditch Piping and Conserved Water



Through 2016 a total of 17 piping transactions and 13 conserved water applications were completed. In some cases multi-year projects were developed from a single conserved water application, but each of the transactions in Table 7 involved an agreement for a given amount of instream water in return for a given payment. The conserved water totals 26 cfs and the total cost of this water was $17.1 million (in 2016 dollars). The reliable, discounted volume of 132,186 AF means that overall the cost-effectiveness of the conserved water comes to $130 per AF. This is significantly above the costs of the transfer and lease water.

Table 7. Canal Piping and Conserved Water Transactions

Transaction Name	Conserved Water #	Payment Year	Effective Year	Payment Amount (current $)	CPI Adjusted Cost (2016 $)	Face Value Eflows		Reliable Discounted Volume (RD-AF)	Cost-Effectiveness (in 2016 $)		
						Volume (FV-AFY)	Rate (FV-cfs)		Volume (FV-AFY)	Rate (FV-cfs)	Volume (RD-AF)
Cloverdale	33	2000	2009	$ 260,488	$ 363,060	849	2.0	10,794	$ 428	$ 181,530	$ 34
Fryrear	34	2000	2005	$ 275,000	$ 383,286	637	1.5	7,867	$ 602	$ 255,524	$ 49
McKenzie Phase V	44	2008	2007	$ 600,000	$ 668,844	641	1.5	6,936	$ 1,044	$ 442,943	$ 96
McKenzie Phase IV	49	2008	2008	$ 932,000	$ 1,038,938	641	1.5	6,922	$ 1,621	$ 688,039	$ 150
McKenzie Phase III	50	2009	2009	$ 897,000	$ 1,003,493	641	1.5	6,925	$ 1,566	$ 664,565	$ 145
McKenzie Phase II	51	2009	2009	$ 990,700	$ 1,108,317	641	1.5	6,697	$ 1,729	$ 733,985	$ 165
McKenzie Phase I	56	2010	2010	$ 1,092,000	$ 1,201,928	641	1.5	6,914	$ 1,875	$ 795,979	$ 174
Main Canal Phase 1	66	2010	2010	$ 1,882,079	$ 2,071,542	849	2.0	10,472	$ 2,440	$ 1,035,771	$ 198
Main Canal Phase 2	66	2011	2011	$ 1,681,519	$ 1,794,159	849	2.0	10,836	$ 2,113	$ 897,080	$ 166
Main Canal Phase 3	66	2012	2011	$ 1,890,400	$ 1,976,137	849	2.0	10,470	$ 2,328	$ 988,069	$ 189
Main Canal Phase 3.b	66	2012	2011	$ 500,000	$ 522,677	424	1.0	5,230	$ 1,231	$ 522,677	$ 100
Main Canal Phase 3.c	66	2012	2012	$ 500,000	$ 522,677	424	1.0	5,283	$ 1,231	$ 522,677	$ 99
Uncle John Ditch	71	2012	2015	$ 805,000	$ 841,510	1,057	2.5	13,055	$ 796	$ 337,820	$ 64
Main Canal Phase 4	77	2013	2014	$ 1,321,328	$ 1,361,315	565	1.3	7,036	$ 2,411	$ 1,023,545	$ 193
Main Canal Phase 5	78	2014	2015	$ 1,161,593	$ 1,177,643	565	1.3	7,213	$ 2,086	$ 885,446	$ 163
Main Canal Phase 6	79	2015	2015	$ 985,168	$ 997,596	569	1.3	7,189	$ 1,754	$ 744,475	$ 139
Hurtley	83	2012	2015	$ 85,000	$ 88,855	183	0.4	2,344	$ 487	$ 206,640	$ 38
Totals				$ 15,859,275	$ 17,121,978	11,024	26.0	132,186	$ 1,553	$ 659,273	$ 130

Note: Face Value is abbreviated as FV, AF refers to an acre-foot and AFY refers to an acre-foot in perpetuity. See Section 4.4 for an explanation of CPI Adjusted Cost and Reliable Discounted Volume.

The piping partnership between TSID, TSID landowners and the DRC is obviously a major achievement. Part and parcel of the success was structuring these piping projects to reflect a joint investment by the district and the DRC, and then sharing the costs and the benefits of the projects.

Nevertheless, these accomplishments were not controversy-free or particularly easy to achieve. A number of projects were protested or otherwise delayed by water right holders and landowners affected by these projects. Plans to reduce the entire TSID certificate ran into opposition amid questions of whose rights were being reduced and who was benefitting from the project. For example, on the McKenzie project, the district ultimately had to form a sub-district so that the reduction to the certificate was applied only to the water rights and priorities held by the landowners served by this canal.

More problematic was opposition due to the expected negative localized impacts of piping. In Central Oregon, many locals have challenged piping projects due to the loss of valued water features and the prospect of desiccation and death of mature trees lining the canals. Protests of two early Whychus Creek piping projects, the Cloverdale and Fryrear, by a local family running a destination resort with a golf course were based in part on the aesthetics of replacing a water feature replete with mature Ponderosa Pine with a dirt mound. This problem led to redesign of the project and, ultimately, in order to get the conserved water approved, a concession on the amount of water that would be certificated to instream use. The large gap between payment and the effective date of the conserved water – five years for Fryrear and nine years for Cloverdale – provide an indication of the difficulty in resolving these issues.

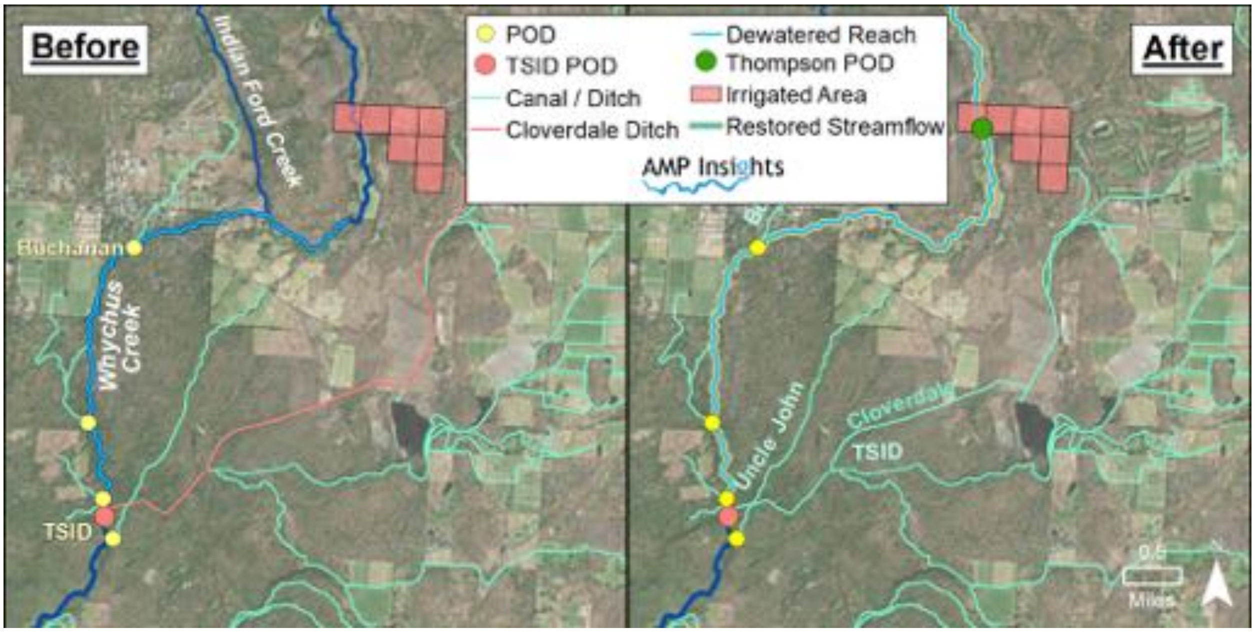
Subsequently, a landowner adjacent to the upper part of the McKenzie Canal, owning no rights, raised a similar issue and gained some traction locally. The landowner filed suit claiming that the district lacked the necessary easement and could not enter her property and install the pipe. This resulted in reversing the project to start from the end of the canal and work back up to the top, and many years of meetings and negotiations to address the problem (Three Sisters Irrigation District n.d.). However, the legal basis for the complaint had little chance of success. The district had a right of way for the canal that predated the land grants of the properties in the McKenzie Canyon. Indeed, well-funded protestants fighting a piping project in nearby Swalley Irrigation District took a similar claim to district court and later appealed the decision to the 9th Circuit Court of Appeals (Swalley Irrigation v. Alvis 2009). In that case the appeals court upheld the lower court ruling that the piping of an irrigation canal was a use allowed outright by the canal easement. The court found that the piping project merely removed an incidental benefit of the district's use of the easement. On the McKenzie project, no resolution was found and the district pressed ahead with the last phase of the project. Protesters tried to block the machinery, were arrested and charged, and when released counter-sued the district manager (Cornelius 2010).

3.5.4 Change in Point of Diversion and Conserved Water

A move of a water right from one point of diversion to another is a transfer under Oregon rules. If the move is from upstream to downstream then when the water right is exercised there will be an increase in streamflow from the old to the new point of diversion. If water is saved by taking the water further downstream then it is possible to file a conserved water application in order to effect the transfer and protect the water savings as in instream water right certificate. In Whychus Creek two very different point of diversion changes were carried out, one early in the transactions program and one much later. Although such changes are often regarded as "low hanging fruit" they do require willing landowners and, thus, are not necessarily the first transactions that will be undertaken.

The first transaction involved a water right that was part of the consolidation of rights on the TSID system in the mid-1990s. The irrigated lands (see Figure 20) are found downstream of Sisters and the confluence with Indian Ford Creek and are adjacent to the creek. As shown in the figure, the water had been diverted far upstream at the TSID diversion routed across the district and then dropped back towards the creek. In the early 2000s, the conservation-minded landowners worked with the Oregon Water Trust and the DRC to develop an infiltration gallery and pull the water directly from the creek. In doing so, they departed from the district, and were able to protect 0.61 cfs for instream use. In addition, the remaining rights of 1.51 cfs will rewater the creek in the crucial section from the TSID point of diversion on through Sisters to the new point of diversion (instead of being diverted at the TSID point of diversion). That said it could be that this portion of water from the remaining rights would be served from groundwater discharge in and around the confluence with Indian Ford Creek. For this reason the 1.51 cfs is not counted as part of the instream flow benefit of the transaction in the upper portion of Whychus Creek.

FIGURE 20. THOMPSON CHANGE IN POINT OF DIVERSION

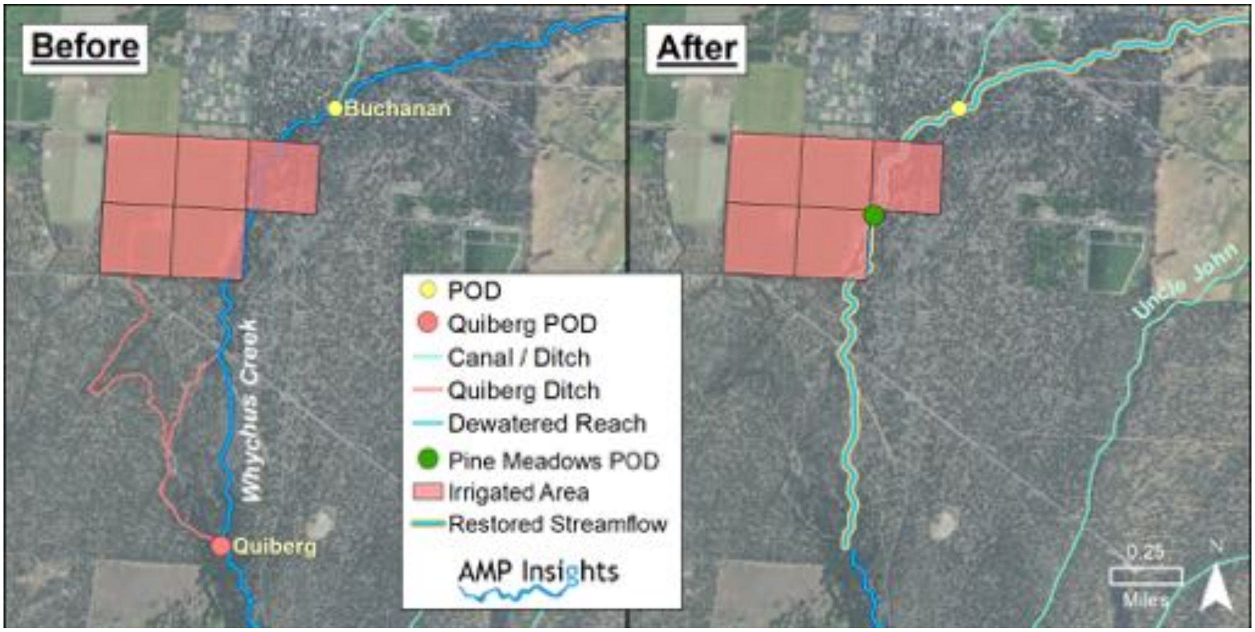


A second project was undertaken much later on in 2014. The landowner involved has one of the few senior individual rights on the creek and had been approached by the DRC regarding a water rights transfer but with no success. In attempting to remove remaining entrainments (barriers) on the creek the Upper Deschutes Watershed Council approached the family, leading to the Pine Meadow Ranch point of diversion change. As shown in Figure 21, the Quiberg ditch involved first a diversion from the creek a number of miles upstream from the property. This portion of the creek is extremely flat and is loosely speaking a distributary, i.e. there are a number of braided channels that accommodate flood flows. The Quiberg diversion routes the water into the westernmost of these distributaries and then subsequently diverts the water again, this time into a ditch that carries the water to the property. Any water not diverted at this second turnout would find its way back to the creek. Thus, it is likely that historically in the summer months the entire flow of the creek would have been diverted at the Quiberg point of diversion with a portion taken by the second turnout and the remainder sent on down to the Buchanan and Smith Ditches.

