Upper Deschutes Watershed Council
Technical Report

2010 Whychus Creek Monitoring Report

Mork, L. and Houston, R. Editors

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Symbols and Abbreviations

BLM	Bureau of Land Management
CTWS	Confederated Tribes of the Warm Springs Reservation
DRC	Deschutes River Conservancy
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Admistration
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OWEB	Oregon Watershed Enhancement Board
OWRD	Oregon Water Resources Department
PGE	Portland General Electric
TSID	Three Sisters Irrigation District
UDWC	Upper Deschutes Watershed Council
EPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey

0S	Age 0+ summer salmonid stage
0W	Age 0+ winter salmonid life stage
1S	Age 1+ summer salmonid life stage
1W	Age 1+ winter salmonid life stage
7DMAX	Seven day moving average maximum temperature
BACI	Before After Control Impact
°C	Degree Celsius
cfs	Cubic feet per second
CI	Confidence Interval
CL	Confidence Level
df	Degrees of freedom
DO	Dissolved oxygen
°F	Fahrenheit
mg/L	Milligrams per liter
OAR	Oregon Administrative Rules
PBACI	Paired Before After Control Impact
QA/QC	Quality assurance / quality control
S	Standard distance from regression line
Spawning	Spawning and rearing salmonid life stages
StDev	Standard deviation from mean
TMDL	Total Maximum Daily Load

Restoration Effectiveness Monitoring in Whychus Creek

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Introduction

Local, federal, state, and private agencies and organizations have coalesced around the reintroduction of steelhead into Whychus Creek. The creek, a tributary to Oregon's Deschutes River, was historically one of the most important steelhead spawning streams in the upper Deschutes Basin (Nehlsen 1995). The construction of the Pelton Round Butte dam complex on the Deschutes River in the 1960s eliminated anadromous runs in Whychus Creek.

Fisheries managers agreed to restore fish passage at and reintroduce anadromous fish above the Pelton Round Butte dam complex as part of a hydroelectric relicensing agreement signed in 2005 (FERC 2005). A group of non-profits, public agencies, and private actors had informally cooperated to restore habitat conditions in the Whychus Creek since the mid 1990s. The selection of the creek as a focal area for reintroduction catalyzed existing restoration efforts, drawing state and regional restoration investors to the region.

As restoration investments and commitments increased, restoration partners saw the need to formalize their relationships. The Bonneville Environmental Foundation led the development of the Upper Deschutes Model Watershed in 2006 to foster collaboration between organizations committed to restoring aquatic and riparian habitat in the upper Deschutes Basin. This program, led by the Upper Deschutes Watershed Council (UDWC), provides a nucleus for coordinated restoration in Whychus Creek.

Restoration funders have increasingly looked to quantify the ecological outcomes of their investments. Habitat improvement projects *should* lead to more resilient fish populations. Fish passage projects *should* lead to increased spawning upstream of historic barriers. Stream flow restoration *should* lead to cooler stream temperatures. The lack of monitoring associated with river restoration (Bash and Ryan 2002, O'Donnell and Galat 2008, Souchon *et al* 2008) has made it difficult to quantify these outcomes, let alone document cause-and-effect relationships between specific actions and ecological outcomes.

So, why are so few restoration practitioners monitoring? A survey of 85 restoration project managers in Washington identified limited resources as the primary barrier to restoration project evaluation (Bash and Ryan 2002). Experiences in the Deschutes Basin suggest that the traditional project-based funding model grossly underfunds monitoring. Project-based restoration funding available through grants typically offers little, if any, opportunity for long-term monitoring. Grants are short-term, focused on immediate results and driven by budget cycles rather than ecological processes. This funding model leads restoration practitioners to focus on implementing projects instead of monitoring outcomes. The Upper Deschutes Model Watershed's approach to monitoring restoration effectiveness in Whychus Creek acknowledges these limitations and seeks to leverage limited resources to improve monitoring. The UDWC has developed a monitoring approach for Whychus Creek that focuses on tracking the status and trends of selected physical and biological indicators. These indicators represent conditions in the creek, prior to and following the implementation of a suite of restoration projects begun in 2009.

In an ideal active adaptive management watershed restoration scenario, restoration practitioners would hypothesize about how individual restoration activities would affect the stream structures and functions or lead to responses in target species. Practitioners would then design each restoration activity as an experiment and evaluate their hypotheses using controls, statistical tools and other standard experimental practices.

While this scenario may appear to be ideal, it is not possible in Whychus Creek for three reasons. First, the multiple restoration actions occurring simultaneously along the creek make it difficult to verify cause and effect relationships between specific actions and changes in physical and biological conditions. Second, the multiple agencies and organizations managing and restoring Whychus Creek work under different mandates set by local, state or federal regulations, community interests or other factors. These different mandates make it impractical to establish controls for the rigorous experimental designs necessary for validation monitoring. Finally, there are very limited resources available for monitoring in Whychus Creek. Therefore, from a practical standpoint, any monitoring must be completed as efficiently as possible by using existing data. The reliance on existing data inherently limits the types of analyses and the conclusions that can be developed.

The monitoring approach selected by the UDWC focuses on tracking the status and trends of key physical and biological indicators in Whychus Creek. The UDWC selected these indicators based on a conceptual model of factors limiting salmonid production in the creek (Figure 1). They expect that ongoing restoration actions will ameliorate the limiting factors identified in the conceptual model and that selected indicators will respond to changes in these limiting factors. This approach will not test cause and effect relationships between restoration actions and changes in selected indicators. It will demonstrate whether these indicators have moved closer to desired conditions. The UDWC drew indicators from seven broad categories: stream flow, water quality, habitat quality, stream connectivity, fish entrainment, macroinvertebrates, and fish populations. The 2010 Whychus Creek Monitoring Report includes chapters for five of these indicators: streamflow, water quality, stream connectivity, fish entrainment, and fish populations. Minimal new habitat quality data and no new macroinvertebrate data were collected on Whychus Creek in 2010. The status of these indicators will be updated in the 2011 Whychus Creek Monitoring Report.

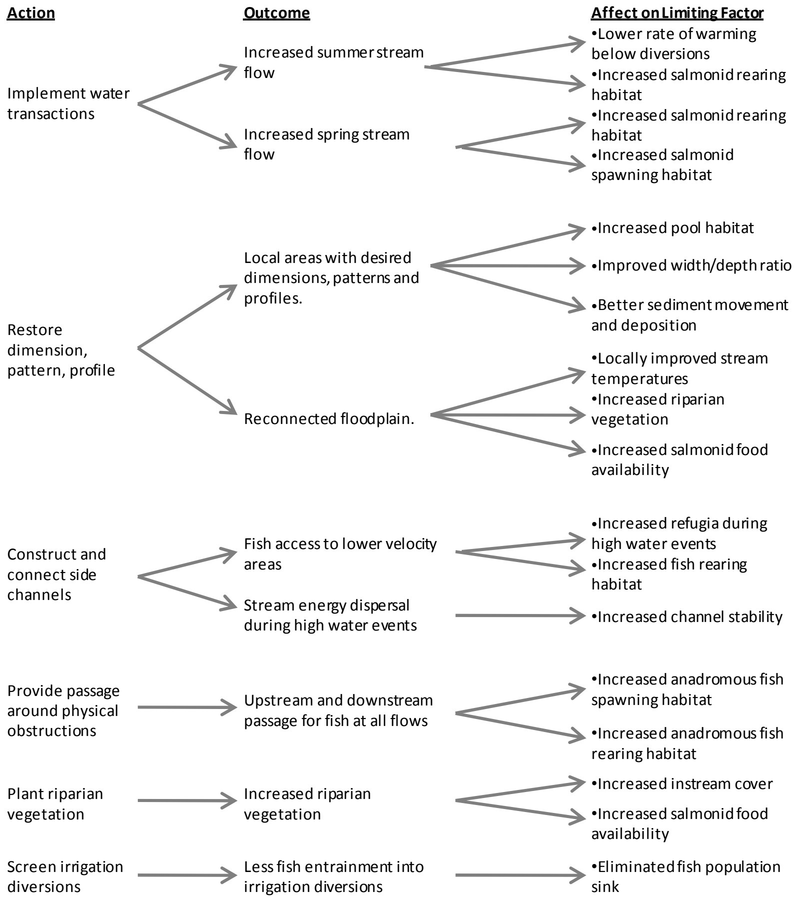

Figure 1.
This conceptual model illustrates the expected influences on each life stage of resident and anadromous salmonids in Whychus Creek. The UDWC expects that the ongoing restoration actions will affect the limiting factors identified in the conceptual model.

Study Area

Whychus Creek originates in the Cascade Mountains near Sisters, OR. The creek's watershed encompasses approximately 162,000 acres and 40 stream miles in Deschutes and Jefferson Counties in central Oregon. The watershed extends from the crest of the Cascade Mountains to the creek's confluence with the Deschutes River, approximately three miles upstream of Lake Billy Chinook(Figure 2). Elevations range from 10,358 feet at the peak of South Sister to 2,100 feet at the confluence with the Deschutes River.

Snow melt in the Cascade Mountains drives stream flow through Whychus Creek. The high permeability of the surrounding landscape leads to high infiltration and subsurface transport of water (USFS 1998, Gannett *et al* 2001). Associated springs located along the creek, particularly in the Camp Polk and Alder Springs areas, increase flows by 25% to 300% (UDWC 2000). Tributaries to Whychus Creek include Snow Creek, Pole Creek, and Indian Ford Creek.

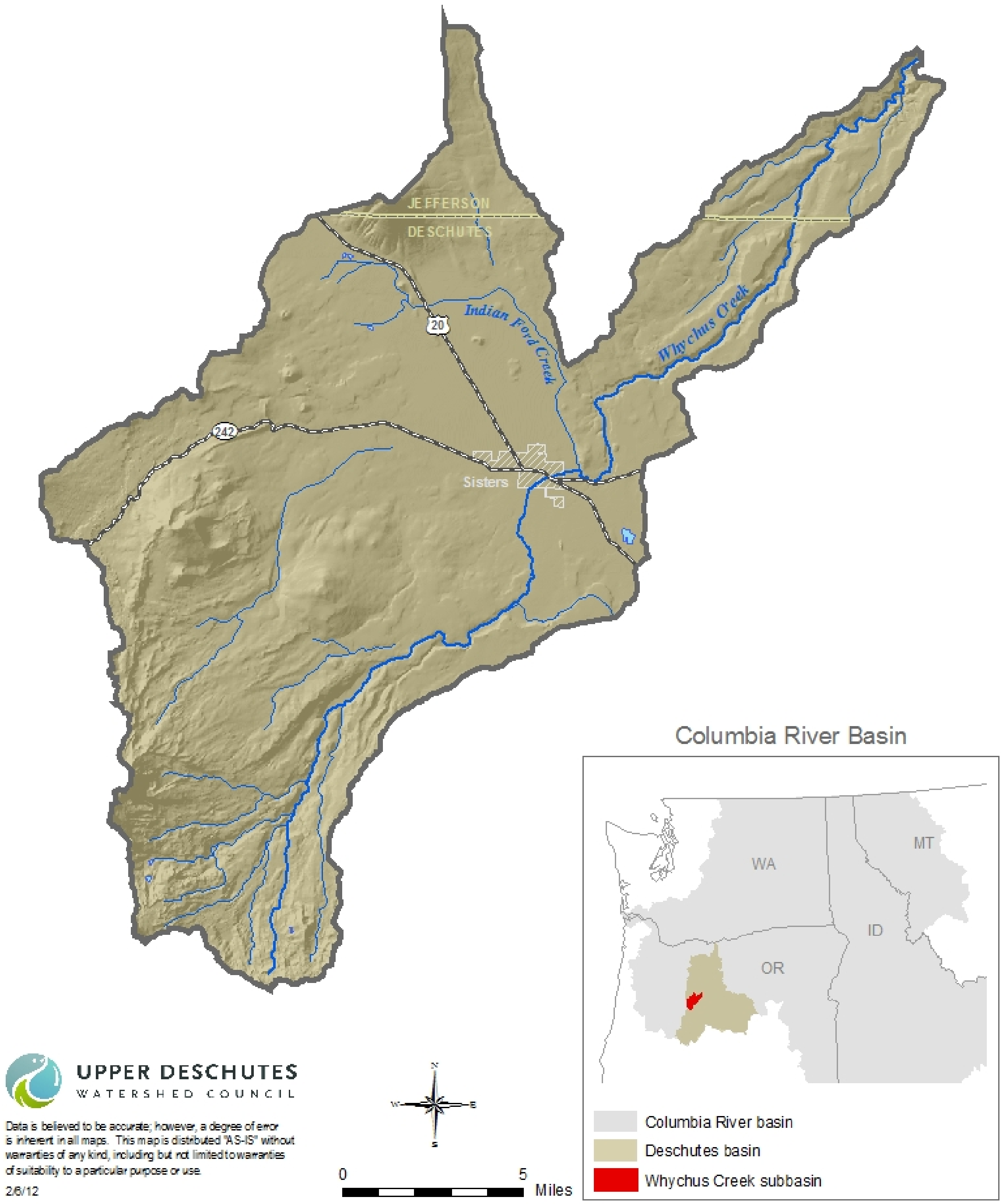

Figure 2.
Whychus Creek extends from the Cascade Range to the Deschutes River. The creek's watershed encompasses approximately 162,000 acres of Deschutes and Jefferson Counties in central Oregon

Irrigators cumulatively divert up to 90% of the water from Whychus Creek at several points upstream of the City of Sisters. These diversions result in a highly modified stream flow regime that varies greatly depending upon the season and the reach. A baseline inventory identified six permanent or seasonal fish passage barriers associated with these diversions blocking upstream fish passage in Whychus Creek from approximately river mile 15 through river mile 25 (UDWC 2008). Fish passage barriers isolate upstream resident fish populations and limit the amount of habitat accessible to anadromous fish.

Land use has impacted fish habitat along Whychus Creek since the early European settlers moved into the area. Livestock grazing, urban development, irrigation diversions and other activities have all gradually affected fish habitat quality. In addition, the channelization of 18 miles of creek in the 1960s severely damaged specific reaches (USFS 1998). Channelization, riparian vegetation removal and stream flow modification have reduced the availability of pools, shade, in-stream structure and other important habitat components (USFS 1998).

Restoring anadromous runs to a stream with highly degraded habitat could be a futile effort if stream conditions are unsuitable to support salmonid spawning, rearing, and migration. The 2005 relicensing agreement committed dam operators to investing in passage facilities at and habitat restoration upstream of the Pelton Round Butte complex. Fisheries managers introduced the first cohort of more than 200,000 steelhead fry into Whychus Creek in 2007. Additional releases have occurred every year since and will continue according to a jointly developed fish management plan.

Agencies and organizations have embarked on a creek-scale restoration effort in Whychus Creek. Restoration projects slated for the creek range from site-specific land acquisition and channel reconstruction to coordinated barrier removal and stream flow restoration. Restoration practitioners envision the implementation of these projects over a ten-year period beginning in 2009.

Technical Studies

Annual technical studies analyze and interpret available data to examine the status and trends of physical and biological indicators in Whychus Creek. These studies document changes from baseline conditions following the implementation of large scale habitat restoration actions along the creek, including streamflow restoration, channel realignment, fish passage improvements, screening of irrigation diversions, and other restoration actions. Baseline conditions are reported in the 2009 Whychus Creek Monitoring Technical Report (UDWC). These conditions were established following some streamflow restoration but prior to any other restoration efforts.

Golden (2012) documents summer stream flow conditions in Whychus Creek from 2009-2010. It focuses on metrics representing low flow conditions in the creek. Mork (2012a) answers questions related to stream temperatures, dissolved oxygen and pH in Whychus Creek. It draws from twelve years of data to examine water quality in relation to state standards and to stream flow restoration. Restored stream flow has likely affected metrics in each of these reports.

Two reports quantify habitat improvements resulting from restoration projects completed subsequent to baseline analyses. Mork (2012b) documents the status of fish passage barriers as a measure of stream connectivity along the creek. Restoration partners expect to provide passage at each of the original six barriers identified in the 2009 report. Mork (2012c) discusses reductions in fish entrainment potential on the creek. It sets unscreened irrigation diversions and the cumulative flows diverted through them as a proxy for entrainment potential with the expectation that restoration partners will screen each of these diversions in the future.

The final report updates the status of fish populations in the creek. Although the ongoing reintroduction of steelhead and chinook in Whychus Creek prevents meaningful application of population data for these species as an indicator of restoration effectiveness, continuing to track fish population trends in Whychus will provide critical information for future evaluation of reintroduction and restoration efforts. Mork (2012d) integrates USFS and PGE and CTWS's 2009-2010 steelhead and chinook survey results. It outlines the status of fish populations in the creek and discusses how additional sampling and new methods planned for future years will expand the current understanding of these populations.

Whychus Creek macroinvertebrate communities were not monitored and no new habitat surveys were conducted on Whychus in 2010. Macroinvertebrates will be sampled in 2011 and results included in the 2011 Whychus Creek Monitoring Report. UDWC will continue to work with ODFW to update the 2009 habitat quality analysis (Golden 2010) and incorporate any new habitat survey data.

These five reports evaluate improvements in stream conditions in 2009 and 2010 as measured by the status of physical and biological indicators subsequent to major streamflow and channel restoration and irrigation diversion retrofits. The reports and the data that they contain will help restoration partners to understand the effectiveness of their action at moving the creek towards desired conditions. Restoration partners expect to draw from these reports to continually improve restoration implementation and monitoring in the creek.

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Whychus Creek Stream Flow

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Abstract

Irrigation diversions in Whychus Creek, a tributary to Oregon's Deschutes River, divert up to 90% of the flow from the creek during the summer irrigation season. Restoration partners have focused on restoring summer stream flow in the creek to support the reintroduction of steelhead trout and chinook salmon. The Deschutes River Conservancy (DRC) used stream gage data from Whychus Creek to determine the baseline status of selected stream flow metrics prior to large scale stream restoration along the creek. Three metrics characterize low flows in the creek. The minimum 30 day moving average flow represents annual low flow conditions. May median flow represents late spring/early summer conditions. August median flow represents late summer conditions. Minimum 30 day moving average flows generally occurred in August and early September. They increased or remained constant in every year except for 2005 and 2009. May median flows exhibited both inter-annual and intra-annual variation. May median flow ranged from a low of 5.4 cfs in 2003 to high of 58 cfs in 2009. August median flows also exhibited inter-annual and intra-annual variation but intra-annual variation was lower than in May. August median flow ranged from a low of 2.6 cfs in 2002 to high of 25 cfs in 2008. These results indicate that Whychus Creek still experiences low flows during both late spring/early summer and late summer/early fall flow, two periods when irrigation demands generally exceed water availability. Extreme flows, however, appear to be decreasing in magnitude during both of these periods. These results highlight the need for restoration partners to focus their efforts on both of these periods. As restoration continues to increase flows in Whychus Creek, restoration partners should continue to evaluate both early and late season flow as well as extreme low flows to fully describe restoration outcomes.

Introduction

Stream habitat alteration occurs in two different ways. Human disturbances directly alter stream habitat. Human disturbances also prevent natural disturbances from occurring. Both of these types of disturbance alter stream habitat (NRC 2002). Irrigation diversions along Whychus Creek divert up to 90% of the creek's flow from April through October (Figure 1) and cause both of these types of disturbances.Restoration partners have identified these stream flow alterations as a primary factor limiting fish production in Whychus Creek.

The entire hydrograph affects what a stream looks like and how it functions (Poff *et al* 1997). Different components of the hydrograph may drive different ecological processes (Doyle *et al* 2005). Changes in stream flow can affect biological characteristics such as macroinvertebrate assemblages (Dewson *et al* 2008, Konrad *et al* 2008, James *et al* 2008, Monk *et al* 2008, Wills *et al* 2006), fish communities (Xenopoulos *et al* 2006, Decker e*t al* 2008), and riparian vegetation (Stromberg *et al* 2005). By removing up to 90% of the stream flow from Whychus Creek, irrigation diversions have eliminated all but the low flow components of the hydrograph during the summer and likely affected each of these characteristics. Monitoring the status and trends of stream flow in Whychus Creek will illuminate whether the stream is moving towards or away from desired conditions.

Hydrologists have developed a wide range of hydrograph related metrics to track stream flow conditions over time. These different metrics relate to different components of the hydrographthat affect physical and biological conditions in a stream. Olden and Poff (2003) identify 171 metrics that appeared in 13 papers. These metrics relate to the magnitude, frequency, rate of change, duration, or timing of flow events. Monk *et al* (2007) built off of Olden and Poff (2003) to identify an additional 30 metrics. Others have attempted to identify a subset of metrics that represent hydrologic alteration across a wide range of conditions (Olden and Poff 2003, Monk *et al* 2007, Yang *et al* 2008, Gao *et al* 2009). Researchers have not yet identified a single subset of metrics that represent alteration in all types of streams. Different types of streams have different hydrologic characteristics. For example, groundwater dominated streams exhibit relatively low seasonal variability while snowmelt dominated streams exhibit clear seasonal patterns.The type of stream, surrounding geography, and the desired conditions in that stream define the appropriate set of metrics.

This study focuses on low flow metrics that relate to expected stream flow restoration. Pyrce (2004) identifies and categorizes low flow indices from published and unpublished sources. Many of these focus on seven day averages and their exceedances. Although these metrics appear to be widely used across the United States, they were originally intended for specific purposes such as water quality regulation and may not be appropriate for the identification of ecological flows (Pyrce 2004).

This study uses three metrics selected from the Indicators of Hydrologic Alteration that represent flow magnitude and timing (Richter *et al* 1996, Figure 4). Generally, flow magnitude relates to habitat availability within a stream or river (Richter *et al* 1996). However, flow timing also affects habitat availability. Yang *et al* (2008) studied the relationship between fish communities and flow in the Illinois River. Their results suggest that low flow timing affects fish diversity while low flow magnitude affects overall abundance.