The Pine Meadows Ranch transaction therefore provides significant habitat, as well as flow, benefits. The diversion was moved down to a point on the ranch itself, where water is pumped out of the river and directly on to the farm. The Ranch had a water right of 3.72 cfs of which 1.0 cfs was certificated instream as conserved water as part of the overall project. Note that in Table 2 the Quiberg Ditch is said to carry 8.72 cfs of water rights. A large portion of these are for the property to the west and south (adjacent to the irrigated area demarcated in red in the figure). These rights were transferred to the Quiberg point of diversion from the Pole Creek Ditch prior to 1997, but seemed to have been moved back to the Pole

Creek Ditch (without refiling for this change). This can be inferred as the Pine Meadows Ranch conserved water and transfer applications for the point of diversion lists only the 3.72 cfs of water rights and the other remaining rights remain on the books at the old point of diversion. In addition, the Upper Deschutes Watershed Council website provides a video showing the removal of the old point of diversion (Upper Deschutes Watershed Council n.d.).

FIGURE 21. PINE MEADOWS RANCH CHANGE IN POINT OF DIVERSION



These two point of diversion transactions cost a total of $558,000 (2016 dollars) and resulted in 1.6 cfs of water rights and 11,748 reliable discounted AF of water. At an average of $48/AF these projects are less cost-effective than the transfers and leases, but more cost-effective than conserved water. However, as the particulars of these two projects suggest such point of diversion changes are fairly opportunistic and will be limited in terms of their contribution to a much larger instream flow target. It is also worth noting restoring the conserved water to the creek and routing the remaining Pine Meadows Ranch down the channel all the way to the ranch provide a habitat benefit that is not well reflected by the 1.0 cfs of permanent instream water rights created by the project.

TABLE 8. DOWNSTREAM POD CHANGES AND CONSERVED WATER TRANSACTIONS

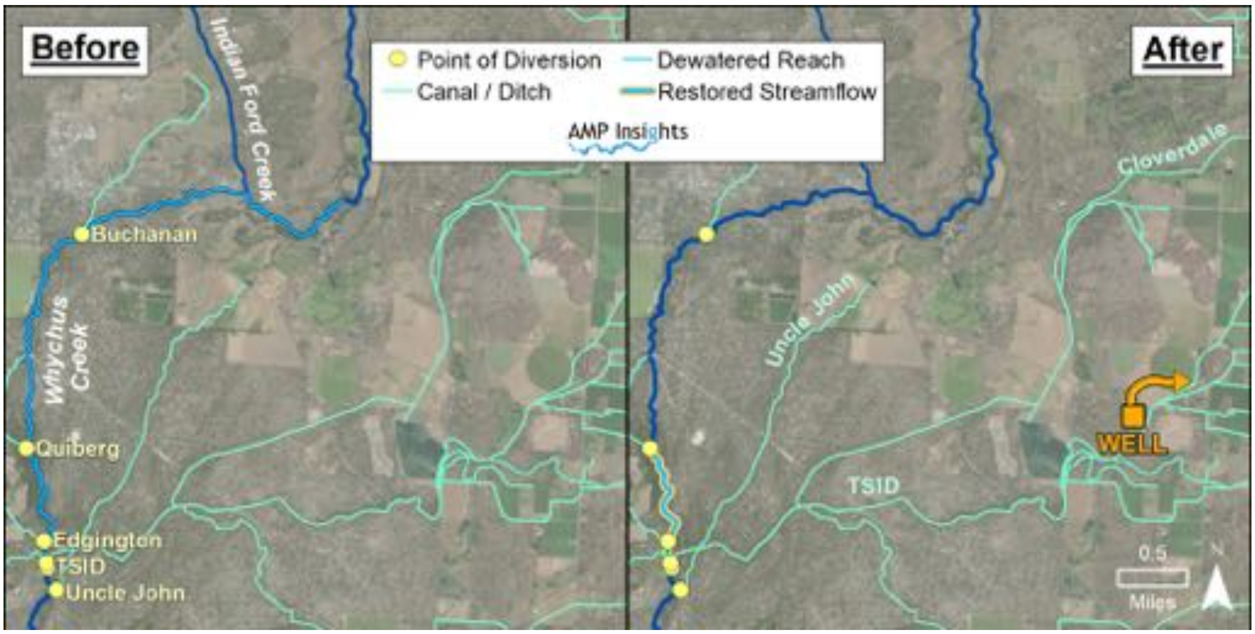
Transaction Name	Conserved Water #	Payment Year	Effective Year	Payment Amount (current $)	CPI Adjusted Cost (2016 $)	Face Value Eflows		Reliable Discounted Volume (RD-AF)	Cost-Effectiveness (in 2016 $)		
						Volume (FV-AFY)	Rate (FV-cfs)		Volume (FV-AFY)	Rate (FV-cfs)	Volume (RD-AF)
Thompson	30	2002	2005	$ 114,800	$ 153,156	259	0.6	3,045	$ 592	$ 251,075	$ 50
Pine Meadow Ranch	82	2014	2014	$ 400,000	$ 405,527	424	1.0	8,703	$ 955	$ 405,527	$ 47
Totals				$ 514,800	$ 558,683	683	1.6	11,748	$ 818	$ 347,008	$ 48

Note: Face Value is abbreviated as FV, AF refers to an acre-foot and AFY refers to an acre-foot in perpetuity. See Section 4.4 for an explanation of CPI Adjusted Cost and Reliable Discounted Volume.

3.5.5 Source Switch: Surface to Groundwater Switch

Depending on the relationship between available water sources, the stream and the irrigation demands the possibility of switching between sources, either permanently or temporarily, can be an important transactional tool in flow restoration efforts. In Whychus, early opposition to the Cloverdale and Fryrear piping projects led to the proposition by the protestants on those projects that it might be easier and cheaper to solve the summer low flow problem by exchanging the use of surface water for groundwater in TSID during the summer months. This proposition led to a small three-year experimental transaction in which a streamflow trigger was used to initiate pumping from a groundwater well (on the protestants property) near to the TSID main canal and the non-diversion of a corresponding flow rate in the creek (Figure 22). As the arrangement was a water management agreement between TSID and the DRC the resulting instream flow was not legally protected instream. As such it could be diverted directly downstream by the Quiberg Ditch. And if it was called on by TSID to the TSID diversion but not diverted, upstream junior user could also have cried foul and called on the watermaster to reallocate the water back upstream.

FIGURE 22: TSID SURFACE TO GROUNDWATER SWITCH



The costs involved refurbishing the well at the outset in 2005 and then payments in each year (2005 to 2007) to cover the costs of pumping the water. The trigger was set at the then DRC target for streamflow of 20 cfs and the maximum pumping rate was 3.67 cfs. Initially, the option to use the pump was set to run from June 1 to October 31st but this was subsequently abbreviated to an end date of September 30th. Due to the large up-front cost the cost-effectiveness varied between the three years Table 9. On average the cost was $51/AF. Clearly, the running costs at about $19/AF would have brought down the overall costs of the transaction had the project run for additional years.

TABLE 9. SURFACE TO GROUNDWATER SWITCH TRANSACTIONS

Transaction Year	Payment Amount (current $)	CPI Adjusted Cost (2016 $)	Reliable Discounted Volume (RD-AF)	Cost-Effectiveness (2016 $ per RD-AF)
2005	$ 14,016	$ 17,225	105	$ 164
2007	$ 2,502	$ 2,979	157	$ 19
2007	$ 3,628	$ 4,199	218	$ 19
Totals	$ 20,146	$ 24,403	480	$ 51

Note: Face Value is abbreviated as FV, AF refers to an acre-foot.
See Section 4.4 for an explanation of CPI Adjusted Cost and Reliable Discounted Volume.

This small pilot project was based on a much larger concept for an exchange project that could reach 15 cfs in pumping capacity and require an investment of potentially several million dollars – including an endowment to fund the pumping in perpetuity. However, the 2005 application for the groundwater right (G-16558) that was to be part of this water rights exchange was deemed likely to interfere with spring discharge adjacent to Whychus Creek. OWRD proposed to deny the groundwater application in 2007, effectively also ending the utility of the pilot project. The groundwater application was withdrawn in 2013. The corresponding water right exchange application (T-10030) that would enable the switch was never able to proceed as an exchange can only be processed for a water right subject to transfer, and not merely a permit application. The exchange application was formally denied in 2011. While this project ultimately proved infeasible, the pilot project and relationship-building involved in the larger project was instrumental in building trust between the partners and aided in resolving the protests over the Cloverdale and Fryrear projects.

3.6 Summary of Transaction Program

Table 10 summarizes the results by type of transaction. In some cases it is not useful to sum the units due to differences in the term (duration) of the different transactions. All told 83 transactions were completed in the 2000 to 2016 period. A total of $17.4 million was expended through 2016, with a cost in 2016 dollars of $18.7 million. Approximately 13,500 AF and 323.2 cfs of water rights have been dedicated to instream use in perpetuity. The average costs per grouping for these permanent transactions varies considerably. The cost per face value of flow volume varies from $500/AFY for transfers to $1,500/AFY for piping and the cost per face value for flow rate varies from over $170,000/cfs to 660,000/cfs. For the compensated transactions, the average cost per AF of reliable discounted water comes to $100/AF, with leasing and transfers at $17/AF and $27/AF on the low end and piping on the high end at $130/AF.

Table 10: Transaction Totals

Transaction Name	Payment Amount (current $)	CPI Adjusted Cost (2016 $)	Face Value Eflows		Reliable Discounted Volume (RD-AF)	Face Value Indicators (2016 $)		Cost-Effectiveness in 2016 $ by Volume (RD-AF)
			Volume (FV-AFY)	Rate (FV-cfs)		Volume (FV-AFY)	Rate (FV-cfs)	
Transfers - Paid	$ 749,058	$ 854,115	1,543	4.1	31,816	$ 553	$ 207,814	$ 27
Transfers - Unpaid	$ -	$ -	226	0.5	4,642			n/a
Piping	$ 15,859,275	$ 17,121,978	11,024	26.0	132,186	$ 1,553	$ 659,273	$ 130
POD Changes	$ 514,800	$ 558,683	683	1.6	11,748	$ 818	$ 347,008	$ 48
Leases - Paid	$ 160,871	$ 181,592			10,779			$ 17
Leases - Unpaid	$ -	$ -			4,116			n/a
SW-GW Switch	$ 20,146	$ 24,403			480			$ 51
Totals	$ 17,304,150	$ 18,740,771			195,767			$ 96
Totals - Paid	$ 17,304,150	$ 18,740,771			187,009			$ 100

Note: Face Value is abbreviated as FV, AF refers to an acre-foot and AFY refers to an acre-foot in perpetuity. See Section 4.4 for an explanation of CPI Adjusted Cost and Reliable Discounted Volume.

Transactional activity in the watershed was halting at first, but after 2002 the numbers of transactions began increasing steadily (Figure 23 and Figure 24). Once the large piping projects began in 2008 the expenditure level increased significantly to a peak of over $3.5 million per year in 2012. In the last few years transactions and expenditure have dropped to just a handful of transactions and an average of about $1 million per year. After a relatively slow year in 2016 it will be interesting to see if transactions continue apace in future years or whether with the gains in streamflow already made efforts will be limited to leases from TSID and the occasional transfer of remaining senior individual water rights. As shown in **Error! Reference source not found.** many of the main canals in TSID are now piped. Separate from the EWT Program the district has also piped many of its laterals. At some point then the gradual abandonment of ditches due to junior rights, the closing down of others due to urbanization and transfers, the completion of all likely point of diversion changes and the piping of the district system mean that there will be no large EWTs left to be had in the watershed.

Figure 23. Transactions and Payments, 1997 to 2016

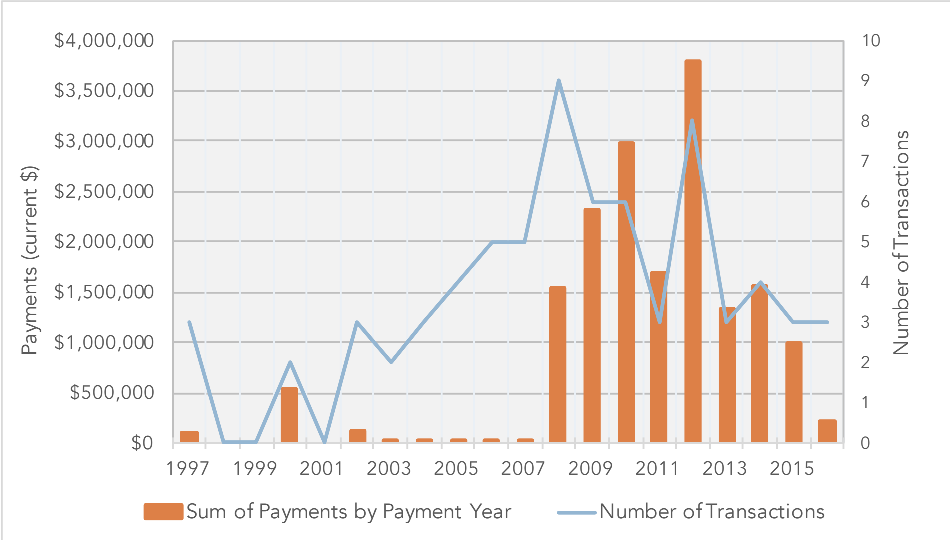


Figure 24. Cumulative Face Value of Acquired Flow by Transaction Type, 1997 to 2016

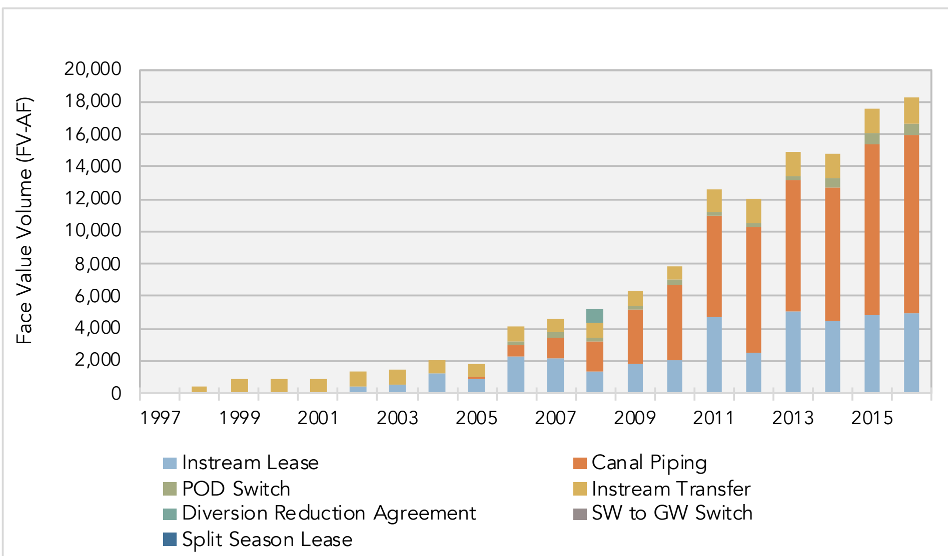
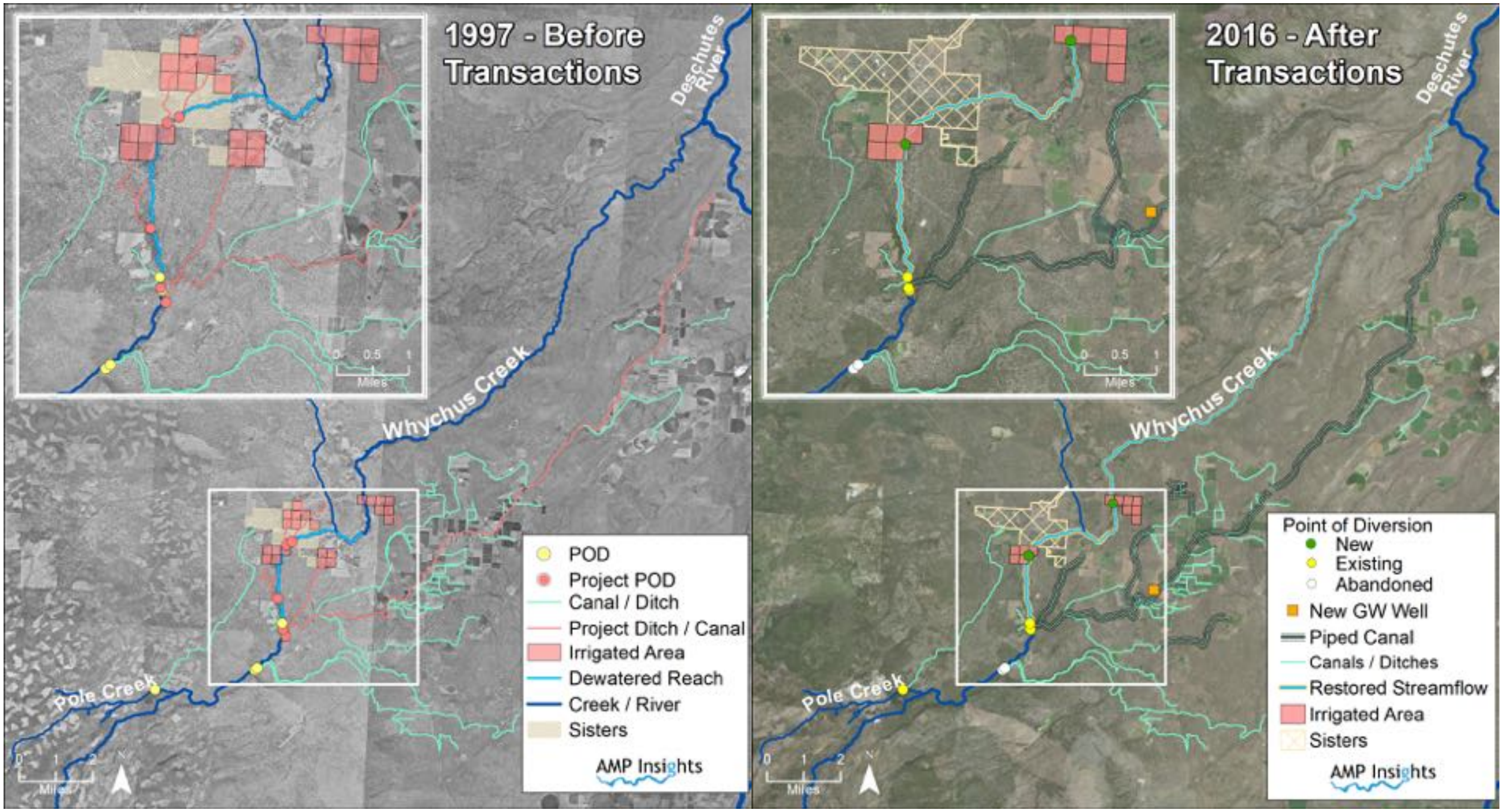


Figure 25: Whychus Creek and Diversions in 1997 and 2016, Before and After Transactions



4. Environmental Water Transactions Performance

This section evaluates the performance of the transaction program in terms of attaining environmental flow targets, securing environmental flow and achieving cost-effectiveness. The environmental flow indicators used here are based on the indicators developed as part of a collaborative project under the Science for Nature and People Program of the National Center for Ecological Analysis and Synthesis at the University of California at Santa Barbara (Kendy et al. 2018). The goal of the indicators is to measure the improvement in environmental flows according to the following metrics:

- environmental flow target attainment: volumetric (acre-feet and percent change) and temporal (percent of days) attainment of streamflow targets;
- environmental flow security: reliability and duration of acquired environmental flows; and
- environmental flow cost-effectiveness: inflation adjusted costs compared to the reliable discounted environmental flow volume.

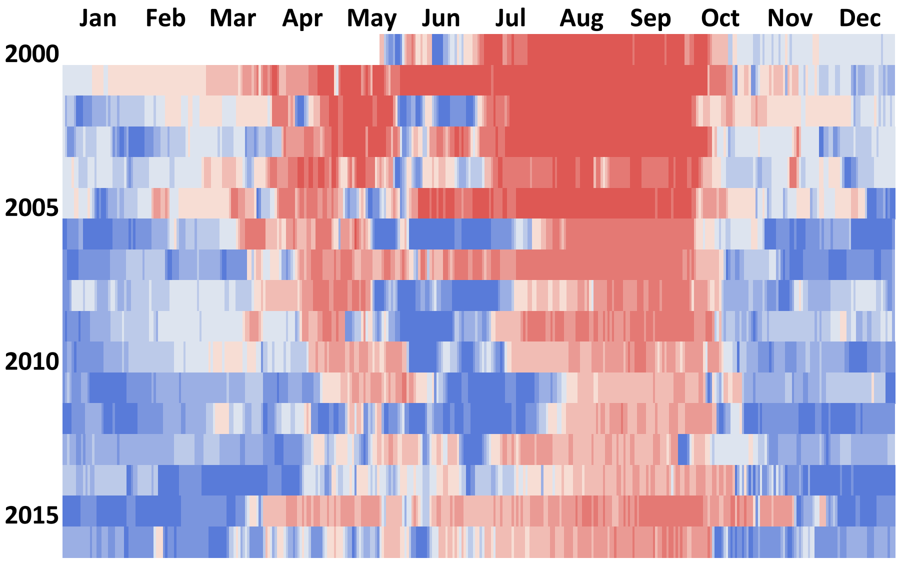
4.1 Streamflow in Upper Whychus Creek

Before turning to the formal performance metrics a brief overview of streamflow and streamflow compared to the streamflow targets reported in Section 3.4 is provided in order to provide a visual depiction of streamflow and progress made towards targets during the 2000 to 2016 period.

4.1.1 Streamflow

Historically, the last diversion on the upper reach of the creek – the Buchanan ditch – occurred just above the City of Sisters (see Figure 14). The streamflow gage located in Sisters therefore provides data on how flows have changed with the environmental water transactions completed in this reach. The gage was installed in May of 2000, after the transactions had begun, so there is no pre-transaction baseline data on streamflow in the reach. Nevertheless, daily streamflow data through to the end of 2016 is provided below in raster plot format. Figure 26 shows higher streamflow (i.e., more blues than reds, and lighter as opposed to darker reds) in 2016 (at the bottom of the plot) compared with earlier years (2000) is at the top of the plot.

Figure 26: Streamflow Below Diversions, 2000-2016 (OWRD Gage at Sisters)



Streamflow (CFS)

Percentile		Low Value	High Value
0-10%		0	8
10-20%		8	17
20-30%		17	23
30-40%		23	32
40-50%		32	42
Median			42
50-60%		42	49
60-70%		49	59
70-80%		59	72
80-90%		72	102
90-100%		102	1,100

Notes: Daily streamflow (cfs) raster graphs for Oregon Water Resources Department (OWRD) gaging station 14076050, Whychus Creek at Sisters. Gage readings begin in May of 2000. Each cell represents a single day.