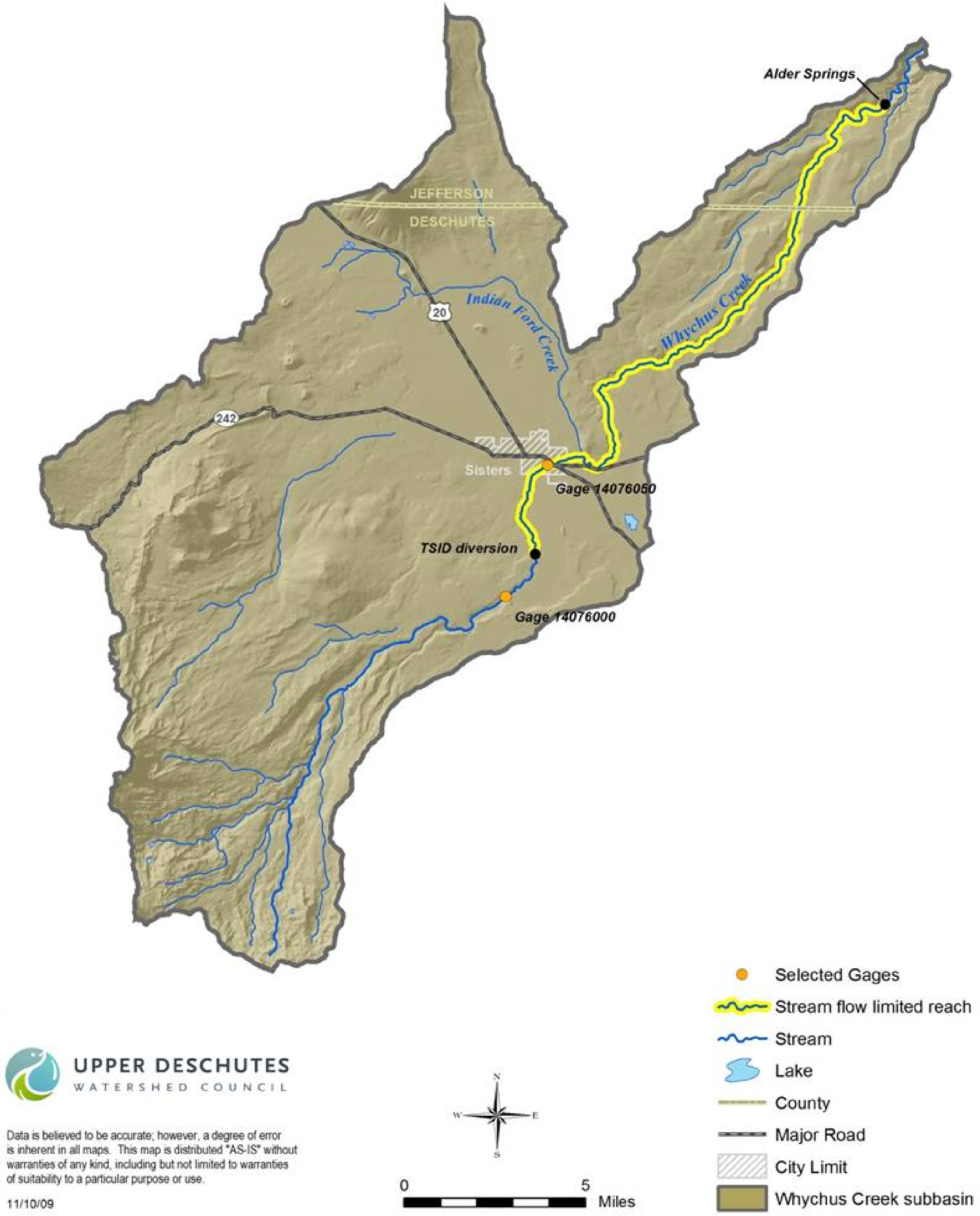

Figure 3.
Stream flow limits stream function in Whychus Creek downstream from the Three Sisters Irrigation District Diversion. Spring inputs near the mouth of Whychus Creek increase stream flow and improve conditions in the creek.

Metric	Appears In
30 day minimum	Gaoet al2009, Richter et al1996
May median flow	Gaoet al2009, Richter et al1996
August median flow	Richter et al1996

Figure 4.
The three metrics selected for this report relate to the stream flow restoration goals identified by restoration partners. They represent discharge magnitude and timing during low flow periods.

The status and trends of these metrics will inform restoration partners about the effectiveness of stream flow restoration. These metrics do not represent the entire hydrograph. Instead, they represent conditions in the creek during the summer irrigation season. Irrigation diversions alter flows more during this period than during other times of year. Restoration partners have addressed and expect to address primarily low summer flows over the next ten years. The existing legal framework surrounding stream flow restoration, combined with a lack of storage reservoirs along the creek, hinders the restoration of other components of the hydrograph.

Minimum 30 Day

The minimum 30 day moving average flow generally represents annual low flow conditions in Whychus Creek. As Richter *et al* (1996) note, life stages of aquatic organisms often link to hydrologic cycles. Changes in the timing and magnitude of the minimum 30 day moving average flow may affect these organisms. Restoration partners expect both the timing and magnitude of this metric to change as a result of restoration activities in Whychus Creek.

May Median

May median flow may provide a general indicator of spawning habitat availability in Whychus Creek.Redband trout spawning in the Deschutes Basin centers on the month of May (Oregon Department of Fish and Wildlife 2005). Increasing irrigation demands prior to peak runoff typically stress water supplies in the creek during this period.Restoration partners expect to increase May stream flows through water transactions with irrigators.

Richter *et al* (1996) suggest the use of mean monthly flows to characterize the central tendency of stream flows. Median monthly flows provide a similar measure of central tendency that minimizes the influence of outliers (Helsel and Hirsch 2002). Using the median instead of the mean may provide a better measure of central tendency when human actions lead to outliers such as extreme low or high flow events.

August Median

August median daily average flow provides an indicator of late summer flow availability in Whychus Creek.Decreasing snow pack and steady irrigation demands typically stress water supplies in the creek during this period and stream flow often reaches a nadir.Low flow magnitude provides one measure of habitat availability during this period (Richter *et al* 1996).

Methods

Data Collection

The Oregon Water Resources Department (OWRD) maintains several gages along Whychus Creek. They operate gage 14076050 at the City of Sisters, downstream from major irrigation diversions along the creek (Figure 1). OWRD began operating this gage in 2000 and has continued operating it through the publication of this report in 2012.This report uses data from this gage. OWRD operates another gage, 14075000, upstream from all diversions on Whychus Creek. They have published stream flow data for this gage from 1906 through 2012. Why not estimate historic stream flows at the City of Sisters over a longer time period for these analyses? Water transactions for stream flow restoration in Whychus Creek occurred during every year of the study period. Baseline conditions at the beginning of the study period are neither static nor represented by historic conditions. The period from 2000 through 2010 reflects current conditions in the creek.

Gage 14076050records stream stage in Whychus Creek at Sisters, OR.The gage consists of a float-tape system that records stream stage every fifteen minutes (Burright A. Personal communication. August 24, 2009).OWRD obtained preliminary data from this gage on a near-realtime basis through an automated, remote telemetry-based process. OWRD reviewed this data based on their knowledge of site conditions and site-specific stage-discharge relationships. They estimated any missing values and revised any values believed to be erroneous (OWRD 2009a). OWRD reviewed this data again before publishing it as daily average discharge data online. OWRD had published final data from May 18, 2000 through September 30, 2008 and from October 1, 2009 through September 30, 2010 when this report was prepared. OWRD had published provisional data from October 1, 2008 through September 30, 2009 and October 1, 2010 through October 31 2010 when this report was prepared.

Data Analysis

The Deschutes River Conservancy(DRC) analyzed published or provisional stream flow data for gage 14076050. The DRC analyzed this data for each water year,extending from October 1 through September 30, between 2000 and 2010. OWRD installed this gage in 2000 and only published data for the 2000 water year after May 17. All analyses except for the August median flow omitted year 2000 due to incomplete data.

Minimum 30 Day

The DRC used spreadsheet software to determine the timing and magnitude of the minimum 30 day moving average flow at gage 14076050. The DRC considered each water year independently. Moving averages extended to 14 days before and 15 days after the date for which the value was being calculated. Initial data exploration suggested that low flow periods extended across water years. Dividing the data by water year, October 1 through September 30, did not fully represent the low flow periods experienced each season. The DRC used an extended water year, November 1 through October 31, to capture low flow periods that extended across water years. The DRC completed this analysis for extended water years 2001 through 2010.

May Median

The DRC used spreadsheet software to determine the median daily average flow during the month of May for years 2001 through 2010. The DRConly had partial data for 2000 and did not include that data in this analysis.

August Median

The DRC used spreadsheet software to determine the median daily average flow during the month of August for years 2000 through 2010. The DRC had full data for August 2000 and included that data in this analysis.

Results

Minimum 30 Day

The minimum 30 day moving average discharge at the Oregon Water Resources Department's gage number 14076050 generally occurred during August and early September (Figure 5). This discharge ranged from 2.40 cfs in 2002 to 16.00 cfs in 2008. It increased or remained constant each year except for 2005 and 2009.

Year	30 Day Minimum (cfs)	Dates
2001	2.55	9/25/2001 – 9/27/2001
2002	2.40	8/8/2002 - 8/14/2002
2003	3.60	9/19/2003 – 10/1/2003
2004	8.15	8/6/2004 - 8/18/2004
2005	6.70	8/4/2005 - 8/11/2005, 8/15/2005 - 8/19/2005
2006	12.00	8/24/2006 - 8/27/2006
2007	12.00	8/28/2007 - 8/31/2007
2008	16.00	4/25/2008 - 5/7/2008, 9/7/2008 - 9/30/2008
2009	13.00	9/14/2009-9/22/2009
2010	19.00	9/1/2010-9/13/2010

Figure 5.
The minimum 30 day moving average discharge of Whychus Creek at the Oregon Water Resources Department's gage number 14076050 provides one indicator of low flow magnitude and timing.

May Median

The DRC analyzed stream flow data as described above. Average May flow in Whychus Creek at the Oregon Water Resources Department's gage number 14076050 exhibited both inter-annual and intra-annual variation (Figure 6). Median flow during the month of May ranged from a low of 5.4 cfs in 2003 to high of 58 cfs in 2009. 2006 exhibited the greatest intra-annual variation in May flow, with a 20th percentile value of 22 cfs and an 80th percentile value of 122 cfs.

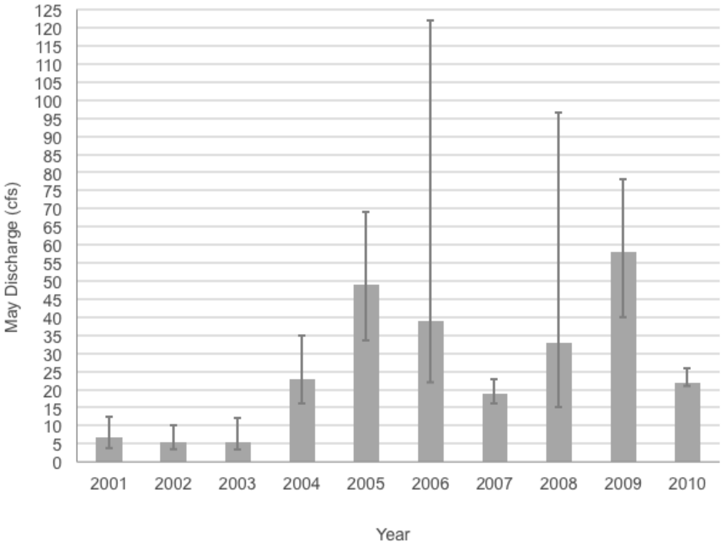

Figure 6.
The median of the average daily discharge of Whychus Creek at the Oregon Water Resources Department's gage number 14076050 during the month of May provides one indicator of low flow magnitude. Error bars represent the 20th and 80th percentile discharges during the month of May at this location.

August Median

Median discharge during the month of August exhibited both inter-annual and intra-annual variation at gage number 14076050 (Figure 7). 2002 exhibited the lowest median discharge during the month of August, with a median daily average discharge of 2.6 cfs. 2008 exhibited the highest median discharge during the month of August, with a median daily average discharge of 25 cfs. 2008 exhibited the greatest intra-annual variation in discharge, with a 20th percentile discharge of 19.5 cfs and an 80th percentile discharge of 31 cfs.

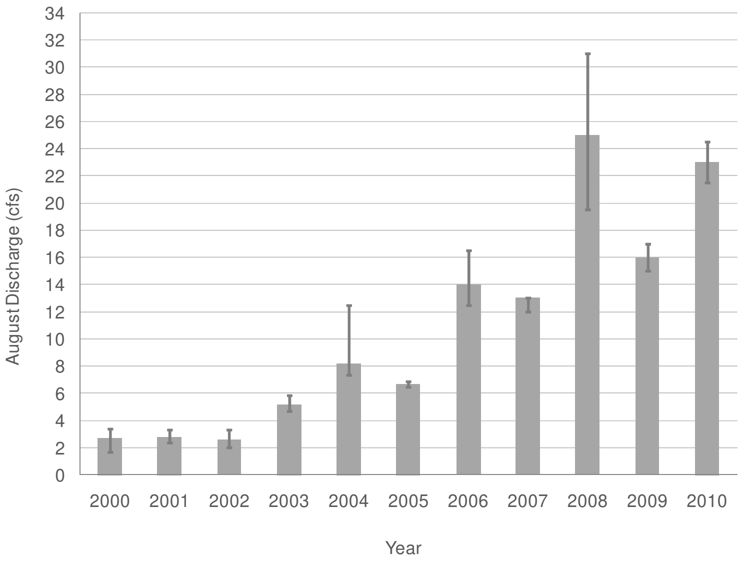

Figure 7.
The median of the average daily discharge of Whychus Creek at the Oregon Water Resources Department's gage number 14076050 during the month of August provides one indicator of low flow magnitude. Error bars represent the 20th and 80th percentile discharges during the month of August at this location.

Discussion

The analyses in this report describe baseline stream flow conditions in Whychus Creek at the beginning of a ten-year period of intensive restoration. They focus on the period from 2000 through 2010. Restoration partners have prioritized the restoration of summer base flow in Whychus Creek downstream from the Three Sisters Irrigation District diversion. The three metrics included in this report characterize low flow conditions in Whychus Creek.These metrics suggest that flow lows continue to occur in both late spring/early summer and late summer/early fall 2009 and 2010 . Minimum 30-day moving average data suggest that flow lows now occur more often in late summer/early fall.

Late Spring/Early Summer Flows

May daily average stream flow results continue to display a wide range of inter-annual and intra-annual variability (Figure 6).Although August monthly median flows tend to be lower than May monthly median flows (Figure 6, Figure 7), May monthly median flows appear to exhibit greater intra-annual variability. Instream water rights awarded to the State of Oregon in the 1990s to support fish populations provide one base flow target. Median daily average flow during the month of May exceeded Oregon's 20 cfs instream water right for Whychus Creek upstream from Indian Ford Creek in six out of ten years (OWRD 1996, Figure 6). It never met Oregon's March, April, and May instream water right of 50 cfs for Whychus Creek downstream from Indian Ford Creek (OWRD 1996, Figure 7).

Restoration partners have focused on late summer stream flow as a metric for restoration effectiveness. Late spring/early summer stream flow may also be important for stream function. As noted earlier, redband trout spawning centers on the month of May (ODFW 2005). Consistently low stream flow during late April, May, and early June may limit available spawning habitat. Extreme low flow events during this period may limit fish production by dewatering existing redds. Results suggests that extreme low flows are occurring less often now than during this period they have in the past, consistent with efforts to restore base flows to Whychus Creek.

Late Summer/Early Fall Flows

This analysis suggests that Whychus Creek continues to experience low flows during late summer and early fall. The annual minimum 30 day moving average stream flow occurred during the month of August or September in each year included in this study (Figure 5). Stream flow naturally decreases during this period, so periodically low late summer and early fall low flows do not necessarily limit stream functions. The magnitude and frequency of these flows in Whychus Creek, though, suggest that low flows may limit fish populations.

The State of Oregon instream water right again provides a rough base flow target in Whychus Creek. Median daily average flows during the month of August exceeded Oregon's 20 cfs instream water right for Whychus Creek upstream from Indian Ford Creek only in 2008 and 2010 (OWRD 1996a, Figure 7).They never met the state instream water right of 33 cfs for Whychus Creek downstream from Indian Ford Creek (OWRD 1996b, Figure 7). Late summer and early fall base flows continue to fall short of these targets and may limit fish populations. Increasing these flows should remain a priority for restoration partners and they should continue to use August or September median flows as an indicator of restoration effectiveness.

Recommended Actions

Restoration partners have focused on restoring base flows to this historically dewatered stream system. They have operated under the assumption that base flows are critical to providing the habitat necessary to support self-sustaining populations of anadromous fish. They used, and continue to use, the instream water rights awarded to the State of Oregon as stream flow targets. Legally protected stream flows are currently approaching state instream water rights for some locations. The reliability of these water rights varies based on water availability in Whychus Creek, leading to inter- and intra-annual variability in the low flow metricts discussed earler. Restoration partners should continue to evaluate these low flow metrics to understand how restoration actions correlate with stream flowoutcomes in Whychus Creek. Evaluating additional extreme low flow metrics may further inform restoration partners as to the success of their actions.

Restoration partners have not focused on restoring non base-flow components of this hydrograph beyond base flow. High stream flow events continue to occur before, during and after the irrigation season. Irrigation operations have reduced the magnitude of but not eliminated these events. Although describing a desired hydrograph would better inform restoration partners about the status of the stream flows in Whychus Creek, it would likely not improve the ability of restoration partners to address other hydrograph components. The absence of any storage reservoirs along Whychus Creek and the continued presence of high flow events have reduced the priority of evaluating non-base flow components of the hydrograph.

The three stream gages operated by the Oregon Water Resources Department on Whychus Creek measure flow above all irrigation diversions, below most irrigation diversions, and below natural spring inputs at 15 minute intervals. Currently, OWRD only publishes daily average stream flow at each of their gages. Daily average flows do not fully represent the range of flows in Whychus Creek; they mask diurnal fluctuations and may not reveal low or high flow peaks. Past reports recommended the use of 15 minute flow data in outcome evaluation. 15 minute interval data may more precisely describe conditions in the creek but it is not necessarily accurate as it does not go through OWRD review and publication. Due to potential inaccuracies in this data, restoration partners expect to continue using this 15 minute interval data for real time evaluation of stream flows but not for long-term outcome evaluation.

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Whychus Creek Water Quality Status, Temperature Trends, and Stream Flow Restoration Targets

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Abstract

Diversion of almost 90% of summer streamflow and channelization of over 50% of the length of Whychus Creek have degraded water quality, leading to an ODEQ listing of water quality limited in 2002, 2004, and 2010. The Upper Deschutes Watershed Council monitored temperature from 1995 through 2010 at eleven sites representing the diversity of flow conditions in Whychus Creek. This report incorporates 2009 and 2010 data to evaluate the current status of temperature in Whychus Creek in relation to state standards for salmonid spawning, rearing and migration, quantify changes in temperature in reaches with restored flows, and refine target flows projected to produce temperatures that meet state standards. Temperatures exceeded state rearing and migration standards at six and five monitoring sites in 2009 and 2010 respectively. Temperatures exceeded the lethal threshold for salmon and steelhead for seven days in 2009, but not at all in 2010. BACI analysis of differences in stream temperature between years indicated that an increase in flow from 2002 to 2010 resulting from streamflow restoration lowered temperatures downstream of the TSID diversion but increased them downstream of Alder Springs. Opposite trends observed from 2006 to 2010 (warmer temperatures downstream of TSID and cooler temperatures downstream of Alder Springs) were attributed to a reduction in actual flow during this period. Regression of 1995-2010 temperature and flow data indicated a minimum flow of 66 cfs is necessary to meet the 18° temperature standard, corroborating previous results. These results provide a scientific basis for adaptive management and restoration planning in Whychus Creek.

Introduction

Restoration partners have identified the Whychus Creek watershed as a priority watershed for conservation and restoration within the upper Deschutes Basin (NWPPC 2004, UDWC 2006). Diversion of almost 90% of average summer flows and historic channelization of nearly 50% of the creek length create conditions that contribute to elevated stream temperatures and may compromise other water quality parameters. As of 2004, Whychus Creek was listed by ODEQ under Clean Water Act Section 303(d) as water quality limited with TMDLs needed for temperature (Category 5) and categorized as having insufficient data for assessment for dissolved oxygen and pH (Category 3) (Table 1, Figure 1). In May 2011 ODEQ submitted their 2010 Water Quality Assessment Integrated Report to the EPA (ODEQ 2011). The 2010 assessment for Whychus Creek is consistent with ODEQ's 2004 findings.

UDWC began monitoring temperature on Whychus Creek in 1995. In 1999 DRC streamflow restoration efforts first returned continuous summer flows to Whychus Creek, and the volume of flows protected instream has increased every year since. Restoration partners expect that increasing streamflow will reduce temperatures in Whychus Creek to more frequently and consistently meet spawning and rearing habitat requirements for native fish including anadromous steelhead trout and Chinook salmon re-introduced to the creek in 2007.

Water temperature affects the growth and survival of aquatic organisms. Temperature naturally fluctuates on both a daily and seasonal basis, with daily fluctuations resulting from continuous changes in solar radiation and air temperature, and seasonal fluctuations in response to changes in climate, solar aspect, and variable amounts of streamflow from snowmelt and precipitation. Water temperatures naturally increase as water flows downstream, and temperatures can decrease as a result of groundwater inflows (springs) or the inflow of cooler tributaries. Anthropogenic changes that alter the natural hydrograph, such as diversions for irrigation and groundwater pumping, also influence temperature.

ODEQ state temperature standards have been established to protect fish and other aquatic life in Oregon waterways (ODEQ 2009). The year-round temperature standard applied to Whychus Creek for salmon and trout rearing and migration specifies that seven-day moving average maximum (7DMAX) temperatures are not to exceed 18˚C. The 2002 303d list also identified Whychus Creek as not meeting the 13˚C state temperature standard for salmon and steelhead spawning. The state temperature standard for salmon and trout spawning is 13˚C. Neither the 2004 nor the 2010 303(d) lists applied this criterion to Whychus Creek because anadromous fish were not present in Whychus Creek when data for these lists were collected. However, this habitat use may resume, and the spawning temperature standard become relevant, as salmon and steelhead reintroduced in 2007begin to return to the creek. Spawning season has yet to be identified for Whychus Creek. This report references the January 1 – May 15 spawning season identified for the Lower Deschutes Subbain. The State of Oregon 1992-1994 Water Quality Standards Review (ODEQ 1995) identified 24˚C as the lethal temperature threshold for salmon and trout.

Dissolved oxygen and pH levels also directly affect aquatic organisms. Waterways naturally produce oxygen through photosynthesis and aeration. Dissolved oxygen is consumed through respiration and degradation of organic plant compounds. The amount of dissolved oxygen available (percent saturation) is also affected by altitude and temperature: water at higher altitudes holds less dissolved oxygen than water at lower altitudes (because the degree of atmospheric pressure is less at higher altitudes), and cold water holds more dissolved oxygen than warm water. When oxygen is consumed at a faster rate than it is produced, dissolved oxygen concentrations fall, negatively affecting aquatic organisms. Salmon and trout, especially in their early life stages, are very susceptible to low dissolved oxygen concentrations.

Water pH levels (alkalinity) are primarily affected by plant photosynthesis, but can also be influenced by the chemistry of the local substrate. The volcanic soils of the Upper Deschutes Basin may increase the acidity (and decrease pH) of basin waterways. Water pH directly influences salmon and trout egg development, egg hatching, and embryo development, with consequent effects on aquatic insect populations. Extreme pH levels can negatively impact fish by increasing the availability and toxicity of pollutants such as heavy metals and ammonia.

The 2004 and 2011 ODEQ 303(d) lists classify Whychus Creek as having insufficient data for assessment for dissolved oxygen and pH. UDWC analyses of data collected from 2006 to 2008 indicated that Whychus Creek met state dissolved oxygen standards for steelhead and salmon rearing and migration, although dissolved oxygen levels did not consistently meet state criteria for salmon and trout spawning. Because dissolved oxygen saturation is directly affected by temperature, we can expect dissolved oxygen levels to track temperature trends. While observed trends in stream temperature continue to cool, and in the absence of other novel environmental conditions, we expect dissolved oxygen levels to improve or remain constant. Under these circumstances temperature data are an appropriate proxy for dissolved oxygen data, and indicate dissolved oxygen levels that will continue to meet the state standard for salmon and trout rearing and migration. UDWC discontinued monitoring dissolved oxygen on Whychus Creek in 2009 on this premise. A consistent warming trend in temperature would flag potentially deteriorating dissolved oxygen conditions and warrant resuming monitoring of dissolved oxygen. Although 2006-2008 data indicated pH standards were not consistently met in the summer, low pH values were attributed to the influence of volcanic soils and were not expected either to limit ecological function or to be affected by increased flows with streamflow restoration. Accordingly this parameter was also discontinued as of 2009. While this report does not present dissolved oxygen or pH data, we consider the observed trends in temperature to provide a strong surrogate measure of water quality in Whychus Creek. For further discussion of temperature, dissolved oxygen, pH, and state standards for each parameter, refer to *Whychus Creek Water Quality Status, Temperature Trends, and Streamflow Restoration Targets* (Jones 2010).

The streamflow and habitat restoration efforts of Deschutes River Conservancy (DRC), UDWC, and restoration partners aim to improve water temperatures to meet the18˚C state standard and support sustainable anadromous and resident fish populations by reducing warming rates, reconnecting the creek to floodplains and groundwater, and increasing the extent of riparian shading. DRC and restoration partners identified a streamflow target for Whychus Creek according to Oregon Department of Fish and Wildlife's requested instream water rights. ODFW March, April and May instream water rights conserve 20 cfs upstream and 50 cfs downstream of Indian Ford Creek (River Mile 18); ODFW rights for August and September, when flows are historically low, specify 20 cfs upstream and 33 cfs downstream of Indian Ford Creek. Requested instream water rights correspond to recommended minimum flows identified through the Oregon Method, which relates streamflow to fish habitat availability (Thompson 1972), but the minimum flows identified may not be sufficient to create suitable conditions for fish or meet state temperature standards.

Whychus Creek Water Quality Status, Temperature Trends, and Streamflow Restoration Targets (Jones 2010) presented baseline information on the status of temperature, dissolved oxygen, and pH in Whychus Creek, documented preliminary changes in temperature observed with streamflow restoration, and developed a regression model describing the relationship between temperature and flow to identify streamflow restoration targets. We present new temperature data for Whychus Creek that updates 2009 analyses to evaluate the current status of temperature in Whychus Creek in relation to state standards for salmonid spawning, rearing and migration, quantify changes in temperature in reaches with restored flows, and refine target flows projected to produce temperatures that meet state standards.

Table 1. 2010 Oregon Clean Water Act Section 303(d) status of Whychus Creek.

	Parameter	**Temperature**		**Dissolved Oxygen**		**pH**	
	Beneficial Use	Salmon & Trout Rearing & Migration	Steelhead Spawning	Salmon & Steelhead Non-Spawning	Salmon & Trout Spawning	Multiple Uses	Multiple Uses
	Season	Year Round	January 1 - May 15	Year Round	January 1 - May 15	Fall/ Winter/ Spring	Summer
	Standard	18° C	12° C	8.0 mg / L @ 90% Sat	11.0 mg / L @ 90% Sat	6.5-8.5 SU	6.5-8.5 SU
ODEQ Reach	0 - 40.3	TMDL Needed	Not Applicable	Not Applicable	Insufficient Data for Section 303(d) Assessment	Insufficient Data for Section 303(d) Assessment	Insufficient Data for Section 303(d) Assessment
	1 - 13.3	Not Applicable	Not Applicable	Insufficient Data for Section 303(d) Assessment	Not Applicable	Not Applicable	Not Applicable
	13.3 - 40.3	Not Applicable	Not Applicable	Insufficient Data for Section 303(d) Assessment	Not Applicable	Not Applicable	Not Applicable

Source: ODEQ 2011

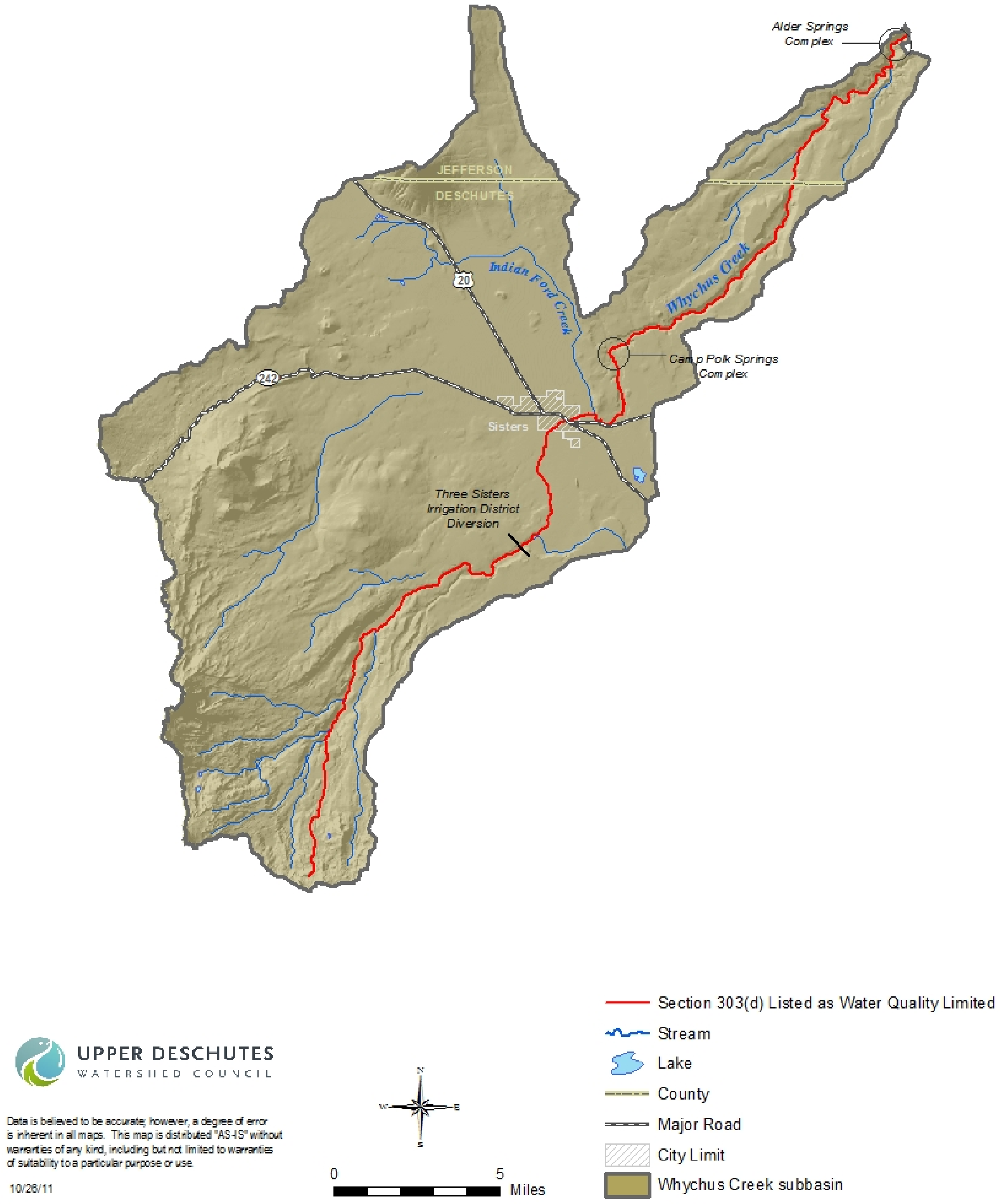


Figure 1.
Whychus Creek is listed as Water Quality Limited from River Mile (RM) 0.0 to RM 40.3 under ODEQ's 2002, 2004, and 2010 303(d) lists. (ODEQ 2011).

Methods

Data collection

Beginning in 1995, UDWC and partners collected continuous temperature data annually at a subset of thirteen locations on Whychus Creek between RM 38 and RM 0.25 (Figure 2, Appendix A). All temperature data used in analyses were collected by USFS, BLM Crooked River National Grasslands, ODEQ, and UDWC. Coordinated monitoring efforts were conducted according to standard methods and protocols outlined in the ODEQ-approved UDWC Quality Assurance Project Plan (UDWC 2008a) and summarized in UDWC Water Quality Monitoring Program Standard Operating Procedures (UDWC 2008b).

In 2009 UDWC, Deschutes Land Trust, private landowners and other restoration partners reached an agreement to restore 1.9 miles of the historic channel of Whychus Creek. The planned restoration will divert the creek from the existing channel into the historic meadow channel, and the UDWC monitoring station historically located on the existing channel will no longer be creekside. To replace this monitoring location and generate pre-restoration data above and below the restoration project site UDWC established two new temperature monitoring stations, one upstream and and one downstream of the planned restoration. As of 2009 UDWC discontinued temperature monitoring at the old Rimrock temperature monitoring station at WC 009.00 and began monitoring temperatures at these two locations.

We obtained average daily streamflow (QD) data for Whychus Creek from Oregon Water Resources Department (OWRD) gage 14076050 at the City of Sisters (OWRD 2011). This gage is located downstream from the Three Sister's Irrigation District diversion and other major irrigation diversions. We used data collected at this gage from 2000 to 2010 in this report, including some data considered by OWRD to be provisional and subject to change.

Temperature status

We evaluated 2009 and 2010 seven day moving average maximum daily temperatures (7DMAX) in relation to the 18˚C state temperature standard for salmonid rearing and migration and the 13˚C state standard for salmonid spawning according to methods described in the ODEQ *Assessment Methodology for Oregon's 2004/2006 Integrated Report on Water Quality Status* (ODEQ 2006). At monitoring sites where July 7DMAX temperatures exceeded the18˚C standard, we compared temperatures to flows recorded at Sister's City Park in relation to ODFW water rights and DRC streamflow restoration targets. We also compared the status of Whychus Creek temperatures in 2009 and 2010 to 1995-2008 results (Jones 2010).

We calculated the average rate of temperature change for Whychus Creek on the hottest water days of 2009 and 2010 from the farthest upstream site at RM 38 (WC 038.00) to the farthest downstream site at RM 0.25 (WC 000.25) by dividing the difference in temperature between these two sites by the distance between the two sites. We defined the hottest water day as the day with the single hottest seven day moving average maximum temperature (7DMAX). For each reach between temperature monitoring sites we calculated the amount by which the longitudinal rate of change exceeded or was lower than the average rate of change. Higher than average longitudinal changes in temperature identify reaches in which the rate of warming increased, allowing restoration partners to prioritize these areas for research and restoration planning. Lower than average longitudinal changes in temperature highlight reaches where cooling occurred and which may accordingly be prioritized for additional conservation measures.

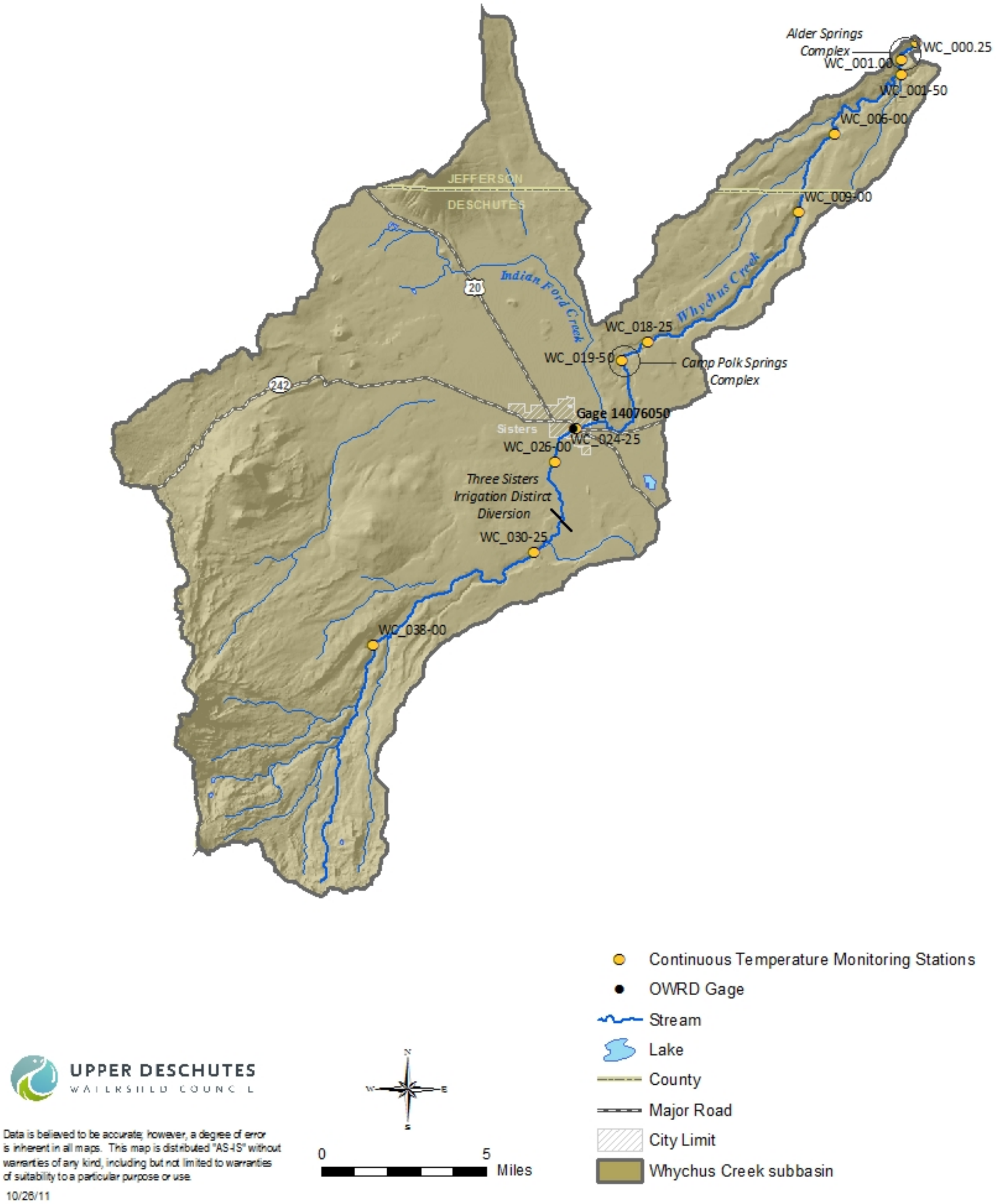


Figure 2.

Continuous temperature monitoring stations monitored in 2009 and 2010 and OWRD Gage 14076050 on Whychus Creek.

Streamflow restoration effectiveness

We selected five locations on Whychus Creek where UDWC has monitored temperature continuously since 2002 to illustrate the local and longitudinal effects of restored flows on stream temperature (Figure 2). Using these stations as reach boundaries, we designated a reference reach and three restoration reaches. The reference reach (WC 038.00 – WC 030.25) represents natural flow conditions upstream of all irrigation diversions. Restoration reach 1 (WC 030.25 – WC 024.25) shows local impacts of streamflow restoration immediately downstream of the most significant irrigation diversion on the creek; restoration reach 2 (WC 030.25 – WC 006.00) demonstrates longitudinal effects of restored flows 18 miles downstream of the site of significant streamflow restoration; and restoration reach 3 (WC 030.25 – WC 000.25) illustrates the longitudinal effects of streamflow restoration after significant coldwater inputs from Alder Springs. By using temperature data from the upstream and downstream boundaries of each reach we were able to calculate the temperature differential across each reach to quantify the longitudinal change in water temperature.

To control for natural variability in streamflow, climate (e.g. precipitation, solar radiation, air temperature, etc.) and other environmental factors that influence inter-annual differences in temperature we used a paired before-after control-impact (BACI) design that compares pre- (before) and post- (after) restoration changes between years within a reference (control) reach to changes between years within a restoration (impact) reach (Smith 2002). By accounting for inter-annual environmental variability this analysis allows differences in temperature observed between reference and restoration reaches to be attributed to the effects of streamflow restoration. We compared July temperature data from three years: 2002, 2006, and 2010. Although flows were first protected instream in 1999, 2002 data represent an early stage in flow restoration characterized by low but continuous flows, and serve as our baseline data for evaluating restoration effectiveness. Data from 2006 represent an interim response of temperature to flow restoration, and 2010 data provide a comparison of present conditions to baseline and 2006 conditions to show how temperatures in restoration reaches have changed relative to temperatures in the reference reach since 2002. We restricted data included in the analysis to one month of the year to reduce the effect of inter-annual seasonal variation in the analysis (Helsel and Hirsch 2002) and selected July as the month during which the hottest water day occurs most frequently (UDWC 2003; UDWC 2008c). We calculated values for analysis from daily median temperatures, a statistic which reflects small changes in temperature more precisely than the daily mean or daily maximum temperature, and at a finer time scale than the seven day moving average maximum temperature (7DMAX).

To quantify the reach temperature differential, defined as the upstream to downstream change in temperature, we subtracted the downstream temperature from the associated upstream temperature for each reach in each year. For each reach we obtained the difference in reach temperature differential from one data year to the next by subtracting the temperature differential for the more recent data year from the temperature differential for the previous data year. We used the mean of the resulting differences to compare how restoration reaches changed between data years relative to the reference reach.

Analyses were conducted using R open source statistical software (R Core Development Team 2007).We used normal plots and a Shapiro-Wilk normality test to establish normal distribution of the calculated between-years differences in temperature differentials for each reach. Where data were normally distributed we used a t-test to compare the mean of the between-years difference in temperature differential (hence, “the mean”) for each restoration reach to the mean for the reference reach; for reaches where data were non-normal we used an exact permutation test (Hothorn and Hornik 2006) to compare the restoration reach and reference reach means. An exact permutation test for paired samples compares the observed statistic, the difference of means from two experimental groups, to the expected statistic under a permutation distribution created by randomly resampling from all possible permutations of the data from treatment and control groups. Here the observed statistic is the difference of the restoration and reference reach means. For each restoration reach- reference reach pair and for each combination of data years we evaluated the following four hypotheses:

1) H_0: There is no difference between the mean for the restoration reach and the mean for the reference reach.

2) H_1: The mean for the restoration reach and the mean for the reference reach are statistically different.

3) H_2: The mean for the restoration reach is significantly less than the mean for the reference reach; the restoration reach has cooled relative to the reference reach

4) H_3: The mean for the restoration reach is significantly greater than the mean for the reference reach; the restoration reach has warmed relative to the reference reach.

We compared 2002-2010 and 2006-2010 results to relative changes in temperature observed from 2002-2006.

Target Streamflow

We included 2009 and 2010 data with our 2000-2008 dataset to perform a temperature-streamflow regression that refines the target streamflow projected to result in temperatures at or below the 18˚C state standard. As in our restoration effectiveness analysis, we restricted data included in the regression to one month of the year to reduce the effect of inter-annual seasonal variation (Helsel and Hirsch 2002) and selected July as the month during which the hottest water day occurs most frequently (UDWC 2003; UDWC 2008a). We used July 7DMAX temperature data for each year included in the analysis from two monitoring stations, WC 024.25 and WC 006.00, to identify the streamflow required at each of these sites to achieve a 7DMAX temperature of 18˚C. Temperature data from WC 024.25 represent stream conditions immediately below diversion of all but protected flows; data from WC 006.00 represent the historical worst temperature conditions on the creek, and thus the location that is both most critically in need of and also stands to benefit the most from streamflow restoration. Daily streamflow data for all July days from 2000-2010 were collected at OWRD gage 14076050 at Sisters and downloaded from the OWRD Near Real Time Hydrographic Data website as average daily flow (QD; OWRD 2011).

To describe the relationship between flow and temperature at the two locations we performed a regression of temperature and flow data. The resulting equations accurately represent the relationship between flow and temperature only for the specific locations, within the evaluated time period, and within the range of flows observed. We paired 7DMAX temperature with the corresponding natural log of the average daily flow (LnQD) for each July day included in the analysis, then ranked flow data and assigned associated temperatures from all July days to each flow value, excluding flows with one or no corresponding temperature record ($n \leq 1$), to calculate the mean of all 2000-2010 July 7DMAX temperatures observed at each flow level. We plotted flows versus mean temperature and fitted a regression trendline that best described the data by adding polynomial terms to the corresponding regression equation. We evaluated S and R^2 values to assess the fit of the regression model to the temperature-flow data. S is the standard error and represents the standard distance (°C) that mean 7DMAX temperature values fall from the regression line. A better fit between the regression line and the data results in a lower S value. R^2 represents the proportion of the variation in mean 7DMAX temperatures that is explained by streamflow (Ln QD). As the fit of the regression to the data improves, the R^2 value increases toward a maximum 100%. Using the regression equation for each location, we calculated the predicted temperature and 95% confidence interval for all flows within the observed range (Appendix B). We calculated the 95% confidence interval (CI) as:

$$Y \pm Y^{(Z_{1-\alpha/2}{}^{S(x) / \sqrt{N})}}$$

$$\text{where } Z_{1-\alpha/2} = Z_{1-0.05/2} = Z_{0.475} = 1.9 \text{ (NIST 2011)}$$

We compared the resulting 2000-2010 temperature-flow regressions and predicted temperatures at given flows for each site to 2000-2008 regressions (Jones 2010) and to Heat Source model scenarios for the same locations on Whychus Creek (Watershed Sciences and MaxDepth Aquatics 2008). Because available Heat Source scenarios assume 33 cfs at WC 024.25 and 62 cfs at WC 006.00, we compared 2000-2010 temperature calculations for these flows.

Results

Temperature status

Seven-day moving average maximum (7DMAX) temperatures exceeded the 18˚C state standard for steelhead and salmon rearing and migration at six sites between RM 19.5 and RM 1 in 2009 and at five sites between RM 18.5 and RM 1.5 in 2010 (**Figure 3**). July 7DMAX temperatures at the OWRD City of Sisters stream gage 14076050 (WC 024.25) immediately downstream of the most significant irrigation diversion on the creek did not exceed the 18˚C standard in 2009 nor in 2010; however, 18 miles downstream at Road 6360 (WC 006.00), 7DMAX temperatures were in excess of the 18˚C standard for 13 days in July 2009 and for 25 days in July 2010. Temperatures exceeded the 24˚C lethal threshold for steelhead and redband trout at Road 6360 for seven days in 2009. Lethal temperatures were not recorded at any site on Whychus Creek in 2010.

July 2009 temperatures of 22.8˚C to 25.2˚C at Road 6360 corresponded to Sisters City Park flows ranging from 14 cfs to 28 cfs, well below the 33 cfs streamflow target for Whychus Creek downstream of Indian Ford Creek. (These temperatures represent the only data available for Road 6360 in 2009.) July 2010 temperatures at Road 6360 ranged from 20.4˚C to 21.6˚C when Sisters City Park flows were below the 33 cfs target (24 cfs to 30 cfs; 15 days), and exceeded 18˚C at Sisters City Park flows ranging from 24 cfs to 102 cfs (25 days).

Continuous temperature data were available for the 2009 spawning season from April 21 to May 15 and for the 2010 season from April 10 to May 15 (Figure 3). Temperatures recorded during these dates exceeded the 13˚C spawning habitat requirement and potential state standard at five sites between RM 19.5 and RM 1.5 in 2009 and at six sites between the same locations in 2010. Spawning season 7DMAX temperatures never exceeded the 13˚C habitat requirement at the OWRD City of Sisters stream gage (WC 024.25) in 2009 nor in 2010, but temperatures at Road 6360 (WC0 06.00) were in excess of the 13˚C habitat requirement for 8 days between April 21 and May 15, 2009, and for 15 days between April 10 and May 15, 2010.