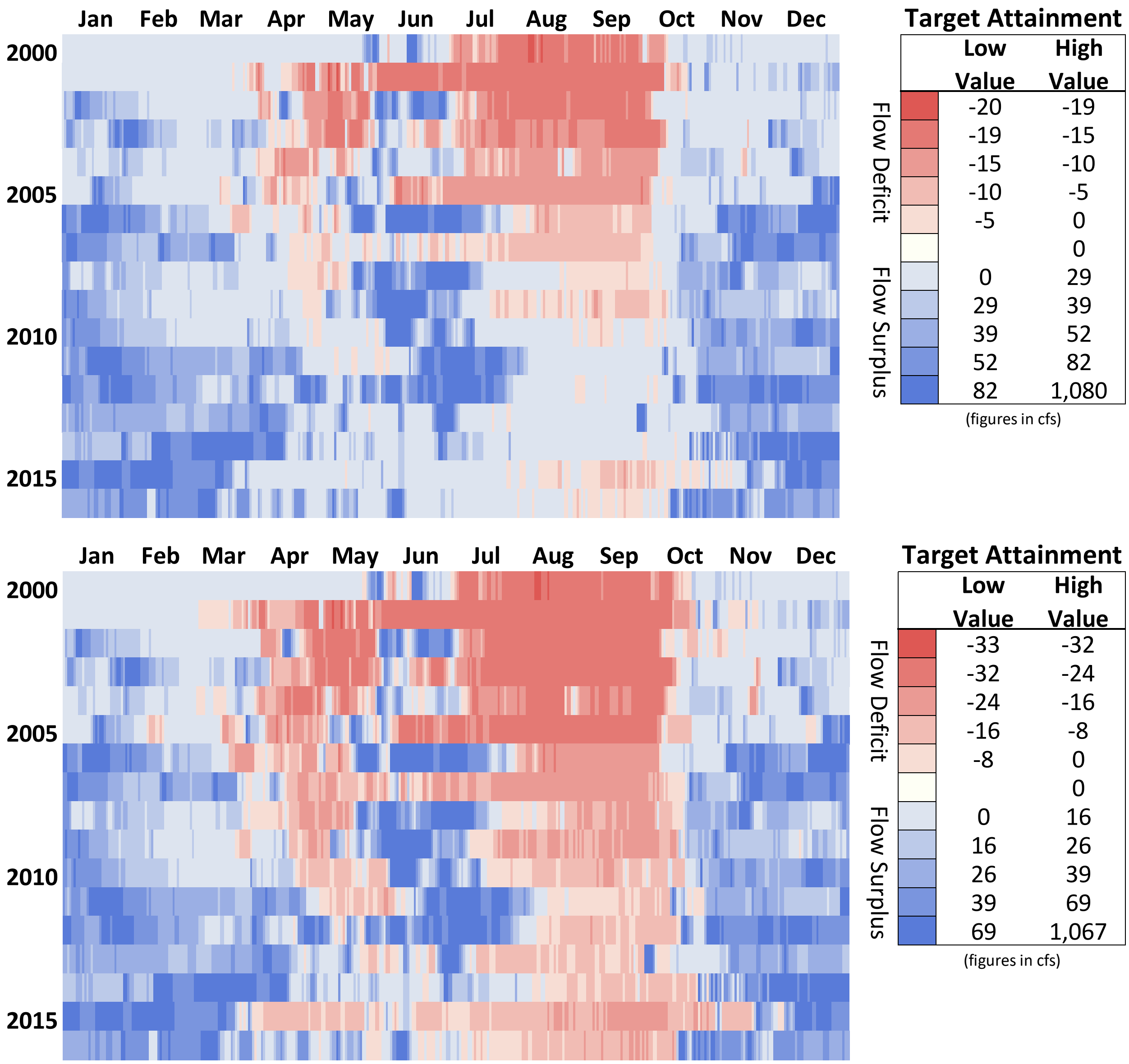
4.1.2 Streamflow versus Streamflow Targets

The degree to which target streamflow levels are realized during the period can be represented in a raster graphic, similar to that above, by subtracting the streamflow target from the actual streamflow and replotting the resulting data. A negative result would indicate a flow deficit and a positive result would mean that target flows are met. This is shown in the raster graphic format for the 20 cfs and 33 cfs streamflow targets in

Figure 27. From this point forward the flow graphics are provided for both targets as each of these was in place during the period being evaluated here.

From 2001 and on attainment of the streamflow target improves (more blue and less red, from top to bottom of each of the graphics). Both streamflow targets are generally met in the winter months and during the peak snowmelt period. This period varies from year to year but generally begins in May and extends into most of June. In the early years of the transaction program, before significant volumes of environmental water were placed instream, the flow targets often are not met early in the irrigation season in April and into May. This reflects low baseflow amounts before snowmelt begins and the onset of irrigation diversions in early April. After high snowmelt-driven flows recede, streamflow falls short of target from June-July through late October. This is most pronounced in the early 2000s. The lower streamflow target (20 cfs) is being met most of the irrigation season by 2011. Even during the 2015 irrigation season, one of the driest years on record, there was little to no flow gap. For the higher streamflow target (33 cfs) target, progress is also shown as the extent and severity of the streamflow deficit relative to targets diminish significantly. However, with this target the flow deficit compared to target is not overcome in the later summer and early fall. The flow gap in the early irrigation season is pronounced in early years but is greatly reduced. The exception of course is 2015 when the higher streamflow target is not met for most of the irrigation season.

FIGURE 27: FLOW GAP BELOW DIVERSIONS FOR 20 CFS TARGET [TOP] AND 33 CFS TARGET [BOTTOM], 2000 TO 2016



Notes: Daily streamflow (cfs) raster graphs for Oregon Water Resources Department (OWRD) gaging station 14076050, Whychus Creek at Sisters. Blue cells indicate days with flow in excess of target, red indicates a flow deficit relative to target.

4.2 Environmental Flows Target Attainment in upper Whychus Creek

In this section performance of the program in attaining environmental flow targets is quantified. Graphics and figures are provided for attainment against both the 20 and 33 cfs targets. The comparison of actual streamflow to target streamflow is compiled only for the irrigation season, as the transaction program is not designed to improve flows in the November to March period. In addition, the first complete set of irrigation season data is for 2001 so the metrics are presented for the period from 2001 to 2016.

4.2.1 Volumetric Attainment of Streamflow Target

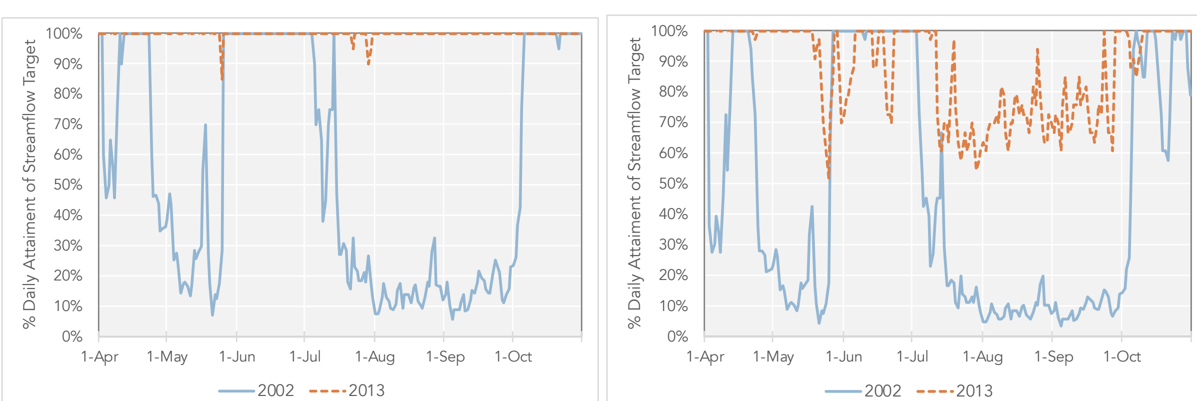
Volumetric attainment is presented in two ways: annual progress in attainment and a comparison of pre-transaction and with transaction years. Figure 28 shows that volumetric attainment of the lower streamflow target (as adopted formally by the DRC in 2003) improved from 30 to 40% in the early 2000s to 100% by 2011. Attainment, of the new, higher flow target reached 90% in the 2011 to 2014 period, short by just 1,300 AF from the target in 2014. The composition of acquired rights includes considerable straddle rights of medium security and, thus, in the low flow year of 2015 volumetric attainment sank to 60%, recovering back to 80% in 2016. The remaining volume to achieve the streamflow target for these drier years is from 5,000 AF (in 2015) to 2,200 AF (in 2016)

FIGURE 28. ANNUAL TARGET FLOW ATTAINMENT IN PERCENT FOR 20 CFS [LEFT] AND 33 CFS [RIGHT] TARGETS, 2001 TO 2016

Notes: Volumetric environmental flow target attainment in upper Whychus Creek, measured as the percent of environmental flow target met during the irrigation season from April 1st to October 31st. The dashed line is the linear regression of the annual data shown by the solid line. Data from OWRD gaging station 14076050, Whychus Creek at Sisters, Oregon

Two years, 2002 and 2013 were selected from the sixteen-year sample for having similar inflows to the system as measured above all diversions and as representing pre-transaction and with-transaction years. Figure 29 portrays the percent of daily attainment of the streamflow target for these two years against the two targets. For the lower target, the transaction program "fills" the flow deficit observed in 2002. For the higher target, progress remains but attainment is limited to 60-70% of the target in a few days early in the irrigation season and during the late summer and early fall.

FIGURE 29. DAILY STREAMFLOW TARGET ATTAINMENT IN PERCENT FOR 20 CFS [LEFT] AND 33 CFS [RIGHT] TARGETS, 2002 (PRE-TRANSACTIONS) AND 2013 (WITH TRANSACTIONS)

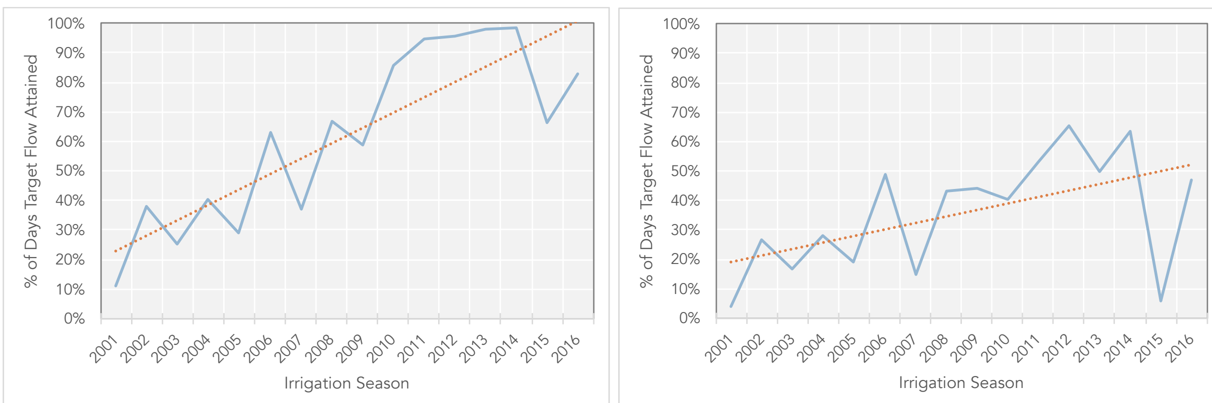


Notes: Volumetric environmental flow target attainment in upper Whychus Creek, measured as the percent of environmental flow target met daily. Data from OWRD gaging station 14076050, Whychus Creek at Sisters, Oregon.

4.2.2 Percent of Days Attainment of Streamflow Target

Another important performance metric is the percent of days that the streamflow target is attained. As shown in Figure 30 the improvement for the lower streamflow target improves from a 10% to 40% range in the early 2000s, to between 95% and 100% by 2014. During the dry year of 2015 this performance dropped to 70%, showing that there is still substantial room to improve the water rights portfolio to cover this lower target in extremely dry years. For the higher target attainment is more modest, rising from near 0% in 2001 to a peak of near 60% in 2012. It is noteworthy that in 2015 the percent of days that the target was attained dropped below 10%. Equally notable is the rebound back up to 50% in 2016.

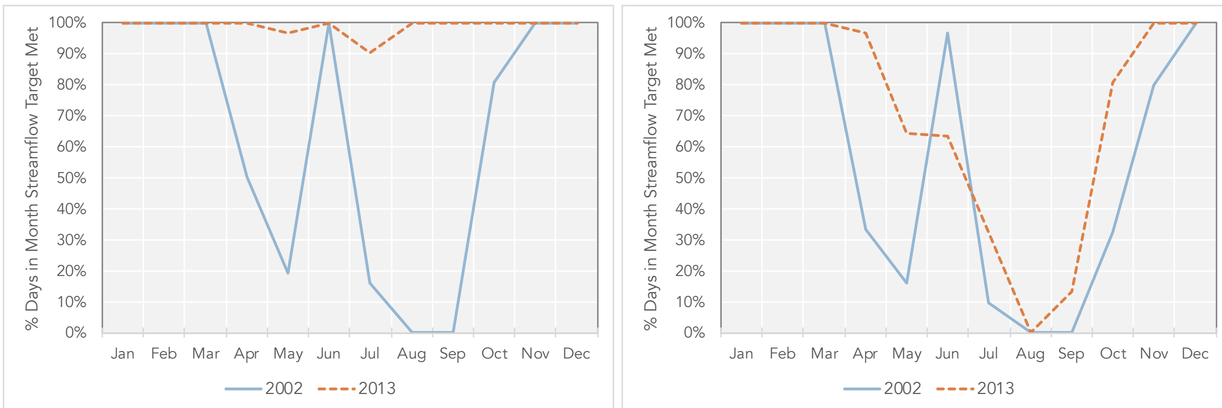
FIGURE 30: ANNUAL PERCENT OF DAYS FLOW DEFICIT VERSUS 20 CFS [LEFT] AND 33 CFS [RIGHT] TARGET



Notes: Volumetric environmental flow target attainment in upper Whychus Creek, measured as the percent of days environmental flow targets were met during the irrigation season. The dashed line is the linear regression of the annual data shown by the solid line. Data from OWRD gaging station 14076050, Whychus Creek at Sisters, Oregon

The annual percent of days indicators mask the severity of the deficit during specific periods during the irrigation season. Figure 31 compares the percent of days the streamflow target is met during each month of the irrigation season for the same years used above, 2002 and 2013. The comparison vividly portrays the "double dip" of flow deficits early and late in the season. Moreover, the graphics show that in 2013, while significant progress was made on the early season flow deficit, the summer – and particularly August – deficit remained more stubborn a challenge. While the prior metrics demonstrate significant increases in streamflow volume the ability of the program to reach the actual target during the peak summer months remains limited.

Figure 31: Monthly Percent of Days Flow Deficit versus 20 cfs [Left] and 33 [Right] cfs Target, 2002 and 2013

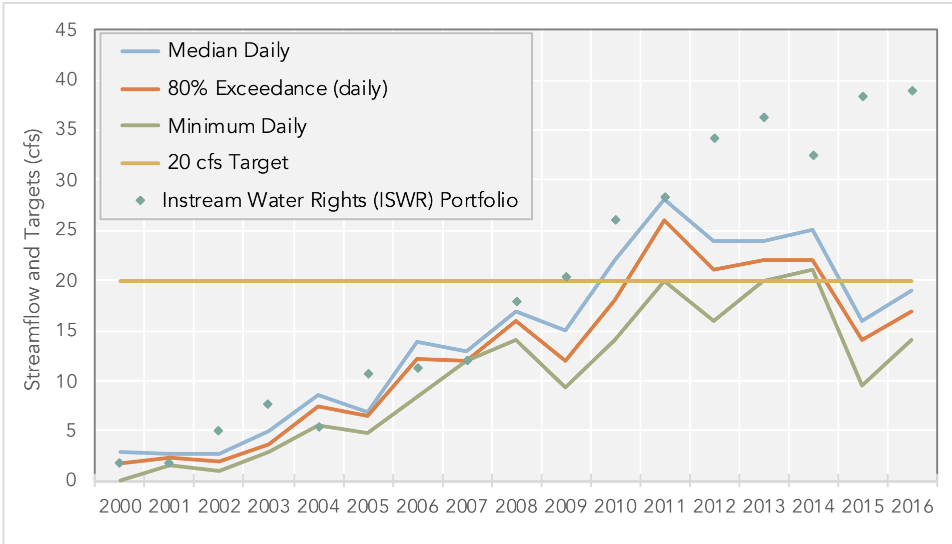


Notes: Volumetric environmental flow target attainment in upper Whychus Creek, measured as the percent of days flow target were met each month. Data from OWRD gaging station 14076050, Whychus Creek at Sisters, Oregon.

4.3 Environmental Flow Security

The preceding section examined program performance to date. In this section, the prospects for the program in the future are examined by quantifying the security of environmental flows obtained so far. Kendy et al. (2017) identified two aspects of environmental flow security: the seniority and permanence of acquired water rights. Figure 33 shows the importance of seniority by plotting streamflow statistics for the August and September period each year against the total instream rights in place during this period. The graphic is necessarily imprecise as the total cfs of instream rights may not be in effect for the entire period of two months. In particular, as discussed earlier, instream leases vary in their season of use and may be effective only for a portion of the period. Generally, though the permanent transactions should be effective for the period shown. Clearly stream flow statistics map to the water rights acquired reasonably well until 2012 when the relationship weakens. In part this is due to the dry year of 2015, but even prior to this year streamflow is not tracking the water rights acquired as closely as in the prior period. In fact, it is noticeable that streamflow seems to be tracking the 20 cfs target and not the water rights. The apparent disassociation between the independent variable of water rights acquired and the dependent variable of streamflow in upper Whychus Creek can be partially explained by examining the seniority and permanence of instream water rights portfolio over time. However, a full understanding of the gap requires consideration the regulation of the instream portfolio over time by water managers.

Figure 32. Streamflow versus Instream Water Rights Acquired, 2000 to 2016



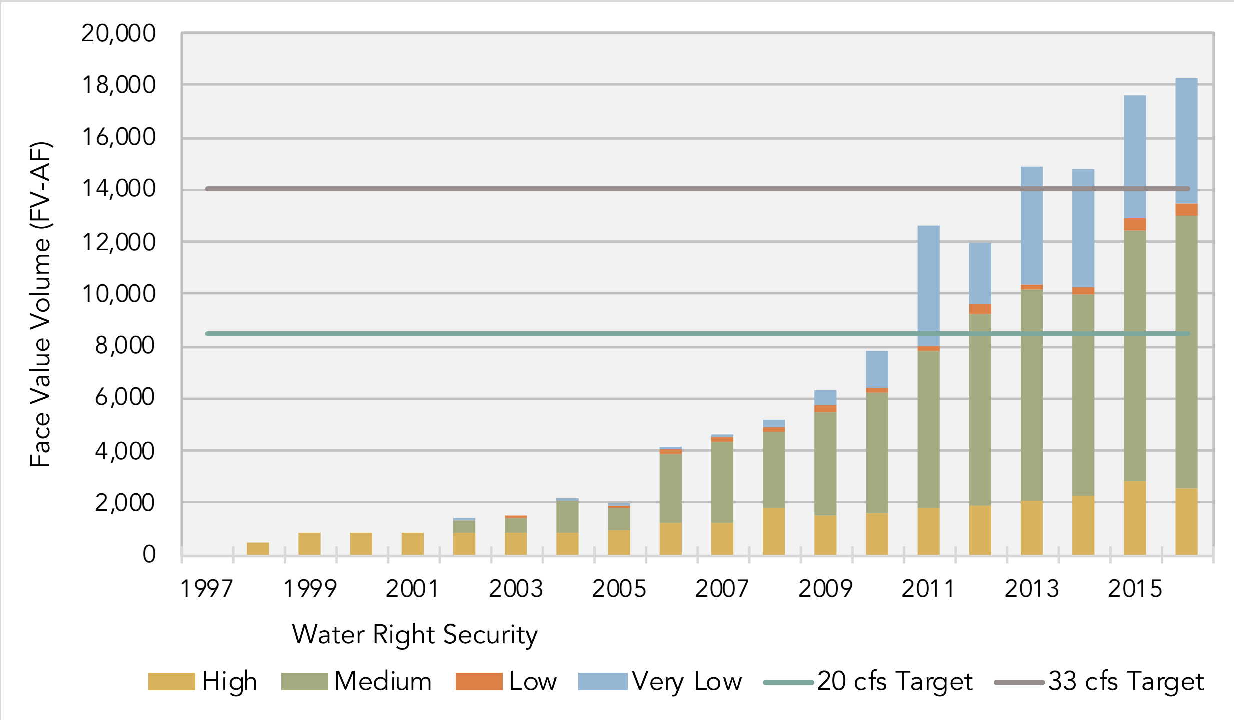
Notes: Lines represent statistical measures of streamflow rate (cfs) for the two-month period August to September each year at OWRD gaging station 14076050, Whychus Creek at Sisters, Oregon. The instream water rights are the total rate (cfs) of instream flow rights protected through the reach in which the gage is located.

4.3.1 Seniority of the Instream Water Right Portfolio

The reliability of the water rights acquired through a transaction program will determine how stable streamflow levels will be in the face of hydrologic variability. As discussed earlier in Section 2.5.6, water rights on Whychus Creek are overallocated when compared to available streamflow. Medium, low and very low security rights will be subject to curtailment when natural flows are low in the creek. Due to the limited number of senior water rights on the creek and the distribution of water rights between TSID and individual water right holders, many of the transactions have involved a combination of rights, including high, medium, low and very low securities. Therefore, it should be expected that the total environmental flow measured in the reach (as shown in the figure) generally will be less than the total of water rights protected instream.

Figure 33 portrays the cumulative priorities of these instream rights in volumetric terms over the life of the transaction program. The rights are shown in volumetric terms in order to account for rights with different seasons of use. From 1998 to 2005, instream flow rights totaled 2,000 AF, or about 14% of the higher stream flow target volume, but they were relatively secure as a roughly 50/50 mix of high and medium security rights. Over time, the volume of instream flow rights has increased to exceed the environmental flow target. However, as the preponderance of TSID piping projects in the transaction mix grew, this led to an increase in the prevalence of medium security rights in the instream water rights portfolio. Since 2006 the portion of total rights that are medium security has varied from 48% to 65%. More recently, as shown in the figure, a significant volume of very low security rights has entered the portfolio. Since 2010 some 18% to 34% of the portfolio was made up of these unreliable rights on an annual basis. In large part this reflects a number of water right holders (including the City of Sisters) that have voluntarily (e.g. with no payment from the DRC) leased junior rights to instream use. Such efforts are more likely intended to keep future options to market these rights (perhaps for mitigation) alive than with a serious intent to provide instream flow. Still, from 2014 to 2016 the portion of instream rights that was of medium or higher security made up about 70% of the total portfolio.

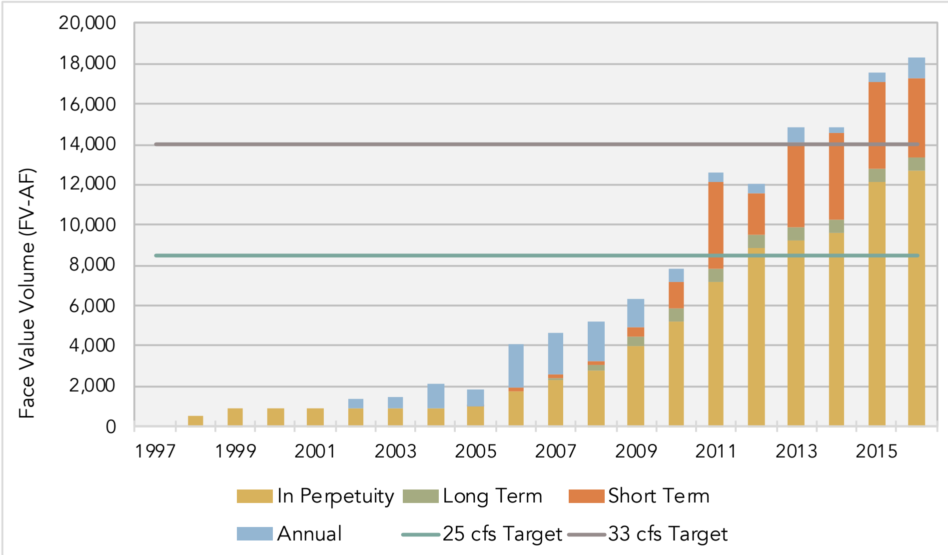
FIGURE 33. CUMULATIVE FACE VALUE INSTREAM WATER RIGHTS ACQUIRED BY WATER RIGHT SECURITY, 1997 TO 2016



4.3.2 Duration of the Instream Water Right Portfolio

Early in the program, the initial Smith-Barclay transfer was complemented by annual leasing, which made up about one-half of the water rights portfolio in from 2003 to 2006. As the conserved water projects accelerated the balance shifted towards permanently protected instream rights. In 2013 fully three-quarters of the portfolio were protected instream in perpetuity. From 2010 on the portion of the portfolio made up from short-term transactions increased rapidly and makes up about one-quarter of the portfolio in recent years.