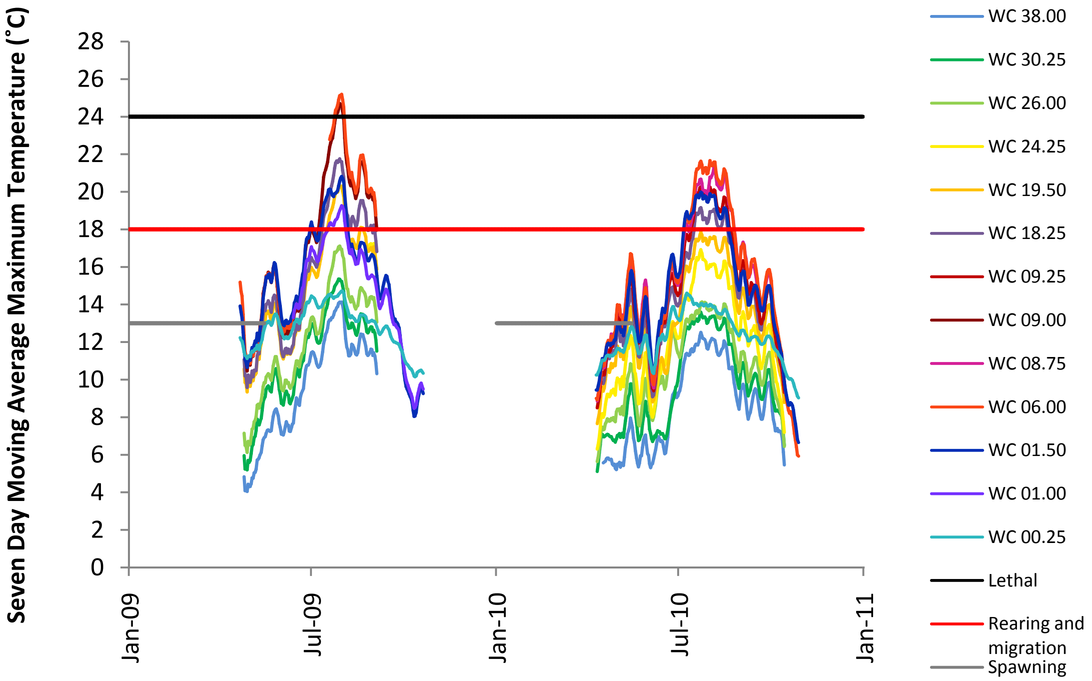


Figure 3.
Temperatures exceeded the 18˚C state standard for salmon and trout rearing and migration at six monitoring locations in 2009 and at five sites in 2010. Temperatures exceeded the January 1- May 15 13˚C spawning standard at five sites in 2009 and at six sites in 2010. Temperatures exceeded the 24˚C lethal threshold at two sites in 2009, but did not meet or exceed the lethal threshold at any monitoring location along Whychus Creek in 2010.

The hottest water days for 2009 and 2010 occurred on July 31 and August 1 respectively. Temperatures at all sites monitored in 2009 and 2010 were lower than or equal to temperatures recorded on July 7, 2007, the hottest water day of 2006, 2007 and 2008 (Figure 4). The longitudinal average rate of change in 2010 was 0.05˚C per mile, down from the 2007 average rate of 0.1˚C per mile (Jones 2010) but higher than the 2009 0.02˚C per mile average (Figure 5). Sites of above-average warming and cooling were generally consistent with 2007 results. The greatest increase over the average rate of change in both 2007 and 2010 occurred between WC 026.00 and WC 024.25, downstream of the TSID diversion (data from WC 024.25 are not available for 2009). High rates of warming also occurred at the downstream monitoring stations for both Camp Polk and Rimrock Ranch, channelized sites characterized by high solar radiation that have been prioritized for stream channel restoration projects. The rate of temperature change in Alder Springs reaches was lower by almost 5 degrees than the average rate of change in both 2009 and 2010, demonstrating a dramatic cooling effect from springs complex flows.

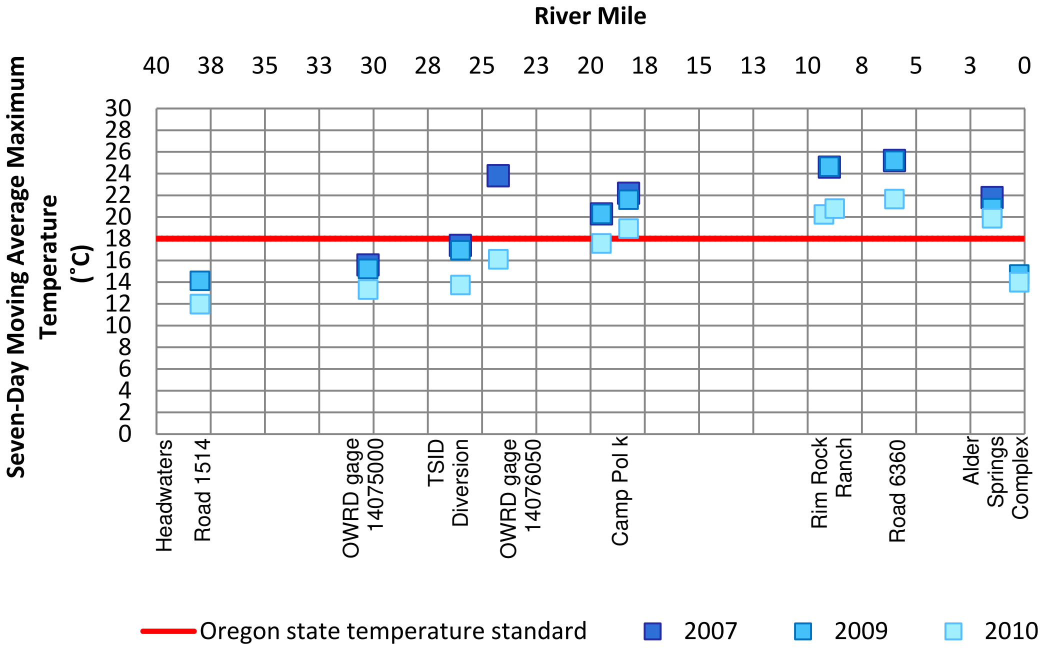


Figure 4.
The longitudinal temperature profile of Whychus Creek on the hottest water days in 2007, 2009 and 2010 shows warming from the headwaters to Alder Springs, where springs complex flows cool stream temperatures.

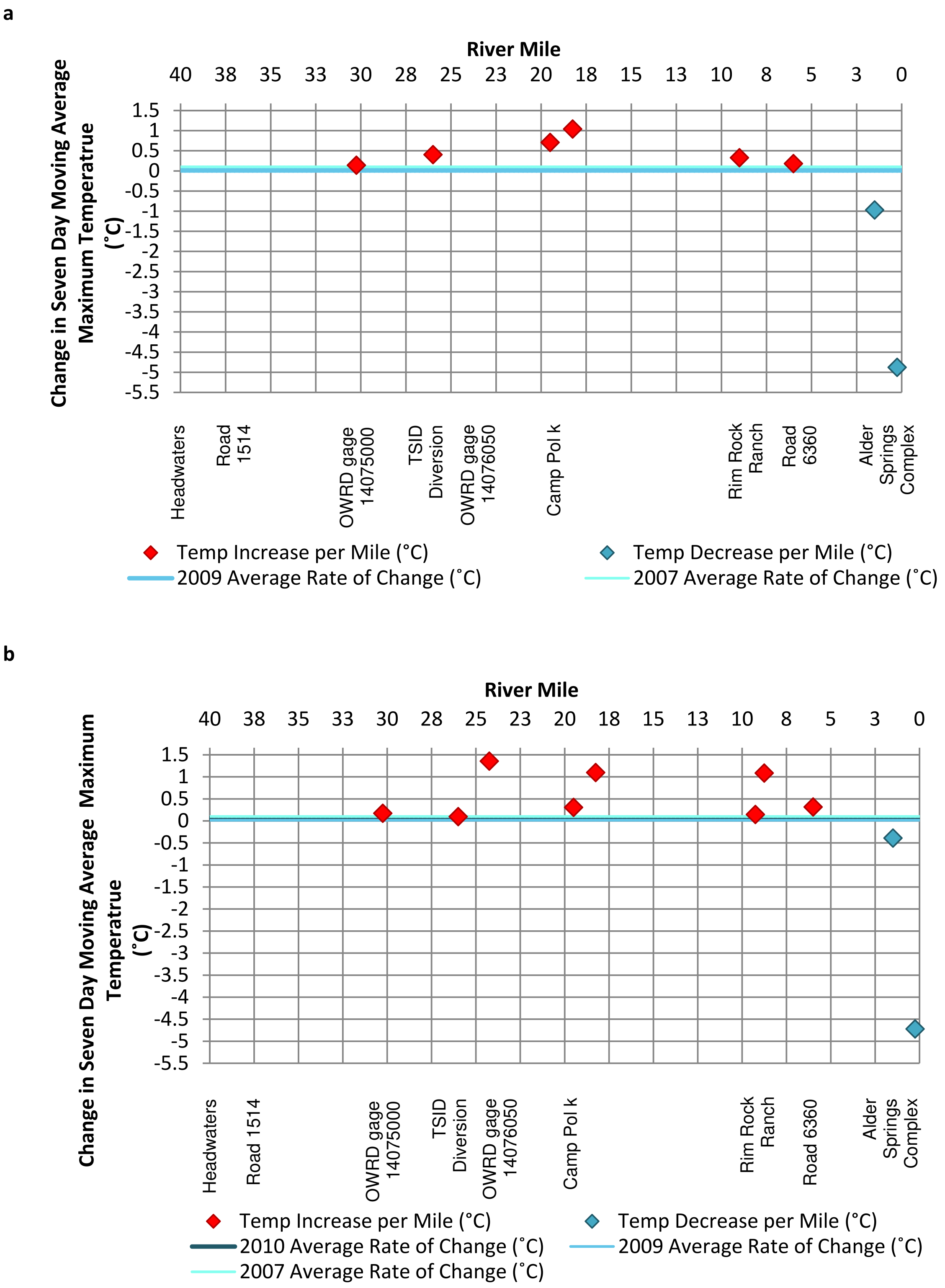


Figure 5.
Longitudinal average rate of temperature change in Whychus Creek in a) 2009 and b) 2010. Higher than average longitudinal changes in temperature identify reaches in which the rate of warming increased and indicate prioritization of these areas for research and restoration planning. Lower than average longitudinal changes in temperature highlight reaches where cooling occurred, indicating an opportunity to preserve optimal conditions through additional conservation measures.

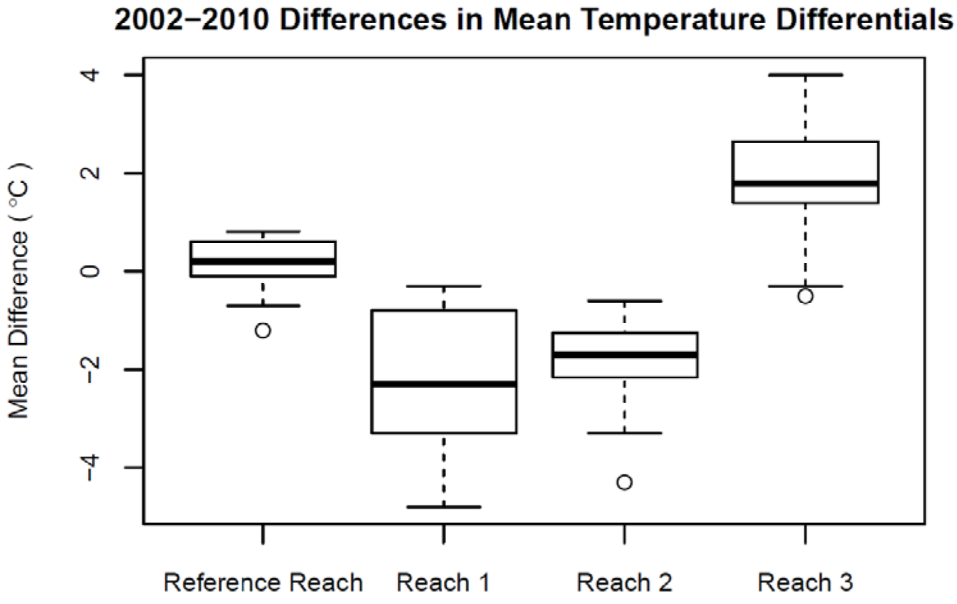
Streamflow restoration effectiveness

The 2002 to 2010 mean differences in reach temperature differentials for restoration reaches 1 and 2 were significantly less than the 2002 to 2010 mean difference for the reference reach (p=0.00), indicating that these two restoration reaches cooled from 2002 to 2010 relative to temperatures in the reference reach (Table 2, Figure 6). The 2002 to 2010 difference for restoration reach 3 was significantly greater than the difference for the reference reach (p=0.00), indicating that restoration reach 3 warmed from 2002 to 2010 relative to the reference reach. These trends were reversed when we compared 2006 to 2010 differences in reach temperature differentials. The 2006-2010 difference for restoration reach 2 was significantly greater than the 2006-2010 difference for the reference reach (p=0.00), indicating warming from 2006 to 2010 in this reach. The 2006-2010 mean difference for restoration reach 1 was also greater than for the reference reach, but not significantly so (p=0.22). Conversely, the 2006-2010 difference for restoration reach 3 was significantly less than the 2006-2010 difference for the reference reach (p=0.00), indicating cooling relative to the reference reach.

Table 2. Mean differences and standard deviations of reach temperature differentials between data years. Values that are less than the reference reach mean indicate a cooling trend from one data year to the next; values that are greater than the reference reach mean indicate a warming trend between data years. Asterisks indicate a significant difference between the specified restoration reach and the reference reach.

	2002-2006	2006-2010	2002-2010
Reference reach	**-0.1±0.5**	**0.2±0.7**	**0.1±0.5**
Restoration reach 1	-2.8±1.3*	0.4±0.5	-2.3±1.4*
Restoration reach 2	-2.9±0.8*	1.0±0.6*	-1.8±0.8*
Restoration reach 3	2.2±1.2*	-0.4±0.7*	1.8±1.1*

a



b

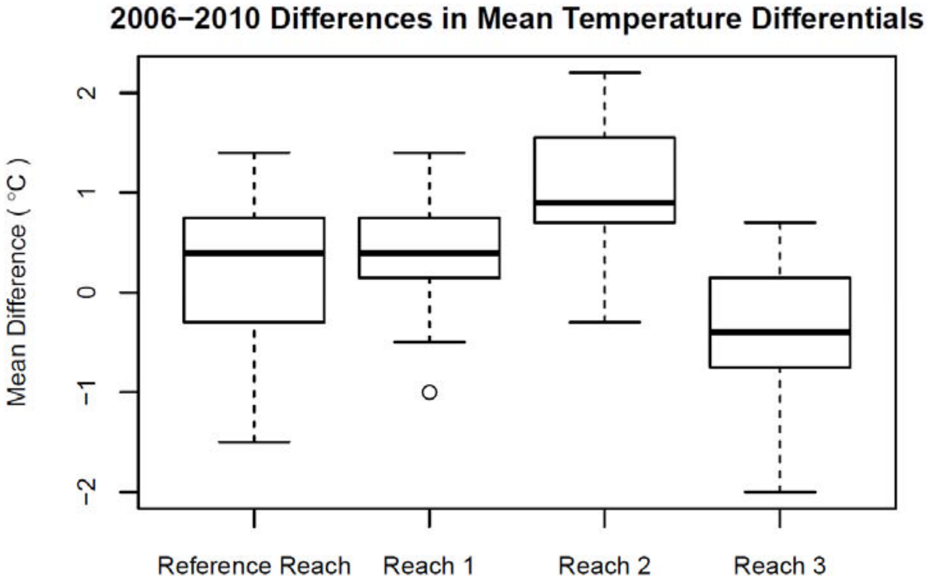


Figure 6.

a) Mean differences in reach temperature differential from 2006 to 2010 were significantly less ($p<0.05$) in restoration reach 2 than in the reference reach but significantly greater in restoration reach 3. b) Mean differences in reach temperature differential from 2002 to 2010 were significantly greater in restoration reaches 1 and 2 than in the reference reach. The mean 2002-2010 difference for restoration reach 3 was significantly less than the reference reach 2002-2010 mean difference.

Target streamflow

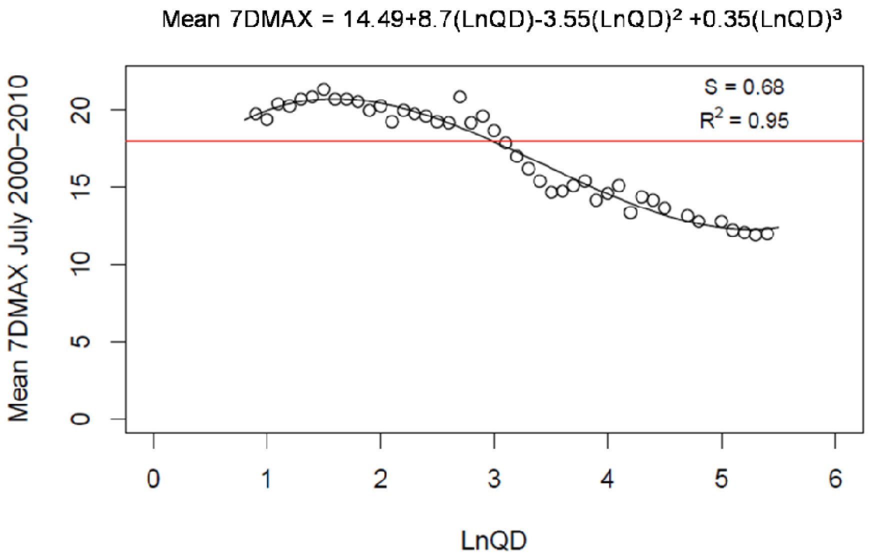
A third-order polynomial regression model produced the best fit to temperature-flow data for both WC 024.25 and WC 006.00 sites (Table 3, Figure 7). Temperatures calculated from the WC 024.25 regression model suggest that 21 cfs (3.0 LnQD) was the minimum streamflow that produced a mean 7DMAX temperature at or below 18°C (± 1.8°C) given temperatures observed from July 2000-2010 at this location, while 20 cfs resulted in a mean 7DMAX temperature of 18.1°C ± 1.8°C (Appendix B). The 2000-2010 model estimate is consistent with the 2000-2008 model prediction of 18.1°C ± 1.7°C at 21 cfs (Jones 2010). However, given confidence intervals, under both the 2000-2010 and the 2000-2008 models the 18°C standard is likely to be met at Sisters City Park at the target streamflow of 20 cfs (3.0 LnQD) above Indian Ford Creek. The 2000-2010 estimated temperature of 16.5± 1.8°C for 33 cfs (3.5 LnQD) differs only slightly from the 2008 Heat Source model which predicted a 7DMAX temperature of 15°C ± 1°C at 33 cfs at the ODFW gage at Sisters City Park (Watershed Sciences and MaxDepth Aquatics 2008).

The regression model for temperature-flow relationships at Road 6360 (WC 006.00) derived from 2000-2010 temperature and flow data predicts 66 cfs (4.2 LnQD) to be the minimum streamflow that will achieve a mean 7DMAX temperature of 18.0 ± 2.1°C. Under this model the target streamflow of 33 cfs below Indian Ford Creek is projected to produce a mean 7DMAX temperature of 20.7°C ± 2.2°C, well above the 18°C state standard but still below the 24°C lethal temperature threshold. This result differs slightly from the 2000-2008 model estimate of 18.0°C± 1.9°C at 78 cfs (4.4 LnQD; the 2000-2008 model predicts 18.6°C± 2.0°C at 66 cfs) and 21.1°C± 2.0°C at 33 cfs, but is supported by Heat Source model predictions which estimate a 7DMAX temperature of 18.5°C± 1°C at 62 cfs; the 2000-2010 model predicts 18.3°C± 2.1°C at 62 cfs.

Table 3. A cubic regression provided the best fit to the 2000-2010 temperature-flow data, with the lowest S and highest R^2 values, for both sites. Temperatures calculated using the corresponding regression equation are expected to be the most accurate of the three regression models.

Regression	**Equation**	**df**	**S**	**R^2**
	WC 024.25 (n=44)			
Linear	24.13-2.27(LnQD)	42	1.04	0.89
Quadratic	$21.84-0.5(\text{LnQD})-0.28(\text{LnQD})^2$	41	0.95	0.91
Cubic	$\mathbf{14.49+8.7(LnQD)-3.55(LnQD)^2+0.35(LnQD)^3}$	**40**	**0.68**	**0.95**
	WC 006.00 (n=38)			
Linear	28.03-2.26(LnQD)	36	1.44	0.78
Quadratic	$22.37+2.46(\text{LnQD})-0.82(\text{LnQD})^2$	35	0.92	0.91
Cubic	$\mathbf{16.89+9.59(LnQD)-3.48(LnQD)^2+0.3(LnQD)^3}$	**34**	**0.8**	**0.93**

a



b

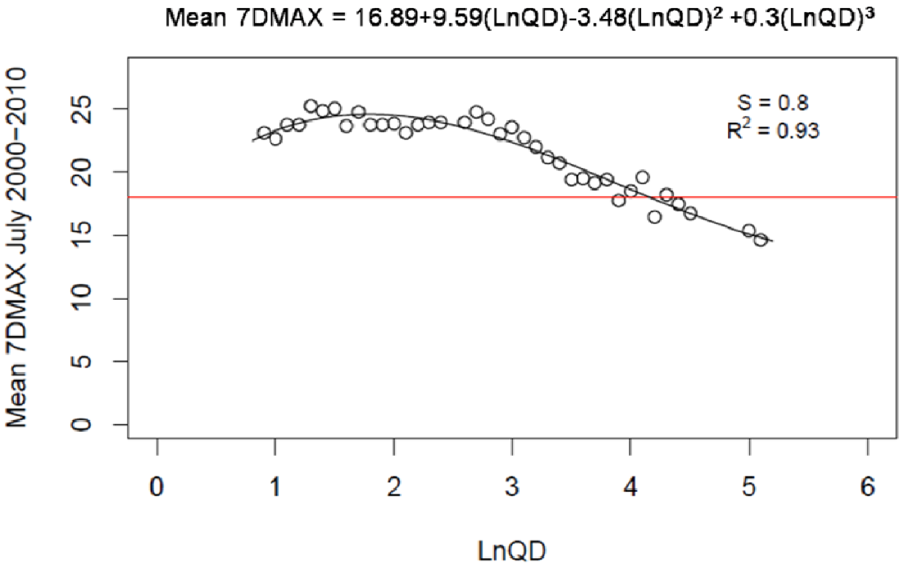


Figure 7.
Regression models fitted to temperature-flow data describe the relationship between temperature and flow observed during July 2000-2010 at a) Sister's City Park (WC 024.25) and b) Road 6360 (WC 006.00). Corresponding regression equations can be used to calculate temperature at a given flow.

Discussion

Temperature status

Temperatures observed in 2009 and 2010 between RM 19.5 and RM 1 are consistent with the ODEQ 2011 303(d) Category 5 listing of Whychus Creek as water quality limited. Although July temperatures at Sister's City Park (WC 024.25) never exceeded the 18˚C state standard in 2009 nor in 2010, temperatures at Road 6360 (WC 006.00) regularly exceeded this criterion, with almost half of 2009 July days and 80% of 2010 July days above 18˚C. Because the state standard is biologically based, we can infer that temperature conditions at this location were frequently marginal to support salmon and trout rearing and migration. Even though temperatures at Road 6360 exceeded the 18˚C standard more frequently in 2010 (25 days compared to 15 days in 2009), fewer days presented lethal conditions in 2010 (zero days) than in 2009 (seven days).