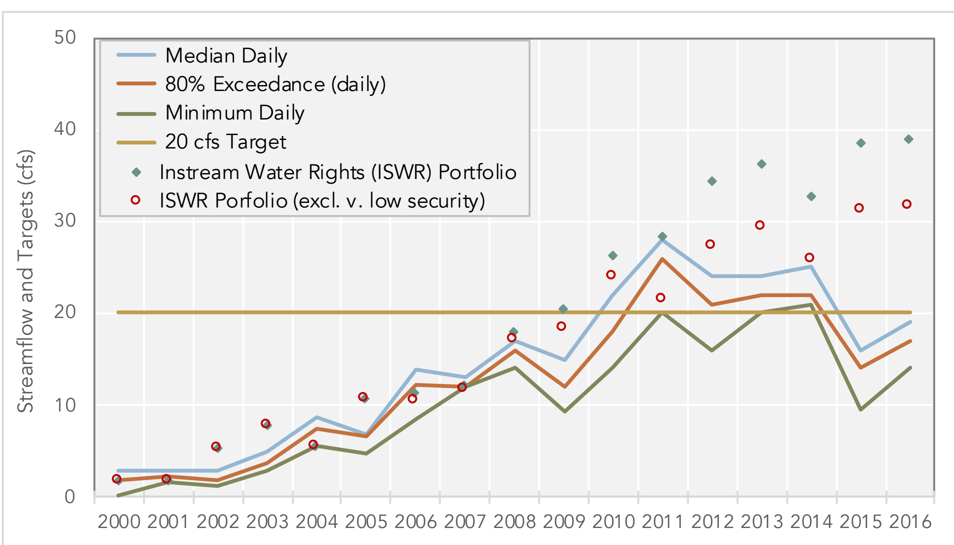
FIGURE 34. CUMULATIVE INSTREAM WATER RIGHTS ACQUIRED BY DURATION OF TRANSACTION, 1997 TO 2016



4.3.3 Performance and Regulation of the Instream Water Right Portfolio

Overall the seniority and permanence of the instream water rights portfolio is impressive with almost three-quarters of the rights being of medium security or higher and long-term or permanent in duration. The gap between the total water rights effective during the critical period and the flow at Sisters, observed in Figure 32, is partially attributable to the series of short-term leases of very low security rights that began in 2010. Perhaps a more accurate rendering of the situation is shown by removing the very low security rights from the plot of the instream portfolio (the red dots in Figure 35) This improves the fit between the late season instream portfolio and flows. Still it is apparent that the pattern of rights to flow has changed since 2011. Whereas previously median flows fluctuated between being lower and higher than the total water rights, it now seems that the median flows are now below, and sometimes significantly below the instream portfolio.

FIGURE 35. STREAMFLOW VERSUS INSTREAM WATER RIGHTS ACQUIRED (EXCLUDING VERY LOW SECURITY RIGHTS), 2000 TO 2016



So, the question is what has changed? One obvious cause of this gap is that the proportion of medium to high security rights has changed significantly. Once the very low security rights are deducted from the total instream portfolio the portion of medium security rights is at about 75% since 2012. Earlier, these two were much more in balance. That said, from 2009 to 2011 the figure was 69% to 74% and yet flows tracked the instream portfolio according to the prior pattern during this period. So, something else must be going on. As noted earlier one simple assessment is that once flows began hitting and exceeding the initial target of 20 cfs the continued gain in the instream portfolio was not matched by a corresponding gain in instream flow. This raises the question of how water rights have been and are being regulated on the creek.

Normally water rights in a stream will be regulated by priority. While this would be the default assumption for the treatment of instream rights there is no reason to assume this must be the case. EWT practitioners in the Pacific Northwest do complain that watermasters treat out-of-stream rights more favorably than instream rights, However, there are no systematic studies showing that instream rights are treated better or worse than other rights. One way to understand what has transpired in Whychus Creek is to ask whether it looks like the period before 2011 or the period after 2012 looks more like what would be expected given the seniority of the instream portfolio.

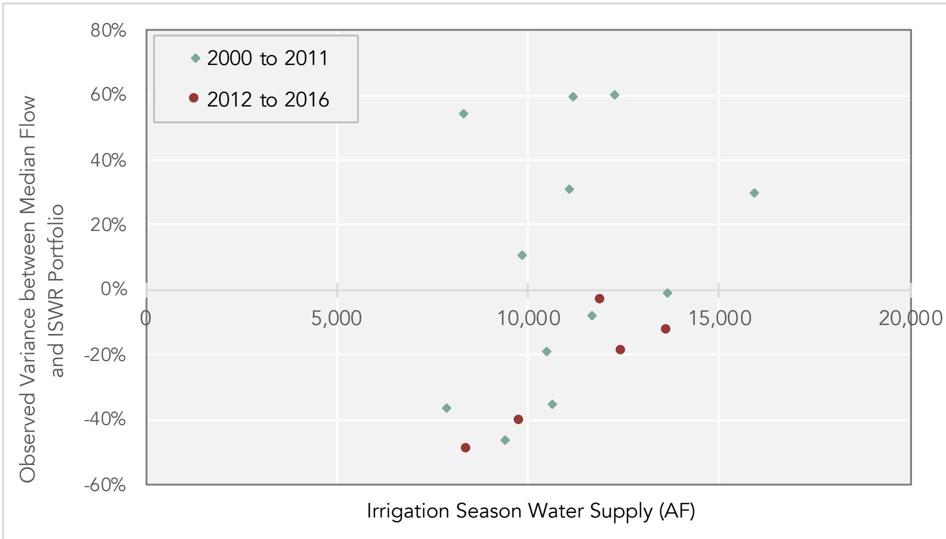
With regulation by priority, an instream portfolio made up of a mixture of priorities on an overallocated stream should yield less than the face value of rights during low flow periods. Clearly this appears to be the case in Whychus post-2011, but prior to 2011there were years that even in late summer the median flow exceeded the instream portfolio. Is this then a case of favorable treatment of the instream portfolio in the early years or an unfavorable treatment of the portfolio after 2011?

To answer this question the variance between the observed median flow (at the gage below diversions) and the instream portfolio (excluding very low security rights) was computed for August and September for each year in the 17-year period from 2000 to 2017. For 2000, median flows were 2.9 cfs and the instream rights totaled 1.8 cfs. This yields 1.1 cfs of excess or 60% above the portfolio. Normally it would be expected that in years where the flows match up well with the portfolio of rights this would reflects abundant water supply. Each year was assigned a “wet”, “normal” and “dry” designation based on whether the percent variation in flow was 10% higher, between 10% higher and 10% lower, or more than 10% lower than the rights, respectively.

The observed regulation behavior was then compared with actual water supply. The actual type of irrigation water year was derived by taking the August and September total inflow volume to the system (from the gage above all diversions) for each year and calculating the percent variance from the mean for the 17-year period. In 2000 the inflow volume was 12,286 AF which was an 11% variation from the mean of 11,079 AF. This variance was classified as wet, normal and dry as for the observed data set. In the 12 years to 2011 there was a match in the classification in only four years. For the five years to 2016 there were three matches (2014, 2015 and 2016) a much higher level of concurrence. As described above there was a match in 2000 (60% and 11%). In 2001 the actual variation from the mean was -25%, indicating low water supply availability in late summer. Yet median flows were 33% higher than the 1.8 cfs so there was no match. This crude analysis suggests preferential treatment for the instream rights in the earlier period.

Perhaps a better representation of the two periods is provided in Figure 36. Here the actual water supply above diversions (on the x-axis) is plotted against the observed variance of median flows below diversions with the instream water rights portfolio (on the y-axis). While there is still some variance, the 2012 to 2016 years line up well and demonstrate the expected relationship – as actual water supply increases the instream portfolio is curtailed. The 200 to 2011 period shows no such pattern overall and exhibits a very low correlation between the two variables in the scatterplot. The conclusion from this analysis is that in recent years the manner in which the instream portfolio is regulated better approximates actual water supply conditions than during the period up to 2011.

FIGURE 36. ACTUAL WATER SUPPLY VS. THE OBSERVED VARIANCE IN REGULATION OF THE INSTREAM PORTFOLIO



There are a number of potential explanations for this somewhat unexpected behavior – favorable treatment of instream rights. The first is simply that operationally it would have been extremely difficult in the early years for water managers to hit a 1.8 cfs target, many miles downstream from a crudely controlled diversion of 80 to 100 cfs (the TSID diversion). Fast forward to recent years and with the new state-of-the-art TSID off-channel diversion structure, the removal of the old Reed, Quiberg and Buchanan diversions it is much easier to regulate the creek in strict priority. It should be added that while OWRD regulates the stream the de factor control over water reaching the gage at Sisters has always been the TSID Manager. To this infrastructure efficiency explanation should be added a behavioral explanation. In the early years of the transaction program there was an incentive for TSID to perform well (or over-perform) in delivering instream water. Set-backs on the Fryrear and Cloverdale conserved water applications meant that DRC had paid for infrastructure but not received the instream water right. At the same time a constant stream of new projects were being put forward to the DRC for funding by TSID. In such circumstances it is not surprising that the TSID Manager would do whatever was possible to make sure that instream flows at Sisters continued to increase at a steady rate, even if water right applications were on hold.

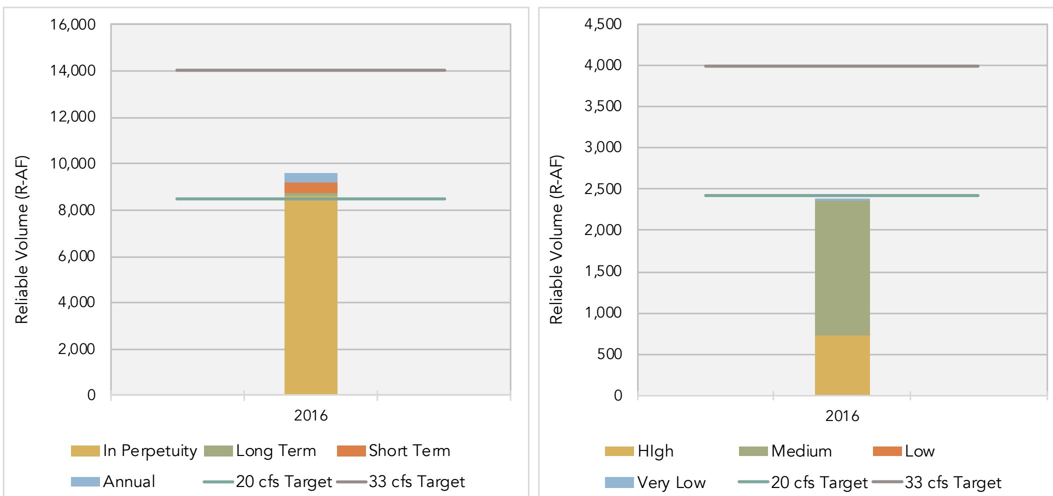
The lessons from this experience are that early cooperation between irrigation and conservation interests, as well as the prospects of future cooperation and funding, may lead to favorable treatment of an instream portfolio early on in the program. However, the infrastructure improvements that accompany such a water transaction program will ultimately improve the ability of water managers to successfully regulate by priority. Then, as the transaction program matures – and as the potential for future cooperation wanes due to completion of available projects – instream performance will drop off as the instream portfolio is regulated just as with other rights.

4.3.4 Environmental Flow Security as of 2016

Figure 37 provides a summary of current status of the security of the instream water rights portfolio with respect to the two sets of targets. The annual transactions included here was an average of the last five years of annual transactions in order to smooth these out. However, as shown above the annual leasing program has continued largely apace since 2002 and, therefore, in looking forward a projection of continued leasing seems warranted. The second part of the figure shows the reliable volumes for August and September (or the critical period). This chart shows the reliable volumes expected by level of security for the water rights. In calculating these values, the percentage reliability of these rights during August and September are used from Table 3.

Looking forward then the existing instream portfolio consists of almost 9,600 AF in reliable volume over the full season. This is 13% more water than is represented by the 20 cfs target. Indeed, the reliable volume of the water rights acquired in perpetuity exceed the 20 cfs target volume. An additional 4,400 AF would be required to meet the 33 cfs target for the full season. As for the late summer, the reliable volume from the instream portfolio during the critical period is approximately that needed to meet the 20 cfs target. An additional 1,600 AF would be required to meet the 33 cfs target. As progress is made towards the full season 33 cfs target, it will likely become more cost-effective to find acquisitions that meet this late season need as opposed to accumulating additional full season water rights.

FIGURE 37. FINAL YEAR FULL SEASON [LEFT] AND CRITICAL PERIOD [RIGHT] RELIABLE VOLUMES



4.4 Environmental Flow Cost-Effectiveness

Cost-effectiveness analysis provides a way for various audiences to evaluate the combined performance of cost and effectiveness for water transactions. The form and metrics for cost-effectiveness metric will vary with the transaction program and the audience for the information (Aylward, Pilz, Kruse, et al. 2016). In the Whychus case a fairly basic volumetric analysis of cost per unit of environmental flow volume is largely sufficient, as the program has sought to provide streamflow throughout the year in a single reach. As noted above, there may be an advantage eventually to obtaining late summer water in the creek. At that time it may be useful to specifically address the cost-effectiveness during this critical period. As effectiveness metrics such as flow during the critical period or direct ecological outcomes. such as number of salmonids benefitted by the environmental flow, are already built into the spreadsheet data structure it is relatively straightforward to extend the basic cost-effectiveness analysis to include these additional cost-effectiveness metrics. For this paper, however, all the basic volumetric cost-effectiveness metrics are reported in $ per AF, meaning in 2016 constant dollars per reliable discounted acre foot of flow volume (or $2016/RD-AF).

As observed earlier, the overall cost-effectiveness of the environmental water transactions carried out from 1997 to 2016 is $100/AF, for those transactions that were compensated (Table 11). If all the environmental water is included irrespective of whether it was directly compensated, then the cost comes down to $96/AF. This is approximately the same as saying that on average the water transaction program has rented one acre-foot of reliable ("wet") water for a single year at a cost in 2016 dollars of $96.

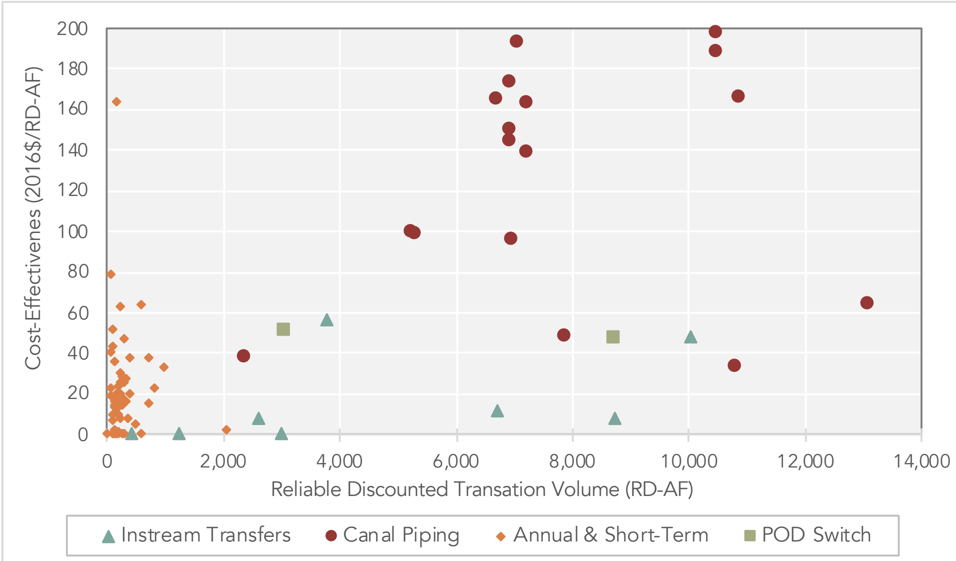
TABLE 11. COST-EFFECTIVENESS SUMMARY

Transaction Name	CPI Adjusted Cost (2016 $)	Face Value Eflows		Reliable Discounted Volume (RD-AF)	Face Value Indicators (2016 $)		Cost-Effectiveness in 2016 $ by Volume
		Volume (FV-AFY)	Rate (FV-cfs)		Volume (FV-AFY)	Rate (FV-cfs)	
Paid Transactiopns							
In Perpetuity/Long-Term							
Transfers	$ 854,115	1,543	4.1	31,816	$ 553	$ 207,814	$ 27
Piping	$ 17,121,978	11,024	26.0	132,186	$ 1,553	$ 659,273	$ 130
POD Changes	$ 558,683	683	1.6	11,748	$ 818	$ 347,008	$ 48
Annual & Short-Term	$ 181,017		5.2	11,259			$ 16
Unpaid	$ -			8,757			n/a
Totals	$ 18,740,771			195,767			$ 96
Totals - Paid	$ 18,740,771			187,009			$ 100

4.4.1 Determinants of Cost-Effectiveness

The average figure masks considerable transaction-by-transaction variability as well as significant variability between the types of transactions. The results for the cost-effectiveness of each type of transaction are presented in Figure 38. Note that in the graphics, the annual and short-term transactions (i.e., instream leases, forbearance agreements and the surface water to groundwater switch transactions) are grouped together to reduce the complexity of the data presentation. These annual and short-term transactions tend to be low cost on average, at $16/AF, but have low discounted volumes. As the DRC leases with TSID at fixed prices the dispersion of individual annual and short-term transactions above $20/AF needs explaining. One reason for this is simply that leases from TSID come with a variety of priority dates. Also, it can be difficult to carry out all phases of the leasing process in time to obtain state approval in advance of the season of the lease. In both these cases, the reliable water actually realized within the season of use may be less than expected. The DRC has tried to address these issues by paying for leases based on "wet water." The DRC does this by trying to back out leased water based on flows at the gage at Sisters and other instream water rights in effect. As noted above for many years environmental flows do not appear to have been regulated according to priority, and thus confidence in such estimates of "wet water" is limited. The dispersion shown in the graphic is therefore in part a result of the approach taken here, that of directly accounting for the effective date of the lease approval and the reliability of the leased water rights in the estimation of the reliable environmental flow volume.

Figure 38. Cost-Effectiveness of Whychus Transactions



The compensated instream transfers vary from $7/AF to $56/AF. The POD switches both fall close to $50/AF. Neither of these show any economies of scale in terms of lower/higher cost-effectiveness by size of transaction. Canal piping, on the other hand, demonstrates some diseconomies of scale with most of the larger volume transactions clustering in the $140/AF to $200/AF range. However, the volume saved by these transactions is not the best indicator of scale. It is more useful to consider the size of the conveyance itself. In Figure 39 the transactions are sorted into those transactions that are truly for “canals”, so the TSID Main Canal and the McKenzie Canal versus those that are smaller conveyances, called “ditches.” Cost-effectiveness for the small ditches at $34/AF to $64/AF is much better than for the large canal projects (at $100/AF to $200/AF). This corresponds well with the larger experience from DRC piping projects in the Deschutes Basin, i.e., that the smaller ditch projects tend to be much less expensive.

Figure 39. Cost-Effectiveness of Main Canal versus Ditch Piping

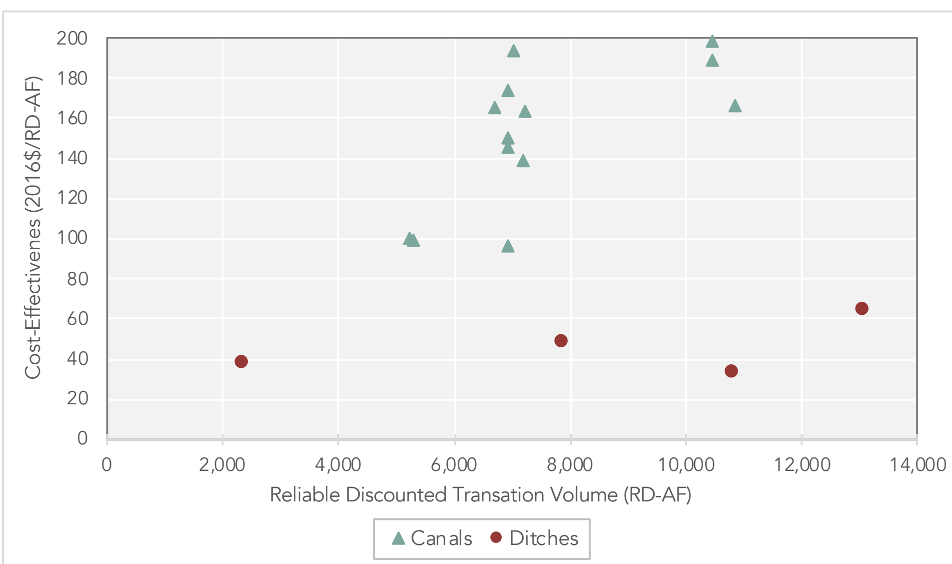
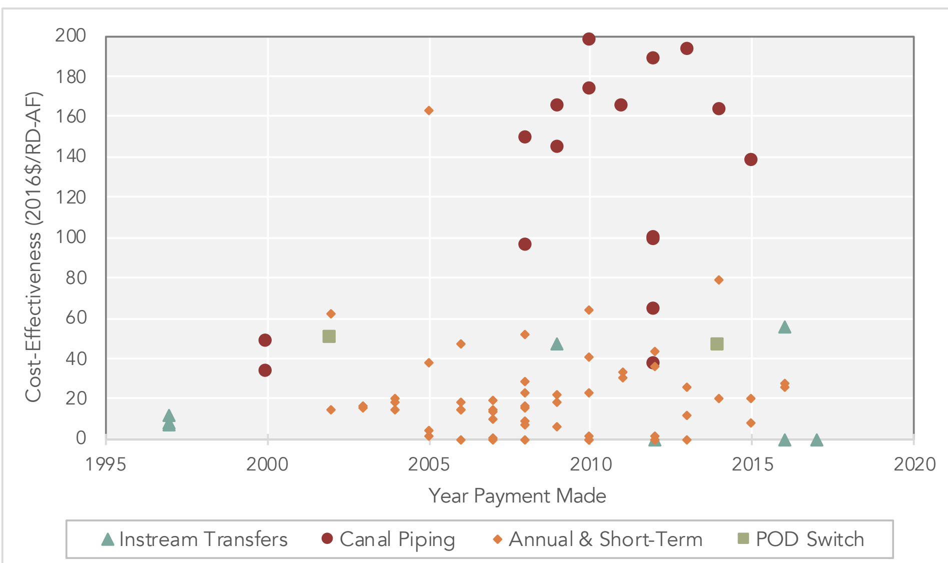


Figure 40 attempts to further explain the variability by plotting cost-effectiveness of transactions over time. Annual and short-term transactions, and POD switches do not show any defined trend over time. However, transfers and piping do show somewhat of a trend towards higher costs over time. Note that as these costs are inflation adjusted these trends are not due to normal inflation in the economy. Rather, the suggestion is that the real costs of these projects are increasing over time. One potential explanation for this is that the earlier projects were "low hanging fruit." Certainly, in the case of transfers, the early Smith-Barclay transfer could be labeled as such. It was the first transfer of its kind in the Deschutes Basin and a transfer of rights off of urbanizing lands. If the prices of the three main transactions, Smith-Barclay (1997), Lazy Z-Willets (2009) and Leithauser (2016) are compared the most rapid annual growth rate in price is between Smith-Barclay and Lazy Z-Willets at 15%. If Lazy Z-Willets is set aside and only Smith-Barclay and Leithauser are examined then the rate of growth in price is 10% annually. Between the two later transactions, the growth rate in price is just over 2%. As valuable as water is in the economy it is unlikely to increase at 15% per year in real terms. In other words, the Smith-Barclay transaction is an outlier, and likely a case of low hanging fruit.

In the case of piping, the early Cloverdale and Fryrear projects may also be seen as low hanging fruit, except that as pointed out the determinative factor here may simply be that they were ditch piping projects, not canal piping projects per se. In this case these could be seen as trial transactions, smaller projects before committing to larger, multi-phase projects. The increasing cost over time for piping projects is therefore largely accounted for by the move from ditch to canal projects in the mid-2000s.

FIGURE 40. COST-EFFECTIVENESS OF WHYCHUS TRANSACTIONS OVER TIME



So how do the costs of water in Whychus Creek compare to other figures around the western US? Water leases across the western US come in all shapes and sizes and at prices varying from around $10/AF to $300/AF. The cost of buying water rights in the West also varies hugely, from $1,000/AF up to $15,000/AF, with a figure of about $2,000/AF being a rough median of sorts for purchasing water from medium value uses, i.e., alfalfa (as opposed to high value in row crops and low value in pasture). Taking a 5% incremental capitalization ratio to adjust capital asset values to rental/lease values these purchase prices are equivalent to $50/AF to $750/AF, with $100/AF for the median. The cost of water acquired in Whychus is therefore on the low end of water prices across the west, but as recounted earlier this should very much be the case given the low value of the water in agricultural use.