Temperature conditions for salmon and trout spawning were slightly better than those for rearing and migration. Temperatures did not exceed the 13˚C standard at WC 024.25 during the January 1 – May 15 spawning season in either 2009 or 2010 but were in excess of the spawning standard for 30% of 2009 spawning season days and over 40% of 2010 spawning season days for which data was available at Road 6360.

While many temperatures exceeding the state standard at Road 6360 were recorded at flows lower than the restoration target, some temperatures in excess of the 18˚C state standard were observed when flows at Sister's City Park were higher than the restoration target of 33 cfs downstream of Indian Ford Creek.

Streamflow restoration effectiveness

Changes in temperature in restoration reaches 1 and 2 from 2002 to 2010 support the hypothesis that increasing flows is effective in reducing stream temperature. Although the increase in flow was substantially greater and the accompanying decrease in temperature in restoration reaches more dramatic from 2002 to 2006 than from 2002 to 2010, restoration reaches 1 and 2 were nonetheless cooler in 2010 than in 2002 relative to changes in temperature in the reference reach over the same period. This result parallels the cooling trend observed from 2002 to 2006 in these two reaches and provides evidence for the effectiveness of increasing flows in reducing stream temperature. These results also corroborate the relationship between streamflow and temperature described by our polynomial regression model.

Our intent in using a BACI study design and tests of statistical significance to quantify changes in temperature in restoration reaches relative to changes in temperature in the reference reach from one data year to the next was to assess the effectiveness of increasing streamflow through restoration to reduce stream temperature. Comparison of changes in temperature differentials for restoration reaches 1 and 2 and the reference reach from 2006 to 2010 shows that temperatures in restoration reaches warmed over this time period significantly more than temperatures observed under the natural flow regime characterizing the reference reach. Although the difference of restoration reach 1 and reference reach means is non-significant, restoration reach 1, immediately below the TSID diversion, shows a preliminary warming trend that becomes more pronounced downstream in the significant longitudinal warming trend observed in restoration reach 2. This result is contrary to the premise that increasing streamflow will reduce stream temperature and consequently improve habitat for native fish. However, whereas DRC water transactions to restore streamflow in Whychus Creek increased flows legally protected in stream from 2006 to 2010, actual flows recorded for July 2010 averaged just over half the 81 cfs average for July 2006. Although documented flows increased from 2006 to 2010, actual flows decreased by almost half; consequently, a comparison of changes in temperature between restoration and reference reaches from 2006 to 2010 evaluating the effects of increased streamflow is meaningless. The 2006-2010 result does nonetheless accurately reflect a warming trend in restoration reaches 1 and 2 associated with a decrease in streamflow from 2006 to 2010.

Restoration reach 3 demonstrated the opposite trend from the two upstream restoration reaches in 2002-2006, 2006-2010, and 2002-2010 comparisons, warming from 2002-2006 and from 2002-2010 while restoration reaches 1 and 2 cooled, and cooling from 2006 to 2010 while the other restoration reaches warmed. Whereas restoration reaches 1 and 2 receive flows primarily from upstream reaches contingent on annual flow and on the volume of water diverted for irrigation with minimal (5 cfs or less) flow contributions from other sources, reach 3 incorporates Alder Springs, which contributes an additional 95 cfs of clean, cold water to Whychus flows (UDWC 2008c). When Whychus flows are lower, the cold water flow contribution of Alder Springs accounts for a relatively greater proportion of the total flow below Alder Springs than when Whychus flows are high, and Alder Springs flows contribute a relatively smaller proportion of the total volume below the springs complex.

Whereas the 95 cfs input of Alder Springs contributed a much greater proportion of total restoration reach 3 flows in 2002 when Whychus Creek flows at Sisters averaged 12 cfs, accounting for 89% of streamflow below the springs complex, these flows represent a much smaller proportion of 2006 reach 3 flows, when flows at Sisters averaged 81 cfs and Alder Springs flows accounted for only 54% of the total volume below the springs. Though cold, the smaller relative contribution of Alder Springs to 2006 and 2010 reach 3 flows and temperatures nonetheless resulted in a net warming over the substantial cooling effect of Alder Springs flows combined with the low 2002 Whychus Creek flows. However, the greater relative proportion of Alder Springs flows in 2010 compared to 2006 (68% in 2010 versus 54% in 2006) may have contributed to the cooling trend observed for reach 3 from 2006 to 2010 relative to the reference reach.

Although baseline flows from Alder Springs have been estimated, there is no permanent stream gage or other ongoing monitoring to measure changes in the contribution of Alder Springs to Whychus Creek. Despite limited knowledge of the specific dynamics of the hydrology of Alder Springs, the most comprehensive synthesis of available groundwater and surface water data indicates that "virtually all groundwater not consumptively used in the Upper Deschutes Basin discharges to the stream system upstream of the vicinity of Pelton Dam. . . Groundwater and surface water are, therefore, directly linked, and removal of groundwater will ultimately diminish streamflow" (USGS 2001). The substantial influence of Alder Springs flows on Whychus Creek temperature in restoration reach 3 suggested by the divergent trends in that reach in 2002-2006, 2006-2010 and 2002-2010 analyses emphasizes the importance of Alder Springs flows in providing a relatively constant temperature refuge, and highlights the potential impacts of groundwater withdrawals on stream conditions in this area. An improved scientific understanding of the hydrology of Alder Springs and the anticipated effects of groundwater withdrawals will allow conservation and restoration partners to better plan to address these effects in the future.

While inclusion of Whychus Creek river miles 000.25 to 006.00 and therefore Alder Springs flows in restoration reach 3 has provided important preliminary information about the influence of Alder Springs on Whychus Creek temperatures, including this reach also confounds the longitudinal effects of restored streamflow on temperature and compromises the utility of this analysis to evaluate the extent to which streamflow restoration is effective in reducing temperature. Future analyses of data from this reach should be refined to isolate the effects of streamflow restoration but also to continue to measure the influence of Alder Springs on temperature and flow.

Target streamflow

The 2000-2010 estimate of temperatures within 0.2-1.7°C of the 18°C state standard at the 20 cfs target streamflow above Indian Ford Creek suggests that 20 cfs is an appropriate target for streamflow restoration in Whychus Creek upstream of this point to meet the state temperature standard as well as salmonid rearing and migration requirements. However, because no additional flows enter Whychus Creek between Sisters City Park and Indian Ford Creek just upstream of RM 20, 33 cfs must be conserved instream above Sisters City Park to meet the 33 cfs protected instream at Indian Ford Creek according to ODFW water rights. The 2000-2010 estimate for WC 006.00 at Road 6360 supports the 2009 conclusion that 33 cfs at Sister's City Park is an inadequate flow to produce temperatures that comply with state standards for steelhead and salmon rearing and migration, and that the 18°C standard will only be predictably met at minimum flows of 66 cfs.

As early as 1895 irrigation diversions dewatered Whychus Creek near Sisters (Bob Main, personal communication c.f. Nehlsen 1995). As of 1950, a series of springs maintained flows of approximately 20 cfs below the dewatered reach from rm 15 to the mouth of the stream (Nielson 1950). As new water rights were issued, additional major sections of the creek became dewatered during the irrigation season (Mathisen 1985). These flows supported steelhead numbers as high as 1000 in 1953 (Montgomery 1953) and up to 20 spawning chinook salmon or redds counted in the creek in 1952. From these data we can infer that summer flows of 20 cfs in the reaches below rm 15 supported steelhead populations that produced up to 1000 spawning adults in 1953 and Chinook populations producing up to 20 spawning adults in 1952. Given the present flow target of 33 cfs below Indian Ford Creek, we expect 7DMAX temperatures to consistently exceed the 18°C state standard at WC 006.00 in July, upholding the 303(d) listing of Whychus Creek as temperature-impaired. However, although the 18°C standard guarantees suitable temperatures for steelhead rearing and migration, the historical record of steelhead and salmon populations persisting in even lower flows than 33 cfs suggests the 20.7°C 7DMAX predicted at this level may nonetheless provide suitable habitat, especially if other habitat features, such as adequate flow for steelhead outmigration and pools and cover for resident redband, are available.

Conclusions

By all metrics, temperatures observed in Whychus Creek chart a cooling trend as flows increase with streamflow restoration. Whychus temperatures were lower on the hottest water day in 2010 than in 2009, and 2009 hottest water day temperatures were lower than those for 2006, 2007 or 2008. The average rate of longitudinal temperature change fell from 2007 to 2009 and again from 2009 to 2010. As of 2010 7DMAX temperatures between RM 19.5 and RM 1 continued to exceed state temperature standards for salmon and trout spawning, rearing and migration, but July 2010 7DMAX temperatures never met or exceeded the 24°C lethal threshold. When flows increased between years, temperatures in reaches with restored flows above Alder Springs cooled more than temperatures in the reference reach representing natural flow conditions, suggesting the cooling observed was in response to increased flows rather than to environmental variability between years.

The temperature-flow relationship described by ten years of data suggests that 20 cfs at Sisters City Park (WC 024.25) is a sufficient flow to meet the 18°C salmon and trout rearing and migration requirement (although because no additional flows enter Whychus Creek between Sisters City Park and Indian Ford Creek just upstream of RM 20, 33 cfs must be conserved above Sisters City Park to meet the volume protected instream at Indian Ford Creek according to ODFW water rights.) Below Sisters City Park, despite flows of 33 cfs protected instream, July 7DMAX temperatures consistently exceed 18°C. This trend is explained by the temperature-flow relationship for Road 6360 (WC 006.00), year after year the hottest point in the river, which indicates that flows below 66 cfs at the OWRD gage at Sisters will fail to meet the rearing and migration temperature standard. Although 66 cfs may not be a politically feasible target for streamflow restoration, these data nonetheless provide a benchmark for restoration. Other restoration actions, such as stream channel restoration projects planned or underway at Camp Polk Meadow Preserve (WC 019.00) and Rimrock Ranch (WC 009.00), will promote cooling in the temperature-impaired reach. Given suitable temperatures in cooler upstream reaches, rearing salmon and trout may survive to migrate through warmer waters to the Deschutes. Our results demonstrate that streamflow restoration has already improved temperature conditions for re-introduced salmon and trout, and expand our understanding of temperature and flow on Whychus Creek to better inform future watershed restoration efforts.

Acknowledgements

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APPENDIX A Whychus Creek continuous temperature monitoring stations 1995-2010. TE = Temperature status, RE = Restoration effectiveness, TS = Target streamflow.

Station ID	Description	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
WC 038.00	Road 1514				TE				TE RE TS				TE RE TS		TE TS	TE RE TS	TE RE TS
WC 030.25	OWRD Gage 14075000					TE			TE RE TS	TE TS	TE TS	TE TS	TE RE TS	TE TS		TE RE TS	TE RE TS
WC 026.00	Road 4606 Footbridge					TE	TE TS						TE TS	TE TS	TE TS		
WC 024.25	OWRD Gage 14076050						TE TS	TE TS	TE RE TS	TE TS	TE TS	TE TS	TE RE TS	TE TS	TE TS	TE RE TS	TE RE TS
WC 019.50	d/s Camp Polk bridge				TE		TE TS	TE TS	TE TS	TE TS	TE TS	TE TS	TE TS	TE TS	TE TS	TE TS	TE TS
WC 018.25	d/s end of Camp Polk							TE TS		TE TS	TE TS	TE TS	TE TS	TE TS	TE TS	TE TS	TE TS
WC 008.75	u/s end of Rimrock Ranch															TE	TE TS
WC 009.00	Rimrock Ranch												TE TS	TE TS	TE TS		
WC 009.25	d/s end of Rimrock Ranch															TE	TE TS
WC 008.25	CRNG						TE TS										
WC 006.00	Road 6360	TE					TE TS	TE TS	TE RE TS			TE TS	TE RE TS	TE TS		TE RE TS	TE RE TS
WC 003.00	u/s Alder Springs	TE															
WC 001.50	d/s of Alder Springs		TE			TE	TE TS	TE TS				TE TS		TE TS	TE TS		
WC 001.00	Diamondback Meadow	TE												TE TS	TE TS		
WC 000.25	Mouth of Whychus Creek		TE			TE		TE TS	TE RE TS	TE TS	TE TS	TE TS	TE RE TS	TE TS	TE TS	TE RE TS	TE RE TS

APPENDIX B Temperatures at given flows.

Whychus Creek at Sister's City Park (WC 024.25)

Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)
2	18.9	1.8	**57**	14.8	1.7	**112**	13.3	1.7	**167**	12.9	1.7
3	20.2	1.8	**58**	14.7	1.7	**113**	13.3	1.7	**168**	12.9	1.7
4	20.7	1.8	**59**	14.7	1.7	**114**	13.2	1.7	**169**	12.9	1.7
5	20.8	1.8	**60**	14.6	1.7	**115**	13.2	1.7	**170**	12.9	1.7
6	20.7	1.8	**61**	14.6	1.7	**116**	13.2	1.7	**171**	12.9	1.7
7	20.6	1.8	**62**	14.5	1.7	**117**	13.2	1.7	**172**	12.9	1.7
8	20.4	1.8	**63**	14.5	1.7	**118**	13.2	1.7	**173**	12.9	1.7
9	20.2	1.8	**64**	14.4	1.7	**119**	13.2	1.7	**174**	12.9	1.7
10	20.0	1.8	**65**	14.4	1.7	**120**	13.2	1.7	**175**	12.9	1.7
11	19.8	1.8	**66**	14.4	1.7	**121**	13.2	1.7	**176**	12.9	1.7
12	19.6	1.8	**67**	14.3	1.7	**122**	13.2	1.7	**177**	12.9	1.7
13	19.4	1.8	**68**	14.3	1.7	**123**	13.2	1.7	**178**	12.9	1.7
14	19.2	1.8	**69**	14.3	1.7	**124**	13.1	1.7	**179**	12.9	1.7
15	19.0	1.8	**70**	14.2	1.7	**125**	13.1	1.7	**180**	12.9	1.7
16	18.8	1.8	**71**	14.2	1.7	**126**	13.1	1.7	**181**	13.0	1.7
17	18.6	1.8	**72**	14.1	1.7	**127**	13.1	1.7	**182**	13.0	1.7
18	18.4	1.8	**73**	14.1	1.7	**128**	13.1	1.7	**183**	13.0	1.7
19	18.3	1.8	**74**	14.1	1.7	**129**	13.1	1.7	**184**	13.0	1.7
20	18.1	1.8	**75**	14.0	1.7	**130**	13.1	1.7	**185**	13.0	1.7
21	17.9	1.8	**76**	14.0	1.7	**131**	13.1	1.7	**186**	13.0	1.7
22	17.8	1.8	**77**	14.0	1.7	**132**	13.1	1.7	**187**	13.0	1.7
23	17.7	1.8	**78**	14.0	1.7	**133**	13.1	1.7	**188**	13.0	1.7
24	17.5	1.8	**79**	13.9	1.7	**134**	13.1	1.7	**189**	13.0	1.7
25	17.4	1.8	**80**	13.9	1.7	**135**	13.1	1.7	**190**	13.0	1.7
26	17.3	1.8	**81**	13.9	1.7	**136**	13.1	1.7	**191**	13.0	1.7
27	17.1	1.8	**82**	13.8	1.7	**137**	13.0	1.7	**192**	13.0	1.7
28	17.0	1.8	**83**	13.8	1.7	**138**	13.0	1.7	**193**	13.0	1.7
29	16.9	1.8	**84**	13.8	1.7	**139**	13.0	1.7	**194**	13.0	1.7
30	16.8	1.8	**85**	13.8	1.7	**140**	13.0	1.7	**195**	13.0	1.7
31	16.7	1.8	**86**	13.7	1.7	**141**	13.0	1.7	**196**	13.0	1.7
32	16.6	1.8	**87**	13.7	1.7	**142**	13.0	1.7	**197**	13.0	1.7
33	16.5	1.8	**88**	13.7	1.7	**143**	13.0	1.7	**198**	13.0	1.7
34	16.4	1.8	**89**	13.7	1.7	**144**	13.0	1.7	**199**	13.0	1.7
35	16.3	1.8	**90**	13.6	1.7	**145**	13.0	1.7	**200**	13.0	1.7
36	16.2	1.7	**91**	13.6	1.7	**146**	13.0	1.7	**201**	13.0	1.7
37	16.1	1.7	**92**	13.6	1.7	**147**	13.0	1.7	**202**	13.0	1.7
38	16.0	1.7	**93**	13.6	1.7	**148**	13.0	1.7	**203**	13.0	1.7
39	15.9	1.7	**94**	13.6	1.7	**149**	13.0	1.7	**204**	13.0	1.7
40	15.8	1.7	**95**	13.5	1.7	**150**	13.0	1.7	**205**	13.0	1.7
41	15.8	1.7	**96**	13.5	1.7	**151**	13.0	1.7	**206**	13.0	1.7
42	15.7	1.7	**97**	13.5	1.7	**152**	13.0	1.7	**207**	13.0	1.7
43	15.6	1.7	**98**	13.5	1.7	**153**	13.0	1.7	**208**	13.0	1.7
44	15.5	1.7	**99**	13.5	1.7	**154**	13.0	1.7	**209**	13.0	1.7
45	15.5	1.7	**100**	13.5	1.7	**155**	13.0	1.7	**210**	13.0	1.7
46	15.4	1.7	**101**	13.4	1.7	**156**	13.0	1.7	**211**	13.0	1.7
47	15.3	1.7	**102**	13.4	1.7	**157**	13.0	1.7	**212**	13.0	1.7
48	15.3	1.7	**103**	13.4	1.7	**158**	13.0	1.7	**213**	13.0	1.7
49	15.2	1.7	**104**	13.4	1.7	**159**	13.0	1.7	**214**	13.0	1.7
50	15.1	1.7	**105**	13.4	1.7	**160**	13.0	1.7	**215**	13.0	1.7
51	15.1	1.7	**106**	13.4	1.7	**161**	13.0	1.7	**216**	13.0	1.7
52	15.0	1.7	**107**	13.3	1.7	**162**	13.0	1.7	**217**	13.0	1.7
53	15.0	1.7	**108**	13.3	1.7	**163**	13.0	1.7	**218**	13.0	1.7
54	14.9	1.7	**109**	13.3	1.7	**164**	13.0	1.7	**219**	13.1	1.7
55	14.9	1.7	**110**	13.3	1.7	**165**	13.0	1.7	**220**	13.1	1.7
56	14.8	1.7	**111**	13.3	1.7	**166**	13.0	1.7	**221**	13.1	1.7

Whychus Creek at Road 6360 (WC 006.00)

Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)	Flow (cfs)	Mean Temp (7DMAX)	CI (±)
2	22.0	2.2	**57**	18.6	2.1	**112**	16.2	2.0	**167**	15.0	2.0
3	23.6	2.2	**58**	18.5	2.1	**113**	16.1	2.0	**168**	15.0	2.0
4	24.3	2.3	**59**	18.5	2.1	**114**	16.1	2.0	**169**	15.0	2.0
5	24.6	2.3	**60**	18.4	2.1	**115**	16.1	2.0	**170**	15.0	2.0
6	24.6	2.3	**61**	18.3	2.1	**116**	16.1	2.0	**171**	15.0	2.0
7	24.6	2.3	**62**	18.3	2.1	**117**	16.0	2.0	**172**	15.0	2.0
8	24.5	2.3	**63**	18.2	2.1	**118**	16.0	2.0	**173**	14.9	2.0
9	24.3	2.3	**64**	18.2	2.1	**119**	16.0	2.0	**174**	14.9	2.0
10	24.2	2.2	**65**	18.1	2.1	**120**	16.0	2.0	**175**	14.9	2.0
11	24.0	2.2	**66**	18.0	2.1	**121**	15.9	2.0	**176**	14.9	2.0
12	23.8	2.2	**67**	18.0	2.1	**122**	15.9	2.0	**177**	14.9	2.0
13	23.7	2.2	**68**	17.9	2.1	**123**	15.9	2.0	**178**	14.9	2.0
14	23.5	2.2	**69**	17.9	2.1	**124**	15.9	2.0	**179**	14.9	2.0
15	23.3	2.2	**70**	17.8	2.1	**125**	15.8	2.0	**180**	14.9	2.0
16	23.1	2.2	**71**	17.8	2.1	**126**	15.8	2.0	**181**	14.8	2.0
17	22.9	2.2	**72**	17.7	2.1	**127**	15.8	2.0	**182**	14.8	2.0
18	22.8	2.2	**73**	17.7	2.1	**128**	15.8	2.0	**183**	14.8	2.0
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20	22.5	2.2	**75**	17.6	2.1	**130**	15.7	2.0	**185**	14.8	2.0
21	22.3	2.2	**76**	17.5	2.1	**131**	15.7	2.0	**186**	14.8	2.0
22	22.1	2.2	**77**	17.5	2.1	**132**	15.7	2.0	**187**	14.8	2.0
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26	21.6	2.2	**81**	17.3	2.1	**136**	15.6	2.0	**191**	14.7	2.0
27	21.4	2.2	**82**	17.2	2.1	**137**	15.6	2.0	**192**	14.7	2.0
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32	20.8	2.2	**87**	17.0	2.1	**142**	15.5	2.0	**197**	14.7	2.0
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35	20.5	2.2	**90**	16.9	2.1	**145**	15.4	2.0	**200**	14.6	2.0
36	20.4	2.2	**91**	16.9	2.1	**146**	15.4	2.0	**201**	14.6	2.0
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39	20.1	2.1	**94**	16.8	2.0	**149**	15.3	2.0	**204**	14.6	2.0
40	20.0	2.1	**95**	16.7	2.0	**150**	15.3	2.0	**205**	14.6	2.0
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43	19.7	2.1	**98**	16.6	2.0	**153**	15.3	2.0	**208**	14.6	2.0
44	19.6	2.1	**99**	16.6	2.0	**154**	15.2	2.0	**209**	14.5	2.0
45	19.5	2.1	**100**	16.6	2.0	**155**	15.2	2.0	**210**	14.5	2.0
46	19.4	2.1	**101**	16.5	2.0	**156**	15.2	2.0	**211**	14.5	2.0
47	19.3	2.1	**102**	16.5	2.0	**157**	15.2	2.0	**212**	14.5	2.0
48	19.3	2.1	**103**	16.5	2.0	**158**	15.2	2.0	**213**	14.5	2.0
49	19.2	2.1	**104**	16.4	2.0	**159**	15.2	2.0	**214**	14.5	2.0
50	19.1	2.1	**105**	16.4	2.0	**160**	15.1	2.0	**215**	14.5	2.0
51	19.0	2.1	**106**	16.4	2.0	**161**	15.1	2.0	**216**	14.5	2.0
52	19.0	2.1	**107**	16.3	2.0	**162**	15.1	2.0	**217**	14.5	2.0
53	18.9	2.1	**108**	16.3	2.0	**163**	15.1	2.0	**218**	14.5	2.0
54	18.8	2.1	**109**	16.3	2.0	**164**	15.1	2.0	**219**	14.5	2.0
55	18.7	2.1	**110**	16.2	2.0	**165**	15.1	2.0	**220**	14.4	2.0
56	18.7	2.1	**111**	16.2	2.0	**166**	15.0	2.0	**221**	14.4	2.0

Stream Connectivity in Whychus Creek

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Abstract

UDWC selected stream connectivity as an indicator of restoration effectiveness in Whychus Creek. Fish passage barriers are the primary feature affecting connectivity in the creek. Monitoring the river miles of habitat opened to resident and anadromous fish through barrier removal will give a measure of stream connectivity. UDWC surveyed fish passage barriers along the creek prior to any barrier removals. We compared survey data to criteria established by both ODFW and NMFS to determine if inventoried barriers were passage barriers for anadromous and resident fish. A total of six barriers were found to limit connectivity in Whychus Creek, effectively dividing the creek into seven reaches of varying length from one mile to 11 miles. From 2009 to 2010 one barrier was retrofitted to provide fish passage, connecting two reaches and reducing total reaches to six. UDWC reached agreements with two water rights holders to implement fish passage restoration projects at three additional barriers. UDWC continues to actively work with water rights holders to provide passage at two other barriers. Removal of all five remaining barriers could provide 15 additional miles of connected habitat for anadromous species.