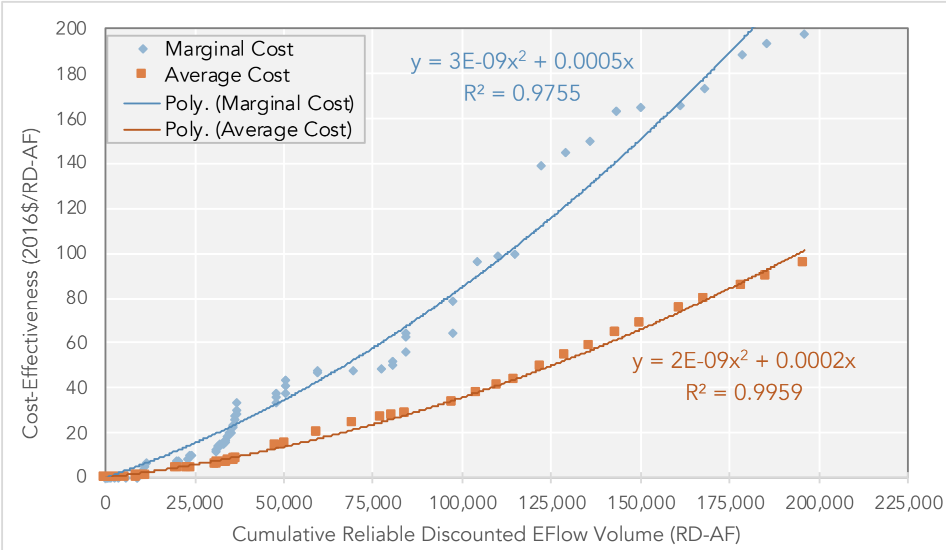
Interestingly, the cost of the piping projects would fall above this median purchase costs of water rights in other western states. It then is useful to consider how piping cost-effectiveness might vary across the western US with respect to that in Whychus Creek? The Whychus area, and the Deschutes generally, might generally be regarded as a high cost location as the lack of a deep soil profile and the prominence of young fractured basalts can greatly increase excavation costs. On the other hand. these same basalts lead to high cost inefficient and leaky canals which, other things equal, would lower cost-effectiveness by increasing the rate of return of the conservation investment. Given that many of the Whychus projects relied on placing pipe in existing canals and ditches, it would seem that the data presented here suggest that large conservation projects may just be more expensive than purchasing water rights, even when compared to prices in areas with higher value agriculture than is found in Whychus Creek and the Deschutes Basin generally.

4.4.2 Marginal and Average Costs

In economics the marginal (or supply) and average cost curves are used to convey the dynamics of a market. Using the cost-effectiveness data generated for Whychus Creek marginal and average cost curves can be constructed for flow restoration in Whychus Creek. In this case, supply is the quantity of reliable discounted environmental flow volume in upper Whychus Creek. The price of purchasing this supply is the cost-effectiveness of the transactions. A marginal cost curve simply charts the price paid for each increment in the quantity of supply, going from the cheapest to the most expensive transaction. The average cost curve is derived from the same data, but instead of taking the price paid for each increment in supply, simply takes the total cost of acquiring supply at a given point and divides it by that supply to get the average cost.

The marginal and average cost curves for flow restoration in Whychus Creek are shown in Figure 41. The normal economic assumption is an increasing supply curve. Buying more of any item will ultimately cost more. Textbook supply curves show that the marginal cost will increase faster and faster giving the curve a convex (upward bending) shape. The average cost curve would then also tend to be increasing but at a lesser rate, widening the gap between the two curves. In the Whychus case, the marginal and average curves display the expected convex shape. With the large number of data points available it is possible to fit polynomial curves with a high degree of explanatory power (R-squared over 0.97 in both cases). As the supply curve bends upward more rapidly than the average cost curve, the difference between the marginal and average cost increases as the supply increases.

FIGURE 41. COST-EFFECTIVENESS OF WHYCHUS PERMANENT TRANSACTIONS: MARGINAL AND AVERAGE COSTS



As this is the first time such curves have been developed for environmental water transactions it is not possible to compare with those from other programs. For the Whychus case the curves do portray how widely the costs of acquiring environmental flows can vary, even in a single small watershed. How should these curves be interpreted and used by those involved in such programs? While both marginal and average costs are important economic indicators, from a programmatic point of view – one focused on the mission of attaining streamflow targets – the long-run average cost may be of most importance. In the Whychus case some 200,000 AF of reliable discounted water was acquired at $100/AF on average. If the programmatic goal is another 50,000 AF then the equations can be used to forecast what this might look like, giving a potential total cost for acquiring the full 250,000 AF and an estimate of the additional funds needed to reach the target.

Of course, DRC staff. board members for the DRC and funders of the DRC may also want to use this information to look at the costs of potential new transactions and wonder if they should approve or invest in this transaction. Is the transaction a "good deal"? Of course, this is difficult to assess exactly. As emphasized above the cost of these transaction does not uniformly go from low to high over time and there are significant differences between the cost-effectiveness of different transaction types. For this purpose, the cost-effectiveness data might best be deployed as shown in Figure 38 and Figure 40.

Returning to the historic analysis it is worth clarifying that although these exact curves were not available during the program's roll out, a general sense of the comparative cost of the different types of transactions was evident to those involved in the program. In the case of Whychus, the DRC Board (and DRC funders) supported the increasingly expensive piping projects despite the presence of low cost leases and lower cost expensive transfers, POD switches, groundwater-switches, etc. There are two obvious reasons for this: the scale of the problem and the social and institutional nature of large environmental water transaction programs.

No doubt, an important rationale was that investing in a portfolio of transactions was necessary in order to reach the large amounts of water needed to meet instream flow targets and to do so in perpetuity. The piping projects promised both large amounts of water and permanence. But in so doing they came at a higher cost. TSID's institutional reluctance to consider instream transfers from within the irrigation district reflected social constraints and effectively closed the door to what might have been a more cost-effective portfolio. While such a path might have been more cost-effective it would have led to the drying up of rural, irrigated lands. While likely of incidental economic impact in the region such action runs counter to social mores and the institutional interests of the irrigation district. The Whychus case demonstrates that cost-effectiveness will not be the only determinant of transaction program strategy. In this case, the availability of large federal challenge grant programs to fund these piping projects, the willingness of TSID to continue an active leasing program, the interest in the local community in maintaining irrigated lands, and a long-term persistent effort to work on transfers, leases and POD changes with the individual water right holders on the creek effectively formed the strategy for restoration of environmental flows.

4.4.3 Conclusions on Cost Effectiveness

The cost-effectiveness results suggest the following three findings about environmental water transactions in Whychus Creek:

1. Conserved water is the least cost-effective transaction but also the most widely deployed approach, and has increased dramatically in real cost over time;
2. Transfers have also increased in cost over time and appear to be of intermediate cost compared to conserved water and leasing; and
3. Leasing is a time-limited and relatively small impact approach, but is a very low cost method of obtaining instream flows.

The Whychus case demonstrates that cost-effectiveness will not be, and should not be, the sole basis for transaction selection. Yet, the large variation in costs does suggest that tracking these costs accurately during program rollout may be useful in project selection and in long run planning.

Three caveats about these metrics include:

1. The cost-effectiveness metrics are in dollar and acre-feet terms but as highly processed figures they cannot be loosely compared to simple dollar or acre-feet terms but only to other 2015 dollar per reliable discounted acre-feet and discounted wet acre-feet terms.
2. The limitation of the basic volumetric cost-effectiveness metric is that it does not convey much about the effectiveness of the expenditure in reaching flows during a particular critical period or reaching a particular ecological target.
3. Comparison of these cost-effectiveness figures with those from other watersheds or basins is would rely on understanding the context in each locale to ascertain if fundamental underlying conditions make the comparison of value or not.

Nevertheless, as all of the transactions investigated here produce acre-feet of water in the same reach towards the same target and the same ecological objective, the cost-effectiveness figures are useful in assessing the cost of flow restoration and comparing different transactional strategies to attain flow and ecological objectives. In addition, as an initial step in this direction observations about the behavior of these costs across transactions and across time are of value, as would be comparison to such behavior in other locations.

5. Appendix: Cost-Effectiveness Metrics

The following discussion is an adaptation of the appendix in Martin et al. (2017) to the Whychus example, which itself is based on Aylward et al. (2016). Please refer to the latter report for a robust discussion of environmental flow cost effectiveness. Cost effectiveness of water transactions is best represented by the inflation adjusted financial cost of acquiring the water rights divided by the discounted reliable water volume.

Inflation Adjusted Cost. The total the water acquisition may include just the water costs or the water costs plus an estimate of the transaction costs incurred in completing the transaction. In this paper only the water costs are reported for Whychus Creek. The measure of price inflation used here is the consumer price index, or CPI, which is available from the US Bureau of Labor Statistics, (https://www.bls.gov/cpi). The base year for the BLS inflation index is 1982. For convenience the reference year selected for this paper is 2016, the most recent year for which transaction data are available. The inflation index is derived with the goal of converting current dollar figures from other years into constant 2016 dollars.

The inflation index for a given year *y*, is as follows:

$$\pi^y = \frac{CPI^{2016}}{CPI^y}$$

For a given transaction *i* with acquisition costs occurring in year *y*, AC_{iy}, the inflation adjusted acquisition cost is calculated as follows

$$AC_i^{2016} = AC_i^y * \pi^y$$

Discounted Reliable Volume.: In order to arrive at a present value for the environmental flow benefit of the water transaction, the stream of future water benefits acquired through the transaction should be discounted. This puts environmental flows expected in future/different years into units commensurate with one another. The priority of the water rights acquired will determine the expected volume of environmental flows over time, i.e., as "wet" water that may be relied upon to meet flow targets. The procedure then is to first derive the reliable volumes across the life of the transaction and then discount these volumes to arrive at a total discounted reliable volume of environmental flow.

Associated with each transaction there may be one or more "packets" of environmental flows, or a flow rate over a given duration denominated by the year of priority. Each of these packets must be evaluated separately for their reliable volume. In the Whychus case each priority is coded to one of four water right securities: high, medium, low and very low as defined in Table 3, with an associate percent reliability,

Information required to compute the reliability is the effective date and termination date for the instream flow, the term (i.e. number or years) for which the flow is acquired, the instream flow rate, and, for transactions with a term greater than one year, the start date and end date of the season of use. Note that for flows legally protected instream these parameters come from the final order for the lease or water right change. For water user agreements these figures must come from the transaction agreement, which should itself live within the bounds of the underlying water right.

Total reliable flow volumes are discounted to account for the fact that the value of time and money change over time. Thus, discount rates are applied to ensure that the value future of the transaction benefits can be assigned a present value. The general formula for calculating the discounted wet environmental flow volume for transaction *i*, with M packets of environmental flows, j, and a transaction term of N years, *t*:

$$RD_i = \sum_{j=1}^{M}\sum_{t=1}^{N}\frac{Q_{ijt} * D_{ijt} * \beta_{ij} * \kappa}{(1+r)^t}$$

Where:

- κ = 1.9835 AF/cfs-day
- β = expected value (in %) for the packet
- D = duration (in days) of the season of use for the packet during year *t*
- Q = instantaneous rate of environmental flows (in cfs) for the packet
- *r*= the discount rate

The duration of the transaction is calculated differently depending on whether it is the first or subsequent year of the transaction and whether the term is for just one year or for multiple years:

$$D_{ij1} = T - X + 1, when\ t = 1, N = 1\ and\ T > X$$
$$D_{ij1} = E(MM/DD) - X(MM/DD) + 1, when\ t = 1\ and\ N > 1$$
$$D_{ijt} = E - \min\{S(MM/DD), T(MM/DD\} + 1, when\ t > 1\ and\ N > 1$$

Where:

- X is the effective date of the transaction (the first date in MM-DD-YYYY that the transaction is in effect, by state final order or by contract)
- T is the termination date (the last date that the transaction is in effect in MM-DD-YYYY)
- S is the annual season of use start date (the first date in the year when the transaction is in effect in MM-DD)
- E is the annual season of use end date (the last date in the year that the transaction is in effect in MM-DD)

***Cost-effectiveness*.** Cost-effectiveness is calculated as the ratio of inflation adjusted acquisition cost to the reliable discounted environmental flow volume:

$$CE_i^{2016} = \frac{AC_i^{2016}}{RD_i}$$

The cost-effectiveness units are $2016 per RD-AF and are analogous to the cost of acquiring 1 acre foot in 2016 (i.e., the present value of one acre foot). The discount rate is selected for this paper is 5%, consistent with US Office of Management and Budget regulations as discussed in Aylward et al (2016).

Total Cost-effectiveness. When aggregating cost-effectiveness data for transactions there are two possibilities. Simple statistics can be calculated based on the cost-effectiveness results for the concerned data set. In the paper such results are indicated along with the relevant statistic, i.e. average, median, etc. However, for the purpose of evaluating portions of a transaction program like the one in the Deschutes an average cost-effectiveness is more useful in representing the cost-effectiveness of a group of transactions. For this purpose the average cost-effectiveness can be taken as the sum of all the money spent on the group of transactions divided by all the reliable discounted acre feet generated by the transactions. So the mean cost-effectiveness for a given type of transaction *k*, out of a set of *i* transactions is calculated as follows:

$$\overline{CE}_k^{2016} = \frac{\sum_{i=k} AC_i^{2016}}{\sum_{i=k} RD_i}$$

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