Introduction

The extent of stream connectivity, as influenced by the existence, condition and location of fish passage barriers, was selected as an indicator to be tracked over time on Whychus Creek. Although stream connectivity can be influenced by poor water quality or other habitat conditions as described below, fish passage barriers are the primary feature affecting connectivity in Whychus Creek. This technical report presents the existing connectivity and conditions of fish barriers in the creek at the close of 2010.

Fish passage barriers are widely recognized as hindering habitat connectivity by obstructing movement of aquatic species with the presence of physical barriers, changing velocities, water quality conditions and overall hydraulic and thermal alterations (Bergkamp *et al* 2000). With this recognition comes the realization that habitat connectivity along river systems is essential to healthy ecological function (Cote *et al* 2009, Wiens 2002).

Passage barriers are therefore a simple and effective indicator of determining how much habitat is available to resident and anadromous fish species in Whychus Creek (Cote *et al* 2009). UDWC and its partners are working with landowners and water right holders to remove all fish passage barriers in Whychus Creek by 2014.

Monitoring the river miles of habitat opened to resident and anadromous fish through barrier removal will give a measure of stream habitat connectivity. This data combined with fish population and habitat quality data will tell us whether anadromous and resident fish are accessing that habitat. While physical barriers such as dams limit accessibility to fish habit, stream conditions including habitat quality and water quality can also function as passage barriers in limiting access to upstream and downstream habitat. Using fish passage barriers as an indicator will help determine whether physical barriers alone are limiting movement of fish along Whychus Creek. The additional accessible river miles serve as a simple metric that allows effective communication of stream conditions to restoration partners and the general community.

Methods

The Oregon Water Resources Department (OWRD) inventoried water rights and associated diversion structures along the entire 40-mile length of Whychus Creek in 2002. Included in this inventory was information on location, presence of dams, pumps, headgates, fish screens and diversion size. This data set provided the basis for data collection efforts related to fish passage barriers. Throughout 2008 and 2009, the locations of existing diversions identified in the OWRD 2002 survey were verified by field surveys. During this verification effort, sections of Whychus Creek between known diversion locations were surveyed to determine if any additional passage barriers existed.

Fish passage criteria are established by ODFW (ODFW) and are described in Oregon Administrative Rules (OAR) 635, Division 412 (ODFW 2009). In addition, NMFS has established fish passage criteria for anadromous species (2008).

Many of the passage barrier structures in Whychus Creek are seasonal in nature and are often constructed of native materials available on hand. Push up dams constructed of river gravels and sediment are good examples of seasonal-type passage barriers. In addition, due to the high variability of flow conditions in Whychus Creek on a seasonal and diurnal level, hydraulic conditions vary greatly. In many instances, structures may meet fish passage criteria under certain flow conditions and seasons and not at others. As a result of these conditions, the inventoried fish passage barriers were classified as either meeting or not meeting ODFW and NMFS criteria for fish passage at the time of the survey. Barriers were defined as partial barriers if they were determined to allow fish passage at some times of year or for some life stages.

Data Collection

Data were collected between 2002 and 2009 by OWRD and UDWC staff. Key information included latitude and longitude, river mile, date of survey, barrier height along with pertinent comments relating to the barrier. This baseline data will be used to monitor habitat (river miles) accessible to anadromous and resident species each year. Data were collected using a handheld GPS device along with measuring tapes and staffs for barrier configuration data. Water right holders were also interviewed to determine how diversions and barriers are operated throughout the year. This information was helpful in determining if barriers were passable for anadromous and resident species at any time throughout the year.

Data Analysis

Survey data were compared to criteria established by both ODFW and NMFS (ODFW 2004, NMFS 2008) to determine if inventoried barriers were indeed passage barriers for anadromous and resident fish. Key criteria and parameters needed to satisfy fish passage include:

(1) Water velocity going over the barrier: must be ≤ 4 ft/sec (adults) and ≤ 2 ft/sec (juveniles)
(2) Channel water depth upstream of barrier: must be ≥ 8 inches
(3) Channel water depth downstream of barrier: must be ≥ 24 inches
(4) Water elevation difference above and below hydraulic jump: must be ≤ 6 inches

Criteria (3) and (4) are the main criteria that established whether barriers blocked anadromous and resident fish passage. It is important to note that not all barriers present fish passage barriers at all times of the year. Based on flow conditions and barrier operation (i.e. irrigation diversion dams), instances occur where passage at barriers is provided at different times of year.

UDWC collected, summarized and analyzed this data. For the purposes of this report a barrier was considered a fish passage barrier if it did not meet the above ODFW and NMFS criteria at any time of the year. New fish passage projects were designed and constructed to meet ODFW and NMFS criteria. From 2009 to 2010 UDWC and restoration partners continued to engage with water rights holders and landowners to plan fish passage restoration projects at remaining passage barriers.

Results

The initial inventory completed in 2009 identified six fish passage barriers along Whychus Creek from river mile 14.7 to river mile 25.2 (**Table 1, Figure 1**). Barriers No. 1 and 2 were partial barriers, allowing anadromous fish at least intermittent access to a total of 21.3 miles of habitat. In December 2010 the Three Sisters Irrigation District dam fish passage restoration project was completed to meet all four fish passage criteria. Although increasing the total miles of upstream habitat accessible to fish will require providing passage at Barriers No. 3 and 4, restoration of fish passage at the TSID dam connected adjacent two- and one-mile sections to create a three-mile reach and reduce the total number of reaches to six (**Figure 2**). UDWC and its partners continue to actively work with landowners and water rights holders to reach agreements to remove or retrofit the remaining passage barriers to provide fish passage for all life stages of anadromous and resident species on a year round basis at all flows.

Table 1. UDWC collected baseline data on passage barriers in Whychus Creek in 2009. Data that were not available were estimated based on OWRD surveys completed in 2002.

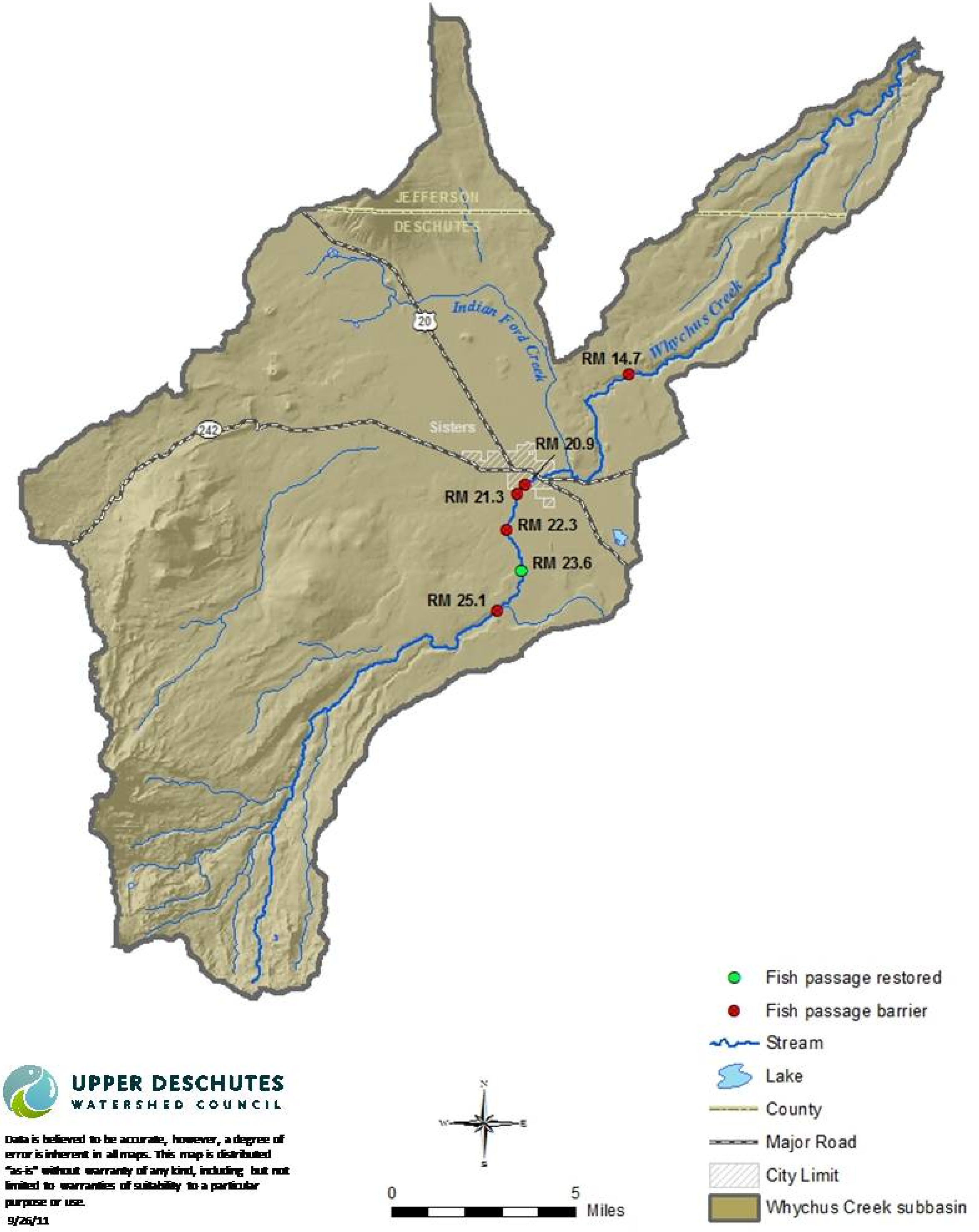
Barrier ID	Baseline Sampling Date	River Mile	Lat	Lon	Span (% of creek)	Dam height (ft)	Jump Height (inches)[1]	Jump Pool Depth (inches)[2]	Passage Barrier (Yes/No)	Notes	Passage Restored (Date)
No. 1	9/30/2002	14.7	44.3292	-121.4930	100%	2.0	No Data	No Data	Yes	Meyer push up diversion dam made of native materials. Passage Barrier determination established by OWRD	
No. 2	8/28/2009	20.9	44.2858	-121.5485	100%	5.0	72.0	12.0	Yes	Leithauser Diversion Dam. Passage provided from April-Oct 15. Passage not provided Oct 15 - April across heavily degraded dam spillway.	
No. 3	4/3/2009	21.3	44.282	-121.5531	100%	2.5	36.0	18.0	Yes	Sokol dam once used to create a backwater for fish rearing. No longer used and not associated with an irrigation water right.	
No. 4	4/3/2009	22.3	44.2678	-121.5584	100%	4.5	48.0	18.0	Yes	Sokol irrigation diversion dam.	
No. 5	8/28/2009	23.6	44.2515	-121.5502	100%	N/A	≤ 6.0	N/A	Yes	Three Sisters Irrigation District Dam. Channel raised to dam height and riffle created. Tallest feature height ≤ 6.0.	Dec-10
No. 6	8/28/2009	25.1	44.2356	-121.5633	100%	3.2	45.0	43.0	Yes	McCallister irrigation diversion dam.	

[1] Water elevation difference above and below the hydraulic jump. **Must be ≤ 6 inches**

[2] Depth of water in plunge pool downstream of hydraulic jump. **Must be ≥ 24 inches**

Reference: *NMFS (National Marine Fisheries Service). 2008. Anadromous Salmonid Passage Facility Design. NMFS, Northwest Region, Portland, Oregon.*

ODFW (Oregon Department of Fish and Wildlife). 2004. Fish Passage Barrier Criteria



Data is believed to be accurate, however, a degree of error is inherent in all maps. This map is distributed "as-is" without warranty of any kind, including but not limited to warranties of suitability to a particular purpose or use.

9/26/11

Figure 1.
In 2009, six barriers impaired stream connectivity on Whychus Creek between river miles 14.2 and 25.1. In 2010 fish passage was restored at one of these barriers. UDWC and restoration partners aim to provide passage at each of these barriers by 2014.

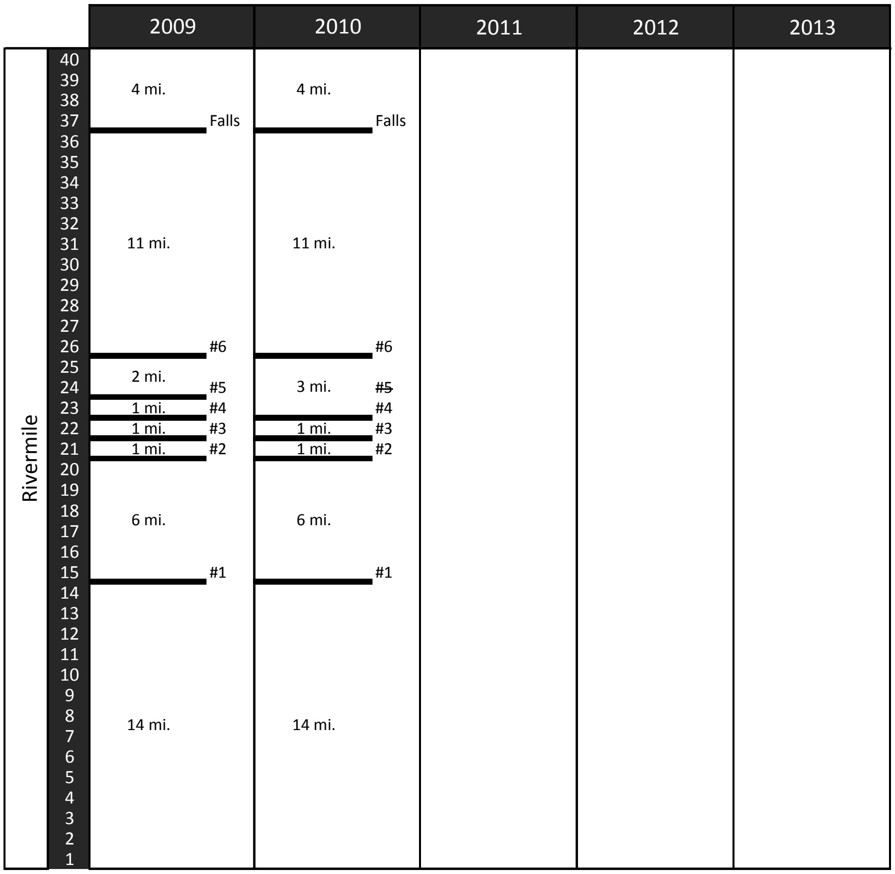


Figure 2.

In 2010 fish passage was restored at Barrier No. 5, reducing the number of barriers limiting connectivity in Whychus Creek to five (numbered per Table 1), and reducing the number of divided reaches to six varying in length from one mile to 11 miles. Whychus Creek Falls, located between river miles 36 and 37, is a natural barrier.

Discussion

Existing barriers determine the number of miles of contiguous stream habitat accessible to fish. Over time, as barriers are removed, contiguous habitat will increase. UDWC will continue to partner with water rights holders to develop and implement projects that will restore fish passage at the remaining five barriers by 2014. Removal of all barriers could provide 22 additional miles of unimpeded access to stream habitat for resident and anadromous species.

As of December 2010, UDWC had advanced conversations with landowners and water rights holders to establish project agreements for three (Barriers No. 2, 3 and 4) of the remaining five passage barriers identified on Whychus Creek. With fish passage at TSID and pending restoration of fish passage at Barrier No. 1, restoration of these three barriers would increase total miles of habitat accessible to 25.1, although accessibility of habitat upstream of river mile 14.7 would remain contingent on passage at Barrier No. 1. As these projects are implemented and this inventory is updated every year, UDWC will continue to monitor the number of river miles of habitat opened to anadromous and resident fish.

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Fish Entrainment Potential in Whychus Creek

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Abstract

The Upper Deschutes Watershed Council (UDWC) selected fish entrainment potential as an indicator of restoration effectiveness on Whychus Creek, a tributary to Oregon's Deschutes River. UDWC described fish entrainment potential by the presence and location of irrigation diversions lacking state and federally approved fish screens. In the absence of detailed knowledge on the impacts of each diversion, the UDWC selected two simple metrics to estimate entrainment potential. The number of unscreened diversions and the total diversion rate associated with the irrigation diversion serve as coarse but cost-effective indicators of entrainment potential. In 2009 UDWC completed a baseline inventory of irrigation diversions on Whychus Creek. This inventory identified 13 active irrigation diversions along Whychus Creek, 12 of which did not have state and federally approved fish screens. Of the roughly 193 cfs of water diverted for irrigation in 2009, only 0.45 cfs or 0.02% of the water diverted for irrigation was diverted through state and federally approved fish screens. From 2009-2010 restoration partners screened two additional diversions, reducing cumulative unscreened diverted flows by 2.12 cfs. Fish screen construction on a third diversion planned for spring 2011 will reduce unscreened diverted flows by an additional 137.68 cfs. UDWC is actively developing plans with water rights holders to screen two more diversions that would reduce the cumulative unscreened diversion rate to 27.25 cfs. It will be possible to monitor how fish entrainment risk declines over time as restoration partners screen existing irrigation diversions.

Introduction

UDWC selected fish entrainment potential as an indicator of restoration effectiveness on Whychus Creek. UDWC described fish entrainment potential by the presence and location of irrigation diversions lacking state and federally approved fish screens. Irrigation diversions can create two types of problems for fish. First, they potentially block upstream and downstream fish passage. Second, unscreened diversions divert fish almost as effectively as they divert water. This technical report updates the 2009 report (Perle 2010) to document the potential for fish entrainment at irrigation diversions in Whychus Creek as of December 2010.

Numerous studies have shown that unscreened irrigation diversions act as sinks for fish populations (Roberts and Rahel 2008, Gale *et al* 2008, Carlson and Rahel 2007). The number of fish currently entrained into irrigation diversions in Whychus Creek is unknown. However, within the Three Sisters Irrigation District canal, one of the major irrigation diversions on Whychus Creek, more than 5,000 fish were rescued in 2006 (M. Riehle, personal communication, 2009).

Screening irrigation diversions with state and federally approved screens reduces the potential for fish entrainment. Gale *et al* (2008) found that fish screens reduced or eliminated fish entrainment in one heavily managed stream in Montana, Skalkaho Creek. They found inter- and intra-annual variations in the proportion of fish entering diversions, and they suggested that variations in the proportion of water diverted accounted for some of the inter-annual variations in the number of fish diverted.

The location, design, timing, and volume of an irrigation diversion may affect its potential to entrain fish. In the absence of detailed knowledge on the impacts of each diversion, UDWC selected two simple metrics to estimate entrainment potential. The number of unscreened diversions and the total diversion rate associated with the irrigation diversion serve as coarse but cost-effective indicators of entrainment potential. By reducing the amount of water diverted through unscreened diversions, UDWC will decrease the magnitude of one factor limiting fish populations.

Methods

The Oregon Water Resources Department (OWRD) inventoried water rights and associated diversion structures along the entire 40 mile length of Whychus Creek in 2002. This inventory included information on diversion location, presence of dams, pumps, headgates, fish screens and diversion size. This dataset provided the basis for data collection efforts related to fish entrainment. Throughout 2008 and 2009, the UDWC verified the locations of existing diversions identified in the OWRD 2002 survey through field surveys.

Fish screening criteria for the State of Oregon are established by ODFW (ODFW) and NMFS (National Marine Fisheries Service). NMFS establishes fish screening criteria for anadromous species (NMFS 2008) and ODFW currently follows NMFS criteria.

Data Collection

OWRD and UDWC staff collected data for irrigation diversions and screens along Whychus Creek. Key information included latitude and longitude, river mile, date of survey, type of diversion and fish screening status along with pertinent comments relating to the fish screen. Data were collected from 2002 through 2009 by OWRD and UDWC staff. This baseline data will be used to monitor fish entrainment each year. Data were collected using a handheld GPS device along with measuring tapes used to measure screen configurations. Water right holders were also interviewed to determine how diversions and barriers are operated throughout the year. New fish screens are built to specifications that meet ODFW and NMFS fish screening criteria. As diversion screening projects are completed, new screen data is compiled with existing data.

Data Analysis

UDWC compared diversion screening data to screening criteria established by both ODFW and NMFS (NMFS 2008). They determined whether inventoried irrigation diversions did indeed provide adequate fish screening for anadromous and resident fish. While some irrigation diversions did have fish screens, the screens themselves may not have been state and federally approved.

UDWC collected, summarized and analyzed this data. Irrigation diversions were classified as either meeting or not meeting state and federal criteria of fish screening for both anadromous and native resident fish species. As one mode of establishing a baseline of risk factors linked to fish entrainment for future years, the flow rate associated with each diversion as well as the total flow rate of unscreened water was tallied. It is expected that irrigation diversions in the coming years will be retrofitted with state and federally approved fish screens. As one measure of potential fish entrainment, the total flow rate of unscreened irrigation water diverted from Whychus Creek will continue to decline as these projects are implemented in the years to come.

Results

The baseline inventory identified 13 active irrigation diversions extending from river mile 9.25 to river mile 25.25, 12 of which did not have state and federally approved fish screens (Table 1, Figure 1). As of 2009 the cumulative maximum irrigation diversion rate through unscreened diversions on Whychus Creek was 192.89 cfs representing almost 100% of the 193.34 cfs total diversion rate associated with existing water rights (Table 1). Of the 192.89 cfs of water diverted for irrigation, only 0.45 cfs or 0.02% of the water diverted for irrigation was diverted through state and federally approved fish screens.

From 2009 to 2010 the total diversion rate was reduced to 178.02 cfs through streamflow restoration. Two additional diversions (Diversions No. 5 and 7) were screened to meet NMFS and ODFW criteria. Flows associated with these screens total 2.12 cfs, reducing the cumulative unscreened diversion rate to 175.45 cfs, 98.5% of the 2010 total diversion rate. Fish screen construction at the Three Sisters Irrigation District diversion is planned for January 2011. At 137.68 cfs as of 2010, the TSID diversion represents the single largest flow withdrawal on Whychus Creek; completion of the TSID fish screen, planned for April 2011, will reduce the cumulative unscreened diversion rate to 37.77 cfs representing just 21% of the 2010 total diversion rate.

UDWC and ODFW, along with many of their partners, continue to actively work with landowners and water right holders to reach agreements to retrofit three of the remaining nine irrigation diversions with state and federally approved fish screens that reduce fish entrainment for both anadromous and native fish species.

Table 1.
ODFW and the Upper Deschutes Watershed Council surveyed diversions along Whychus Creek. The Upper Deschutes Watershed Council identified which diversions met state and federal criteria for fish screens as a proxy for fish entrainment potential. Two additional diversions were screened from 2009-2010, leaving ten diversions unscreened.

2002-2009 Baseline data								2009 - 2010			
Diversion ID	Baseline Sampling Date	River Mile	Diversion Type	Associated Diversion Rate (cfs)	Screen Present at Baseline Inventory	Screen opening size (inches)	Met State & Federal Criteria at Baseline Inventory	Associated Diversion Rate (cfs)	Screened to meet criteria (date)	Meets State & Federal Criteria	Notes
No. 1	8/28/2009	25.25	Gravity	3.88	No	N/A	No	3.88		No	Plainview. Junior water rights. Diversion rarely on.
No. 2	8/28/2009	25.15	Gravity	21.59	No	N/A	No	21.59		No	McCallister
No. 3	8/28/2009	23.90	Gravity	5.52	No	N/A	No	5.52		No	Lazy Z / Uncle John
No. 4	8/28/2009	23.65	Gravity	153.00	No	N/A	No	137.68		No	TSID
No. 5	8/28/2009	23.65	Gravity	1.00	No	N/A	No	1.00	Oct-10	Yes	Edgington
No. 6	8/28/2009	22.30	Gravity	5.00	No	N/A	No	5.00		No	Sokol
No. 7	8/28/2009	20.90	Gravity	1.12	No	N/A	No	1.12	Oct-09	Yes	Leithauser
No. 8	8/28/2009	18.65	Pump	0.07	Yes	1/4	No	0.07		No	No. 9 on OWRD List
No. 9	8/28/2009	18.15	Pump	0.38	Yes	1/4	No	0.38		No	Bradley
No. 10	8/28/2009	17.50	Pump	0.45	Yes	3/32	Yes	0.45	Aug-09	Yes	Deggendorfer
No. 11	9/30/2002	14.75	Pump	0.05	Yes	No Data	No	0.05		No	Meyer. Fish screening assessed by OWRD
No. 12	9/24/2002	11.20	Gravity	0.68	No	N/A	No	0.68		No	Remund.
No. 13	9/24/2002	9.25	Gravity	0.60	No	N/A	No	0.60		No	Baker.
			Baseline Diversion Total	**193.34**			**2010 Diversion Total**	**178.02**			
			Baseline Unscreened Total	**192.89**			**2010 Unscreened Total**	**175.45**			

Reference: *NMFS (National Marine Fisheries Service). 2008. Anadromous Salmonid Passage Facility Design. NMFS, Northwest Region, Portland, Oregon.*

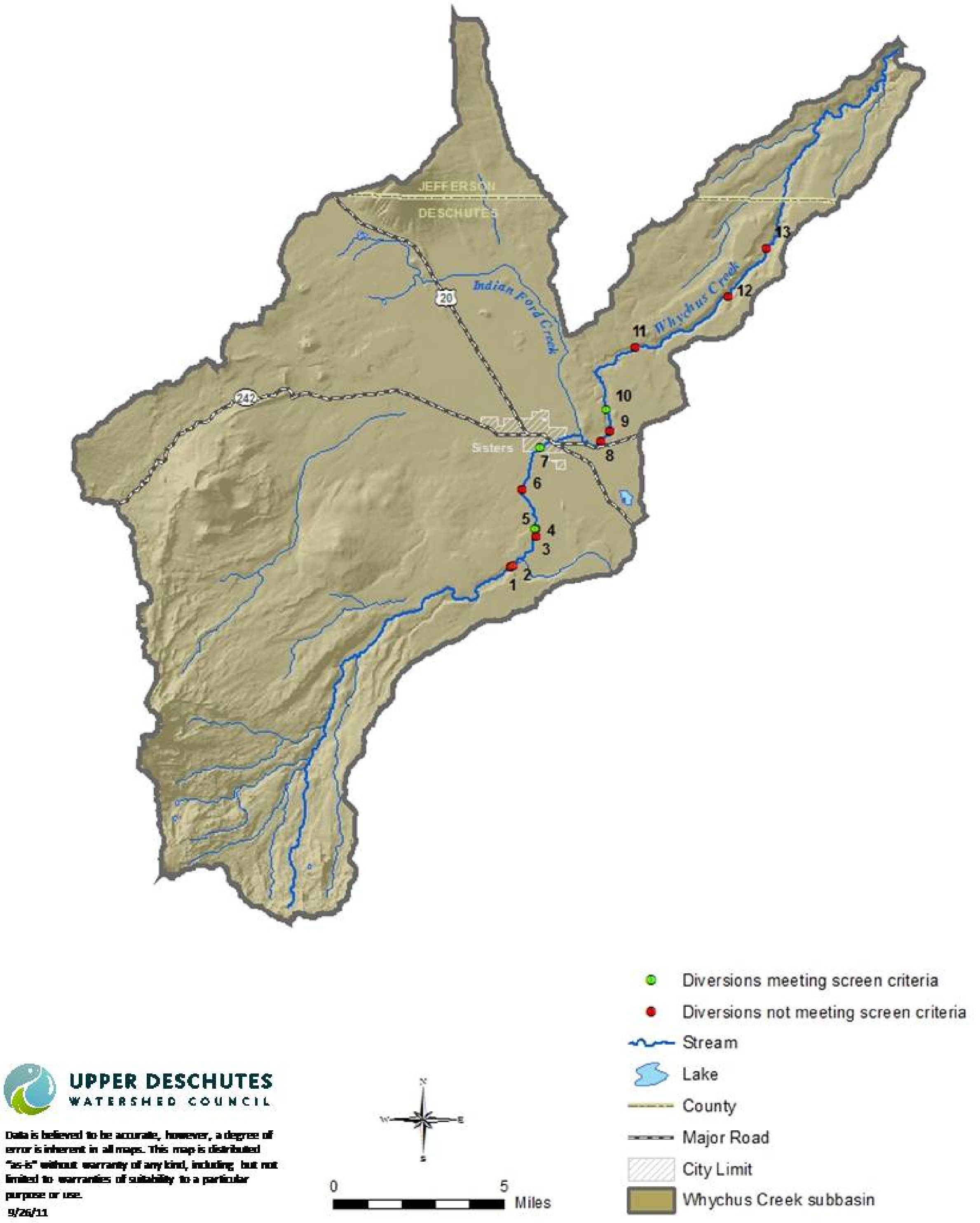

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Figure 1.
In 2009 UDWC identified 13 irrigation diversions including 12 that did not meet federal and state criteria for fish screens on Whychus Creek (NMFS 2008). One diversion identified during baseline data collection met ODFW and NMFS screening criteria. From 2009 to 2010 two additional diversions were screened. Diversions No. 4 and 5 are located within feet of each other on opposite sides of the creek, thus only one of the two points is visible on the map.

Discussion

Although actual fish entrainment potential or risk associated with irrigation diversions takes into account a number of factors including diversion timing, location, structure, design, and geomorphology of the creek (i.e. pool, riffle, etc.), the cumulative diversion rate through unscreened diversions on Whychus Creek is one method of characterizing fish entrainment potential risks to anadromous and native species. Restoration efforts to retrofit all irrigation diversions on Whychus Creek with state and federally approved fish screens are ongoing. Based on this goal and given that UDWC and its partners are not seeking to prioritize which unscreened irrigation diversions pose the most significant fish entrainment risk, cumulative diversion rates through unscreened diversions represent a good metric for determining progress on reducing fish entrainment over time.

As of December 2010, the UDWC is actively working with water right holders and landowners to plan screening projects for two (Diversions No. 3 and 6) additional diversions. Fish screening at these diversions could reduce the cumulative unscreened diversion rate by an additional 10.5 cfs. With the 137.68 cfs reduction in unscreened flows at TSID planned for 2011, total unscreened flows would be reduced to 27.25 cfs. By screening these two diversions, 85% of flows associated with unscreened diversions as of 2010 will be diverted through state and federally approved fish screens, although diversion rates associated with unscreened diversions may also be reduced as streamflow restoration continues. As these projects are implemented and this inventory updated every year, UDWC will continue to monitor how fish entrainment risk is diminished over time.

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Native Fish Monitoring in Whychus Creek

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Abstract

A suite of restoration actions on Whychus Creek aims to restore the stream habitat, flows, fish passage, and water quality necessary to support self-sustaining populations of reintroduced chinook salmon (*Oncorhyncus tshawytscha*) and steelhead trout (*Oncorhyncus mykiss*), native resident redband trout, and bull trout. Steelhead and salmon were reintroduced to Whychus Creek in 2007 and hundreds of thousands of fry continue to be released annually. Restoration partners including Portland General Electric and USFS conduct native fish monitoring annually at five locations along Whychus Creek to quantify *O. mykiss* density and census *O. mykiss* redds. The Whychus Creek Monitoring Plan identified PGE monitoring data as a biological indicator of restoration effectiveness, and the Upper Deschutes Watershed Council summarizes pertinent fish data annually to evaluate fish population trends in relation to restoration actions. *O. mykiss* accounted for the majority of fish caught in 2009 and in 2010. *O. mykiss* density ranged from 11-106 *O. mykiss*/100m^2 in five Whychus reaches in 2010, up from 12-57/100m^2 in 2009. A shift in size distribution from pre-reintroduction numbers to include a majority of fish less than 100mm in length likely reflects the influence of ongoing steelhead fry releases. Redd counts detected 65 redds in 2010, up from 43 identified in 2009. The majority of redds detected were located in the Alder Springs area in both years. Although improved sampling techniques have produced a marked increase in accuracy of population estimates, any broader application of data continues to be limited by annual steelhead releases and the inability to differentiate between resident and anadromous forms of juvenile *O. mykiss* pending genetic analysis. Fish population data provide important baseline information but remain a poor short-term indicator of restoration effectiveness.

Introduction

Anadromous populations of summer steelhead (*Oncorhyncus mykiss*) and spring chinook salmon (*Oncorhyncus tshawytscha*) were extirpated from the Upper Deschutes sub-basin following completion of the Pelton-Round Butte hydroelectric project dams in 1964. With dam re-licensing in 2005, Portland General Electric and the Confederated Tribes of Warm Springs agreed to restore anadromous populations in the Upper Deschutes sub-basin. Steelhead fry were reintroduced in Whychus Creek and the Crooked River system in 2007 and have been released in the hundreds of thousands every year since; chinook fry and smolts, and steelhead smolts, were first released in 2009 (Table 2; Gauvin 2011). Under the 2005 FERC re-licensing agreement for the Pelton-Round Butte hydroelectric project, Portland General Electric (PGE) conducts native fish monitoring annually in Upper Deschutes sub-basin tributaries supporting salmon and steelhead reintroduction, and publishes a report summarizing monitoring results. The primary objective of PGE's native fish monitoring is to describe *O. mykiss* populations and spawning activity within the study reaches, including population size, size-frequency distributions, and redd counts. In 2009 USFS also conducted mark-recapture surveys to generate population estimates for steelhead and chinook at one additional site upstream of PGE sampling locations.

Table 2. Steelhead and Chinook fry and smolts stocked in Whychus Creek by year. Source: Gauvin 2011.

	Steelhead		Chinook	
Year	Fry	Smolts	Fry	Smolts
2007	275,000	-	-	-
2008	290,650	-	-	-
2009	278,823	-	71,603	-
2010	229,797	3,600	73,613	5,207

Restoration partners on Whychus Creek aim to restore the stream habitat, flows, passage and water quality necessary to support appropriate life history stages of steelhead and Chinook, as well as resident redband and bull trout (UDWC 2009). A key component of the restoration strategy is long-term monitoring to evaluate the effectiveness of restoration actions. Fish populations were selected as one of two biological indicators of restoration effectiveness in Whychus Creek both for the ready availability of data through PGE's monitoring program and because recovery of anadromous populations is a central objective of the restoration effort; therefore, increases in abundance and distribution of reintroduced and resident native fish would seem to signal success in restoration of stream conditions suitable to support these populations.

Fish Populations in Whychus Creek

Historically, Whychus Creek provided important spawning and rearing habitat for anadromous summer steelhead (*Oncorynchus mykiss*), chinook salmon (*Oncorhynchus tshawytscha*) and pacific lamprey (*Lampetra tridentata*). The construction of the Pelton Round Butte hydroelectric dams led to the extirpation of anadromous fish species from the upper Deschutes River and its tributaries during the 1960s. The dams fragmented the remaining populations of resident fish species by preventing migration between the lower and upper Deschutes sub-basins.

Fish species presently occurring in Whychus Creek include native redband trout (*Oncorynchus mykiss*), non-native brown trout (*Salmo trutta*), longnose dace (*Rhinichthys cataractae*), and sculpin (*Cottidae*). Non-native brook trout (*Salvelinus fontinalis*) were caught during native fish monitoring surveys in 2007 and 2008 but have not been observed since; bridgelip sucker (*Catostomus columbianus*) were last observed in 2006, also during PGE's native fish monitoring. No current sampling effort specifically targets either of these species, but they are believed to persist at low abundance in Whychus Creek(M. Hill 2011, personal communication). Native bull trout (*Salvelinus confluentus*) have been observed in Whychus Creek below Alder Springs (Fies *et al* 1996). PGE captured one bull trout each year in the Alder Springs area during 2003-2005 (M. Hill 2009, personal communication) but none have been captured since 2005.

Chinook salmon

Chinook use of Whychus Creek in the early 1950s appears to have been consistent although low, with spawners and redds numbering from single digits to the low teens, and limited to the lower few miles of the creek (Nehlsen 1995). Chinook spawning in Whychus diminished through the late 50s, with the last spawners and redds counted in 1959. Chinook reintroduction efforts will be focused on Whychus Creek and the Metolius River sub-basin (ODFW and CTWS 2008). The preliminary escapement goal for upper basin spring chinook salmon is 1000 adults annually above PRB; however, a model simulation for chinook recovery in the Metolius Basin (not including Whychus) estimates smolt production of approximately 350 adults through 2040.

Sockeye salmon (*Onchorhyncus nerka*) historically occurred in Suttle Lake (Metolius sub-basin), but they probably did not occur in Whychus Creek due to the lack of access to a lake system necessary for the rearing of sockeye juveniles. Kokanee salmon, the landlocked form of sockeye, now utilize Lake Billy Chinook for rearing. These kokanee may be descended from Suttle Lake sockeye that were trapped behind the dams. Fies *et al* (1996) reported an observation of 11 kokanee salmon adults (spawners) in Whychus Creek downstream from Alder Springs during a survey in 1991. This may indicate a potential for anadromous sockeye salmon to spawn in Whychus Creek and rear in Lake Billy Chinook if runs are reestablished above the dams.

O. mykiss

Redband trout and summer steelhead trout are both classified as Oncorynchus mykiss (Behnke 2002). Redband exhibit a resident life history behavior and spend their entire life within a stream system, although they may migrate within the system. Small numbers of redband trout in the upper Deschutes River system migrate between Lake Billy Chinook and tributary streams (Groves et al 1999). Summer steelhead are anadromous, with juveniles rearing in streams for 1-3 years, migrating to the ocean where they remain for 1-3 years, then returning to their natal watersheds as adults to spawn. Adult steelhead may survive after spawning, return to the ocean, and then return again to streams to spawn, although Behnke (2002) reports the rate of repeat spawning of steelhead to generally be less than 10% in most populations.

Redband trout and summer steelhead naturally coexist in the lower Deschutes River downstream from the Pelton Round Butte dams. Resident and anadromous forms of *O. mykiss* may have both historically occurred in Whychus Creek as well. It is uncertain to what extent both life history forms will again coexist in Whychus Creek as steelhead runs are reestablished. The habitats of juvenile redband and steelhead are similar, and there will likely be some level of interaction between the two life history forms, including competition for resources and perhaps spawning interaction. Zimmerman and Reeves (1999) provide evidence that steelhead and redband trout in the lower Deschutes River are reproductively isolated by their utilization of different spawning habitats and by differences in their time of spawning. Behnke (2002) also suggests that populations of resident and anadromous forms of *O. mykiss* may maintain their genetic distinction by spawning in separate areas within the same stream system. Ackerman *et al* (2007) and Cramer and Beamesderfer (2006) suggest that Whychus Creek will produce primarily anadromous, not resident, O. mykiss, based on stream flows and temperature.

Steelhead adults and redds numbered in the low hundreds in Whychus Creek throughout the 1950s but declined precipitously with the construction of the Pelton and Round Butte dams, and were eliminated altogether when fish passage efforts were abandoned (Nehlsen 1995). The reintroduction plan identifies a preliminary escapement goal of 955 adult summer steelhead. A simplistic model simulation estimates smolt production for Whychus Creek at 450 smolts through 2040 (ODFW and CTWS 2008).

Fish populations as biological indicators of restoration effectiveness

Intuitively, the abundance and distribution of native fish appear to be good biological measures of the success of watershed restoration actions. Improvements in watershed health and the suitability and availability of fish habitat would seem to support a corresponding increase in the numbers and distribution of fish. Abundant fish populations generally indicate good water quality and quantity, stream channel integrity and structure, healthy riparian and upland systems, and freedom from barriers to fish migration. Increased fish production is often viewed as a desirable outcome of watershed restoration programs because of the inherent cultural, recreational, and commercial values that are associated with species such as chinook salmon, steelhead, and redband trout.

Dale and Beyeler (2001) identify eight criteria for selection of ecological indicators as resource management tools. These include ease of measurement, sensitivity to stresses on the system, predictable response to stress, anticipatory (displaying measurable changes before substantial ecosystem change occurs), predictive of changes that can be averted by management actions, integrative (complement other indicators to provide a comprehensive assessment of a system), having a known reponse to disturbances, and low variability in response. Fish populations in Whychus Creek, particularly while steelhead and chinook reintroduction is ongoing, meet very few, if any, of these criteria.

UDWC's 2010 *Whychus Creek Baseline Technical Report: Native Fish Monitoring* (Kunkel 2010) evaluated the relative utility of fish populations in Whychus Creek as biological indicators of restoration effectiveness. This report identified multiple obstacles to the use of available data to evaluate the short-term response of Whychus fish populations to changes in habitat resulting from restoration actions. Foremost among these are annual releases of steelhead fry and smolts, which at least in part drive *O. mykiss* abundance and mask any response of the existing population to changes in stream conditions. Releases are scheduled to continue until it is determined that steelhead populations may be sufficiently established as to be self-sustaining (ODFW and CTWS 2008). Attempts to estimate abundance of juvenile steelhead or redband trout are confounded by the inability to differentiate juvenile steelhead and redband without conducting expensive genetic analyses. Short term changes to habitat following restoration frequently do not reflect the fully restored condition of the creek and may even adversely affect fish populations; independent of population fluctuations resulting from ongoing yearly releases, fish population trends may only provide some measure of habitat suitability years after restoration projects are completed, once sediments, stream banks, aquatic and riparian vegetation conditions have stabilized.

Given these obstacles, available fish population data is of limited use as a biological indicator of restoration effectiveness in Whychus Creek. However, PGE's native fish monitoring data will provide a useful baseline for recovery of anadromous species and fish population trends in Whychus Creek and the Upper Deschutes sub-basin, and may be useful in the future as a long-term indicator of restoration effectiveness. In particular, PGE is scheduled to conduct analyses to differentiate between juvenile redband and steelhead beginning five years after returning steelhead are first passed upstream of the dams. In the interim, UDWC will continue to track PGE's native fish monitoring and summarize their findings in an annual technical report. As restoration projects are completed and additional fish population data become available, UDWC will re-evaluate the use of these data as a biological indicator of restoration effectiveness.

This technical report summarizes results of 2009 and 2010 PGE population estimates and redd counts of *O. mykiss*. 2009 and 2010 results are compared to 2007 and 2008 findings; 2006 native fish monitoring data were collected using different methods and are not comparable to 2007-2010 data and therefore are not considered in this report. We also present results of 2009 USFS fish surveys on Whychus Creek.

O. mykiss Population Estimates

Methods

PGE Native Fish Monitoring

PGE fisheries managers chose four study reaches in 2002 (Figure 1) to represent the range of habitats in Whychus Creek (Lewis 2003). A fifth reach was added in 2009. Reach 1 is located downstream from Alder Springs at river mile (rm) 1.5 / river kilometer (rkm) 2.5. Reach 2 is downstream from USFS Road 6360 at rm 6 (rkm 9). Reach 3 is at Camp Polk at rm 19 (rkm 25.5). Reach 4 is downstream from Hwy 20 in Sisters at rm 23.5 (rkm 34.5). Reach 5 is located on Wolftree property at rm 17.5 (rkm 25).

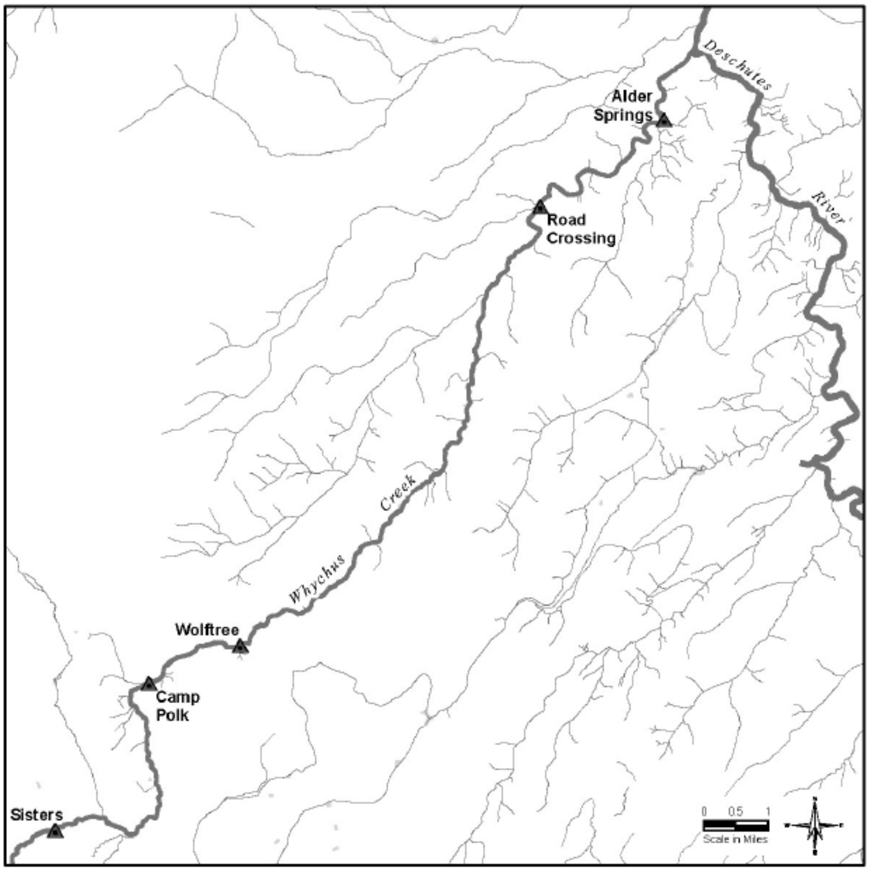

Figure 1. Study reaches on Whychus Creek for fish population estimates. Alder Springs, Road 6360 Crossing, Camp Polk and Sisters reaches (reaches 1-4) have been surveyed annually since 2006; Wolftree (Reach 5) was sampled in 2009 and 2010.

Fish population sampling was conducted during the low flow period in August and September of each year. In 2009 the majority of study reaches were increased to approximately 200 m in length from 100m in 2006-2008. Reach length remained at 100m where large numbers of *O. mykiss* (>100) were captured and marked in an initial pass and where habitat characteristics prevented the secure placement of block nets. Block nets were set at the upper and lower ends of selected habitat units within each study reach. In 2010 an additional net was placed midsection to evaluate block net effectiveness and mark-recapture sampling assumptions. Mark-recapture electrofishing was conducted following protocols adapted from ODFW (Scheerer *et al* 2007). Two electrofishers were used where stream width and flows allowed. *O.*

mykiss > 60 mm were measured and marked. In 2010 Chinook salmon parr and brown trout were also marked where numerous enough to generate mark-recapture estimates. Fish population estimates were calculated using Chapman's modification of the Peterson mark recapture formula to reduce overestimates of population size (Ricker 1975). Length frequency distributions were compared for years before and after steelhead fry releases. These methods are adapted slightly from those used in 2007 and 2008, and 2009 and 2010 population data are comparable to 2007 and 2008 data.

USFS Fish Surveys

In 2009, USFS selected three sites downstream of the Three Sisters Irrigation Diversion dam and upstream of PGE sampling reaches to collect baseline fish population and species composition data for future analysis of fish population response to restoration. USFS conducted mark-recapture surveys of steelhead along a 264-m reach following the same sampling protocol used by PGE. Length and weight of captured *O. mykiss* were recorded. Population estimates were calculated from mark-recapture data using the Petersen equation with the Chapman modification to reduce overestimation. USFS conducted single-pass electrofishing in the other two sites to determine species composition.

Results

PGE Native Fish Monitoring

Species Composition

The majority of fish captured in Whychus Creek in 2009 and 2010 were *O. mykiss*. Other species captured included chinook salmon parr, brown trout, sculpin, and longnose dace. *O. mykiss* juveniles captured during 2007-2010 native fish monitoring included both resident redband and released steelhead. Brown trout were captured in all Whychus reaches in 2009, and in large numbers in all reaches except reach 4 (Sisters) in 2010.

Population Estimates

Whychus Creek *O. mykiss* population estimates varied widely between years, and no increasing or decreasing trend was detected over four years of sampling (Table 2). Although steelhead fry have been released every year since 2007 and some proportion of individuals would be expected to remain in the creek during one to two subsequent years of sampling, density for each study reach has fluctuated between years with no consistent pattern between reaches (Figure 2). One possible explanation for fluctuating populations despite annual releases of steelhead fry and smolts is high winter and spring flows which may flush fry out of Whychus Creek, affecting fry distribution, or resulting in high fry mortalities (Quesada and Hill 2009). Size distribution of *O. mykiss* from 2007-2010 included a greater proportion of captured fish less than 100 mm in length than from 2002-2006, prior to steelhead reintroduction, suggesting that releases of steelhead fry have increased the relative proportion of fish in this size class.

Table 2. O. mykiss abundance estimates from 2007-2010. 2006 data was not comparable due to differences in sampling methods.

	O. mykiss /100m^2			
Reach	2007	2008	2009	2010
1 (Alder Springs)	48 (± 28)	24 (± 24)	12 (± 4)	11 (± 4)
2 (Road 6360)	25 (± 10)	9 (± 3)	24 (± 9)	13 (± 4)
3 (Camp Polk)	60 (± 13)	52 (± 21)	57 (± 15)	27 (± 9)
4 (Sisters)	20 (± 10)	5 (± 2)	23 (± 14)	18 (± 6)
5 (Wolftree)	-	-	21 (±7)	106 (± 29)
USFS Site 1 (TSID)	-	-	2.4 (1.5-4.0)	-

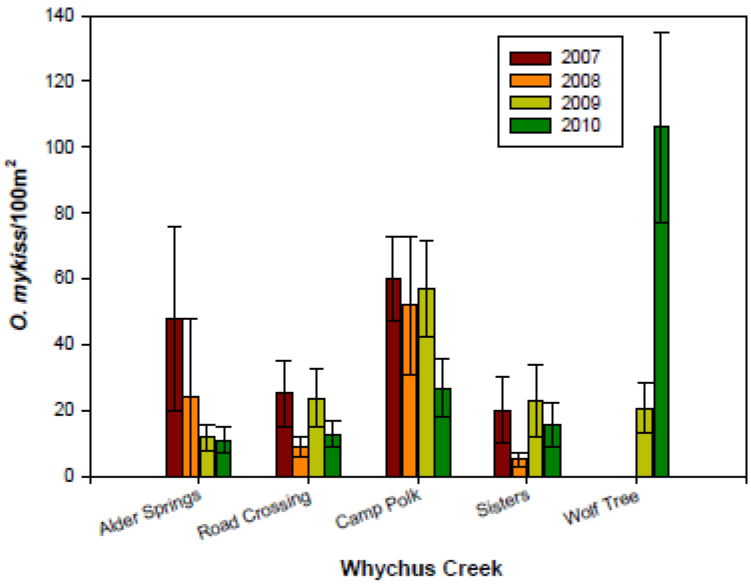

Figure 2.
O. mykiss densities for five Whychus Creek sites from 2007 to 2010. Reproduced with permission from Quesada *et al* 2011.

USFS Fish Surveys

Species captured at three 2009 sites downstream of TSID included *O. mykiss*, chinook, and sculpin. USFS estimated 43 *O. mykiss* (27-71, 95% confidence interval) and 7 chinook (3-15) present in the 264m reach sampled, resulting in densities of 2.4/100m^2 (1.5-4.0) for *O. mykiss* and 0.4/100m^2 (0.2-0.9) for chinook. *O. mykiss* captured ranged from 40 to 232 mm in length; chinook parr measured 101 to 111 mm.

Discussion

Fish population estimates

PGE researchers have made substantial progress in refining sampling methods, resulting in more accurate population estimates. Precision (95% confidence interval) around estimates of abundance increased by 10% from 2007-2008 to 2009, and by 7% from 2009-2010. Increased capture efficiency and confidence around abundance estimates were attributed to the use of 2 electrofishers and increased reach length during 2009 and 2010 sampling, and to the use of continuous direct current (DC) in 2010.

Mark-recapture sampling of chinook salmon and brown trout first conducted in 2010 will provide information on these populations and their potential interactions with *O. mykiss*.

Because PGE 2006 data were not comparable to 2007 and 2008 data, Hill and Quesada compared 2007 and 2008 results with mark-recapture estimates conducted by the Forest Service in the Camp Polk reach in 2006 (Hill and Quesada 2008; Dachtler 2007). Dachtler estimated a density of 5 fish/100m^2 in 2006, compared to Hill and Quesada's subsequent estimates for this reach of 60 fish/100m^2 in 2007, 52 fish/100m^2 in 2008, and 57 fish/m^2 in 2009. Although *O. mykiss* density in the Camp Polk reach fell to 27 fish/m^2 in 2010, the magnitude of difference between 2006 estimates and estimates for subsequent years probably indicates an actual change in fish density from pre-reintroduction levels as a result of annual releases of steelhead fry in Whychus Creek. The low densities of *O. mykiss* observed during USFS surveys below TSID, upstream of several barriers to fish passage and where no reintroductions have occurred, provide support for this explanation. (However, chinook parr detected at USFS Site 1 appear to have successfully migrated up a high-flow side channel; the closest Chinook reintroduction site is 2.1 km downstream.)

Steelhead fry releases may affect the abundance and distribution of resident redband trout in several ways. If releases result in *O. mykiss* densities that exceed the habitat capacity of sample reaches, competition may result in displacement of redband or steelhead fry, or both. Fry may be displaced to different locations in Whychus Creek, or they may be displaced out of Whychus Creek and into the Deschutes River. The physical condition of fry may also be affected when fry densities are high enough that food resources become limiting. High fry densities, displacement, and reduced physical condition may result in increased vulnerability to predation by larger *O. mykiss,* brown and brook trout, or other predators, as well as vulnerability to disease or other sources of mortality. Steelhead fry releases are synchronized with historical natural timing of fry emergence, however, when releases occur prior to the emergence of redband fry, released steelhead may gain a competitive advantage.

O. mykiss population estimates from 2007 to 2010 provide reliable data for comparison with future years. The inability to differentiate between redband and steelhead juveniles continues to limit conclusions about the relative abundance of the two life histories and any potential interactions between the two populations. In 2010 PGE started collecting genetic samples from a subset of *O. mykiss* captured during electrofishing that may be used in the future to differentiate between juvenile steelhead and redband. PGE plans to collect additional samples in 2011 which may be used for genetic analysis. As noted previously, PGE is scheduled to conduct analyses to differentiate between juvenile redband and steelhead five and ten years after returning steelhead are first passed upstream of the dams. The ability to differentiate between juvenile steelhead and redband will provide valuable information on abundance of each life history and interactions of the two populations.

Smolt production estimates

Beginning in 2009 PGE operated screwtraps to estimate numbers of steelhead, chinook and redband juveniles outmigrating from Whychus Creek and other tributaries and to mark downstream migrants for later identification. Recovery of marked fish will provide data to estimate the relative contribution of smolts from each tributary, and, if measures are taken to differentiate redband and steelhead, will provide information on out-migration of resident fish. Fish traps deployed in Whychus Creek have been difficult to operate effectively due to vandalism and widely fluctuating flows during the downstream migration period (Hill and Quesada 2010, Hill and Quesada 2011). Resulting 2009 and 2010 data were inadequate to develop smolt production estimates. PGE's 2011 Juvenile Migration study plan includes operating a screw trap in the upper Deschutes arm of Lake Billy Chinook. While this outmigration data will not directly reflect smolt production in Whychus Creek, it will provide a measure of the relative contribution of the Upper Deschutes to total *O. mykiss* production in the Upper Deschutes sub-basin.

Predicting parr capacity

The Unit Characteristic Method (UCM) is a model developed to predict the *O. mykiss* capacity of a stream based on habitat characteristics (Ackerman *et al* 2007, Cramer and Ackerman 2009). UCM predictions have been used to inform reintroduction numbers in the Upper Deschutes Subbasin. A well-founded understanding of the density of parr a given stream is likely to support could give fisheries managers a benchmark that would indicate a healthy and viable *O. mykiss* population. However, validating the UCM for the dynamic, highly variably hydrographs of east side streams has proven problematic. Kunkel (2010) reported that early attempts to validate the UCM model using Whychus Creek habitat and mark-recapture survey data failed to produce a consistent relationship between population estimates and UCM model predictions. A 2009 attempt by Hill et al. to adjust UCM parameters for east side streams and validate the UCM against data for Whychus and two other Upper Deschutes Subbasin tributaries also failed to predict observed numbers of parr within a 95% confidence interval (Hill *et al* 2009). Although a validated model that accurately predicts parr density for Whychus would be helpful in establishing recovery targets for reintroduced populations, model developers continue to encounter substantial discrepancies between UCM predictions and fish population estimates for Upper Deschutes Subbasin tributaries. Attempts to validate the model are ongoing.

***O. mykiss* Redd Counts**

Methods

Four areas of Whychus Creek were identified in 2006 as sites for *O. mykiss* redd surveys (Figure 3). The four sites were subdivided into 10 individual reaches to help identify the distribution of redds. PGE and the Forest Service surveyed the four sites every two weeks from March through July in 2006 – 2009. Relatively high stream flows and turbidity prevented surveys during some periods in 2006; in 2008 through 2010, although surveys were conducted throughout the spawning season, high flows and turbidity limited surveys from late May through July. Surveys were conducted by one or two surveyors walking downstream, identifying redds, and placing flagging near each redd to avoid recounting redds on subsequent surveys.

Channel reconstruction projects at Rimrock Ranch (pending) and Camp Polk (2008-present) may prevent researchers from attributing changes in spawning populations to steelhead reintroduction. To address this obstacle and to adopt a sampling design that will support accurate estimates of spawning distribution and redds per kilometer, in 2010 PGE implemented a rotating panel design recommended by the American Fisheries Society (Gallagher *et al* 2007) and similar to that used by the ODFW Coastal Salmonid Inventory Project (ODFW 2007). In addition to the original four sites surveyed since 2006, PGE surveyed four new rotating panel design sites. The rotating panel design includes annual surveys of two designated reaches, with an additional two randomly chosen reaches surveyed each year. Data from the four original sites will help to establish a population trend and to identify temporal as well as spatial spawning distribution.

Beginning in 2009 PGE measured a sub-sample of redband trout redds as baseline data to use in differentiating redband and steelhead redds and spawning distribution once adult steelhead return to Whychus. Measurements of pot and spill included width, length, depth, and substrate size. Temperature data were also collected.

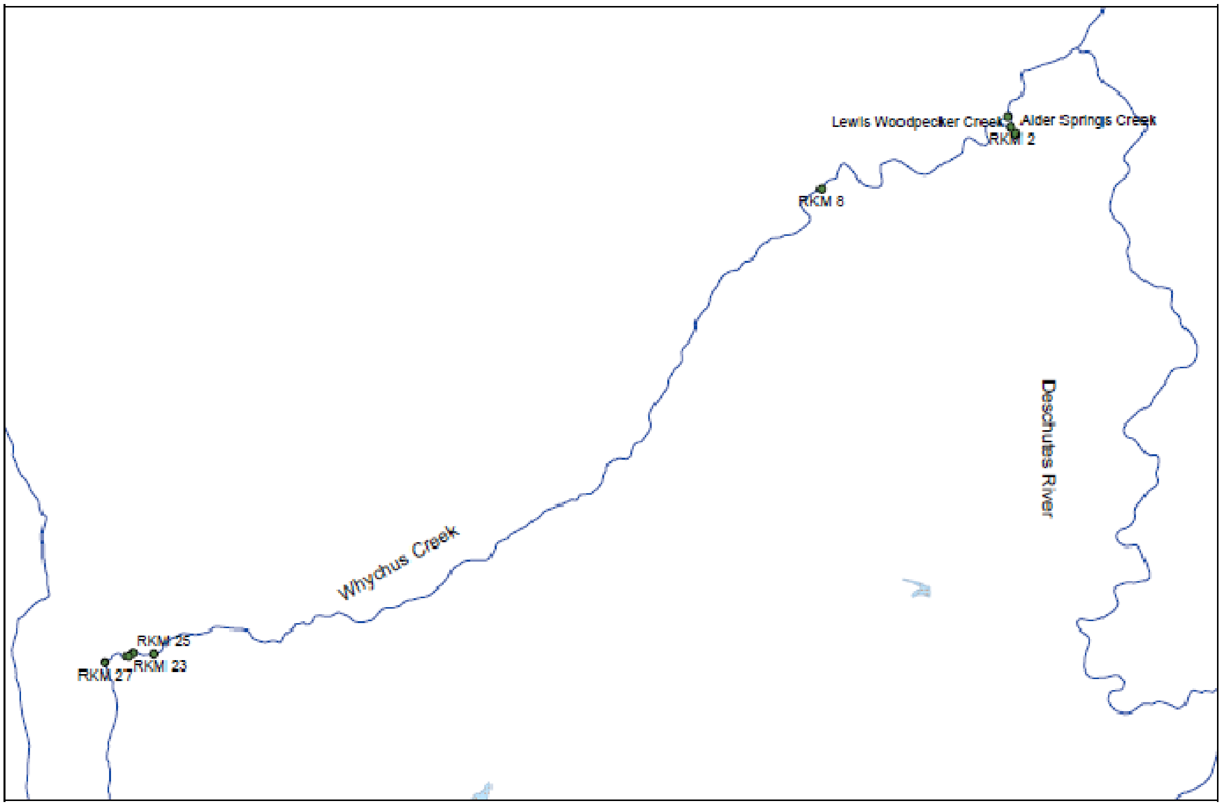

Figure 3.
Redband redds were counted in eight reaches in 2010: two designated index reaches, at rkm 2 (reach 1 and 2) and rkm 27 (reach 8), two randomly selected reaches at rkm 8 (near the FS Road 6360 crossing) and rkm 23; and in four additional reaches (reach 2, Alder Springs Creek; reach 3, Lewis Woodpecker Creek; reach 6, rkm 25; and reach 7, rkm 26) surveyed from 2006-2009. Reproduced with permission from Quesada *et al* 2011.

Results

As of 2010 no adult steelhead have been passed above the dams and therefore all redds observed during May-July surveys are assumed to be from redband trout; other salmonid species occurring in Whychus Creek are fall-spawning fish. Surveyors detected a total of 65 redds in 2010, averaging to 12 redds/km (Table 3). Consistent with previous years, the Alder Springs area accounted for over half (55.4%) of all redds observed (Figure 4).

Table 3. Redds detected by site and year, and totals for each year. “ns” indicates sites not sampled.

	Year			
Site	**2007**	**2008**	**2009**	**2010**
Alder Springs	69	48	24	36
Road 6360 Crossing	ns	ns	ns	3
Rimrock	38	18	10	ns
Turin	ns	ns	ns	12
Camp Polk	21	8	9	14
Upstream of Sisters	1	0	0	ns
Total	**129**	**74**	**43**	**65**

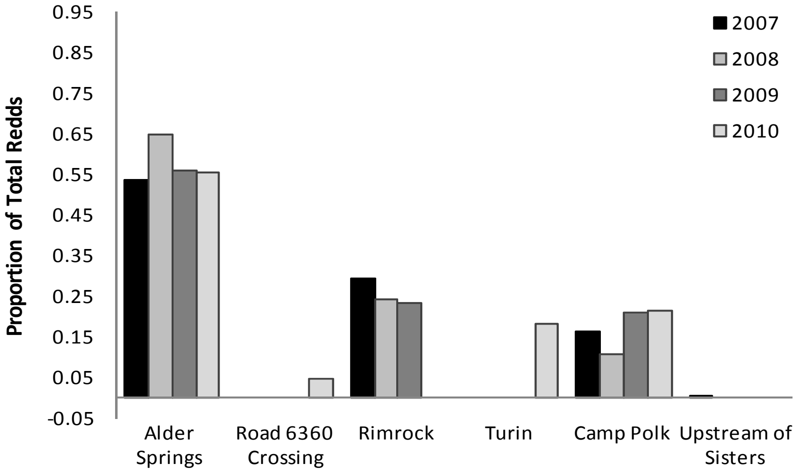

Figure 4.
Proportion of total redds detected by year in six Whychus Creek sites. Although Alder Springs, Rimrock, Camp Polk and Upstream of Sisters sites were sampled each year from 2007-2009, no redds were detected at the Upstream of Sisters site in 2008 and 2009. Road 6360 and Turin sites were first sampled in 2010; the Upstream of Sisters site was not sampled in 2010.

Four redds were measured in 2010 to supplement data from 28 redds measured in 2009 (Figure 5). Data collected prior to the return of adult steelhead to Whychus Creek will be used as a baseline to differentiate redband and trout redds and develop spawner estimates for both life histories (Zimmerman and Reeves 1999).

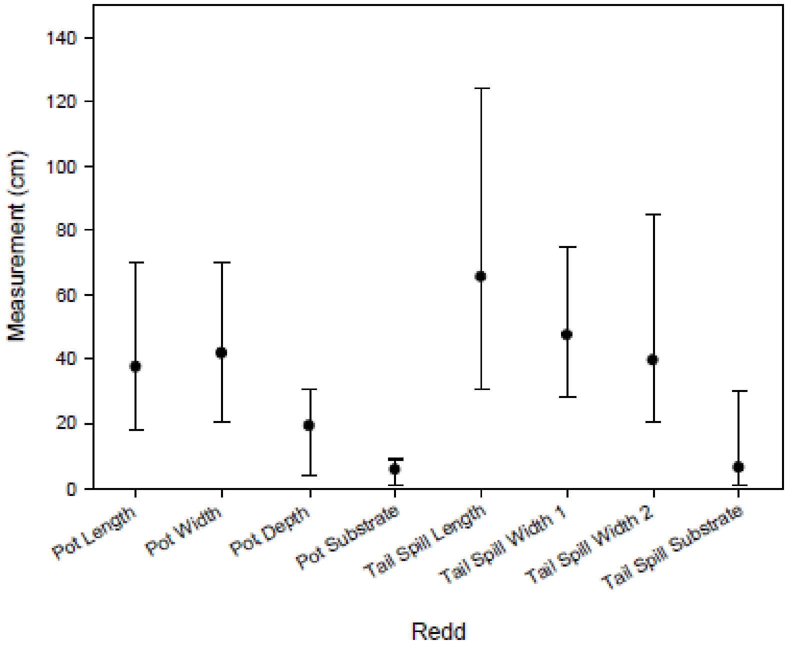

Figure 5.
Average values of redband trout redd measurements in Whychus Creek in 2009 and 2010 (n = 32) Reproduced with permission from Quesada *et al* 2011.

Discussion

Redd numbers have remained relatively consistent across years with the exception of 2007 (Table 3). The high number of redds detected in 2007 corresponds to the only sampling year during which high and turbid flows did not impede surveys. The greatest proportion of redds have consistently been observed in the Alder Springs Area (53-65% from 2007 to 2010). Rimrock Ranch, Reach 5, accounted for approximately a quarter of redds detected (23-29%) from 2007 to 2009. Together, Alder Springs and Rimrock Ranch accounted for 80-90% of all redds observed from 2007 to 2009. The Camp Polk area, from rkm 25 to rkm 27, accounted for approximately 20% in both 2009 and 2010. Only one redd was observed between 2007 and 2009 in reaches 9 and 10 upstream of Sisters. Barriers above and below reach sections 9 and 10 likely inhibit migration of spawning fish which may account for low redd numbers. These reaches were not sampled in 2010.

Accurate information on numbers and distribution of spawning fish will be useful for documenting O. mykiss reproduction and spawning habitat use. As steelhead reintroduction and watershed restoration efforts continue and stream conditions improve, the numbers and distribution of *O. mykiss* are anticipated to change. There will likely be considerable changes in redd numbers and distribution when adult steelhead begin returning to Whychus Creek to spawn. As noted earlier, there may also be interactions between redband and steelhead spawners. Conditions external to Whychus Creek have the potential to strongly influence spawning trends for anadromous steelhead and chinook. Smolts produced in Whychus Creek will be subject to many variable factors, including downstream passage, flow, and water quality conditions, predation, ocean survival, tribal, sport, and recreational fishing, and adult passage upstream. These and other external factors may greatly affect smolt-to-adult survival.

Conclusion

Changes made to PGE native fish monitoring protocols in 2009 and 2010 will contribute substantially to the utility of the resulting data in describing fish populations in Whychus Creek. Increased accuracy of population estimates will improve our understanding of *O. mykiss* abundance across years. Inclusion of chinook and brown trout in mark-recapture sampling will allow researchers to evaluate chinook recovery and track population trends for non-native brown trout. Future USFS fish surveys at TSID will complement downstream PGE population estimates. With analysis of genetic samples first collected in 2010, researchers will be able to describe juvenile resident redband and reintroduced steelhead abundance, trends, and interactions between the two populations. The rotating panel design implemented in 2010 redd counts will provide a reliable index of spawning fish numbers, and redd measurements will differentiate redband from steelhead spawners and provide a basis for establishing spawning distributions for the two life histories. As outmigrant trapping locations and methods continue to be refined, researchers will be able to infer at least a rough estimate of Whychus smolt production from estimates for the Deschutes arm of Lake Billy Chinook.

Restoration partners originally expected that biological indicators would provide an effective means for evaluating trends in watershed restoration. In the short term, the data available on fish populations and especially *O. mykiss* in Whychus Creek are inadequate to evaluate how restoration may be influencing population trends for either reintroduced anadromous species or native resident fish. Over the long term, as stream conditions stabilize following restoration, adult steelhead and chinook salmon return to spawn in Whychus, and steelhead and chinook releases are ultimately replaced by spawning runs, fish population trends will more directly reflect stream habitat and watershed conditions. When these criteria are met, fish population data may provide a more useful indicator of restoration effectiveness.

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